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The **Associated Programme on Flood Management** (APFM) is a joint initiative of the World Meteorological Organization (WMO) and the Global Water Partnership (GWP).

It promotes the concept of Integrated Flood Management (IFM) as a new approach to flood management. The programme is financially supported by the governments of Japan, Switzerland and Germany.

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To the reader

This publication is part of the *"Flood Management Tools Series"* being compiled by the Associated Programme on Flood Management. The *"Flood Proofing"* Tool is based on available literature, and draws findings from relevant works wherever possible.

This Tool addresses the needs of practitioners and allows them to easily access relevant guidance materials. The Tool is considered as a resource guide/material for practitioners and not an academic paper. References used are mostly available on the Internet and hyperlinks are provided in the *References* section.

This Tool is a *"living document"* and will be updated based on sharing of experiences with its readers. The Associated Programme on Flood Management encourages disaster managers and related experts engaged in flood proofing around the globe to participate in the enrichment of the Tool. For this purpose, **comments and other inputs are cordially invited**. Authorship and contributions would be appropriately acknowledged. Please kindly submit your inputs to the following email address: apfm@wmo.int under Subject: *"Flood Proofing"*.

Acknowledgements

This Tool makes use of the works of many organizations and experts, as listed in the references. Acknowledgement is due to the members of the Climate and Water Department in WMO and the members of the Technical Support Unit of the APFM for their competent technical guidance and frank discussions on the issues and for bringing various perspectives into focus.

EXECUTIVE SUMMARY

1 This tool aims to provide various options of flood proofing measures that are not limited to structural measures of building protection, with a target of practitioners responsible for flood management. By precise definition, flood proofing is described as structural measures to protect buildings or facilities from flood water. This tool, however, broadens the range of flood proofing including both structural and non. structural measures against flood damage before or during flooding. The tool covers two purposes of flood management: flood resistance and flood resilience. The flood resistance keeps out flood water to prevent flood damage, and the flood resilience minimizes the impacts of flood once a flood occurs.

2 Because it is getting difficult for many governments to bear the increasing fiscal cost of investing in structural flood protection, governments need to rely more on non-structural measures of regulations and incentive mechanisms in addition to conventional large-scale flood prevention measures. Furthermore, residents and communities need to make more individual efforts on flood proofing of their properties.

3 The tool is mainly intended for persons responsible for planning flood management, designing flood defence systems, and operating flood control systems in the public and private sectors. The major stakeholders relevant to the tool include flood managers, elected political leaders, local groups and NGOs, private organizations (insurance companies, property developers, etc.), and local residents and communities.

4 Although there are different types of floods, the tool focuses on the management of riverine floods (flood from rivers), pluvial floods (flood caused by heavy rain), and coastal floods (flood from the sea). In general, these kinds of floods can be forecasted from weather patterns or on-site observation and allow people to have a certain time for disaster preparation. Effective flood proofing measures are derived from an understanding of flood characteristics such as water depth, velocity, and duration.

5 The structural measures are comprised of two categories: (1) large-scale flood control infrastructures mainly constructed by governmental organizations; and (2) small-scale flood proofing measures implemented by individuals. The structural measures introduced here focus on small-scale and defensive means of flood protection. Such small-scale flood proofing measures are carried out by building owners following technical guidelines or regulations set by public institutions.

6 The non-structural measures focus on regulatory and institutional systems that uniformly affect a designated area. The non-structural measures also teach residents to live rationally under the threats of flooding through land management and disaster preparedness. The tool describes various non-structural measures, such as spatial and flood management plan, risk assessment, regulation, stormwater management, wetland protection, flood insurance, and funding and subsidy.

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1 INTRODUCTION

1.1 Rationale and objectives

7 Implementing large-scale flood control projects, such as dams, levees and diversions are getting difficultbecause of limited budget in public sectors and increasing environmental and social concerns about the negative impacts of these projects. These flood control measures cannot provide adequate prevention against flood disasters if they do not perform to their design levels due to poor maintenance or if the actual flood exceeds the expected flood level. Furthermore climate change, especially change of rainfall patterns and intensity, is projected to increase vulnerabilities and chances of flood disasters in the future.

8 In order to overcome the above-mentioned challenges, comprehensive flood control measures based on the Integrated Flood Management (IFM) concept are necessary. Governments need to rely more on non-structural measures of regulations and incentive mechanisms in addition to conventional large-scale flood prevention measures, while residents and communities need to make more individual efforts on flood proofing of their properties.

9 This tool aims to provide various options of flood proofing measures that are not limited to structural measures of building protection, with a target of practitioners responsible for flood management. The tool covers two purposes of flood management: flood resistance and flood resilience. The flood resistance keeps out flood water to prevent flood damage, and the flood resilience minimizes the impacts of flood once a flood occurs.

1.2 Target readers

10 This tool is mainly intended for persons responsible for planning flood management, designing flood defence systems, and operating flood control systems in the public and private sectors.

The following major stakeholders who are in charge of flood management and flood proofing are also targets of the tool:

– Flood managers: public officials of national and local governments, personnel of utility companies;
– Elected political leaders: make decisions on flood management policies and planning;
– Local groups and NGOs: work in community-based flood management;
– Private organizations: insurance companies, property developers, etc.;
– Local residents and communities.

1.3 Target flood disaster

11 Although there are different types of floods, this tool focuses on the management of riverine floods (flood from rivers), pluvial floods (flood caused by heavy rain), and coastal floods (flood from the sea). In general, these kinds of floods can be forecasted from weather patterns or on-site observation and allow people to have a certain time for disaster preparation. However, the tool does not deal with flash flood and mudflow that can cause sudden damage in a restricted area. Because of their strong impact force, flood proofing structures against such damage is not feasible at the level of individual buildings. Effective flood proofing measures are derived from an understanding of flood characteristics such as water depth, velocity, and duration.

1.4 Scope of flood proofing

12 By precise definition, flood proofing is described as structural measures to protect buildings or facilities from flood water. FEMA defines flood proofing as *"a combination of adjustments and/ or additions of features to individual buildings that are designed to eliminate or reduce the potential for flood damage"* (FEMA, 1986). This tool, however, broadens the range of flood proofing including both structural and non-structural measures against flood damage before or during flooding **(Table 1)**. The structural measures focus on small-scale and defensive means of flood protection. On the other hand, the non-structural measures focus on regulatory and institutional systems that uniformly affect a designated area. Although flood hazard maps and flood forecasting and warning systems are effective measures, these specific measures are explained in other available references.

Table 1 — Scope of flood proofing in this tool

	Focused in this tool	Not-focused in this tool
Disaster	• Riverine flood • Pluvial flood • Coastal flood	• Flash flood • Mudflow
Time-scale	• Disaster prevention before flood • Flood emergency response • Improvement from pre-disaster level after flood disaster	• Rescue operation • Disaster relief • Recovery and reconstruction after flood disaster
Structural measures	• Small-scale • Household and community level	• Large-scale • National and local government level
Non-structural measures	• Spatial and flood management plan • Risk assessment • Regulation • Stormwater management • Wetland protection • Flood insurance • Funding and subsidy	• Flood hazard map • Flood forecasting and warning

2 STRUCTURAL MEASURES

13 Structural measures explained in this section are comprised of two categories: (1) large-scale flood control infrastructures mainly constructed by governmental organizations; and (2) small-scale flood proofing measures implemented by individuals. The large-scale infrastructures bring the benefit of flood protection to the wide area of floodplain, but often require a large amount of capital for their implementation and are long-term projects from their planning stage until completion. They also necessitate consensus building among stakeholders and environmental consideration. On the other hand, small-scale flood proofing measures are carried out by building owners following technical guidelines or regulations set by public institutions.

14 The large-scale infrastructure is a flood control system that aims at reducing the risk of flooding in different ways (DEFRA, 2002):

- **Flood storage –** hold back some water and let it out at a controlled rate;
- **Channel improvements/control structures –** increase conveyance to achieve high flows;
- **Diversion channel –** divert water around the area;
- **Flood walls/banks –** build flood defences to prevent water getting into protected areas.

15 The small-scale flood proofing includes the following sections:

- **Wetproofing –** control the flooding of a building, thereby limiting damage;
- **Dryproofing –** keep a building impermeable to flood water;
- **Land raising/Elevation of building –** make the lowest floor above flood level;
- **Building relocation –** move a building out of flood hazard area.

2.1 Large-scale flood control infrastructures

16 Structural measures such as dams, reservoirs, levees, floodwalls, channel alterations and diversions modify flooding by changing the volume of runoff, peak flow, flood duration and

location and extent of flooding (FIFM Task Force, 1992). Such flood control projects have saved a large amount of property damage and protected a number of people in floodplains. However, the high construction costs of large-scale structural measures have made some projects unaffordable. In addition, the structures are often criticized for damaging riparian habitat and scenic areas, for deteriorating water quality, and for creating a false sense of security to induce further development in flood hazard areas. Another issue is how to deal with aging flood control structures that are reaching the end of their useful life or losing their intended function (e.g. loss of reservoir volume by sedimentation (WMO, 2011).

17 Flood control dams store flood water in the reservoirs and alter the timing and level of peak flows. Because dam projects provide water, electric power, or can be used for recreational purposes, they often attract new development even in hazardous floodplains.

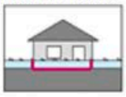
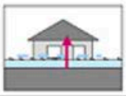
18 Levees and floodwalls are constructed parallel to streams or shorelines of lakes and oceans in order to protect residents living behind them.

19 Channel alterations may increase the flow-carrying capacity of a stream and rapidly convey storm runoff through populated areas to downstream. The alterations include straightening, deepening, or widening the channel, removing debris, improving bridges, and removing instream obstructions. In response to criticism of adverse environmental impacts, alternative designs of more gradual slopes, meandering streams, or natural vegetation are developed to minimize destruction of wildlife habitat. Diversions either reroute a whole stream or transport excessive and potentially damaging flood water elsewhere.

2.2 Flood proofing selection

20 If a building is located in an area that has a tendency to become inundated, it can be protected by wetproofing or dryproofing. The advantage of dryproofing is that a building is kept dry and the contents inside the building are not affected by flood (TUHH, 2010) **(Table 2)**. Its disadvantage is that the stability of the building structure can be jeopardized because of the heavier load of flood water. On the other hand, wetproofing is a more cost effective measure because the structure is not affected or compromised by the water flow. The disadvantage is limited occupancy of the building caused by flood water and the availability of water resistant materials.

Table 2 — Flood resilience built environment . Methodology (TUHH, 2010)

Strategy	Measure	Main characteristics	Techniques available
Wetproofing 	Controlled flooding of building using water resistant materials 	Flood damage potential of a building is reduced by applying water resistant materials. Due to economic or technical reasons, the lower parts of the building (basement) are partly flooded and not used for living. At the same time, the ground floor can be dry-proofed.	e.g. water resistant paints and coating, lime based plaster, plasters of synthetic resin, mineral fibre, insulation tiles, oil based paints
	Adapting the occupancy of the building		Raising the contents of the building, heating tanks and electrical appliances above the expected flood level
Dryproofing 	Sealing 	Building is sealed i.e. the external walls are used to hold back the flood water	Water resistant concrete
			Polymer bituminous seal
			Protection (sealing) of the openings
			Installing non-return valves (anti-flooding device) within the private sewage system as a protection from the sewerage backflow
	Shielding 	Floodwater does not reach the building itself. Barriers are installed at some distance from the building or a group of properties.	Flood barriers, flood skirts
Other	Elevating the building contents 	Using easily movable contents in the lower parts of the building	e.g. movable furniture (e.g. with wheels), rugs rather than fitted carpets

21 When choosing appropriate measures of flood proofing, consider the necessary factors, such as potential sources of flooding, predicted flood level, duration, frequency, depth, etc. (DCLG, 2007). **Figure 1** illustrates options for flood avoidance measures at a building site level depending on design flood water depth. Up to a threshold of 0.3m and 0.6m, designers may adopt a water exclusion strategy (dryproofing) or a water entry strategy (wetproofing).

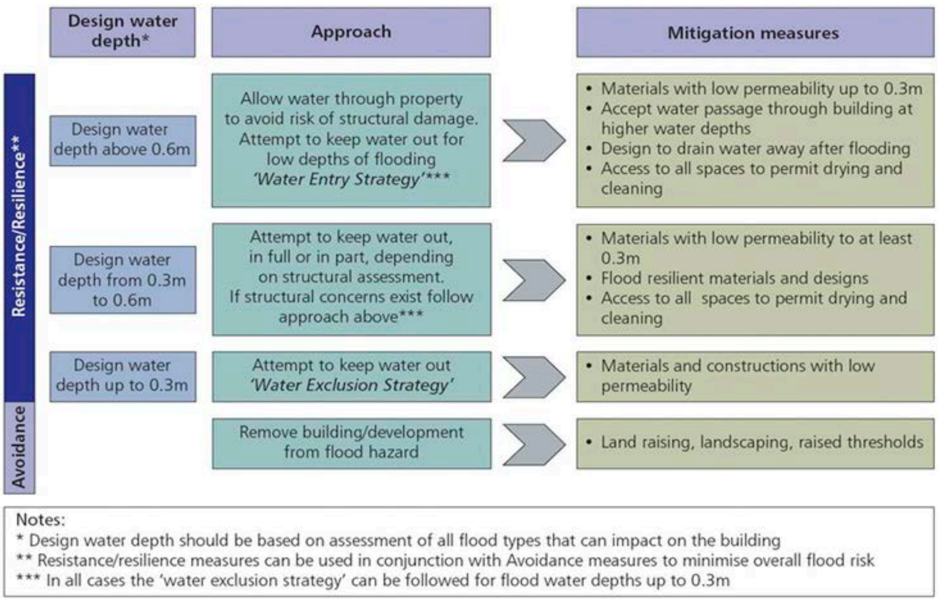


Figure 1 — Flood resilient design approach (DCLG, 2007)

22 The US Army Corps of Engineers provide a flood proofing matrix **(Appendix A)** to understand the relationship of flooding, site and building characteristics to the applicability of different flood proofing measures (USACE, 1998). The matrix defines the thresholds of flood depth as 3 feet (0.9 m) and 6 feet (1.8 m) and those of flood velocity as 3 ft/s (0.9 m/s) and 5 ft/s (1.5 m/s).

23 The Hamburg University of Technology (TUHH, 2009) has developed an online platform, called Flood Resilience Tool **(FLORETO)**, to allow single household tenants to assess the flood risk and select the most suitable flood proofing method or action. The platform, while contributing to flood awareness raising at the general public level, through interactive tools, workshops and dialogue, aims at building the capacity of the single citizen, providing them the knowledge to participate in the decision making process and letting them assume an active role in their properties' flood risk management.

2.3 Wetproofing

24 Wetproofing (or wet floodproofing) is different from dryproofing in that it allows flood water to enter a structure, though both floodproofing methods have the same purpose, that of preventing damage to the structure and its contents and creating no additional threats to public safety (FEMA, 1993).

25 Before adopting the wetproofing method, the site situation should be carefully considered. Wetproofing is not appropriate if the site experiences rapidly rising flood water, high-velocity flood waters, and a short flood warning time. In this case, elevation or relocation of buildings are more preferable solutions. If a wetproofed facility requires some preparation time for minimizing flood damage, for example shifting or elevating equipment or content, sufficient warning time is necessary. If the facility needs to be accessed during flooding, safe access routes should be secured for either escaping from, or gaining access to, the site.

26 Equalizing water levels on the inside and outside of a building by wetproofing can result in some advantages for the building structure. Firstly, because the difference in interior and exterior water levels causes hydrostatic pressure on the building walls, equalizing water levels by keeping the change at the same rate minimizes the hydrostatic pressure and thus the building does not require such a strong structure to withstand such pressure. Secondly, inside water reduces the buoyancy effect of hydrostatic uplift forces. Although a wetproofed building is relatively less affected by hydrostatic and hydrodynamic forces, the structure must be adequately anchored to prevent floatation, collapse, or lateral movement. Without engaging in major structural reform, wetproofing is often a more cost effective measure for buildings.

27 On the other hand, disadvantages of wetproofing are obviously caused by water entering the building. To prevent damage to the contents of a building, mechanical and utility facilities (such as electrical, heating, ventilation, plumbing, and air conditioning equipment) must be elevated above the expected flood level or must be protected from flood water entering or accumulating within the various components. Empty liquid containers, including the ones buried underground, should withstand a buoyant force by anchoring or even filling them with potable water before flooding (of course, after the flood quality control should be established and implemented before using the water stored in the tank). Because windows are especially

vulnerable to flood waters and debris, protective screens, reinforced glass and impact-resistant plastic are recommended solutions.

28 Because most of the existing facilities do not expect to come into contact with water and often use permeable construction materials, retrofitting wetproofing techniques by applying flood resistant materials are necessary. The materials must be resistant to flood forces, deterioration caused by repeated inundation, and excessive moisture and humidity during and after flooding. Because flood water contains silt, chemicals, and organic materials, which can be hazardous to the structure and the residents, the structure and the materials need to be easily cleaned without leaving any contaminants. Concrete, hard brick, plastic, metal, and pressure-treated wood are possibly suitable materials for covering walls and floors. Cleaning up after a flood includes washing and disinfecting walls, floors, and other surfaces. Because flood-induced mould and contaminants are hazardous to human health, wetproofing is not suitable for living spaces (FEMA, 2009). After the cleaning process, the drying out process can take up to six weeks to remedy any structural damage and health problems.

29 Under the National Flood Insurance Program (NFIP) in the US, the wetproofing technique is applied in only limited situations in river and coastal flood zones. The NFIP regulations stipulate building design and construction criteria for new constructions and substantial improvements necessary to existing buildings. Less strict regulations are applied to a facility if it is used for parking, building access, or limited storage, if it allows flood water to enter and exit automatically through at least two openings which may be covered with screens etc., and if it is constructed of water resistant materials. Another category for which adopting wetproofing could be considered includes structures located near water and functionally dependent on water uses, such as docking, seafood processing, port facilities, and ship repair facilities. Moreover wetproofing may be suitable for agricultural structures used for production, harvesting, storage and drying, provided that agricultural commodities and livestock are raised and kept dryproof.

30 Wetproofed structures must meet the required technical standards, conducting site-specific evaluation by technical experts or designated government offices, if necessary. In addition to the standards, all kinds of local or national regulations, building codes, etc. should be met. It should be noted that some local regulations may exceed national regulations. Combining wetproofing with dryproofing and elevation may achieve optimal protection for the site. Before implementation, an economical assessment and evaluation is required to understand if the cost of business interruption and cleanup activities may make wetproofing less feasible in comparison with dryproofing.

2.4 Dryproofing

31 Dryproofing makes a building watertight and substantially impermeable to floodwaters (FEMA, 1993b). Before selecting dryproofing as a viable floodplain management tool, numerous factors must be considered, such as flood warning time, purpose of building usages, mode of building entry and exit, flood depths, floodwater velocities, floating debris impact, flood frequency, etc. Compared to wetproofing, dryproofing requires a more reinforced building structure to withstand floodwater pressures and impact forces caused by debris. Other important factors to be considered in dryproofing are watertight closures for doors and windows, prevention of floodwater seepage through walls, and check valves to prevent reverse flows from sewage.

The flood proof function must work sufficiently for design flood level and additional freeboard is recommended because flood depth estimation includes a certain error and may be influenced by future development in the basin.

32 Sufficient warning time, which is calculated by the rate of floodwater rise and the existing flood warning system, is necessary for evacuation from a flood prone building, for installation of removable flood shields or gates, and for operation of sump pumps and check valves. If the warning time is limited, for example the structure is located in a flash flood area, flood proofed buildings should not be considered as the necessary operations to make it flood proof will require too much time. FEMA suggests flood velocity of 5 ft/s (1.5 m/s) and flood depth of 3 feet (90 cm) as thresholds for adopting dryproofing. If the flood exceeds these limits, the cost of dryproofing may become too significant and the dryproofing method is therefore not feasible. Any areas susceptible to severe debris flow, such as mountainous regions or areas facing ice flow in winter, are not suitable for flood proofed buildings in a cost-effective manner.

33 The building structure must be able to resist four types of flood-related forces: (1) hydrostatic flood force that freestanding water exerts on a submerged object; (2) buoyancy force that a building receives from surrounding floodwaters; (3) hydrodynamic force that vertical surfaces receive from moving floodwaters; and (4) debris impact force to withstand the flood-borne debris strikes on the side of building. FEMA provides an estimation formula for each force **(Appendix B)**. For more detailed standards of dryproofing structure design, FEMA has a comprehensive guidance and case study report *"Engineering Principles and Practices for Retrofitting Flood.Prone Residential Structures"* (FEMA, 2001). For new constructions and improvement of existing buildings, flood proofing checklists are prepared by FEMA **(Appendices C & D)**.

2.4.1 Sealing

34 Doors, windows and air vents of buildings are potential flow paths where flood water runs into properties (DCLG, 2007). Raising the threshold of doors as high as possible without disturbing accessibility is a primary prevention measure. Sealed polyvinyl chloride (PVC) framed doors are a more preferable option than wooden doors and the doors should be properly fitted to their frames. Windows are also vulnerable to flood water and preventive measures of fitting and sealing similar to those for doors should be taken. The windows should adequately resist the pressure of flood water and prevent damage that could be caused by debris flows. Regarding ventilation vents, special designs of air vents that prevent water from entering into the premises are available on the market. Various case studies of preventing flood damage to buildings are introduced on the website of the National Flood Forum (http://www.floodforum.org.uk/).

2.4.2 Permanent and fixed flood barriers

35 A permanent flood protection system including a levee (flood bank) and a floodwall prevents water from entering into protected areas. Levees are usually built of compacted soil and floodwalls are made of concrete or steel (FEMA, 2009). Because a levee requires more land space than a floodwall of the same height, the floodwall is suitable for smaller areas. It should be noted that levees and floodwalls could give residents a false sense of security. Levees and floodwalls provide flood protection up to their design level, therefore flood events larger than these levels override them and cause damage in the same way as if there were no flood protection facilities. They need regular inspection and maintenance to ensure that the designed

flood protection functions properly. Problems such as walls cracking, loss of vegetation and erosion must be quickly fixed. Because new levees or flood walls push away flood water to other areas or block flood flows, it is necessary to confirm that local zoning regulations do not prohibit the construction of flood barriers. Construction of such measures should be coordinated at city/basin level.

36 The height of a levee or floodwall is calculated by the expected flood level plus necessary freeboard. Then the height defines design requirement, the cost of construction and the necessary land space. FEMA indicates the thresholds of structure height of residential levees and floodwalls as flood depths of 5 feet (1.5 m) and 3 feet (0.9 m), respectively. A floodwall is more resilient to overflowing than a levee, and even a small volume of flood overflow can erode the levee and cause it to fail. In order to prevent a levee overflowing, its height is often raised with sandbags.

37 Because levees are constructed with soil, attention should be paid to the soil type **(Figure 2)**. Wet, fine-grained, or highly organic soils are very permeable and not suitable for levees. Instead, soils containing clay content are impervious and prevent seepage through levees and their foundations, which is one of the leading causes of levee failure. Because high-velocity flows can erode and scour a levee and become a threat to its failure, the slopes of the levee can be planted with vegetation or even protected with concrete or broken rocks. Levees and floodwalls prevent flood forces, but seepage through the ground below them can still reach a building and cause damage by hydrostatic pressure and buoyancy force. In order to prevent such damage occurring, flood barriers are located away from the building or drains and a sump pump can be installed to discharge water out of the protected area.

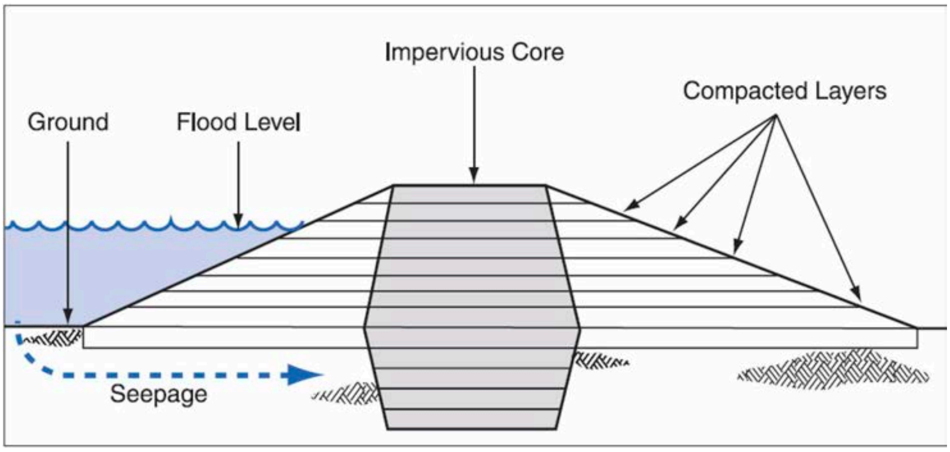


Figure 2 — Levees constructed with compacted layers of soil and an impervious core (FEMA, 2009)

38 There are two types of floodwalls: gravity floodwall and cantilever floodwall **(Figure 3)**. Both types are designed to resist overturning and displacement by flood forces, which are common causes of floodwall failure. Compared with the cantilever floodwall, the gravity floodwall is easy to design and build. Because the size of a gravity floodwall increases significantly as flood depths increase, the cantilever floodwall is much more practical.

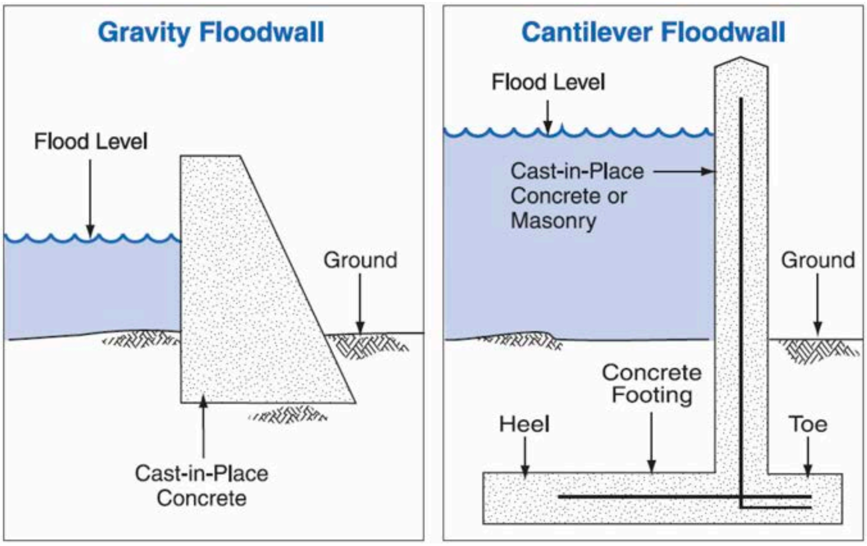


Figure 3 — Gravity and cantilever flood walls (FEMA, 2009)

2.4.3 Temporary flood protection system

39 A temporary and removable flood protection system is provided in locations where permanent flood defences would not be suitable because they are not technically, economically or environmentally feasible (DEFRA, 2002). The temporary system includes a pre-installed system that requires operation; the system may be installed in a pre-constructed foundation, or it may also be a system where the whole of it is movable and needs to be installed. DEFRA defines the first two systems as "demountable systems" and the third one as a "temporary system" **(Figure 4 & 5)**. These systems are further classified by their different structures, such as earth filled containers, air and water filled tubes, and panel type flood barriers.

40 In contrast to a permanent flood protection system, a temporary system brings an additional risk of operational failure. Taking this fact into consideration, a permanent system should be given priority if it is feasible and locally acceptable. In the event of a temporary system being adopted, it should be ensured that the movable parts of the system are at a minimum and that the reliability of all the operational processes including mobilization, installation and closure are at a maximum. If the temporary system requires significant preparation time, it is suitable for location at the downstream of a large river basin.

41 A temporary flood protection system can allow a dual function by ensuring effective flood control performance without obstructing the ordinary use of the building, for example access through a floodwall, or parking lot turning into a flood protection site. A temporary system also adds additional safety to a permanent system, which is often the case in critical disaster situations. There are several factors affecting the risk of operational failure, such as sufficient lead-in time, reliability of flood forecasting and warning, system maintenance, and training of operators. Because the flood warning system usually triggers the operational process of the temporary system, technical and human operational reliability is a pre-requisite for the temporary system. Regular training and emergency exercises together with flood operation manuals increase the reliability of the total system. Different temporary systems need different levels of installation skills and preparation time. Site-specific conditions, such as the location of the stockyard of the system parts, transportation means, and available resources of personnel and

equipment, also affect the selection of an appropriate temporary system. Detailed advantages and disadvantages of different temporary systems and commercially available products are explained in *Temporary and Demountable Flood Defences* (DEFRA, 2002).

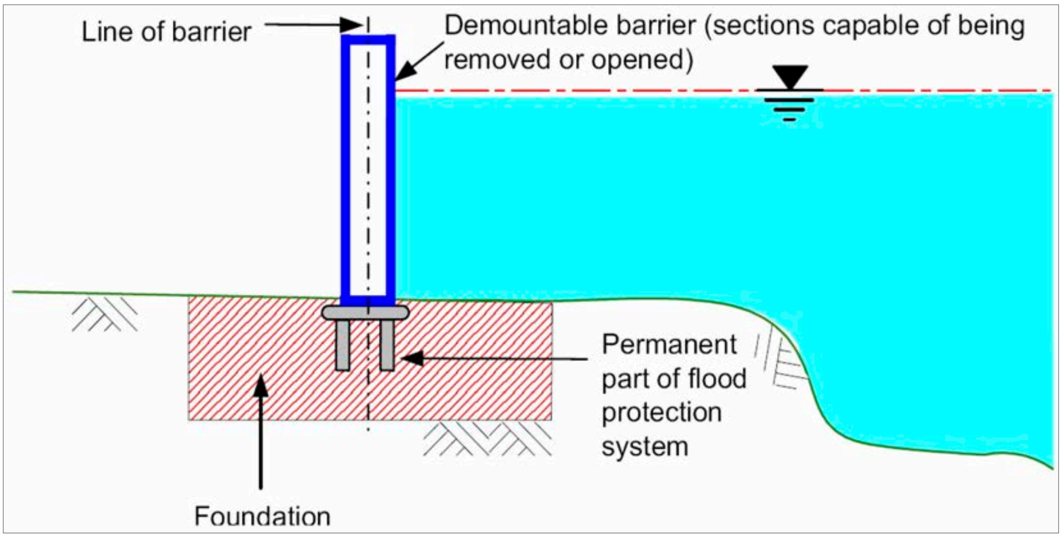


Figure 4 — Typical elements of a demountable flood protection system (DEFRA, 2002)

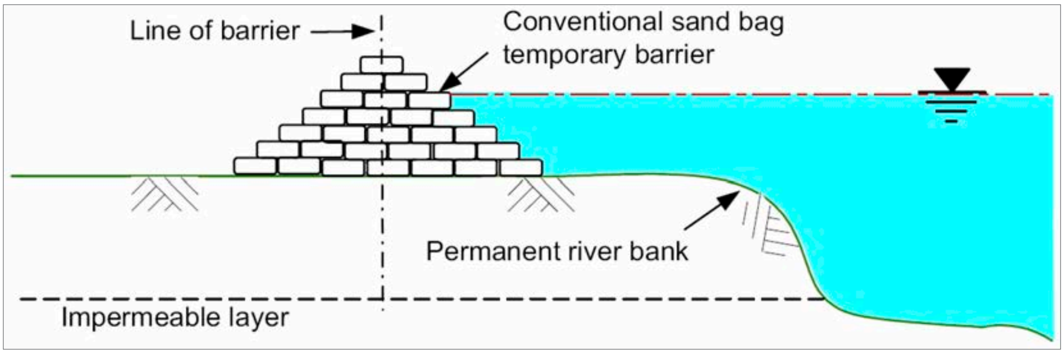


Figure 5 — Typical elements of a temporary flood protection system (DEFRA, 2002)

2.5 Land raising

42 In the United States, National Flood Insurance Program (NFIP) regulations only allow landfill, encroachment, and other developments within a floodway if they are proven through standard hydrologic and hydraulic analyses not to increase flood levels in the community during the base flood discharge (FEMA, 1993). New developments and significant improvements are, in general, required to not cause negative impacts, not only to increasing flood heights, but also in creating additional threats to public safety, inducing extra public expenditure, creating nuisances, or conflicting with existing local regulations.

43 Land raising (or placement of fill) requires an understanding of local site conditions, soil characteristics, methods of placing and compacting the land, etc. (FEMA, 2001b). The permeability of soils affects water infiltration on the site, which in turn influences the safety of the foundations or basement structure. The higher the lowest floor of building is elevated in comparison with the expected flood level, the safer the building becomes. If the elevation of the building is not

high enough compared to the expected flood level or if it includes a basement below the flood level, additional measures of dryproofing and elevating the building should also be considered.

44 In order to combat hydrostatic force and buoyancy force, appropriate buffer zones around a building should be installed with a setback distance from the edge of the flood hazard area. The fill soil should be homogeneous and of a low permeability. A drainage system installed around the building foundations with a sump pump can lower the level of seepage and make the structure safer. FEMA provides the method of calculating such seepage flow **(Appendix E)**.

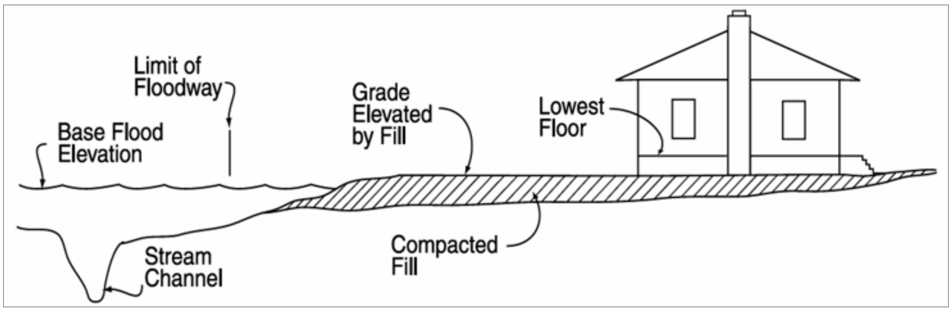


Figure 6 — Land raising (FEMA, 2001b)

45 Raising houses, tube wells, and latrines above the expected flood level is an effective flood mitigation measure in developing countries. In India, there are examples of raised platforms in flood shelters constructed for local people and their cattle (WMO, 2005). In rural Bangladesh, homestead plinths of local people were raised to reduce vulnerability to flood disaster (Practical Action Bangladesh, 2010) **(Figure 7)**. In order to reduce water-borne diseases, especially during periods of inundation, tube-well platforms were raised above the highest ever recorded flood level with freeboard.

Figure 7 — Raised house and tube-well enable families to cope with floods (Practical Action Bangladesh, 2010)

46 Major sanitation problems in flood-prone areas of developing countries are surface water contamination and difficult access to latrines during floods (Kazi and Rahman, 1999). Because overflow of a pit latrine poses serious health and environmental risks, the top of the latrine is extended above the expected flood level to avoid flood water intrusion into the pit which would expand its volume **(Figure 8)**. One effective measure of preventing groundwater contamination by latrines is to surround the pit latrine with a sand filter and make the bottom of the pit impermeable. These measures are very simple and easily implemented by local people; however raising awareness about sanitary conditions and motivating people is the key to success of these projects.

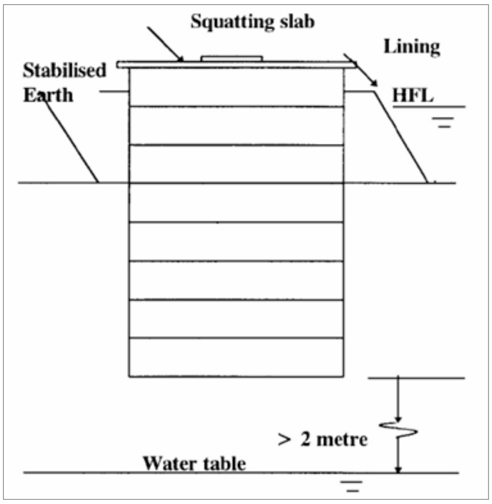


Figure 8 — Earth stabilized raised pit latrine (Kazi and Rahman, 1999)

2.6 Elevation of building

47 In order to protect an existing building from flooding, elevation of the building is one retrofitting method. The two major types of elevating living spaces above the expected flood level are: (1) lifting up a building on a new or extended foundation; and (2) extending a building upward by elevating the existing floor or adding a new upper story utilizing an existing foundation (FEMA, 2009). The first method separates the building from its foundation, raises it on a hydraulic jack, and constructs a new or extended foundation below it **(Figure 9)**. The new and extended foundation can be continuous walls, or separate piers, posts, columns or piles and can be exposed to flooding. The second method removes the roof, extends the building walls, and constructs a raised floor **(Figure 10)**. The abandoned lower area can then be used for parking, building access or storage.

48 The height of elevation is determined by the expected flood level, that is, the lowest floor of the living space must be above the flood level, including freeboard. As with a wetproofing measure, the foundation of the elevated building must be able to withstand hydrostatic pressure, hydrodynamic pressure, debris impact, and erosion by flooding. Design experts should be consulted for these elevation projects to evaluate whether the existing foundations can support an increased load to the building. If the project site is subject to high winds, earthquakes, or other hazards, such horizontal and vertical forces must be also considered. More detailed elevation techniques are explained in *Homeowner's Guide to Retrofitting* (FEMA, 2009).

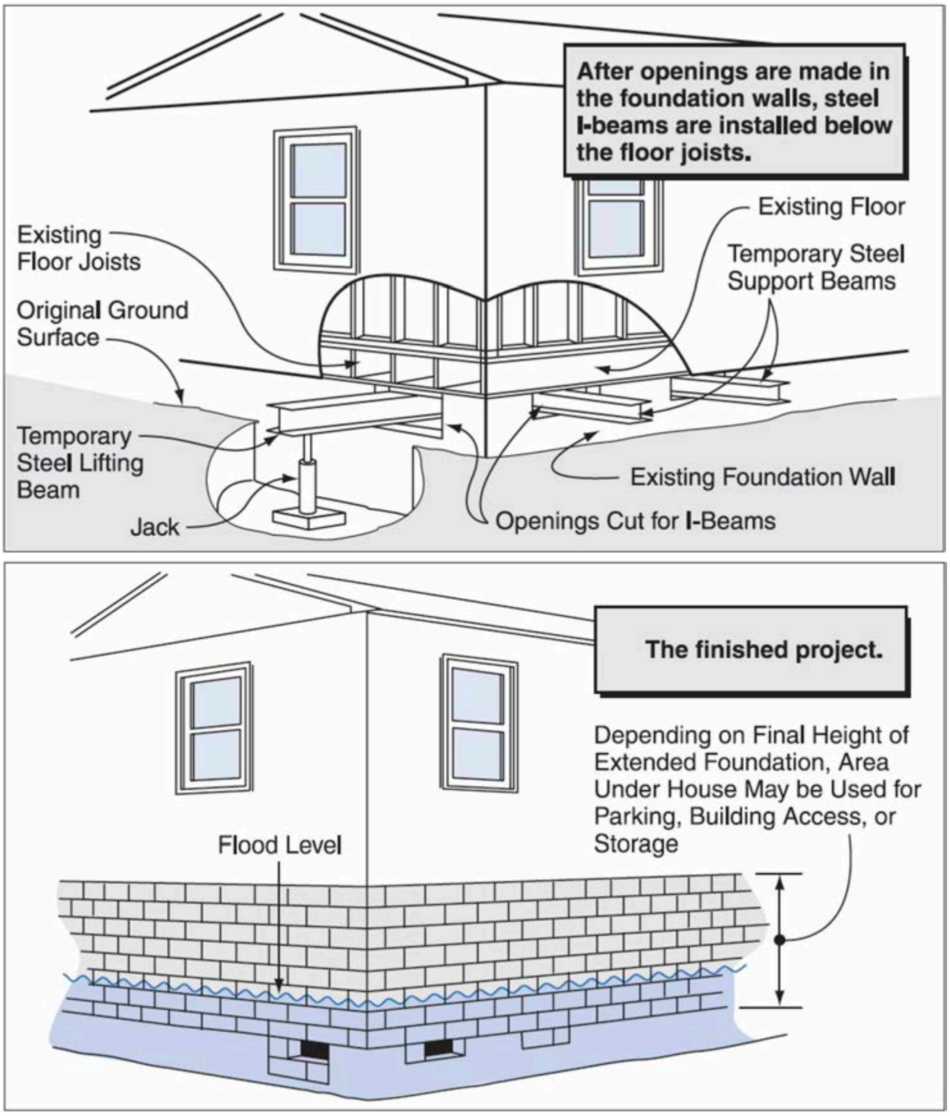


Figure 9 — Elevating a basement foundation home on extended foundation walls (FEMA, 2009)

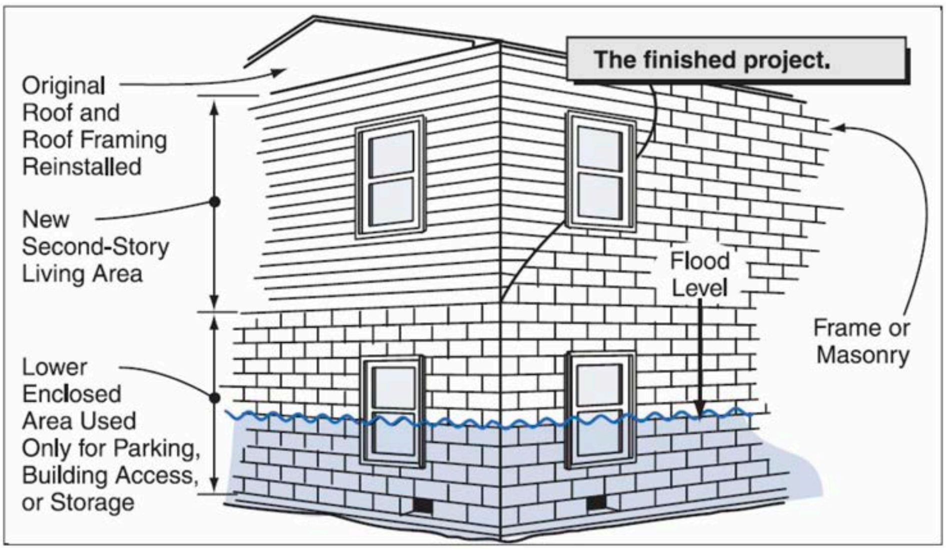


Figure 10 — Home elevated by adding a new second story over an abandoned lower floor (FEMA, 2009)

49 In response to Hurricane Katrina, FEMA evaluated building damage from the hurricane and provided recommendations on building structures in *Summary Report on Building Performance - Hurricane Katrina 2005* (FEMA, 2006). The assessment found that the buildings that survived the hurricane event have some elements in common, such as high first floor elevations, a well-embedded deep pile foundation, and structurally connected foundation and building frame. **Figure 11** shows that elevation successfully protected the building from flooding which is estimated at the height of the red line.

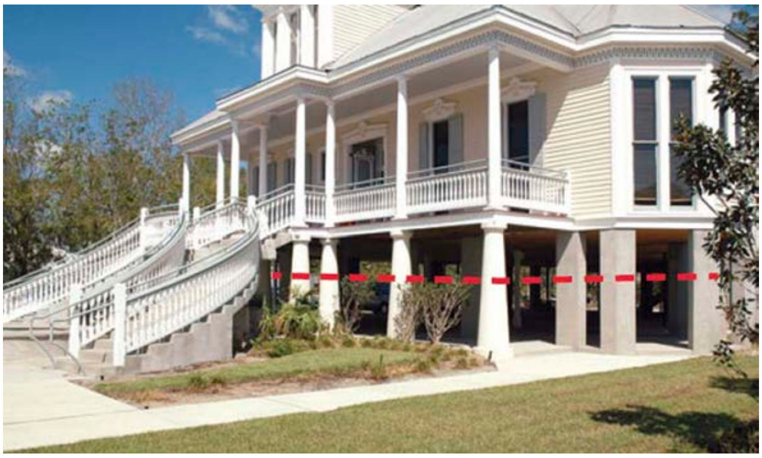


Figure 11 — Success example of elevation following Hurricane Katrina in Mandeville, Louisiana (FEMA, 2006)

2.7 Building relocation

50 Moving a building out of the existing flood hazard area is the safest solution among several retrofitting methods; however it is also usually the most expensive method (FEMA, 2009). When a community acquires a flood-prone home from the owner, relocation is often applied, as well as demolition of the building.

51 Relocation includes the following process: lifting up a building from its foundation, placing it on a trailer, transporting it to a new safe area, and setting it onto a new foundation. As with the elevation of a building, a relocated building must be structurally sound enough to withstand all the stresses during the relocation process. Similar techniques as used for the elevation of buildings are used for lifting and setting a building structure. The moving process requires trailer wheel sets to be placed beneath steel beams supporting the building. The size and weight of a building affects the relocation process and the necessary equipment. A single-story, wooden framed building with a rectangular shape is easier to be relocated than a multi-story, solid masonry one.

52 Given that relocation requires a moving route between the old and new sites, this adds additional consideration because of the route restrictions, such as width of roads, load limits on bridges, and clearance of facilities along the route. If a building is too large to fit on any moving route, it may be cut into sections, moved separately, and reassembled at the new site. Taking public roads and changing utility lines requires the necessary permits from local governments or utility companies. The relocated building also needs to meet all zoning ordinances and building codes in the new site.

53 Because relocation is a costly but effective method to prevent recurrence of flood damage, it is often used for preserving historical buildings and monuments. The City of Grand Forks, North Dakota, USA was severely hit by the Red River flood in April 1997 (FEMA, 2001). The Boomtown Building, one of the city's oldest structures and a property of the National Register of Historic Places, was also a casualty of the flood. In order to make way for a new dike, the building had to move to another location with the financial support of the city **(Figure 12)**.

54 Another famous example of relocation of an historical monument is shown by the Abu Simbel temples in Egypt **(Figure 13)**. Following the rise of the Nile waters as a result of the construction of the Aswan High Dam, a multinational team of archaeologists, engineers and skilled heavy equipment operators working together under the UNESCO banner, began in 1964 the salvage of the Abu Simbel temples. Between 1964 and 1968, the entire site was carefully cut into large blocks (up to 30 tons, averaging 20 tons), dismantled, lifted and reassembled in a new location 65 meters higher and 200 meters back from the river, for a total cost of some USD 40 million at the time (De Carvalho, 1966).

Figure 12 — Relocation of the Boomtown Building after the 1997 Red River flood in Grand Forks, North Dakota (FEMA, 2001)

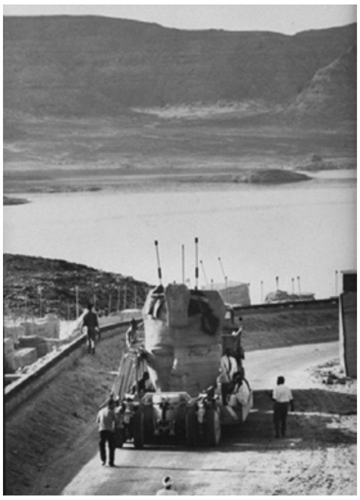


Figure 13 — Sandstone head of Ramses II being moved to be reassembled at the new site of Abu Simbel, 1966, in view of submersion of the original site due to the construction of the Aswan High Dam.
(Photo: © Terrence Spencer/Time and Life Pictures/Getty Image)

3 NON-STRUCTURAL MEASURES

55 Structural measures try to keep floodwaters away from people, while non-structural measures keep people away from floodwaters (ADB, 2007). Non-structural measures also teach residents to live rationally amid the threats of flooding through carefully designed land management and disaster preparedness. Because it is getting difficult for many governments to bear the increasing fiscal cost of investing in structural flood protection, non-structural flood control measures including land management and flood insurance are considered to be viable options.

3.1 Spatial plans

56 A spatial plan is aimed at creating a framework to promote economic, environmental and social well being in the planning area regardless of national, regional, or local level (DCLG, 2008). A planning authority sets out the strategy "how the area should be developed" in coordination with other policies such as flood, transport and waste management and with similar plans in adjacent areas. The spatial plan is formulated and discussed with relevant stakeholders including regulatory agencies, public transport providers, utility companies, local landowners, etc.

57 The spatial plan contains policies of land management and key development projects, leading to economic growth of the region. The plan ensures that the necessary land for housing and business activities is supplied at the right time and in suitable locations. In addition to the new supply of land, existing and available buildings and housing should be fully utilized. The spatial planning also delivers a supporting infrastructure for regional development as well as environmental assets of protected areas, habitats and landscapes. These fundamental conditions, in conjunction with a sufficient workforce and attractive investment opportunities, promote economic prosperity in the region. The spatial plan can be visually explained by information maps showing designated natural areas, development sites, flood hazard areas, etc.

3.2 Flood management plans

58 Floodplain management has a goal to reduce losses caused by flood and to protect the floodplain functions including natural values (FEMA, 1998a). In order to reduce human susceptibility to flood damage, a floodplain management plan is prepared to avoid hazardous or unwise use of floodplains. When new development is permitted in the floodplain, the development should minimize not only the flood risk to people's life and property but also the risk to natural resources by construction projects.

59 Floodplain management is supported by zoning codes and building codes that regulate floodplain usage and steer the development away from hazardous areas or from nature preservation areas. Critical facilities to provide public services and utilities should be carefully designed and located in the floodplain in order to function even during flood time.

60 The floodplain management plan defines flood control projects to protect development areas. In addition to conventional large-scale flood control infrastructures, such as dikes, floodwalls, shoreline protection, dams, and reservoirs, runoff control and on-site detention measures have recently become more important. The environmental aspect is also an essential part of the plan. Land use regulations designate natural resources to be preserved and sensitive natural areas to be protected.

61 The floodplain management plan also assists individuals and communities to prepare for, respond to, and recover from flooding to mitigate the social impact of floods. The necessary information and education on self-help and protective measures should be provided to residents during non-flood periods.

62 In case of flood, a flood emergency operation plan should be prepared in advance for a flood proofed building requiring human intervention such as the closure of flood gates (FEMA, 1993b). Each flood proofing component must work properly under any conditions. For example, if flood gates and flood pumps are operated by electricity, a backup generator should be installed in case of electric power failure. The emergency plan lists all flood proofing components and necessary materials for their operation and maintenance.

63 As for human factors, the emergency plan identifies command and control systems, with the responsibilities of leaders and personnel. After the emergency operation is completed, the personnel evacuate the facility. The emergency plan must explain an evacuation process for all personnel through safe access routes. For the success of an emergency operation, there needs to be a regular training and exercise programme to keep personnel aware of their duties.

64 Flood proofing structure requires regular inspection and maintenance to ensure appropriate functioning of the flood proofing components during flooding. A maintenance plan describes inspection intervals and repair requirements of the flood proofing components, for example mechanical parts of pumps and generators, flood shields for their watertight function, waterproofed walls for cracks and leaks, and levees for cracks, leaks, and excessive vegetation.

3.3 Flood risk assessment

65 When making a spatial plan or a flood management plan, flood risk assessment is conducted in the target floodplain. If new development is planned in an area at risk of flooding, its flood risk should be appraised beforehand to avoid inappropriate development in the flood hazard area (DCLG, 2010). In addition to its own safety from flood risk, the development should not increase flood risk in other areas and hopefully decrease overall flood risk. If flood risk remains, it should be effectively managed by coordinating with other strategies including spatial plan, river basin management plan and flood emergency plan.

66 In general, the flood risk management process takes the following three steps: appraisal, management and reduction of flood risk. Firstly, the assessment identifies land at risk and then its risk level is evaluated against flooding from river, sea and other sources. Secondly, the possible development is identified in the area where flood risk to people and their property can be avoided as much as possible. The development policy is recommended to consider the impacts of climate change in the future. Thirdly, the developed land is protected by flood defences, flood storage facilities, or re-created wetlands. The residual risk, for example flood exceeding a design level, should be safely managed. If road and railway embankments can act as an additional flood defence, such an infrastructure is incorporated in flood risk management.

67 One practical risk management approach is the source-pathway-receptor model **(Table 3)**. In order to avoid increasing the source of flood risk, inappropriate development in a flood hazard area is refrained, or run-off from new development onto other properties is minimized. Then the flood pathway, which is a route and storage of flood water in a river or coastal system, is appropriately modified by a flood defence infrastructure. Lastly flood resilience measures are taken to mitigate the impact to the receptor, such as people, property, infrastructure, and habitat.

Table 3 — Flood risk management measures: source-pathway-receptor model (CIRIA, 2010)

Flood risk management measures		
SOURCE CONTROL ***Measures that reduce the likelihood of high flows/water levels occurring***	***PATHWAY MODIFICATIONS*** ***Measures that modify or block the pathways taken by floodwater to a site***	***RECEPTOR RESILIENCE*** ***Measures that reduce the vulnerability of receptors to the impacts of a flood.***

➢ **land-use policies**
➢ sustainable drainage
  ➢ *detention basins*
  ➢ *filter drains/strips*
  ➢ *flow control systems*
  ➢ *infiltration basins/ trenches*
  ➢ *permeable paving*
  ➢ *retention ponds*
  ➢ *soakaways/swales*
  ➢ *wetlands*
  ➢ *greenroofs/walls*
➢ rainwater harvesting
➢ attenuation reservoirs
➢ **river regulation**
➢ river restoration and floodplain rehabilitation
➢ oversized pipes/attenuation tanks within the drainage network.
	➢ ground raising
	➢ construction of floodwalls and embankments
	➢ construction of diversion channels or tunnels
	➢ removal or modification of existing structures
	➢ demountable flood defences
	➢ temporary flood defences
	➢ designing drainage networks for exceedance, eg overland flow routing
	➢ managed realignment to "make space for water"
	➢ flood resistance measures (dry-proofing).
	
	Non-structural measures are shown in bold.
		➢ **business continuity management**
		➢ **flood risk identification and mapping**
		➢ **planning policies and development control**
		➢ **risk transfer (eg flood insurance)**
		➢ **flood forecasting and warning**
		➢ **improved emergency response procedures**
		➢ **improved preparedness**
		➢ **desktop incident management exercise**
		➢ **feedback from lessons identified**
		➢ flood resilience measures (wet-proofing).

3.4 Floodplain zoning

68 Flood zoning is defined by national regulations or ordinances of local government as a basis for safe and appropriate land use. Local zoning ordinances are often stricter than the uniform requirements in the country as a whole. This section introduces the examples of flood zone classification in the UK and the USA.

69 In the UK, flood zones are defined based on the probability of flooding from rivers and the sea (DCLG, 2010). The flood zones do not consider the presence of existing flood defences, because they can be breached and not functioning during floods. There are four types of flood zones: low, medium, and high probability of flooding, and the functional floodplain **(Table 4)**.

Table 4 — Flood zone classification (DCLG, 2010)

Flood zone	Definition (Flood probability in any year)	Appropriate land uses (Refer to Table 5)	Inappropriate land uses
Zone 1 Low Probability	• Less than 1 in 1000 annual probability of river or sea flooding (<0.1%)	(1)-(5) All uses	
Zone 2 Medium Probability	• Between a 1 in 100 and 1 in 1000 annual probability of river flooding (1% – 0.1%), or • Between a 1 in 200 and 1 in 1000 annual probability of sea flooding (0.5% – 0.1%)	(1) Essential infrastructure (3) More vulnerable (4) Less vulnerable (5) Water-compatible	
Zone 3a High Probability	• A 1 in 100 or greater annual probability of river flooding (>1%), or • A 1 in 200 or greater annual probability of flooding from the sea (>0.5%)	(4) Less vulnerable (5) Water-compatible	(2) Highly vulnerable
Zone 3b Functional Floodplain	• Land where water has to flow or be stored in times of flood, • A 1 in 20 or greater annual probability of flooding (5%), or • Land designed to flood in an extreme flooding (0.1%)	(5) Water-compatible	(2) Highly vulnerable (3) More vulnerable (4) Less vulnerable

Table 5 — Flood risk vulnerability classification (DCLG, 2010)

Classification	Examples of facilities
(1) Essential infrastructure	Transportation, Utility (Water, Electricity)
(2) Highly vulnerable	Police station, Fire station, Basement dwelling
(3) More vulnerable	Hospital, Hotel, Residential care home, Educational facility
(4) Less vulnerable	Office, Shop, Restaurant, Agricultural facility
(5) Water-compatible	Flood control infrastructure, Docks, Outdoor sports facility

70 FEMA defines the Flood Insurance Rate Map Zones, which designate floodplains and coastal areas (sea, lake and inlet) subject to flood hazard (FEMA, 1998a) **(Table 6)**. The area is classified by possibilities of flood occurrence and existence of flood protection facilities. The zone

classification is widely used by community officials in charge of flood management, by property owners to find flood hazards, by insurance agents, etc.

71 A zones include riverine and lake floodplains, and coastal floodplains landward of V zones (FEMA, 1999). Among A zones, a floodway that carries the majority of flood flow and is related to high velocity flows and debris impact is regarded as a special flood hazard area. V zones located along coastlines are associated with high velocity flows, breaking waves and debris. Any new development in the special flood hazard area must not increase the flood threat and must be protected from flood damage.

Table 6 — Flood Insurance Rate Map Zones (FEMA, 1998a)

Zone	Definition
Zone A	• Special flood hazard area • 100 year or base floodplain
Zone V, VE	• Special flood hazard area • Coastal area subject to a velocity hazard (wave action)
Zone X (shaded) (formerly Zone B)	• Area of moderate flood hazard • Area between the limits of the 100 year and 500 year floods • Shallow flooding areas with average depths of less than one foot • Drainage areas less than one square mile • Areas protected by levees from the 100 year flood
Zone X (unshaded) (formerly Zone C)	• Area of minimal flood hazard • Area above the 500 year flood level • Area with ponding and local drainage problems • Area outside the 500 year flood and protected by levee from the 100 year flood
Zone D	• Area of undetermined but possible flood hazards

3.5 Building codes

72 Local governments stipulate a wide range of regulations to manage floodplain development, which include building codes, land use regulations, and various ordinances on zoning, storm water management, etc. (FEMA, 1999). Buildings and their utilities are regulated by not only building codes but also other associated codes such as fire prevention code, mechanical code, plumbing code, electrical code, fuel gas code, and sewage disposal code.

73 A large part of flood damage consists of components of building utility systems such as heating, ventilating, and air conditioning systems, fuel systems, electrical systems, sewage management systems, and potable water systems. For example, inundation of electrical parts (switches, fuse boxes, control panels, etc.) causes short-circuits, electrical shock and fires. The damage to fuel systems includes floatation of fuel tanks which leads to debris and fire hazard, and severance of pipe connection which contaminates the flood water with fuel oil and makes the cleaning of damaged houses much more difficult.

74 Local communities regulate new construction or substantial improvement of buildings in a flood hazard area and ensure that the buildings and their utilities are appropriately protected from flood damage. The utility systems are either elevated above expected flood levels, or sealed in watertight enclosures if located below such levels. The detailed protecting techniques for utilities are explained in *Protecting Building Utilities From Flood Damage.*

3.6 Health and sanitary regulations

75 Water supply systems must be designed to minimize or eliminate infiltration of flood water into the systems in flood-prone areas (FEMA, 1998a). Sanitary sewage systems must be designed to minimize or eliminate both infiltration into and discharge from the systems. Manholes should be raised above the expected flood level or equipped with seals to prevent leakage. In order to prevent sewage from backing up into the building, an automatic backflow valve should be installed. Onsite waste disposal systems should be located in places that are accessible even during flooding and should not release contamination into flood water.

76 Items that are hazardous or vulnerable to flood conditions and stored in flood hazard areas require prohibition or protection depending on the degree of hazard (USACE, 1995). Such items are hazardous to the welfare of the general public if they are highly flammable, explosive, or corrosive in the event of a flood-induced spill (ammonia, benzene, chlorine, etc.). Some items are hazardous when stockpiled in a large quantity, although smaller amounts of them may be permitted (matches, paints, soaps, etc.). Other items may necessitate extensive repairs or cause an excessive period of inoperation resulting from prolonged exposure to water and moisture (books, carpet, computers, etc.). A complete list of major hazardous materials is explained in *Flood Proofing Regulations.*

3.7 Stormwater management

77 Stormwater management is the removal of rainwater that falls onto properties (FIFM Task Force, 1992). Urbanization turns agricultural or rural areas into developed and more impervious lands with roofs, roads, and parking, contributing to additional runoff into a stream. If the existing discharge network of stormwater becomes insufficient to cope with the increased runoff, localized flooding will occur. In order to mitigate such flood damage, on-site detention measures are recommended. Retaining runoff on the site helps to manage the total runoff within a river basin so that discharges from different areas reach the main stream at different times and thus reduce peak flows downstream. *"Urban Flood Risk Management"* (WMO, 2008) explains various mitigation measures of stormwater management such as infiltration trenches, multipurpose detention basins, and rainwater harvesting.

3.8 Wetland protection, River restoration

78 Wetlands, in their natural conditions, slow the flow of flood water, store it for some time and slowly release it downstream; this function of flood storage and flood peak reduction protects downstream property from flood damage (USFWS, 1984) **(Figure 14)**. Located between watercourses and uplands, wetlands also have the function of protecting uplands from erosion. Wetland vegetation such as reeds, willows, etc., help to work towards this purpose by catching sediment with their roots, lowering wave heights, and reducing flow velocity through friction.

79 Various human and natural threats cause wetland loss and degradation, for example drainage for crop production, stream alteration for navigation and flood protection, roads and commercial development, sedimentation, and droughts. Wetland protection efforts have been shown to slow wetland losses and improve the quality of remaining wetlands.

80 Although erosion of stream banks and shorelines is a natural phenomenon, excessive erosion causes loss of property, threats to infrastructure, habitat destruction, and water quality degradation (NIRPC, 2000). A conventional erosion control measure has been armoured channels with a hard surface such as concrete or rock. Because such a measure is typically expensive and destructive to water habitat, natural bank stabilization techniques have been installed for appropriate sites. By planting native species for erosion control, the plants adapt in stream channels or shorelines and stabilize embankments efficiently.

81 Along the edge of streams and wetlands, a riparian buffer zone that is a continuous vegetated strip of land is critical to the health and quality of water bodies and wetlands. In addition to stabilizing stream banks and shorelines, natural buffer zones filter pollutants from runoff water and enhance fish and wildlife habitat. Wider buffer zones allow streams to create natural meandering patterns, which retard flooding to protect downstream areas.

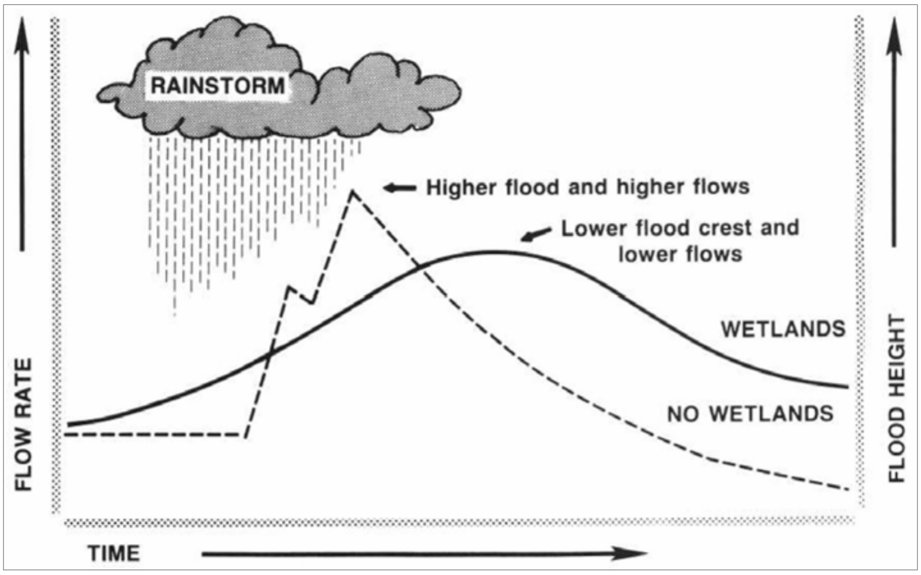


Figure 14 — Wetland value in reducing flood crests and flow rates after rainstorms (USFWS, 1984)

3.9 Property Acquisition, Home buyout

82 Buying land with a building in flood-prone areas, and turning that property into open space, is an effective mitigation measure, providing complete and permanent protection from future flood hazards (FEMA, 1998b). Property acquisition (buyout) reduces the emotional and financial costs incurred in future flood disasters, otherwise the flood would cause evacuation, rescue, and recovery efforts in every flood event. In addition to solving a flood hazard problem, the acquisition brings other advantages, such as protecting habitat, providing recreational opportunities, increasing flood storage, or enhancing natural and cultural resources. Fifteen homes were purchased and cleared by the government on Wimpole Drive in Nashville, Tennessee after the September 1999 flood (Metropolitan Government of Nashville, 2010) **(Figure 15)**. As a result, flood damage was avoided in the same place during the May 2010 flood.

83 Property acquisition must be the most practical, cost-effective, and environmentally sound alternative to reducing future flood risks and solving repetitive flood damage among a range of options considered. Each property is acquired at fair market value, and then the acquired

property is either demolished or relocated outside the floodplain. The remaining open space can be used for recreation, preservation, cultivation, parking lots, etc. Instead of purchasing property, a conservation easement, which allows the property owner to retain the title to his property but prevents him from developing it, is a practical measure, especially in agricultural areas.

84 The property must be provided by the owner who voluntarily agrees to sell it, and then the space is maintained as an all-time open space in accordance with the community's land management policy. In order to proceed with acquiring the property, communication between the local community and the property owner is crucial. A town meeting targeting the property owners serves such a purpose, to summarize hazard mitigation, and explain the system of acquisition including the pros and cons, fair compensation and any other alternatives. Property acquisition may take a long time, at least six months and even up to one and half years. When implemented, due consideration is necessary regarding any long-term impacts on the local community from the point of view of socioeconomic change, fairness among residents, and local property tax.

Figure 15 — Home buyout on Wimpole Drive in Nashville, Tennessee (Metropolitan Government of Nashville, 2010)

3.10 Flood insurance

85 The insurance is a mechanism of cost-sharing arrangements among property owners, the insurance industry, and governments (ADB, 2007). Structural measures can have inverse incentives for flood management that may lower the cost of living and investments in flood hazard areas, and subsequently increase the population and economic activities there. Population and economic growth increases potential flood damage and requires further structural measures. On the other hand, flood insurance works the opposite way by adding the insurance premium to people's cost of living and investments and discouraging migration into, and establishing businesses in, flood-prone areas. Flood insurance schemes establish an automatic mechanism for transferring benefits from non-affected persons to flood-affected victims.

86 There are some challenges on both supply and demand sides of flood insurance. From the point of view of the supply side, insurers find it hard to design an insurance product where it is difficult to assess the flood risk and estimate potential flood damage. Many developing countries do not have flood maps and this makes it difficult for insurers to develop flood insurance. Assessing actual flood damage accurately is another challenge for insurers. Limited access to reinsurance markets increases the cost of insurance. Global climate change that causes extreme weather disturbances is projected to adversely affect the commercial viability of flood insurance.

87 In terms of the demand side, insurance coverage should be large enough to optimize risk sharing and offer affordable insurance premiums. Property owners must be well aware of flood risk and insurance premiums in order to make sound decisions when building or purchasing properties in flood-prone areas. If residents in flood risk areas expect the government to compensate them for their flood disaster loss, then they will not buy flood insurance. The poor households that are vulnerable to floods and need flood insurance the most cannot afford to buy it.

88 In many countries, governments are involved in flood insurance programmes to a certain degree. One criterion of flood insurance is the degree of government intervention in the insurance. The two main insurance types are a market-led insurance scheme (e.g. the UK) and a government-led insurance scheme (e.g. the USA). The success of flood insurance depends on the partnership between the government and the private insurance industry. The other important criterion is a mandatory or optional flood insurance scheme. The mandatory insurance can act like a tax system. However, it poses the problem that non-exposed property owners are forced to buy unnecessary insurance. The optional system has a problem of adverse selection, in that insurers tend to select customers in safe areas but it is the customers in risky areas who tend to buy insurance.

89 In the UK, insurance against flood impact has been a standard part of household and small business insurance policies since the early 1960s (DEFRA, 2008). Flood insurance is available as widely as possible by insurers, while the government reduces flood risk by investing in flood prevention measures and preventing inappropriate development in flood risk areas. Since 2000, this role sharing has been implemented through a *"Statement of Principles on Flood Insurance,"* which was agreed between the Association of British Insurers and the UK government and revised in 2008. However, both parties recognized that the Statement distorted the insurance market, and a long-term strategy to reduce flood risk was being sought in the areas of flood risk assessment, policy making, building design, etc.

90 The US created the National Flood Insurance Program (NFIP) in 1968 to enable property owners to purchase insurance protection against flood losses (FEMA, 1999). If a local community enforces floodplain management requirements of the NFIP to reduce future flood risks in flood hazard areas, the Federal Government will provide flood insurance to the owners as a financial protection within the community. The community must regulate all development, which includes any changes to buildings, and filling, dredging or paving operations. FEMA prepares basic information for the requirements such as maps of flood hazard areas and the degree of risk in those areas in the form of different zones.

3.11 Funding, Subsidies

91 FEMA manages the Hazard Mitigation Grant Program **(HMGP)**, which assists States and local communities in implementing flood hazard mitigation projects including development of the hazard mitigation program, flood proofing of structures, acquisition of property, and relocation of buildings (FEMA, 1998b). The States select a project applied by local communities followed by final approval by FEMA.

92 FEMA also provides the Flood Mitigation Assistance **(FMA)** program, which provides funds to States and local communities to help in implementing measures to reduce flood risk of buildings insured under the National Flood Insurance Program. The States offer two types of FMA grants to their communities: planning grants to develop or update flood mitigation plans, and project grants to carry out flood mitigation measures (elevation, dry flood proofing, and property acquisition).

93 Another assistance provided by FEMA to the owners of substantially or repetitively damaged buildings is Increased Cost of Compliance **(ICC)** coverage included in the NFIP flood insurance policy (FEMA, 1999). Policyholders can be reimbursed not only for the costs to repair actual flood damage, but also the additional cost to improve the damaged building to the level of the community's flood management requirements.

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APPENDIX A - INSTRUCTIONS FOR USING THE FLOOD PROOFING MATRIX

(USACE, 1998)

Step 1 Select the appropriate row for each of the nine characteristics that best reflect the flooding, site, and building structure characteristics.

Step 2 Circle the N/A (not applicable) boxes in the rows of characteristics selected.

Step 3 Examine each column representing the different flood proofing measures. If one or more N/A boxes are circled in a column representing a flood proofing measure, that alternative should be eliminated from consideration unless special features (as footnoted) are applied to overcome the N/A concern.

Step 4 Test the flood proofing measures that do not have circled N/A boxes for compliance with your community's flood plain management ordinance and building permit requirements.

Step 5 Flood proofing measures that would be in compliance with community requirements should now be further evaluated for economic, aesthetic, risk, and other considerations. A preferred measure should evolve from this evaluation.

Step 6 Obtain professional engineering and construction services for detailed design and implementation of the preferred flood proofing measure. Professional advice may rule out the preferred measure, and an alternate measure will need to be selected.

N/A[2] Dry flood proofing can work with these depths if the walls and floor are designed to resist the hydrostatic force and if the structure is designed to not become buoyant.

N/A[3] Space and aesthetics usually limit levee and floodwall heights for flood proofing to 6 feet. owever, from an engineering viewpoint, greater heights are common.

N/A[4] Hydrodynamic force directly on the structure eliminates this measure.

N/A[5] Scour due to fast flood velocity eliminates this measure.

N/A[6] Flash flooding does not allow time for human intervention; thus, these measures must perform without human activity being involved. Openings in foundation walls must be large enough to equalize water forces and should not have removable covers. Closures and shields must be permanently in place, and wet flood proofing cannot include last.minute modifications.

N/A[7] Permeable soils allow seepage under floodwalls and levees; therefore, some type of cutoff feature would be needed beneath structures. Permeable soils also allow hydrostatic force to directly affect the structure; therefore, the walls and floor must be designed to resist hydrostatic force and buoyancy.

FLOOD PROOFING MATRIX		FLOOD PROOFING MEASURES									
		Elevation on Foundation Walls	Elevation on Piers	Elevation on Posts or Columns	Elevation on Piles[1]	Elevation on Fill[1]	Relocation	Floodwalls and Levees	Floodwalls and Levees with Closures	Dry Flood Proofing	Wet Flood Proofing
FLOODING CHARACTERISTICS	**Flood Depth**										
	Shallow (less than 3 feet)										
	Moderate (3 to 6 feet)									N/A[1]	
	Deep (greater than 6 feet)							N/A[2]	N/A[2]	N/A[1]	
	Flood Velocity										
	Slow (less than 3 fps)										
	Moderate (3 to 5 fps)	N/A[3]								N/A[3]	N/A[3]
	Fast (greater than 5 fps)	N/A[3/4]	N/A[4]							N/A[3/4]	N/A[3/4]
	Flash Flooding										
	Yes (less than 1 hour)								N/A[5]	N/A[5]	N/A[5]
	No										
	Ice and Debris Flow										
	Yes	N/A								N/A	N/A
	No										
SITE CHARACTERISTICS	**Site Location**										
	Coastal Floodplain	N/A	N/A					N/A	N/A	N/A	N/A
	Riverine Floodplain										
	Soil Type										
	Permeable							N/A[6]	N/A[6]	N/A[6]	
	Impermeable										
BUILDING CHARACTERISTICS	**Building Foundation**										
	Slab on Grade										
	Crawl Space									N/A	
	Basement		N/A	N/A	N/A					N/A	
	Building Construction										
	Concrete or Masonary										
	Metal										
	Wood										N/A
	Building Condition										
	Excellent to Good										
	Fair to Poor	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A

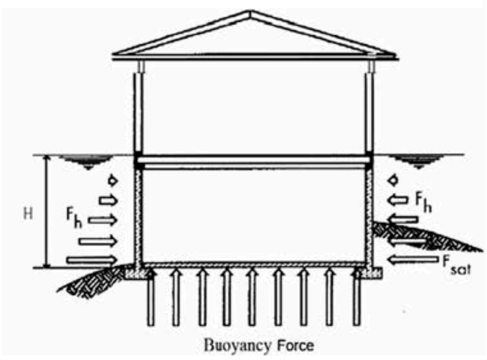
1 For an existing structure, the structure must be temporarily relocated to place fill and piles.

APPENDIX B - CALCULATION OF FLOOD FORCES

(FEMA, 1993b)

Hydrostatic Pressures by Water Depth

Height (H) (Water Depth)	Ph (LBS/SQ.FT.)
1	62.4
2	124.8
3	187.2
4	249.6
5	312.0
6	374.4
7	436.8
8	499.2
9	561.6
10	624.0



Hydrostatic Pressure Diagram

Resultant Lateral Force Due to Hydrostatic Pressure from Freestanding Water:

$F_h = \frac{1}{2}wH^2$

where: F_h lateral force from freestanding water (in pounds per linear foot of surface)
w specific weight of water (62.4 pounds per cubic foot)
H height of the standing water (to the floodproof design level)

If any portion of the building is below grade, then calculate the Resultant Cumulative Lateral Force

Due to Hydrostatic Pressure from Saturated Soil:

$F_{sat} = \frac{1}{2}SD^2+F_h$

where: F_{sat} lateral force from saturated soil
S equivalent fluid weight of saturated soil (in pounds per cubic foot)
D depth of saturated soil (in feet)
F_h lateral force from freestanding water

Buoyancy Force:

$F_b = wAH$

where: F_b force due to buoyancy
w specific weight of water (62.4 pounds per cubic foot)
A area of horizontal surface (floor or slab) being acted upon (in square feet)
H is the depth of building below the floodproofing design level (in feet)

Hydrodynamic Force:

$F_d = C_d m \frac{1}{2}(V)^2 A$

where: F_d lateral force due to hydrodynamic pressure
C_d drag coefficient
m mass density of water (1.94 slugs per cubic foot)
V velocity of the water (in feet per second)
A area of the wall affected (in square feet)

Debris Impact Force:

$F_i = (WV)/(gt)$

where: F_i impact force
W weight of the object (in pounds)
V velocity of the object (in feet per second)
g acceleration due to gravity (32.2 feet per second^2)
t duration of impact (in seconds)

Note: See Appendix C of the FEMA "Design Manual for Retrofitting Flood-Prone Residential Structures" for further information.

APPENDIX C - FLOOD RESISTANT NEW CONSTRUCTION CHECKLIST

(FEMA, 1999)

Property ID:
Property Name:
Property Address:
Reviewed By / Date:

- ☐ Met with the building official, floodplain manager, and other relevant community officials
- ☐ Identified the Base Flood Elevation, First Floor Elevation, and Design Flood Elevation (DFE)
- ☐ Building utilities must be protected from flood damage up to the DFE
- ☐ Elevated all controls, equipment, piping wiring, ducts, etc. above the DFE

Heating, Ventilating, and Air Conditioning System:

- ☐ All components are elevated above the DFE
- ☐ Protected controls from flood inundation
- ☐ Protected exterior units from floodwater inundation, scour, and impact
- ☐ Protected exterior piping and wall penetrations below the DFE from impact and water infiltration
- ☐ Protected boilers from water infiltration and impact damage

Fuel System:

- ☐ All components are elevated above the DFE
- ☐ Protected exterior piping and wall penetrations below the DFE from impact and water infiltration
- ☐ Protected fuel tank from impact, buoyancy, and scour

Electrical System:

- ☐ All components are elevated above the DFE
- ☐ Protected transformers, switch panels, service connections and meters from water infiltration
- ☐ Protected wiring, outlets and switches from water infiltration and damage
- ☐ Protected wall penetrations below the DFE from water infiltration

Plumbing:

- ☐ All components are elevated above the DFE
- ☐ Protected plumbing components below the DFE from impact and scour
- ☐ Protected sewer tank and distribution system from impact, buoyancy, and scour
- ☐ Protected wall penetrations below the DFE from water infiltration
- ☐ Protected water taps and drains below the DFE from infiltration and impact damage
- ☐ Protected water heaters from water infiltration and impact damage

APPENDIX D - FLOOD RESISTANT RETROFITTING FIELD INVESTIGATION WORKSHEET

(FEMA, 1999)

Owner Name:..Prepared By:
Address:..Date:
Property Location:..Design Flood Elevation (DFE)_______

Heating, Ventilating, and Air Conditioning System:

- ☐ Can all equipment be protected in-place?
- ☐ Is it feasible to install a curb or "pony" wall around equipment to act as a barrier?
- ☐ Is it feasible to construct a waterproof vault around equipment below the DFE?
- ☐ Can reasonably sized sump pumps keep water away from the equipment?
- ☐ Can equipment feasibly be relocated?
- ☐ To a pedestal or balcony above the DFE?
- ☐ To a higher level on the same floor level?
- ☐ To the next floor level?
- ☐ Is space available for the equipment in the alternate location?
- ☐ Can existing spaces be modified to accept equipment?
- ☐ Is additional space needed?
- ☐ Do local codes restrict such relocations?

Fuel System:

- ☐ Can all equipment be protected in-place?
- ☐ Is the tank properly protected against horizontal and vertical forces from velocity flow and buoyancy?
- ☐ Is it feasible to install a curb or "pony" wall around equipment to act as a barrier?
- ☐ Is it feasible to construct a waterproof vault around equipment below the DFE?
- ☐ Can reasonably sized sump pumps keep water away from the equipment?
- ☐ Is the meter properly protected against velocity and impact forces?
- ☐ Do local code officials and the gas company allow the meter to be relocated to a higher location?
- ☐ Can equipment feasibly be relocated?
- ☐ To a pedestal or balcony above the DFE?
- ☐ To a higher level on the same floor level?
- ☐ To the next floor level?
- ☐ Is space available for the equipment in the alternate location?
- ☐ Can existing spaces be modified to accept equipment?
- ☐ Is additional space needed?
- ☐ Do local codes restrict such relocations?

Electrical System:

- ☐ Is it feasible to relocate the meter base and service lateral above the DFE?
- ☐ Is it feasible to relocate the main panel and branch circuits above the DFE?
- ☐ Is it feasible to relocate appliances, receptacles, and circuits above the DFE?
- ☐ Is it feasible to relocate light switches and receptacles above the DFE?
- ☐ Can ground fault interrupter protection be added to circuits below the DFE?
- ☐ Can service lateral outside penetrations be sealed to prevent water entrance?
- ☐ Can cables and/or conduit be mechanically fastened to prevent damage during flooding?
- ☐ Can splices and connections be made water resistant or relocated above the DFE?
- ☐ Do local code officials and electric companies allow the elevation of the meter?

Sewage Management Systems:

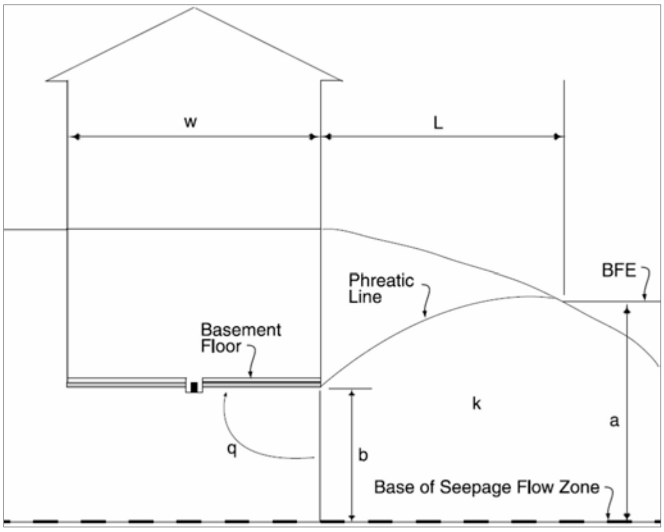
- ☐ Can the on-site system be protected in-place?
- ☐ Is it feasible to anchor the tank?
- ☐ Can the distribution box and leech field be protected from scour and impact forces?
- ☐ Can the supply lines be properly protected from scour and impact forces?
- ☐ Can backflow prevention valves be used to minimize flow of sewage into the building?
- ☐ Can equipment feasibly be relocated?
- ☐ Can the system be moved to a higher elevation on the property?
- ☐ Can the tank be relocated to a higher elevation or indoors?
- ☐ Can the drains and toilets be relocated above the DFE?
- ☐ Is space available for the equipment in the alternate location?
- ☐ Can existing spaces be modified to accept equipment?
- ☐ Is additional space needed?
- ☐ Do local codes restrict such relocations?

Potable Water Systems:

- ☐ Can the well be protected in-place?
- ☐ Is it feasible to install a curb or "pony" wall around equipment to act as a barrier?
- ☐ Is it feasible to construct a waterproof vault around equipment below the DFE?
- ☐ Can the wellhead and tank be protected from scour and impact forces?
- ☐ Can the supply lines be properly protected from scour and impact forces?
- ☐ Can backflow prevention valves be used to minimize flow of floodwaters into the water source?
- ☐ Can equipment feasibly be relocated?
- ☐ Can the well be moved to a higher elevation on the property?
- ☐ Can the electric controls for the well be protected from inundation?
- ☐ Can the tank be relocated to a higher elevation or indoors?
- ☐ Can the taps be relocated above the DFE?
- ☐ Is space available for the equipment in the alternate location?
- ☐ Can existing spaces be modified to accept equipment?
- ☐ Is additional space needed?
- ☐ Do local codes restrict such relocations?

APPENDIX E - CALCULATION OF SEEPAGE FLOW

(FEMA, 2001b)



The Dupuit equation for the quantity of seepage flow is:

$$q = k(a2 - b2)/2L$$

where:

- q is the flow in cubic feet per second for a 1-foot width of seepage zone
- k is the soil permeability in feet per second (fps) (maximum value of k is 1x10.3 fps)
- a and b are hydraulic heads in feet ($a < b + 5$)
- L is the length of the flow zone in feet ($L > 20$ feet)

To obtain q, the total seepage flow, in cubic feet per second, q must be multiplied by the length around the periphery of the four sides of the structure. This is a simplified approach that obviates the need for a three-dimensional flow net calculation and is reasonably conservative.

It should be noted that the soil permeability does not affect the geometry of the seepage zone or the geometry of the phreatic line. The permeability does have a significant effect on the quantity of seepage that must be collected and discharged by the drainage layer and the sump pump. The calculation of the quantity q provides a basis for the selection of a sump pump of adequate capacity.

To allow for possible errors in the estimation of the soil permeability, the pump should have a capacity of at least four times the calculated value of q. As noted in the requirements section, a standard sump pump of $^1/_4$ horsepower or greater will generally satisfy the requirements of seepage removal for the conditions described above.

For more information, please contact:

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