MAKING SCHOOLS SAFE AGAINST FLOODS 5

5.1 INTRODUCTION

This chapter introduces the nature and probability of floods and the types of flood damage that result when school facilities are located in flood hazard areas. Avoidance of such areas is the most effective way to minimize risks to occupants, including health hazards and damage to property. When a school must be built in a flood hazard area, site layout and facility design measures can minimize damage and risks. The chapter also provides an overview of measures that designers should consider in order to reduce risks at existing schools that are already located in areas prone to flooding.

5.2 NATURE AND PROBABILITY OF FLOODS

Flooding is the most common natural hazard in the United States, affecting over 20,000 local jurisdictions and representing more than 70 percent of Presidential Disaster Declarations. Several evaluations have estimated that 10 percent of the Nation's land area is subject to flooding. Some communities have very little land that is identified as exposed to flooding, although others lie entirely within the floodplain.

Flooding is a natural process that may manifest in a variety of forms: long-duration flooding along rivers that drain large watersheds; flash floods that send a devastating wall of water down a mountain canyon; and coastal flooding that accompanies high tides and on-shore winds, hurricanes, and Nor'easters.

Four Examples of Schools Vulnerable to Flood Hazards

Two schools in Gurnee, Illinois, were damaged by floods in 1986. The school district's actual costs were over $1.6 million to repair and replace the facilities, supplies, and materials. Not included in these figures are the costs for transportation and rental, and disruption of the school year for children who, for several months, attended school in a vacant department store 4 miles away. For an additional 2 years of renovation and reconstruction, the children attended school in another community, 8 miles away. One school was later rebuilt as a flood protected facility for a cost of $17 million, all of which was paid by local taxpayers.

In April 2003, a dry floodproofed private school in Jackson, Mississippi, experienced a soaking when a sudden downpour dumped 9 inches of rain on the area. Because the event occurred in the pre-dawn hours when no one was on site to install the floodproofing measures (e.g., water-tight doors and special seals), water entered the building, causing damage to carpets, walls, furniture, and equipment.

Continued on next page

In 1989, Hurricane Hugo vividly revealed the importance of knowing whether schools are prone to flooding. The local emergency manager's records identified the McClellanville, South Carolina, school as an approved hurricane shelter. Unfortunately, that designation was based on erroneous information because the school turned out to be four feet lower than indicated in those records. When storm surge flooding inundated the school, people had to break through the ceiling and lift everyone up to the attic.

Flooding in the spring of 2001 tested flood protection for the Oak Grove Lutheran High School in Fargo, North Dakota. Prompted by the failure of temporary earth and sandbag dikes during the 1997 Red River flood of record, which resulted in over $3.5 million in damage to the school, the city designed and constructed a brick-faced permanent floodwall. Five access points, wide enough for vehicles, were protected with an "invisible" closure that is an integral part of the floodwall. A crew of six was able to install the closures in less than 2 hours.

When the natural process is unaltered by human activity, flooding is not a problem. In fact, species of plants and animals that live adjacent to bodies of water are adapted to a regimen of periodic flooding.

Flooding is only considered a problem when human development is located in flood-prone areas. Problems can result, not only exposing people to dangerous situations and property to damage, but also disrupting the natural functions of floodplains and redirecting surface flows onto lands that are not normally subject to flooding.

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

- Channel obstructions due to fallen trees, accumulated debris, and ice jams
- Channel obstructions due to road and railroad crossings where the bridge or culvert openings are insufficient to convey floodwaters
- Erosion of shorelines and stream banks, often with episodic collapse of large areas of land
- Deposition of sediment that settles out of floodwaters or is carried inland by wave action
- Failure of dams (whether due to seismic activity, lack of maintenance, flows that exceed the design, or destructive acts) may suddenly and unexpectedly release large volumes of water

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

5.2.1 Characteristics of Flooding

Each type of flooding has characteristics that are important aspects of the hazard and that must be considered in the selection of school sites, the design of new schools, and the expansion or retrofit of existing flood-prone schools in ways that minimize damage.

Riverine flooding is due to the accumulation of runoff from rainfall or snowmelt such that the volume of flow exceeds the capacity of waterway channels and spreads out over the adjacent land. Riverine flooding flows downstream under the force of gravity. Its depth, duration, and velocity are functions of many factors, including watershed size and slope, degree of upstream development, soil types and nature of vegetation, steepness of the topography, and characteristics of storms (or depth of snowpack and rapidity of melting). Figure 5-1 illustrates a cross-section of a riverine floodplain.

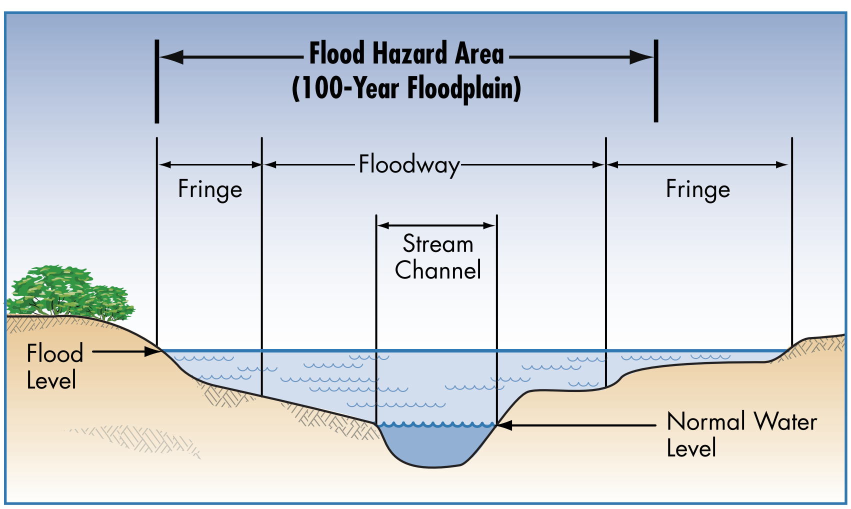

Figure 5-1
The riverine floodplain

Coastal flooding is experienced along the Atlantic, Gulf, and Pacific coasts, and many larger lakes, including the Great Lakes. Coastal flooding is influenced by storm surges associated with tropical cyclonic weather systems (hurricanes, tropical storms, tropical depressions, typhoons), extratropical systems (Nor'easters), and tsunamis (surge induced by seismic activity). Coastal flooding is also generally characterized by wind-driven waves. Wind-driven waves affect reaches along the Great Lakes shorelines, where winds blowing across the broad expanses of water generate wind-driven waves that can rival those experienced along other coastal shorelines. Some Great Lakes shorelines experience coastal erosion, in part associated with fluctuations in water levels. Figure 5-2 is a schematic of the coastal floodplain.

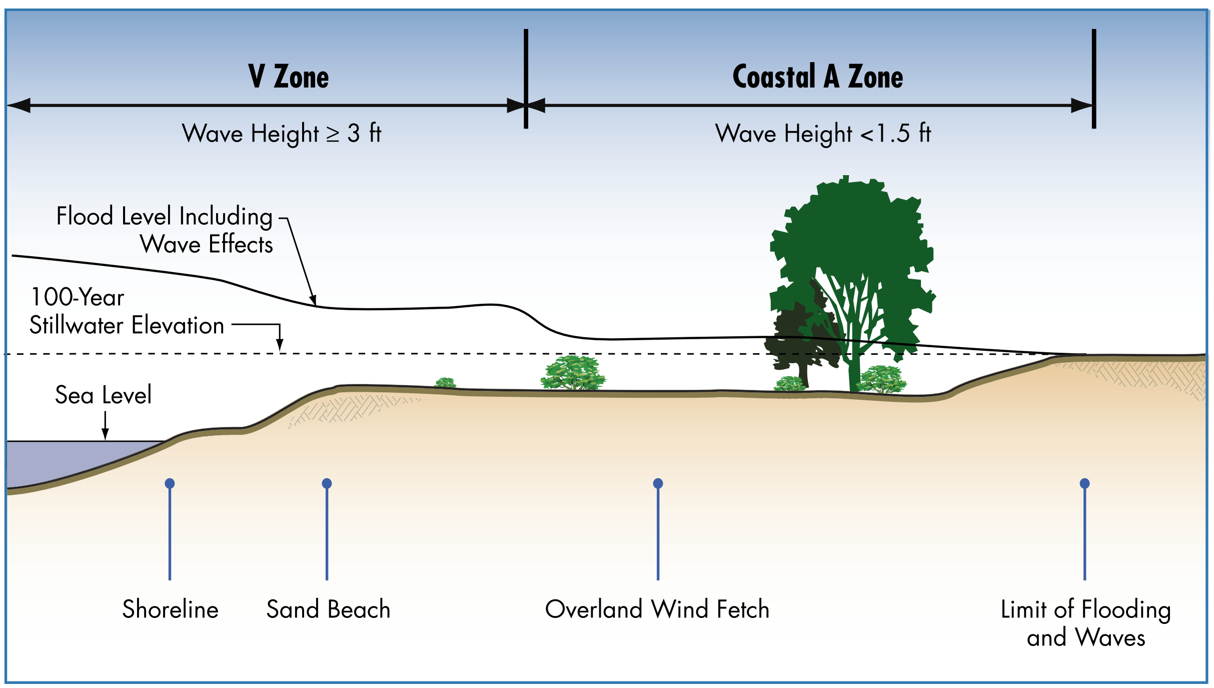

Figure 5-2 The coastal floodplain

Riverine and coastal flooding can be characterized by a number of factors that become important in the selection of school sites, site design, and design of school buildings:

- **Depth.** The most obvious characteristic of any flood is the depth of water. Depending on many factors, such as the shape of a river valley or the presence of obstructing bridges, riverine flooding may rise just a few feet or tens of feet above normal. The depth of coastal flooding is influenced by such factors as the tidal cycle, the duration of the storm, the elevation of the land, and the presence of waves. Depth is a critical factor in building design because the hydrostatic forces that are exerted on a vertical surface (such as a foundation wall) are directly related to depth and because costs associated with protecting buildings from flooding significantly increase with depth.

- **Duration.** Duration is the measure of how long the water remains above normal levels. The duration of riverine flooding is primarily a function of watershed size and the longitudinal slope (which influences how fast water drains away). Small watersheds are more likely to be "flashy," which refers to the rapidity with which floodwaters rise and fall. Areas adjacent to large rivers may be flooded for weeks or months. Most coastal flooding is influenced by the normal tidal cycle, as well as how fast coastal storms move out of the area. Areas subject to coastal flooding can experience long duration flooding where drainage is slow, or may be impacted on the order of 12-24 hours if storms move rapidly. Flooding of large lakes, including those behind dams, can be of very long duration because of the sheer volume of water that must flow past a control point. For building design, duration is important because it affects access, building usability, saturation and

> Local drainage problems create ponding and local flooding that often is not directly associated with a body of water such as a creek or river. Although these problem areas generally are relatively shallow and often are not characterized by high velocity, considerable damage may result, especially when poor drainage causes repetitive damage. Some local drainage problems are exacerbated by old or undersized drainage system infrastructure. Because drainage problems typically occur as sheetflow or along waterways with very small drainage areas, this type of flooding often is not mapped or regulated.

stability of soils, and building materials. Information about flood duration is sometimes available as part of a flood study or could be developed by a qualified engineer.

- **Velocity.** The rates at which floodwaters move range from extremely rapid (associated with flash floods) to nearly stagnant (in backwater areas and expansive floodplains). Velocity is important in site planning because of the potential for erosion. In structural design, velocity is a factor in hydrodynamic loads, including impact loads and drag forces. With respect to public safety, even shallow high velocity water poses threats to pedestrians and vehicles. Accurate estimates of velocities are difficult to make, although limited information may be found in floodplain studies.

- **Wave action.** Waves contribute to erosion and scour, and also contribute significantly to loads on buildings. The magnitude of wave forces can be 10 or more times higher than wind and other design loads. Waves must be accounted for along coastal shorelines, in flood hazard areas that are inland of open coasts, and other areas subject to waves, including areas with sufficient fetch that winds generate waves (such as lakes and expansive riverine floodplains).

- **Impacts from debris and ice.** Floating debris and ice contribute to loads that must be accounted for in design. The methods and models used to predict and delineate flood hazard areas do not specifically incorporate debris, thus there are few sources to characterize potential impacts other than past observations.

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

5.2.2 Probability of Occurrence

In order to guide and regulate development, and to develop specific designs to resist flood forces, it is necessary to identify the "design flood." For decades, the design flood has been referred to as the "base flood." More precisely, it is the "1%-annual chance flood," but is commonly called the "100-year flood." The latter term is often mis-understood because it conveys the impression that a flood of that magnitude will occur only every 100 years. Statistically, the 1%-annual chance flood has one chance in 100 of occurring in any given year. The fact that a 1%-annual chance flood is experienced at a specific location does not alter the probability that a comparable flood will occur at the same location in the next year, or even twice in one year.

Regardless of the flood selected for design purposes, the designer must determine specific characteristics associated with that flood. A flood of a specific return frequency is determined in a multi-step process that typically involves using computer models that are in the public domain. If a sufficiently long record of floods exists, the design flood may be determined by applying statistical tools to the record. Alternatively, sometimes water resource engineers apply computer models to simulate different rainfall events over watersheds and to predict how much water will run off and accumulate in channels. Other computer models are used to characterize the flow of water down the watershed and predict how high it will rise. For coastal areas, both historical storms and simulated storm models can be used to predict the probability that floodwaters will rise to a certain level.

The National Flood Insurance Program (NFIP), described in Sections 5.3.1 and 5.3.2, uses the 1%-annual chance flood as the basis for flood hazard maps, for setting insurance rates, and for application of regulations in order to minimize future flood damage. The 1%-annual chance flood is also used to examine older buildings to determine measures that are applied in order to reduce future damage.

Communities are encouraged to treat schools as essential critical facilities because of the significant and long-term impacts on students and the community if a damaged school is closed for an extended period of time. Essential and critical facilities usually are intended to remain operational in the event of extreme environmental loading from floods, hurricanes, snow, or seismic events. A higher level of protection has been determined to be appropriate for facilities that are important to protect in order to enhance rapid recovery, including hospitals, emergency operations centers, emergency shelters, water treatment plants, and other buildings that support vital services.

5.2.3 Hazard Identification and Flood Data

Flood hazard maps are prepared to identify areas of the landscape that are subject to flooding, usually flooding by the 1%-annual chance flood. Maps prepared by the NFIP are the minimum basis of state and local floodplain regulatory programs. Some states and communities have prepared maps that reflect a floodplain determined using a "higher standard," such as assuming the upper watershed area is built-out completely according to existing zoning. Some communities use a flood of record or a historically significant flood as the basis for regulation.

The flood hazard maps used by the appropriate regulatory authority should be consulted during site selection, site design, and building design (whether for new buildings or existing buildings). Since the NFIP began producing Flood Insurance Rate Maps (FIRMs), these maps have been prepared for over 19,200 communities. FIRMS are prepared for each local jurisdiction that has been determined to have some degree of flood risk and, typically, the maps may be viewed by visiting community planning or permit offices[1]. Many FIRMs do not show detailed information about

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

predicted flood elevations along all bodies of water and the 0.2%-annual chance flood hazard areas often are not shown. In these cases, additional engineering analyses are necessary in order to determine the flood-prone areas and the appropriate characteristics of flooding required for site layout and building design.

If a proposed school site or an existing school is affected by flooding, a site-specific topographic survey is critical for delineating the land that is below the design flood elevation (DFE). If detailed flood elevation information is not available, a floodplain study may be required to identify the important flood characteristics and data required for sound design. Having flood hazard areas delineated on a map conveys a degree of precision that may be misleading. Flood maps have a number of limitations that should be examined, especially during site selection and design of essential and critical facilities such as schools:

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

- NFIP FIRMs and Flood Insurance Studies (FISs) were prepared to meet the requirements of the NFIP. For the most part, floodplains along smaller streams and drainage areas (less than 1 square mile) are not shown.

- Especially for older maps, the topography used to delineate the flood boundary may have had contour intervals of 5, 10, or even 20 feet, which significantly affects the precision with which the boundary is determined. The actual elevation of the ground relative to the flood elevation is critical, as opposed to whether an area is shown as being in or out of the mapped flood hazard area.

- Older maps may not reasonably account for upland development that increases rainfall-runoff and tends to increase flooding.

- The scale of the maps may not itself to precise determinations.

- Flooding may have been altered by development, whether upland development that increases runoff or local modifications that alter the shape of the land surface of the floodplain (such as fills or levees).

- Local conditions are not reflected, especially conditions that change regularly, such as streambank erosion and shoreline erosion.

The flood hazard maps prepared by the NFIP show different zones that identify some differences in flooding characteristics:

- **A Zones.** Flood hazard areas where engineering analyses have not been performed to develop detailed flood elevations and boundaries, also called "unnumbered A Zones" or "approximate A Zones," for the base flood (1%-annual chance flood). Additional engineering analysis and site-specific assessments usually are required to determine the design flood elevation.

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

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

- **AO and AH Zones.** Areas of shallow flooding are generally shown where the flood depth averages from 1 to 3 feet, where a clearly defined channel does not exist, where the path of flooding is unpredictable, and where velocity flow may be evident. These zones are characterized by ponding or sheetflow.

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

- **Unshaded X (or C) Zones.** These zones are all land areas not mapped as flood hazard areas (either 1%- or 0.2%-annual chance flood hazard areas) that are outside of the floodplain that is designated for the purposes of regulating development pursuant to the NFIP. These zones may still be subject to small stream flooding and local drainage problems.

- **V Zones (V, VE, and V1-V30).** Also known as "coastal high hazard areas," V Zones are relatively narrow areas along open coastlines and some large lake shores that are subject to high-velocity wave action from storms or seismic sources. V Zones extend from off-shore to the inland limit of a primary frontal dune or to an inland limit where breaking waves are predicted to be at least 3 feet in height.[2]

- **Coastal A Zone.** The principal sources of flooding in Coastal A Zones are astronomical tides, storm surges, seiches, or tsunamis. These zones extend inland to include areas where the potential for breaking wave heights exists during conditions of the base flood. Coastal A Zones are not delineated on NFIP maps; this zone is identified in ASCE 7 and ASCE 24 because waves sufficient to contribute to damage are present.

[2] Because V Zones are generally limited in extent, such areas are unlikely sites for schools. The specific design and construction provisions for V Zones are not addressed in this manual. More information can be found in FEMA 55, *Coastal Construction Manual*.

Flood Hazard Zones

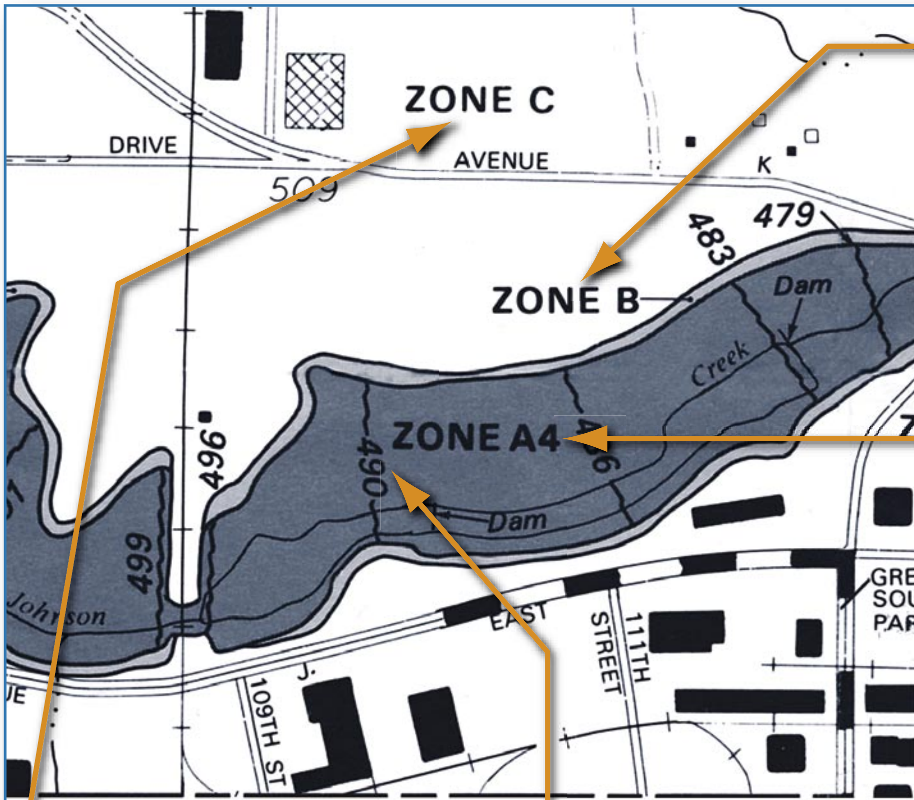

Figure 5-3 Riverine flood hazard zones

Flood hazards and characteristics of flooding must be identified in order to appropriately evaluate the impact of site development, to calculate flood loads, to design floodproofing measures, or to identify and prioritize retrofit measures for existing schools. Many characteristics are not shown on the flood hazard maps but may be found in the FIS or the study or report prepared by the entity that produced the flood hazard map. Otherwise, additional research is required. Table 5-1, on page 5-22, outlines a series of questions to facilitate this objective.

5.2.4 Design Flood Elevation

> The DFE is the highest elevation of either the flood hazard area shown on a community's Flood Insurance Rate Map, or another flood as legally designated by a community (e.g., accounting for future development).

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

Figure 5-4 shows the relationship between the BFE and the DFE. School planners and designers should check with the appropriate regulatory authority to determine the minimum flood elevation to be used in site planning and design. For essential and critical facilities such as schools, it is common that state and local regulations cite the 0.2% chance flood (500-year flood) as the design minimum or the regulations may call for added freeboard of 1, 2, or 3 feet above the minimum flood elevation.

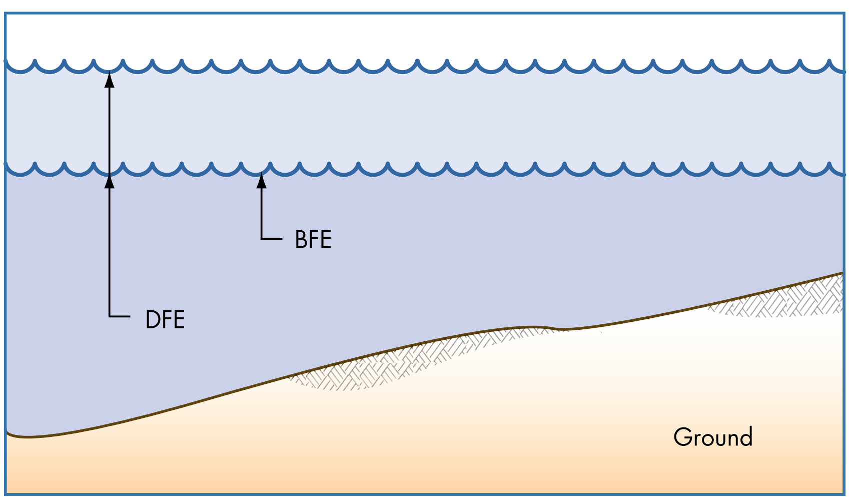

Figure 5-4 Definition sketch – flood elevations

5.3 SCOPE, EFFECTIVENESS, AND LIMITATIONS OF BUILDING CODES AND FLOODPLAIN MANAGEMENT REQUIREMENTS

With respect to design and construction to resist flood damage, the existing minimum requirements in model building codes and regulations are based on the National Flood Insurance Program. The original authorizing legislation for the NFIP was passed in 1968. Congress expressly found that "a program of flood insurance can promote the public interest by encouraging sound land use by minimizing exposure of property to flood losses . . . "

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

> Construction of public schools may be regulated by a state board or agency and thus may not be subject to local permit requirements, including local floodplain management regulations. In these cases, the NFIP minimum requirements must still be satisfied, whether through regulation, executive order, or a state building code.

5.3.1 Overview of the NFIP

The NFIP is intended to encourage states and local governments to recognize and incorporate flood hazards in land use and development decisions. In some states and communities, this is achieved by guiding development to areas with lower risk. When decisions result in development within flood hazard areas, application of the criteria set forth in Federal Regulation at 44 CFR §60.3 minimize exposure and flood-related damage. State and local governments are responsible for the application of the provisions of the NFIP through regulatory permitting processes. At the federal level, the NFIP is managed by FEMA and has three main elements:

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

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

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

Federal flood insurance is designed to provide property owners, including school districts, an alternative to disaster assistance and disaster loans. Disaster assistance has limited coverage for full costs to repair and clean up and is available only after the President of the United States signs a disaster declaration for the area. Importantly, school districts should be aware that they may be subject to a mandated reduction in disaster assistance payments if a public school building is not covered by flood insurance. NFIP flood insurance claims are paid any time damage from a qualifying flood event occurs, regardless of whether a major disaster is declared.

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

5.3.2 Summary of the NFIP Minimum Requirements

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

> "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).

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

The NFIP's broad performance requirements for site work are as follows:

- Building sites shall be reasonably safe from flooding.
- Adequate site drainage shall be provided to reduce exposure to flooding.

- New and replacement sanitary sewage systems shall be designed to minimize or eliminate infiltration of floodwaters into the systems and discharges from the systems into floodwaters.

- Development in floodways shall be prohibited unless engineering analyses show that there will be no increases in flood levels.

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

- Buildings shall be designed and adequately anchored to prevent flotation, collapse, or lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy.

- Buildings shall be constructed by methods and practices that minimize flood damage (primarily by elevating to or above the base flood level or by specially designed and certified floodproofing measures).

- Buildings shall be constructed with electrical, heating, ventilation, plumbing, and air conditioning equipment and other service facilities that are designed and/or located so as to prevent water from entering or accumulating within the components.

Designers should determine if there are any applicable state-specific requirements pertinent to floodplain development. Some states require that local jurisdictions apply standards that exceed the minimum requirements of the NFIP. Some states have direct permitting authority programs that impose higher standards, while some states have direct permitting authority over certain types of construction or certain types of applicants.

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

5.3.3 Model Building Codes and Standards

The 2000 and 2003 editions of the International Building Code (IBC) and the 2003 edition of the National Fire Protection Association's Building Construction and Safety Code (NFPA 5000) are the first model codes to include comprehensive provisions to address flood hazards. Both codes are consistent with the minimum provisions of the NFIP that pertain to design and construction of buildings. The NFIP requirements that pertain to site development and floodways generally are found in other local ordinances. The codes require designers to identify anticipated environmental loads and load combinations, including wind loads, seismic loads, snow loads, soil conditions and flood loads.

The IBC and NFPA 5000 reference standards that are developed through a rigorous consensus process. The best known is *Minimum Design Loads for Buildings and Other Structures* (ASCE 7), produced by the American Society of Civil Engineers (ASCE). The model building codes require that applicable loads be accounted for in the design. The designer must identify the pertinent, site-specific characteristics and then use ASCE 7 to determine the specific loads and combined loads. In effect, it is similar to a local floodplain ordinance that requires determination of the environmental condition (in/out of the mapped flood hazard area, DFE/depth of water) and then specifies certain conditions that must be met during design and construction. The 1998 edition of ASCE 7 was the first version of the standard to explicitly include flood loads, including hydrostatic loads, hydrodynamic loads (velocity and waves), and debris impact loads.

The IBC and NFPA 5000 also refer to a standard first published by ASCE in 1998, *Flood Resistant Design and Construction* (ASCE 24). Developed through a consensus process, ASCE 24 addresses specific topics pertinent to designing buildings in flood hazard areas, including floodways, coastal high hazard areas, and other high-risk flood hazard areas such as alluvial fans, flash flood areas, mudslide areas, erosion-prone areas, and high velocity areas.

5.4 RISK REDUCTION: AVOIDING FLOOD HAZARDS

Flood hazards are unlike earthquake hazards and wind hazards. Those hazards often are assigned at the county level because the hazards themselves do not significantly vary from one geographic location within a county to another. Of course, there may be site-specific variations in those hazards, such as soils susceptible to liquifaction during seismic activity, or local topographic differences that influence wind speeds. However, for the most part, the earthquake and wind hazards cannot be avoided by choosing alternative locations.

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

Section 5.6 describes the damage that is sustained by existing buildings that are exposed to flood hazards, including: site damage; structural and nonstructural building damage; destruction or impairment of service equipment; loss of contents; and health and safety threats due to contaminated floodwaters. These types of damage, along with loss of function and community service, are avoided if schools are located away from flood hazard areas. Damage is minimized when schools that must be located in flood hazard areas are built in compliance with minimum requirements.

5.4.1 Benefits/Costs: Determining Acceptable Risk

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

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

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

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

Section 5.6 describes damage and losses that are incurred by buildings exposed to flooding. Direct damage includes damage to physical property, including the site, the building, building materials, utilities, and building contents. Indirect damage that is not listed includes health hazards, functionality impacts, emergency response, evacuation, and expenses associated with occupying another building during repairs.

For the most part, benefits are difficult to measure because they are associated with damage that does not occur, cleanup that is not required, and service that is uninterrupted because flooding does not shut down a school. In addition, benefits accrue over long periods of time, thus making it more difficult to make a direct comparison of benefits with costs of mitigation. Mitigation costs can more readily be expressed in terms of the higher costs of a flood-free site or the initial capital costs of work designed to resist flood damage. Thus, without a full accounting of both benefits and costs, decision makers may not be able to make fully informed decisions. Some questions that should be answered include:

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

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

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

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

- ❍ If access to the school is periodically restricted due to flooding, especially long-duration flooding, what cost impacts will result? How often would the school district have to provide an alternate location to continue classes?

5.4.2 Identifying Flood Hazards at School Sites

To the extent practical, schools and attendant athletic fields and facilities should be located outside of known flood hazard areas. The best available information regarding flooding should be examined, including flood hazard maps, records of historical flooding, and advice from local experts, and others who can evaluate flood risks.

As part of site selection and to guide locating the school building and other improvements on a site, designers should investigate site-specific flood hazard characteristics. Table 5-1 outlines questions that will produce information that must be determined prior to initiating site layout and design work.

Table 5-1: Flood Hazards at School Sites

Evaluation Question	Evaluation Y or N or Comment	Guidance	Data Reference
Is the site near a body of water (with or without a mapped flood hazard area)?		All bodies of water are subject to flooding, but not all have been designated as floodplain on FIRMs. This provides information about the flood hazard on the site and, if present, determines certain regulatory requirements.	FIRM or local flood hazard maps; available for review in local planning and permit offices. Site-specific analyses should be performed by qualified water resources engineers.
Is the site affected by a regulatory floodway?		Development in floodways, including fill and construction of buildings, is prohibited unless demonstrated that there will be no resulting increase in flood elevations.	FIRM, Flood Hazard Floodway Boundary Map, local flood hazard maps; available for review in local planning and permit offices.

Table 5-1: Flood Hazards at School Sites (continued)

Evaluation Question	Evaluation Y or N or Comment	Guidance	Data Reference
Has the site been affected by past flood events?		Records of actual flooding augment studies that predict flooding, especially if historic events resulted in deeper or more widespread flooding.	Local planning and permit offices; local historical society; State Department of Transportation; State Water Resources or Emergency Management Agency; Natural Resources Conservation Service; U.S. Army Corps of Engineers.
Can the site be accessed by emergency and fire vehicles during flood events?		Firefighting efforts during floods are compounded when access roads are flood-prone.	Topographic map with delineated flood hazard area and flood depths used for site layout and access road design.
What is the required minimum protection level required by regulatory authorities?		The 100-year and 500-year flood levels are the minimum required protection levels for projects in mapped flood hazard areas. Critical facilities (including schools) may be required to be above the 500-year flood level. Lower levels of protection may be allowed outside the regulated areas, but are not recommended.	Authority having jurisdiction that establishes design criteria for schools; state building codes and floodplain regulations; local building codes and floodplain regulations.
What is the DFE?		Land below the DFE is in the "floodplain" and subject to regulatory provisions. The DFE is the basis for minimum protection measures; critical facilities (including schools) should be protected to at least 2- or 3-feet higher.	FIRM; local flood hazard map; flood profiles along waterways with detailed studies; site-specific studies for flood hazard areas identified without flood elevations.
What is the predicted depth of flooding?		The depth of flooding influences site layout, site modifications, design of protection measures, and computation of loads on buildings. Sites with deep flooding are less feasible to develop efficiently and cost effectively.	The DFE minus the ground elevation at specific site yields the predicted depth of water. For large parcels of land, the depth of flooding is likely to vary over the site.

Table 5- 1: Flood Hazards at School Sites (continued)

Evaluation Question	Evaluation Y or N or Comment	Guidance	Data Reference
What is the expected velocity of floodwaters on the school site?		Velocity is the rate at which water moves and is measured in feet per second. Velocity is a factor in computing loads associated with hydrodynamic forces, including drag on building surfaces. Depending in part on soil types and vegetative cover, velocity is related to erosion, including streambank erosion, erosion of earthen fill, and local scour around buildings. Velocity also affects public safety.	Approximations of velocity may be interpolated from data in the Floodway Data Table if the waterway was studied using detailed methods, application of approximation methods based on continuity, local observations and sources, or site-specific studies.
Are waves expected to affect the floodplain on the site? (Note: Coastal high hazard areas (V Zones) are not addressed in this manual.)		Waves can exert considerable dynamic forces on buildings and contribute to erosion and scour. Wind-driven waves occur in areas subject to coastal flooding (see discussion on Coastal A Zones) and where unobstructed winds affect wide floodplains (large lakes and major rivers). Standing waves may occur in riverine floodplains where high velocities are present.	FIS (coastal areas); local observations of past events; interpolation of results of site-specific engineering analyses (hydraulic modeling).
Are heavy debris loads and sediment deposits expected (e.g, on alluvial fans)?		Removal of debris and sediment deposits can be expensive, especially from finely graded athletic fields. Impact loads associated with floating debris must be accounted for in design.	Local observations of past events; examination of local land forms created by flood-borne sediments.
How long will water remain on the school site?		Duration of flooding affects the stability of permeable and porous building materials. Unless specifically designed for total saturation, earthen fills may become unstable under long-duration flood conditions. Duration may affect site access and emergency response.	Local observations of past events; examination of site-specific engineering analyses (hydrologic modeling).
How quickly will floodwaters affect the site?		Warning time is a key factor in the safe and orderly evacuation of a school. Certain protective measures require adequate warning time so that specific actions can be taken by skilled personnel.	Local emergency manager; local observations; National Weather Service.

Table 5- 1: Flood Hazards at School Sites (continued)

Evaluation Question	Evaluation Y or N or Comment	Guidance	Data Reference
If the waterway is on or adjacent to the school site, is there evidence of bank erosion?		Erosion is a natural riverine process. Land adjacent to actively eroding waterways is considered unstable over the long term. Improvements should not be exposed to active erosion, or the site design must include stabilization measures.	Site inspection; local observations of past events; soils testing.
Is the site within the area predicted to flood if a levee or floodwall fails or is overtopped?		Flood protection works may be distant from sites and not readily observable. Although a low probability event, failure or overtopping can cause unexpected and catastrophic damage because the protected lands are not regulated as flood hazard areas.	Local public works department; state floodplain management agency; U.S. Army Corps of Engineers.
Is the site within the area predicted to flood if an upstream dam fails?		The effects of an upstream dam failure are not shown on the FIRM or most flood hazard maps prepared locally. Although dam failure is considered a very unlikely event, the potential threat should be evaluated due to the catastrophic consequences. (Note: Owners of certain dams should have Emergency Action Plans geared towards notification and evacuation of vulnerable populations.)	Local emergency management office; state dam safety office.
Is there a formal channel maintenance program?		Flooding can be exacerbated by debris blockages or build-up of excessive sediment in the channel.	Local public works or road maintenance department.
Are there nearby locations on the waterway where debris may affect the flow of water (e.g., bridges, culverts, narrow valleys)?		Flooding may be exacerbated by debris blockages where flow is constricted.	Local public works or road maintenance department.

5.5 RISK REDUCTION: FLOOD-RESISTANT NEW SCHOOLS

When a decision is made to build a new school on a site that is affected by flooding, the characteristics of the site and the nature of flooding must be examined prior to making several design decisions. The most important consideration is location of the buildings.

Risks and certain costs associated with flood-resistant construction are minimized by putting principal buildings on the highest available ground. Positioning the buildings, parking lots, and athletic fields is influenced by identification of all site constraints, which include such factors as presence of flood hazard areas (see Table 5-1), wetlands, poor soils, steep slopes, sensitive habitats, mature tree stands, and other environmental factors required by the authority that approves development plans and all applicable regulatory authorities.

Several aspects of design of flood-resistant buildings and sites are important and are described in this section, including site modifications, foundation type and elevation considerations, floodproofing options, flood-resistant accessory structures, building service equipment and utility installations, and access roads.

5.5.1 Site Modifications

When sites that are affected by flood hazard areas must be used, and when flood hazard areas cannot be avoided, it may be appropriate to evaluate certain site modifications that may be feasible to provide a level of protection to buildings. The evaluations involve engineering analyses in order to determine if the desired level of protection can be provided cost-effectively, while ensuring that site modifications do not alter the floodplain in ways that increase flooding. Typical site modifications (with cautions that must be examined to determine effectiveness) include:

- **Earthen fill.** Fill can be placed in the flood hazard area with the effect of moving the floodplain boundary. If the fill is placed and compacted to be stable during the rise and fall of floodwaters and is protected from erosion, modifying a site with fill in order to elevate a school is preferred over other methods of elevation. Not only will the building be less exposed to flood forces, but, under some circumstances (long duration floods), the school may be able to continue to function. Whether nonstructural fill is placed solely to modify the site, or structural fill is placed for the purpose of elevating buildings, placement of fill can change flooding characteristics. Engineering analyses can be conducted to determine if eliminating floodplain storage by fill will result in changing the flow of water, creating higher flow velocities, or increasing the water surface elevation.

- **Excavation.** Excavation alone rarely results in significantly altering the floodplain on a given parcel of land. It is more commonly used in conjunction with fill in order to off-set or compensate for the adverse impacts of fill.

- **Earthen levee or dike.** A levee is a specially designed barrier that modifies the floodplain by keeping the water away. Levees are significant structures that require detailed, site-specific geotechnical investigations; engineering analyses to identify whether flooding will be made worse on other properties; structural and site design to suit existing constraints; design of interior drainage (on the land side); and long-term commitment for maintenance, inspection, and repairs. It is important to remember that areas protected by levees are protected only up to a certain design flood level; once overtopped, most levees fail and catastrophic flooding of previously protected areas results. Levees that protect essential and critical facilities usually are designed for the 0.2%-annual chance flood (500-year) and have added height (called “freeboard”) to increase the factor of safety (see Figure 5-4).

- **Floodwall.** Floodwalls are similar to levees in that they provide protection only up to a certain design flood level, and overtopping can result in catastrophic flooding. A floodwall typically is a significant structure that is designed specifically to hold back water of a certain depth based on the design flood for the site. Generally, due to design factors, floodwalls are most effective in areas with relatively shallow flooding. As with levees, designs must accommodate interior drainage on the land side, and maintenance and operations are critical for adequate performance. Floodwalls that protect essential and critical facilities usually are designed for the 0.2%-annual chance flood (500-year) and have added height (freeboard) to increase the factor of safety.

5.5.2 Elevation Considerations

The selection of the appropriate method of elevating school buildings above the design flood elevation depends on many factors, including cost, level of safety and property protection desired, nature of the flood hazard area, etc. The minimum requirement is that the lowest floor (including basement) be at or above the DFE (plus freeboard, if required); given the importance of school buildings, additional height above that elevation is appropriate. Elevation can be accomplished by different foundation methods:

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

- **Slab-on-grade on structural fill.** This is considered to be the safest method to elevate a building. Structural fill can be placed and shaped so that, when water rises up to the DFE, it will not touch the building (Figure 5-5) and building access is maintained. The fill must be designed to minimize adverse impacts such as increasing flood elevations on adjacent properties, increasing erosive velocities, and causing local drainage problems. To ensure stability, especially as floodwaters recede and the soils drain, fill must be designed for the anticipated water depths and duration. A geotechnical engineer or soil scientist may need to examine underlying soils to determine if consolidation over time may occur. In addition, the effects of long-term compaction of the fill should be considered, and may prompt additional elevation as a factor of safety. The horizontal extent of fill from the foundation should be designed to facilitate access by emergency and fire vehicles, with a minimum 25-foot width recommended. Designers are cautioned to avoid excavating a basement into fill without added structural protection due to the potential for significant hydrostatic loads and uplift on basement floors.

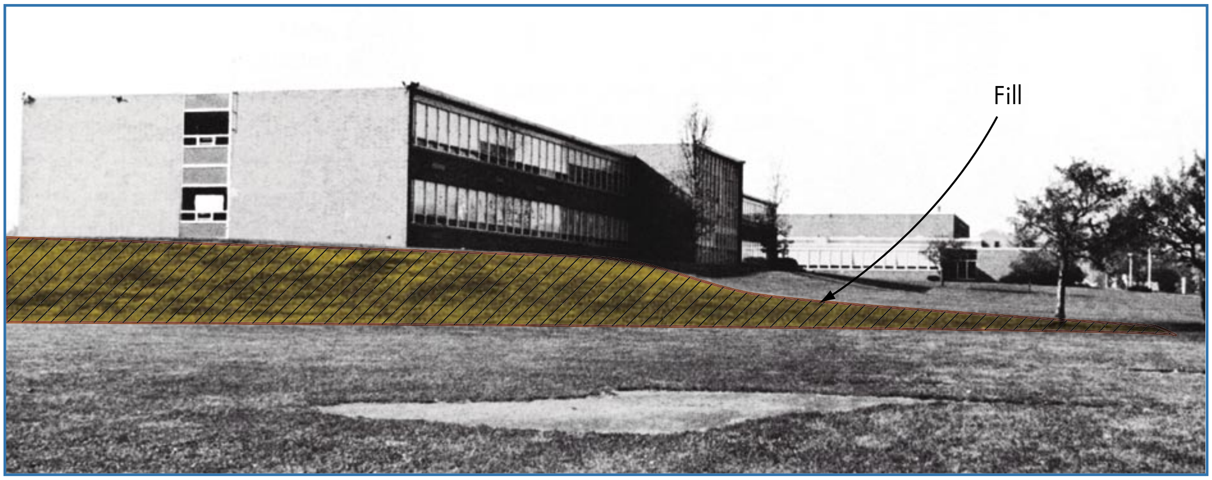

Figure 5-5 High school in Bloomsburg, PA, elevated on fill

SOURCE: U.S. ARMY CORPS OF ENGINEERS, *FLOOD-PROOFING SYSTEMS & TECHNIQUES*, 1984

- **Stem walls (earth-filled perimeter walls).** Stem wall foundations are designed to come in contact with floodwaters on the exterior. They are more stable than perimeter walls (crawlspaces), but could experience structural damage if undermined by local scour and erosion. Designs must account for anticipated debris and ice impacts and incorporate methods and materials to minimize impact damage.

- **Columns or shear walls.** Open foundations minimize changes to the floodplain and local drainage patterns, and the area under the building can be used for student activities or parking (see Figure 5-6). Columns and shear walls must also account for hydrodynamic loads and debris and ice impact loads. Flood loads on shear walls are reduced if they are oriented parallel to the anticipated direction of flow. Erodible soils may be present and local scour may occur; both must be accounted for in designs by extending the foundation wall below the expected scour depth.

Figure 5-6 Elementary school in Jefferson County, OH, elevated on columns

SOURCE: U.S. ARMY CORPS OF ENGINEERS, *FLOOD-PROOFING SYSTEMS & TECHNIQUES,* 1984

- **Extended solid perimeter walls (crawlspace).** Unlike stem wall foundations, solid perimeter walls enclose an open area and must be designed with openings specifically intended to equalize interior and exterior water levels to prevent differential hydrostatic pressures that could lead to structural damage. Wall design must also account for hydrodynamic loads, and debris and ice impact loads. The enclosed area (the crawlspace) must not contain equipment (including ductwork) below the DFE (plus freeboard, if required). Designers must provide adequate underfloor ventilation and subsurface drainage to minimize moisture problems after flooding.

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

5.5.3 Floodproofing Considerations

According to the model building codes and the NFIP regulations, schools are treated as nonresidential buildings and may be dry floodproofed using measures to prevent water from penetrating the building envelope and utilities. However, careful consideration of the implications of potential physical damage and safety should be undertaken before a decision is made to construct new schools using floodproofing methods.

All flood protection measures are designed for certain flood conditions. Therefore, there is always a chance that the design will be exceeded (i.e., water will rise higher than accounted for in the design). When this happens to a dry floodproofed building, the consequences can be catastrophic. As a general rule, floodproofing is a poor choice for new essential and critical facilities (including schools) when avoidance of the floodplain or elevation methods to raise the building above the flood level can be applied. Floodproofing may be acceptable for retrofitting existing schools under certain circumstances (see Section 5.7.4).

> Floodproofed schools must never be considered safe for occupancy during periods of high water; floodproofing measures are intended only to reduce physical damage.

Dry floodproofing involves a combination of design and special features that are intended to prevent the entry of water into a building while also resisting flood forces. It involves structural reinforcement so that exterior walls are sufficiently robust to withstand the loads described in Section 5.2.1 (hydrostatic pressure, hydrodynamic loads, wave loads, and debris impact loads). For NFIP flood insurance, floodproofing must extend at least 1 foot above the BFE or premiums will be very costly. Therefore, a higher level of protection is recommended. Exterior walls must also be designed to prevent infiltration and seepage of water, whether through the wall itself or through any openings, including where utility lines penetrate the envelope. Floodproofing techniques are considered to be permanent measures if they are always in place and do not require any specific action to be effective.

If located below the DFE, typical doors and windows present significant failure points. Special doors and window shields are available commercially and can be designed to provide protection against fairly deep floodwaters. The building must be specifically designed for these protective measures or loads may cause frames to separate from the building.

Use of contingent floodproofing measures that require installation or activation, such as window shields or inflatable barriers, significantly reduces the certainty that floodproofing will be effective. Rigorous adherence to a periodic maintenance plan is critical to ensure proper functioning. Not only must the school have a formal, written plan, but the people responsible for implementing the measures must be informed and trained. Also critical to success is that school personnel must receive a credible warning with sufficient time to allow getting to the site and putting the measures in place. In addition, floodproofing devices often rely on flexible seals that require periodic maintenance and that, over time, may deteriorate and become ineffective. Therefore, a maintenance plan must be developed and an annual inspection and training must be conducted.

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

5.5.4 Accessory Structures

Depending on the nature of structures that are accessory to a school, full compliance with floodplain management regulations is required and is appropriate to minimize future damage. Buildings that serve educational purposes (e.g., offices, classrooms), even if detached from the primary school building, are not accessory in nature. Portable classrooms are not accessory structures; accessory structures commonly associated with schools include storage sheds, bleachers, garages, restrooms, and refreshment stands.

Accessory structures may be "wet floodproofed" using techniques that allow them to flood while minimizing damage. They must be anchored to resist flotation, collapse, and lateral movement. Flood-resistant materials must be used and utilities elevated above the DFE (plus freeboard, if required). Openings must be provided to allow the free inflow and outflow of floodwaters to minimize hydrostatic loads that cause structural damage. Other flood damage and flood loads must be accounted for by other means. Because wet floodproofed accessory buildings are designed to flood, school staff must be aware that contents will be damaged.

5.5.5 Utility Installations

Utilities associated with new schools in flood hazard areas must be protected either by elevation or special design measures. Utilities subject to this provision include all systems, equipment, and fixtures, including mechanical, electrical, plumbing, and heating, ventilating, and air conditioning systems and equipment. Potable water systems (wellheads and distribution lines) and wastewater collection lines are addressed in Section 5.7.6.

Utility systems and equipment are best protected when elevated above the DFE (plus freeboard, if required). Equipment inside elevated buildings is also elevated and equipment inside accessory structures must be elevated if the accessory building is wet floodproofed. Exterior equipment must be elevated on fill or on platforms, or other support structures. Designers should pay particular attention to underfloor utilities and ductwork to ensure that they are properly elevated.

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

5.5.6 Potable Water and Wastewater Systems

New installations of potable water systems and wastewater collection systems are required to resist flood damage, including damage associated with infiltration of floodwaters and discharge of effluent. Health concerns arise when water supply systems are exposed to floodwaters and contamination from flooded sewage systems pose health and environmental risks. On-site water supply wellheads should be protected with watertight casings to minimize infiltration of surface waters.

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

On-site sewage disposal systems are unlikely for most new school construction. However, in the event such systems are considered, designers are advised that local or state health departments may impose constraints that limit or prevent locating septic fields in floodplain soils or within a mapped flood hazard area. If allowed, septic fields should be located on the highest available ground to minimize inundation and impairment by floodwaters.

5.5.7 Storage Tank Installations

Whether above ground or under ground, storage tanks located in flood hazard areas must be designed to resist flotation, collapse, and lateral movement. Aboveground tanks must be elevated or adequately anchored to account for maximum buoyancy under design flood conditions, assuming the tanks are empty. Similarly, underground tanks must be anchored for maximum buoyancy under design flood conditions, assuming the tanks are empty. In all cases, designers are cautioned to address hydrodynamic loads and debris impact loads that may affect tanks that are exposed to floodwaters. Vents and fill openings or cleanout accesses should be elevated above the DFE or designed to prevent the inflow of floodwaters or outflow of the contents of tanks.

5.5.8 Access Roads

Access roads to schools should be designed to minimize impacts on flood hazard areas, minimize damage to the road itself, and to minimize exposing vehicles to dangerous situations, although balancing those elements can be difficult, depending on the site and specific flood characteristics. Designers should take the following into consideration:

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

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

- **Drainage structure and road surface design.** The placement of multiple drainage culverts, even if not needed for local drainage, can facilitate the passage of floodwaters and minimize the potential for a road embankment to act as a dam. Embankments should be designed to remain stable during high water and as waters recede, and should be sloped and protected to resist erosion and scour. For roads that are designed to flood, the surface and shoulders should be designed to resist erosion.

5.6 VULNERABILITY: WHAT FLOODS CAN DO TO EXISTING SCHOOLS

Existing flood-prone schools are exposed to damage, and the nature and severity of damage is a function of site-specific flood characteristics. As described below, damage may include: site damage; structural and nonstructural building damage; destruction or impairment of service equipment; loss of contents; and health and safety threats due to contaminated floodwater.

Regardless of the nature and severity of damage, flooded schools are closed while cleanup and repairs are undertaken. The length of the closure, and thus the impact on the ability of the school district to return to teaching, depends on the severity of the damage and lingering health hazards. It may also depend on whether the building was fully insured or whether disaster assistance is made available quickly to allow speedy repairs and reconstruction. Sometimes repairs are put on hold pending a decision on whether a school should even be rebuilt at the flood-prone site. When damage is substantial, reconstruction is allowed only if compliance with flood-resistant design provisions is achieved (see Section 5.7.3).

5.6.1 Site Damage

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

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

- **Debris and sediment removal.** Even when buildings are not subject to flood damage, floods can produce large quantities of debris and sediment that can damage a site and that are expensive to remove, especially from athletic fields.

- **Fences.** Some fences trap floating debris and can significantly restrict the free flow of floodwaters. Fences can be damaged by flowing water and can be flattened if the buildup of debris results in significant loads.

- **Playing field surfaces.** In addition to damage by erosion and scour, graded grass fields and applied track surfaces can be damaged by standing water and deposited sediments.

- **Accessory structures.** Accessory structures such as storage sheds, bleachers, restrooms, and refreshment stands can sustain both structural and nonstructural damage. Such structures may be designed and built using techniques that minimize damage potential.

- **Access roads.** Access roads that extend across flood-prone areas may be damaged by erosion, washout of drainage culverts, failure of fill materials, and loss of surface.

- **Other.** Objects outside of buildings, including cars and school buses, can be damaged or washed away.

5.6.2 Structural Damage

Structural damage includes all damage to the load-bearing portions of a building. Damage to other components of buildings is described below: finish materials (Section 5.6.3), utility service equipment (Section 5.6.4), and contents (Section 5.6.5). Structural damage can be caused by each of the characteristics of flooding described in Section 5.2.1:

- **Depth.** The hydrostatic load or pressure against a wall or foundation is directly related to the depth of water (see Figure 5-7). Standard stud and siding, or brick faced walls, may collapse under hydrostatic loads associated with relatively shallow depths of water. Reinforced masonry walls perform better than unreinforced masonry walls, although an engineering analysis is required to determine performance. Walls and floors of below-grade areas (basements) are particularly susceptible to damage by hydrostatic pressure. When soils are saturated, pressures against below-grade walls are a function of the total depth of water, including the depth below-grade and the weight of the saturated soils.

- **Buoyancy and uplift.** If below-grade areas are essentially watertight, buoyancy or uplift forces can rupture concrete floors or float a building out of the ground (see Figure 5-8). Flood-prone buildings that are not adequately anchored can be floated or pushed off foundations. Although rare for large and heavy school buildings, this is a concern for outbuildings and portable (temporary) classrooms.

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

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

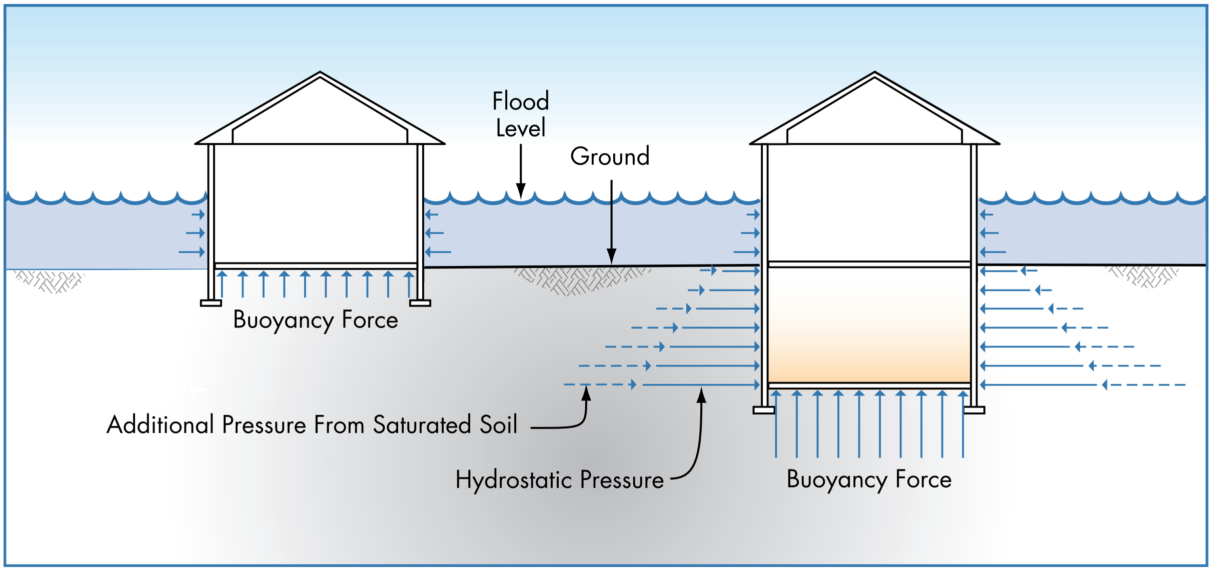

Figure 5-7 Hydrostatic force diagram

Figure 5-8
Fractured concrete basement floor, Gurnee, IL, 1986

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

5.6.3 Saturation Damage

Many flood-prone buildings are exposed to flooding that is not fast moving or that may be relatively shallow and not result in structural damage. Simple saturation of the building and its furnishings can result in significant and costly damage, including long-term health complications associated with mold. Floodwaters often are contaminated with chemicals or petroleum products. Under such circumstances, recovery generally involves removal of nonstructural materials and finishes because cleanup and decontamination is expensive and time-consuming. Damage to contents is discussed in Section 5.6.5.

Saturation damage varies somewhat as a function of duration. Use of water-resistant materials will help to minimize saturation damage and reduce the costs of cleanup and restoration to service (see Flood-Resistant Materials Requirements, FIA-TB-2):

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

- **Flooring.** Most schools have durable floors that resist water damage. Ground floors typically are slab-on-grade and finished with tile or sheet goods. Flooring adhesives since the early 1990s likely are latex-based and tend to break down when saturated. Most carpeting, even indoor-outdoor materials, are difficult to clean. Wood floors are particularly susceptible to saturation damage. Short duration inundation may not cause permanent deformation of some wood floors, such as may be present in older buildings. However, because of low tolerance for surface variations, gymnasium floors are particularly sensitive and tend to warp after flooding of any duration.

- **Wall and wood components.** When soaked for long periods of time, some building components change composition or shape. Wet wood will swell and, if dried too quickly, will crack, split or warp. Plywood can delaminate and wood door and window frames may swell and become unstable. Gypsum wallboard, wood composition panels, other wall materials, and wood cabinetry not intended for wet locations can fall apart (see Figure 5-9). The longer these materials are wet, the more moisture, sediment, and pollutants they will absorb. Some wall materials such as the paper facing on gypsum wallboard, "wick" standing water, resulting in damage above the actual high-water line (see Figure 5-10).

- **Metal components.** Metal structural components are unlikely to be permanently damaged by inundation. Metal partitions are particularly susceptible when saturated because they cannot be thoroughly dried and cleaned. Depending on the degree of corrosion protection on the metal, repetitive flooding by saline coastal waters may contribute to long-term corrosion.

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

Figure 5-9
Damaged walls and cabinets, Peoria County, IL

Figure 5-10
Basement damage at a grade school in Gurnee, IL, 1986

5.6.4 Utility System Damage

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

- **Displacement of equipment and appliances.** Installation below the flood level exposes equipment and appliances to various flood forces, including drag due to flowing water and buoyancy. Gas-fired appliances are particularly dangerous: flotation can separate the appliance from the gas source, resulting in building fires, and explosive situations. Displaced equipment may dislodge lines from fuel oil tanks, not only contributing to the threat of fires, but also causing water pollution and environmental damage. Firefighting efforts are compounded if access to the school is limited due to flooded roads.

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

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

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

- **Mold and dust.** Furnaces, air handlers, and ductwork that have been submerged must be thoroughly cleaned and sanitized. Otherwise, damp conditions contribute to the growth of mold and the sediment can be circulated throughout the school, causing respiratory problems.

- **Gas-fired systems.** Water-borne sediment can impair safe functioning of jets and controls in gas-fired furnaces and water heaters, necessitating that they be professionally cleaned and inspected prior to restoration of service.

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

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

Damage to public utility service (potable water supply and wastewater collection) can have consequential damage to schools:

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

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

5.6.5 Contents Damage

Schools may contain high value contents that can be damaged and unrecoverable when subjected to flooding. For the purpose of this discussion about the nature of flood-related contents damage, the term "contents" includes furniture, computers, laboratory equipment and materials, records, and library materials. The following types of contents often are considered total losses:

- **Furniture.** Depending on the nature of wood furniture, it may withstand short-duration inundation, requiring only cleanup. In long-duration flooding, porous woods become saturated and swollen, and joints may separate. Furniture with coverings or pads generally cannot be restored. Metal furniture is difficult to thoroughly dry and clean, is subject to corrosion, and typically is discarded.

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

- **School records.** When offices are located in flood-prone space, valuable school records may be lost. Although expensive, some recovery of computerized and paper records may be possible with special procedures.

- **Library books and collections.** It is generally not economical to recover library materials and special collections that are saturated by floodwaters.

- **Laboratory materials and equipment.** Depending on the nature of laboratory materials, cleanup may require special procedures. Generally, equipment is difficult to restore to safe functioning.

- **Kitchen goods and equipment.** Stainless steel equipment and surfaces generally have cleanable surfaces that can be disinfected and restored to service. Because of contamination, kitchen contents and perishables cannot be recovered.

5.7 RISK REDUCTION: PROTECTING EXISTING SCHOOLS

Schools that already are located in flood hazard areas may be made more resistant to flood damage. School districts may take such action when flood hazards are identified and there is a desire to proactively undertake risk reduction measures. Interest may be prompted by a flood or by the requirement to address flood resistance as part of proposed substantial improvements or additions. Table 5-2 offers some questions to help identify building characteristics that are important when considering risk reduction measures.

> School districts should be aware of the importance of flood insurance for flood-prone existing schools. If not insured for flood peril, the amount of flood insurance coverage that should have been in place will be deducted from any federal disaster assistance payment that would otherwise have been made available. A district may have to absorb up to $1 million in unreimbursed flood damage per building because the NFIP offers $500,000 in building coverage and $500,000 in contents coverage.

Work on existing school buildings and sites is subject to codes and regulations and the appropriate regulatory authority with jurisdiction should be consulted. With respect to reducing flood risks, work generally falls into the following categories described in Sections 5.7.1 though 5.7.8.

Table 5-2: Characteristics of Existing School Buildings

Question	Guidance
What is the construction type and the foundation type and what are their bearing capacities?	Dry floodproofing creates large unbalanced forces that can jeopardize walls and foundations that are not designed to resist the hydrostatic and hydrodynamic loads.
Is the building suitable for elevation-in-place or relocation to higher ground?	Elevating a building provides a higher degree of protection than dry floodproofing. Depending on the type and soundness of the foundation, even large buildings can be elevated or relocated.
Are any building spaces below-grade (basements)?	Below-grade spaces and their contents are most vulnerable. If flooding is allowed, rapid pump out can unbalance forces if the surrounding soil is saturated, leading to structural failure. If intended to be dry floodproofed, buoyant forces must be taken into consideration.
What types of openings penetrate the building envelope below the DFE (doors, windows, cracks, vent openings, plumbing fixtures, floor drains, etc.)?	For dry floodproofing to be effective, every opening must be identified and measures taken to permanently seal or to prepare special barriers to resist infiltration. Sewage backflow can enter through unprotected plumbing fixtures.
Are utility systems and HVAC equipment (including ductwork) below the DFE?	Relocating utility equipment to higher floors or elevated additions or platforms minimizes damage and facilitates rapid reoccupancy.
Are electrical panels and primary service below the DFE? Is the emergency power generator?	Relocating electrical panels to higher floors or elevated additions or platforms minimizes damage and facilitates rapid reoccupancy.

5.7.1 Site Modifications

Modifying an existing school property that is subject to flooding requires careful examination by an experienced professional engineer. Determining the suitability of a specific measure requires a complex evaluation of many factors, including the nature of flooding and the nature of the site. Table 5-1 identifies questions to be examined relative to flood hazards that influence the measures that may be applicable to modifying existing school sites. Some characteristics may make it infeasible to apply flood-resistant measures to existing schools (e.g., depths greater than 3 to 4 feet, very high velocities, flash flooding or rapid rate of rise [insufficient warning], and very long duration). Each of these measures has limitations, including the fact that the level of protection will be exceeded by floods that are larger than the design flood.

Site modifications may be designed to keep water away from a building. In each case, careful attention must be given to internal drainage. The rain that falls on the school and the portion of the site inside these flood protection measures will collect and must be accounted for or it may contribute to damage. Two general approaches are taken: provide sufficient ponding storage capacity or install pumps to transfer accumulated runoff outside the protection measure. Site modifications include:

> Schools protected by local berms, levees, and floodwalls should never be occupied during flood conditions. The consequences of failure or flood levels overtopping these measures can be catastrophic and create high-risk conditions.

- **Regrading the site (berm).** Where a school is exposed to relatively shallow flooding and sufficient land area is available, regrading the site or construction of a non-engineered earthen berm may provide adequate protection.

- **Earthen levee or dike.** Earthen levees are engineered structures that are designed to keep water away from land area and buildings (Figure 5-11). Hydraulic evaluations and geotechnical investigations are required to determine their feasibility and effectiveness. For existing school sites, constraints include the availability of land (levees have a large “footprint” and require large land areas), cost (including availability of suitable fill material and long-term maintenance), and difficulties with site access. Levees rarely are used to protect a single site, although they may offer a reasonable solution for a group of buildings. Locating levees and floodwalls within a designated floodway generally is not allowed. Rapid onset flooding makes it impractical to design a flood levee with access points that require installation of a closure system. Earthen levees may also be subject to high velocity flows that cause erosion and affect the stability of earthen levees.

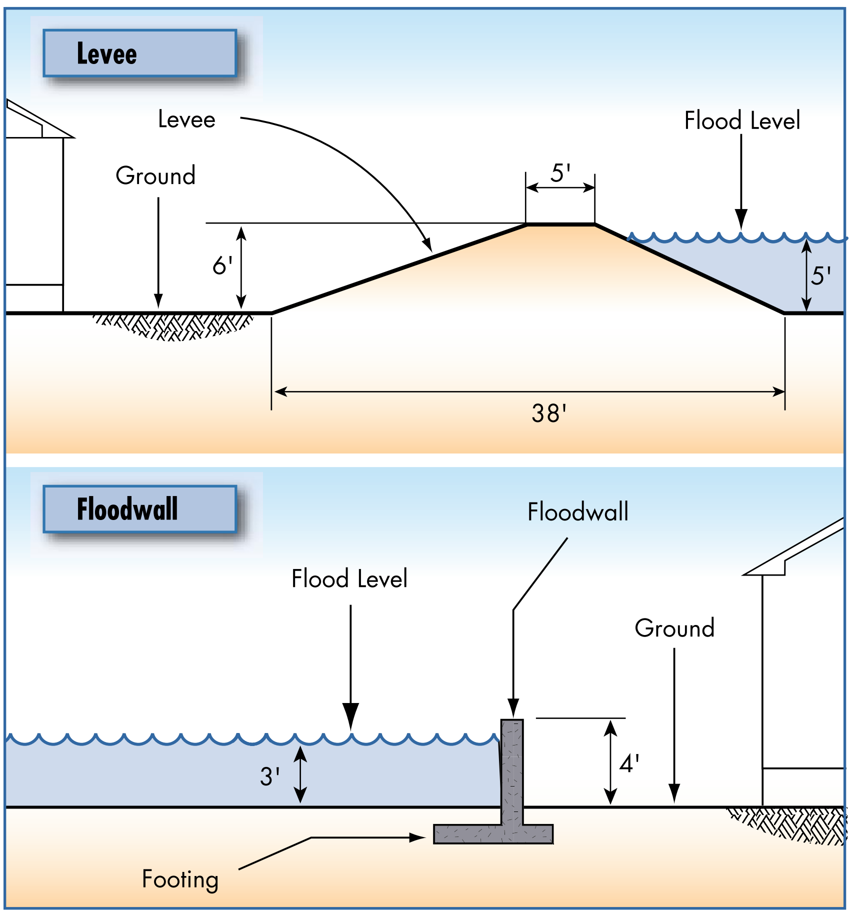

Figure 5-11
Schematic of typical earthen levee and permanent floodwall

- **Permanent floodwall.** Floodwalls are freestanding, permanent engineered structures that are designed to prevent encroachment of floodwaters. Typically, floodwalls are located at some distance from buildings so that structural modification of the existing building is not required. Floodwalls may protect only the low side of a site (in which case they must "tie" into high ground) or completely surround a site (which may affect access because special closure structures are required and must be installed before the on-set of flooding, Figure 5-12).

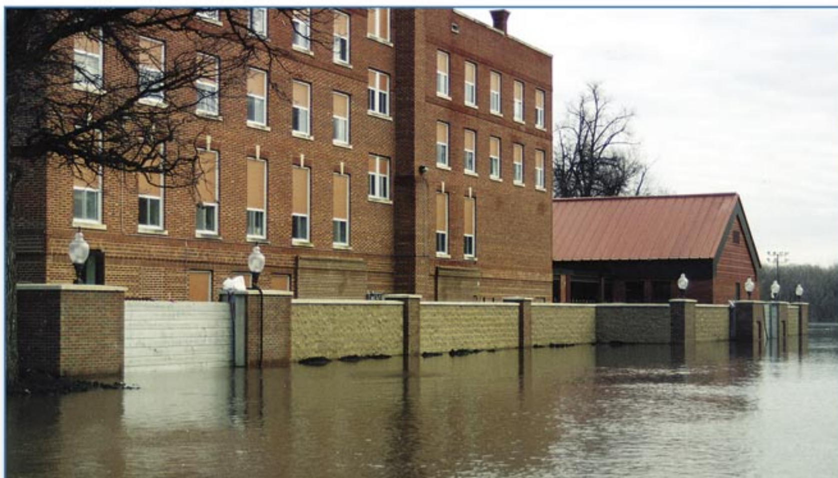

Figure 5-12
Masonry floodwall with multiple engineered closures at Oak Grove Lutheran School, Fargo, ND

SOURCE: FLOOD CONTROL AMERICA, LLC.

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

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

Other significant constraining factors include poor soils and insufficient land area. These also make site modifications either infeasible or very costly. A school may be among several buildings and properties that can be protected, increasing the benefits. For any type of barrier, rainfall that collects on the land side must be accounted for in the design.

5.7.2 Additions

The model building codes treat additions as new construction. Therefore, additions to existing schools that are located in flood hazard areas are required to comply with the code. Elevation of an addition on fill may not be feasible unless structural fill can be placed adjacent to an existing building. Section 5.5.2 outlines other elevation options that are applicable to additions. Utility service equipment for the addition must also meet the requirements for new construction and new installations (see Section 5.5.5).

With respect to code compliance and designing additions to resist flood damage, one of the more significant issues that may come up is ease of access. If the lowest floor of the existing school building is below the DFE, steps, ramps, or elevators will be required for the transition to the new addition. Under the regulations of the NFIP and guidance that FEMA offers to jurisdictions that may wish to consider variances, it is not considered appropriate to grant a variance to the elevation requirement for an addition because alternative means of access are available.

5.7.3 Repairs, Renovations, and Upgrades

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

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

The model building codes and the regulations of the NFIP and the model building codes require that work that constitutes 'substantial improvement' of an existing building be in compliance with the flood-resistant provisions of the code. Non-substantial improvements should take into account measures to reduce future flood damage, such as many described in Section 5.7.7 and wet floodproofing measures that allow water to enter the building to avoid structural damage, and emergency measures (see Section 5.7.8).

Compliance with flood-resistant provisions means the building must be elevated or dry floodproofed. Both options can be difficult for schools, given the typical size and complexity of school buildings. Dry floodproofing is described in Section 5.7.4 and is generally limited to water depths on the order of 3 to 5 feet.

Elevating an existing building presents an entirely different set of challenges and also requires detailed structural engineering analyses. It involves the same equipment and methods used to move other types of buildings, and expert building movers have successfully moved large, heavy, and complex buildings, sometimes by segmenting them. A school building that is elevated-in-place must meet the same performance standards set for new construction (see Section 5.5).

5.7.4 Retrofit Dry Floodproofing

Modifications of an existing building may be required, including construction of a reinforced supplementary wall, measures to counter buoyancy (especially if there is below-grade space), installation of special watertight doors or barriers, and providing watertight seals around points of entry of utility lines. The details of structural investigations and structural design of such protection measures are beyond the scope of this manual.

> Dry floodproofing refers to measures and methods to render a building envelope and utility systems substantially impermeable to floodwaters.

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

- Structural strength of walls.
- The effects of buoyancy on below-grade areas.
- Protection where utilities enter the building; and the seepage of water through walls. Secondary walls can be constructed immediately adjacent to existing walls, with a waterproof membrane, to provide adequate strength.

Application of waterproofing products or membranes may minimize infiltration of water through exterior walls, although there are limitations and concerns with durability. Measures that require human intervention are considered emergency measures and are discussed in Section 5.7.8.

5.7.5 Utility Installations

Some aspects of an existing school's utility systems may be modified to reduce damage. The effectiveness of such measures depends not only on the nature of flooding, but the type of utility and the degree of exposure. Table 5-2 listed some questions that will help facility planners and designers to examine risk reduction measures.

Even if a school building is unlikely to sustain extensive structural damage due to flooding, high costs and delayed reoccupancy may result from flood-damaged utility systems. Risk reduction design measures can be applied whether undertaken as part of large-scale retrofits of existing schools or as separate projects:

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

- **Elevate components.** Whether located inside or outside of the building, some components of utility systems can be elevated-in-place on platforms, including electric transformers, water heaters, air conditioning compressors, furnaces, boilers, and heat pumps (see Figures 5-13 and 5-14).

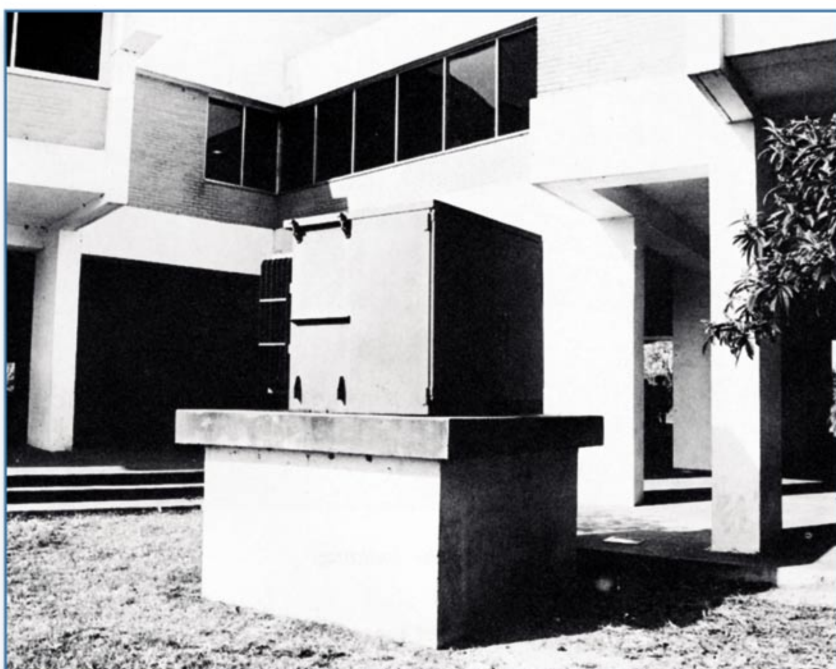

Figure 5-13
Elevated electric transformer at an elementary school in Verret, LA

SOURCE: U.S. ARMY CORPS OF ENGINEERS, *FLOOD-PROOFING SYSTEMS & TECHNIQUES*, 1984

Figure 5-14
Elevated utilities behind an elementary school in Wrightsville Beach, NC

- **Anchor tanks and raise openings.** Existing tanks can be elevated or anchored (both underground and aboveground tanks), as described in Section 5.5.7. If anchored below the DFE, tank inlets, vents, fill pipes, and openings should be elevated above the DFE or fitted with covers designed to prevent the inflow of floodwaters or outflow of the contents of the tanks.

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

- **Elevate control equipment.** Control panels, gas meters, and electrical panels can be elevated, even if the equipment cannot be protected.

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

5.7.6 Potable Water and Wastewater Systems

All plumbing fixtures that are connected to the potable water system may become weak points in the system if they allow floodwaters to contaminate the system. Relocating such uses to at least 2 feet above the DFE provides protection. Wellheads can be sealed with watertight casings or protected with a sealed enclosure.

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

5.7.7 Other Damage Reduction Measures

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

- ❍ Retrofit the building envelope with openings specifically designed to allow floodwaters to flow in and out to minimize hydrostatic pressure on walls. Although allowing water to enter the building, this measure minimizes the likelihood of major structural damage. Walls that enclose interior spaces would also be retrofitted with openings.
- ❍ Replace interior walls that have cavities with flood-resistant construction or removable panels to facilitate cleanup and drying.
- ❍ Abandon use of below-grade areas (basements) by filling to prevent structural damage.

- ❍ Permanently relocate high-value uses that often are found on the ground floor of schools (e.g., offices, school records, libraries, and computer laboratories) to higher floors or elevated additions.
- ❍ Install backflow devices in sewer lines.
- ❍ Pre-plan actions to move damageable furniture and high-value contents from lower floor to higher floors, when a flood warning is issued.
- ❍ Replace wall, flooring, and finish materials with flood-resistant materials.
- ❍ Use epoxy or other impervious paints on concrete and other pervious surfaces to minimize contamination.
- ❍ Install separate electric circuits and ground fault interrupter circuit breakers in areas that will flood. Emergency measures should be provided so that electrical service can be shut down to avoid electrocution hazards.
- ❍ Relocate chemicals to areas not subject to flooding.

5.7.8 Emergency Measures

Emergency response to flooding is outside the scope of this manual. However, because some existing schools may not be retrofitted to provide protection against the design flood, it may be appropriate to examine feasible emergency measures that may provide some protection. The following discussion pertains only to emergency measures that have been used to reduce flood damage to older buildings that are already located in flood hazard areas. These measures do not achieve compliance with building and life safety codes, do not provide protection to occupants, and experience a very high frequency of failure.

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

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

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

- **Panels for doors.** For shallow and short-duration flooding, plywood panels or panels of other sturdy material can be made for doorways to minimize the entry of floodwaters. Effectiveness is increased significantly if a flexible gasket or sealant is provided and the mounting hardware is designed to apply even pressure. Personnel must know where the materials are stored and be trained in deployment.

5.8 THE SCHOOL AS AN EMERGENCY SHELTER

Emergency managers regularly identify schools to serve as short-term and/or long-term shelters. They are attractive sites for shelters because they have kitchen facilities that are designed to serve many people, restroom facilities that are likely to be adequate for many people, and space for cots in gymnasiums, cafeterias, and wide corridors.

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

Additional measures that may be appropriate for consideration by the school district and designer include:

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

5.9 REFERENCES AND SOURCES OF ADDITIONAL INFORMATION

Obtaining Selected Publications:

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

- U.S. Army Corps of Engineers publications can be found online at: http://www.usace.army.mil/inet/functions/cw/cecwp/NFPC/nfpc.htm.

American Society of Civil Engineers, Inc. *Flood Resistant Design and Construction*, ASCE/SEI 24-98, Reston, VA, 2000.

American Society of Civil Engineers, Inc. *Minimum Design Loads for Buildings and Other Structures*, ASCE-7-02, Reston, VA, 2002.

Federal Emergency Management Agency, *Answers to Questions about Substantially Damaged Buildings*, FEMA 213, Washington, DC, May 1991.

Federal Emergency Management Agency, *Answers to Questions about the National Flood Insurance Program*, FEMA 387, August 2001.

Federal Emergency Management Agency, *Coastal Construction Manual*, FEMA 55 (3rd Edition), 2000.

Federal Emergency Management Agency, *Design and Construction Guidance for Community Shelters*, FEMA 361, Washington, DC, July 2000.

Federal Emergency Management Agency, *Engineering Principles and Practices for Retrofitting Flood-prone Residential Buildings*, FEMA 259, Washington, DC, January 1995.

Federal Emergency Management Agency, *Floodproofing Non-Residential Structures*, FEMA 102, Washington, DC, May 1986.

Federal Emergency Management Agency, *Protecting Building Utilities From Flood Damage: Principles and Practices for the Design and Construction of Flood Resistant Building Utility Systems,* FEMA 348, Washington, DC, November 1999.

Federal Emergency Management Agency and American Red Cross, *Repairing Your Flooded Home,* FEMA 234/ARC 4477. Washington, DC. (available at http://www.redcross.org, local Red Cross chapters, and FEMA).

Federal Emergency Management Agency, NFIP Technical Bulletins:

- *User's Guide to Technical Bulletins*, FIA-TB-0, April 1993.
- *Openings in Foundation Walls*, FIA-TB-1, April 1993.
- *Flood-Resistant Materials Requirements*, FIA-TB-2, April 1993.
- *Non-Residential Floodproofing—Requirements and Certification*, FIA-TB-3, April 1993.
- *Elevator Installation*, FIA-TB-4, April 1993.
- *Free-of-Obstruction Requirements*, FIA-TB-5, April 1993.
- *Below-Grade Parking Requirements*, FIA-TB-6, April 1993.
- *Wet Floodproofing Requirements*, FIA-TB-7, December 1993.
- *Corrosion Protection for Metal Connections in Coastal Areas*, FIA-TB-8, 1996.
- *Design and Construction Guidance for Breakaway Walls Below Elevated Coastal Buildings*, FIA-TB-9, 1999.
- *Ensuring That Structures Built on Fill In or Near Special Flood Hazard Areas Are Reasonably Safe From Flooding*, FIA-TB-10, 2001.
- *Crawlspace Construction for Buildings Located in Special Flood Hazard Areas,* FIA-TB-11, 2001.

International Code Council, Inc. *ICC Performance Code for Buildings and Facilities*™, Country Club Hills, IL, 2003.

International Code Council, Inc. *International Building Code*®, Country Club Hills, IL, 2003.

National Fire Protection Association. *Building Construction and Safety Code* (NFPA 5000), Quincy, MA, 2003.

U.S. Army Corps of Engineers, *Flood-Proofing Systems & Techniques,* 1984.

U.S. Army Corps of Engineers, *Flood-Proofing Regulations*, EP 1165-2-314, 1992.

U.S. Army Corps of Engineers, *National Flood-Proofing Committee, Flood-Proofing – How To Evaluate Your Options,* Washington, DC, July 1993.

U.S. Army Corps of Engineers, *Flood-Proofing Programs,* Techniques and References, Washington, DC, 1996.

U.S. Army Corps of Engineers, *Flood-Proofing Performance - Successes & Failures,* Washington, DC, 1998.

Organizations and Agencies

Federal Emergency Management Agency: 10 regional offices (www.fema.gov) can be contacted for advice and guidance on NFIP mapping and regulations.

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

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

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

5.10 GLOSSARY OF FLOOD PROTECTION TERMS

Base flood. The flood having a 1 percent chance of being equaled or exceeded in any given year; sometimes referred to as the 100-year flood.

Base flood elevation (BFE). The height of the base (1 percent or 100-year) flood in relation to a specified datum, usually the National Geodetic Vertical Datum of 1929 or the North American Vertical Datum of 1988.

Design flood. The greater of the following two flood events: (1) the base flood, affecting those areas identified as special flood hazard areas on a community's Flood Insurance Rate Map (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.

Design flood elevation (DFE). The elevation of the design flood, including wave height, relative to the datum specified on a community's flood hazard map.

Dry floodproofing. An adjustment, modification, or addition of a feature or combinations of these that eliminate or reduce the potential for flood damage by sealing walls and closing openings to keep water from entering a building.

FEMA. Federal Emergency Management Agency, the federal agency that administers the National Flood Insurance Program (NFIP).

Flood Insurance Rate Map (FIRM). Insurance and floodplain management map issued by FEMA that identifies areas of base flood hazard in a community. Some areas' maps also include base flood elevations, 500-year floodplain boundaries, and regulatory floodway boundaries.

Flood Insurance Study (FIS). Engineering study performed by FEMA to identify flood hazard areas, flood insurance risk zones, and other flood data in a community; used in the development of the FIRM.

Floodplain. The area including a watercourse and the land adjacent to it that is flooded during a flood of a given recurrence interval (e.g., 10-year flood, 50-year flood, 100-year flood, etc.).

Floodplain management regulations. Zoning ordinances, subdivision regulations, building codes, health regulations, or special-purpose ordinances, that set flood protection standards for new construction and land use.

Floodway. The stream channel and that portion of the adjacent floodplain that must remain open to permit passage of the base flood.

Freeboard. The additional height to which a building is protected from flooding above the base flood elevation to provide additional factor of safety and to account for uncertainties, usually 1 to 3 feet for critical/essential facilities.

Human intervention. Actions that must be taken by one or more persons in order for a building to be floodproofed before floodwaters arrive.

Hydrodynamic force. The force of moving water, including the impact of debris and high velocities.

Hydrostatic pressure. The pressure put on a structure by the weight of standing water. The deeper the water, the more it weighs and the greater the hydrostatic pressure.

Lowest floor. The lowest floor of the lowest enclosed area (including a basement) of a building.

National Flood Insurance Program (NFIP). Federal program to identify flood-prone areas nationwide and make flood insurance available for properties in communities that participate in the program.

Substantial damage. Damage to a building from any cause such that the cost to repair it to its pre-damaged condition is equal to 50 percent or more of its pre-damaged value.

Substantial improvement. A modification or remodeling of a building such that the value of the addition or remodeling is equal to 50 percent or more of the building's original appraised value.

Wet floodproofing. Permanent or contingent measures applied to a building and/or its contents that prevent or provide resistance to damage from flooding by modifying interior finishes, removing damageable items from lower areas, and allowing water into the building.