Guidelines for improving flood-resistance for existing buildings

Behm, Randall L.; Coulbourne, William L.; Kriebel, David L.; McKenna, Kimberly K.

https://doi.org/10.4224/40002709

Guidelines for Improving Flood-Resistance for Existing Buildings

Prepared by: **Coulbourne Consulting**
Annapolis, MD
Authors: **Randall L. Behm, PE, CFM**
William L. Coulbourne, PE
David L. Kriebel, PhD, PE
Kimberly K. McKenna, PG

For: **National Research Council Canada**
NRC Contract No. 930582

This page is intentionally left blank

TABLE OF CONTENTS

This page is intentionally left blank

LIST OF TABLES

LIST OF FIGURES

This page is intentionally left blank.

ACKNOWLEDGEMENTS

The Coulbourne Consulting team appreciates the help and guidance from the National Research Council (NRC) of Canada in the preparation of this guidance document. We especially thank Dr, Ahmed Attar, Dr. Zoubir Lounis, Dr. Naveed Khaliq, Ms. Marianne Armstrong, and Ms. Fiona Hill. The many discussions held jointly between the NRC and the consulting team made it possible to cover as many topics related to flooding and design for flood-resistant buildings as are covered in this report.

The efforts of the consulting team members are very much appreciated. The consulting team included Dr. David Kriebel, Mr. Randall Behm, Ms. Kimberly McKenna, and Mr. William L. Coulbourne. Mr. Alex Ferencz provided graphic support to the team. Everyone's diligence, thoughtfulness, and creativeness allowed the team to meet our objectives in a timely manner in spite of the inconvenience encountered in working during the COVID-19 crisis.

Finally, the consulting team would like to thank the many provincial, city, and town floodplain experts who provided information and background on how each one dealt with the flood hazard in their own communities. These perspectives and numerous flood loading data generation case studies from across Canada helped guide our approach to develop the guidance on designing for flood-resistant buildings.

.

EXECUTIVE SUMMARY

This report has been written as a guidance document on how to mitigate flood risk to existing buildings and how to make them more flood resistant. Much of the guidance has been developed from flood risk management information that exists in the United States where guidance from the Federal Emergency Management Agency (FEMA) and the United States Army Corps of Engineers (USACE) already exists. There are also flood risk management standards which have been developed by the American Society of Civil Engineers (ASCE), which have also been incorporated into this document.

The guidance provides a process for the identification of flood risk to existing buildings from which engineers and architects can use a standardized approach in determining applicable mitigation techniques in accordance with a proposed Importance Categories table for existing buildings in the NBC. Currently, there is much diversity in how provinces treat flood hazard in terms of both the annualized exceedance probability (AEP) and in how the flood hazard information is displayed to the public.

The recommended flood design levels, as described above, are linked to the Importance Categories table in the NBC. The recommended mitigation levels for existing buildings are:

Importance Category from NBC	Recommended Flood Design AEP
Low	1:100
Normal	1:250
High	1:500
Post-disaster	1:750

The flood resiliency of an existing building can be increased over current recommendations if the Importance Category of the building will utilize a larger mean recurrence interval than what has been previously used.

Section 1 of this guidance discusses the objectives, scope and limitations, and Section 2 provides a discussion on flooding and flood risk. Section 3 of this guidance considers the usage of and the flood resiliency of five common foundation types; basement, crawlspace, slab on grade, piling, and post/column. The foundation type is based upon building design, location, soil conditions, climate and costs. Section 4 covers the five most common mitigation techniques; acquisition, relocation, elevation, wet and dry flood proofing. A subsection discusses the usage of basements in flood prone areas.

Section 5 provides a discussion on the consideration of critical facilities and public safety operations, and Section 6 introduces the steps recommended for conducting a flood risk vulnerability assessment. Section 7 discusses the process for determining an effective mitigation technique for implementation, and Section 8 summarizes flood loads as described in Chapter 3 of the companion report: *Flood Load Formulas and Provisions of the Guide for Design of Flood-Resistant Buildings*, prepared by Coulbourne Consulting.

Associated with the mitigation techniques presented in Section 4, is a discussion of temporary and permanent flood barriers in Section 9. This information is followed by a discussion of flood resistant materials in Section 10, and flood related costs in Section 11.

Appendix A contains two examples for mitigating the flood hazard to existing buildings. The first example discusses an existing residential building located in a riverine environment and the second example discusses a medical facility located in a coastal environment. Both examples utilize the recommended flood design AEP for existing buildings as discussed above.

While there are many varying levels of flood conditions and numerous foundation types, this guide recommends those methods, or approaches that are currently considered best practices and those that are more easily applied by practitioners for mitigating flood risk to existing buildings.

This page is intentionally left blank

1 Introduction

This technical report has been developed for use in Canada in support of guidelines for improving the flood resistance of existing buildings. Currently, there are no national recommendations for assessing, evaluating, and mitigating the flood risk to existing buildings. The guidance and recommendations provided in this document are intended to assist in identifying the risk of flooding to individual buildings, and to evaluate potential mitigation techniques for implementation.

1.1 Background and Purpose

The threat of flooding and the damages associated with flooding are increasing globally. As sea level rise begins to affect coastal communities and the intensity of rainfall and snowmelt increases throughout interior watersheds, the adverse impact on existing buildings is increasing substantially. The Report of the United Nations (UN) Secretary-General on the 2019 Climate Action Summit, dated December 2019, reiterates the scientific findings on climate change and sea level rise. The UN report states that sea level rise is accelerating due to the melting of global ice sheets and there is a potential for several metres of sea level rise within a few centuries. A 2016 report from the Office of the Parliamentary Budget Office titled "Estimate of the Average Annual Cost for Disaster Financial Assistance Arrangements due to Weather Events" currently estimates annual total losses due to flooding to be $2B. As the risk of flooding also increases, residential and nonresidential buildings are becoming more susceptible to flood damages, which is anticipated to take an economic toll on the existing building stock as it becomes more vulnerable to flooding.

The purpose of this Technical Report is to provide information on the techniques commonly implemented for mitigating flood risk to existing buildings. The report will describe the factors influencing the vulnerability of buildings to flooding and will provide details on the potential opportunities for improving flood-resistance. The attributes of each technique will be discussed and illustrated and the potential limitations of each technique will be identified as it is applied to either coastal, lake, or riverine flooding.

1.2 Objectives

The objectives of this technical report are to 1) provide information on flood risk to buildings; 2) discuss common building foundations; 3) describe the common techniques used for mitigating flood impacts on existing buildings and increasing their flood resiliency; 4) discuss the importance of reducing flood risk to critical facilities, including post-disaster buildings; 5) provide the process for conducting a flood risk vulnerability assessment; 6) discuss how to determine effective techniques for implementation; and 7) provide information on barriers, flood resistant materials, and economic considerations.

1.3 Expected Use of the Guidance

The technical guidance provided in this report is intended for use by building owners, engineers, architects and floodplain management professionals to assist in determining how to improve flood resistance to existing buildings of varying importance and occupancy. The information provided in this report is also recommended to be used for training programs for practitioners in the form of webinars and workshops. Provinces and municipalities may consider utilizing the guidance for flood ordinances or converting the information into instructional material for local building officials.

1.4 Scope and Limitations

As flooding and flood damages continue to increase across the provinces, there is a growing interest in mitigating damages to existing buildings and making them more resilient to future flooding. This report discusses the potential mitigation opportunities for five common foundation types. While there may be additional foundation types or variations to the foundations included herein, the scope of this report is to present material which provides a basic understanding of the five most common foundation types.

The flood resistant techniques presented in this report are directed at retrofitting existing buildings to increase their resiliency to flooding. Unlike structural projects, such as levees or extensive floodwalls, which protect multiple buildings from flooding, the flood resistant techniques are applied to individual buildings. The existing buildings conform to the Building Use and Occupancy Importance in the National Building Code of Canada and correspond to a building importance classification of either low, normal, high, or post-disaster. The building use varies from those with limited human occupancy to those supporting critical operations such as hospitals or facilities which support power transmission, water and sewage treatment. These techniques are applicable to riverine, coastal, and lake shorelines.

The techniques presented are applicable to buildings which can vary from one or multi-family residential, to commercial, public, or industrial facilities. The scope of the report also considers the establishment of standards for flood risk to critical facilities and for public safety operations. A critical operation can be defined as providing a service that, if interrupted during the operational period, will cause severe impacts to the public, significant financial loss, extreme damages to the facility, or interruption to the delivery of services essential to the community's continued operation. A critical classification is an output that, when disrupted during the operational period, impacts the entire operation or multiple outputs, causing hardships on the public, loss of life, or significant economic loss. It is important to distinguish between critical and important operations. An important classification is an output that, when disrupted during the operational period, will disrupt the efficient management and flow of public services. While there are limitations in defining each and every critical facility or operation, it is important for government officials to determine their facilities and operations which are mission critical and community important.

In order to determine the flood risk vulnerability of an individual building, this report offers a building attributes table for recording building data pertinent for assessing the flood risk vulnerability, and a template for recording building, site, and flood data. For mitigation to existing buildings to occur, it is important to identify the flood characteristics (depth, velocity, rate of rise, debris) for the area where buildings are being assessed. Flood resistant measures can be designed for flood waters deeper than 3.7 m (12 feet), but within this guidance that height is used as the maximum height for qualifying several of the measures in an effort to prevent the habitation of buildings and to reduce the potential for loss of life. After identifying the flood characteristics, the site characteristics (coastal or riverine, or permeable or impermeable soils) are important to identify. Finally, the building characteristics (foundation type, exterior construction materials, and building condition) are required for conducting the assessment. In addition to these three categories (flood, site, and building), the potential intangible community benefits of implementing a mitigation project may be desired. While this category may appear to be limited in some situations, the person or team conducting the vulnerability assessment can consider expansion of potential benefits beyond those identified in the report (avoidance of adverse impacts; the reduction in emergency costs; the reduction in public infrastructure damages; restoration of the ecosystem; the potential for recreation; community cohesion; and the elimination of flood risk to specific buildings).

A flood risk management matrix, developed as a planning tool, is illustrated and presented for the purposes of determining a potential mitigation technique from the data collected on flood, site, and building characteristics. It is possible for more than one technique to appear to be justified for implementation based upon these three categories, which is where the community benefits or values may be utilized for determining the best-fit technique.

While the cost of each mitigation technique is important in the consideration of project implementation, there are too many unknowns (building size, building shape, construction materials, building condition, flood depth, flood velocity) which can be a limitation in conducting a direct cost comparison between techniques. There are numerous ways to elevate a structure, and depending upon the flood, site, and building characteristics, the costs can vary significantly. This report provides instruction as to selecting a potential mitigation technique based upon specific input criteria, from which the designer can incorporate costs for economic consideration.

Mitigation of an existing building to increase its flood resiliency will require an understanding of flood loads. The four categories of flood loads (hydrostatic, hydrodynamic, debris, and wave) discussed in this report and detailed in Chapter 3; *Flood Load Formulas and Provisions of the Guide for design of Flood-Resistant Buildings* report are important in determining the retrofit requirements of each individual building, as well as the siting of specific buildings. The damage potential may be higher for buildings located adjacent to and downstream from the greatest flood forces. In certain scenarios, adjacent buildings may shield other buildings or debris from adjacent buildings may cause significant damage to nearby buildings.

In order to prevent extensive flood damages, human intervention may be required for the installation of barriers. While there are many permanent and temporary products available to consumers for the prevention of flooding, this report recommends the use of flood barriers which have been tested and certified under simulated flood conditions. Permanent barriers which require little or no human intervention are more desirable than temporary barriers which may require significant human intervention to become operational.

The flood resistant techniques described in this report require the use of flood resistant materials to perform adequately during a flood event. An extensive list of flood resistant materials from the Federal Emergency Management Agency is illustrated as five classes of materials ranging from those that are highly resistant to flood water damage, to those that have no resistance to flooding. As more materials are tested for use in providing flood damage resistance, the user is recommended to utilize the updates to the list of flood resistant materials through the Federal Emergency Management Agency.

2 Flooding and Flood Risk

Flooding from natural hydrological processes can be defined as the excessive flow of water from rainfall, snowmelt, or ocean originating storms and sea level rise exceeding the capacity of channels and coastal or lakeside beachfronts. Flooding occurs when the flow of water extends beyond existing streambanks and coastal boundaries and into areas not typically inundated by flood water.

2.1 Riverine Flooding

Riverine flooding occurs when excessive runoff from rainfall or snowmelt exceeds the conveyance carrying capacity of existing channels and flows overbank into areas generally not intended for normal runoff.

2.2 Coastal Flooding

Coastal flooding occurs from excessive seawater originating from storm driven waves, sea level rise, and/or cyclic tides and extends inland such that buildings and/or land area are impacted by this water.

2.3 Flood Risk

Flood risk can be defined as being a function of the probability of flooding multiplied by the consequences of flooding, or generally shown as:

$Flood\ Risk\ =\ \mathrm{f}\,[(\text{probability of flooding})\ \mathrm{x}\ (\text{consequences of flooding})]$ Eq (2-1)

The probability of flooding can be defined as the frequency of flooding at a specific location. The frequency can be modified, and flood risk reduced, through structural measures such as the construction of dams, levees, floodwalls, channel diversions, and channel modifications. Each of these structural measures modifies the probability of flooding at the location where they are constructed.

The consequences of flooding are defined as the potential damages which occur from flood water adversely impacting structures vulnerable to and exposed to flooding. The flood risk can be reduced through mitigation of existing buildings and construction of new buildings, generally defined as nonstructural mitigation measures, to become more flood resistant.

Nonstructural mitigation measures are applied to individual buildings to increase resiliency to flooding without adversely affecting or changing the natural characteristics of the floodplain such as depth, duration, and areal extent of flooding. Nonstructural mitigation is utilized for mitigating loss of life as well as existing and future flood damages.

2.3.1 Reducing Flood Risk through Mitigation

The focus of this report is on the use of mitigation techniques to reduce the consequences associated with flooding. As will be described later, these techniques can be applied to existing buildings as well as to new buildings. As an example of flood risk being reduced through the reduction of consequences consider Figure 2.1. A small community resides alongside a river, which is known to be impacted by occasional flooding. For this example, let's consider the residential buildings are single story, without basement and have a value of $150,000 each, excluding the land and building contents. The existing conditions, as shown in Figure 2.1, are represented by an open floodplain. Discharge-Probability, Stage-Discharge, and Damage-Stage curves are illustrated for these conditions.

Table 2.1 presents information for four return intervals (500-, 100-, 50-, and the 20-year events). The existing conditions depth of flooding associated with the return interval and the percent building damage, as developed by the USACE (Economic Guidance Memorandum 01-03, Generic Depth-Damage Relationships, December 2000), are illustrated for one $150,000 residential building. The corresponding building damages are also shown. The cost of elevating the building is not included. The purpose is to illustrate that flood damages can be reduced through mitigation, such as elevation.

If this residential building were to be elevated 1.2 metres, as illustrated in Figure 2-1 for the With Elevation conditions, the Discharge-Probability and Stage-Discharge curves are shown with no changes from the existing conditions. Since the building has been elevated, the Damage-Stage curve has been modified and indicates that damages do not begin until the depth of flooding surpasses 1.2 metres of elevation. This is also illustrated in Table 2-1, where flood damages have been reduced over the return interval due to the mitigation in the form of elevation.

If an inventory of all at risk structures were to be created and the depth-damages integrated over the entire return interval, the flood risk for existing conditions versus with-mitigation conditions could be developed. The results would indicate the value in reducing flood risk by implementing mitigation techniques. This process can be used for individual buildings as well as an entire group of buildings.

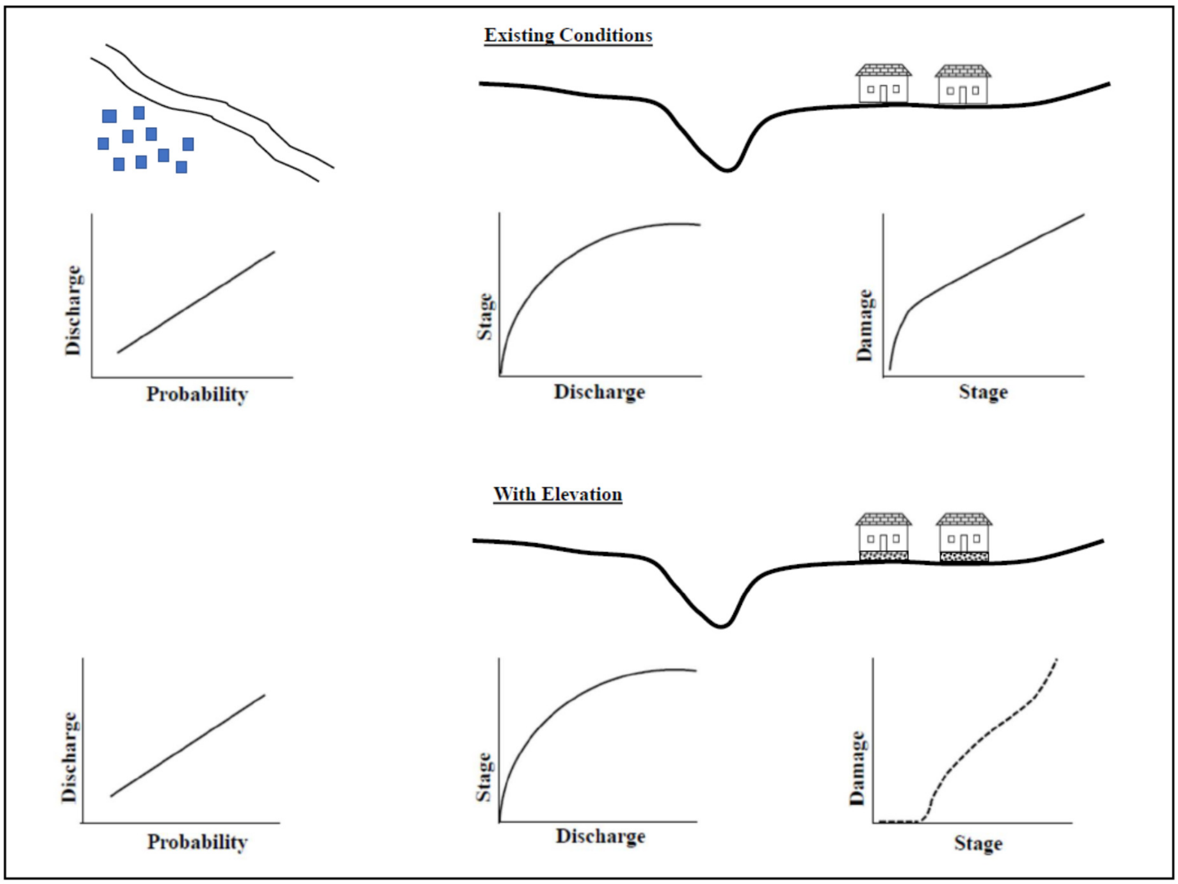

Figure 2-1 Generic Depth-Damage Relationships (source: USACE Library)

Table 2-1 Flood Risk Comparison for Existing and With-Mitigation Conditions

		Existing Conditions			With Mitigation		
Probability	Return Interval	Flood Depth (m)	% Structure Damage	Damages $	Flood Depth (m)	% Structure Damage	Damages $
0.002	500-Yr	1.8	58.6	87,900	0.6	32.1	48,150
0.010	100-Yr	1.2	47.1	70,650	0	13.4	20,100
0.020	50-Yr	0.6	32.1	48,150	-0.6	0	0
0.050	20-Yr	0.3	23.3	34,950	-0.9	0	0

While this methodology for considering flood risk is useful in determining the potential change in risk between existing conditions and the with-mitigation conditions, it does not include economic data for determining the feasibility. In order to determine the economic feasibility of reducing flood risk, either through implementation of structural measures or nonstructural measures, the estimated annual damages and estimated anuualized costs would be required. Sections 7 and 10 provide additional information on this topic.

3 Typical Building Foundations

Every building is constructed on a foundation, but not every building is constructed on the same type of foundation. The foundation type is based upon several complex factors, such as the building design, the site location, soil and moisture conditions, climate, and costs. In general, residential and nonresidential construction will have one of three common foundations: full basement, crawlspace, or slab on grade. Other variations, such as columns, posts, piers, piles, and compacted fill are also included in the following discussion. Figure 3-1 illustrates some of the most common building foundation types for which flood resistance can be improved.

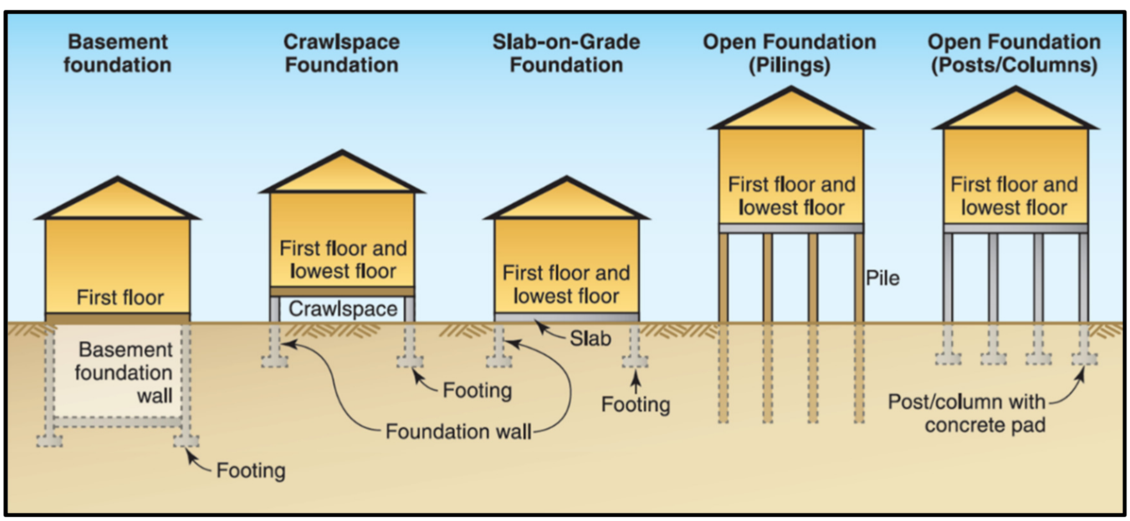

Figure 3-1 Common Building Foundations (source: FEMA Homeowner's Guide to Retrofitting)

The following paragraphs further describe these common building types.

3.1 Basement Foundation

A full or partial basement is commonly described as any area of a building with a lowest floor that is located below the natural ground level on all sides. A full basement consists of structural foundation walls that are supported on structural footings located along the perimeter of the basement. Footings are required by the building code to extend below the frost line, the depth to which the ground freezes during the winter. The full basement dimensions will match most of or all of the floor space of the level above, while the partial basement dimensions will only match a portion of the above floor space. Basement foundations are generally at least 2.0 m (~ 6 feet) minimum clear height and newer residential construction may have taller basements to facilitate using the area as living space. Basement foundation walls may be constructed of poured concrete, common masonry units (cinder blocks), or possibly even stone. Figure 3-2 illustrates a building supported by a basement foundation.

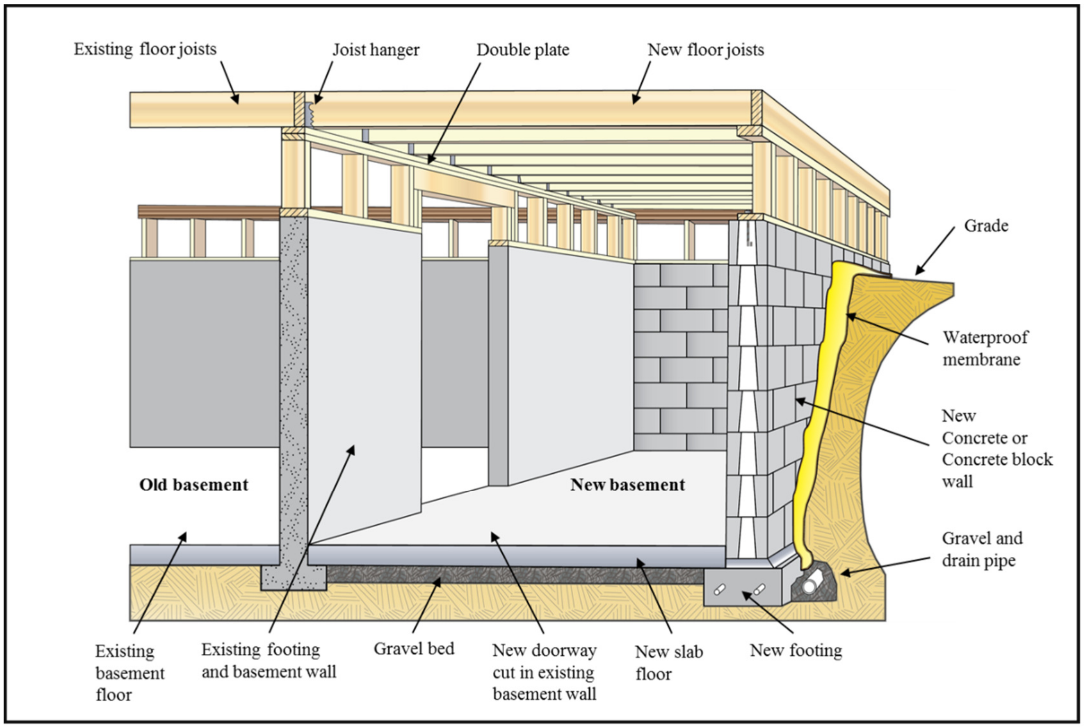

Figure 3-2 Basement Foundation (source: JWK Inspectors)

3.2 Crawlspace Foundation

A crawlspace foundation is typically a shallow unfinished area located below the first floor and used for access to plumbing, wiring, and mechanical systems. Crawlspaces are commonly used to elevate the lowest floors of residential and some nonresidential structures above a specified design elevation. Crawlspace foundations are preferably designed and constructed so that the floor of the crawlspace is located at or above the lowest grade adjacent to the structure. Figure 3-3 illustrates a building on a crawlspace foundation.

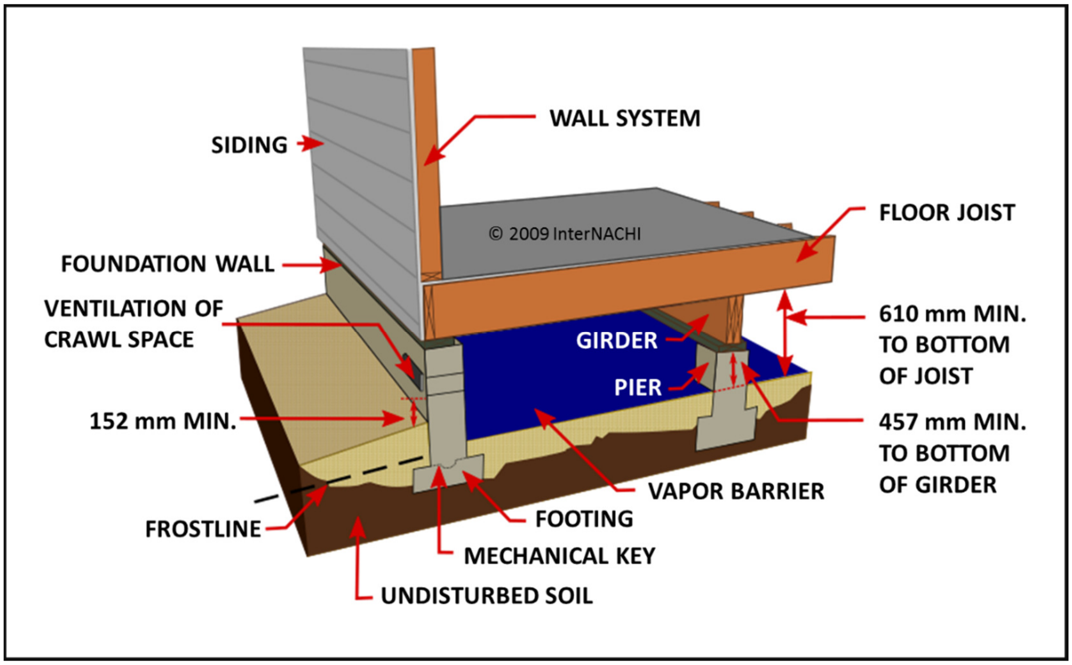

Figure 3-3 Crawlspace Foundation (source: InterNachi Corporation)

3.3 Slab on Grade

The typical slab on grade foundation is designed using a concrete mix with a slab depth which is suitable for supporting the building and contents proposed for the site. The slab on grade foundation can be designed as a non-reinforced concrete slab or as a reinforced concrete slab. Figure 3-4 illustrates a reinforced slab on grade foundation. The footings should extend below the average annual frost line in order to prevent foundation upheaval.

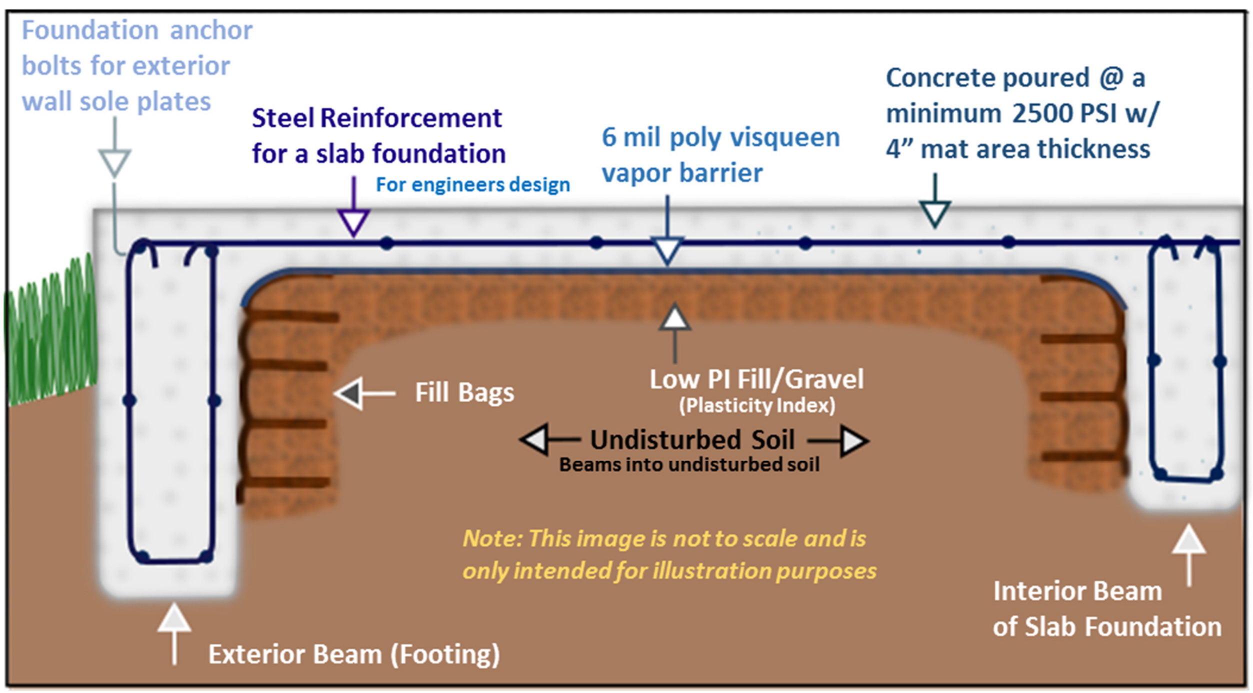

Figure 3-4 Reinforced Slab on Grade Foundation (source: JWK Inspectors)

3.3.1 Non-Reinforced Slab on Grade

The concrete slab is poured onto and directly supported by the soil under the slab. The slab on grade foundation can be installed on natural ground, a layer of stone or onto porous material. Since a poured concrete slab on grade foundation does not have any voids below it and has a slab depth usually no greater than 152 mm (6 inches), it functions in a compression mode only. If placed into tension, the slab on grade foundation may fail. If there are concerns regarding the ability of the proposed site to support the slab on grade, the thickness of the slab may be increased.

3.3.2 Reinforced Slab on Grade

In some instances, the natural sub grade support is inadequate in supporting the foundation and must be designed with steel reinforcement to support itself. When reinforcing steel is required, the design of the slab on grade is an engineered structural slab which will span any settlement that may occur within the sub grade. When water is present in the sub grade, the design should incorporate resistance to uplift which the buildup of hydrostatic pressure could create caused by flooding or excessive ground water.

3.4 Buildings Supported on Piers or Pilings

The pier supported foundations are generally represented as an engineered collection of large diameters, typically cylindrical columns, to support the superstructure of the building and to transfer large loads to the subsurface. A pier may consist of sections of reinforced concrete, galvanized, or epoxy-coated steel pipe that are driven into the soil until achieving a specified bearing strength. Figure 3-5 illustrates a building supported on piers utilizing reinforced concrete.

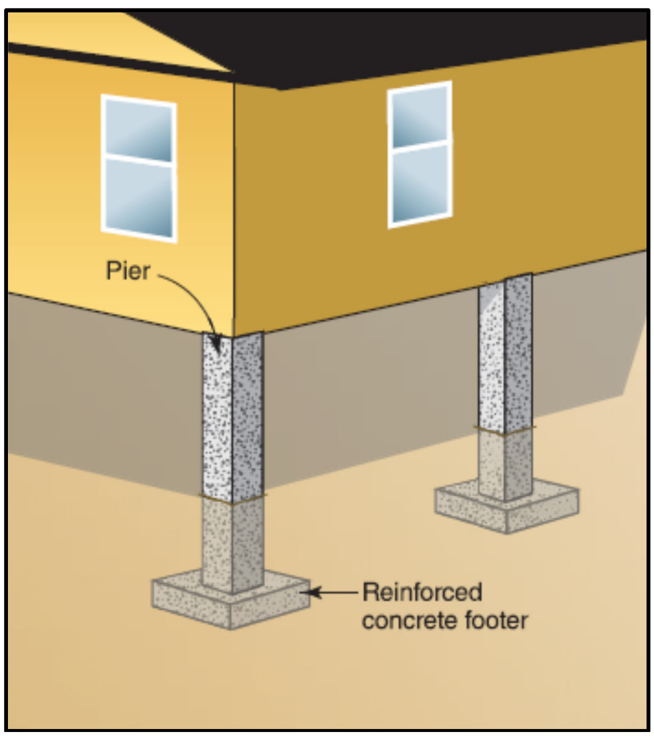

Figure 3-5 Pier Foundation (source: FEMA Homeowner's Guide to Retrofitting)

The pile support foundation for residential construction typically occurs as one of two types of piles: driven (cased or uncased) or bored. The pile is a slender column or long cylinder which can be constructed of wood, concrete or steel which is used to support the structure and transfer the load at a desired depth either by end bearing or friction with the soil. Figure 3-6 illustrates a building elevated on piles.

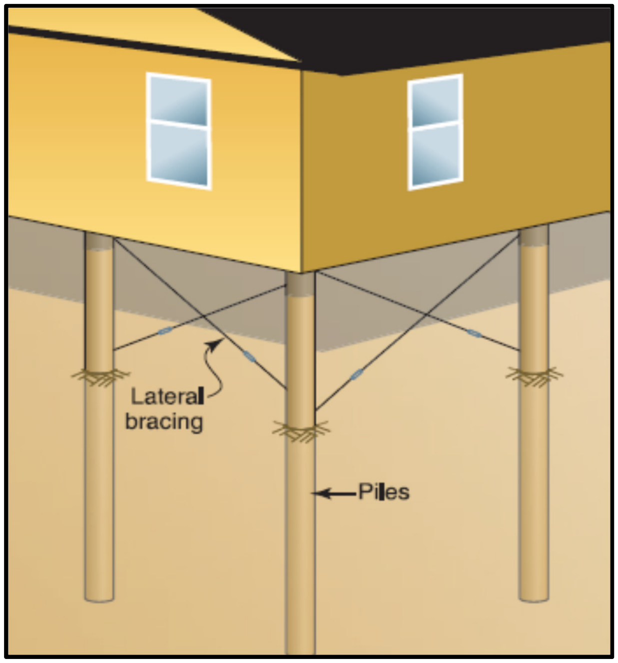

Figure 3-6 Pile Foundation (source: source: FEMA Homeowner's Guide to Retrofitting)

3.5 Open Foundation Supported on Columns and Posts

A structure supported by a column or post is a single-point loading system, supporting the weight of framed structures, where the load is spread by a concrete pad to the bearing layer of soil or rock below. Typically, columns are not as large as piers, and therefore even though driven below the frost depth, they are not as resistive as piers or piles to lateral flood forces.

A structure supported by an engineered post is typically made of wood and is driven into the subsurface ground to achieve a specified bearing strength. The post is used to transfer the weight of the structure to the ground. Generally, posts are not as large as piers, and therefore even though driven below the frost depth, they are not as resistive as piers or piles to lateral forces associated with flood loads. Figure 3-7 illustrates the common posts/column foundation.

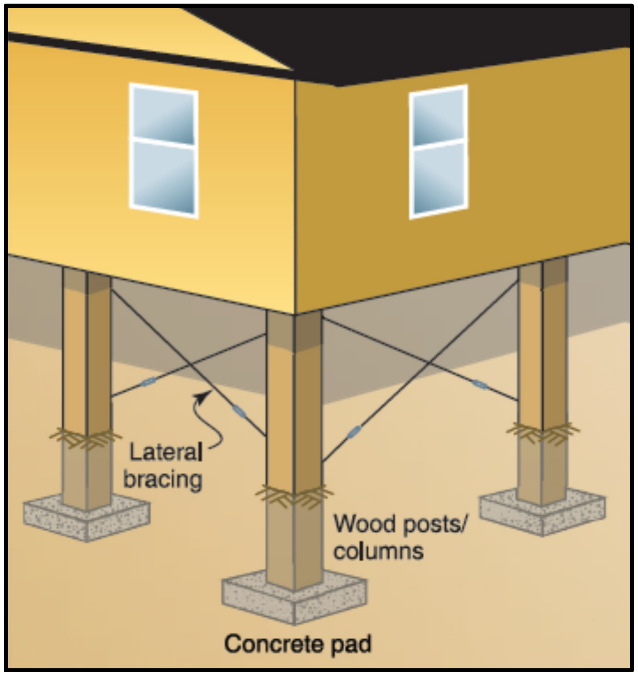

Figure 3-7 Post/Column Foundation (source: FEMA Homeowner's Guide to Retrofitting)

3.6 Buildings Elevated on Compacted Fill

Compacted fill material can be used to elevate a structure above the surrounding terrain. The fill material should not cause adverse impacts on adjacent properties by directing runoff or flood waters onto those properties. Figure 3-8 illustrates an elevated building on compacted fill.

Figure 3-8 Elevation on Compacted Fill (source: Behm Hazard Mitigation, LLC)

4 Flood Resistant Techniques

Flood resistant techniques for existing buildings are engineered and are proven methods for reducing flood risk and flood damages to structures located in a floodplain and vulnerable to flooding. These techniques adapt to flood characteristics such as the depth of flooding, the velocity of flooding, the frequency, the duration, and the aerial extent of flooding, without significantly altering or modifying the natural floodplain. In other words, these techniques, when implemented correctly, do not adversely affect any of the floodplain characteristics. In addition to being very effective for both short- and long-term flood risk and flood damage reduction, flood resistant techniques can be designed to be cost effective, environmentally acceptable, and resilient to flooding when compared to infrastructure measures such as levees, floodwalls, and dams. A particular advantage of nonstructural flood resistant techniques is that, when compared to structural measures, they appear to be more sustainable over the long term with minimal costs for operation, maintenance, repair, rehabilitation, and replacement. This section illustrates the nonstructural flood resistant techniques, which when implemented appropriately will reduce future flood damages.

4.1 Acquisition

This technique is typically reserved for structures which are extremely vulnerable to high risk flooding, where the occurrence of flooding may result in a substantially damaged structure, unsuitable for post-flood occupancy. The damages can be the result of deep inundation and/or flood water surge against and into the structure. Acquisition is generally a government sponsored technique requiring the availability of funds for the purchase of the structure and the associated land from the owner as part of the technique. The acquired structure can either be demolished or if in adequate condition, sold and relocated to a site external to the floodplain. If acquired and demolished, some communities are finding a benefit in salvaging materials (wiring, plumbing, flooring, fixtures) rather than disposing of materials into landfills. Figure 4-1 illustrates an example of building acquisition and demolition to evacuate the flood hazard area.

Figure 4-1 Acquisition and Demolition (source: USACE Library)

4.2 Relocation

This technique requires moving the vulnerable structure to a site external to the floodplain. Similar to acquisition, the relocation technique is generally supported with government funding. This technique also requires the purchase of the land upon which the structure was located and land to be made available for the relocation site. While this technique achieves a high level of flood risk reduction for vulnerable structures, it is an expensive measure to effectively implement. Development of relocation sites where vulnerable structures could be moved to achieve the objective of reducing flood risk and retaining such aspects as community tax base, neighborhood cohesion, or cultural and historic significance can be an integral part of any relocation project. Figure 4-2 illustrates an example of a building being relocated.

Figure 4-2 Relocation (source: USACE Library)

4.3 Elevation

This technique requires lifting the entire structure to a specified height above the design flood elevation. Flood water velocity and hydrodynamic forces on the structure must be considered to ensure the stability of the elevated structure. Elevation of a habitable structure is generally limited to 4.5 m (15 feet), as the cost of elevating, the risk to inhabitants, and the risk to first responders' increases beyond this height. There are several methods for elevating structures which are described below.

4.3.1 Extended Foundation Walls

Since the foundation is the primary supporting system of a house and other nonresidential structure, a perimeter of poured concrete is used as a footing from which common masonry units are extended upward to a specified design height. If in satisfactory condition, the existing footing and foundation wall may be added onto, or if necessary, a new footing and foundation may be required to be constructed to achieve the desired elevation. Because the extended foundation results in an enclosed area, flood vents for equalizing hydrostatic pressure caused by flooding are required to be incorporated into the foundation walls. Figure 4-3 illustrates an example of elevation on extended foundation walls. Floors located below a specified flood elevation should have vented openings to allow the equalization of flood water. A new flood vent is evident in the bottom portion of the right-side foundation wall.

Figure 4-3 Elevation on Extended Foundation (source: USACE Library)

4.3.2 Slab on Grade

This technique requires the concrete slab incorporate reinforcement steel in order to allow the slab to operate in compression and tension modes. If elevating a non-reinforced slab, the building will be required to be separated from the slab, elevated to above the design flood elevation, and connected to a new floor, typically constructed of wood. A reinforced slab on grade foundation may be possible to elevate without separating the building from the slab. Figure 4-4 illustrates an example of an elevated slab on grade foundation.

Figure 4-4 Slab on Grade Elevation (source: USACE Library)

4.3.3 Piers

As described in section 3.4, an engineered pier foundation may be utilized to elevate an existing building to be above a specified flood elevation. Piers are larger than posts and columns, and designed for most severe flood velocities and scour potential. A potential benefit to elevating onto piers is that the space located under the building may be used for parking or temporary storage of materials which should be moved prior to a flood event. Figure 4-5 illustrates an example of elevation of a building on piers.

Figure 4-5 Elevation on Piers (source: Flood Mitigation Industry Association)

4.3.4 Posts

The engineered post used as a technique for elevating an existing building is made of wood and is driven into the subsurface ground to achieve a specified bearing strength. As with a pier, the post is used to transfer the weight of the structure to the ground. Typically, posts are not as large as piers, and therefore even though driven below the frost depth, they are not as resistive as piers or piles to high flood velocities and generally not resistive to large flood-borne debris/ice loads. A potential benefit to elevating onto posts is that the space located under the building may be used for parking or temporary storage of materials which should be moved prior to a flood event. Figure 4-6 illustrates an example of elevation of a building on posts.

Figure 4-6 Elevation on Posts (source: USACE Library)

4.3.5 Columns

The column foundation can be utilized to elevate an existing building to be above a specified flood elevation. Columns are more cost effective than piers, but are not as resistive as piers or piles to high flood velocities and generally not as resistive to large flood-borne debris/ice loads. A potential benefit to elevating onto columns is that the space located under the building may be used for parking or temporary storage of materials which should be moved prior to a flood event. Figure 4-7 illustrates an example of elevation of a building on columns.

Figure 4-7 Elevation on Columns (source: USACE Library)

4.3.6 Piles

For this technique, piles are driven to a greater depth than pots or columns to achieve a higher strength which is more resistive to high flood velocities, scour, and waves, large flood-borne debris, and ice loads. A potential benefit to elevating onto a pile is that the space located under the building may be used for parking or temporary storage of materials which should be moved prior to a flood event. Figure 4-8 illustrates an example of elevation of a building on piles.

Figure 4-8 Elevation on Piles (source: USACE Library)

4.3.7 Compacted Fill

This elevation technique requires the placement and compaction of clean fill material to a specified height above the design flood elevation. Since the amount and placement of fill requires a significant amount of area, this measure is typically relegated to rural settings. When conducted for use in an urban area, retaining walls may be utilized to control the area of fill. The fill material or retaining walls should not cause adverse impacts on adjacent properties or structures. Erosion during high velocity flood events, where the compacted fill material may erode exposing the structure to additional risks, should be considered during the design process. Figure 4-9 illustrates an example of elevation of a building on compacted fill.

Figure 4-9 Elevation on Compacted Fill (source: USACE Library)

One additional elevation technique, although not currently accepted by FEMA, is the Amphibious foundation system. This technique is an alternative to permanent static elevation for housing in areas where flood waters do not rise rapidly and wave action is minimal. Amphibious foundation systems are purported to raise the building to as high an elevation as is necessary to remain safely above water, then lowers back into place as the flood water recedes.

4.4 Basements

A basement is commonly defined as any area of a building having one or more floors which are completely or partly located below ground on all sides. The basement has historically been used as a utility space where such items as the furnace, water heater, electrical breaker panel or fuse box, and high velocity air-conditioning systems are located. In newer homes, the basement area is sometimes used as an additional living area. The basement area may also be used for storage and vehicle parking.

When considering flood risk and flood vulnerability, basement areas, particularly those which are inhabited, may be more vulnerable to flooding and flood damage due to their location below ground surface. As flooding occurs and the above ground depth of flooding increases, the ground becomes saturated, increasing forces on the exterior of the basement foundation walls, possibly causing catastrophic failure. When the above ground depth of flooding increases, there is also the potential for flood water to penetrate the first floor and damage the basement area.

This section of the report is not meant to deter the use of basements for habitation, but to increase awareness to the potential flood risk and vulnerability associated with basement habitation and the possible mitigation measures available.

4.4.1 Abandonment

Within the US National flood Insurance Program (USNFIP) and the Federal Emergency Management Agency (FEMA), basements located below the design flood elevation are only allowed in communities that have obtained a basement exception from FEMA. Nonresidential basements that have been flood proofed are allowed.

If a full or partial basement exists, has been completely developed prior to elevation and cannot be re-developed post-elevation, partial compensation for removal of the basement space should be considered by the owner. Typically, a basement area does not have the same value as the above ground finished living area. Abandonment of the basement is applicable when flooding is anticipated to infiltrate the lower level unless the required elevation of the first floor is no greater than 4.5 m (15 feet) above the adjacent grade, where the recommendation should be considered for acquisition or relocation of the building. If a basement that contains utilities and/or appliances is abandoned, then the existing building must contain sufficient room to relocate the utilities and/or appliances or a utility addition must be constructed at or above the design flood elevation. Figure 4-10 illustrates an example of an at-risk basement being abandoned while the first floor of the building is being elevated above a specified flood elevation.

Figure 4-10 Basement Abandonment (source: USACE Library)

4.4.2 Hardening and Interior Drainage

While flood proofing is implemented to prevent damages to existing buildings, it is not intended to create usable space below the flood protection level in residential buildings. In the United States, nonresidential buildings are allowed to be flood proofed, while residential basement flood proofing is not permitted in most areas of the country. At issue is the concern that a residential building basement may be a habitable floor, making it a higher risk to injury or loss of life in the event of a flood.

Because of the concern over habitation of basement areas, and the hardship that administrative requirements regarding basements may have on communities, the community officials have to demonstrate that areas of special flood hazard in which basements will be permitted are subject to shallow and low velocity flooding and that there is adequate flood warning time to ensure that all residents are notified of impending floods. Flood characteristics must include:

- flood depths that are 1.5 m (5 feet) or less for developable lots that are contiguous to land above the historical 100-year flood frequency level and 1 m (three feet) or less for other lots;
- flood velocities that are 1.5 m (5 feet) per second or less; and flood warning times that are 12 hours or greater. Flood warning times of two hours or greater may be approved if the community demonstrates that it has a flood warning system and emergency plan in operation that is adequate to ensure safe evacuation of flood plain residents.
- any basement area, together with attendant utilities and sanitary facilities below the flood proofed design level, must be watertight with walls that are impermeable to the passage of water without human intervention. Basement walls should be built with the capacity to resist hydrostatic and hydrodynamic loads and the effects of buoyancy resulting from flooding to the floodproofed design level, and should be designed so that minimal damage will occur

from floods that exceed that level. The floodproofed design level should be an elevation 0.30 metres (1 foot) above the level of the design level flood where the difference between this flood and the 0.2% annual chance exceedance flood is 1 m (3 feet) or less and 0.6 m (2 feet) above the design flood level where the difference is greater than 1 m (3 feet).

- the top of the floor of any basement area should be no lower than 1.5 m (5 feet) below the elevation of the base flood;
- the area surrounding the structure on all sides should be filled to or above the elevation of the base flood. Fill must be compacted with slopes protected by vegetative cover;
- a registered professional engineer or architect should develop or review the building's structural design, specifications, and plans, including consideration of the depth, velocity, and duration of flooding and type and permeability of soils at the building site, and certify that the basement design and methods of construction proposed are in accordance with accepted standards of practice for meeting the provisions of this paragraph;
- the building should be inspected by the building inspector or other authorized representative of the community to verify that the structure is built according to its design and those provisions of this section which are verifiable.

Exterior walls and floor slabs are subject to hydrostatic and hydrodynamic forces associated with flooding. Floor slabs should be properly reinforced and made sufficiently thick to prevent buoyancy forces from cracking them. Additionally, sufficient water-proofing should be applied to the slab and joints to assist in eliminating or minimizing the potential for water intrusion and seepage. Perimeter and underdrain systems should be directed to a location outside the building to eliminate the need for sump pits, which is another location where water can infiltrate into the building.

Excavation for below-grade walls should allow for application of a waterproofing membrane or coating. Wall penetrations, if required, should be located above the design water surface elevation, if possible, to prevent intrusion of flood water.

While cast-in-place walls work best for preventing the infiltration of flood water, a concrete masonry unit (CMU) block wall with concrete or mortar filled units and an exterior waterproofing membrane can also be successful in making the basement impermeable. See Figure 4-11 for a cross section of a substantially impermeable CMU wall system.

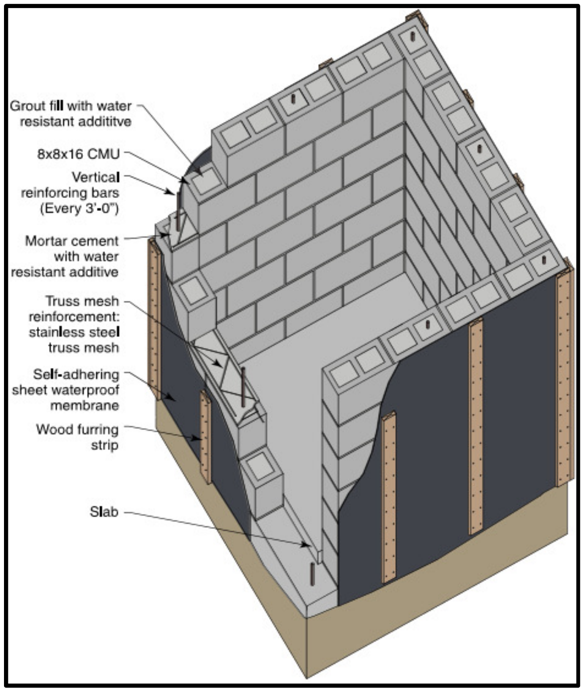

Figure 4-11 CMU Wall System (source: FEMA Homeowner's Guide to Retrofitting)

When flood water saturates the soils surrounding a building, there is a high probability of seeping through the exterior walls, foundations, and floor. Interior drain systems for buildings are designed to keep water from accumulating in below-grade interior areas. These systems do not require the soil to be excavated from around the exterior below-grade walls to install underdrains.

Sump pumps are a common method of dewatering below-grade enclosed areas. The sump is generally constructed so that its low point is located below the base of the floor slab. Water in the areas adjacent to below-grade walls and floor migrate along the lines of least resistance, which should be toward and into the sump. It may be necessary to provide a more readily accessible path of least resistance for water that has collected in the fill material and around the structure to follow a path into the sump. To achieve this, pipe segments are inserted and sometimes drilled through the below-grade wall and into the fill material behind, purposefully allowing the interior to flood. Gravel is placed around the pipe segments on the exterior of the foundation wall to filter the surrounding soil, not allowing it to enter the interior of the building. The pipe segments are then connected to larger diameter pipes running along a gravel-filled trench or cove area into the floor slab and into one or more sumps (see Figure 4-12). Interior drainage systems can be overwhelmed by a quickly rising water table and are subject to potential power outages.

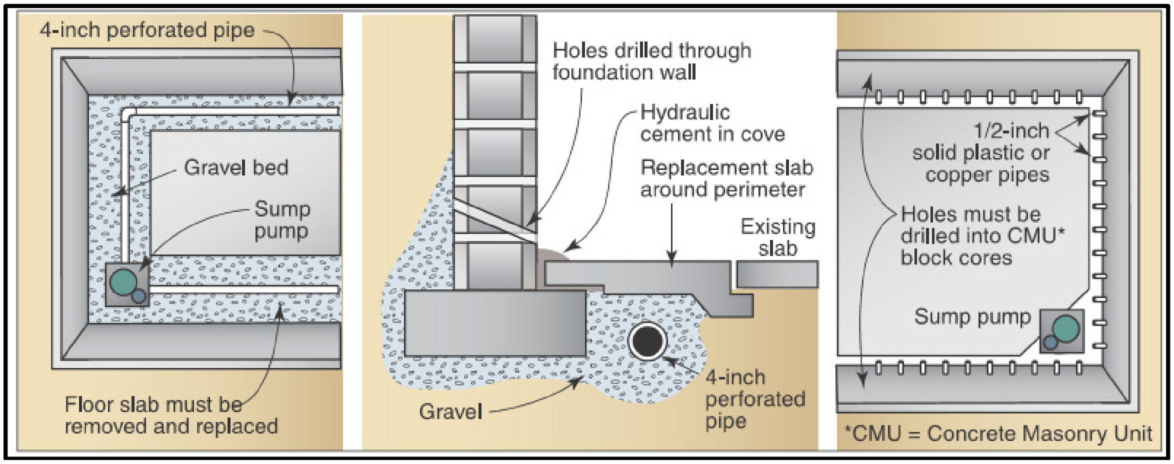

Figure 4-12 Interior Drainage (source: FEMA Homeowner's Guide to Retrofitting)

Submersible or pedestal sump pumps are commonly used for interior drainage systems. The submersible type pump has a water-tight motor connected directly to the pump casing and is installed at the bottom of the sump. Pedestal sump pumps have an open motor supported on a pipe column with the pump at its base and a long shaft inside the column connecting the motor to the pump intake.

During a flood event, a slow rise of flood waters may result in a small seepage of water into the sump pit. A constant speed sump pump will likely cycle on and off several times to empty the sump pit until the flood protection level is reached, when the pump will likely need to accommodate a more constant flow of water into the sump pit. A variable speed sump pump can be adjusted to address the variability in the flow rates into the sump pit. The more consistent operation of a variable speed pump will likely reduce the size of the generator system needed to compensate for the startup electrical draw required for the pump system. A large commercial application using large constant speed sump pumps could require either the installation of a larger generator system or reductions in the number of other types of equipment that can be run on a smaller generator system.

FEMA P-936 Flood Proofing Non-Residential Buildings provides additional information regarding building hardening and interior drainage systems.

4.5 Wet Flood Proofing

This technique is applicable as either a stand-alone measure or as a measure combined with other measures. Construction materials and finishing materials are required to be water resistant and all utilities must be elevated to be above the design flood elevation. Wet flood proofing is applicable to residential and nonresidential commercial and industrial buildings when combined with a flood warning and flood preparedness plan which would provide information on the urgency of the flood threat, the rate of rise of flood waters, and requirements within individual buildings for preparing for the flood. These preparedness requirements may include removing storage materials and installing flood barriers to prevent flood water from penetrating beyond the designated wet flood proofed area. This technique is generally not applicable to large flood depths or large flood velocities, which could create large forces on interior walls, or for flash flood conditions which may not allow external hydrodynamic pressures to equalize quickly. Figure 4-13 illustrates an example of wet flood proofing, where a flood vent allows flood water to enter a crawlspace/basement, equalizing the pressure on the foundation walls thereby preventing catastrophic failure.

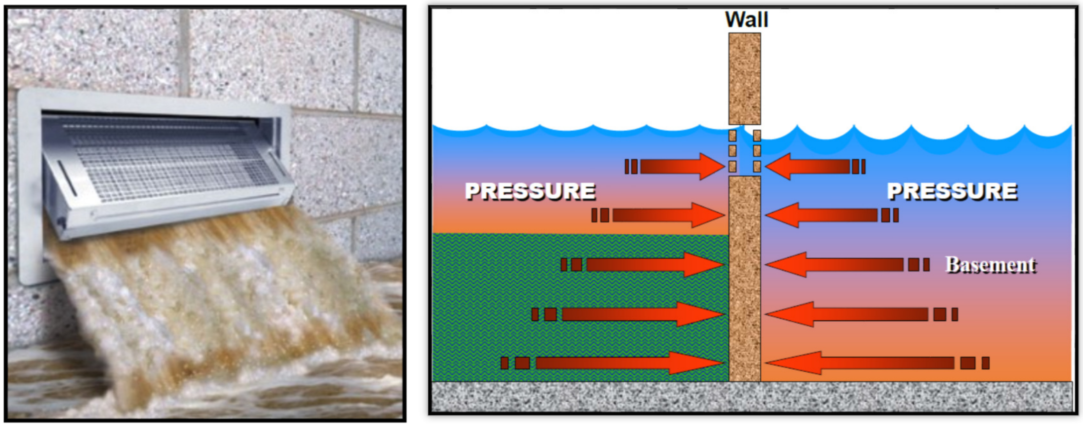

Figure 4-13 Wet Flood Proofing (source: USACE Library)

4.6 Dry Flood Proofing

This technique consists of waterproofing the structure with flood resistant materials and can be implemented on residential homes as well as nonresidential commercial and industrial buildings. This technique can result in lower damages associated with flooding. Based on laboratory testing, the walls of a “conventional” built structure can generally be dry flood proofed up to 1 m (3-feet). A structural analysis of the wall strength would be required if it was desired to achieve a higher level of protection. A sump pump and perhaps a French drain system should be installed as part of the measure to prevent seepage of flood waters into the structure. Closure panels should be incorporated into all openings. This concept is not recommended for basements or crawlspaces due to excessive costs of reinforcing the exterior walls, preventing seepage, and the possibility of making the whole structure buoyant. Excessive velocities can damage the flood proofing materials, and unless a passive system is incorporated into the design, there may not be adequate time to install closures during a flash flood event. Figure 4-14 illustrates an example of the exterior of a library being dry flood proofed.

Figure 4-14 Dry Flood Proofing (source: USACE Library)

4.7 Protecting Utilities

Flooding in the coastal or riverine environments can cause significant damages to unprotected residential and nonresidential utilities. Corrosion, contamination, short circuiting of electrical systems, and backup of sewage systems are a few of the common concerns associated with flooding of utility systems. Elevation or component protection are the primary methods used for protecting systems. Additional information may be found within FEMA Technical Fact Sheet No. 8.3; Protecting Utilities.

4.7.1 Electrical

Service connections (lines, panels, metres, and junction boxes) should be secured at an elevation above the projected design water elevation, to the landward side of vertical support members, when possible. Drip loops should be used for electrical wiring to minimize water entry at wall penetrations. Electrical components should never be attached to break away walls.

4.7.2 Water/Sewage

Anti-backflow valves should be incorporated into sewer lines to prevent sewer backup. Plumbing runs should be installed inside joists for added protection. Electrical components associated with plumbing (shut-off valves, water heater, sprinkler system) should be installed above the projected design water elevation.

4.7.3 Heating, Ventilation and Air Conditioning (HVAC)

All HVAC components (condensers, air handlers, ductwork, and electrical components) should be installed above the projected design water elevation. Outside components/units should be elevated and secured to prevent vibration and damage from wind-blown debris and flood waters.

4.7.4 Fuel Storage

Fuel storage containers should be protected through either elevation, anchoring at ground level, or being buried below ground surface. No matter which method is selected, the fuel storage container must be secure from floating during all flood events. Figure 4-15 illustrates an example of an appropriately anchored fuel storage container.

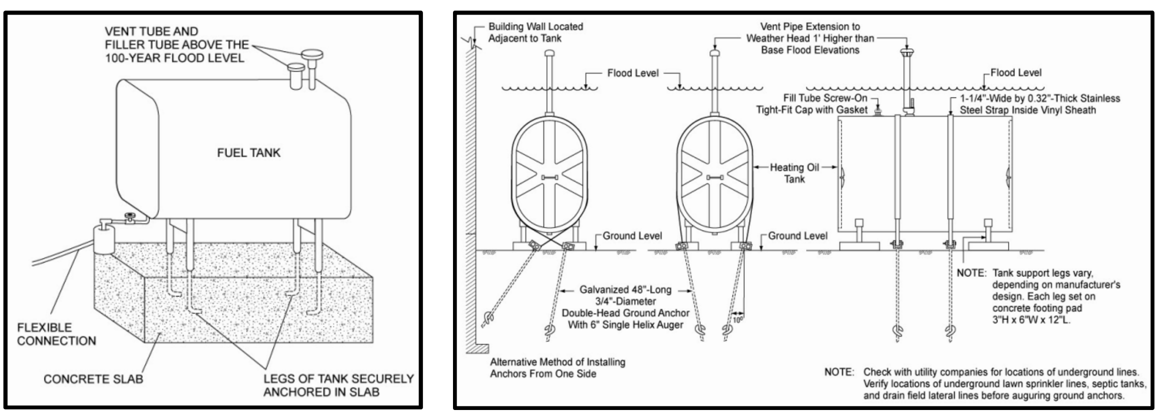

Figure 4-15 Anchoring Fuel Tanks (source: FEMA Anchor Fuel Tanks)

5 Consideration for Critical Facilities and Public Safety Operations

The effects of flooding within a community may become catastrophic when critical facilities designed for public health and safety are unable to continue operating.

5.1 Defining Critical Facilities

There are facilities which support public health and safety, as well as operating as the economic engine for many communities where even a slight chance of flooding is too great a threat. When these facilities become inoperable during a flood event, the extent of flooding goes beyond the footprint of the structure and results in discontinuation of all operations within the entire service area. These facilities should be given special consideration when formulating allowable floodplain activities. If possible, a critical facility should not be located within an area of designated flood risk. If a critical facility must be located in a floodplain, it should be provided a higher level of flood protection so that it can continue to function and provide services during and after the flood event. Communities should develop emergency action plans to continue to provide critical services during the flood.

FEMA defines four kinds of critical facilities:

- Structures or facilities that produce, use or store highly volatile, flammable, explosive, toxic and/or water-reactive materials.
- Hospitals, nursing homes and housing likely to have occupants who may not be sufficiently mobile to avoid injury or death during a flood.
- Police stations, fire stations, vehicle and equipment storage facilities, and emergency operations centres that are needed for flood response activities before, during and after a flood.
- Public and private utility facilities that are vital to maintaining or restoring normal services to flooded areas before, during and after a flood.

5.2 Defining Public Safety Operations

The National Building Code (NBC) of Canada 2015 provides categories of "High Importance" classifications and "Post-disaster buildings" that includes hospitals and emergency response facilities. Table 5.1 from the NBC provides information regarding the importance categories of different buildings.

Table 5-1 Building Use and Occupancy and Importance Category in National Building Code of Canada (NBC 2015)

<table>
<tr><th>Use and Occupancy</th><th>Importance Category</th></tr>
<tr><td>Buildings that represent a low direct or indirect hazard to human life in the event of failure, including:
• low human-occupancy buildings, where it can be shown that collapse is not likely to cause injury or other serious consequences
• minor storage buildings</td><td>Low</td></tr>
<tr><td>All buildings except those listed in Importance Categories Low, High and Post-disaster</td><td>Normal</td></tr>
<tr><td>Buildings that are likely to be used as post-disaster shelters, including buildings whose primary use is:
• as an elementary, middle or secondary school
• as a community centre
Manufacturing and storage facilities containing toxic, explosive or otherhazardous substances in sufficient quantities to be dangerous to the public if released</td><td>High</td></tr>
<tr><td>Post-disaster buildings are buildings that are essential to the provision of services in the event of a disaster, and include:
• hospitals, emergency treatment facilities and blood banks
• telephone exchanges
• power generating stations and electrical substations
• control centres for air, land and marine transportation
• public water treatment and storage facilities, and pumping stations
• sewage treatment facilities and buildings having critical national defence functions
• buildings of the following types, unless exempted from this designation by the authority having jurisdiction:
o emergency response facilities
o fire, rescue and police stations, and housing for vehicles, aircraft or boats used for such purposes
o communications facilities, including radio and television stations</td><td>Post-disaster</td></tr>
</table>

See the National Building Code of Canada 2015, Volume 1, for the background, special notes and definitions associated with NBC Table 4.1.2.1 shown above as Table 5.1.

The recommended Mean Recurrence Interval (MRI) flood design for improving flood resistance to existing buildings is illustrated in Table 5-2. Because achieving full elevation compliance established for new building construction may be difficult and cost prohibitive to achieve in renovating or rebuilding existing buildings, the minimum flood design MRI for existing buildings is reduced below the requirement for new buildings.

Table 5-2 Mean Recurrence Interval (MRI) Recommendation for NBC Importance Categories for Buildings

Use or Occupancy Class from NBC	Recommended Flood Design MRI
Low	100-year
Normal	250-year
High	500-year
Post-disaster	750-year

Within Table 5-2, it can be seen that the flood resiliency for an existing building can be increased if the Importance Category will utilize a larger MRI than what has been previously used. For example, rather than considering a 100-year MRI, plus an additional freeboard amount, for a normal Importance Category, a 250-year MRI is recommended. The larger recommended MRI incorporates a flood construction elevation, which should be sufficient for the calculated flood risk.

5.3 Establishing Standards for Flood Risk to Critical Facilities and Public Safety Operations

Terminology regarding "critical operations" has become difficult to define and understand in today’s environment. The definition differs from one organization to another and sometimes even within the same organization. When asked to identify the critical operations of their community, many officials will identify systems and components rather than identifying the true critical facilities required to support the community wide critical operations.

It is true that every community has commercial and industrial operations that cannot be disrupted without jeopardizing community resiliency. And those operations may well justify investments in facility infrastructure, for components such as emergency power generation, redundancy in electrical systems, or even flood protection. All of these are employed in order to prevent unacceptable downtime. As services and operations are reviewed within a community, it is imperative that officials and facility managers determine those services critical and necessary for sustaining public health as well as important government and economic operations.

A loss of services which affects an entire population should be considered "mission critical" or "mission important," depending on the impact. A disruption that affects a single facility or service can be considered "community important." Community officials often overlook the need to understand and communicate which government services are reliant upon other facilities. Seemingly unrelated operations that could impact government services must be identified prior to flooding.

It is important to develop standards which assist in the identity of those facilities and operations which directly provide critical public health and safety services, and those facilities and operations which are mission critical, and community important. After standards have been established, officials can move forward with activities to ensure their community is becoming more resistant to flooding.

6 Conducting a Flood Risk Vulnerability Assessment

Flood risk vulnerability assessments inform the selection of an appropriate nonstructural technique, inform cost estimates, and assist in the identification of a logical aggregation of structures for mitigation purposes. The following information provides a systematic approach to conducting a flood risk vulnerability assessment as part of the planning process and is applicable for establishing decision points for any size assessment area. Additional information on conducting a flood risk vulnerability assessment is available through the USACE National Nonstructural Committee Publication Field Assessment Guide for Conducting Nonstructural Assessments, April 2019.

6.1 Determining the Assessment Location and Structure Sampling

It is recommended that the flood risk vulnerability assessment be conducted based upon a sampling of structures rather than the entire structure data set which have been determined to be at flood risk. This is recommended so that it can be determined in a relatively small investment of time and funds if potential flood resistant mitigation measures exist. If the assessment has positive results, then the sampling of structures can be expanded to the entire data set. The assessment area can be divided into smaller sub areas associated with geographic, political, or cultural boundaries in order to expedite the assessment. For the assessment, it is recommended that approximately ten to twenty percent of the structures located within a sub area be assessed, unless the majority of structures represent a similar construction type, wherein a smaller percentage of structures may be selected. This sampling process for the assessment may result in the identification of a comprehensive stand-alone nonstructural plan, a combination of structural and nonstructural plans, or perhaps it will be determined that nonstructural measures are not economically feasible and are not a part of any flood risk reduction plan.

The downside of increasing net project benefits through acquisition and/or relocation is that the community's tax base could be adversely impacted by the loss of structures from the tax roll. If a family displaced through acquisition, see Figure 4-1, is unable to find replacement housing within the same general vicinity, the community's dollars collected from property taxes could be reduced Property tax is a real estate tax based upon the value of property, calculated by a local government, which is paid by the owner of the property. The tax is usually based on the value of the owned property, including land. If the property is removed, there is no basis for taxation. Property taxes typically provide for local road construction and maintenance, local government staff salaries, and possibly for the needs of a public-school district. Municipal employees, such as police, fire fighters, and the public works department are also paid through property taxes. As the nonstructural work plan is being developed, remember to communicate these potential issues thoroughly with the study sponsor.

6.2 Identifying Flood Stages and Velocities

The stage or depth of flooding corresponds to the discharge of flood waters within a specific damage area. The stage will generally increase as the discharge increases. The stage of flooding can vary along the length of a river due to the geometry of the channel and overbank areas, the amount of and type of vegetation, obstructions to runoff, and the slope of the channel. The velocity is the speed, typically provided as metres per second, which the flood waters travel through a specific drainage area. The availability of flood stages and velocities for more frequent flood events as well as for less frequent events provides the assessment team valuable information for determining potential mitigation measures while in the field. The elevation of the first floor as well as the elevation of windows in exterior walls, specifically the lower window sill, can be compared to the available flood stages and assist in determining what frequency flood event is practical for providing protection from flooding. Likewise, the velocity of a flood event can determine if erosion will occur, or if hydrodynamic forces on the exterior of a structure may be too strong to withstand without modifying the structural integrity of the exterior wall(s). Chapters 2 (Design Flood Conditions and Considerations) and 3 (Flood Load Formulas and Provisions) in the report: guide for Design of Flood-Resistant Buildings provide information about how to determine flood elevations for various time periods and how to determine velocity in riverine flood locations.

6.3 Developing an Inventory of Vulnerable Structures

As the total number of buildings and building types are being identified as part of the assessment inventory, the buildings being assessed are only a percentage of the overall structure count and require specific data from which informed decisions can be made. Table 6-1 illustrates some of the pertinent building attributes which are recommended for conducting an assessment of vulnerable structures. After identifying the structures to be assessed, it may be possible to collect some of the data prior to conducting the site visit. For instance, floor plans, elevations, dimensions, and other useful data may be available on-line or from several municipal or Provincial offices. The lowest adjacent ground elevations may be available from existing Light Detection and Ranging (LiDAR) data. First floor elevations may be approximated from the LiDAR data and estimating the height above ground using Google Maps Street View. Detailed information can be and should be obtained if the proposed flood resistant measures proceed to implementation.

Research into community resilience indicates the importance of planning and developing inter-agency contacts and relationships within the local government authority before an extreme natural hazard event occurs. Communicate data needs with the study sponsor and Provincial agencies to determine what data may be available.

Table 6-1 Building Attributes

Structure Data	Data Definition
Building Identification Number	Specific to Structure (geo referenced, coordinates, etc.)
Structure Address	Specific Postal Location of Structure
Critical Facility	Yes / No
Lowest Adjacent Ground Elevation	Elevation of Lowest Ground at Structure
First Floor Elevation	Elevation of Finished First Floor
Structure Category	Residential, Commercial, Industrial, Public
Structure Use	What is the Specific Use of Structure
Total Stories	Total Number of Floors Above Grade
Structure Footprint	Total Square Metres Area of At-Grade Floor
Number of Structural Corners	Total Number of Corners in Perimeter
Structure Foundation Type	Slab, Reinforced Slab, CMU, Piers, Columns, Posts, Stone
Structure Perimeter Distance	Total Length of All Exterior Sides of Structure
Exterior Wall Construction	Wood, Masonry, Brick, Metal, Stone, Concrete, Other
Structure Visual Condition	Good / Fair / Poor
Garage	Attached, Detached, None
Doorways	Number of Pedestrian Doorways
Basement	Full Basement, Half, Crawl Space, None
Structure Photos	Photograph of Four Sides of Structure
Utilities Location	Electrical, Gas, Water, Sewer, Oil, Propane, Coal, Other
Structure Value	Assessed Value of Structure
Fireplace	Yes / No
Structure Owner	Who Owns the Structure
Year Structure Built	Year Structure was Constructed (Any Historic Significance)
Water Surface Elevation	Elevation or Depth of Water at Structure (H&H activity)
Water Velocity	Erosive Potential of Flood Waters (H&H activity)

6.4 Determining Flood Risk Vulnerability of Existing Structures

The guidance provided in this report focuses on individual buildings. For comprehensive flood resiliency within a neighborhood or community, the individual buildings should also be considered in groupings (i.e., healthcare facilities with multiple structures, commercial and industrial complexes, or residential development) to ensure potential interdependencies are addressed. As the individual structure assessment is conducted and pertinent data is collected, that data can be illustrated as shown in Table 6-2. This data can be used to determine the flood risk through simple comparison of building and flood elevations.

Table 6-2 Structure Assessment Data Template

Structure Identifier Number		First Floor Elevation (FF)	
Occupancy type		Lowest Adjacent Grade (LAG)	
Number of Structural Corners		Basement/Crawlspace Elevation	
Number of Stories		1:100 AEP Elevation	
Building Construction Material		1:100 AEP Velocity	
Foundation Material		1:500 AEP Elevation	
Slab/Crawlspace/Basement		1:500 AEP Velocity	
Condition (Good/Fair/Poor)		FF minus 1:100 AEP Elevation	
1st Floor Window Count		FF minus LAG	
1st Floor Pedestrian Door Count		Flood Depth (1:100 AEP-LAG)	
1st Floor Vehicle Door Count		Perimeter Distance (metres)	

As Table 6-2 is populated with data for individual buildings, the flood risk can be determined. For existing buildings, the flood risk is determined as a comparison to the 1:100 annual exceedance probability. From Table 5-2, the recommended MRI flood design for improving flood resistance to existing buildings can be identified for building use and occupancy importance, where a larger annual exceedance probability may be used for building importance from low, normal, high, to post-disaster classes.

As flood waters impinge against existing buildings, it is important to determine basic information which can assist in determining the flood risk and vulnerability of each individual building. The elevation data collected (first floor, lowest adjacent grade, annual exceedance probability elevation, and flood depth) are utilized to quantify the risk of flooding. In general, as the depth of flooding increases, the flood risk increases.

The other building attributes (occupancy, structural corners, construction material, foundation material, foundation type, condition, and number of windows, pedestrian doors, and vehicle doors) can be used to determine the vulnerability of each individual building to flooding. Minimal flood vulnerability may occur to a building constructed on a slab-on-grade foundation, with masonry walls in overall good condition, where the depth of flooding is small, impinging onto the building below the window sill elevation, where there are also very few pedestrian doors and no vehicle doors.

Large flood vulnerability may occur to a building which has a basement foundation, with wood siding in overall poor condition, where the depth of flooding is significant (greater than two metres), exceeding the window sill elevation, where there are also numerous pedestrian and vehicle doors, which allow passage of flood water.

7 Determining an Effective Mitigation Technique for Implementation

After the inventory data for individual structures has been collected and assessed, the process for determining the most effective flood resistant technique for implementation can proceed. There are generally four categories of investigation which are considered when determining the most effective technique for implementation. Each of the categories are discussed below.

7.1 Identifying Flood Characteristics

This category focuses on the flood characteristics of depth and velocity as well as whether the flooding is rapidly formed and if the flood waters would transport debris or ice. These characteristics are important in determining the effectiveness of some techniques as some measures are not suitable for certain flood characteristics. The total depth of flooding is the difference between the water surface elevation and the lowest adjacent ground elevation located next to the building being assessed. While flood resistant measures can be designed for flood waters deeper than 3.7 m (12 feet), that height is used as the maximum height for qualifying several of the measures as it is generally believed that with flood depths greater than 3.7 m, and for moderate to high velocities, as well as potential presence of debris and ice, buildings should not be inhabited in order to reduce the potential for loss of life. By limiting which measures could be supported for implementation, also places caution on the side of first responders who place themselves at greater risk if having to respond to situations where the depth of flooding exceeds 3.7 m in height.

7.2 Identifying Site Characteristics

This category focuses on the specific site location of the building being assessed and the type of soils surrounding the foundation of the building. The location of a structure may also influence the technique selected for potential implementation, such as coastal beach front which has significantly higher velocities and wave forces than coastal interior and riverine locations. The coastal beach front is the location of the intersection of the ocean and the land, as well as the Great Lakes and the shoreline, where wave runup and setup may influence the flood elevation and hydrodynamic forces. The coastal interior is located inland from the beach front and Great Lakes shoreline, where wave surge is reduced to still water characteristics. Additionally, the soil type, permeable or impermeable, will also influence the determination of the most effective measure for the given site conditions. A structure located on permeable soil will be difficult to dry flood proof without installing a perimeter barrier around the entire building, both above and below ground surface, in order to prevent flood water from penetrating the walls of the building or the floor from below.

7.3 Identifying Building Characteristics

This category considers the building foundation, the exterior envelope of the building, and the overall condition of the building. All three of these categories (flood, site, and building) can influence the determination of an effective measure for implementation. For example, if a building is determined to have a slab on grade foundation, there could be potential restrictions regarding which physical nonstructural measures may be considered for implementation depending upon if the slab is reinforced or not. For non-reinforced slabs, there could be significantly higher costs for any of the elevation techniques as the existing slab would be separated from the building and a new floor constructed, if the building were to be elevated. Slabs which are not reinforced with steel do not possess sufficient tension resistance for maintaining stability when elevated. These non-reinforced slabs may crack, then fail when elevated. Additional concerns are identified for the foundations according to the flood resistant technique being considered for implementation.

It is also important to determine if the building being considered for retrofitting with flood resistant measures contains a crawlspace or basement. Either feature can pose a limitation to any of the elevation measures unless proficiently water proofed, or unless abandonment of the crawlspace or basement is considered. If the existing feature was used to house utilities and appliances, the abandonment of the feature may require the modified building to contain a utility addition in order to compensate for lost space. Crawlspaces or basements are not elevated unless the measure to elevate is accomplished by the placement of compacted fill material on which the crawlspace or basement can be constructed.

In general, any exterior envelope can be incorporated into a flood resistant retrofit project, but some exterior walls may require modification depending upon the measure being considered. For example, the exterior walls of a building may require modification if dry flood proofing were being proposed. Additionally, the overall condition of the structure may influence the determination of which flood resistant technique is considered to be most effective for implementation.

7.4 Identifying Community-Based Benefits

This category considers some of the intangible benefits which are important in developing community-based projects rather than projects which may be satisfactory for increasing the flood resiliency of individual buildings, but lack those elements which foster the development and sustainability of cohesive neighborhoods. The purpose for this category is to assist in determining which measure should be specifically considered for implementation. When assessing a structure using the other three categories (flood, site, building), it is possible that two or more measures may appear to be equivalent in their potential for implementation. When this happens, it is suggested that community benefits be considered in order to identify the most preferential and effective measure for implementation. For example, a community may be fully supportive of reducing their overall flood risk by removing those buildings most susceptible to flooding through relocation or acquisition. However, a different community may want to maintain community cohesion, and prefer utilizing an assortment of techniques in order to achieve those goals. Some potential areas for providing community benefits could be the avoidance of adverse impact; the reduction in emergency costs; the reduction in public infrastructure damages; restoration of the ecosystem; the potential for recreation; community cohesion; and the elimination of flood risk to specific buildings.

7.5 Determining a Technique for Implementation

A planning tool used by several U.S. Federal and state agencies to assist in the determination of a flood resistant technique for implementation is a Flood Risk Management Matrix, similar to what is shown in Figure 7-1. This matrix allows for the consideration of each of the categories described above in determining the most effective flood resistant technique for implementation.

The Flood Risk Management Matrix provides a systematic approach to determining a potential mitigation measure for residential or nonresidential buildings. The process requires the user to consider known information for the categories of Flood Characteristics, Site Characteristics, Building Characteristics, and Community Economics. As the known data is applied within each of the four categories, an affirmative response of "Y" for yes is circled for each of the appropriate mitigation techniques. After the user works their way through the entire Matrix, the "Ys" are totaled within each column. The column(s) with the greatest amount of "Ys" is indicative of potential flood resistance technique(s) that should be pursued in more detail for possible implementation.

FLOOD RISK MANAGEMENT MATRIX		FLOOD RESISTANT MITIGATION MEASURES									
		Elevation									
		Extended Foundation	Piers	Posts	Columns	Piles	Fill (compacted)	Relocation	Acquisition	Dry Flood Proofing	Wet Flood Proofing
Flood Characteristics	**Flood Depth**										
	Shallow (< 1 meter)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Deep (2 to 4 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Very Deep (> 4 meters)	N	N	N	N	N	N	Y	Y	N	N
	Flood Velocity										
	Low (less than 1 meter per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2.4 meters per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
	High (greater than 2.4 meters per second)	N	Y	N	N	Y	N	Y	Y	N	N
	Flash Flooding										
	Yes (less than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	N	N
	No (more than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Debris /Ice Flow										
	Yes	N	Y	N	N	Y	Y	Y	Y	N	N
	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Site Characteristics	**Site Location**										
	Coastal Beach Front	N	N	N	N	Y	N	Y	Y	N	N
	Coastal Interior (Low Velocity)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Riverine Floodplain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Soil Type										
	Permeable	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Impermeable	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Characteristics	**Building Foundation**										
	Slab on Grade (reinforced)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Crawlspace	N	N	N	N	N	Y	Y	Y	N	Y
	Basement	N	N	N	N	N	Y	Y	Y	N	Y
	Abandonment of Crawlspace/Basement	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Building Envelope/Exterior										
	Concrete, Stone, or Masonry	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Metal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Wood	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Overall Building Condition										
	Excellent to Fair	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Fair to Poor	N	N	N	N	N	N	N	Y	N	N
Community Economics	**Community Benefits (project area)**										
	Avoids Adverse Impact on Adjacent Property	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Reduction in Emergency Costs	N	N	N	N	N	N	Y	Y	N	N
	Public Infrastructure Damage Reduced	N	N	N	N	N	N	Y	Y	N	N
	Ecosystem Restoration Potential	N	N	N	N	N	N	Y	Y	N	N
	Recreation Potential	N	N	N	N	N	N	Y	Y	N	N
	Community (Project Area) Cohesion	Y	Y	Y	Y	Y	Y	N	N	Y	Y
	Flood Risk Eliminated to Building	N	N	N	N	N	N	Y	Y	N	N

Figure 7-1 Flood Risk Management Matrix (source: modified from USACE Library)

7.6 Developing Cost Estimates

Costs for mitigation measures were not supported as a category of the Matrix, as unit costs can vary widely from one region to another and are dependent upon overall building size, the age of the building, the type of construction, the number of structural corners, as well as each of the individual categories illustrated in the Matrix. For comparison purposes, the user should consider that if two or more measures appear to be equal for potential implementation, there are several inherent factors which may assist in selecting the preferred measure. For instance, when considering elevation, generally due to the confined parcel space within an urbanized environment, elevation on fill may not be acceptable. Or when considering reducing flood damages for a nonresidential structure, which is impacted by shallow flooding, it would probably be most cost effective to consider dry flood proofing versus elevation of any type, particularly if the structure has a slab on grade foundation, not reinforced, and surrounding structures are remaining at grade.

There would be a significant cost to replace the non-reinforced slab with a reinforced slab and then the aesthetics of elevating one structure when surrounding structures remain at their existing grade would suggest that dry flood proofing would be the most economical solution. The costs should be estimated along with the specific flood resistant measure(s) that has been determined from the criteria identified within the Flood Risk Management Matrix. It is important to not only determine the most effective mitigation for individual buildings, but for consideration of community-based benefits from a comprehensive mitigation program, which may be formulated from the desire to incorporate open space, aesthetics, and life loss reduction.

8 Flood Load Determination for Existing Buildings

Once an effective technique or a set of effective techniques have been identified for implementation, the flood loads should to be determined. There are four categories of flood loads which can act as forces on a building. They are the hydrostatic, the hydrodynamic, debris, and impact from waves. For a complete description of flood load determination, the reader is directed to Chapter 3; Flood Load Formulas and Provisions of the Guide for Design of Flood-Resistant Buildings report, which contains detailed design information for establishing flood forces on building elements. Each flood load category is also summarized below.

8.1 Hydrostatic Flood Loads

The hydrostatic flood loads are exerted on a building by still or slowly moving water. Hydrostatic flood loads act perpendicular against the surface that they are exerted against. These loads increase linearly with the depth of water and buoyant forces act vertically and can be determined by multiplying the specific weight of water and the volume of flood water displaced by a submerged object. Buoyant forces act upward on the bottom of foundation walls and floor slabs and are resisted by the weight of the building and the structural capacity of the slab.

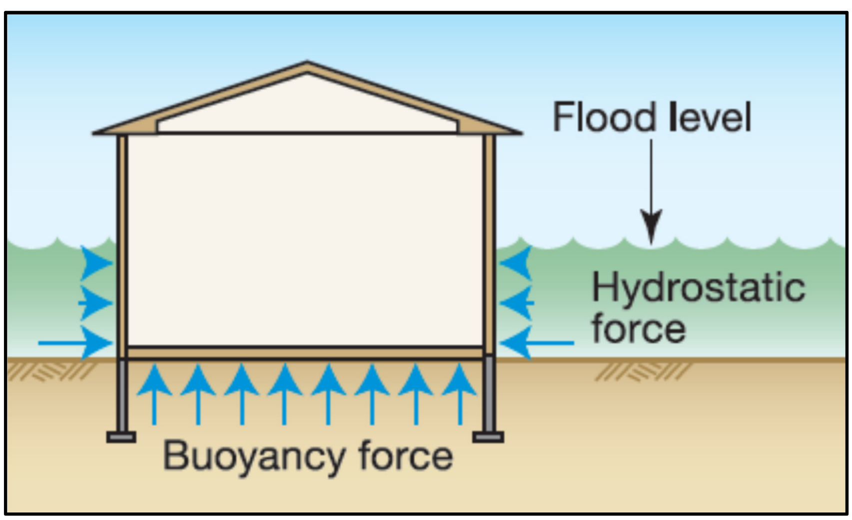

Figure 8-1 Hydrostatic Flood Load (source: FEMA P259 Engineering Principles and Practices)

8.1.1 Hydrostatic Pressures

Hydrostatic loads originate from fluid hydrostatic pressures that depend on the effective weight of water above a point of interest that is submerged. Hydrostatic pressure may be given by

$$P_h = \rho g z = \gamma z \qquad \text{(Eq. 8-1)}$$

where

P_h = hydrostatic pressure, in N/m^2 (or lb/ft^2)
z = depth of submergence, from SWL to point of interest (including in submerged soils)
g = acceleration due to gravity, 9.81 m/s^2 (32.2 ft/s^2)
ρ = water density, 1,000 kg/m^3 fresh, 1,025 kg/m^3 salt (1.94 slug/ft^3 fresh, 1.99 slug/ft^3 salt)
γ = water unit weight, 9,810 N/m^3 fresh or 10,055 N/m^3 salt (62.4 lb/ft^3 fresh, 64.0 lb/ft^3 salt)

Values of fluid density and unit weight given above are standard reference values, and some adjustment could be warranted in certain local situations. For example, the ASCE7-16 (2016) chapter on tsunami loads requires a 10% increase in fluid density when strong flows result in substantial suspended sediment and debris entrained in moving waters.

8.1.2 Buoyancy

A fundamental effect of hydrostatic pressures is that any portion of a structure or structural element (or the entire structure) that is wholly or partially submerged in water will experience a vertical buoyant force due to the effects of hydrostatic pressures around the perimeter of the structural element (or water tight structure). For any object shape, the vertical buoyant force can be given by Archimedes Principle as

$$F_B = \rho\, g\, \forall = \gamma\, \forall \qquad \text{(Eq. 8-2)}$$

where

F_B = vertical buoyant force due to hydrostatic pressures, in N (or lb)
$\forall$ = volume of water displaced by the structural element, in m^3 (or ft^3)

8.1.3 Vertical Hydrostatic Force

In cases when a more fundamental method of computing vertical hydrostatic forces is required, the vertical hydrostatic force can be computed as

$$F_v = \left(P_{bot} - P_{top}\right)A_h = \left(\rho\, g\, Z_{bot} - \rho\, g\, Z_{top}\right)A_h \qquad \text{(Eq. 8-3)}$$

where

F_v = vertical hydrostatic force, in N (lb)
P_{bot} = hydrostatic pressure on bottom of structure or element, based on Z_{bot}
P_{top} = hydrostatic pressure on top of structure or element, based on submerged depth to top Z_{top}
A_h = contact area over which pressures act, in horizontal plane
Z_{bot} = submerged depth to bottom of structure or element, from free water surface
Z_{top} = submerged depth to top of structure or element, from free water surface

In some cases when either the top or bottom of a structural element is exposed to air, either the top or bottom pressures would be atmospheric, i.e. P = 0.

When determining the vertical hydrostatic forces for an entire building, Equation (8-3) should be applied to each submerged structural element and then summed for all submerged elements of the building and foundation. In some cases, when the entire structure is submerged or when major portions of the structure are submerged, the direct application of the buoyant force from Equation (8-2) may be simpler in lieu of applying Equation (8-3) to each structural element.

Hydrostatic uplift forces can be quite large, especially for large volume structures and for dry-floodproofed structures. For this reason, the most important provisions to reduce vertical flood loading is to adopt one of two strategies: (1) elevate fully enclosed spaces above the design flood water level or (2) allow flood waters to enter the spaces to equalize hydrostatic pressures.

8.1.4 Lateral Hydrostatic Force

Hydrostatic fluid pressures induce lateral or horizontal hydrostatic loads when they act over a vertical structural surface. Because of the depth variation, pressures are zero at the free water surface but increase linearly with increasing depth, Z, below the surface, giving rise to the classic triangular hydrostatic pressure distribution. The net lateral force is then obtained by depth-integrating (or finding the area under) the hydrostatic pressure distribution.

On a full-depth vertical wall (extending above the water surface), the horizontal hydrostatic force per unit width (units of N/m) is given by

$$f_H = ½ \rho g d_f^2 \qquad \text{(Eq. 8-4)}$$

where

f_H = hydrostatic force per unit width along the wall, in N/m (or lb/ft)
d_f = design flood depth, based on design flood level minus ground elevation, including any added depth due to erosion or scour

For a wall width, w, the total hydrostatic force (units of N) would be

$$F_H = w f_h = w ½ \rho g d_f^2 \qquad \text{(Eq. 8-5)}$$

where

F_H = hydrostatic force on the wall, in N or lbs
w = width of the wall perpendicular to the flow, in m (ft)

For computation of overturning moments, the point of application of the load based on the triangular pressure distribution is at a vertical location 2/3 d_f below the water surface, or 1/3 d_f above the ground level.

ASCE 7 (2016) requires hydrostatic forces to be based on the design flood depth plus an additional 0.30 m (1 ft) as an added factor of safety to account for uncertainties in defining the still water level. One reason for this provision is that flood codes in the U.S. adopt a 100-year MRI flood event, so the addition of 0.3 m (1 ft) raises the effective MRI for design to something higher than 100 years. But the effective MRI for design then differs, sometimes dramatically, in different parts of the country or between riverine and coastal conditions. For Canada, a more robust approach would be to adopt a higher MRI design event that would give more consistent flood risk across the country.

8.2 Hydrodynamic Flood Loads

Hydrodynamic flood loads are exerted on buildings by water flowing around the building. These types of flood loads are a function of flow velocity and the geometry of the building. As illustrated in Figure 8-2, upstream surfaces receive positive (frontal) pressures, side surfaces experience the effects of drag, and downstream surfaces have negative (suction) pressures. These flood loads can occur in riverine as well as coastal environments.

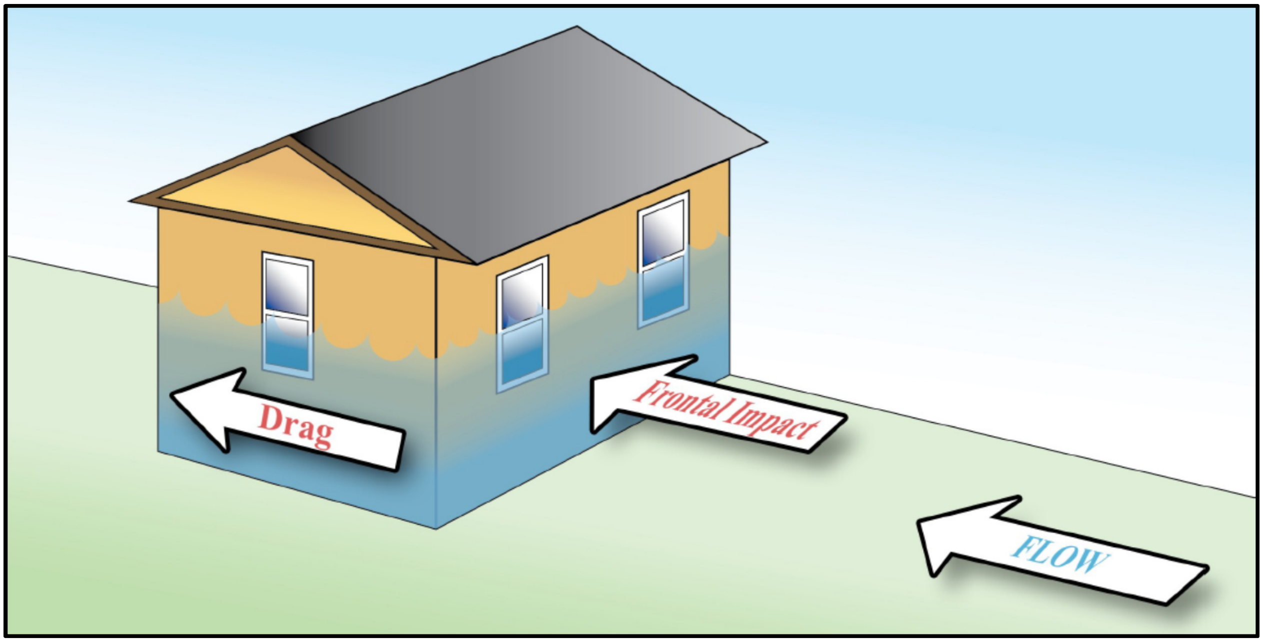

Figure 8-2 Hydrodynamic Flood Load (source: Coulbourne Consulting)

8.2.1 Stagnation Pressure and Water Level Rise

As steady flow interacts with a column, wall, or building, fluid pressures on the upstream side of the obstruction will increase above the value from hydrostatic pressure based on the design flood depth df. The pressure rise will approach the stagnation pressure

$$P_s = ½ \rho V^2 \qquad \text{(Eq. 8-6)}$$

where

P_s = stagnation pressure
V = flow velocity, averaged over depth, in m/s (ft/s)

If the obstruction is wide, the water surface elevation also rises at the leading edge, producing an increase in depth equal to the velocity head, $V^2/2g$. While these pressures and water level increase are not frequently used to compute loads, they may be important in some circumstances. For example, if doors or windows on the upstream side of a building fail, fluid pressures and water levels inside the building may increase above hydrostatic values for the design flood depth df by the amount of the stagnation pressure.

Water levels similarly drop along the sides of the object (sometimes called the drawdown) and then recover somewhat at the rear. The pressure changes are treated in most fluid mechanics texts and are often complicated to predict. However, the drop in pressure along the sides may be

approximated as $-½\, \rho\, V^2$ with a water surface change of $- V^2/2g$. Water levels and pressures at the rear are often near zero (ambient) but may depend on the shape and dimensions of the object.
The resulting situation would create unbalanced fluid pressures around the perimeter of the building. Methods of treating these pressures on each distinct wall are commonly used when defining wind loads on buildings, where pressure coefficients are defined for front, rear, and side walls, e.g., a pressure coefficient could be added to Equation (8-6) to account for variation in pressures on each wall of a building. These methods are not yet adopted in any building code for flood loads, though research papers can be found on this topic.

8.2.2 Simplified Hydrodynamic Drag

As a simplified method for estimating hydrodynamic effects when the flow velocity is low, most design codes and other guidance, e.g. ASCE7 (2016), Australian Code (2016), and FEMA (2011), contain a method of estimating fluid forces on a building based on the assumption that water levels on the upstream side are increased by the stagnation pressure. In these cases, provided the flow velocity is less than 3 m/s (10 ft/sec), it is permissible to convert hydrodynamic loads into equivalent static loads using an equivalent hydrostatic surcharge of

$$\Delta d_f = \alpha V^2/2g \qquad \text{(Eq. 8-7)}$$

where

Δd_f = increase in water level on upstream side compared to downstream side, in m (ft)
a = shape factor or drag coefficient = 1.25

8.2.3 Hydrodynamic Drag

A more fundamental method of computing the hydrodynamic force exerted by steady uniform flows on structural components is to use a standard drag force expression as

$$F_D = ½\, C_D\, \rho V^2 A_p \qquad \text{(Eq. 8-8)}$$

where

F_D = hydrodynamic drag force, in N (or lbs)
C_D = drag coefficient, function of structure shape and dimensions
V = velocity of flood water, in m/s (or ft/s)
A_p = the projected area of structure or structural element exposed to the moving water

8.3 Debris Impact Loads

Debris can also act as a load when it is transported by flood water and impacts against a structure. Debris loads act horizontally against the structure. Designers that retrofit existing buildings should become familiar with the type and size of debris typically transported in the project area. It is difficult to determine the magnitude of debris impact loading due to the uncertainty in the size and weight of the debris. ASCE 7 has identified debris loading due to the accumulation of debris against a structure or due to an impact of an individual floating object. Both of these debris loads may possibly affect buildings located in riverine environments. Debris loads associated with coastal flooding are likely due to floating object impacts only. Figure 8-3 illustrates two examples of flood related debris loads.

Figure 8-3 Debris Loads (source: Report on Guide for Design of Flood-Resistant Buildings)

8.3.1 Debris Accumulations

Loads due to debris accumulations are assumed to be represented as steady loads applied statically to a structure. These loads should be analyzed for effect on any structural element that may support trapped debris, as well as on the global structural analysis.

Limited guidance exists for predicting the forces of drift accumulation. For buildings, the Commentary in ASCE7 (2016) and the USACE (1995) "Flood Proofing" guide suggests a uniform load of 1.48 kN/m (100 lb/ft) acting in a strip 0.3 m (1 foot) thick along the length of the structure at the waterline. More rigorous prediction of the forces due to drift accumulation can be based on the increased fluid drag forces on the drift accumulation. This is given in ASCE7 (2016) by the standard drag force expression

$$F_{Da} = ½\, C_D\, \rho V^{2} A_a \qquad \text{(Eq. 8-9)}$$

where

F_{Da} = drag force due to debris accumulation, in N (lb)
V = flow velocity upstream of debris accumulation, in m/s (ft/s)
A_a = projected area of the debris accumulation into the flow, approximated by depth of accumulation times width of accumulation perpendicular to flow, in m^2 (ft^2)
C_D = drag coefficient, assumed to equal 1

8.3.2 Debris Impact from FEMA and ASCE 7 (2016) Flood Load Chapter

In the ASCE 7 (2016) Chapter 5 on Flood Loads, debris impact loads are included in the Commentary but not in the main code provisions. As a result, inclusion of debris impact in flood conditions is not compulsory. This method, also outlined in FEMA (2011), had its origin in the City of Honolulu building code and was further developed by FEMA based on guidance from laboratory tests using logs towed into a rigid target.

The expression used in ASCE7 for debris impacts is based on an impulse-momentum approach and is given by

$$F_{di} = 1.57\, C_{de}\, C_{bl}\, C_{or}\, R_{max}\, W\, V \,/\, (g\, \Delta t) \qquad \text{(Eq. 8-10)}$$

Where

F_{di} = impact force, in N (lbs)

W = weight of debris, in N (lbs)
V = velocity of flood water propelling debris, in m/s (ft/s)
Δt= impact duration or time to reduce object velocity to zero, in sec, taken as 0.03 sec
C_{de} = depth reduction coefficient
C_{bl} = debris blockage coefficient
C_{or} = debris orientation coefficient, recommended as 0.8
R_{max} = structural response coefficient

8.3.3 Debris Impact Loads from ASCE 7-16 Tsunami Load Chapter

In the ASCE7 (2016) Chapter 6 on Tsunami Loads, debris loads are included in the main code, making it mandatory to include debris loads in tsunami resistant building design. The approach used in ASCE7 (2016) Chapter 6 is based on an elastic response model in which loads are governed by the elasticity and stiffness of the debris-structure interaction. The maximum instantaneous debris impact force, F_{di}, is given by

$$F_{di} = C_{or} V (k M)^{1/2} \quad \text{(Eq. 8-11)}$$

where

C_{or} = orientation coefficient, equal to 0.65 for logs and poles;
V = maximum flow velocity at the site occurring at depths sufficient to float debris;
k = effective stiffness of the impacting debris or of the impacted structural element(s) deformed by the impact, whichever is less; and
M = debris mass, also given as W/g

8.4 Wave Loads

Some coastal and large lake shoreline areas may be impacted by wind-driven flood loads commonly referred to as wave action. As illustrated in Figure 8-4, the effect of waves is based upon the still water elevation, the wave crest, and the wave runup.

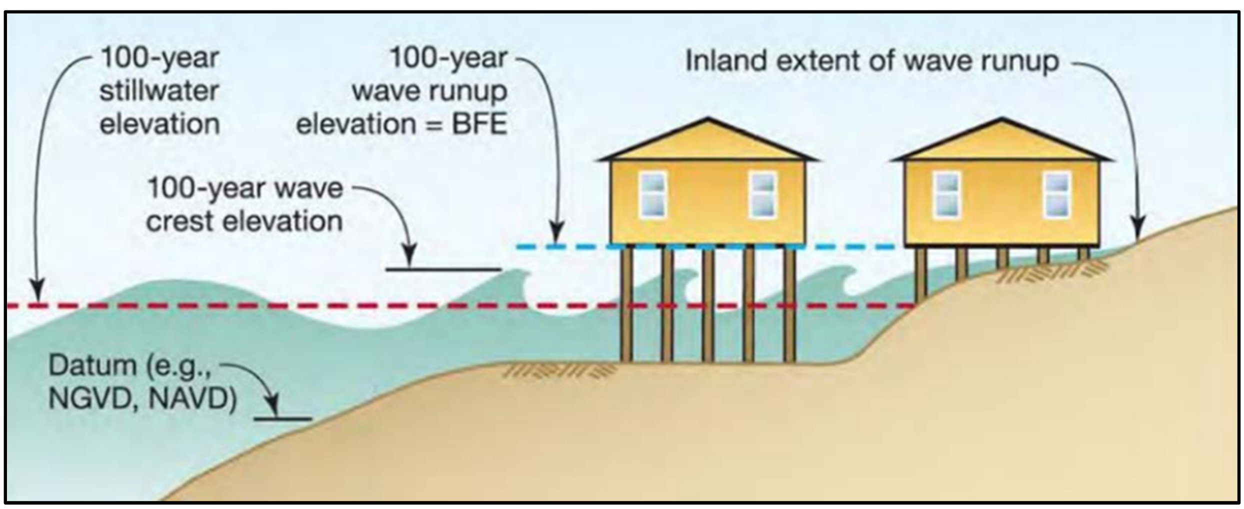

Figure 8-4 Wave Loading (source: FEMA Coastal Construction Manual 2011)

When waves reach the shoreline, they travel inland to allow the flood water to achieve a greater elevation than would occur if waves were not present. The elevation achieved by waves inland from the shoreline is referred to as wave runup. Another component of wave action is the setup, where there is an increase in the mean water elevation caused by the action of breaking waves.

Since wave runup reaches greater elevations than wave setup, runup is typically used to delineate the wave effects in the vicinity of the shoreline.

8.4.1 Significant Wave Height

Significant wave height changes with water depth due to shoaling, refraction, and diffraction, e.g. Goda (1985), Dean and Dalrymple (1991), and Kamphuis (2010). Depending on the site conditions, wave transformation processes will generally cause significant height to change as the waves move closer to shore, often reaching a maximum at a location where depth-limited breaking is first initiated.

For application in flooded coastal regions, where the over-ground flooded depth, df, is expected to be small, and waves likely started breaking farther offshore, random wave heights are likely limited by wave breaking. USACE (2002) guidance indicates that in shallow water with active wave breaking, an approximate upper-bound on the significant wave height limited by breaking is given by

$$H_{sb} = 0.6\, d_f \qquad \text{(Eq. 8-12)}$$

where

H_{sb} = significant wave height with depth limited wave breaking, in m (ft)
d_f = local still water depth in coastal location, in m (ft)

Kamphuis (2000) has developed a refined wave breaking model that includes beach slope, based primarily on physical model tests performed at Queens University. In shallow water, the Kamphuis method gives the significant wave height with breaking as a function of the local nearshore ground slope as

$$H_{sb} = 0.56\, e^{3.5\, tan\theta}\ d_f \qquad \text{(Eq. 8-13)}$$

where

$tan\ \theta$ = local beach slope (rise over run)

For slopes of 1:100, 1:50, 1:20, 1:10, and 1:7.5, the Kamphuis method gives H_{sb} as 0.58, 0.60, 0.67, 0.79, and 0.89 times the depth, respectively.

8.4.2 Maximum or Design Wave Height

While the significant wave height defines the overall characteristics of the sea state, it is a statistical value and does not indicate the largest individual wave that may occur in the sea state. Many formulas used to compute wave loads adopt wave heights larger than the significant height. For random waves, a wave height with a 2% probability of exceedance is often adopted as a reasonable value for design. Goda (1985) notes that the maximum wave height in a random sea may be in the range of 1.6 H_s to 2.0 H_s, but such waves have an exceedance probability of much less than 1%. Waves in the range of 1.4 Hs to 1.5 H_s are exceeded by roughly 1 to 2 percent of the waves in a random sea and form a more reasonable value for use when computing shallow water flood loads. For structural design in shallow flooded regions, the upper limit on individual wave heights also corresponds to the largest breaking wave height that can occur in any water depth, H_b. In shallow water, the height of the largest breaking waves can be approximated using the traditional form of the Miche criterion. The USACE (2002) gives this limiting wave height as

$$H_b = 0.9\, d_f \qquad \text{(Eq. 8-14)}$$

where

H_b = maximum breaking wave height in m (ft)

More detailed guidance on the maximum individual breaking wave in shallow water includes the effects of beach slope, as well as the effects of wave period. Several methods have been proposed in the coastal engineering literature for estimating H_b for specific combinations of wave and beach conditions, see Goda (1985), USACE (2002), or Kamphuis (2010). For flood design codes, where over-ground water depth is expected to be small, many of these exist in simplified form as a function of just the local water depth. In a more general form, the depth-limited breaking wave height in shallow water can be given by

$$H_b = \kappa\, d_f \qquad \text{(Eq. 8-15)}$$

where

κ = breaker height to depth ratio, or breaker index

For very flat ground slopes, FEMA guidance, FEMA (2011), as well as the ASCE7 (2016) standard, base the maximum wave height on Solitary wave theory (theoretically valid only for flat to very mild slopes) with $\kappa = 0.78$. For general use, the value $\kappa = 0.9$ is more appropriate. But it is known that the breaker index can increase as slope increases. For waves over very steep slopes, it is known that the local ratio of wave height to water depth can be $\kappa = 1.2$ to 1.4, and in some cases can be higher due to flow convergence or other local effects.

Comparison of the maximum breaking wave height in Equation (8-14) to the significant wave height in Equation (8-12) shows that in shallow water, the breaking height is about 50% larger than the significant height, or $H_b = 1.5\ H_{sb}$. Use of the shallow water significant wave height Kamphuis (2000), in Equation (8-13), along with the 1.5 factor to relate to maximum breaking waves to significant wave height, gives $\kappa = 0.87$, 0.90, 1.00 , 1.19, and 1.34 for ground slopes of 1:100, 1:50, 1:20, 1:10, and 1:7.5, respectively.

8.4.3 Wave Runup

As waves reach a shoreline, a last transformation of wave energy causes waves to rush up the beach slope, or a structure slope, to an elevation above the still water level and to a location landward of the still water shoreline. Wave runup, R, is then defined as the vertical elevation reached by water as the wave rushes up the slope.

The horizontal extent of wave runup is related to the vertical runup as

$$X_R = R/tan\theta \qquad \text{(Eq. 8-16)}$$

where

R = vertical runup above SWL
X_R = horizontal runup excursion landward from SWL shoreline
$tan\theta$ = average ground slope of foreshore, for slope angle θ

8.4.3.1 Runup on Beaches

For natural sand beaches, that typically have mild slopes, the runup method of Stockdon et al. (2006) is one method recommended by FEMA (2018). Unlike most other runup prediction methods that are based on small scale laboratory tests, the Stockdon et al. method is based on field observations from a wide range of beaches from the North Sea, the US Atlantic coast, and the US Pacific coast. For dissipative beaches, Stockdon et al. (2006) give a runup expression as a linear function of the Irribarren Number as

$$R_{2\%}/H_S = 0.73\ \xi \qquad \text{(Eq. 8-17)}$$

where

$R_{2\%}$ = vertical runup above SWL at 2% exceedance level
H_s = significant wave height
$\xi = \tan\theta / (Hs/Lo)^{1/2}$ = Irribarren Number or Surf Similarity Parameter
L_o = deep water wavelength = $gT_p^2/2\pi$.

8.4.3.2 Runup on Coastal Structures or Steep Bluffs

For steep slopes with low porosity, including natural bluffs and coastal structures, the runup method outlined in TAW (1999) or EurOtop (2018) is suggested by FEMA (2018). This applies to steep slopes of about 1:8 to 1:1. The TAW method is based on Dutch research and design experience for application to sea dikes and is similar to the Upper Bound Limit of Wave Uprush given by the Ontario Ministry of Natural Resources (2001). The TAW method may be summarized (simplified from the original) as

$$R_{2\%}/H_S = 1.75\ \gamma_r\ \xi \qquad \text{for } \xi < 1.8 \qquad \text{(Eq. 8-18a)}$$

or

$$R_{2\%}/H_S = \gamma_r\ (4.3 - 1.6/\xi^{1/2}) \qquad \text{for } \xi > 1.8 \qquad \text{(Eq. 8-18b)}$$

where

γ_r = reduction factor for ground roughness, structure shape, and angle of wave attack

8.4.4 Wave Forces

Wave loads during floods result from water waves striking a structure after propagating over flooded ground, i.e. over an area of normally dry ground that has been inundated during a flood. As noted, this often leads to the use of shallow water assumptions for breaking waves when describing wave motions, e.g. USACE (2002).

8.4.4.1 Breaking Wave Loads on Piles and Columns

For breaking waves subject to shallow water conditions, guidance from FEMA and ASCE7 (2016) suggest the maximum drag force due to breaking waves can be estimated as

$$F_b = ½\ C_{Db}\ \rho g\ D\ H_b^2 \qquad \text{(Eq. 8-19)}$$

where

F_b = breaking wave force, in N (lbs)
C_{Db} = breaking wave drag coefficient (1.75 for round piles, 2.25 for square piles)
D = pile diameter for round pile, or 1.4 times width of pile for square, in m (ft)
H_b = breaking wave height, in m (ft)

8.4.4.2 Breaking Wave Loads on Vertical Walls

Breaking wave loads on full depth vertical walls are calculated by one of two methods. ASCE7 (2016) adopts methods outlined by FEMA (2011), based on a USACE study of breaking wave loads by Walton et al. (1989). Future revisions to ASCE 7 (draft version of ASCE 7-22) will likely switch to a method developed in Japan by Goda (1985) that was originally developed for wave interaction with the vertical face of concrete caisson breakwaters.

Loads on Full-Depth Walls from FEMA and ASCE 7 (2016). A key feature is that with wave reflection, the crest of the wave at the wall (sum of incident plus reflected waves) is at an elevation of 1.2 df above the still water level. The resulting pressure distribution reaches a maximum at the still water line and then diminishes with values given by

$$P_1 = (1.2 + C_p)\rho \; g \; d_f \qquad \text{(Eq. 8-20a)}$$

$$P_2 = 1.2 \, \rho \; g \; d_f \qquad \text{(Eq. 8-20b)}$$

where

P_1 = pressure in N/m^2 (lb/ft^2) at the design still water level
P_2 = pressure in N/m^2 (lb/ft^2) at the ground level
C_p = dynamic pressure coefficient ($1.6 < C_p < 3.5$, per Table 3-5)

The force per unit width of this pressure distribution is given by the area under the pressure distribution as:

$$f_{wb} = 1.1 \, C_p \, \rho g \, d_f^2 + 1.9 \, \rho \, g \, d_f^2 \qquad \text{(Eq. 8-21)}$$

where

f_{wb} = net breaking wave force per unit width of structure, in N/m (or lb/ft)

The total load on a wall of width w is given by:

$$F_{wb} = w \, f_{wb} \qquad \text{(Eq. 8-22)}$$

9 Temporary and Permanent Flood Barriers

Reducing flood risk and the damages associated with flooding has resulted in numerous commercial products for flood protection. Many of the products are classified as temporary, where the product must be deployed and erected each time there is a threat of flooding, while other products are classified as permanent, where they are always maintained in a deployed state. No matter whether a building is being protected by temporary barriers or permanent barriers, the building should be safely evacuated prior to the flood event. The following sections provide additional insight into the use of temporary and permanent flood barriers, standards for flood barriers, and concerns regarding non-certified flood barriers.

9.1 Temporary Flood Protection Barriers

The building owner, tenant, or assigned agent of the owner is typically responsible for deploying and erecting the temporary flood barriers in advance of a flood event. In that light, the detailed planning, purchase of flood proofing materials, deployment and implementation lies solely with the building owner. The successful use of temporary flood protection barriers requires the determination of flood characteristics, site characteristics, and building characteristics as described in sections 7.1, 7.2, and 7.3. It is strongly recommended that buildings which are at risk of flooding be assessed and equipped with permanent and certified flood barriers as discussed in Section 9.2. The temporary barriers discussed herein should be utilized as a last- minute effort to deter or limit flooding, and under no circumstance should the building(s) implementing these measures be occupied during the flood event. The building owner should ensure that the materials recommended for protecting the building have been obtained prior to the start of the flood season. Materials required for implementing a preventive barrier to flooding should be stockpiled in an accessible location. Materials remaining from the previous flood season should be inspected to determine condition for reuse.

9.1.1 Common Temporary Flood Barriers

Some of the more frequent materials required for implementing successful temporary flood proofing measures include:

- Closures panels (plywood and other material). A temporary closure system consisting of 25.4 mm (1-inch) thick plywood or Oriented Strand Board (OSB) is often recommended for flood barrier construction at doorways and windows; no closure should have a horizontal or vertical span in excess of 1.0 m (3 feet) without incorporating additional supports. Because 25.4 mm (1-inch) paneling may be expensive, a 25.4 mm (1-inch) closure can be pre-made by using a grid of screws to connect two boards of lesser thickness. Vent openings can usually be protected with a lesser thickness. All materials should be water-resistant. The closure panel should be measured, cut, and identified for the specific location in the temporary flood barrier and should be available for use from one flood season to the next. The panels should be held in place with water resistant caulking, nails, screws and/or liquid nail. For doorways which open inwards, or for over the top of window glass, the closure panel should extend onto the exterior wall.

- Sand and sandbags. Sandbags are an integral component of many temporary barriers to flooding. Sandbags should be made of nylon or polyethylene. Generally, bags can be placed in a single row up to 3 bags high. Berms more than 3 bags high should be constructed in pyramid fashion; these berms should be as many bags-wide at the base as they are bags-high. Bags should be filled between half-way and two-thirds full, should not be tied and should be placed with the top of the bag tucked under the bag. After placement of each layer, the bags should be walked on to provide a better seal with adjacent bags. The bags in each course should be placed so that they cover to the maximum possible extent the joints in between the bags in the same course and also between the bags in the course below.

  Sandbag closures at doorways and similar openings can work well but must be carefully sealed at the ends. The building owner may prefer to use a plywood or other type of closure panel.

- Caulk and sealant for building exterior. If any portion of the building to be protected consists of brick, stone, stucco, concrete, cinder block, or tile, the use of a water-resistant sealant is recommended. The sealant should be applied to all porous surfaces, which have been thoroughly cleaned and dried to allow deep penetration and maximum resistance to the effects of water. The sealant should be extended above the area of proposed protection for best coverage. Manufacturer's information indicate that commercial sealants may last up to 20 years without discoloration. In addition, if large cracks and voids in the building exterior need to be filled; many products carried by local hardware stores are compatible with the materials on the exterior of the building.

- Interior drainage pump and power supply. In order to prevent flood damages due to seepage of flood waters through the temporary flood barrier or resulting from a rising water table, it may be recommended that pumps be incorporated into the protection measures. Pumps will be needed inside the building to collect seepage. At a minimum, one pump with a capacity of at least 75.7 litres (20 gallons) per minute should be considered for installation in the structure for every 186 square metres (2,000 square feet) of floor space. 115-volt AC powered pumps can be used provided that electricity is available throughout the duration of the flood event. The owner may consider installing a permanent sump pump with sump pit, or can bring in one or more pumps for temporary use. If loss of electrical power during a flood is a concern, the owner could employ a gasoline-powered electric generator to power the AC pump, or could use one or more battery-powered sump pumps. The user will have to be aware that the battery life is limited; therefore, a spare battery should be kept on-hand. The life of the battery recommended in the battery powered back-up sump pump is 10 to 14.5 hours of pump use. Because it is impossible to know how much the pump will be operating, the user will need to monitor it often and be prepared to replace the battery. If there is no basement or crawlspace, the owner may elect to use a floor-type pump that can maintain the depth of water on the floor to 0.32 cm (1/8 inch). If the building being protected does have a basement or crawlspace, the pump must be placed at the lowest elevation in order to work most efficiently. In some instances, the owner may consider cutting a small hole through the floor of a closet space, for concealment purposes, and lowering the pump to the lower level. For a slab on grade structure, the pump should be placed in a location upon the floor where flood waters may begin to collect. In all cases, the owner should consider placing the pump at a location where the discharge hose is easily positioned to extend beyond the limits of the protection measures.

  The discharge side of the pump should be sized to match a common 25.4 mm (1-inch) diameter garden hose or should be equipped with an adaptor to 25.4 mm (1 inch). If there is a sandbag berm, a pump with significant capacity will be needed to collect rainfall, seepage and rising groundwater within the area of the berm.

9.1.2 Implementing Temporary Barriers

Due to the temporary nature of these barriers, there are several factors which should be considered prior to and during deployment:

- In advance of a flood event, computer modeling may be available from federal or state agencies, to forecast the estimated depth, velocity, and duration of flooding. The building owner can use this information as well as the structural condition of the building to determine how best to protect the building. Due to potential concerns over the structural integrity of exterior walls, it is generally considered a good flood risk management technique to allow no temporary flood proofing measures to be placed to a height which exceeds 1.0 m (3 feet) above the elevation of the first floor of the building without conducting a detailed structural analysis of the exterior walls. The hydrostatic forces of the flood waters can cause a catastrophic collapse of the walls of a building due to the lack of lateral resistance from the building as flood waters rise higher against the sides of the building. And, since the characteristics of a flood (the depth, velocity and duration) may change during a flood event, it is noted that it is possible for failure of foundations, walls, and closure panels to occur at a flood depth of less than 1.0 m (3 feet).

- It is possible that a building may be exposed to a flood depth greater than the temporary flood barriers that have been erected. The building should not be occupied during the flood event.

- Intense and more frequent storm events that can cause localized flooding may occur and there may not be sufficient warning time for the owner or tenant to implement the temporary flood barriers.

- Preparing a structure for a flood requires significant effort and it is almost impossible to accurately predict the actual depth to which flood waters from an approaching storm may rise. Therefore, the owner or tenant cannot be certain that the projected flood event will actually occur. The owner or tenant must determine their own comfort level and balance the risk of not having the building permanently protected, versus the risk that the effort to erect temporary flood barriers may or may not be necessary.

- In order to prevent unsanitary water from backing up into the building during a flood event, the owner should ensure that the sanitary drain line is fitted with an anti-back-flow device.

- Since these measures are temporary and the structural integrity of the exterior walls probably has not occurred prior to the flood event, it is strongly recommended that barriers be limited to no more than 1 metre in height. Constructing temporary barriers to a greater height could result in catastrophic wall failure if the structural integrity of the exterior walls is lacking.

9.2 Permanent Flood Protection Barriers

Permanent barriers are typically affixed to, or erected in close proximity to, the building to which they are protecting from flooding and are generally recommended as a passive device in order to reduce or eliminate the need for human interaction in the implementation process. A passive barrier requires no storage or the substantial placement of materials and equipment prior to a flood event. Since the barriers are permanent, they become a feature of the building. When permanent barriers are used for pedestrian and vehicular openings, they are generally designed as flood resistant doors or panels, capable of sustaining design flood loads without failure, and are operational just by closing the door or raising the panel. The pedestrian opening barrier may also appear as a swing panel within a flood wall as shown in Figure 9-1. There are several variations of vehicular barriers, from being concealed below the ground surface, provided as a swing gate, or as stop logs as shown in Figure 9-2.

Figure 9-1 and Figure 9-2 Flood Barriers (source: Association of State Floodplain Managers)

9.3 American National Standards Institute 2510 Standards for Flood Abatement

Preventing flood waters from entering a building requires the use of flood barriers. While there are many products marketed as flood barriers, very few have been tested and certified for preventing damages. In the U.S., the Association of State Floodplain Managers (ASFPM) in collaboration with Factory Mutual Approvals, which is the independent testing arm of international insurance carrier Factory Mutual Global, tests and certifies industrial and commercial flood fight products and services, and the US Army Corps of Engineers National Nonstructural Committee (NNC) have implemented a national program of testing and certifying flood barrier products used for flood proofing and flood fighting. The purpose of this program is to provide an unbiased process of evaluating products in terms of resistance to water forces, material properties, and consistency of product manufacturing. This is accomplished by testing the product against water related forces in a laboratory setting, testing the product against material forces in a laboratory setting, and periodic inspection of the product manufacturing process for consistency of the product relative to the particular product that received the original water and material testing. Products meeting the consistency of manufacturing criteria and the established standards for the material and water testing can be certified as the American National Standards Institute (ANSI) standard. Since the testing part of the program is conducted in a laboratory setting, not all forces and impacts to which the product could be subjected to during an actual flood event will be tested.

The ANSI has established examination and laboratory testing requirements for flood abatement equipment, which is provided as ANSI 2510. With the recent design and production of numerous products marketed for flood protection, there has been a critical need for standards to which the products should be tested and certified to prior to field use during a flood event. This standard sets the performance standards for opening barriers, perimeter barriers, anti-backflow valves, and flood abatement pumps.

9.3.1 ANSI 2510 Standards Background

The standards are intended to verify that the product will meet stated conditions of performance, safety, and quality. The standards set performance requirements for flood mitigation equipment in the following product categories:

- Flood Barriers for Opening Barrier Applications
- Flood Barriers for Perimeter Barrier Applications
- Flood Mitigation Valves (anti backflow)
- Flood Mitigation Pumps
- Penetration Sealing Devices

The standard is limited to the flood mitigation product. Flood waters may produce high hydrostatic or hydrodynamic loading on a protected structure. Appropriate measures must be taken to ensure that an exterior wall structure (or similar) is able to withstand anticipated flood loading. Some wall construction assemblies often are able to withstand 1.0 m (3-foot) or less of flood loading without requiring reinforcement or additional water proofing. A full structural analysis must be conducted by qualified personnel to ensure loading beyond the 1.0 m (3-foot) prescriptive limit.

Once certified, manufacturers may not change a product or service without prior written authorization by Factory Mutual Approvals. Continued certification is based upon:

- the suitability of the product;
- production or availability of the product as currently certified;
- the continued use of acceptable quality assurance procedures;
- satisfactory field experience;
- compliance with the terms stipulated in the Master Agreement, which obligates the manufacturer to allow re-examination of the product and surveillance audits at FM Approvals' discretion.;
- satisfactory re-examination of samples for continued conformity to requirements; and
- satisfactory audits conducted as part of the product surveillance audit program.

9.3.2 Product Performance

The performance requirements for flood mitigation equipment are composed of two different categories: (i) General Component and Material Testing; and (ii) Performance Testing. All flood mitigation equipment, and their applicable components, are subject to the General Component and Material Testing. In addition to this component testing, performance testing of the system/assembly is required specific to the product category. While there are performance testing standards for each of the five equipment categories mentioned in section 8.3.1, Tables 9-1, 9-2, and 9-3 illustrate testing for flood barriers. The performance testing of flood barriers for perimeter barrier application has been designed to simulate quasi-static as well as riverine flooding conditions, including hydrostatic load, large wave loads for riverine conditions, multiple debris impact, strong currents, and overtopping conditions.

All tests in Table 9-1 replicate events that can be anticipated during a single flood occurrence. As a result, all tests listed in the table must be completed in sequence with the same barrier assembly.

In the U.S., the performance testing is conducted at the US Army Corps of Engineers, Engineering Research and Development Center (ERDC) Coastal and Hydraulics Laboratory, located in Vicksburg, Mississippi. The design, description, and capabilities of the facility are further described in the ANSI 2510 standards. The construction of the barrier must comply with the test set-up and constraints of the facility. Special construction may be required to connect a barrier to the wing walls of the test basin. Leakage from this construction will be included in the test results. However, the construction is not required to be part of the design of the flood barrier. Additionally, special construction may be required for any pre-installed foundation components. Alternative test facilities may be accepted for testing at the sole discretion of FM Approvals. None currently exist outside of the United States.

Major and minor repairs to the flood barrier during any portion of the performance test series are only allowed at the discretion of FM Approvals. A major repair may require re-testing of the entire performance test series and/or additional testing. A maximum of three minor repairs shall be allowed, but may require adjustments to the barrier's Design, Installation, Operation, and Maintenance Manual. No repairs shall be allowed that can put facility personnel into harm's way.

Table 9-1 Perimeter Flood Barrier Performance Tests (source: ANSI/FM Approvals 2510)

Test Description	Water Condition(s)		Duration
	Water Depth*	Other	
Deployment	N/A	N/A	Per Manufacturer's Specification
Hydrostatic Load	1.0 ft (0.30 m)	N/A	22 hr
	2.0 ft (0.61 m)	N/A	22 hr
	100 percent x h	N/A	22 hr
Wave-Induced Hydrodynamic Load	66.7 percent x h	low waves 2-3 in (51-76 mm)	7 hr
	66.7 percent x h	medium waves 6-8 in (152-203 mm)	10 min (3 times)
	66.7 percent x h	high waves 10-12 in (254-305 mm)	10 min
	80 percent x h	low waves 2-3 in (51-76 mm)	1 hr (min) - 7 hr (max)
	80 percent x h	medium waves 6-8 in (152-203 mm)	10 min (3 times)
	80 percent x h	high waves 10-12 in (254-305 mm)	10 min
Overtopping	≥1 in (25 mm) overflow	N/A	1 hr
Debris Impact	66.7 percent x h	12 in. (30 cm) diameter log 610 lb (277 kg) weight at 7 ft/s (2.13 m/s)	N/A
	66.7 percent x h	17 in (43 cm) diameter log 790 lb (358 kg) weight 7 ft/s (2.13 m/s)	N/A
Current	66.7 percent x h	7 ft/s (2.13 m/s) current	1 hr
Post Hydrostatic Load	100 percent x h	N/A	1 hr (min) - 22 hr (max)

* The manufacturer's specified maximum design water depth for the barrier is defined as "*h*".

In accordance with the performance standards, flood barriers for perimeter barrier applications shall be capable of withstanding wave-induced hydrodynamic load conditions from various water depths and wave heights. The permanent deflection of the barrier shall be less than or equal to 150 mm (6 inches), as measured from the horizontal and vertical centre of each wall.

In addition, during low wave conditions, the leakage rate shall not exceed 186 litres per hour per metre length (15 gallons per hour per foot length), where the barrier's length is measured along the centre point of the barrier's seal to the ground.

There is no leakage rate requirement for medium and high wave conditions. However, during these wave conditions the barrier shall not fatigue, experience fill-loss, wall sliding, overturning, or other permanent deflection in excess of the requirement.

The barrier shall be impacted with waves generated perpendicular to the face of the centre wall of the barrier as detailed in Table 9-2.

Table 9-2 Wave Testing Spectrum (source: ANSI/FM Approvals 2510)

Wave Description	*Wave Height (Measured from trough to crest)*	*Mean Wave Period*	*Test Duration*
Low Waves	2-3 in (51-76 mm)	2 seconds	7 hr*
Medium Waves	6-8 in (152-203 mm)	2 seconds	10 min (3 times)
High Waves	10-12 in (254-305 mm)	2 seconds	10 min

* For a water depth of 80 percent x h, if no negative effects are observed during the first hour of testing (i.e. increased leakage rates or deflection measurements), the test duration may be reduced to 1 hour.

The performance testing of flood barriers for opening barrier applications has been designed to simulate quasi-static flood conditions. All tests must be completed in sequence as shown in Table 9-3, with the same flood barrier system.

If the product under evaluation is available in a range of sizes, a worst-case system representing the maximum protected opening width shall be tested to the manufacturer's maximum design water depth. Depending on design consistency across size ranges, testing of the worst case may allow for smaller sizes to be considered for certification with little or no further testing.

If a barrier is submitted for modular configurations having intermediate support mullions (or similar) between multiple barrier sections, a minimum of two sections with one intermediate support shall be performance tested. Certification will be restricted to the maximum width measured between each section (between one edge and the intermediate support). Single-span configurations shall also be tested if the maximum width of the single-span configuration exceeds the maximum section width of the modular configuration.

Table 9-3 Opening Flood Barrier Performance Tests (source: ANSI/FM Approvals 2510)

Test Description	*Condition**	*Duration*
Deployment	N/A	Per Manufacturer's Specifications
Hydrostatic Load	10 percent x $h \pm 0.25$ in (0.6 cm)**	2 hr
Hydrostatic Load	100 percent x $h \pm 0.25$ in (0.6 cm)**	20 hr
Redeploy	Disassemble and redeploy	Per Manufacturer's Specifications
Dynamic Impact Load	Water drained, two 600J impacts (minimum)	N/A
Post Hydrostatic Load	10 percent x h ± 0.25 in (0.6 cm)**	1 hr
Post Hydrostatic Load	100 percent x h ± 0.25 in (0.6 cm)**	1 hr

* The manufacturer's specified maximum design water depth for the barrier is defined as "*h*."

** Hydrostatic load testing may be required at additional water depths, at the discretion of FM Approvals, if the design of the barrier is such that increased leakage may occur at other depths besides those prescribed above. Additional water depths shall be tested for a minimum duration of 1 hr. Hydrostatic Load testing at 10 percent x *h* may be waived if the design of the barrier is such that compression forces applied by the water column do not influence the barrier's sealing capabilities.

Several of the barrier, closure, and flood fight pump products which have achieved ANSI/FM Approvals 2510 certification are shown in Figures 9-3 and 9-4.

Figure 9-3 Certified Barrier Products (source: Association of State Floodplain Managers)

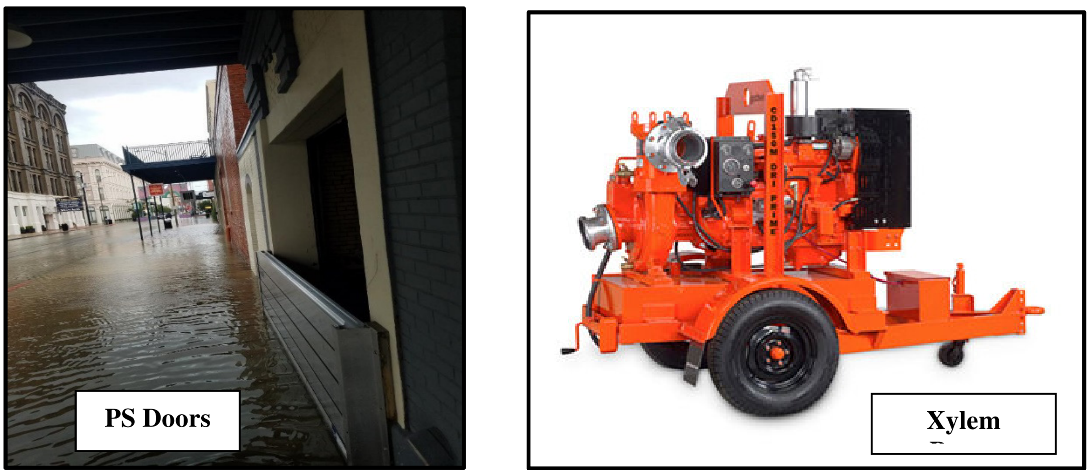

Figure 9-4 Opening Closure and Pump (source: Association of State Floodplain Managers)

9.4 Non-Certified Barriers

The continual development of flood protection products in recent years has resulted in the production of products which may or may not be successful when deployed to prevent flooding. As the frequency of flooding continues to increase and as communities and government entities purchase products for their arsenal of flood prevention materials, it has become imperative that flood abatement products, in the form of permanent or temporary barriers, be successful when deployed during a flood event.

The failure of a barrier may result in substantial property damages and be catastrophic when resulting in life loss. For flood risk mitigation using such barriers, it is recommended that only those products which have met the testing and certification of ANSI 2510 be utilized.

10 Flood Resistant Materials

Providing protection to buildings that are located within a flood hazard area is an important goal of this report. The U.S. National Flood Insurance Program (USNFIP) has developed regulations to include minimum building design criteria that apply to new construction, repair, and substantial improvement of existing buildings in designated flood hazard areas.

The USNFIP regulations require the use of construction materials that are resistant to flood damage. The lowest floor of a residential building, defined as a non-commercial structure designed for habitation purposes only, must be elevated to or above the design level (design level) flood elevation. The lowest floor of a nonresidential building, defined as a mixed-use building where the primary use is commercial or non-habitational, must be elevated to or above the design level elevation or dry floodproofed to the design level elevation. As currently practiced in most of the US, the design level elevation is synonymous with the 100-year Mean Return Interval (MRI) flood elevation. Additional information is available through FEMA Technical Bulletin No. 2; Flood Damage-Resistant Materials Requirements, August 2008.

10.1 Use of Flood Resistant Materials

All building construction below the design flood level elevation is susceptible to flooding and should consist of flood damage-resistant building materials. The following information from FEMA Technical Bulletin 2 provides guidance on what constitutes "materials resistant to flood damage" and how and when these materials must be used to improve a building's ability to resist flood damages.

Flood-resistant material is to be defined as "any building product [material, component or system] capable of withstanding direct and prolonged contact with flood waters without sustaining significant damage." The term "prolonged contact" is defined as at least 72 hours within the USNFIP, and the term "significant damage" means any damage requiring more than cosmetic repair. "Cosmetic repair" includes cleaning, sanitizing, and resurfacing (sanding, repair of joints, repainting) of the material. The cost of cosmetic repair should also be less than the cost of replacement of affected materials and systems. Individual materials that are considered flood damage-resistant must not cause degradation of adjacent materials or the systems of which the material is a part.

10.2 Classifying Flood Resistant Materials

Table 10-1 describes five classes of materials ranging from those that are highly resistant to flood water damage, to those that have no resistance to flooding. Materials are broadly described as structural materials and finish materials based on how they are used in normal building construction practices.

Table 10-1 Class Description of Materials
(source: FEMA TB2 Flood Damage-Resistant Materials Requirements)

NFIP	Class	Class Description
ACCEPTABLE	5	Highly resistant to flood water[1] damage, including damage caused by moving water.[2] These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class are permitted for partially enclosed or outside uses with essentially unmitigated flood exposure.
ACCEPTABLE	4	Resistant to flood water[1] damage from wetting and drying, but less durable when exposed to moving water.[2] These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class may be exposed to and/or submerged in flood waters in interior spaces and do not require special waterproofing protection.
UNACCEPTABLE	3	Resistant to clean water[4] damage, but not flood water damage. Materials in this class may be submerged in clean water during periods of flooding. These materials can survive wetting and drying, but may not be able to be successfully cleaned after floods to render them free of most[3] harmful pollutants.
UNACCEPTABLE	2	Not resistant to clean water[4] damage. Materials in this class are used in predominantly dry spaces that may be subject to occasional water vapor and/or slight seepage. These materials cannot survive the wetting and drying associated with floods.
UNACCEPTABLE	1	Not resistant to clean water[4] damage or moisture damage. Materials in this class are used in spaces with conditions of complete dryness. These materials cannot survive the wetting and drying associated with floods.

Notes*:

1 Flood water is assumed to be considered "black" water; black water contains pollutants such as sewage, chemicals, heavy metals, or other toxic substances that are potentially hazardous to humans.

2 Moving water is defined as water moving at low velocities of 5 feet per second (fps)or less. Water moving at velocities greater than 5 fps may cause structure damage to building materials.

3 Some materials can be successfully cleaned of most of the pollutants typically found in flood water. However, some individual pollutants such as heating oil can be extremely difficult to remove from uncoated concrete. These materials are flood damage-resistant except when exposed to individual pollutants that cannot be successfully cleaned.

4 Clean water includes potable water as well as "gray" water; gray water is wastewater collected from normal uses (laundry, bathing, food preparation, etc.).

The lists of materials, by generic names, and notes of whether the materials are acceptable or unacceptable for use below the design level elevation are listed in Table 10-2. All building materials are in some fashion fastened or connected to the structure. Fasteners and connectors also must be resistant to flood damage.

Flood damage-resistance is determined by factors that may be a function of the specific application and by the characteristics of flood waters. Each situation requires sound judgment and knowledge of probable contaminants in local flood waters to select materials that are required to resist flood damage. For materials and products that are listed in Table 10-2, the manufacturers' use and installation instructions must be followed to ensure maximum performance. Masonry and wood products used below the design level elevation must comply with the applicable standards published by the American Society for Testing and Materials (ASTM), the American Concrete Institute (ACI), the Truss Plate Institute (TPI), the American Forest & Paper Association (AF&PA), and other appropriate organizations.

Table 10-2 does not list all available structural materials and finish materials. For materials and products not listed, manufacturers' literature (i.e., specifications, materials safety data sheets, test reports) should be evaluated to determine if the product meets flood damage-resistance requirements. Materials and products that are not listed in Table 10-2 may be used if accepted by the local building official. Acceptance should be based on sufficient evidence, provided by the applicant, that the materials proposed to be used below the design level elevation will resist flood damage without requiring more than cosmetic repair and cleaning.

Class 1, 2, and 3 materials are unacceptable for below the design level elevation applications for one or more of the following reasons:

- Normal adhesives specified for above-grade use are water soluble or are not resistant to alkali or acid in water, including groundwater seepage and vapor.
- The materials contain wood or paper products, or other materials that dissolve or deteriorate, lose structural integrity, or are adversely affected by water.
- Sheet-type floor coverings (linoleum, rubber tile) or wall coverings (wallpaper) restrict drying of the materials they cover.
- Materials are dimensionally unstable.
- Materials absorb or retain excessive water after submergence.

In some cases, the combination of acceptable materials can negatively impact the classification of individual materials. This is illustrated by the following examples:

- Vinyl tile with chemical-set adhesives is an acceptable flooring material when placed on a concrete structural floor. However, when the same vinyl tile is applied over a plywood structural floor, it is no longer considered acceptable.

- Polyester-epoxy or oil-based paints are acceptable wall finishes when applied to a concrete structural wall. When the same paint is applied to wood, it is no longer considered acceptable.

Table 10-2 Types, Uses, and Classifications of Materials
(source: FEMA TB2 Flood Damage-Resistant Materials Requirements)

Types of Building Materials	**Uses of Building Materials**		**Classes of Building Materials**				
			Acceptable		**Unacceptable**		
	Floors	**Walls/ Ceilings**	**5**	**4**	**3**	**2**	**1**
Structural Materials (floor slabs, beams, subfloors, framing, and interior/exterior sheathing)							
Asbestos-cement board		*	*				
Brick							
Face or glazed		*	*				
Common (clay)		*		*			
Cast stone (in waterproof mortar)		*	*				
Cement board/fiber-cement board		*	*				
Cement/latex, formed-in-place	*			*			
Clay tile, structural glazed		*	*				
Concrete, precast or cast-in-place	*	*	*				
Concrete block[1]		*	*				
Gypsum products							
Paper-faced gypsum board		*			*		
Non-paper-faced gypsum board		*		*			
Green board		*				*	
Keene's cement or plaster		*			*		
Plaster, otherwise, including acoustical		*				*	
Sheathing panels, exterior grade		*			*		
Water-resistant, fiber-reinforced gypsum exterior sheathing		*		*			
Hardboard (high-density fiberboard)							
Tempered, enamel or plastic coated		*				*	
All other types		*					*
Mineral fiberboard		*					*
Oriented-strand board (OSB)							
Exterior grade	*	*				*	
Edge swell-resistant OSB	*	*				*	
All other types	*	*					*
Particle board	*						*
Plywood							
Marine grade	*	*	*				
Preservative-treated, alkaline copper quaternary (ACQ) or copper azole (C-A)	*	*		*			

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Structural Materials (floor slabs, beams, subfloors, framing, and interior/exterior sheathing)							
Preservative-treated, Borate[2]	*	*	*				
Exterior grade/Exposure1 (WBP – weather and boil proof)	*	*		*			
All other types	*	*					*
Recycled plastic lumber (RPL)							
Commingled, with 80-90% polyethylene (PE)	*		*				
Fiber-reinforced, with glass fiber strands	*		*				
High-density polyethylene (HDPE), up to 95%	*		*				
Wood-filled, with 50% sawdust or wood fiber	*				*		
Stone							
Natural or artificial non-absorbent solid or veneer, waterproof grout	*	*	*				
All other applications		*				*	
Structural Building Components							
Floor trusses, wood, solid (2x4s), decay-resistant or preservative-treated	*	*		*			
Floor trusses, steel[3]	*		*				
Headers and beams, solid (2x4s) or plywood, exterior grade or preservative-treated		*		*			
Headers and beams, OSB, exterior grade or edge-swell resistant		*				*	
Headers and beams, steel[3]		*	*				
I-joists	*					*	
Wall panels, plywood, exterior grade or preservative-treated		*		*			
Wall panels, OSB, exterior grade or edge-swell resistant		*				*	
Wall panels, steel[3]		*		*			

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Structural Materials (floor slabs, beams, subfloors, framing, and interior/exterior sheathing)							
Wood							
Solid, standard, structural (2x4s)		*		*			
Solid, standard, finish/trim		*			*		
Solid, decay-resistant[4]	*	*	*				
Solid, preservative-treated, ACQ or C-A		*		*			
Solid, preservative-treated, Borate[2]		*		*			
Finish Materials (floor coverings, wall and ceiling finishes, insulation, cabinets, doors, partitions, and windows)							
Asphalt tile[5]							
With asphaltic adhesives	*				*		
All other types	*						*
Cabinets, built-in							
Wood		*				*	
Particle board		*					*
Metal[3]		*		*			
Carpeting	*						*
Ceramic and porcelain tile							
With mortar set	*	*		*			
With organic adhesives	*	*				*	
Concrete tile, with mortar set	*		*				
Corkboard		*				*	
Doors							
Wood, hollow		*				*	
Wood, lightweight panel construction		*				*	
Wood, solid		*				*	
Metal, hollow[3]		*		*			
Metal, wood core[3]		*		*			
Metal, foam-filled core[3]		*		*			
Fiberglass, wood core		*		*			
Epoxy, formed-in-place	*		*				

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Finish Materials (floor coverings, wall and ceiling finishes, insulation, cabinets, doors, partitions, and windows)							
Glass (sheets, coloured tiles, panels)		*		*			
Glass blocks		*	*				
Insulation							
Sprayed polyurethane foam (SPUF) or closed-cell plastic foams	*	*	*				
Inorganic – fiberglass, mineral wool: batts, blankets, or blown	*	*			*		
All other types (cellulose, cotton, open-cell plastic foams, etc.)	*	*				*	
Linoleum	*						*
Magnesite (magnesium oxychloride)	*						*
Mastic felt-base floor covering	*						*
Mastic flooring, formed-in-place	*		*				
Metals, non-ferrous (aluminum, copper, or zinc tiles)		*			*		
Metals							
Non-ferrous (aluminum, copper, or zinc tiles)		*			*		
Metals, ferrous[3]		*		*			
Paint							
Polyester-epoxy and other oil-based waterproof types		*		*			
Latex		*		*			
Partitions, folding							
Wood		*				*	
Metal[3]		*		*			
Fabric-covered		*					*
Partitions, stationary (free-standing)							
Wood frame		*		*			
Metal[3]		*		*			
Glass, unreinforced		*		*			
Glass, reinforced		*		*			
Gypsum, solid or block		*					*

Types of Building Materials	Uses of Building Materials		Classes of Building Materials				
			Acceptable		Unacceptable		
	Floors	Walls/ Ceilings	5	4	3	2	1
Finish Materials (floor coverings, wall and ceiling finishes, insulation, cabinets, doors, partitions, and windows)							
Polyurethane, formed-in-place	*		*				
Polyvinyl acetate (PVA) emulsion cement	*						*
Rubber							
Moldings and trim with epoxy polyamide adhesive or latex-hydraulic cement		*		*			
All other applications		*					*
Rubber sheets or tiles[5]							
With chemical-set adhesives[6]	*		*				
All other applications	*						*
Silicone floor, formed-in-place	*		*				
Steel (panels, trim, tile)							
With waterproof adhesives[3]		*	*				
With non-waterproof adhesives		*				*	
Terrazo	*			*			
Vinyl asbestos tile (semi-flexible vinyl)[5]							
With asphaltic adhesives	*		*				
All other applications	*						*
Vinyl sheets or tiles (coated on cork or wood product backings)	*						*
Vinyl sheets or tiles (homogeneous)[5]							
With chemical-set adhesives[6]	*			*			
All other applications	*						*
Wall coverings							
Paper, burlap, cloth types		*					*
Vinyl, plastic, wall paper		*					*
Wood floor coverings							
Wood (solid)	*						*
Engineered wood flooring	*					*	
Plastic laminate flooring	*					*	
Wood composition blocks, laid in cement mortar	*					*	
Wood composition blocks, dipped and laid in hot pitch or bitumen	*					*	

Notes*:

5 Unfilled concrete block cells can create a reservoir that can hold water following a flood, which can make the blocks difficult or impossible to clean if the flood waters are contaminated.

6 Borate preservative-treated wood meets the NFIP requirements for flood damage-resistance; however, the borate can leach out of the wood if the material is continuously exposed to standing or moving water.

7 Not recommended in areas subject to salt-water flooding.

8 Examples of decay-resistant lumber include heart wood of redwood, cedar, and black locust. Refer to Section 2302 of the International Building Code® (IBC®) and Section R202 of the International Residential Code® (IRC®) for guidance.

9 Using normally specified suspended flooring (i.e., above-grade) adhesives, including sulfite liquor (lignin or "linoleum paste"), rubber/asphaltic dispersions, or "alcohol" type resinous adhesives (culmar, oleoresin).

10 Examples include epoxy-polyamide adhesives or latex-hydraulic cement.

* In addition to the requirements of TB 2 for flood damage resistance, building materials must also comply with any additional requirements of applicable building codes. For example, for wood products such as solid 2x4s and plywood, applicable building code requirements typically include protection against decay and termites and will specify use of preservative-treated or decay- resistant wood for certain applications. Applications that require preservative-treated or decay resistant species include wood in contact with the ground, wood exposed to weather, wood on exterior foundation walls, or wood members close to the exposed ground. In some cases, applicable building code requirements (such as those in ASCE 24-05 and IRC 2006) do not reflect updated guidance in TB 2 and specify that all wood used below the design flood elevation be preservative-treated or naturally decay-resistant regardless of proximity to ground or exposure to weather. (Revision made in October 2010)

The classifications of materials listed in Table 10-2 above do not take into account the effects of long-duration exposure to flood waters or contaminants carried by flood waters. This is illustrated by the following US examples:

- Following Hurricane Katrina, FEMA deployed a Mitigation Assessment Team (MAT) to examine how building materials performed after long-duration exposure (2 to 3 weeks) to flood waters (reference FEMA 549). The field survey revealed that some materials absorbed flood borne biological and chemical contaminants. However, it is not known at this time if a shorter duration flood event would have significantly altered the absorption rates of those contaminants.

- Building owners, design professionals, and local officials should consider potential exposure to flood borne contaminants when selecting flood damage-resistant materials. For example, Table 10-2 lists cast-in-place concrete, concrete block, and solid structural wood (2x4s, etc.), as acceptable flood damage-resistant materials. However, experience has shown that buildings with those materials can be rendered unacceptable for habitation after being subjected to flood waters with significant quantities of petroleum-based products such as home heating oil. Commonly used cleaning and remediation practices do not reduce the “off-gassing” of volatile hydrocarbons from embedded oil residues to acceptable levels that are established by the Environmental Protection Agency in the U.S. or other organization. Other materials, when exposed to these types of contaminants, may also not perform acceptably as food damage-resistant materials.

10.3 Fasteners and Connectors

Fasteners typically refers to nails, screws, bolts, and anchors. Connectors typically are manufactured devices used to connect two or more building components. Joist hangers, post bases, hurricane ties and clips, and mud-sill anchors are examples of connectors. Fasteners and connectors must be made of flood damage-resistant materials in order to provide flood resistance to building located in a flood hazard area.

The flood resistance performance of buildings that are exposed to flooding is, at least in part, a function of the fasteners and connectors used to connect the components together. When preservative-treated woods are used, particular attention is required for fasteners and connectors because some treatments are more corrosive than others, which could shorten the service life of the fasteners and connectors. For example, alkaline copper quaternary (ACQ) treatments are more corrosive than traditional acid copper chromate (ACC) treatments. If corrosion occurs, buildings are less likely to withstand flood loads and other loads. Fasteners and connectors made of stainless steel, hot-dipped zinc-coated galvanized steel, silicon bronze, or copper are recommended for use with preservative-treated wood.

FEMA Technical Bulletin 2 (2008), consistent with ASCE 24 (2014) and the International Code Series, recommends that stainless steel or hot-dip galvanized fasteners and connectors be used below the design level elevation in both inland (noncorrosive) and coastal (corrosive) areas. In coastal environments where airborne salts contribute to corrosion, it is recommended that corrosion resistant fasteners and connectors be used throughout the building where they may be exposed.

10.4 Construction Examples

The following examples illustrate the possible construction techniques for retrofitting existing buildings to become more flood resistant.

10.4.1 Building Elevated on Solid Foundation Walls

Figure 10-1 illustrates a solid foundation wall (crawlspace) elevated to meet the minimum requirement that the lowest floor be at the approved design level elevation.

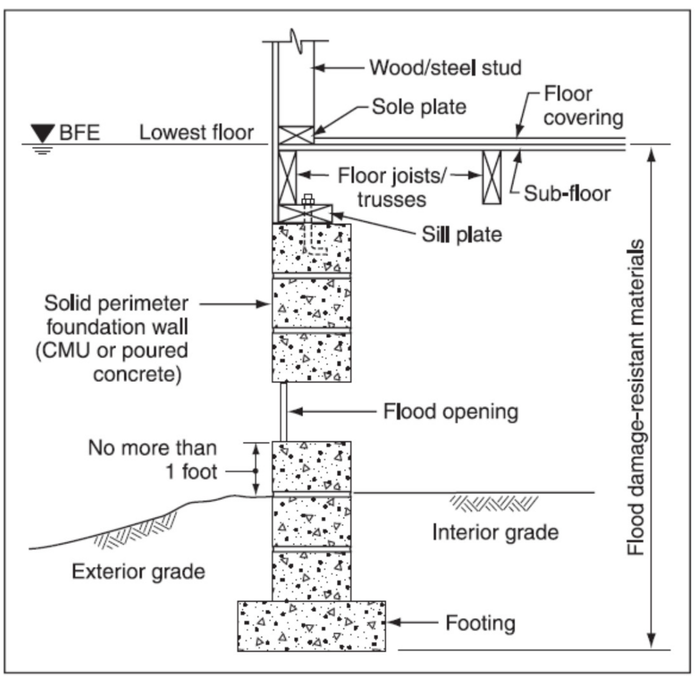

Figure 10-1 Solid Wall Opening
(source: FEMA TB2 Openings in Foundation Walls and Walls of Enclosures)

Figure 10-2 illustrates framed wall enclosures, typically used for parking of vehicles. Building access, or storage are located below the design level elevation.

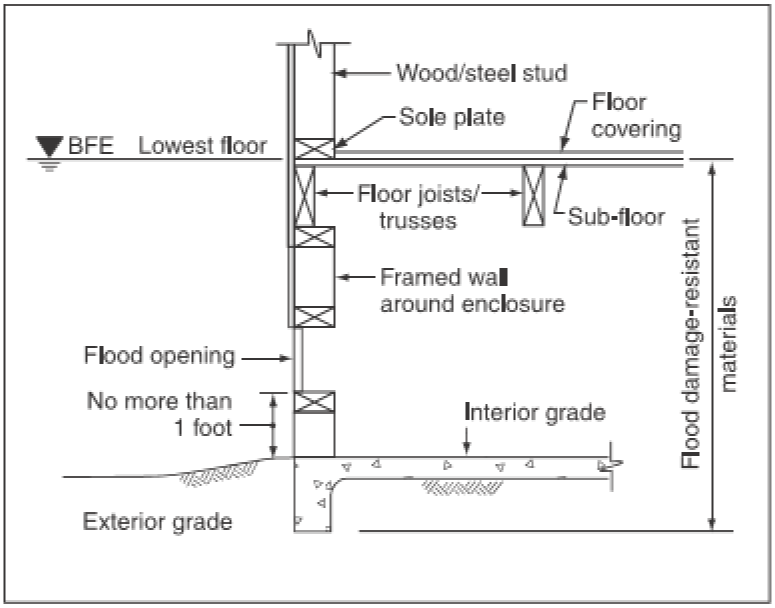

Figure 10-2 Framed Wall Opening
(source: FEMA TB2 Openings in Foundation Walls and Walls of Enclosures)

The USNFIP regulations require that the bottom of the lowest horizontal structural member of the lowest floor (usually the floor beam or girder) of buildings in coastal flood zones V (Areas located along coasts subject to inundation by the 100-year MRI flood event with additional hazards associated with storm-induced waves. Because detailed coastal analyses have not been performed, no 100-year elevations or flood depths are shown.), VE and Vl-V30 (Areas located along coasts subject to inundation by the 100-year MRI flood event with additional hazards due to storm-induced velocity wave action. 100-year elevations derived from detailed hydraulic coastal analyses are shown within these zones.) be at or above the design flood level elevation. Therefore, all materials below the bottom of those members must be flood damage-resistant materials. This requirement applies to lattice work and screening, and also to materials used to construct breakaway walls that enclose areas below the lowest floor. Depending on the selected design parameters, breakaway walls may remain in place during low-level floods and must be flood damage-resistant so that they can be readily cleaned and not deteriorate over time due to wetting. Figure 10-3 illustrates the requirement.

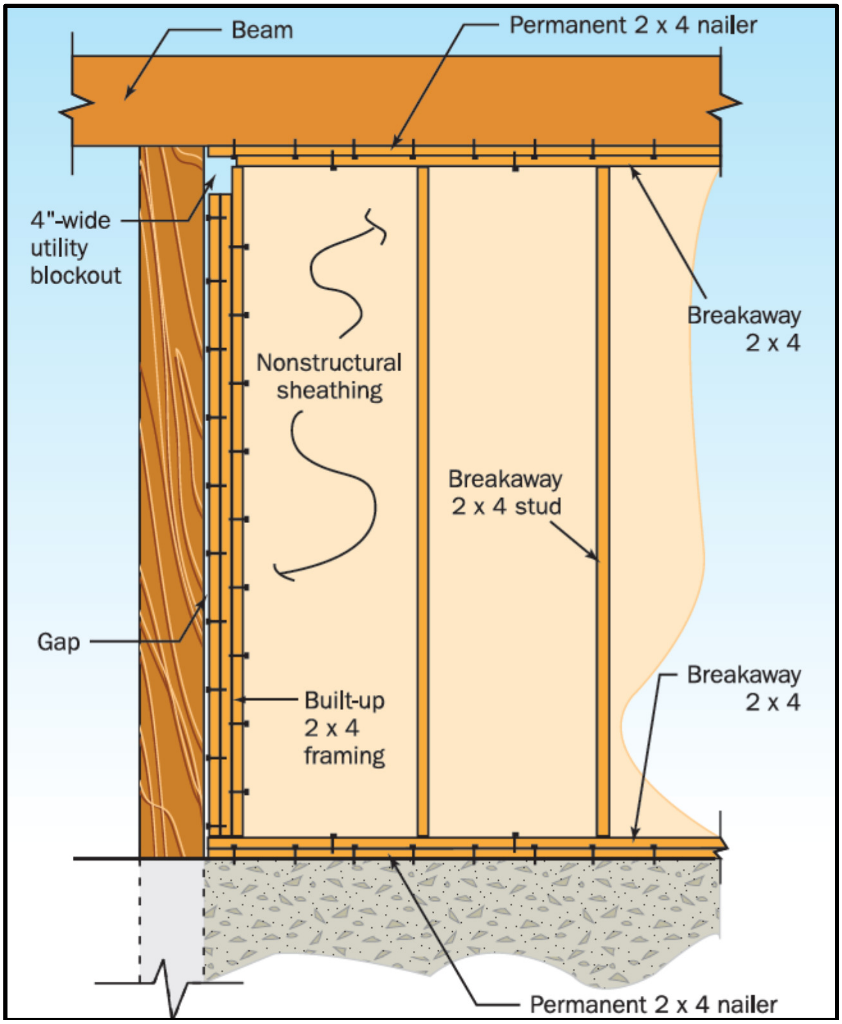

Figure 10-3 Breakaway Wall (source: FEMA Enclosures and Breakaway Walls)

10.4.2 Accessory Buildings

An accessory structure, such as tool shed or detached garage, which is located on the same parcel of property as a primary structure and its use is incidental to the use of the primary structure, may be allowed in flood hazard areas provided it is located, installed, and constructed in ways that comply with building code requirements. Accessory buildings typically are limited to the uses specified for enclosures below the design level elevation: parking of vehicles and storage. As with other buildings, accessory buildings located below the design level elevation should be required to be constructed with flood damage-resistant materials. In addition, accessory buildings should be anchored to resist flotation, collapse, and lateral movement and comply with other requirements based on the flood hazard zone.

10.4.3 Wet Flood Proofing

Wet flood proofing is a method to reduce damage that typically involves three elements: allowing flood waters to enter and exit a building to minimize structural damage, using flood damage-resistant materials, and elevating utility service and equipment. When a building is retrofitted to be wet flood proofed, non-flood damage-resistant materials that are located below the design level elevation should be removed and replaced with flood damage-resistant materials. This will reduce the costs of repair and facilitate faster recovery.

Wet flood proofing should not be allowed in lieu of complying with the lowest floor elevation requirements for new residential buildings (or dry flood proofing of nonresidential buildings in A flood zones). In the U.S., the A zone is an area with a 1% annual chance of exceedance of flooding. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones. Some "A" flood zones (AE, A1-30) identify the 100-year flood elevation for use in determining mitigation strategies. The exception is accessory buildings, as previously noted. Figure 10-4 illustrates some suggested retrofitting of interior walls in a pre-flood designated area building. Note that the techniques illustrated in this figure should not be used to bring buildings which have received significant damage from flooding into compliance with building codes.

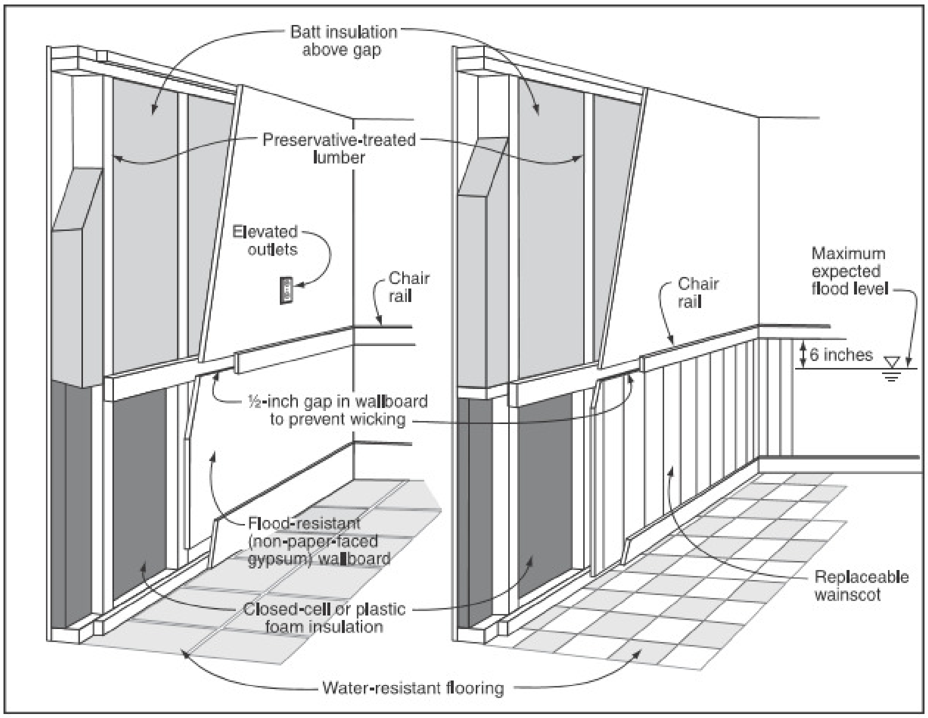

Figure 10-4 Wet Flood Proofing Technique Using Flood Damage-Resistant Materials
(source: FEMA TB2 Flood Damage-Resistant Materials Requirements)

11 Flood Mitigation Costs

11.1 Cost Variables

The estimated total cost of mitigating existing buildings with flood damage resistant materials will vary depending upon the size of the building footprint, regional cost factors, and seasonal price fluctuations. Local building officials and residential construction contractors can provide cost estimates for materials and installation.

When considering mitigation measures for increasing the flood-resistance of an existing building it is important to identify all of the exterior dimensions. Without determining these dimensions, it is unclear as to the material requirements for implementing techniques such as dry flood proofing or elevation. As illustrated in Figure 11-1, two buildings, each having identical first floor areas of 1,200 units are compared. When considering perimeter distances, the building on the right has a larger perimeter distance than the building on the left. That additional linear distance is important in determining the total costs for temporary or permanent dry flood proofing this building. If elevation of the building is being considered, it is important to determine the number of structural corners of the building footprint. For this example, the building on the right contains 6 structural corners, two more than the building on the left. Again, this is important when determining costs for implementing mitigation measures.

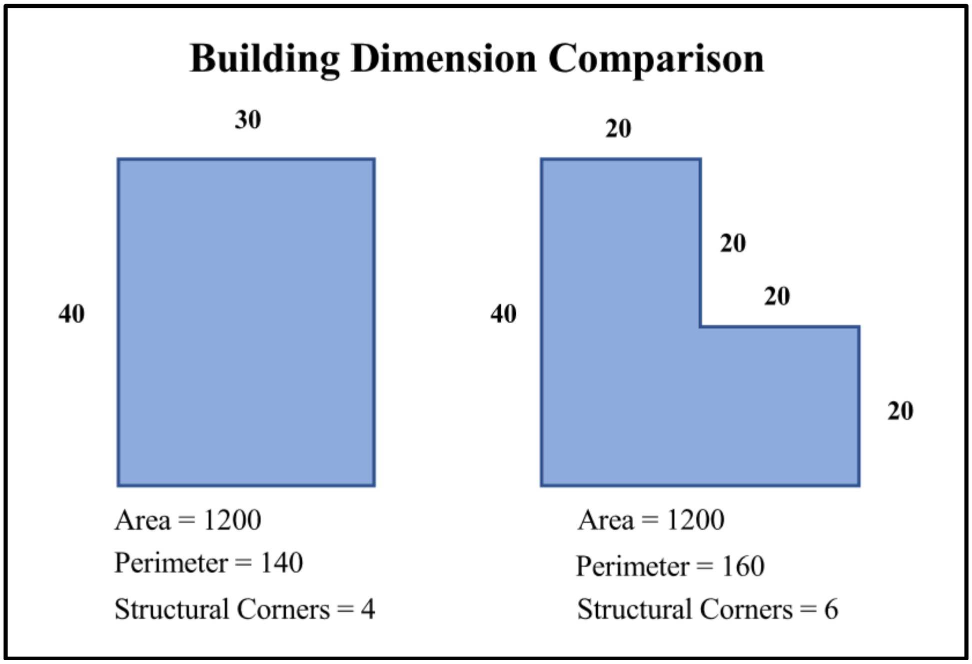

Figure 11-1 Comparison of Building Dimensions

11.2 Temporary Measures

As described in section 9.1.1, temporary flood proofing measures are those which, in order to protect a building and its contents from damage, must be implemented every time there is a risk of flooding. A flood proofing plan should be developed from which the building owner can itemize and catalog material needs for exterior walls and entrances. An annual review of the plan is recommended in order to determine repair and replacement needs for doorways and walls in order to attach temporary barriers, or the repair and replacement requirements of any of the temporary measures used to protect the building. Costs will vary from flood season to flood season as repair and replacement needs are considered.

11.3 Permanent Measures

As described in Section 9.2, permanent barriers are affixed to, or located adjacent to, buildings that they are protecting from flooding. As with a flood proofing plan for temporary measures, a flood proofing plan should be developed and reviewed annually. The plan should identify the flood protection features of the system, reinforce the actions required to be taken to protect the building, and catalog materials which may require annual repair or replacement. The costs will vary from flood season to flood season as all features and components of the permanent barrier system will require review for repair and replacement.

11.4 Relative Costs

As previously noted, it is difficult to determine the exact cost for mitigating an individual building or group of buildings by implementing flood-resistant techniques without knowing specific information regarding the flood characteristics (projected depth, velocity, and duration), site characteristics (location and soil type), and structure characteristics (style, foundation, and condition) of the individual building(s). In lieu of those specific details, the following tables provide the relative costs for mitigating buildings through comparison of similar style structures on different type of foundations, varying flood protection heights, varying mitigating components, and by comparison of mitigation technique.

Table 11-1 illustrates the relative increase in mitigation costs for buildings on basement, crawlspace, or open foundation as compared to similar style buildings located on slab-on-grade foundation.

Table 11-1 Relative Costs of Relocation
(source: FEMA P312 Homeowner's Guide to Retrofitting)

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame	Basement, crawlspace, or open foundation	Elevate on continuous foundation walls or open foundation	Lowest
Frame with masonry veneer		Elevate on continuous foundation walls or open foundation	↓
Load bearing masonry		Extend existing walls and create new elevated living area	↓
Frame	Slab-on-grade	Elevate on continuous foundation walls or open foundation	↓
Frame with masonry veneer		Elevate on continuous foundation walls or open foundation	↓
Load bearing masonry		Elevate on continuous foundation walls or open foundation	Highest

Table 11-2 illustrates the relative increase in wet flood proofing mitigation costs for buildings with a crawlspace or basement for increasing flood heights.

Table 11-2 Relative Costs of Wet Flood Proofing
(source: FEMA P312 Homeowner's Guide to Retrofitting)

Construction Type	Existing Foundation	Retrofit	Relative Cost
Frame, frame with masonry veneer, or load bearing masonry	Crawlspace	Wet floodproof crawlspace to a height of 2 ft to 4 ft above LAG*	Lowest
	Basement	Wet floodproof unfinished basement to a height of 2 ft to 4 ft above the basement floor	↓
	Basement	Wet floodproof unfinished basement to a height of 8 ft above the basement floor	Highest

Table 11-3 illustrates the relative increase in flood mitigation costs for six different mitigation techniques. While it is important to obtain the specific details regarding flood characteristics, site characteristics and building characteristics for each individual building, enough information has been developed to illustrate a comparison of the mitigation costs for similar style buildings.

Table 11-3 Relative Mitigation Costs
(source: modified from FEMA Homeowner's Guide to Retrofitting)

Measure	Construction Type	Existing Foundation	Retrofit	Relative Cost
Wet Flood Proofing	Frame, Masonry Veneer, or Masonry	Crawlspace or Basement	Wet floodproof crawlspace to a height of 1.2 metres above lowest adjacent grade or wet floodproof unfinished basement to a height of 2.4 metres above basement floor	Lowest
Dry Flood Proofing	Masonry Veneer or Masonry	Slab-on-Grade or Crawlspace	Dry floodproof to a maximum of 0.9 metres above lowest adjacent grade	↓
Barrier Systems	Frame, Masonry Veneer, or Masonry	Basement, Crawlspace, or Open Foundation	Levee constructed to 1.8 metres above grade or floodwall constructed to 1.2 metres above grade	↓
Elevation	Frame, Masonry Veneer, or Masonry	Basement, Crawlspace, or Open Foundation	Elevate on continuous foundation walls or open foundation	↓
Relocation	Frame, Masonry Veneer, or Masonry	Basement, Crawlspace, or Open Foundation	Elevate on continuous foundation walls or open foundation	↓
Elevation	Frame, Masonry Veneer, or Masonry	Slab-on-Grade	Elevate on continuous foundation walls or open foundation	↓
Relocation	Frame, Masonry Veneer, or Masonry	Slab-on-Grade	Elevate on continuous foundation walls or open foundation	Highest
Demolition	Frame, Masonry Veneer, or Masonry	Slab-on-Grade, Crawlspace, Basement, or Open Foundation	Demolish existing building and buy or build a home elsewhere	Varies

The reader should use the preceding cost comparisons tables as a guide and not as a specific process for selecting a mitigation technique. The tables illustrate the relative costs for mitigating buildings when comparing the different factors which influence cost.

12 Recommendations

This section of the report provides recommendations for prescriptive guidance and its commentary for describing the use of this report and the proposed guidance.

12.1 Prescriptive Guidance

In order to better manage flood risk and reduce future flood damages to existing buildings, it is recommended to adopt modifications to the Building Use and Occupancy and Importance Category in the National Building Code of Canada (National Building Code of Canada 2015, Volume 1, Table 4.1.2.1), as discussed in Section 5.2 and reflected in Table 12-1.

Adoption of a minimum flood design MRI for existing buildings which are vulnerable to flooding, will result in increased resiliency and lower flood damages.

Table 12-1 MRI Recommendation for NBC Importance Categories for Buildings

Importance Category	Recommended Flood Design MRI
Low	100-year
Normal	250-year
High	500-year
Post-disaster	750-year

12.2 Commentary

The proposed commentary should include Table 12-1 as described in Section 5.2 and consider the following:

- Section 6: Conducting a Flood Risk Vulnerability Assessment
    - Incorporating Table 6-1 Building Attributes
    - Incorporating Table 6-2 Structure Assessment Data Template
- Section 7: Determining an Effective Mitigation Technique for Implementation
    - Incorporating Figure 7-1 Flood Risk Management Matrix
- Section 8: Flood Load Determination for Existing Buildings
    - Chapter 3; Flood Load Formulas and Provisions of the Guide for Design of Flood-Resistant Buildings Report
- Section 9: Temporary and Permanent Flood Barriers
    - Section 9.2 Permanent Flood Fighting Barriers
    - Section 9.3 American National Standards Institute 2510 Standards for Flood Abatement
- Section 10: Flood Resistant Materials
    - Reference Table 10-1 Class Description of Materials
    - Reference Table 10-2 Types, Uses, and classifications of Materials

13 References

American National Standards Institute (ANSI), 2020. FM 2510 Standards for Flood Abatement Equipment.

American Society of Civil Engineers, 2014. Flood Resistant Design and Construction, ASCE Standard 24-14, Reston, VA.

American Society of Civil Engineers, 2016. Minimum Design Loads for Buildings and Other Structures. ASCE Standard 7-16.

Association of State Floodplain Managers, Madison, WI.

Australian NCC 2016 Building Code of Australia – Volume Two

Coulbourne Consulting, 2020. Guide for Design of Flood-Resistant Buildings, Report to National Research Council of Canada, Annapolis, MD.

Dean, R.G. and Dalrymple, R.A., 1991, Water Wave Mechanics for Engineers and Scientists, World Scientific Publishing Company.

EurOtop, 2018. Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. Van der Meer, J.W., Allsop, N.W.H., Bruce, T., De Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P. and Zanuttigh, B., www.overtopping-manual.com

Federal Emergency Management Agency (FEMA), 2008. Technical Bulletin Number 2, Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program, Federal Emergency Management Agency, Washington, DC.

FEMA, 2009. Enclosures and Breakaway Walls, Federal Emergency Management Agency, Washington DC.

FEMA, 2010. Home Builder's Guide to Coastal Construction Technical Fact Sheet Series FEMA P-499 / Fact Sheet 8.3, Washington DC.

FEMA, 2011. Anchor Fuel Tanks, Federal Emergency Management Agency, Washington DC.

FEMA, 2011. P-55, Coastal Construction Manual, Federal Emergency Management Agency, Washington, DC.

FEMA, 2012. P-259, Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures, Federal Emergency Management Agency, Washington, DC.

FEMA. 2013. P-936, Floodproofing Non-Residential Buildings, Federal Emergency Management Agency, Washington, DC.

FEMA, 2014. P-312, Homeowner's Guide to Retrofitting, Federal Emergency Management Agency, Washington, DC.

FEMA, 2018, Guidance for Flood Risk Analysis and Mapping: Coastal Wave Runup and Overtopping, Guidance Document 89, Federal Emergency Management Agency, Washington, DC.

FEMA, 2020. Technical Bulletin Number 1, Requirements for Flood Openings in Foundation Walls and Walls of Enclosures, Federal Emergency Management Agency, Washington, DC.

Flood Mitigation Industry Association (FMIA), Mandeville, LA.

Goda, Y., 1985. Random Seas and Design of Maritime Structures. 3rd Edition June 2010.

JWK Inspections, Basement Foundations, San Antonio, TX.

Kamphuis, J. W., 2010. Introduction to Coastal Engineering and Management, World Scientific Publishing Company.

National Building Code of Canada (NBC), 2015. National Research Council of Canada, Ottawa, Canada.

Ontario Ministry of Natural Resources, 2001. Understanding Natural Hazards: Great Lake – St Lawrence River System and Large Inland lakes, River, and Stream Systems and Hazardous Sites, Queens Printer for Ontario.

Stockdon, H.F., Holman, R.A., Howd, P.A., and Sallenger, A.H., 2006. Empirical Parameterization of Setup, Swash, and Runup, Coastal Engineering, 53: 545-630.

TAW, 1999. Wave Run-up and Wave Overtopping at Dikes, (in Dutch; Original Title: "Leidraad Toetsen op Veiligheid"), Technical Advisory Committee on Flood Defence.

United Nations 2019. Report of the United Nations Secretary-General on the 2019 Climate Action Summit.

US Army Corps of Engineers (USACE). Library, National Nonstructural Committee, Washington DC.

US Army Corps of Engineers (USACE), 1995. Flood Proofing Guide, EP 1165-2-314.

US Army Corps of Engineers (USACE), 2000. Economic Guidance Memorandum 01-03, Generic Depth-Damage Relationships.

US Army Corps of Engineers (USACE), 2002. Coastal Engineering Manual, EM 1110-2-1100, Vicksburg, MS.

US Army Corps of Engineers (USACE), 2019. Nonstructural Flood Risk Management Matrix User Guide, Washington DC.

US Army Corps of Engineers (USACE), 2019. Field Assessment Guide for Conducting Nonstructural Assessments, Washington DC.

US Title 44 Code of Federal Regulations, Emergency Management and Assistance, Washington DC, August 2020.

US National Flood Insurance Program, Federal Emergency Management Agency, Washington DC.

Walton, T., Ahrens, J., Truitt, C. and Dean, R., 1989. Criteria for Evaluating Coastal Flood Protection Structures, US Army Corps of Engineers, Report CERC-89-15.

APPENDIX A

Flood Hazard Mitigation Examples

Two examples for mitigating the flood hazard to existing buildings; the first located within a riverine environment, and the second located within a coastal environment, are provided. The examples progress through the process of conducting a flood risk vulnerability assessment, determining an effective technique for implementation, and consideration of flood loads.

A.1 Riverine Example

For this example, the building illustrated in Figure A-1 is known to be at risk of riverine flooding. The building is a single-family residential dwelling.

Figure A- 1 Riverine Flooding Example Building (source: USACE Library)

As described in Section 5.2; Defining Public Safety Operations, a recommended flood construction level has been identified for building importance category from the NBC and is shown again in Table A-1. For this example, the building use is considered normal and the recommended flood design MRI is 1:250.

Table A- 1 Importance Category - Normal

Importance Category	Recommended Flood Design MRI
Low	1:100
Normal	1:250
High	1:500
Post-disaster	1:750

Section 6.4; Determining Flood Risk Vulnerability of Existing Buildings, provides a template for recording building and flood information data, useful in determining the flood risk to individual buildings. The template is provided in Table A-2 with building and flood data presented for the building shown in Figure A-1.

From the background data illustrated in Table A-2, the existing building becomes flooded during a 1:100 AEP event. The building use is considered normal and the recommended first floor elevation after mitigation is the 1:250 AEP elevation. In order to achieve this flood construction level, the first floor will require being elevated from the current 21.1 metres to 23.3 metres, a distance of 2.2 metres in order to reduce the current flood risk to the building.

The building is located over a small crawlspace, which currently takes on water during a flood event equivalent to the 1:100 AEP.

Table A- 2 Structure Assessment Data

Structure Identifier Number	A001	First Floor Elevation (FF)	21.1 m
Occupancy type	Residential	Lowest Adjacent Grade (LAG)	20.8 m
Number of Structural Corners	Four	Basement/Crawlspace Elevation	20.5 m
Number of Stories	Two	1:100 AEP Elevation	22.8 m
Building Construction Material	Wood Frame	1:100 AEP Velocity	1.24 m/s
Foundation Material	Brick / CMU	1:250 AEP Elevation	23.3 m
Slab/Crawlspace/Basement	Crawlspace	1:250 AEP Velocity	1.48 m/s
Condition (Good/Fair/Poor)	Good	FF minus 1:100 AEP Elevation	-1.7 m
1st Floor Window Count	Nine	FF minus LAG	0.3 m
1st Floor Pedestrian Door Count	Two	Flood Depth (1:250 AEP-LAG)	2.5 m
1st Floor Vehicle Door Count	N/A	Perimeter Distance (meters)	30.5 m

As described in Section 7; Determining an Effective Technique for Implementation, and illustrated on Table A-3, there are three categories of flood risk management characteristics (flood, site, and building), as well as a category associated with community-based benefits, which support the identification of one or more potential techniques for reducing future flood risk.

Under Flood Characteristics, the flood depth is 2.5 metres when comparing the 1:250 AEP elevation to the lowest adjacent grade. The flood velocity is moderate 1.48 metres per second, while there are no reports of flash flooding, and there are no reports supporting significant debris.

Under Site Characteristics, the site location is a riverine floodplain and the soil type is permeable.

Under Building Characteristics, due to the current flood risk, there would be the requirement to abandon or modify the existing crawlspace. The building envelope/exterior is wood, and the overall building condition appears to be excellent to fair.

For the Community Benefits category, discussions are typically conducted with project officials in order to determine information regarding emergency costs, public infrastructure, ecosystem restoration opportunities, recreation, and community cohesion. For this example, two areas; Avoids Adverse Impact on Adjacent Property, and Community Cohesion were considered.

Progressing through Table A-3 and the categories aforementioned results in a series of yes (Y) responses. These responses are cumulated within each column. For this example, five techniques appear to provide the flood risk reduction required to achieve the 1:250 AEP elevation. The other five techniques were less desirable in reducing the flood risk.

For the current flood risk conditions, the techniques of Extended Foundation, Piers, Posts, Columns, or Piles all appear to reduce the level of flood risk if implemented. Flood loads, material costs, as well as owner and community preferences (ordinances) may dictate the final technique chosen for implementation.

Table A- 3 Example A-1 Flood Risk Management Matrix

FLOOD RISK MANAGEMENT MATRIX		FLOOD RESISTANT MITIGATION MEASURES									
		Elevation									
		Extended Foundation	Piers	Posts	Columns	Piles	Fill (compacted)	Relocation	Acquisition	Dry Flood Proofing	Wet Flood Proofing
Flood Characteristics	**Flood Depth**										
	Shallow (< 1 meter)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Deep (2 to 4 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Very Deep (> 4 meters)	N	N	N	N	N	N	Y	Y	N	N
	Flood Velocity										
	Low (less than 1 meter per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2.4 meters per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
	High (greater than 2.4 meters per second)	N	Y	N	N	Y	N	Y	Y	N	N
	Flash Flooding										
	Yes (less than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	N	N
	No (more than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Debris /Ice Flow										
	Yes	N	Y	N	N	Y	Y	Y	Y	N	N
	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Site Characteristics	**Site Location**										
	Coastal Beach Front	N	N	N	N	Y	N	Y	Y	N	N
	Coastal Interior (Low Velocity)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Riverine Floodplain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Soil Type										
	Permeable	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Impermeable	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Characteristics	**Building Foundation**										
	Slab on Grade (reinforced)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Crawlspace	N	N	N	N	N	Y	Y	Y	N	Y
	Basement	N	N	N	N	N	Y	Y	Y	N	Y
	Abandonment of Crawlspace/Basement	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Building Envelope/Exterior										
	Concrete, Stone, or Masonry	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Metal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Wood	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Overall Building Condition										
	Excellent to Fair	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Fair to Poor	N	N	N	N	N	N	N	Y	N	N
Community Economics	**Community Benefits (project area)**										
	Avoids Adverse Impact on Adjacent Property	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Reduction in Emergency Costs	N	N	N	N	N	N	Y	Y	N	N
	Public Infrastructure Damage Reduced	N	N	N	N	N	N	Y	Y	N	N
	Ecosystem Restoration Potential	N	N	N	N	N	N	Y	Y	N	N
	Recreation Potential	N	N	N	N	N	N	Y	Y	N	N
	Community (Project Area) Cohesion	Y	Y	Y	Y	Y	Y	N	N	Y	Y
	Flood Risk Eliminated to Building	N	N	N	N	N	N	Y	Y	N	N
	Total Ys	11	11	11	11	11	10	10	10	9	10

The Extended Foundation technique was chosen and the resultant project is portrayed in Figure A-2. It is also possible to have considered elevation by piers, posts, columns, and piles. But for this example, surrounding structures had similar style foundations and due to community cohesion, this technique was chosen. As described in section 11, either actual costs or relative costs can also be used to assist in making the final determination as to which alternative to implement. In this example, the building has been elevated by extending the foundation upward. The first-floor elevation is at the 1:250 AEP elevation, thereby reducing future flood damages and the overall flood risk. Flood vents have been incorporated into the new crawlspace in order to allow flood water to enter and equalize hydrostatic forces between the exterior and interior of the foundation walls.

As discussed in Section 8 of this report and more thoroughly in Chapter 3; Flood Load Formulas and Provisions of the Guide for Design of Flood-Resistant Buildings report, the hydrostatic, hydrodynamic, and debris impact loads can be determined. These loads can be used by engineers and architects to determine the foundation and wall design requirements to support the technique being recommended for reducing the existing and future flood risks to the building.

By elevating the building on an extended foundation, there are no adverse impacts on adjacent properties and if similar buildings are also elevated, this area retains a cohesiveness which continues to support families and a viable tax base.

Figure A- 2 Building Retrofitted with Elevation on Extended Foundation (source: USACE Library)

If and when flooding is projected to occur, it is recommended that this building be evacuated in order to prevent possible injuries or loss of life to the occupants or to first responders. After the flood waters have receded and the appropriate officials have ensured that it is safe to return, only then should residents be allowed to reoccupy the building.

A.2 Coastal Example

For this example, the building, portrayed by schematic, and illustrated in Figure A-3 is considered to be at risk of coastal flooding. The building is a medical facility and would be essential for post-disaster activities.

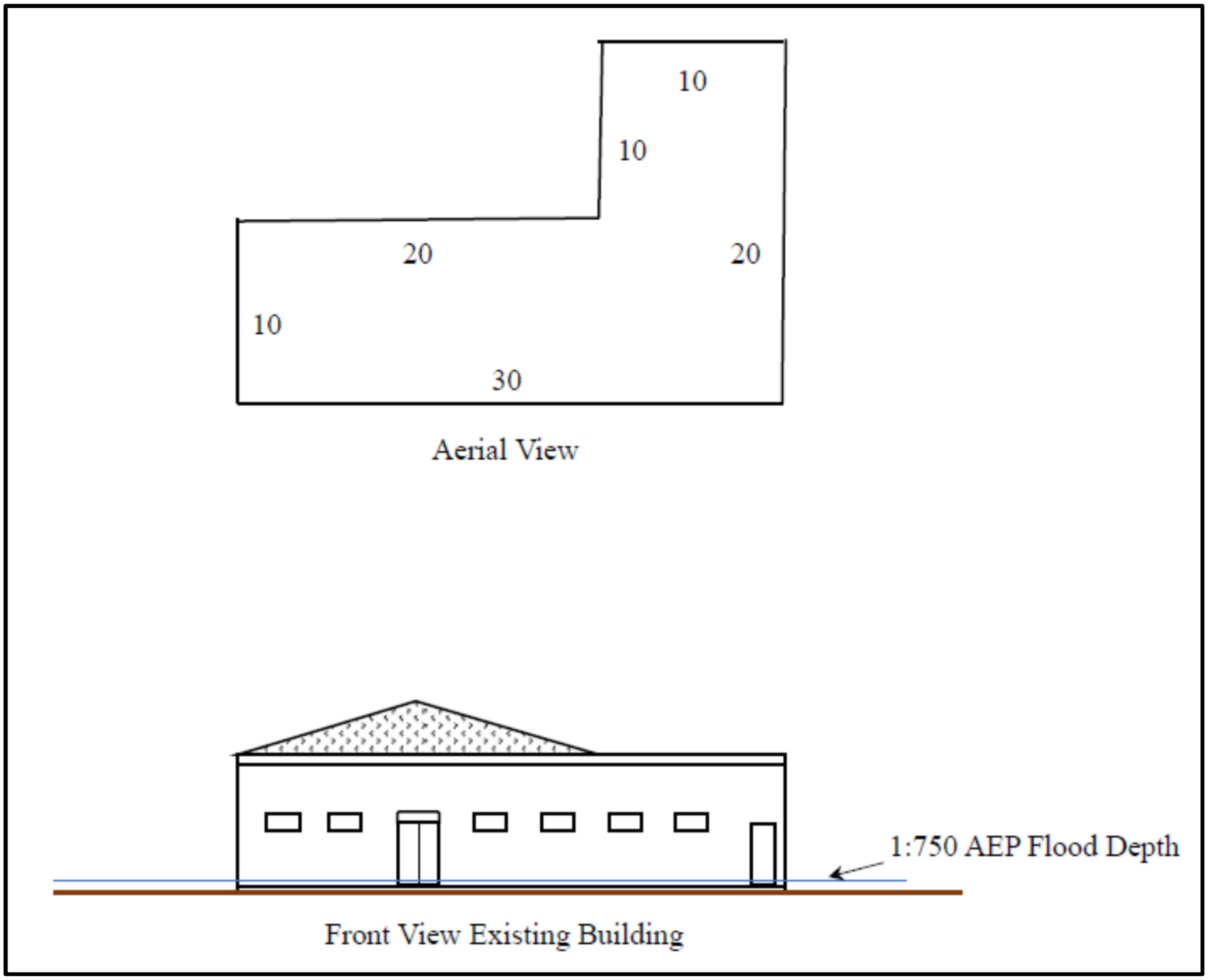

Figure A- 3 Coastal Flooding Example Building

As described in Section 5.2; Defining Public Safety Operations, a recommended flood construction level has been identified for building use or occupancy class from NBC and is shown again in Table A-4. For this example, the building use is considered post-disaster and the recommended flood design mean recurrence interval is 1:750.

Table A- 4 Importance Category - High

Importance Category	Recommended Flood Design MRI
Low	1:100
Normal	1:250
High	1:500
Post-disaster	1:750

Section 6.4; Determining Flood Risk Vulnerability of Existing Buildings, provides a template for recording building and flood information data, useful in determining the flood risk to individual buildings. The template is provided in Table 8-5 with building and flood data presented for the building shown in Figure A-3.

Background data regarding the flood risk vulnerability is collected from existing data and/or from a site visit. From the data illustrated in Table A-5, the existing building becomes slightly flooded during a 1:500 AEP event. The building use is considered post-disaster, since it operates as a medical facility. The recommended first floor elevation after mitigation is the 1:750 AEP elevation. In order to achieve this, the first floor will require being protected from potential flooding.

The building consists of a slab on grade foundation, which currently takes on water during a flood event equivalent to the 1:500 AEP.

Table A- 5 Structure Assessment Data

Structure Identifier Number	A002	First Floor Elevation (FF)	4.1 m
Occupancy type	Nonresidential School	Lowest Adjacent Grade (LAG)	3.9 m
Number of Structural Corners	Four	Basement/Crawlspace Elevation	NA
Number of Stories	One	1:500 AEP Elevation	4.2 m
Building Construction Material	Brick/CMU	1:500 AEP Velocity	1.4 m/s
Foundation Material	CMU	1:750 AEP Elevation	4.6 m
Slab/Crawlspace/Basement	None	1:750 AEP Velocity	1.6 m/s
Condition (Good/Fair/Poor)	Good	FF minus 1:750 AEP Elevation	-0.5 m
1st Floor Window Count	20	FF minus LAG	0.2 m
1st Floor Pedestrian Door Count	6	Flood Depth (1:750 AEP-LAG)	0.7 m
1st Floor Vehicle Door Count	N/A	Perimeter Distance (metres)	100 m

As described in Section 7; Determining an Effective Technique for Implementation, and illustrated in Table A-6, there are three categories of flood risk management characteristics (flood, site, and building), as well as a category associated with community-based benefits, which support the identification of one or more potential techniques for reducing future flood risk.

Under Flood Characteristics, the flood depth is 0.7 metres when comparing the 1:750 AEP elevation to the lowest adjacent grade. The flood velocity is moderate at 1.6 metres per second, while there are no reports of flash flooding, and there are no reports supporting significant debris. Under Site Characteristics, the site location is a coastal interior floodplain and the soil type is impermeable. Had the site location been coastal beach front or the soil conditions been permeable, there would have been additional limitations as to which techniques could be considered for implementation.

Under Building Characteristics, the structure foundation is a slab on grade. The building envelope/exterior is brick/CMU, and the overall building condition appears to be excellent to fair. For the Community Benefits category, discussions are typically conducted with project officials in order to determine information regarding emergency costs, public infrastructure, ecosystem restoration opportunities, recreation, and community cohesion. For this example, two areas; Avoids Adverse Impact on Adjacent Property, and Community Cohesion were considered.

Progressing through Table A-6 and the categories aforementioned results in a series of yes (Y) responses. These responses are cumulated within each column. For this example, six techniques appear to provide the flood risk reduction required to achieve the 1:750 AEP elevation. The other four techniques were less desirable in reducing the flood risk.

For the current flood risk conditions, the techniques of Extended Foundation, Piers, Posts, Columns, or Piles all appear to reduce the level of flood risk if implemented. The size of the building is 400 square metres, with 6 structural corners. Elevating the structure would appear to be cost prohibitive, particularly if the slab is not reinforced with steel to allow for a significant amount of tensile strength. Material costs, flood loads, as well as owner and community preferences (ordinances) may dictate the final technique chosen for implementation.

Table A- 6 Example 8-2 Flood Risk Management Matrix

FLOOD RISK MANAGEMENT MATRIX		FLOOD RESISTANT MITIGATION MEASURES									
		Elevation									
		Extended Foundation	Piers	Posts	Columns	Piles	Fill (compacted)	Relocation	Acquisition	Dry Flood Proofing	Wet Flood Proofing
Flood Characteristics	**Flood Depth**										
	Shallow (< 1 meter)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Deep (2 to 4 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Very Deep (> 4 meters)	N	N	N	N	N	N	Y	Y	N	N
	Flood Velocity										
	Low (less than 1 meter per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2.4 meters per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
	High (greater than 2.4 meters per second)	N	Y	N	N	Y	N	Y	Y	N	N
	Flash Flooding										
	Yes (less than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	N	N
	No (more than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Debris /Ice Flow										
	Yes	N	Y	N	N	Y	Y	Y	Y	N	N
	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Site Characteristics	**Site Location**										
	Coastal Beach Front	N	N	N	N	Y	N	Y	Y	N	N
	Coastal Interior (Low Velocity)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Riverine Floodplain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Soil Type										
	Permeable	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Impermeable	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Characteristics	**Building Foundation**										
	Slab on Grade (reinforced)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Crawlspace	N	N	N	N	N	Y	Y	Y	N	Y
	Basement	N	N	N	N	N	Y	Y	Y	N	Y
	Abandonment of Crawlspace/Basement	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Building Envelope/Exterior										
	Concrete, Stone, or Masonry	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Metal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Wood	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Overall Building Condition										
	Excellent to Fair	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Fair to Poor	N	N	N	N	N	N	N	Y	N	N
Community Economics	**Community Benefits (project area)**										
	Avoids Adverse Impact on Adjacent Property	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Reduction in Emergency Costs	N	N	N	N	N	N	Y	Y	N	N
	Public Infrastructure Damage Reduced	N	N	N	N	N	N	Y	Y	N	N
	Ecosystem Restoration Potential	N	N	N	N	N	N	Y	Y	N	N
	Recreation Potential	N	N	N	N	N	N	Y	Y	N	N
	Community (Project Area) Cohesion	Y	Y	Y	Y	Y	Y	N	N	Y	Y
	Flood Risk Eliminated to Building	N	N	N	N	N	N	Y	Y	N	N
	Total Ys	11	11	11	11	11	10	10	10	11	10

For this example, the Dry Flood Proofing technique was chosen and the resultant project is portrayed in Figure A-4. The building has been protected from flooding to the 1:750 AEP flood event by dry flood proofing the entire exterior. The first-floor elevation remains at an elevation of 4.1 metres, but is protected to 4.6 metres, thereby reducing future flood damages. Flood barriers have been incorporated into the dry flood proofing at all pedestrian entrances in order to prevent flood water from entering the building. As described in section 11, either actual costs or relative costs can also be used to assist in making the final determination as to which alternative to consider for implementation.

As discussed in Section 8 of this report and more thoroughly in Chapter 3; Flood Load Formulas and Provisions of the Guide for Design of Flood-Resistant Buildings report, the hydrostatic, hydrodynamic, debris impact, and wave loads can be determined. These loads can be used by engineers and architects to determine foundation and wall design requirements to support the technique being recommended for reducing the existing and future flood risk to the building.
By dry flood proofing the building, there are no adverse impacts on adjacent properties. Since the building functions as a medical facility the community retains a need for the building at its' current location. While relocation or acquisition and rebuilding at a site less prone to flooding would be desirable, the costs may be too high to make these techniques more economically feasible than the dry flood proofing option.

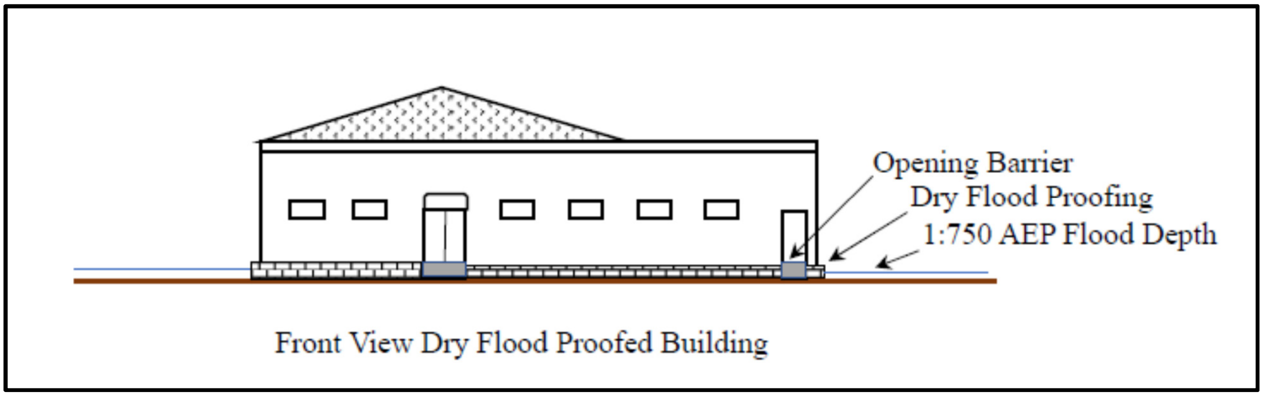

Figure A- 4 Building Retrofitted with Dry Flood Proofing

If and when flooding is projected to occur, it is recommended that this building be evacuated in order to prevent possible injuries or loss of life to the occupants or to first responders. After the flood waters have receded and the appropriate officials have ensured that it is safe to return, only then should occupants be allowed to return to the building.

GLOSSARY/DEFINITIONS

Annual Exceedance Probability (AEP): the annual likelihood of a flood occurring, expressed as a fraction of 1.0. The 0.01 AEP flood is equivalent to both the 1% annual probability flood, and the 100-year return period flood (or a flood with a 100-yr Mean Recurrence Interval (MRI)), although the term AEP is less misleading than the concept of return periods to many people.

Base Map: A map that depicts cultural features (e.g., roads, railroads, bridges, water features, place names and administrative boundaries).

Climate Change: Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Cross-section: A survey string of channel and floodplain elevations that is taken perpendicular to the main flow direction in a river.

Coastal Flooding: Coastal flooding can be defined as flooding associated with a defined shoreline along an ocean (or large lake). This can be due to a combination of high tides, storm surges, waves, rising sea levels and riverine flooding.

Design Flood: A specific flood magnitude that is used for design purposes, including delineating Flood Hazard Areas. In Canada, the 0.01 AEP flood is used as the minimum Design Flood for delineating Flood Hazard Areas, and many jurisdictions use higher magnitude floods (e.g. 0.005 AEP flood) or Design Storms or historical events. The Design Flood is usually expressed as flow in metres per second, and hydraulic analysis is then used to calculate the corresponding flood water elevation and extent.

Flood Awareness Map: Communication maps that serve to inform members of the public regarding the history of flooding in their communities, as well as the potential for future flooding and the risks that such flooding would pose to residential properties, businesses, cultural assets, infrastructure and human life. These poster-style maps include a range of additional content types, such as photographs, descriptive text and graphics.

Flood Construction Level: FCL is determined using freeboard along with observed or calculated water surface elevation for the designated design flood.

Flood Fringe Areas: The area between the Floodway and the delineated extent of flooding for a Design Flood. In some parts of Canada, the Flood Fringe Area is often defined as having a flood depth below 1 metre and a flood velocity less than 1 metre per second. The regulatory flood elevation may represent the 1:100-year event, the 1:200-year event or the 1:500-year event.

Flood Hazard Area: The delineated extent of flooding for a Design Flood (e.g. 0.01 AEP flood), which includes the 'Floodway' and the 'Flood Fringe Area'.

Flood Hazard Management: The operation of a program of corrective and preventative measures for reducing flood damage, including, but not limited to, development plans, emergency preparedness plans, flood-control works, and land use regulations.

Flood Hazard Map: A flood delineation at a given location, based on the flood's anticipated magnitude (e.g. its depth, horizontal extent, and flow velocity) and its annual exceedance probability. It shows the extent of the regulatory flood hazard, often including two zones: floodway and flood fringe areas. This type of map is used for regulatory planning purposes.

Flood Inundation Map: Maps that show the extent of actual floods or potential flood water coverage during flood events of different magnitudes (AEPs). They are intended to aid in the management of emergency preparedness plans for communities situated within floodplains and flood prone areas.

Flood Mitigation: A sustained action taken to reduce or eliminate long-term risk to people and property from flood hazards and their effects. Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from specific events.

Floodplain: A low-lying, relatively flat area of land adjacent to a river or stream that is subject to flooding. Floodplains are generally made up of alluvium (sand, silt, and clay) deposited by past flood events.

Floodplain Map: A map showing areas near to a waterbody (e.g. river or lake) that are predicted to be inundated during flood events.

Flood Protection: Any combination of structural and non-structural additions, changes, or adjustments to structures, which reduce or eliminate risk of flood damage to real estate or improved real property, water and sanitation facilities, or structures and their contents.

Flood Risk Map: Maps that contain the flood hazard or inundation delineations along with additional socio-economic values, such as potential loss or property vulnerability levels. These maps serve to identify the social, economic and environmental consequences to communities during a potential flood event.

Flood Risk: Flood risk is a combination of the likelihood of a flood event occurring (**Flood Hazard**) and the social or economic consequences of that event when it occurs (the exposure to the flood hazard).

Floodway: The channel and adjacent area where flood depths and velocities are greatest and most destructive. In Canada, the Floodway is often defined as having a flood depth above 1 metre and flood velocity greater than 1 metre per second and the floodway elevation represents the 1:20-year flood event or areas having a flood depth below 1 metre and flood velocity less than 1 metre per second.

Flow: The rate of flow of water measured in volume per unit time – for example, cubic metres per second (m^3/s). Flow is different from the speed or velocity of flow, which is a measure of how fast the water is moving – for example, metres per second (m/s).

Freeboard: A vertical height of water added to calculated flood elevations to provide additional protection from flooding, or to account for uncertainty from sources including climate change and data limitations.

Higher High-Water Large Tide Level (HHWLT): The elevation of the highest tide level which controls coastal flood elevations. This level will usually be a historical tide level taken from a tide gauge.

Hydraulic Analysis: An engineering analysis of flow scenarios carried out to provide estimates of the water surface elevations and behavior for selected recurrence intervals.

Hydraulics: The study of the dynamics of movement of a given amount of water in a watershed.

Hydrologic Analysis: An engineering analysis of a flooding source carried out to establish peak flood discharges and their frequencies of occurrence.

Hydrology: Scientific study of the movement, distribution, and quality of water as it relates to the land.

Infiltration: The penetration of water through the ground surface into the sub-surface soil.

Lake Flooding: Flooding associated with a defined shoreline along a lake. This can be due to a combination of high-water levels, waves, storm surges and riverine flooding.

Light Detection and Ranging (LiDAR): A remote sensing technology which uses lasers to collect accurate continuous elevation data.

Mean Recurrence Interval (MRI): The estimated average time or recurrence interval between events such as earthquakes, floods, landslides, or a river discharge to occur. MRI is also commonly known as return period.

Peak Flow: The maximum flow occurring during a flood event measured at a given point in the river system (see **Flow**).

Pluvial Flooding: The temporary inundation by water of normally dry land, usually caused by extreme rainfall events and not necessarily near to water bodies. Pluvial flooding is common in urban areas where water temporarily accumulates due to more rainfall entering an area than can be removed by infiltration into the ground and discharge through infrastructure (e.g. storm sewers).

Regulatory Flood: A specific flooding event designated as the Design Flood in a certain jurisdiction.

(Relative) Sea-Level Change: the change in sea level that is observed or experienced relative to a fixed location on land. Relative sea-level change is the combination of absolute/global sea-level change and vertical land motion. Land uplift decreases relative sea-level rise and land subsidence increases relative sea-level rise.

Return Period: Annual Exceedance Probability expressed in terms of years, rather than annual probability of a specific flood occurring. For example, the 0.01 AEP is equivalent to the 100-year return period flood.

Riverine Flooding: The temporary inundation by water of normally dry land adjacent to a river and caused by rainfall, snowmelt, stream blockages including ice jams, failure of engineering works including dams, or other factors.

Runoff: The amount of precipitation or water deriving from snowmelt and rainfall that drains into the surface drainage network to become streamflow.

Stage: Equivalent to water level measured with reference to a specified geodetic datum.

Still Water Level: The elevation of the water if all gravity waves are at rest. This is the elevation that is measured in the field in a stilling well.

Storm Surge: The increases in coastal water levels above predicted astronomical tide level (i.e. tidal anomaly) resulting from a range of location-dependent factors including low atmospheric pressure, wind and wave set-up and astronomical tidal waves, together with any other factors that increase tidal water levels.

Velocity of Flood water: The speed at which flood waters are moving, typically measured in metres per second (m/s).

Watershed: Drainage basin or watershed. It is the area of land draining to a particular location and includes the upstream drainage area of the main waterway as well as any tributary streams.

Water Level: The mean elevation of the water when averaged over a period of time long enough (about one minute) to eliminate oscillations caused by surface gravity waves which have periods in the order of a few seconds.

SYMBOLS

a ….. coefficient of drag or shape factor (not less than 1.25)
A_a ….. projected area of the debris accumulation into the flow, approximated by depth of accumulation times width of accumulation perpendicular to flow, in m^2 (ft^2)
A_h ….. contact area over which pressures act, in horizontal plane
A_p ….. projected area of structure subjected to moving water in m^2 (ft^2)
C_B ….. blockage coefficient
C_{bl} ….. debris blockage coefficient
C_D ….. drag coefficient, function of structure shape and dimensions
C_{Db} ….. drag coefficient for breaking waves
C_{de} ….. depth reduction coefficient
C_{or} ….. debris orientation coefficient
C_p ….. dynamic pressure coefficient ($1.6 < Cp < 3.5$) see Table 3.5.
D ….. pile or column diameter in m (ft) for circular sections, or for a square pile or column, 1.4 times the width of the pile or column in m (ft)
d_f ….. design flood depth, based on design flood level minus ground elevation, including any added depth due to erosion or scour, as defined in Chapter 2
F ….. force on structural element, in N (lb)
F_b ….. force by breaking waves on vertical piles or columns in N (lb)
F_B ….. vertical buoyant force due to hydrostatic pressures, in N (or lb)
F_D ….. hydrodynamic drag force, in N (or lbs)
F_{da} ….. drag force due to debris accumulation, in N (lb)
F_{di} ….. debris impact force in N (lb)
f_H ….. hydrostatic force per unit width along the wall, in N/m (or lb/ft)
F_H ….. hydrostatic force on the wall, in N or lbs
f_{wb} ….. net breaking wave force per unit width of structure, in N/m (or lb/ft)
F_v ….. vertical hydrostatic force, in N (lb)
g ….. acceleration due to gravity, 9.81 m/s^2 (32.2 ft/s^2)
H ….. wave height from crest to trough in m (ft)
H_b ….. breaking wave height in m (ft)
H_s ….. significant wave height in m (ft)
H_{sb} ….. significant wave height with depth limited wave breaking, in m (ft)
k ….. effective stiffness of the impacting debris or of the impacted structural element(s) deformed by the impact, whichever is less
Lo ….. deep water wavelength = $gT_p^2/2\pi$
p ….. water pressure exerted on a structure in N/m^2 (lb/ft^2)
P_1 ….. pressure in N/m2 (lb/ft2) at the design stillwater level
P_2 ….. pressure in N/m2 (lb/ft2) at the ground level
P_{bot} ….. hydrostatic pressure on bottom of structure or element, based on Z_{bot}
P_{top} ….. hydrostatic pressure on top of structure or element, based on submerged depth to top Z_{top}
P_h ….. hydrostatic pressure, in N/m^2 (or lb/ft^2)
P_s ….. stagnation pressure
R ….. vertical runup distance from the stillwater elevation in ft (m)

$R_{2\%}$ ….. vertical runup above SWL at 2% exceedance level
R_{max} ….. structural response coefficient
Tp ….. wave period corresponding to the significant wave height in seconds (s)
V ….. velocity of water in m/s (ft/s)
$\forall$ ….. volume of water displaced by the structural element, in m^3 (or ft^3)
w ….. width of the wall perpendicular to the flow, in m (ft)
X_R ….. horizontal runup excursion landward from SWL shoreline
z ….. depth of submergence, from SWL to point of interest (including in submerged soils)
Z_{bot} ….. submerged depth to bottom of structure or element, from free water surface
Z_{top} ….. submerged depth to top of structure or element, from free water surface
ρ ….. water density, 1,000 kg/m^3 fresh, 1,025 kg/m^3 salt (1.94 $slug/ft^3$ fresh, 1.99 $slug/ft^3$ salt)
P ….. pressure, in N/m^2 (or lb/ft^2)
γ ….. unit weight of water, 9,810 N/m^3 fresh or 10,055 N/m^3 salt (62.4 lb/ft^3 fresh, 64.0 lb/ft^3 salt)
γ_r ….. reduction factor for ground roughness, structure shape, and angle of wave attack
Δt ….. impact duration (time to reduce object velocity to zero), in s
η ….. the elevation in m (ft) referenced the stillwater level below which the wave pressure is assumed to act, or the minimum elevation at which the wave pressure equals zero
κ ….. breaker height to depth ratio, or breaker index
ξ ….. $\tan\theta / (Hs/Lo)^{1/2}$ = Irribarren Number or Surf Similarity Parameter
$\tan\theta$ ….. local beach slope (rise over run)