FLOOD

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1.0 SCOPE

This data sheet provides recommendations for the prevention and mitigation of losses due to flooding and stormwater runoff. Flood prevention and mitigation is an approach that relies on permanent solutions and emergency actions. Solutions include flood gates and barriers, flood pumps, waterproofing, emergency power, permanently relocating equipment, flood defense systems, etc. Permanent solutions are preferred whenever practical.

Detailed guidance on the design of flood protection for locations subject to direct wave action associated with coastal flooding is beyond the scope of this document. Avoid building in such areas. The forces associated with direct wave action will challenge the integrity of buildings unless the buildings and grounds are properly designed. Each coastal location is unique and requires a full understanding of the geotechnical issues along with dynamic wave and wind impacts.

The design, inspection, and maintenance of dams and levees are also beyond the scope of this document. Refer to Data Sheet 10-1, *Pre-Incident and Emergency Response Planning,* for information on flood emergency response plans (FERPs).

This data sheet does not address how to find or interpret flood information or maps.

1.1 Hazards

Flooding can occur adjacent to bodies of water, on normally dry land far from flood sources, or from a combination of exposures. For the purposes of this data sheet, flood exposures have been grouped into the following categories:

A. River, riverine, fluvial flooding: Rivers, lakes, man-made drainage channels, smaller watercourses overflowing due to upstream heavy rains, melting snow, and dam releases.

B. Alluvial fan flooding: Flooding that occurs in areas at the base of steep-sloped areas; as the water exits the steep area it fans out in the flat areas in a random manner.

C. Coastal flooding: Oceans, bays, estuaries, and rivers affected by coastal waters overflowing due to abnormal high tides, coastal storms, high winds or tsunamis. It is not uncommon for inland areas along rivers to be affected by tidal flooding; for example, for the Thames River in England or the Yangtze River in China, coastal flooding can influence the river for 100 km and 200 km, respectively, from the river’s mouth.

D. Stormwater flooding: Stormwater flooding is caused by the accumulation of runoff on land and paved areas from rainfall before it enters a stream, river, body of water, or a manmade drainage system. Stormwater flooding often happens due to poor drainage, insufficient drainage, overtaxed drainage systems, inappropriate landscaping, and building design. Another term for stormwater flooding is surface water flooding.

It is important to note that the above flood types may mix as flooding occurs. Coastal rivers and estuaries may be affected by both river flooding due to upstream rains and coastal storms. Flooding in these areas may flood solely due to upstream rainfall or a coastal storm or a combination. Another example of mixed flooding is a flood event that may be exacerbated by a stormwater event occurring at the same time as a river or coastal flood.

When flood water enters a building, it not only damages the structure itself and the contents inside, but can also leave a facility’s stored or in-process products stained, rusted, and deformed. Flood water also can cause equipment to malfunction. Electrical switchgear and electronics may require major repair or replacement. Water may fill below-grade areas and remain there after the flood recedes. Business interruption can vary from a few days to more than a year based on the depth of water, duration of flooding, wave and water velocity impact, and sensitivity of the occupancy to water damage.

A facility that is not properly designed to minimize the effects of flooding will have more costly and frequent flood losses; possibly even a major loss that jeopardizes market share and bottom line for years to come.

1.2 Changes

October 2025. Interim revision. The following changes are included:

A. Section 2.2.2, Stormwater Runoff and Terrain Management was completely rewritten to improve wording. The technical intent was not changed.

B. Section 3.6.1, Freeboard is a Key Design Consideration, was rewritten.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Flooding can be caused by bodies of water (rivers, streams, oceans, bays, lakes, canals, etc.) overflowing their normal boundaries, or as the result of stormwater runoff accumulating in normally dry areas. Protecting a facility from the negative effects of flooding, however, is not as simple as merely locating it outside known flood zones; inappropriate site layout and building design can create a stormwater runoff flood exposure anywhere. In addition, off-site flooding can block access routes to and from the site, as well as interrupt vital utilities.

If a facility is located within a known flood zone, the challenge of managing the flood risk is greatly increased. The goals then become to ensure that:

A. operations can continue without interruption, and

B. the facility suffers the least possible amount of physical damage.

These goals can be achieved by developing a flood-mitigation strategy throughout the facility that addresses overall layout, electrical and mechanical systems, and vital utilities, and applying it during all phases of the site's lifespan, including design and construction. While instituting the flood-mitigation strategy is most effective during the design and construction phases, practical mitigation solutions included in this data sheet can be very effective for existing locations.

It is important to recognize that flood prevention and mitigation is a systemic strategy to protect property and business continuity. This section contains recommendations that can be implemented individually or in combination with each other. Effective and successful flood prevention and mitigation will often require the application of multiple recommendations simultaneously and systematically in a timely manner (see Section 3.4 and Table 3).

Use FM Approved products whenever they are applicable and available. For a list of FM Approved products, see the *Approval Guide,* an online resource of FM Approvals (www.approvalguide.com)

2.2 Construction and Location

2.2.1 Site Selection for New Construction

2.2.1.1 Select a location where the entire site and all access routes (highway, marine, railroad, etc.) are outside 0.2% annual exceedance (500-year) flood zones (by both elevation and footprint). Verify flood studies for the selected site are up-to-date by having a qualified hydrologist review the study and recent flood data.

2.2.1.2 Select a building site that is above the predicted 0.2% annual exceedance (500-year) flood elevation and includes 1 to 2 ft (0.3 to 0.6 m) of freeboard. The building site should be at least 500 ft (152 m) from direct wave impacts and or high flood-flow velocities (i.e., above 7 fps [2 m/s]).

2.2.1.3 Select a site that is not in an area protected by a levee or other man-made flood control works.

2.2.1.4 Ensure electrical and communication services, drinking and process water, wastewater treatment, steam supplies, etc. obtained from off-site locations will remain unaffected during flooding in their area. If this cannot be ensured, establish alternative sources for backup.

2.2.2 Stormwater Runoff and Terrain Management

The stormwater recommendations and risk improvement solutions apply for greenfield sites or when a site is undergoing renovations that include changes to building footprints, landscaping or roadways. An opportunity exists to correct pre-existing storm water ponding or exposure to buildings, equipment or property during renovations.

FM recommends that proper design of a facility's stormwater system and terrain landscaping is needed to ensure key assets and utilities are not affected by rainstorms up to the 100-year return period. Regulations focus on impact outside a site while FM's focus is on impact to the site.

FM acknowledges that municipal stormwater systems are designed to local code (usually between two and 25 years return period); and a stormwater pipe system will be overwhelmed in a 100-year rainstorm, leading to overland flow and ponding. This situation is acceptable provided:

- The resulting surface inundation (roads, land, etc.) produced by a 100-year rainstorm does not cause any damage to property (buildings, outdoor equipment and storage) and/or business interruption.
- The surface inundation for the 100-year rainstorm is calculated for the critical rainfall duration. This is the rainfall duration that maximizes surface inundation and exposure to property and business.
- Key buildings, entry points to basements and outdoor utilities equipment have adequate freeboard (see Section 2.2.2.9) above the maximum inundation to account for uncertainty in the stormwater analysis.

Fig. 2.2.2. Stormwater runoff overwhelming drainage inlets

2.2.2.1 Design the site's stormwater management system to handle the 100-year rainfall event for the critical rainfall duration without any impact or damage to key assets and utilities.

The adequacy of the system should be verified for the expected lifespan of the property to ensure the 100-year standard of protection is maintained throughout. To this end, the stormwater analysis should account for future changes in the watershed of the drainage system (urbanization, etc.) and the expected impact of climate change. Use creditable governmental climate studies, or have a study completed to estimate rainfall changes. The intent is to avoid expensive and disruptive future upgrades of the stormwater system.

2.2.2.2 Use ground grading to direct runoff away from buildings, key assets and utilities. Where possible, minimize surface inundation.

2.2.2.3 Ensure all runoff that drains towards the project (including off-site areas) is accounted for in the evaluation of the 100-year rainfall event for design of the site's stormwater system. Off-site portion(s) of the watershed can contribute substantially to flooding at a site when their own stormwater system is overwhelmed in a 100-year rainstorm.

2.2.2.4 Ensure that catch basins, grates and entry points to the stormwater system are adequately located and spaced for efficient collection of the runoff from roads, paved areas, etc. Doing so can prevent bypassing or splash-over of the entry point and reduce excessive accumulation of surface runoff in critical areas where accumulation can lead to flooding of key properties and assets.

Alterations or re-surfacing of paved areas should consider the existing stormwater system entry points, location and elevation to ensure proper operation and collection of runoff.

2.2.2.5 Use landscaping material that is not easily dislodged by rain, which could increase the risk of catch basin blockage and/or clogging of the pipe network.

2.2.2.6 Include de-silting features in areas where runoff is loaded with solids (from soil erosion or wind-blown). These features include sediment sumps in manholes and dedicated silt traps near areas of erosion.

Ensure regular maintenance is provided to maintain the capacity of the stormwater system in areas affected by wind-blown soil (e.g. arid zones or sites handling materials that can be moved by wind). Assume the stormwater system to be ineffective if capacity cannot be maintained.

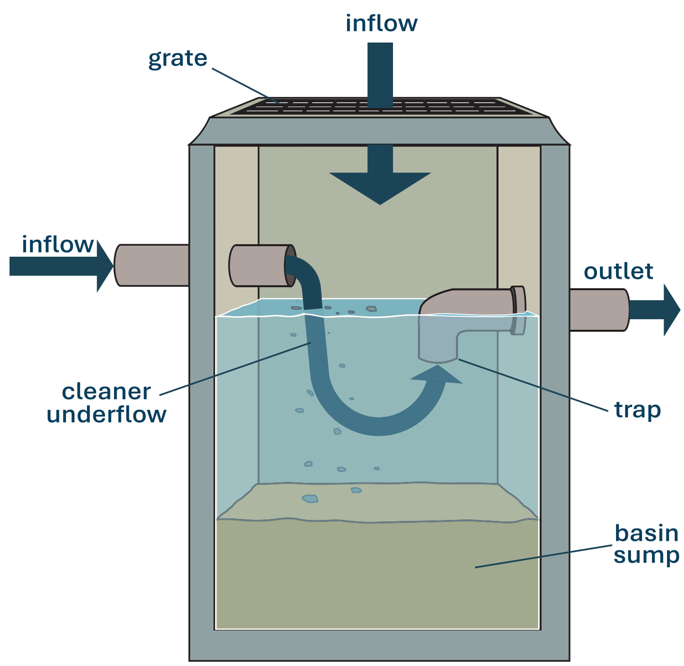


Fig. 2.2.2.6. Typical drainage catch basin arrangement

2.2.2.7 When on-site storage is necessary, typically to prevent an increase in runoff response due to urbanization, the stormwater analysis must identify the critical rainfall duration that maximizes the water level within the storage. Size the outlet structure and emergency spillway for this critical scenario. Direct overflow from the on-site storage away from buildings and critical assets.

Surface water ponding should be designed to ensure a fixed relief point is below building entry points or outdoor assets to ensure full redundancy in the system. Where provision of a relief point is not feasible, provide storage and/or pump capacity to evacuate the expected maximum flow rate/volume for the 100-year rainfall event of critical duration.

2.2.2.8 Do not locate buildings, key infrastructure, utilities, fire protection and water supplies within the natural or man-made drainage flow paths of the watershed(s) affecting a site or areas inundated by the 100-year rainstorm.

2.2.2.9 Design building finished floor elevations, entry points, openings, utilities and other penetrations at least 1 ft (0.3 m) above the 100-year storm water elevation. Increase the minimum freeboard to accommodate the impact of uncertainty and future conditions. See Sections 2.2.2.1 and 2.2.2.11 for further details. See also Figure 2.2.2.9.

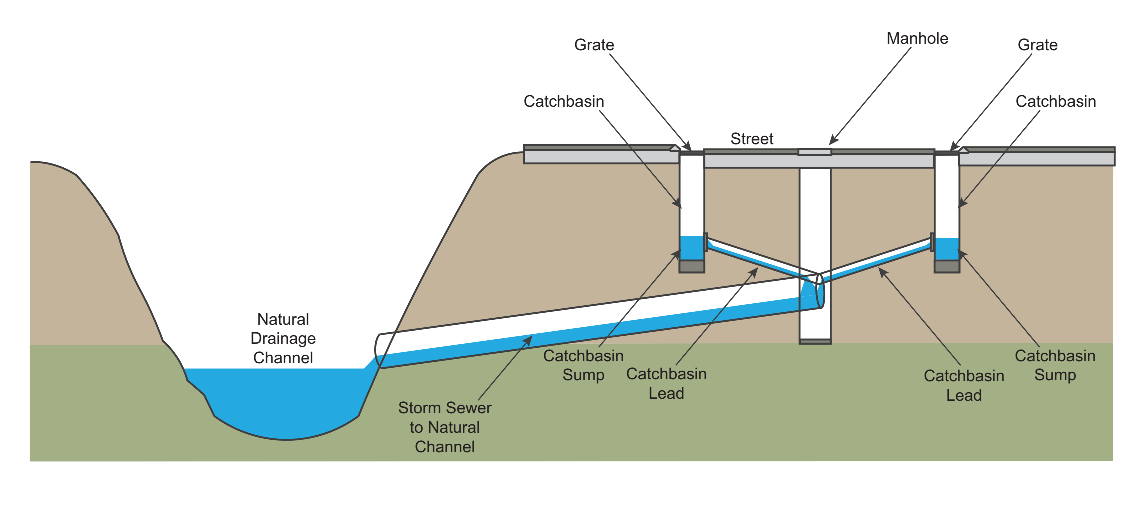


Fig. 2.2.2.9. Drainage systems interacting with body of water receiving flow

2.2.2.10 Supply stormwater pump systems that provide drainage to low-lying/below grade areas with backflow prevention devices. Use backflow valves or high inlet to control backflow in the event of pump failure. Ensure pumps have access to an emergency power supply during rainstorm events.

2.2.2.11 Monitor stormwater systems with a history of poor performance during significant rainfall events, and conduct a dedicated Hydrological and Hydraulic (H&H) stormwater study to identify causes and improvement options.

2.2.2.12 Design roof drainage downpipe connections to the stormwater system so they prevent backflow under peak 100-year rainstorm conditions.

2.2.3 Elevating the Entire Site

If it is not possible to comply with the recommendations in Section 2.2.1, Site Selection, the risk of flooding may be greatly reduced by building up land levels.

2.2.3.1 Build up the entire site so it is above the predicted 0.2% annual exceedance (500-year) flood elevation. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

2.2.3.2 Do not raise the land in areas subject to high or moderate velocity flows (above 7 fps[2 m/s]). If this cannot be avoided, provide erosion protection designed by a qualified engineer.

2.2.3.3 Design fill material to be stable when exposed to flood action, including rapid rise and drawdown, prolonged inundation, scour, and erosion.

2.2.3.4 Ensure the facility and grounds are designed by a qualified registered civil or structural engineer with previous experience in flood-related loading and geotechnical conditions.

2.2.3.5 Ensure the geotechnical properties used for the foundation design (e.g., bearing and frictional resistance, active and passive pressure, and settlement) are based on diminished structural capacities that are associated with flood level and floodwater action.

2.2.3.6 Comply with all of the recommendations in Section 2.2.2, Stormwater Runoff and Terrain Management.

2.2.4 Elevating Individual Buildings and Key Equipment

If it is not possible to comply with the recommendations in Sections 2.2.1, Site Selection, or 2.2.3, Elevating the Entire Site, the risk of flooding to specific buildings and equipment may be greatly reduced by designing them to be above the flood elevation.

2.2.4.1 Design buildings, outside storage areas and equipment (whether owned by the facility or a utility company) to be above the predicted 0.2% annual exceedance (500-year) flood elevation by using raised foundations or elevated structures. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

2.2.4.2 Design foundations, buildings, and outdoor structures to withstand the predicted 0.2% annual exceedance (500-year) flood elevation to resist erosion from high water velocity. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

2.2.4.3 Do not build foundations in areas subject to high or moderate velocity flows (above 7 fps [2 m/s]). If this cannot be avoided, provide erosion protection designed by a qualified engineer.

2.2.4.4 Avoid narrowing, re-routing, or changing the onsite watercourse. If this cannot be avoided, have an engineer specializing in hydraulics ensure the hydraulic capacity or stability of the watercourse is not reduced.

2.2.4.5 Design and build structures to adequately resist all flood-related loads and conditions, including hydrostatic loads, hydrodynamic loads, breaking wave action, debris impact, ice floes, ice and debris jams, rapid rise and drawdown of floodwaters, prolonged inundation, soil liquefaction, soil consolidation and subsistence, sediment deposition, mud slides, and wave-induced and flood-related erosion and scour. Consider long-term erosion over the design life of the structure when determining the effects of flooding on building and foundation design.

2.2.4.6 Ensure design considerations also account for other applicable loads (e.g., gravity and wind) that will act on the structure concurrently with the flood.

2.2.4.7 Consider all appropriate load combinations when analyzing flood loads for actions, including overturning, sliding, undermining (erosion and scour), and uplift (buoyant forces).

2.2.4.8 Use load combinations, load factors, and resistance factors as specified in the governing model codes and standards. Where local codes do not specify load combinations with flood loads, use load combinations from the most recent editions of ASCE 7 or the International Building Code (IBC). However, in no case use flood load factors of less than 1.3 in strength design or 1.0 in allowable stress design.

2.2.4.9 Comply with all of the recommendations in Section 2.2.2, Stormwater Runoff and Terrain Management.

2.2.4.10 Retain a qualified registered civil/structural engineer with previous experience in flood-related loading and flood-related geotechnical conditions to design buildings, structures, and protective works (e.g., flood walls, retaining walls, bulkheads, levees, dams, channels, and diversions).

2.2.5 Lessening Damage for New Buildings Not Built Above Flood Levels

If the recommendations in Sections 2.2.1, 2.2.3, or 2.2.4 cannot be complied with, adhere to the recommendations in this section to lessen the impact of flooding.

2.2.5.1 Ensure the lowest floors of buildings are built at the highest elevation possible. 0.2% annual exceedance (500-year) flood levels aren’t reached during every event, so increasing the building’s lowest floor elevation will reduce the number of flood losses.

2.2.5.2 Use building construction and finish material that will minimize damage and speed cleanup. Use materials that will ensure walls can be easily cleaned, dried, and sanitized. For example, concrete walls will be easier to restore than walls with fiberglass insulation and gypsum wallboard. Ceramic tile floors will suffer less damage than wood floors. Metal and glass doors will suffer less damage than wooden doors.

2.2.5.3 Design exterior walls and building entry points to keep out water as long as possible without relying on any human actions (e.g., closing flood gates). Do not install access that will compromise the integrity (completeness) of the barriers; install ramps or stairways that go over the barriers instead.

2.2.5.4 Comply with all of the recommendations in Section 2.2.2, Stormwater Runoff and Terrain Management.

2.2.6 Lessening Damage for Existing Buildings and Equipment

In order to successfully implement flood mitigation, a series or system of improvement actions must be undertaken to waterproof the perimeter of a site, building, and selected areas within a building or equipment. These actions include closing openings, waterproofing walls, sealing wall penetrations, and installing FM Approved flood abatement pumps, non-return valves, backflow valves, backwater valves, etc. Failing to address every water entry point can lead to flood damage.

A. Site Protection

This concept involves permanent, designed flood defenses along the perimeter of a site using floodwalls, earthen embankments, roadway gates, raised ground, etc., or a combination of each.

Flood pumps should be considered to reduce the likelihood that ponding from rainfall, seepage, or other bodies of water will create a flood risk within the perimeter.

B. Building Protection

This concept involves flood-proofing the exposed perimeter of the building to reduce exposure. The walls, floors, openings, doorways, vents, and penetrations of the building perimeter (including below grade) are addressed using a combination of permanently or temporarily installed flood barriers, flood pumps, backwater valves, and other flood-proofing products. The walls (including below grade) and floors should be non-permeable or improved.

C. Partial Building Protection

This concept involves flood-proofing a portion of a building. This allows water to enter the building, but protects key areas to reduce loss and expedite recovery. It may include protecting an exterior corner of a building along with two internal walls, one external wall, and three interior walls or a room that has only interior walls. There are multiple combinations.

D. Protection of Equipment, Production Lines, and/or Storage

This concept involves flood-proofing specific equipment, production lines, or storage areas. It may include the permanent (preferred) or temporary elevation of equipment above flood levels, or the use of permanent or temporary barriers to protect a given space.

E. Relocation

This concept involves permanently relocating equipment and/or storage to a higher floor, another non-exposed building onsite or offsite.

Mobile equipment and vehicles should not be located in flood-exposed areas.

F. Temporary Perimeter Flood Protection Systems

These systems may be used as part of a design or can be used in an emergency basis. In an emergency, the devices would be placed over ground that hasn't been designed/studied to support the flood loads. Temporary flood protection systems rely on a crew to set up the system as the flood is approaching, thus adding a level of uncertainty.

G. Hybrid Solution

This method involves a mixture of the above concepts to provide a feasible and cost-effective solution.

Figure 2.2.6 shows a representation of the concepts described above. Buildings 1 and 2 and the outdoor equipment area are protected by a designed site protection system. Building 3 is protected by a building protection system. Building 4 shows key areas that utilize partial building protection along with an area with protection of equipment. There is also an outdoor area to the right of Building 3 that demonstrates the protection of equipment for outdoor areas. The offices in Building 4 are shown as relocated to an upper floor and demonstrates the relocation concept. The entire figure demonstrates a hybrid type of solution.

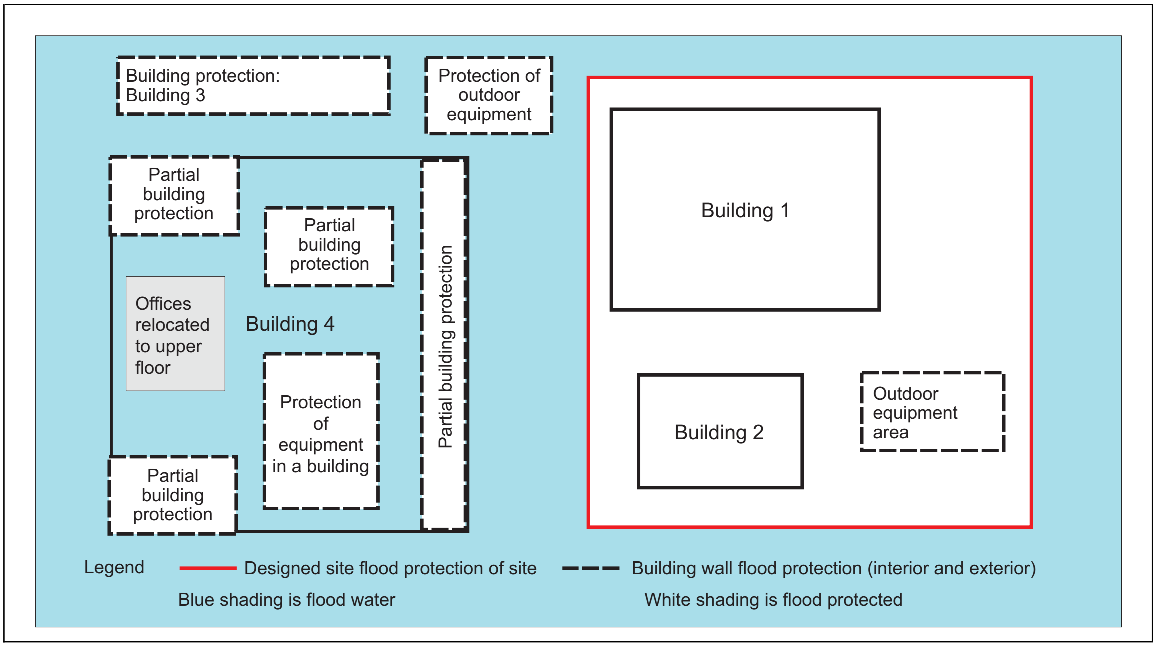


Fig. 2.2.6. Schematic for lessening damage at existing sites using a hybrid solution

2.2.6.1 Permanent Site Flood Protection Systems

This section focuses on permanent flood protection systems, levees, and floodwalls specifically designed for the site. A successful design will address the local flood scenario and requires knowledge of structures, hydrology, hydraulics, interior drainage configuration, soils, and the owner’s technical ability to operate and maintain the system. Site flood protection must form a complete line of protection, surrounding the site or tying into sufficient high ground that it will not be circumvented by flood water upstream or downstream of the site. Interruption to normal site access routes and utility supplies while the flood protection system is in place should be considered in the design. This section is not intended as a design standard, but provides minimum guidelines.

2.2.6.1.1 Clients of FM should submit request for proposal (RFP) specifications and plans to FM well before the let of any contract. The conceptual plan for providing site-level protection should be shared with FM early in the planning stage. This will allow for a common understanding of the flood scenario and appropriate flood control system design, including the site protection as well as stormwater removal, blocking underground conduits for flood water, temporary site access and utility supply.

2.2.6.1.2 Ensure the design is based on an up-to-date flood study that details the flood levels for the 1% annual exceedance (100-year) and 0.2% annual exceedance (500-year) recurrence intervals. The use of the most severe historical flood levels, while useful for the calibration of the detailed study, is discouraged as a design criteria. If such information is not readily available or current, have a hydrology and hydraulics study performed to determine the 1% annual exceedance (100-year) and 0.2% annual exceedance (500-year) water-surface elevations.

2.2.6.1.3 Retain a qualified firm experienced in the design and construction of flood protection systems. Design of the individual flood protection components differs from the “dry” design (e.g., retaining walls) because flood-exposed structures need to include static and dynamic water loads. Care is required to account for changes due to soil properties during flood loading and hydrostatic uplift forces. **Use a minimum factor of safety of 1.5.** Ensure the design incorporates the flood duration and any features needed to minimize the potential for foundation failure. The design should include not only the static hydraulic forces on the wall, but also the momentum dependent upon the expected water velocity, as well as floating debris in the flood water.

2.2.6.1.4 The height of riverine/fluvial systems should preferably be 0.2% annual exceedance (500-year) plus a minimum of 3 ft (0.9 m) of floodwall and levee freeboard or a value as determined by the designer based on the local conditions. Local conditions for assessing the floodwall and levee freeboard should include kinetic energy, super-elevation at bends, uncertainties in the estimated flood level and topographic data, changes in the flood levels during the life of the defense, settlement of the flood defense over its life, and wave action.

Exceptions to the riverine/fluvial 3 ft (0.9 m) floodwall and levee freeboard should be supported by engineering analyses to demonstrate the adequacy of a reduced floodwall and levee freeboard. The analyses should include a review of all the factors affecting the floodwall and levee freeboard requirement under local conditions, and the stability of the levee under flood conditions with regard to wave overtopping and erosion.

2.2.6.1.5 Coastal systems should also be designed for the 0.2% annual exceedance (500-year) water level and to prevent overtopping from associated wave action. The floodwall and levee freeboard should include the design wave or wave run-up (whichever is greater) plus 1 ft (0.3 m). The wave run-up is assumed to include wave setup.

2.2.6.1.6 Ensure the designer uses nationally recognized levee and floodwall standards (see Section 4.2.1). The United State Army Corps of Engineers (USACE) standards or international equivalents are acceptable to establish design criteria. Note that if the entire design configuration includes crediting for structures such as railroad embankments, highways, buildings, walls, and similar features they should be analyzed by the designer and proven to be able to withstand the design flood event.

The design should minimize pedestrian, roadway, or railroad openings that will require deployment of barriers during flooding. Selection of the barrier type should be based on the owner's capability to deploy the barrier prior to the arrival of the flood. In addition, the opening type should be based on the magnitude of the warning time. The opening's foundation should be designed to account for flood loading, seepage, and the closure device loading (see Section 2.2.6.1.3).

2.2.6.1.7 Assemble an written inventory of all water entry points that penetrate the flood protection system and allow water to enter the protected area. This includes storm sewers, sanitary sewers, various utilities conduits, tunnels, and similar penetrations. Flood water entry points should be designed to prevent backflow from the flooding source. Drain lines should be provided with backwater valves. Use the written inventory as part of the flood protection actions implemented prior to the flood.

2.2.6.1.8 Ensure the design includes details related to the flood abatement pumps to remove the rainwater, seepage, and smaller bodies of water that freely flow through the site during non-flood conditions. Reliable power sources and anti-siphon devices should be included in the design. Where possible, FM Approved flood abatement pumps should be provided.

2.2.6.1.9 An operations and maintenance manual that details how the system will be operated during a flood should be provided by the designer. A maintenance schedule for the life of the system should also be provided.

2.2.6.2 Complete and Partial Building Protection

2.2.6.2.1 Hire a structural engineer to review the stability and waterproofing capabilities of buildings walls, floors, and foundations and to identify other water entry points.

Most buildings are not waterproof or are not strong enough to rely on existing walls to keep water out. Two examples are wood-framed buildings and metal panel walls. Buildings of substantial construction, such as reinforced concrete, concrete block, etc. can be used for flood depths lower than 3 ft (0.9 m), often without the need for reinforcing. Flood depths of more than 3 ft (0.9 m) above floor level will subject the ordinary walls and floors to loads that cannot be withstood unless the building was originally designed to do so; providing structural improvements usually is not a cost-effective solution. Additionally, flood depths of more than 3 ft (0.9 m) will increase the likelihood of grade or below-grade floors lifting and buckling due to hydrostatic uplift and may therefore require extensive reinforcing.

2.2.6.2.2 Have all water intrusion points in the floors and walls sealed, including the following:

A. Sanitary systems: Automatic closing devices such as backflow valves on waste water systems should be used. Manual devices can be used, but are not preferred; examples include ball valves, closed gates, and air-filled bladders.

B. Sanitary sewer, combined sewers, storm drains, and floor drains: Automatic closing devices such as backflow valves should be used. Manual devices can be used, but are not preferred; examples include sluice gates, air-filled bladders, etc.

C. Pipe penetrations: Gaps should be permanently sealed with water-resistant materials.

D. Ventilation ductwork and shafts: Ventilation equipment is lightweight and typically can’t withstand the forces developed by flood waters. Ductwork should be rerouted above the flood level, and the remaining openings should be blocked and sealed.

E. Electrical and signaling conduits: Gaps should be permanently sealed with water-resistant materials. This includes penetrations into electrical panels mounted on the wall that may not be apparent without opening the panels.

F. Construction floor and wall joints: Construction joints should be sealed. Walls and floors should be waterproofed to minimize through seepage.

G. Cracks caused by settling, impact, etc.

2.2.6.2.3 Plan for seepage and flood waters to collect in unexpected areas; FM Approved flood abatement pumps should be provided inside the building where walls and barriers are used to keep flood waters from entering the facility. Provide a primary and a backup pump designed to remove a minimum of 50 gpm (190 L/m) in case of seepage or water-pipe leaks. These pumps should be connected to emergency power. Use a certified engineer to estimate seepage rates in order to size the pumps.

2.2.6.2.4 Use FM Approved flood gates, stop logs, etc. for each flood-exposed opening, including doors, windows, air brick/air vent, and garage and loading dock entrances that cannot be permanently sealed. If automatic gates are used, they should be designed to be manually deployable as well. Flood-protection devices should only be installed in buildings that can support the predicted flood loads. The barrier should include 1 to 2 ft (0.3 to 0.6 m) of freeboard where possible. The total height of the barrier should not exceed 3 ft (0.9 m) unless the building can withstand the flood loads. Installation of opening barriers in close proximity to seams between the building floor and the outside sidewalk should be avoided or properly filled so hydrostatic pressure does not introduce a point of entry for water behind the barrier.

Opening barriers listed in the *Approval Guide* will have a leakage rate of not more than 0.08 gal/hr/linear ft (1 L/hr/m). They have not been evaluated for their ability to control coastal high-energy wave action that can occur with hurricanes, typhoons, or cyclones.

2.2.6.2.5 Flood gates can be used in higher velocity areas (flow of greater than 7 fps [2 m/s]) with flood depths up to 3 ft (0.9 m); however, a qualified structural engineer should evaluate the wall’s and gate’s ability to resist the hydrodynamic loads.

2.2.6.2.6 Flood gates, stop logs, etc. should be readily accessible and protected from the elements when stored.

2.2.6.2.7 Flood gates, stop logs, etc., whether permanently installed or for temporary use, should be designed so the facility’s staff can easily install the devices in time to prevent flooding. This installation must be included as part of the FERP. When common storage is used for multiple barriers, ensure the barriers are marked to indicate the proper location for deployment.

2.2.6.2.8 Flood gates, stop logs, etc. and mounting devices should be protected from vehicle damage or theft; concrete bollards may be an option.

2.2.6.2.9 Confirm the following on a regular basis, plus after flooding and prior to predicted flooding.

A. On a monthly basis, confirm the following:

1. The gates are inspected and listed on the inspections forms.
2. The protected openings and gates are well maintained and don’t show signs of damage or housekeeping problems.
3. The openings are kept clear of debris that may impact the barrier’s functionality.
4. The gasket and securement system hasn’t deteriorated.
5. Any new openings that have been added below the predicted flood elevation are properly sealed to withstand pressures during the design event.
6. Flood pumps are properly maintained.

B. On an annual basis, confirm the following:

1. Gate maintenance is adequate (painting, greasing, etc.).
2. Flood gates have been installed, and itemized records kept of these inspections.
3. The gate installation plan is part of the FERP. See Data Sheet 10-1 *Pre-Incident and Emergency Response Planning*.
4. Installation instructions are available.

2.2.6.3 Protection or Relocation of Equipment, Production Lines, and/or Storage

When it is not feasible to provide site perimeter or building protection, consider protecting or relocating equipment, production lines, or storage to reduce the potential flood damage.

2.2.6.3.1 Permanently (preferred) or temporarily elevate key equipment, production lines, or storage above the anticipated flood level. Providing raised floors, platforms, or storage racks is an option.

2.2.6.3.2 Relocate key equipment production lines or storage to upper floors or to a building or site that is not flood-exposed.

2.2.6.3.3 Use protection-in-place strategies when elevation or relocation of equipment, production lines, or storage is not an option. Protection-in-place strategies follow many of the same recommendations as site or building protection recommendations discussed in Sections 2.2.6.1 and 2.2.6.2, but are focused on smaller areas or critical equipment.

2.2.6.4 Temporary Perimeter Flood Protection Systems

The suitability of temporary barriers as part of a design needs to be evaluated with regard to warning time ahead of the flood, deployment time for the barrier, and available staffing to ensure it is deployed in time to prevent flood damage.

Temporary perimeter flood protection systems typically will have leakage rates greater than floodwalls and levees. Temporary perimeter barriers listed in the *Approval Guide* will have a leakage rate of not more than 15 gal/hr/linear ft (186 L/hr/m). The temporary perimeter barrier's Approval testing is conducted on a concrete surface; leakage rates on other surfaces are not part of Approval testing, nor have the systems been evaluated for their ability to control coastal high-energy wave action during hurricanes, typhoons, or cyclones.

2.2.6.4.1 Use FM Approved temporary perimeter barriers.

2.2.6.4.2 Have the temporary perimeter flood protection system designed by a qualified engineering firm. Follow recommendations in Section 2.2.6.1, Permanent Site Flood Protection Systems.

2.2.6.4.3 The time it takes to initiate the flood response, collect materials, gather the response crew, and deploy the protection should be less than half of the warning time determined for the site. If an adequate warning time cannot be provided, formulate an alternative flood protection plan.

2.2.6.4.4 Store temporary perimeter barriers at an accessible location on the site, and protect them against environmental damage and theft.

2.2.6.4.5 Inspect temporary perimeter barriers on a regular basis. Also inspect the temporary barrier installation footprint to ensure changes have not occurred that will render the temporary barriers ineffective or impossible to install.

2.2.6.4.6 Hold annual deployment drills to confirm the system will function as designed.

2.2.6.5 Hybrid Solutions

This concept involves a mixture of the above concepts to provide a feasible and cost-effective solution.

2.3 Occupancy

If the recommendations in Sections 2.2.1, 2.2.2, 2.2.3, or 2.2.4 cannot be complied with, adhere to the recommendations in this section to lessen the impact of flooding.

2.3.1 For each structure, identify areas and floors that are likely to be flooded, and ensure they are used solely for nonessential operations.

2.3.2 Ensure valuable storage is located above the 0.2% annual exceedance (500-year) flood level.

2.3.3 Locate all of the following on floors and in areas above the predicted 0.2% annual exceedance (500-year) flood elevation. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

A. Emergency power equipment

B. Spare parts, motors, and equipment including their controls and supporting equipment.

C. Building, construction and equipment plans, maintenance manuals, etc.

D. The maintenance department and its stores. Undamaged spare parts, maintenance equipment, and hand tools are vital to a quick return to normal operations.

E. Important equipment. If the equipment cannot be relocated to a building that is not flood-exposed, permanently relocate the equipment to mezzanines, platforms, pads or pedestals (plinths) that are above the flood level.

2.3.4 Do not locate any product or equipment that can leak oil, solvent, fuel, etc., in areas that are likely to flood. Doing so may slow the cleanup of the building.

2.3.5 Do not build basements and machinery pits. If they are unavoidable, adhere to the following recommendations:

2.3.5.1 Use noncombustible construction and finish materials that will minimize the damage from water.

2.3.5.2 Seal all piping, wiring, conduit, and penetrations to prevent seepage.

2.3.5.3 Install primary and backup FM Approved flood abatement pumps, with backup power, designed to remove a minimum of 50 gpm (190 L/m), in case of seepage or water-pipe leaks.

2.3.5.4 Do not install equipment vital to production, lighting, heating, or ventilation in this area.

2.3.5.5 Do not place high-value electronic equipment or store critical records in this area.

2.4 Protection

2.4.1 Locate fire pumps, dry-pipe sprinkler system air supplies, gaseous suppression systems, etc., and their associated electrical equipment outside flood-prone areas or above the expected flood level.

2.5 Equipment and Processes

If the recommendations in Sections 2.2.1, 2.2.2, 2.2.3, or 2.2.4 cannot be complied with, adhere to the recommendations in this section to lessen the impact of flooding.

2.5.1 Install process equipment on platforms, pads, or pedestals to be above the predicted 0.2% annual exceedance (500-year) flood elevation. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard. If this is not possible, build a permanent flood barrier around the equipment.

2.5.2 If equipment vital to processes, production lines, or the building's operation is located below the predicted 0.2% annual exceedance (500-year) flood elevation, ensure it is flood-proof if the equipment supports building or process lines expected to remain operational during the flood. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard. Flood-proof electrical equipment is designed for use while being continuously submerged and has an electrical ingress protection (IP) rating of IPX8.

The International Electrotechnical Commission's *International Protection Marking,* IEC standard 60529, lists the categories of protection for mechanical and electrical enclosures from the ingress of body parts, dust, accidental contact, and water. International Protection (IP) listings use the designation "IPXX," with the X's standing for a number that refers to the protection level. The first X is for solids and the second X is for liquid ingress.

Such specialty equipment is custom-built for the application and can be costly, but will prove invaluable if it keeps vital operations in service during a flood.

2.5.3 Provide all structures that may float or experience lateral movement when subjected to flood-related loads with properly designed anchorage to resist the forces of buoyancy, moving water, and wave impact. Structures of concern include storage tanks, silos, bins, sealed conduits and pipes, duct banks, lined pits, and sumps. In addition to protecting the structures themselves, proper anchorage will prevent them from becoming flood-borne debris that could cause damage to surrounding buildings and equipment.

When designing the anchorage, use the conditions that will produce the most severe loads. For example, assume storage tanks are empty when designing tank hold-downs and foundations to resist uplift and overturning, and assume storage tanks are full when designing supports and foundations to resist maximum gravity loads.

Data Sheet 7-88, *Ignitable Liquid Storage Tanks,* Section 2.4, Flood, provides design guidance. This guidance can also be used for tanks storing other liquids or materials.

2.6 Utilities

For locations where the predicted 0.2% annual exceedance (500-year) flood will result in onsite flooding, design onsite utilities as follows:

2.6.1 Ensure all utilities are located above the predicted 0.2% annual exceedance (500-year) flood elevation or are flood resistant. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

2.6.2 Ensure foundations for platforms and plinths used to elevate key equipment (including substations, whether owned by the facility or not) are designed to withstand damage from flooding, including erosion from high-velocity flood water and mechanical impact from floating debris.

2.6.3 Locate climate-control utilities, such as heating, air-conditioning and ventilation (HVAC) systems, chillers, and environmental-control equipment, above the predicted 0.2% annual exceedance (500-year) flood elevation.

Include 1 to 2 ft (0.3 to 0.6 m) of freeboard. Supply these systems from substations that are not exposed to flooding to ensure a controlled environment can be maintained inside a flooded facility to prevent humidity damage.

2.6.4 Design HVAC and utility systems to segregate flood-prone areas from non-flood prone areas.

2.6.5 Locate boilers, their controls and supporting equipment (including blower fans) above the predicted 0.2% annual exceedance (500-year) flood elevation. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

2.7 Electrical

If the recommendations in Sections 2.2.1, 2.2.2, 2.2.3, or 2.2.4 cannot be complied with, adhere to the recommendations in this section to lessen the impact of flooding.

2.7.1 Install electrical equipment above the predicted 0.2% annual exceedance (500-year) flood elevation. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard. This includes all motor control centers (MCCs), distribution panels, switchboards, motors, generators, transformers, communication and control equipment, batteries, battery chargers, uninterrupted power systems (UPSs), electrical outlets, and lighting.

2.7.2 Ensure electrical systems in areas of the facility that are likely to be flooded are isolated from electrical systems in areas that are not.

This will allow the rest of the facility to continue to operate in the event of a flood.

2.7.3 If is not possible to install electrical equipment above the predicted 0.2% annual exceedance (500-year) flood elevation, adhere to the following recommendations:

2.7.3.1 Use electrical equipment that is rated for use while being continuously submerged. Equipment rated for this use has an ingress protection (IP) rating of IPX8.

2.7.3.2 Ensure any cables run below flood level have protected metallic armoring or shields and are designed for use in a wet environment.

2.7.3.3 Protect outdoor, elevated cable runs from high-velocity flood waters that could undermine the cable run support foundations or cause mechanical damage to the cable supports from floating debris.

2.7.3.4 Install water-tight covers over cable trenches to prevent the trenches from being filled with silt and debris carried by flood waters.

2.7.3.5 Locate cable joints and cable terminations above the predicted 0.2% annual exceedance (500-year) flood elevation. Include 1 to 2 ft (0.3 to 0.6 m) of freeboard.

2.7.3.6 Install water sensors and relay devices that will either automatically alarm to a constantly attended location or shut off nonessential electrical devices before flood damage occurs. Have these devices tested as recommended by the manufacturer on an annual basis.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Avoid the Zone

The best way to avoid flooding is to build in areas that are outside the predicted flood footprint and above the predicted 0.2% annual exceedance (500-year) flood elevation, for the following reasons:

A. Flooding is governed by nature and therefore its exact results can be very unpredictable and difficult to model.

B. Flooding is dynamic; flood studies can become outdated due to land development.

C. Flood flows and weather patterns may have changed since the last study.

D. Flood mapping analysis is a complex process often limited by available information and resources.

3.2 Flood Maps and Data

Flood maps provide a static representation of flood exposure and represent the flooding potential at the time the map was developed. Typically, maps will show a high hazard (1% annual exceedance) flood footprint and another less frequent hazard. The available less frequent hazard map varies by country.

The terminology used on flood maps varies by country. In Australia, high hazard flooding also factors in flood depth and velocity. In other parts of the world, the use of base flood elevation or 100-year return frequency in place of the equivalent the 1% annual exceedance is used. Similarly 500-year return frequency is another way of expressing the 0.2% annual exceedance. It is important to understand the terminology of the map or data source before making conclusions on the exposure.

In general, flood maps do not show the more likely events (10% annual exceedance [10-year], 2% annual exceedance [50-year]). Thus, the maps do not show how earlier stages of flooding will start at a facility. A facility may start to flood before it reaches the 1% annual level, resulting in significant flood depths.

The chances of the facility flooding are based on where the floor level is as compared to the flood level associated with the return frequency. Table 3.2 displays the probability of flooding for various return periods.

Table 3.2. Probability of Flooding at Least Once during the Facility's Lifetime

Exposure Level Return Period	*Facility Life (Years)*			
	10	25	50	100
	Flooding Probability			
10 years (10% annual exceedance)	65%	93%	99%	100%
25 years (4% annual exceedance)	34%	64%	87%	98%
50 years (2% annual exceedance)	18%	40%	64%	87%
100 years (1% annual exceedance)	10%	22%	39%	63%
500 years (0.2% annual exceedance)	2%	5%	10%	18%

Other limitations include the following:

A. Frequently, flood losses occur at locations that are not shown to be in a mapped flood zone. Examples not normally covered by a standard flood map include collapse of a road embankment across the floodplain during an event, blockage by debris of a structure diverting floodwaters off the watercourse, diversion of floodwaters via a navigation canal, and faulty operation or failure of a dam.

B. Connections from adjacent flood zones to below-grade areas are not always covered by flood maps.

C. The flood maps may not address smaller bodies of water (e.g., small streams, local drainage ditches, small culverts passing below buildings). Similarly, flood maps do not typically include stormwater (pluvial flooding).

D. Flood defense systems may be shown on flood maps, but the current condition of the flood defense sometimes is not well represented by the maps, which may have been developed years earlier. The system may have reached the end of its designed lifespan or have been poorly maintained. Also, the flood map might not show the increased extent of flooding caused by upstream development, or changes in climate or other environmental factors since the map was developed.

E. Flood maps across the world take various approaches to mapping the flood exposure protected by flood defense systems. Some maps may not take into account flood defenses and show an area as flooding, while some maps will show the same area as not even being flood exposed.

F. As flood maps are developed, the results are checked and compared to historical events whenever good data is available. Frequently, the model assumptions or input data are adjusted so the results will match or closely approximate the historical event. Unfortunately, the historical data almost always covers a short period of time in relation to the frequency intervals being determined. The base historical time period may not be long enough to experience 100- or 500-year return frequency weather patterns expected over 100 or 500 years for the area.

The available flood maps may have been developed based on historical flooding that occurred in the spring when the ground is not frozen. A severe winter rainstorm landing on top of frozen earth will develop runoff almost like rain landing on pavement. A severe thunderstorm after a particularly rainy or heavy snowmelt period results in rainfall onto ground already saturated, causing increased runoff. Such events could generate higher-than-expected flood levels even if the initiating event had a 100-year or 500-year frequency. Factors such as ground saturation level, snow water content, and snow melt rate also reduce the accuracy of flood-forecasting agencies.

3.2.1 Levees Don’t Eliminate the Threat

Building a levee, dike, or floodwall to protect a site is not equivalent to building in areas that are outside the predicted flood footprint. Levees reduce the likelihood of flooding but do not eliminate it. Levees may fail due to poor maintenance, design and construction, unanticipated reasons, or could be overtopped by a flood larger than the design flood elevation. In either case the resultant failure can lead to a greater level of damage due to increased water depths and velocity. Additionally, building a levee system is very costly and requires the following:

- Significant ongoing maintenance.
- A great deal of manual intervention in order to be effective at the time of the flood (e.g., closing gates, operating pumps, etc.).
- Extensive training and emergency planning in order to ensure a successful flood fight.

Levee systems owned by public or private authorities protecting large areas have the same concerns and can be subject to budgetary constraints that force the authority to reduce maintenance and training. The largest drawback of a publicly or privately owned system is that the protected facility is forced to count on others to manage their flood risk.

3.2.2 Site-Specific Flood Studies

If flood maps for a particular area do not exist, are out-of-date, or were developed on a scale that does not adequately address the site’s local factors, an in-depth flood study is required. Hiring a qualified firm to review existing flood maps is sound advice prior to site selection for new facilities, facilities undergoing major renovations, and facilities that have experiences recent close-call flooding events.

Most government flood maps are developed for land planning purposes or government property insurance programs. The maps are developed on a large scale and may not have the accuracy needed at the local or site-specific scale. For example, the United Kingdom Environmental Agency’s flood maps contain the following disclaimer: “This map is for land-use planning. If you are planning a development, you will need to undertake a more detailed flood risk assessment to show how the flood risk to the site, or elsewhere as a result of proposed changes to the site, can be managed as part of your development proposal.”

Governmental maps also may not be updated on a frequent enough basis and may not reflect recent flooding or changes to a body of water or a natural or man-made environment.

3.2.3 Flood Protection Breach Studies

The recent improvements to computer technology and software, and accurate topographic data (such as LiDAR) has made modeling flooding due to levee and floodwall breach analysis possible. Understanding how a potential levee and floodwall breach will affect a site and impact normal business will help a company develop a better strategy to address the flood exposure. Breach studies will help define the warning time available, evacuation plans, the depth of water expected across the property and in buildings, and the water velocity.

3.3 Strategy to Understanding the Flood Potential

In order to determine the correct strategy to address the potential of flooding and its impact on a facility, the flood scenario must be understood. The steps are as follows:

A. Determine which types of flooding expose the site. Sites can be exposed to flooding from more than one source.

B. Determine the expected flood depths.

C. Determine the warning time for flood.

D. Determine the duration of flooding:

1. Consider the impact of long-term flooding as the amount of time flood water remains inside a building. This is a factor in how badly a building and its contents will be damaged.

2. Locations next to large rivers or located in flat flood plains can be impacted longer by standing flood water.

3. Access to the site and transportation routes can be interrupted for extended periods of time.

4. Utilities may be adversely affected longer than the site itself.

E. Determine the property damage and business interruption risks and existing flood mitigation opportunities.

3.4 Understanding Flood Sources and Their Characteristics

Intense rainfall events or melting snow can cause rivers, small streams, lakes, arroyos, etc. to overflow into the surrounding flood plain or cause stormwater flooding.

3.4.1 Flood Sources

3.4.1.1 River Flooding

Rivers and streams are naturally occurring drainage features. Their characteristics vary due to climate, geology, and man-made features and can be altered by redirecting the watercourse or lining the channel with concrete or similar. These can cause changes in river or stream cross sections that change flood elevations and flow patterns. The magnitude and amount of advanced warning of flooding within a river basin is correlated with the size, slope, and duration of the rainfall event relative to the size of the river basin.

3.4.1.2 Dry Stream Bed Flooding (Wadis, Ephemerals, Arroyos, Dry Gulches and Washes)

Typically, these channels drain areas of minimal or sporadic rainfall, which are therefore characterized by rocky, sandy terrain with little vegetation. Flooding that involves dry stream beds will most likely be flash floods associated with heavy, concentrated rainfall. There will be little or no advance warning (few hours at most); high wave fronts; high velocity; high sediment load; possible obstructions at bridges, culverts, etc. causing water to back up; considerable erosion; and short duration.

3.4.1.3 Channel Constrictions

Channel constrictions, such as bridges, culverts, diversion channels, pipes, and sluice ways, can become obstructed by debris or ice carried by flood water.

Types of debris are limitless but include trees, ice, lumber, furniture, process tanks, vehicles, rocks, sheds, concrete pipes, gravel, and coal. In large floods, items that normally are not transported in an annual flood will be carried downstream due to flood waters reaching new areas. A single object, for example an uprooted tree caught in a constriction, can collect smaller debris. When enough debris is gathered, flood waters will back up until relieved. It is not uncommon for debris dams to impound large volumes of water that are suddenly released, causing flood volumes and elevations greatly above the expected flood level.

Relief can occur with breakout flow, which results in flood exposures to sites or buildings not previously exposed. Consequently, some locations identified as not exposed, or exposed at an infrequent recurrence with unconstricted flow in the main channel, would then experience flooding at a higher frequency than anticipated. A bridge choked by debris or ice can cause an upstream levee to be overtopped.

Typical government flood profiles are computed under the assumption that bridges and culverts are unobstructed; 100% open and clear. Depending on the characteristics of the stream, full or partial obstruction of these constrictions can occur. The obstruction alters the flood profile by causing the water surface to rise above the unobstructed flood profile and it might cause breakout flow that conveys flood waters outside of the unobstructed constriction.

Some rivers have an annual issue with ice jamming. Ice jams can be classified into six categories: freeze-up ice jams; break-up ice jams; moving ice jams; stationary ice jams; floating ice jams; and grounded ice jams. Only break-up ice jams result in significant flooding.

Break-up ice jams are frequently associated with rapid rises in river stage, resulting from rainfall and/or snowmelt, and usually occur in the late winter or early spring. Because of the large volume of ice that may be involved and the greater discharges from rain or snowmelt, break-up ice jams can cause flooding of a magnitude similar to, or in excess of, the 100- and 500-year flood.

Ice jam flooding will normally be characterized by several hours to several days' advance notice; rapid rise once the obstruction has occurred; duration dependent upon the weather and emergency action (using explosives to dislodge the ice); low velocity; low sediment loading; impact and push damage from heavy floating ice plates and blocks; and slight erosion hazard.

As the temperature increases or the ice jam is impacted, it may break free, float, and jam again as it impacts other ice, a bridge, etc. or it may break up into large floating plates and blocks. The backed-up water will be released as the jam breaks free, creating a fast moving surge of water. The water surge and the accompanying large pieces of ice can cause increased physical damage to property. While the presence of an ice jam can be monitored, the location, time, and magnitude of release and associated results may be difficult to predict. The effects of ice jam flooding can be much more severe than warm water flooding of the same stream to the same level.

3.4.1.4 Flood Control Dams

Most flood-control dams are constructed in conjunction with a reservoir. Flooding downstream is reduced as water is retained behind the dam. Discharge through the dam is restricted, and resultant downstream flows and flood levels are reduced. In many cases, the published 100-year, 500-year, etc. flood levels consider the many effects of the upstream flood structure and reservoir. Items factored into the flood projections include the duration of the rainfall event, the capacity of the reservoir and its assumed water level at the time of the event, the location of the rainstorm in the watershed, and the effect of other dams and reservoirs.

While a flood-control project upstream may serve to reduce the extent of flooding from a specified design event or scenario, it is still possible that downstream flooding may result from a different scenario. For example, a flood-control dam located 100 miles (161 km) upstream of a site on a moderate-sized river may be designed to provide protection against a regional rainstorm event. However, a very intense, slow moving, localized rainfall event centered downstream of the dam could cause flooding similar in magnitude to the flood the dam was designed to limit (different storm position and intensity; different scenario; same flood level).

Changes to the flood-control systems in a watershed after a study or map is completed can affect the expected flood levels. Flood-control dams are built to a design frequency based on economic feasibility. Some flood-control dams may be built to the 50-year event, while others may be built to the 100-year event or greater. However, a dam built to the 100-year event in 1950 may not contain the 100-year event today due to changes in the watershed since 1950. Local authorities may be aware of the design frequency of the flood-control dam but may not be aware that changes in the watershed may have reduced the effectiveness of the dam.

3.4.1.5 Interior Drainage Flooding Behind Flood Protection

Flooding may occur in a “protected” floodplain even though the main levee, floodwall, or sea wall is not breached or overtopped. Flooding can be caused by rain, interior streams, or from seepage under the levee or sea wall.

3.4.1.6 Coastal Flooding

Coastal flooding is the result of increased sea levels caused by storm force winds. Coastal flooding is usually caused by large ocean storms. Wide and gently sloping continental shelves produce higher storm surges than narrow, steep continental shelves. Normal sea levels will increase and wind will generate waves. Sheltered harbors and bays often have smaller waves. The storm force winds also push water inland across normally dry areas. Coastal storms can create flood levels from 15 to 30 ft (4.6 to 9.1 m) or more above high tide.

Coastal storms can also cause inland flooding. As a storm moves inland, it usually reduces in strength since it is no longer being powered by the rising warm, moist ocean air. When this occurs, the remaining storm will release intense rain over the inland area. This intense rain may lead to severe inland river or stormwater flooding.

3.4.1.7 Alluvial Fan Flooding

Alluvial fans are located at the base of steep-sloped mountainous areas. Often they are located in areas that typically receive very little rainfall. When a major storm occurs, alluvial flooding is sudden and severe and may affect small or large areas.

On these very flat flood plains, the flow tends to be at high velocity, undergoes unpredictable changes in direction, and carries large amounts of sediment. The soils found on alluvial fans tend to be easily eroded and highly porous.

3.4.1.8 Seiche Flooding

A seiche is an oscillation of the water in a lake, sea, or bay caused by seismic disturbances, winds, waves, or abrupt, unusual changes in atmospheric pressure. Large storms with unusually low pressure and high winds can cause water elevation differences of several feet (meters) from one side of a lake to another. The elevation of the water surface coupled with wind-driven waves causes coastal areas to flood and tributary rivers to back up and overflow their banks.

3.4.1.9 Stormwater Flooding

Natural terrain or insufficient drainage design can cause flooding. Stormwater flooding can be classified into three categories: surcharged drainage systems, ponding, and sheet flow.

In many parts of the world, underground drainage is not designed for severe rainstorms. During unusually heavy rainfall, the lack of drainage capability may cause water to back up and enter buildings if not considered during the design. Unfortunately, typical urban drainage systems are sized to handle at most the 25-year storm. Due to the lack of capacity, onsite stormwater runoff may require the use of retention or detention basins to safely handle the 100-year stormwater run-off.

3.4.1.10 Groundwater

The groundwater level is governed by adjacent rivers, lakes, and streams. Depending on the soil conditions, the groundwater level will respond to changes in adjacent water body levels. Usually, this response is slow. However, for long-duration flood events, the groundwater table might affect building basements.

3.4.1.11 Tsunamis

Tsunamis are usually caused by undersea earthquakes. The earthquake causes a displacement of the earth’s crust at the bottom of the ocean. Although they are rare events, tsunamis can reach heights of from 30 to 50 ft (9 to 15 m) as they approach the coast at more than 500 mph (805 km/h).

3.4.1.12 Combined Sewer Systems

Combined sewer system are not always able to handle increased flows during heavy rainfall or flooding. As a result, the system will back up and flow out of manhole covers, drainage inlets, toilets, floor drains, and sinks. Because the water is dirty, the cleanup is complicated due to contaminates.

3.4.1.13 Roof Drainage Flooding

This is localized flooding due to roof drains and downspouts emptying on ground or paved surfaces that don't drain away from a building. See Data Sheet 1-54, *Roof Loads and Drainage.*

3.4.2 Flood Characteristics

Table 3.4.2 gives some general characteristics of the major types of flooding.

Table 3.4.2. Flood Types and Characteristics

Flood Type	*Depth*	*Velocity*	*Warning Time*	*Duration*	*Flow Paths/ Drainage*
Large, long rivers	Varies widely, governed by valley shape; levee-protected areas can be deep.	Low: velocity not expected to increase damage.	Up to 2 weeks or more	Days or weeks	Overbank
Smaller sized rivers	Varies widely, governed by valley shape; levee-protected areas can be deep.	High in steep areas; velocity damage possible. Low in flat areas. Low in ponding areas.	Short; very short in steep-sloped areas	Short: less than 1 day to several days. Flash flood in steep areas: <3 hours.	Overbank
Dry stream beds	High wave fronts; backup at obstructions.	High; velocity damage possible.	Short (few hours at most)	Short: less than 1 day to several days	Flash flooding
Interior drainage behind flood protection	Low level: <3 ft (1 m).	Low; velocity not expected to increase damage.	Short, but varies by flood type	Longer: Varies by flood type	1. Rain or interior streams; 2. seepage under levee or sea wall
Coastal	From 15 to 30 ft (5 to 10 m) or more above high tide	High near coastline; velocity damage possible.	Storm formation: up to 1 week; action stage for facility 2 to 3 days prior to landfall; 1 day out evacuation may be ordered	Short: hours	Ocean water pushed onto land
Alluvial Fan	High level: <3 ft (1 m).	High; velocity damage possible.	Short: <3 hours	Short: <3 hours	Onto base of steep-sloped mountains
Seiche	Several feet (meters).	High; velocity damage possible.	Short: hours	Short: hours	From water oscillation in a lake, sea, bay
Stormwater	Low level: <1 ft (0.3 m) except for below grade spaces.	Potentially high for steep slopes; low for ponding areas.	Short: minutes to 1 hour	Short: minutes to 1 hour	Surcharged drainage systems, ponding, and sheet flow
Groundwater	Low level: <1 ft (0.3 m).	Low; velocity not expected to increase damage.	Long: 1 day to days	Long: 1 day to days	From adjacent rivers, lakes, and streams
Sewer systems	Typically low level: <1 ft (0.3 m).	Low; velocity not expected to increase damage.	Short: minutes to 1 hour	Short: minutes to 1 hour	Flow out of toilets, floor drains, and sinks

3.5 Understanding the Flood Impact

Critical facility assets should be inventoried and the impact of flood considered. In addition to building damage, items to consider include equipment that, once damaged, will cause a bottleneck in resuming operations; information systems; long lead-time equipment; switch gear; and electrical feeds.

Flood damage to fire protection equipment presents a number of significant issues. Flood water often carries heavy debris that can rupture ignitable liquid tanks and damage ignitable liquid and flammable gas piping. Electrical short circuits and other ignition sources are available to start a fire. Once a fire starts, the local fire service may not be able to reach the fire due to flooding. The automatic sprinkler and fire pumps may also be damaged. Therefore, always locate automatic sprinkler valves and pumps outside flood-prone areas.

The impact to utility services should be understood. Be aware of underground substations, equipment, and transformer vaults. Water service, sewage and disposal, electrical service (generation, transmission and distribution), telecommunication, natural gas service, refrigeration, steam, etc. may be affected.

Access to the site may be restricted or closed even if the site is unaffected. Normal supply routes, including highways and railroads, may be closed due to flooding for extended periods of time.

3.6 Understanding All Possible Solutions; Building or Retrofitting in a Flood Prone Area: A Strategy is Needed

This data sheet addresses a wide variety of physical solutions to reduce the severity of flooding to a facility when building in these areas can't be avoided. Human element solutions (those that require humans to respond during flooding) should only be relied upon after all practical physical solutions have been incorporated into the design.

A carefully planned strategy has to be developed and executed during the project's design and construction phases in order to minimize the damage flooding will cause. The ultimate strategy is to ensure that as much of the facility can continue operating without pause during flooding.

There are many concepts that can be used to help reduce flood damage and downtime. The logical options in order of reliability are:

A. Designing the facility to be constructed outside of any flood hazard (new construction) or permanently relocating the existing facility.

B. Raising the site above the 0.2% annual exceedance (500-year) level (new construction).

C. Building permanent 0.2% annual exceedance (500-year) flood defenses around the site.

D. Protecting a portion of the site's critical assets by raising above or protecting to 0.2% annual exceedance (500-year) standards (e.g., building low-level earthen embankments or flood walls, landscaping, and walls to redirect stormwater and sheet flow away from important areas).

E. Deploying emergency devices and emergency response plans until permanent solutions are made. This can include relocation of equipment and production lines to areas higher than the flood. See Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*.

F. Developing plans to make up production while the site is repaired.

If achieving the 0.2% annual exceedance (500-year) standard is not feasible or cost-effective, the 100-year should be considered instead. When deciding on the best strategy, the likelihood of flooding, expected damage, and insurance costs, impact on public image and customers during the lifetime of the site should also be considered.

One of the drawbacks to elevating the entire site outside of the flood hazard is that it can be expensive and not always practicable. When elevating the entire site is not possible, it then becomes necessary to determine which buildings and areas of the facility are likely to be flooded and focus on minimizing the impact the flooding would have to the lower areas, both in terms of physical damage and interruption to business.

Often the most effective flood mitigation approach is a combination of approaches. Proper design of the buildings that will potentially be flooded is required to keep damage to a minimum. Shallow flood waters that fill basements seldom damage the basic structure or the floor above. Structural damage becomes a possibility when deep waters rise up to the first story walls. Wall damage at grade and below level floor does not normally occur when water rises equally both inside and outside, as the forces are hydrostatically balanced.

However, waters rising on the outside only can quickly over-stress a wall and floors at grade or below and cause its collapse or uplift. A rise of several feet of water against one side of an unreinforced brick or concrete block wall is cause for concern.

One of the most important steps ensuring flood damage is minimized after the flood has receded from buildings is to quickly clean up the damage the flood has created. In order to accomplish a fast cleanup, power, heating, and air conditioning has to be restored quickly.

Therefore, when designing the location or selecting equipment for power and HVAC systems, consider the following:

A. Electrical equipment, particularly dry-type transformers, high-voltage air circuit breakers, and modern control equipment that uses semi-conductor circuitry are highly susceptible to water damage.

B. Boilers, furnaces, and ovens will sustain extensive damage. If flood waters rise while the unit is firing or still hot, the unit is susceptible to considerable permanent deflection. Fine silt will penetrate combustion, air, and gaseous fuel piping as well as burner assemblies.

C. Tanks can sustain major damage. Below-floor along with elevated tanks may be hydrostatically damaging the tank, building floor and surrounding equipment. Storage tanks may also move and fill, and supply or vent lines may break. Released contents may contaminate other areas.

D. Equipment located outside, although adequately weather resistant, is susceptible to the same damage as equipment located indoors. Weather protection is usually not sufficiently tight enough to keep out flood water. Velocities of greater than 7 fps (0.2 m/s) will knock over outside equipment that hasn't been specifically designed to resist the force of moving flood water.

Basements flood more often due to the fact they are lower in elevation. Key electrical, process, and analytical equipment is often located in basements and minor flooding events involving the basement has caused large property damage and long closure of facilities or production lines.

3.6.1 Freeboard is a Key Design Consideration

Including freeboard in the design criteria helps minimize damage from unforeseen changes over a site's lifetime. It ensures that uncertainties and changes do not compromise the protection standard, maintaining consistent risk levels over time.

The allocation of freeboard is integral to the design of flood protection. It refers to the additional height above the predicted flood level to which structures are built for mitigating the impact of uncertainties and flow conditions.

For example, the estimated peak design flows—one of the many inputs to a flood map model—have an uncertainty (or confidence interval) associated with them. The upper confidence flow value translates into a higher flood level. The freeboard is intended to contain that higher flood level.

Table 3.6.1 summarizes the freeboard recommended in Section 2.0 of this data sheet. It also indicates which freeboard components to consider based on flood type.

Table 3.6.1. Summary of Recommended Freeboard in Section

Exposure/ Site	Standard of Protection (Years)	Minimum Freeboard ft (m)	*Freeboard Components to consider*												
			Riverine Flooding						Apply to Both			Coastal Flooding			
			Uncertainty Design Flow	Accuracy of Flood Model	Blockage by Debris	Channel Conditions	Kinetic Energy	Urbanization	Settlement of Flood Protection	Climate Change	Wear & Tear	Uncertainty of Still Water Level	Wave Height	Wave Set-up	Wave Runup
SITE															
New Construction	500	1-2 (0.3-0.6)	X	X	X	X	X	X		X		X	X	X	X
Elevating Site	500	1-2 (0.3-0.6)	X	X	X	X		X		X		X	X	X	X
Elevating Building	500	1-2 (0.3-0.6)	X	X	X	X		X		X		X	X	X	X
SITE PROTECTION															
Stormwater	100	0.5 (0.15)	X	X	X			X		X					
Permanent Flood Protection - Riverine/ Fluvial	500	3 (0.9)	X	X	X	X	X	X	X	X	X				
Coastal Flooding Elevation and Flood Depths	500	1-2 (0.3-0.6)							X	X	X	X	X	X	X

The recommended starting level of freeboard is 1-2 ft (0.3-0.6 m). Stormwater uses less freeboard, 0.5 ft (0.15 m), as uncertainty of flood depths is less severe. Riverine/fluvial uses 3 ft (0.9 m), as failure of a flood wall, levee, etc. will lead to large flood depth, severe damage to building, equipment and supplies, and significant operational disruption.

Apply a minimum of 2.0 ft (0.6m) where any of the following critical factors apply:

A. Susceptibility of the building to damage. Occupancies that can't tolerate any water in or near the building should use more freeboard. Examples of highly susceptible occupancies include hospitals, pharmaceutical operations and locations with clean rooms.

B. Areas with frequent flooding approaching or exceeding the regulatory flood level (e.g., design levels inaccurate based on short record or in need of an update).

C. Areas for which the flood maps and studies are older than 10 years.

D. Areas in which upstream development of vacant land has drastically increased (or is projected to increase) since the last flood map was developed.

E. Water levels previously affected by debris blockage, landslides or incorrect operation of hydraulic structures.

3.6.1.1 Riverine Freeboard

Riverine freeboard usually includes increased flood level due to:

- Uncertainty in flow
- Flood modeling inaccuracy (model does not precisely replicate real world)
- Flow velocity (kinetic energy) and the presence of waves that increase flow levels and increase scouring potential.
- Standing and wind waves, including those generated by the passage of vehicles during flood events that splash against the protection.
- Blockage by debris (usually at inlets, bridges/culverts and constrictions). The amount of debris generally increases when the interval between large events allows for the growth of vegetation into the floodplain
- Manmade (e.g., channel improvements/restrictions, weir/dams) and natural (siltation/erosion) changes to the watercourse
- Increased runoff due to urbanization or climate change. Urbanization increases the amount of pervious/low-infiltration area in the watershed, thus increasing the runoff produced by rainfall. For example, in the United Kingdom, studies predict a 20% flood peak increase by 2100 from the impact of climate change over the lifetime of the site. Similar increases are expected in other countries.
- Settlement of the protection (levee, wall, etc.), natural aging processes and operational stresses (e.g. levee). Settlement of flood protection is to be expected if built on poor foundation or foundation that has not been properly compacted. Levees built on compressible foundation will settle. Proper design should include an additional height increase to account for this progression. Operational stress due to traffic and passage can locally reduce the freeboard if adequate maintenance is not provided.

3.6.1.2 Coastal Freeboard

The major components in the uncertainty of protection level needed for coastal exposure include development of the design flood elevation reached and settlement to the site's land, building, equipment and flood protection. The design flood elevation in coastal areas should include the following:

- Still water level: the rise in the water surface above normal water level on the open coast due to wind stress and atmospheric pressure on the water surface.
- Wave set-up: the local increase of still water level due to breaking of waves against the seawall/key/wall.

- Wave run-up: the maximum height waves reach as they move up the slope of a beach, a seawall or wall when they break against it.

Overtopping will occur when any of the above exceeds the height of the seawall/dike or building finished floor.

Sea walls utilize both design shape and materials (blocks, boulders, interlocking tetrapods, etc.) to counter or reduce overtopping.

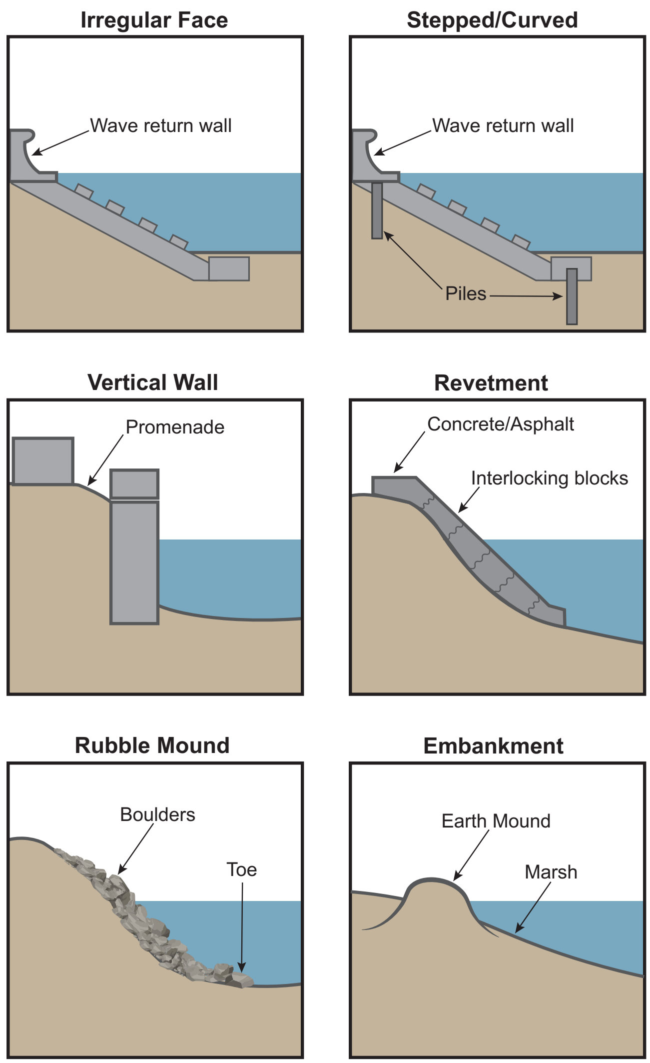


Fig. 3.6.1.2. Methods used to reduce overtopping coastal

3.6.1.3 Stormwater Freeboard

Stormwater freeboard is complex due to the interaction between the drainage pipe system and the overland runoff component. Drainage design often includes overland flow and water storage in retention or detention basins. Rainfall intensity and changes to upstream and downstream development are also factors.

Often, the inundation is limited to ponding from backflow; as the rainfall runoff exceeds the capacity of drainage system. When the drainage system capacity is exceeded, the water ponds until the ponding reaches a relief point; and then a new overland flow path is established.

Establishing the correct freeboard requirement will reduce the likelihood of building, outdoor equipment or storage damage, or interruption to operations. Establishing the correct amount of freeboard should consider the uncertainty in rainfall, reduction of pipe capacity due to lack of maintenance, blockage of entry points to the pipe system, and changes to upstream and downstream development.

3.7 Selecting Flood Mitigation Solutions

3.7.1 Suitable Solution Factors

The solution(s) used to reduce or eliminate a flood exposure will be based on the flood scenario, consequences, solution factors and regular maintenance. Other factors that can be part of the decision-making include preparing for larger rainfall events or flood events that exceed the defined mapped flood hazard zones. Flooding scenarios and the consequences of operations are site-specific and may vary from building to building.

Once the flood scenario is understood, see Sections 3.3 and 3.4. The evaluation of suitable solutions will involve consideration of the solution's strengths and weaknesses and weighing the impact on the facility's normal operations. See Figure 3.7.1.

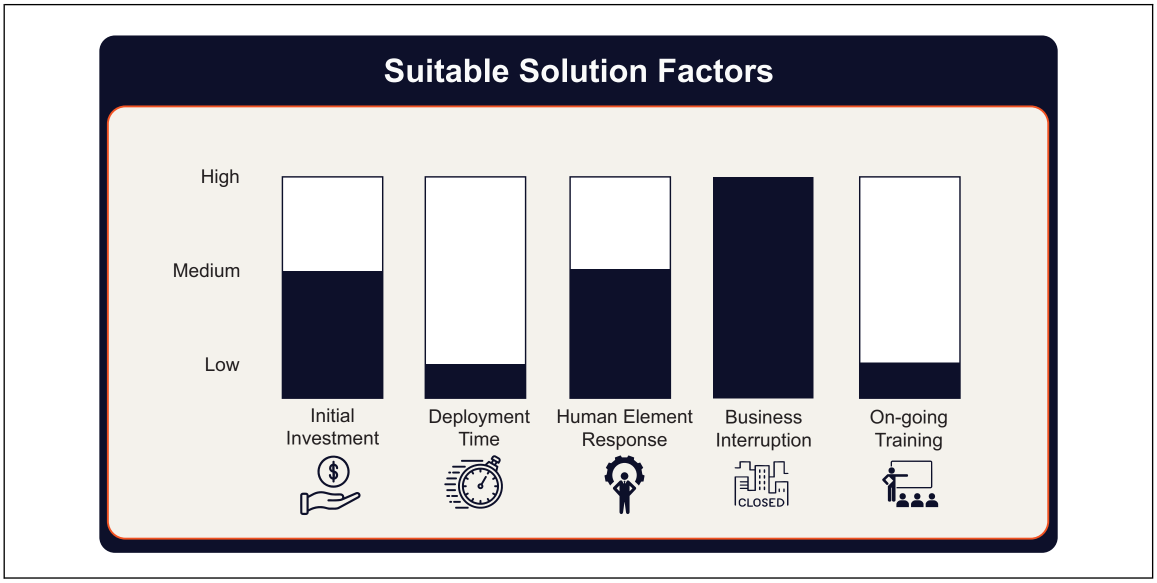


Fig. 3.7.1. An example of weighting the impact of a solution

Initial Investment Cost

This cost includes:

- Purchasing the solution
- Engineering design work
- Physical changes to the site where the device will be temporarily deployed or permanently installed
- Obtaining equipment needed to temporarily deploy the device
- Initial testing
- Providing secure storage areas, etc.

Flood protection solutions can be subject to theft or damage, and the storage design should account for this.

Business Interruption

Deployment of flood protection devices may reduce or eliminate access to the facility and could lead to curtailment or reduction of operations.

Levees and floodwalls require space to build and may change vehicle and pedestrian traffic patterns. Alternative ingress/egress will be needed. If this access is not available, the impact on business needs to be considered.

Temporary protection must be deployed in advance of the flooding. Temporary protection for building openings, such as flood logs to close pedestrian doors, may require the building to remain unoccupied due to fire codes. Deploying air vents or protection for material handling openings may result in reduced operations.

Automatic devices, including automatically-deployed barriers and pedestrian flood doors, will reduce the impact on business interruption during the flood preparation stage.

Another option is the use of permanently-installed flood protection devices that require no action to activate. Examples are floodwalls without openings, window glazing, curbing and elevating equipment.

Deployment Time

Devices deployed during flooding must be deployable within the lead time provided by available weather and flood warning systems. The assembly times should be significantly shorter than the flood warning time.

Deployment time of barriers varies based upon site conditions and the type and size of barriers. Consult with the manufacturer during the selection process about estimated deployment times. Once on site, conduct regular drills to determine actual deployment times.

Additional time should be factored into the deployment schedule to account for unforeseen delays related to staffing or logistical challenges. Deployment time includes transporting the equipment to the flood-prone area, preparing the site, mobilizing the installation crew and installing the device.

Human Element Response

Flood protection devices often require installation by facility staff or contractors. Key factors for successful deployment include the required skill sets, crew size, work hours, and planning for staffing during holidays or outside normal operating hours. Adequately skilled staff must be available to deploy the equipment 24/7/365 or be recalled to the site. The facility must develop and update the FERP as staffing levels change. These considerations should be addressed in advance to ensure a successful outcome.

Ongoing Training

Since flood protection devices are not installed regularly, annual training is essential to ensure the installation crew can deploy them successfully. Additional training should also be provided for new crew members as staffing changes occur.

3.7.2 Types of Flood Protection Solutions

Flood protection solutions are numerous. The best solution is to not have any parts of the facility in a flood exposed area. However, for existing sites, the solutions can involve all or parts of the following:

- Relocating equipment to a higher floor or building outside the flood zone
- Raising equipment permanently above the flood level on concrete or metal structures
- Building floodwalls, curbs, elevation of access points, window glazing
- Eliminating unnecessary openings that will allow flood waters to enter a protected area. Examples of unnecessary openings include windows, basement windows, unnecessary doors, intake/exhaust vents and pipe penetrations.
- Installing flood mitigation valves to prevent backflow of flood waters
- Sealing cracks in walls and floors
- Waterproofing of walls
- Installing automatically deployed devices
- Installing provisions that will reduce deployment time of temporary protection. Examples include mounting channels for flood logs, drop-in panels, and standpipes for flood pumps

- Adding markings or signage to clearly indicate what protection device is to be installed at a given location
- Using solutions that are deployed during flooding. These solutions should only be relied on after all other practical solutions have been incorporated into the design

  - Deploying building opening protection
  - Installing temporary perimeter barrier protection that is deployed away from the building
  - Installing flood protection for key interior rooms or areas
  - Installing flood protection around indoor or outdoor equipment
  - Using penetration sealing devices
  - Using flood pumps
  - Using FM Approved flood mitigation solutions when available

The solution employed will include many of the above. For example, protection of a building can include barrier protection for openings, eliminating excess openings, sealing cracks and penetration in walls and floors, and providing flood pumps. Whenever possible, all unnecessary openings that will allow flood water to enter a building should be eliminated. For the remaining openings, flood barriers can be used in conjunction with other cost-effective improvements to reduce the likelihood that large amounts of water will penetrate the building envelope.

If preventing water from entering the building is impractical, limiting damage by constructing interior protection is still possible. For example, construction of flood protection walls around manufacturing or equipment areas and key interior rooms can be a cost-effective way to reduce flood damage. Another method is to waterproof and strengthen existing partitions and to equip openings around vital mechanical equipment (such as furnaces, boilers, computers and electrical switchgear) with flood gates. The goal of this guidance is to limit the amount of water that will penetrate and collect in the building's interior to a few inches (centimeters) in depth. Facilities that cannot tolerate any water penetration should be relocated to another area. Critical occupancies should be raised above the predicted 0.2% annual exceedance (500-year) flood elevation and should include freeboard.

3.7.3 Advance-Installed Flood Solutions

This section is intended to highlight flood mitigation solutions that provide reliable protection without any automatic or manual action. These solutions are permanently installed well in advance of the flooding event.

3.7.3.1 Levees and Floodwalls – Advance-Installed Flood Solution

Levees reduce the likelihood of flooding but do not eliminate it. Levees require extensive ongoing maintenance, and proper design and construction. Often this protection system includes components that require manual intervention to be effective at the time of the flood (e.g., closing gates, operating pumps, etc.).

Ease of operation and training needed:

A. Complex systems if gates and openings exist

B. Significant training needed

C. Periodic inspections needed to ensure changes have not occurred that defeat protection

3.7.3.2 Curbing – Advance-Installed Flood Solution

An effective means to limit surface water from entering a building is to elevate the curbing adjacent to the roadway surface. This design helps direct surface water to storm drains for removal from the site. Careful design is needed to eliminate or reduce trip hazards.

Ease of operation and training needed: None needed. Perform periodic inspections to ensure changes have not occurred that defeat protection.

3.7.3.3 Elevation of Access Points – Advance-Installed Flood Solution

Similar to the benefit of installing/increasing the heights of curbing, an elevated ramp or stair landing eliminates the flood water flow paths.

Ease of operation and training needed: None needed. Perform periodic inspections to ensure changes have not occurred that defeat protection.

3.7.3.4 Elevation of Critical Equipment – Advance-Installed Flood Solution

Where possible, elevation of critical equipment above that of the designed storm hazard (plus freeboard) will help preserve availability of the equipment during an event. Ancillary equipment also should be raised.

Deployment time: Once installed, no additional effort is needed.

3.7.3.5 Flood Glazing – Advance-Installed Flood Solution

Flood glazing window systems allow visibility in and out of the protected space with the added benefit of resistance to flood water and impacts from floating debris. Common designs offer different configurations of uninterrupted viewing area, or repeating glass panes separated by support mullions. These products are installed at the point of use and do not require additional effort to deploy once installed.

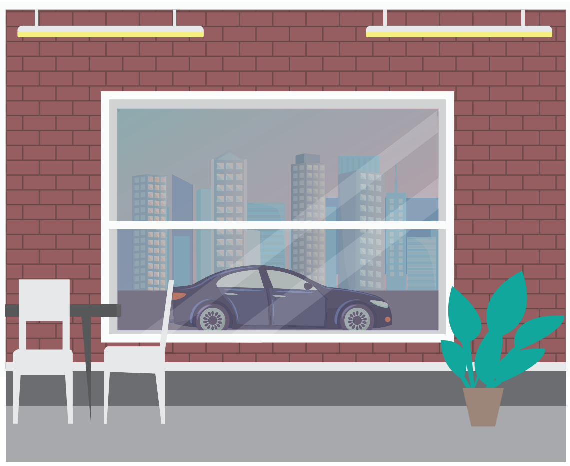


Fig. 3.7.3.5. Window glazing in a building

Ease of operation and training needed:

A. Periodic inspection of installation to ensure that the glass sections are not damaged and that no evidence of seal failure exists.

B. Installation is available for exterior walls or internal applications (i.e., elevator enclosures).

Deployment time: Once installed, no additional effort is needed.

3.7.4 Building - Opening Barriers - Advance-Installed Flood Solutions

A flood mitigation barrier that is permanently mounted to the opening and can be rapidly deployed is a good solution if openings cannot be eliminated. For opening barriers to be effective, the wall construction must be watertight and strong enough to support water pressures to the intended flood protection height. Ideally, the barrier should be designed to allow an untrained person to close it. Another advantage of permanently mounted barriers is their reduced risk of being stolen or misplaced.

Deployment time of barriers varies based upon site conditions, type, and size of barriers. Consult with the manufacturer on estimated deployment times during the selection process. Once on site, conduct regular drills to confirm actual deployment times allow for completion within advance warning timeframes.

3.7.4.1 Pop-Up Flood Mitigation Barriers and Gates – Automatic Deployment

An automatic flood barrier can be installed in an existing doorway. In stowed position, this barrier type allows for normal access to the room. The flow of floodwater to the barrier will cause it to automatically deploy. Use of this barrier eliminates the need for curbing at the opening. Installation requires removal of a floor section and pouring of a foundation to install the barrier

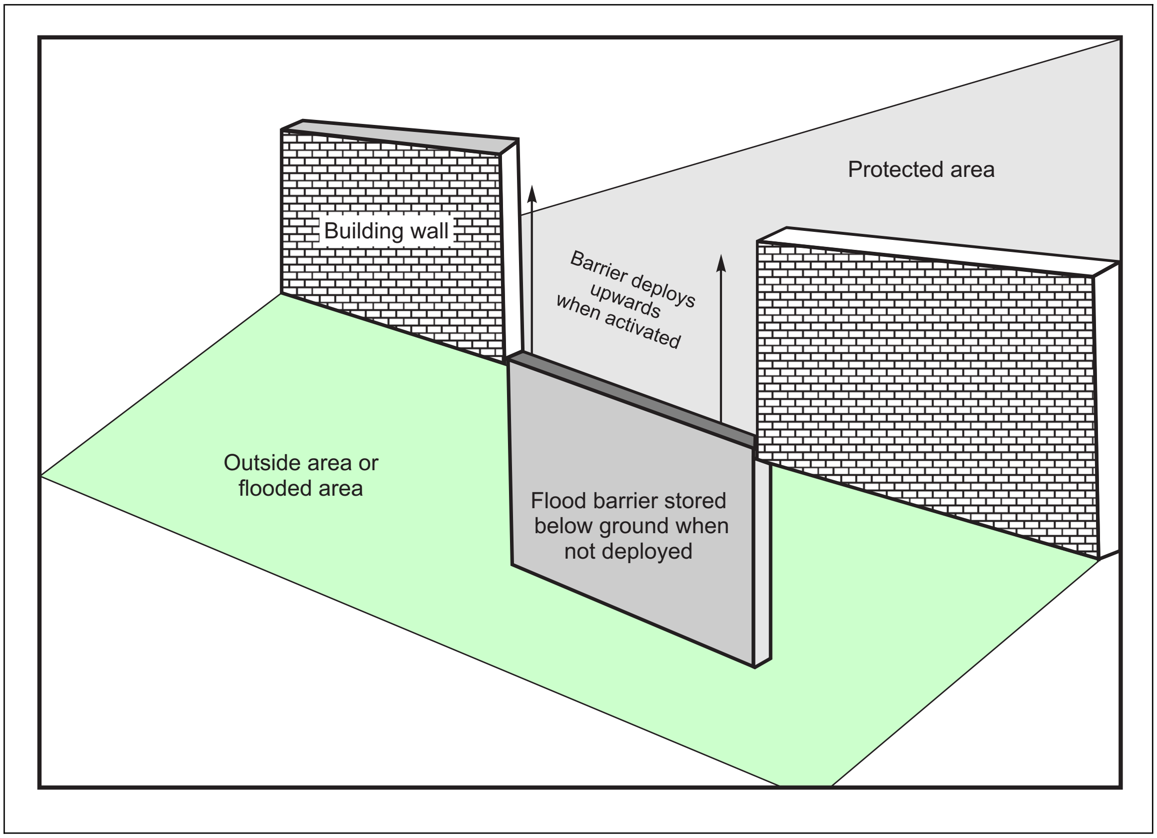


Fig. 3.7.4.1. Automatic flood barrier

Ease of operation and training needed:

A. Fully automatic operation

B. Designs should allow for manual deployment for inspection and maintenance or flood protection.

C. Can be installed either inside or outside of exterior doors.

D. Must be kept free of debris to allow for proper operation.

Deployment time: Automatic or opens manually within minutes.

3.7.4.2 Single or Double Pedestrian Doors - Automatic or Time of Use Manual Deployment

These doors are designed to function as normal pedestrian doors when no flood exists. To prevent impact damage from water-conveyed debris, the doors are metal. Some doors have additional latches that must be closed as the flood approaches.

Ease of operation and training needed:

A. Fully automatic operation or with simple closing latches

B. Must be kept free of debris to allow for proper operation.

Deployment time: Closure of flood doors can be completed in minutes.

Fig. 3.7.4.2-1. Personal flood door inside – this door has additional vertical latches that must be manually deployed

Fig. 3.7.4.2-2. Personal flood door exterior – this door does not have additional latches to close

3.7.4.3 Hinged/Pivot/Swing Gates – Time of Use Manual Deployment

These gates are permanently in place and shut by swinging the barrier closed. Some barriers are hinged to walls like doors; other barriers are hinged to the floor and rotate into place when deployed.

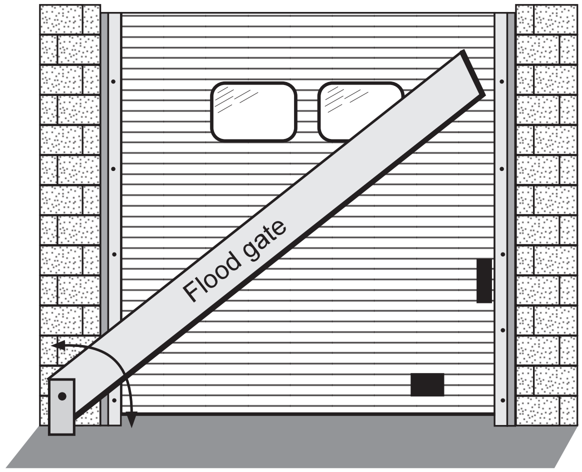


Fig. 3.7.4.3-1. Pivot-type gate with a single pivot point

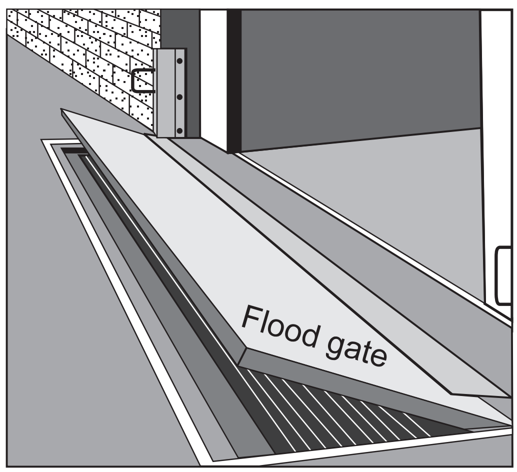


Fig. 3.7.4.3-2. Stored in-ground hinged-type gate, partially deployed

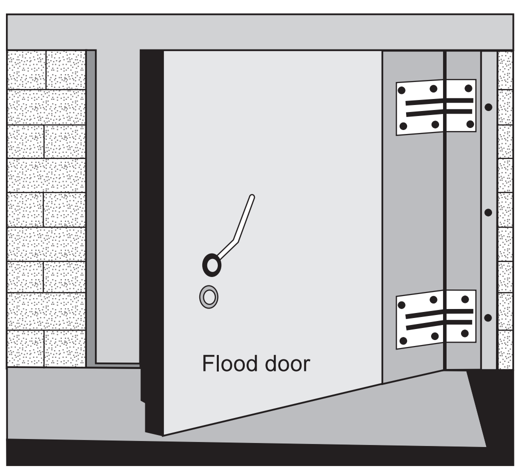


Fig. 3.7.4.3-3. Door-style gate hinged flood, partially deployed

Ease of operation and training needed:

A. A properly designed, hinged gate is very easy to close.

B. Hinged gates protecting personnel doors can be closed by one person.

C. Hinged gates for vehicle openings may require several people to close.

Deployment time: Gates can be closed in minutes.

3.7.4.4 Rolling/Sliding Gates - Time of Use Manual Deployment

Rolling gates are permanently in place and shut by rolling the barrier closed. The rolling mechanism needs to be inspected regularly and kept clear of debris and standing water. In cold climates, ice may accumulate in the tracks and hinder prompt operation.

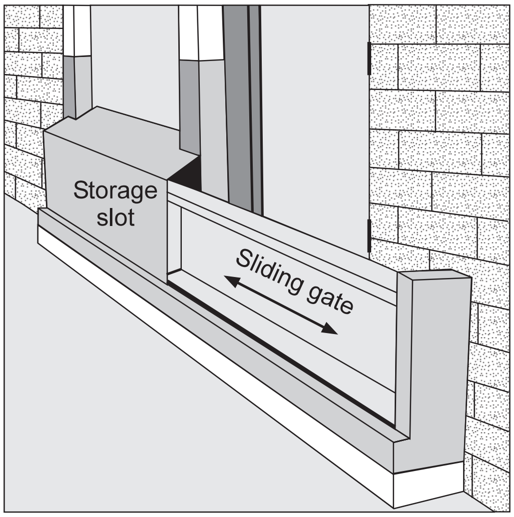


Fig. 3.7.4.4. Rolling gate, shown deployed

Ease of operation and training needed:

A. A properly designed rolling gate is very easy to close.

B. Rolling gates protecting personnel doors can be closed by one person.

C. Rolling gates for vehicle openings may require several people to close.

Deployment time: Rolling gates can be closed in minutes.

3.7.4.5 Drop-from-Above Gates - Time of Use Manual Deployment

These gates have preventive maintenance, ease of operation and training similar to rolling gates.

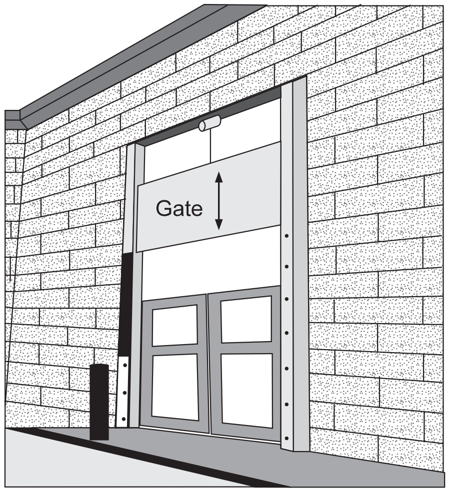


Fig. 3.7.4.5. Drop-from-above gate, shown in storage position

Ease of operation and training needed:

A. A properly designed drop-from-above gate is very easy to close.

B. Gates protecting personnel doors can be closed by one person.

C. Large gates for vehicle openings may require mechanical equipment to close. This equipment should be designed as part of the gate.

Deployment time: Drop-from-above gates can be closed in minutes if closure equipment is part of the design.

3.7.4.6 Hinged Window Opening - Time of Use Manual Deployment

This type of flood barrier can be installed over or in existing windows. The protection devices are made of metal or composite materials and can be hinged from the top, bottom or sides. They are closed manually.

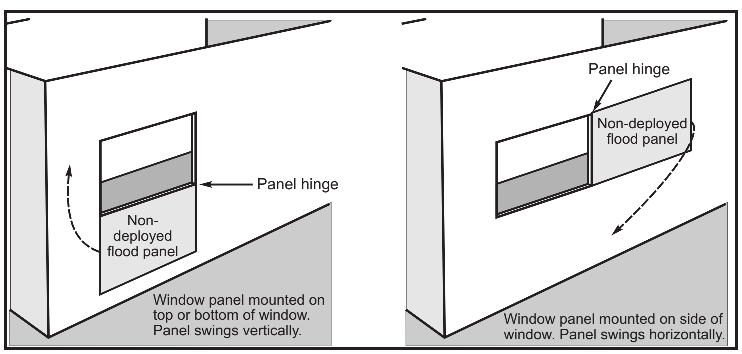


Fig. 3.7.4.6. Garage door protection,interior view shown

Ease of operation and training needed:

A. A properly designed window cover requires minimal effort to deploy.

B. Annual deployment drill and inspection of sealing components is recommended.

Deployment time: Closure of this type barrier can be completed in minutes.

3.7.4.7 Garage/Up-and-Over Doors - Time of Use Manual Deployment

These garage doors are designed to function as normal garage doors when no flood exists. To prevent impact damage from water-conveyed debris, the doors are metal. Some garage doors have additional latches that must be closed as the flood approaches.

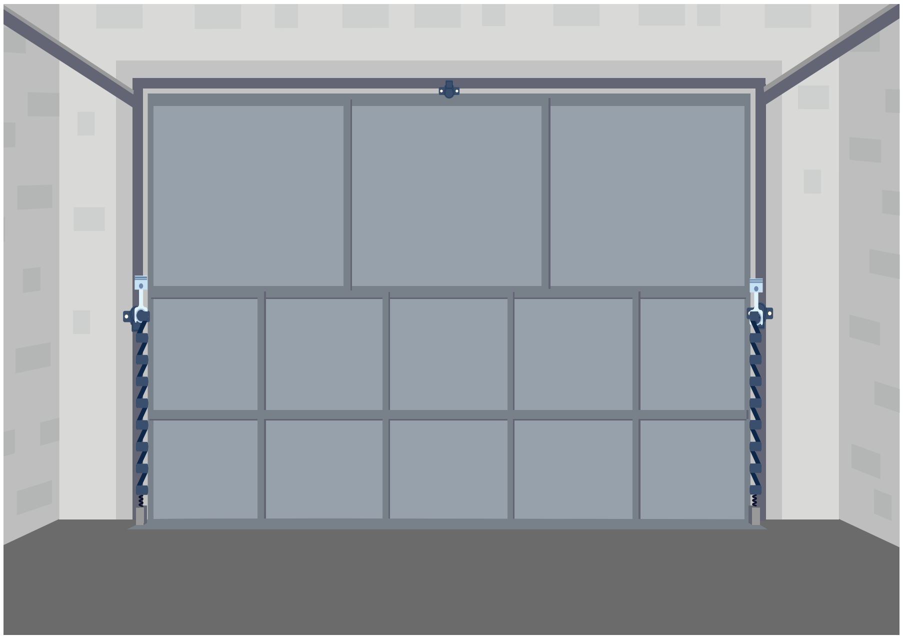


Fig. 3.7.4.7. Garage door protection,interior view shown

Ease of operation and training needed:

A. Fully automatic operation or with simple closing latches

B. Must be kept free of debris to allow for proper operation.

Deployment time: Closure of flood doors can be completed in minutes.

3.7.4.8 Stop Logs - Time of Use Manual Deployment

Stop logs protecting personnel doors are designed to be installed by one or two people. Typically, stop logs vary in height from 6 to 24 in. (15 to 60 cm). Stop logs for roadway and vehicle doors may require lift equipment and vertical support at mid-span. In this type of protection, a series of “flood logs”, removable panels or expanding panels are inserted into a permanent exterior wall-mounted frame on each side of the protected opening. Alternate designs may also include mounting that incorporates the jamb for the opening, anchors for direct wall mounting, or wall mounting inside the protected area.

For larger openings, intermediate support may be used to create repeating sections that span the opening. The intermediate supports must be anchored to the floor via fastening bolts or a foundation channel/bond beam. These products use gasket seals between the lower edge of the log/panel and the sill, the log/panel to mounting frame, and the mounting frame to building. Frequently, tear-resistant plastic sheeting and sandbags are added in front of the stop logs or panels to further reduce water seepage.

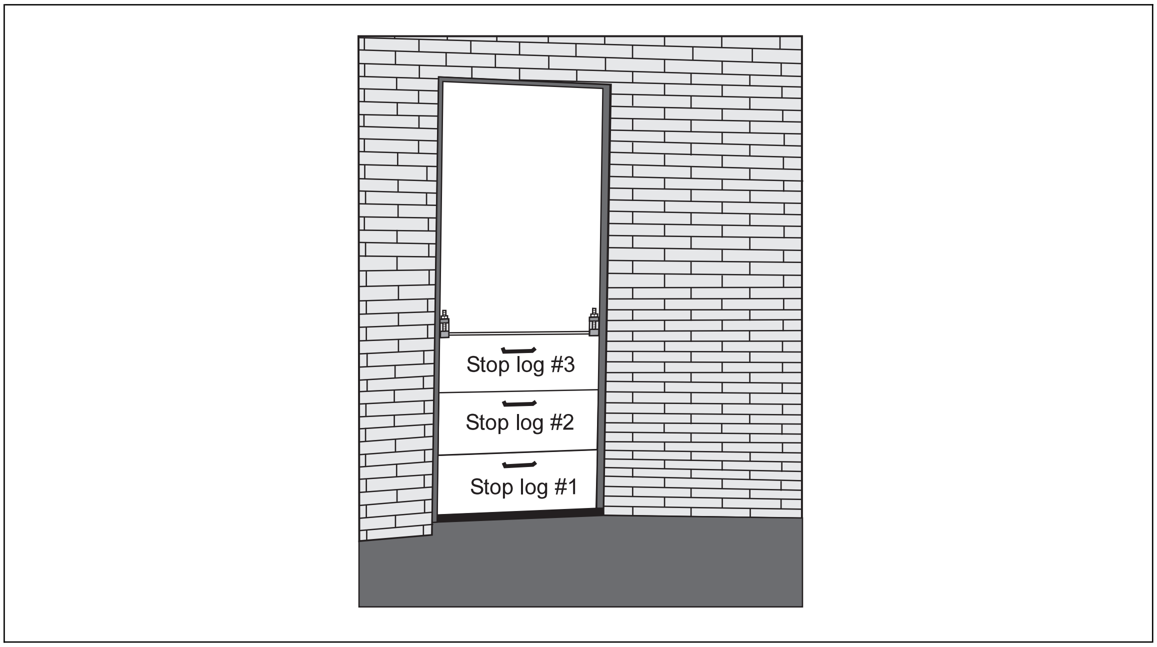


Fig. 3.7.4.8-1. Three stop logs deployed in a doorway

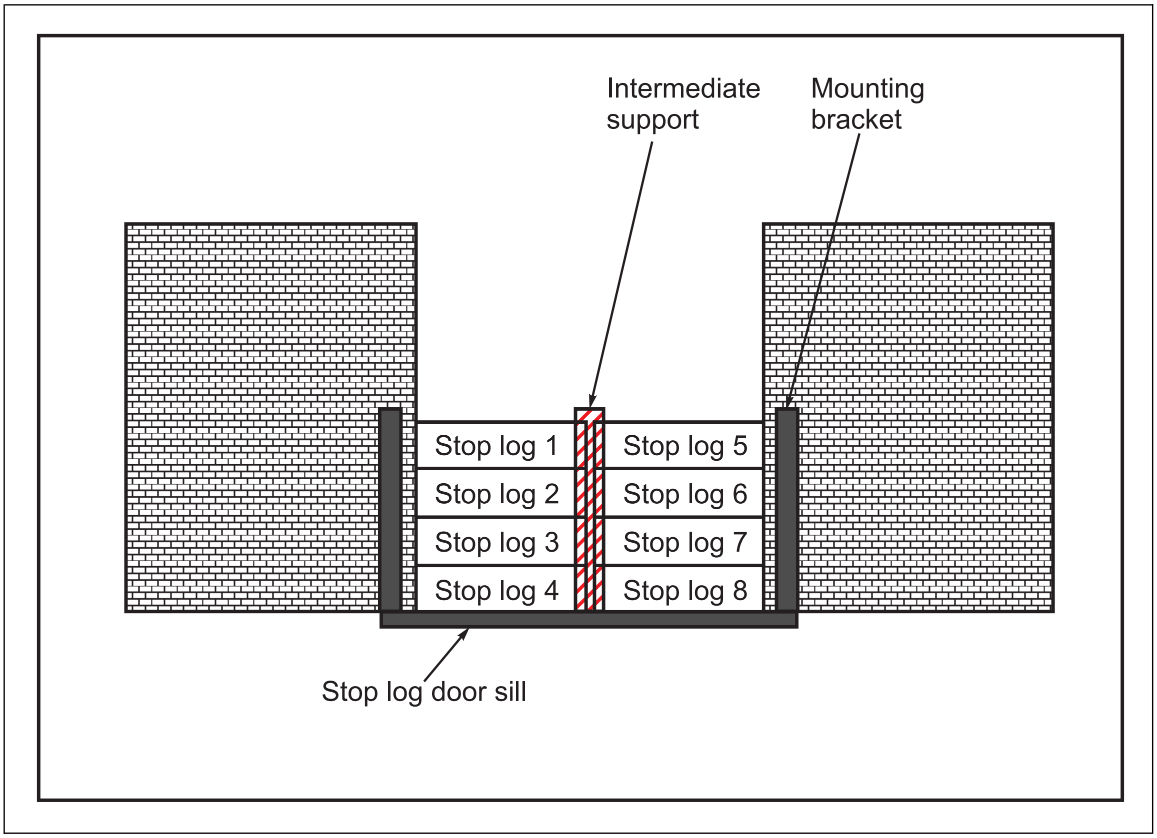


Fig. 3.7.4.8-2. Large opening protected by stop logs with intermediate support

Ease of operation and training needed:

A. Typically, the stop log mounting brackets are permanently installed.

B. This system has multiple components to install, including multiple stop logs and fasteners.

C. The first stop log installed at floor level typically has a larger seal at the bottom.

D. All systems have a fastener at the top of each side to compress the horizontal gaskets downward. Some systems have fasteners for each panel that compress the vertical gasket to form a good seal.

E. Incorrect stop log installation order jeopardizes the seal.

F. Annual training/assembly is recommended.

G. The logs and assembly parts are often stored in another location.

Deployment time: Installation of stop log assembly across an 8 ft (2.4 m) opening will take less than 1.5 hours if the mounting brackets have been previously installed. The marshalling of staff and equipment needed to transport the gates from the storage location and assemble them can be significant and should be included in the time estimates. A test assembly must be conducted to understand the time, equipment and staff necessary to assemble the gate.

3.7.4.9 Removable Panels - Time of Use Manual Deployment

This type of opening barrier typically consists of a removable panel that slides into a permanent sill and frame. These panels may be used in series if intermediate mounting hardware is installed. These panels are typically made of aluminum or other lightweight materials to keep the weight low.

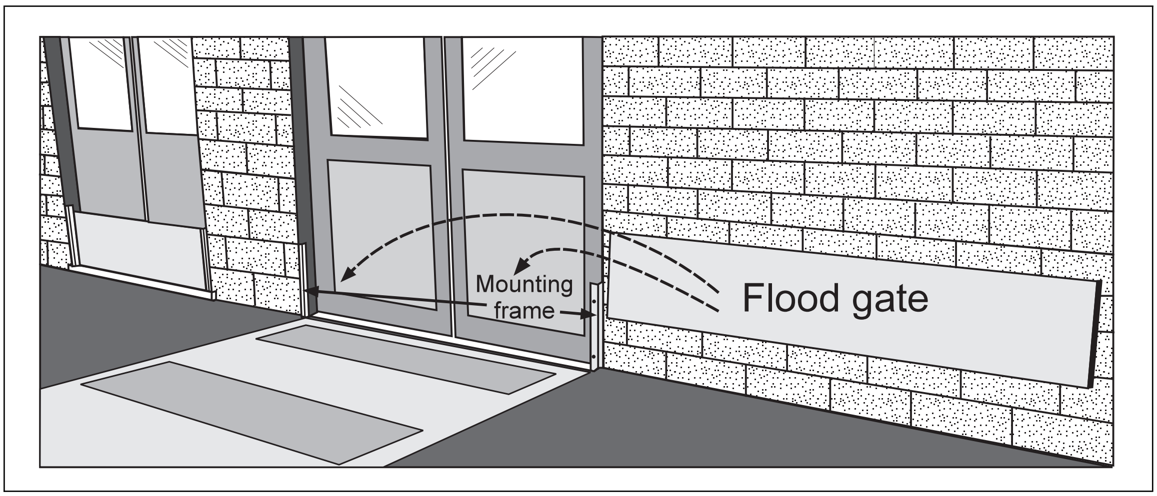


Fig. 3.7.4.9-1. Drop-in-place gate, shown in storage position next to doorway

Ease of operation and training needed:

A. Typically, the mounting brackets are permanently installed.

B. Removable panels are usually easy to install. The weight of the panels may require more than one person to lift them or the use of a mechanical lift.

C. An annual assembly drill is recommended.

D. The panels and assembly parts are often stored in another location.

Deployment time: Deployment of this type of barrier can be done in minutes if the panel and mechanical lifting unit (if required) are stored close to the opening. The marshalling of staff and equipment needed to transport the panels from the storage location and assemble them can be significant and should be included in the time estimates. A test assembly must be conducted to understand the time, equipment and manpower necessary to assemble the gate.

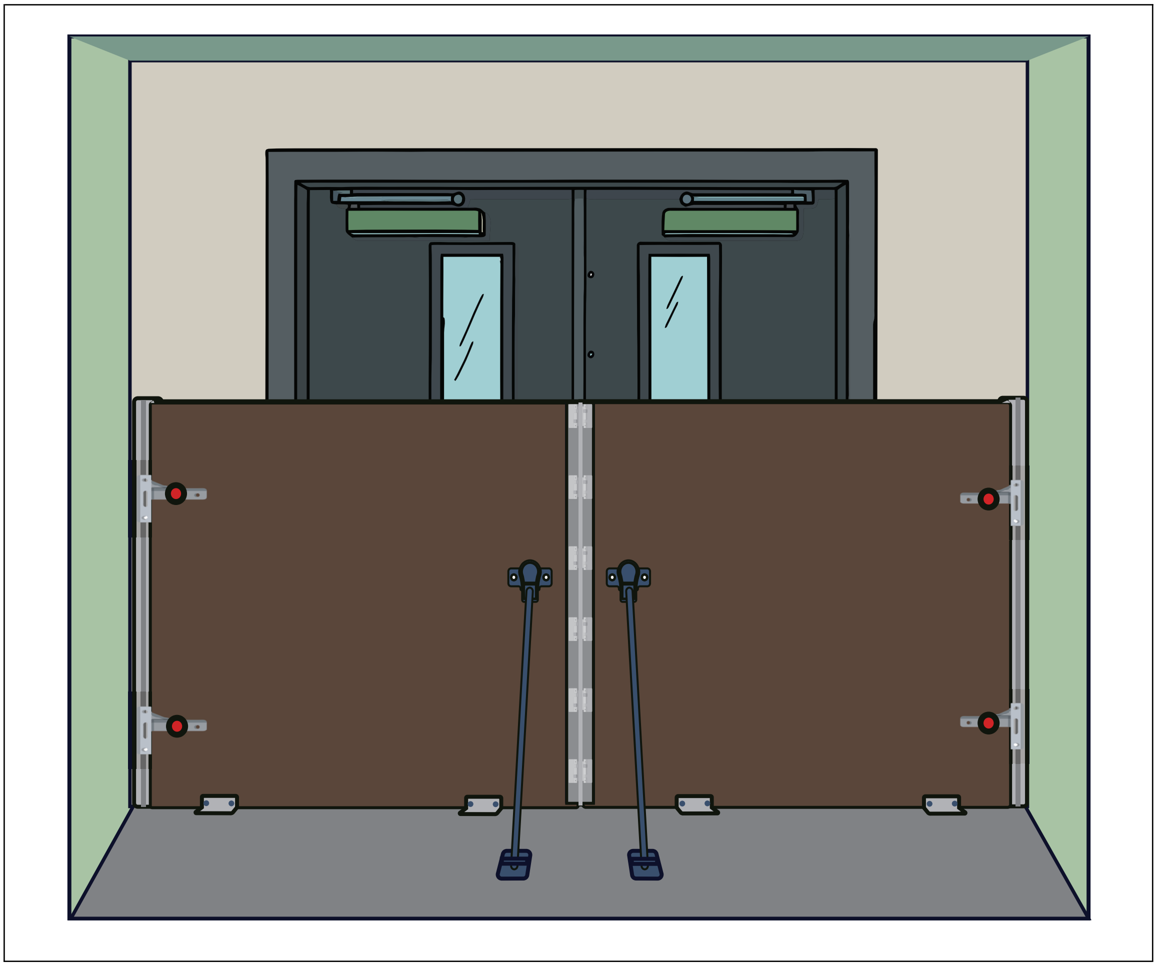


Fig. 3.7.4.9-2. Repeating section flood panel

3.7.4.10 Expandable Panels with or without Mounting Hardware - Time of Use Manual Deployment

These flood panels can use existing door frames or can be used with permanently installed mounting hardware. They may be used in series if intermediate mounting hardware is installed. The gates expand into the door frame or mounting hardware. These flood panels are typically made of a steel or aluminum frame with a waterproof membrane and gaskets to minimize leakage while keeping the weight manageable.

Ease of operation and training needed:

A. The device must fit in the door frame or permanently installed mounting hardware. The device will need to avoid the door's opening hardware, including door latches, hinges, and panic bars.

B. Typically, they are easy to install and can be put in place by one person.

C. An annual assembly drill is recommended.

D. The panels are often stored in another location.

Deployment time: Closure of this type of barrier can be done quickly if the panel is stored near the opening. The marshalling of staff and equipment needed to transport the panels from the storage location and assemble them can be significant and should be included in the time estimates. A test assembly must be conducted to understand the time and staff necessary to assemble the barrier.

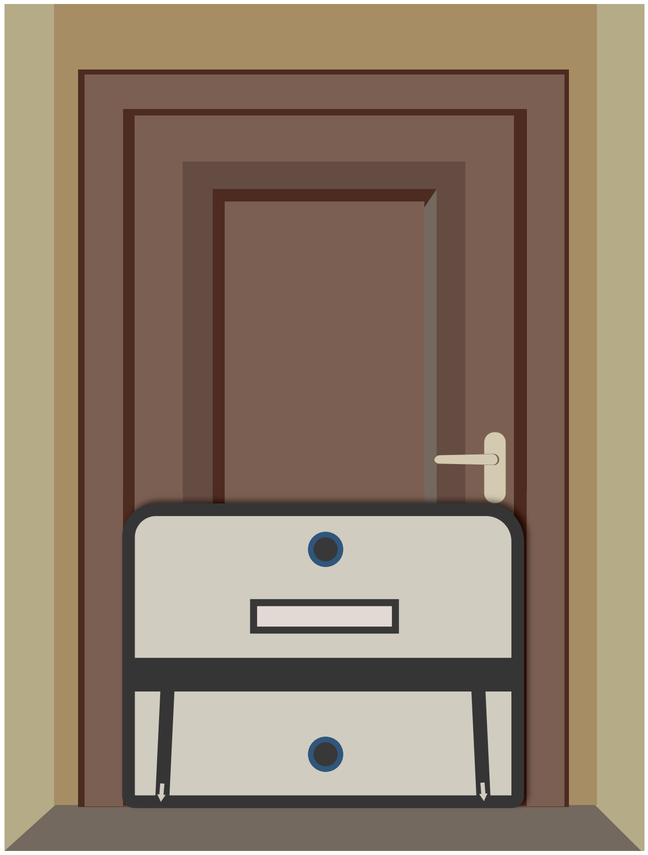


Fig. 3.7.4.10-1. Inflatable expanding panel

Fig. 3.7.4.10-2. Expanding panel with mullion

3.7.5 Building and Perimeter – Flood Mitigation Valves - Advance-Installed Flood Solutions

Multiple styles of valves can be used in flood mitigation applications. Common applications center around inline protection, outfall protection, and open channel water control. Inline protection is where the valve is installed within a run of piping for the purpose of preventing back flow to the building due to surcharge in the drain line. Outfall protection involves the valve at the end of the pipe run as it discharges to atmosphere or into a body of water. These valves are intended to prevent back flow to the site in case the body of water is elevated and changes the flow direction as normal discharge pressure is less than pressure created by flooding. In open channel applications, a sluice gate is often used to control or stop the normal flow within the channel.

3.7.5.1 Inline flood mitigation valves – Automatic Deployment

Ease of operation and training needed:

A. Installation may require one or more people.

B. Periodic inspection and removal of debris that is not completely discharged will increase reliability. Check either the clean-out port of inline valves (if applicable) or at outfall.

Deployment time: Once installed, no additional effort is required.

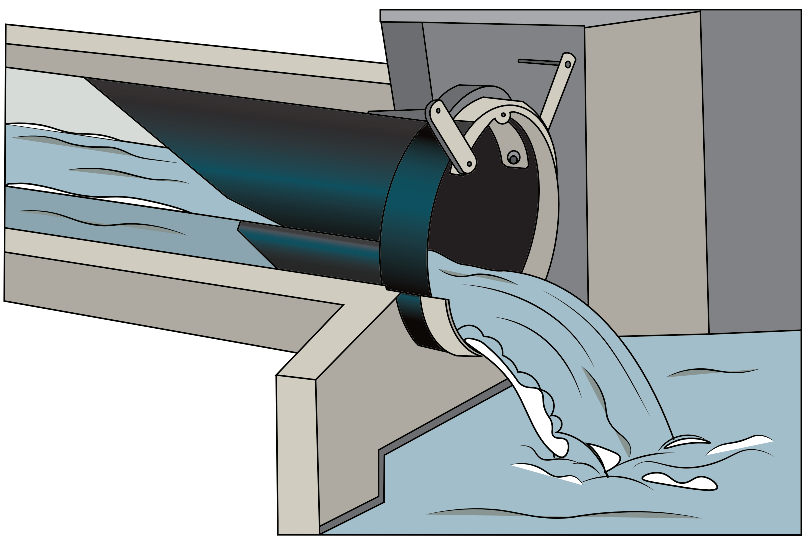


Fig. 3.7.5.1-1. Inline rubber-type mitigation valve

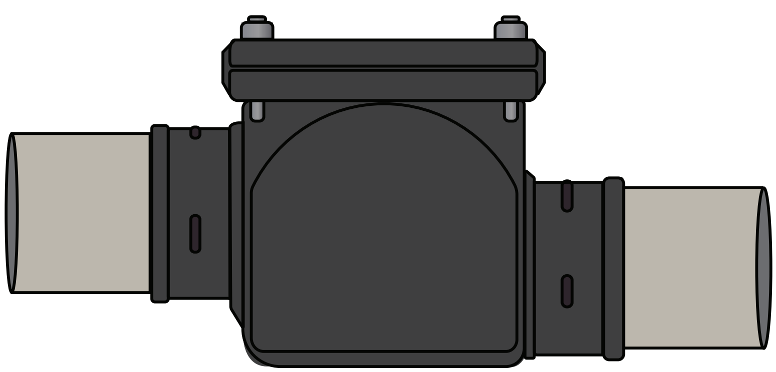


Fig. 3.7.5.1-2. Inline cast-iron mitigation valve

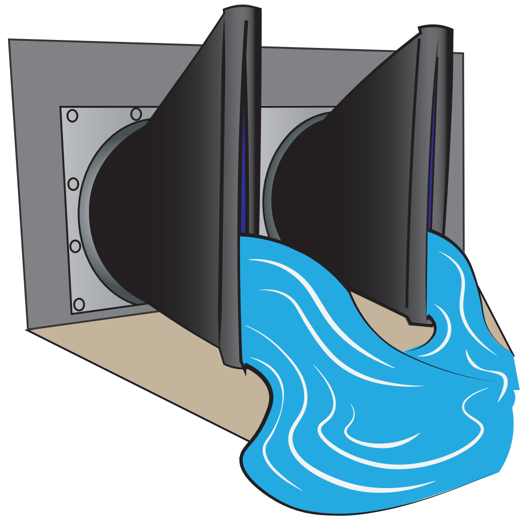


Fig. 3.7.5.1-3. Duckbill-type valve

3.7.5.2 Sluice Gate Valves – Automatic Deployment or Time of Use Manual Deployment

Ease of operation and training needed:

A. Manual operation may require one or more people, depending on the size of the valve.

B. Periodic inspection and removal of debris is required

Deployment time: Sluice gate valves can be closed in minutes.

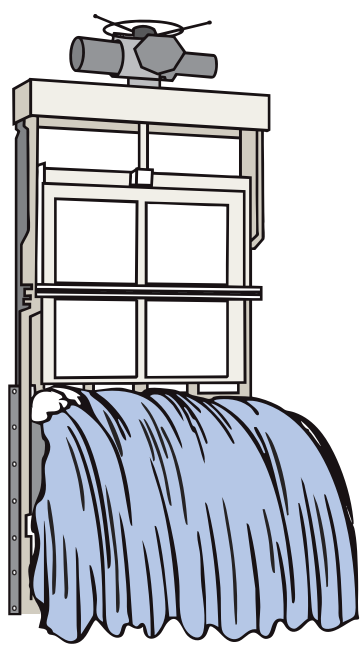


Fig. 3.7.5.2. Sluice gate valve

3.7.6 Building – Penetration Sealing Devices

3.7.6.1 Penetration Sealing Devices – Advance-Installed Flood Solutions

Penetration sealing devices are used to prevent leakage around objects (i.e. pipes, wires/cables, or ducts) that pass through interior or exterior walls, floors or foundations. Depending on the product, the seal may be removed and reused to support servicing or replacement of the object as needed.

Ease of operation and training needed:

A. Typically, these devices can be installed by one person.

B. Periodic inspection of installation is necessary to ensure no evidence of seal failure is visible.

C. Installation frequently includes the use of lubricant to position the seal and tightening of fasteners, per the manufacturer's recommended procedure.

Deployment time: Once installed, no additional effort is required.

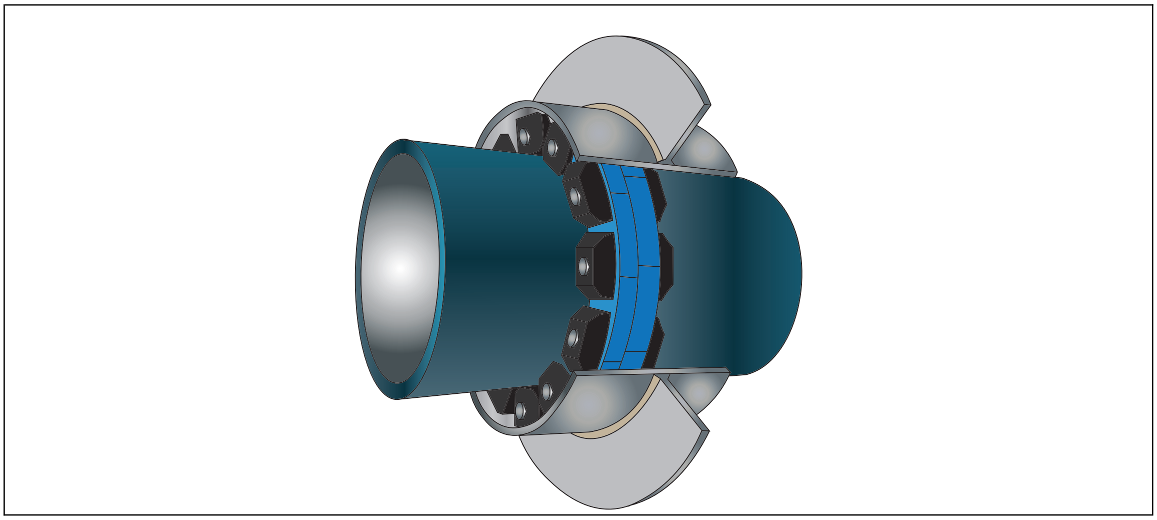


Fig. 3.7.6.1-1. Penetration sealing device; note two compression seals perpendicular to pipe

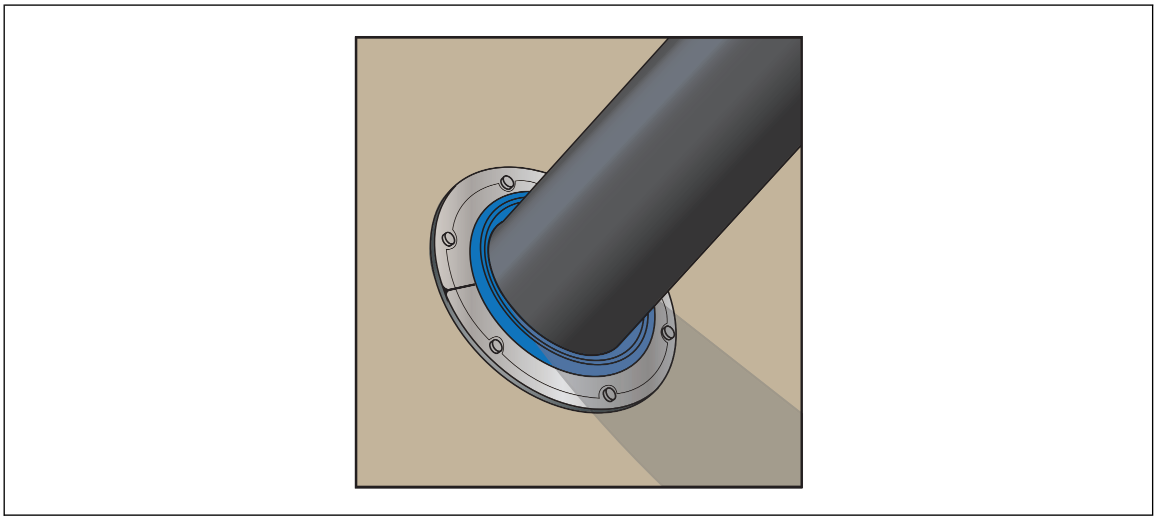


Fig. 3.7.6.1-2. Penetration sealing device; note multiple compression seals parallel to pipe

3.7.6.2 Penetration Sealing Devices – Time of Use Manual Deployment

Wall penetration seals used in temporary applications are commonly drain plugs used to block passages/holes in interior or exterior walls, floors or foundations. Depending on the product, the seal may be removed, cleaned and stored for reuse for future events.

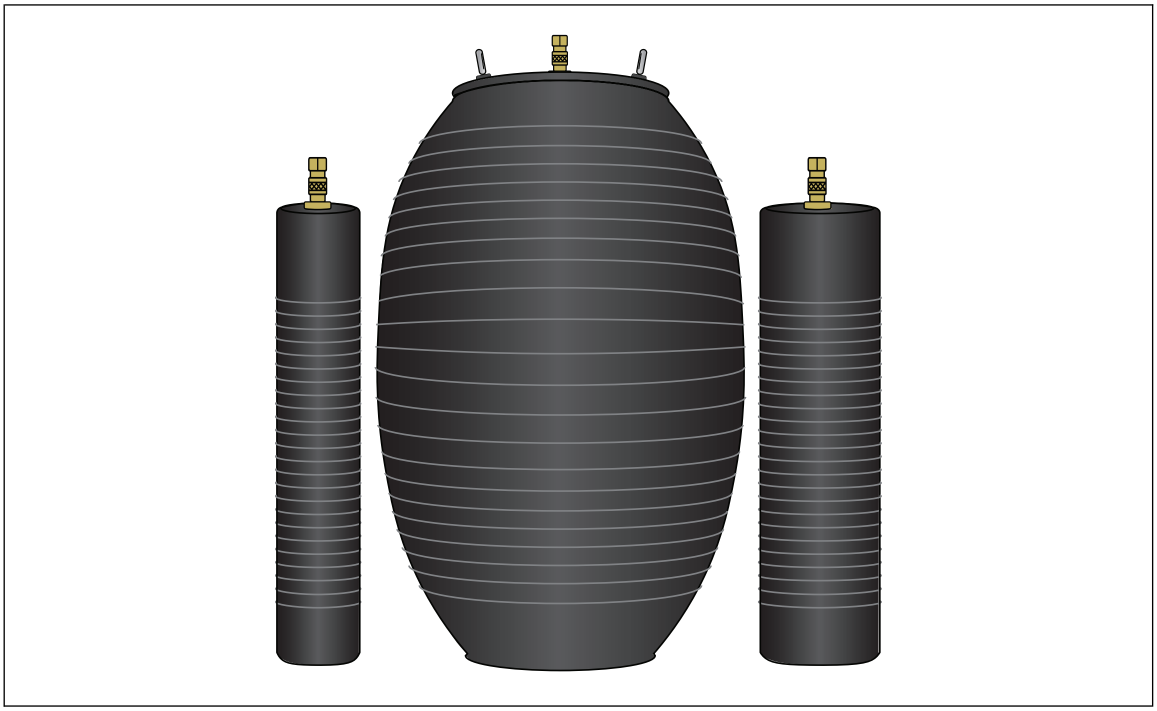


Fig. 3.7.6.2-1. Penetration sealing device, inserted into opening and then inflated

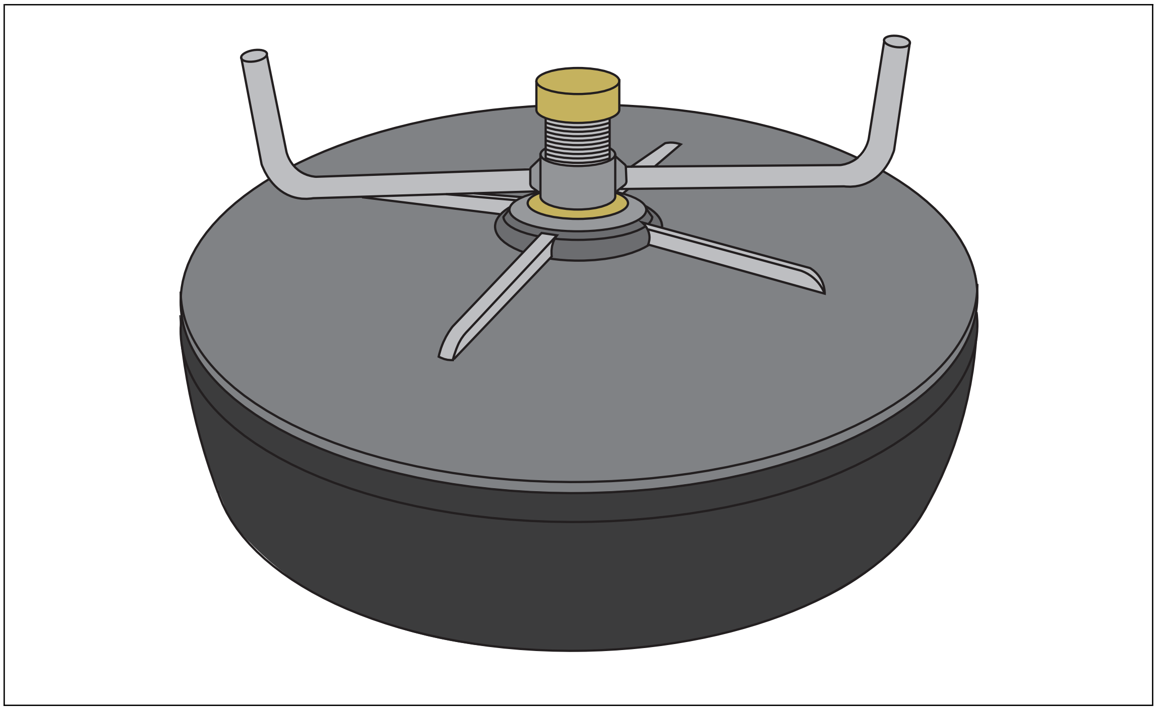


Fig. 3.7.6.2-2. Penetration sealing device, inserted into opening and then mechanically tightened

Ease of operation and training needed:

A. Can typically be installed by one person.

B. Depending on design, sealing will require tightening of fastener or input of compressed air to activate the seal.

C. Periodic inspection of installation is necessary to ensure no evidence of seal failure is visible.

D. Installation frequently includes use of lubricant to position the seal and tightening of fasteners, per the manufacturer's recommended procedure.

Deployment time: Typically installed in minutes, but requires tools or compressed air to activate the seal.

3.7.6.3 Hatch Covers – Time of Use Manual Deployment

These devices cover non-water-tight hatches. The hatches can be on floors or other ground surfaces, or on vertical surfaces.

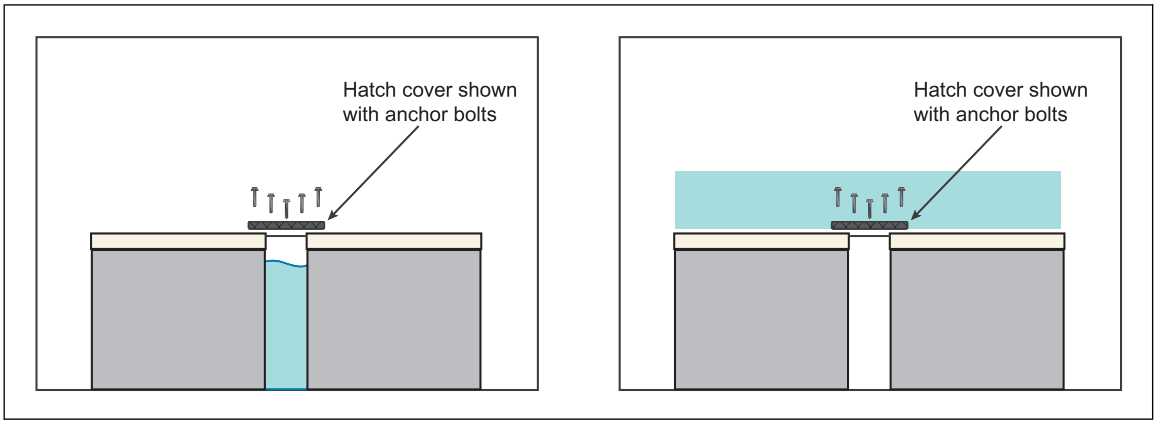


Fig. 3.7.6.3. Hatch cover for vertical tunnel or floor drain. Left image designed to stop water coming from below; right image designed to keep water from penetrating the space below.

Ease of operation and training needed:

A. The complexity of installation will vary based on the access hatch size, location and design.

B. An annual assembly drill is recommended.

Deployment time: Varies based on design.

3.7.7 Designed Deployable Flood Walls- Partially Built in Advance Flood Solutions

3.7.7.1 Designed Deployable Flood Walls - Time of Use Manual Deployment

These systems are typically deployed in areas where a permanent flood wall is not an option, because access or visibility is required when no flood exists.

These devices are essentially a series of repeating stop logs or panels that are installed between vertical support members. They require a designed and permanently installed foundation, vertical support member receptor slots, and other anchoring devices along the length of the system. A designed foundation is essential for developing an effective lower seal and for incorporating vertical support member receptors capable of withstanding the forces exerted by floodwaters. See Section 2.2.6.1, Permanent Site Flood Protection Systems, for additional guidance.

Ease of operation and training needed:

A. Consult with the manufacturer about estimated deployment times during the selection process.

B. This type of system will require significant training to properly assemble. Advise that the stop logs or panels be labeled with their deployment location.

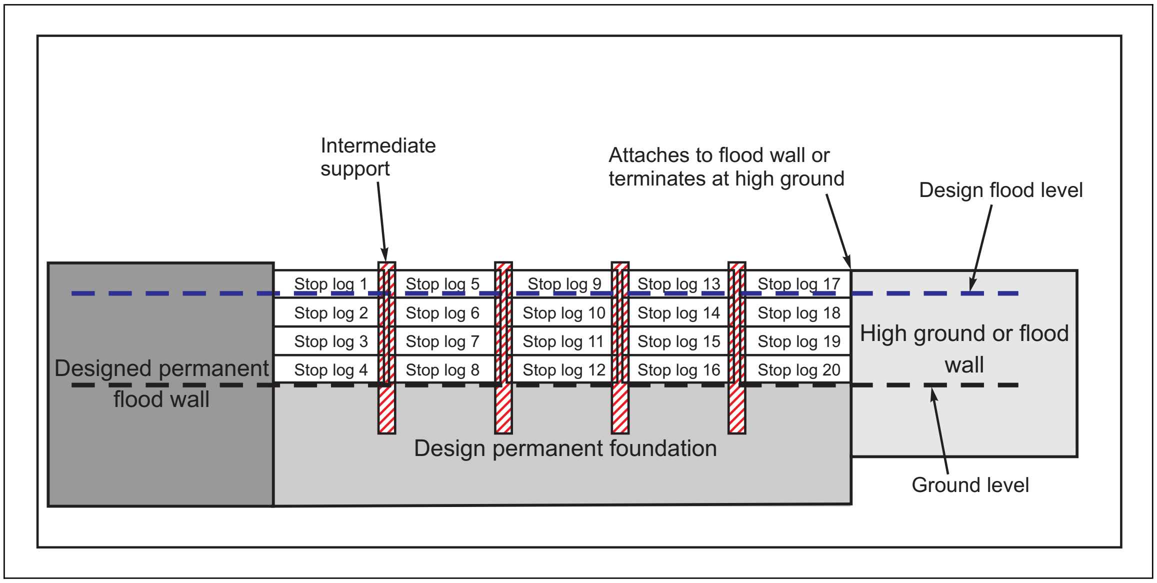


Fig. 3.7.7.1. Designed, semi-permanent deployable flood walls

C. Material area handling equipment will be needed to transport the materials from the storage to the deployment area.

D. The weight of the vertical support members will often require lifting equipment to install the supports into the designed foundation.

E. A timed deployment test should be conducted, including both the transportation of panels and assembly equipment to the opening and the coordination of personnel required to properly assemble the system.

Deployment time: Depending on the length of the protection, distance between storage and deployment locations, and availability of trained workforce needed to deploy, these systems can require significant time to assemble.

3.7.8 Perimeter - Temporary Flood Mitigation Barriers Without Foundations

3.7.8.1 Rigid Flood Panels – Time of Use Manual Deployment

This type of flood protection uses panels that are deployed once a flood is forecast to cause damage. Some types use the product's design and weight of water to prevent movement. Other types may require anchoring to the ground. The location and spacing of anchors will vary based on product and soil conditions. Engineering analysis is required to evaluate soil conditions and determine anchoring requirements. In certain instances (i.e., installations on grassy/loose soil, uneven surfaces), concrete pads are recommended for attachment of anchoring devices. They should not be deployed on sandy, silty or unstable ground.

Ease of operation and training needed:

A. These panels will require lifting equipment or several workers to assemble the device.

B. Annual training and assembly is needed.

C. The crew must be prepared to repair rips of the waterproof canvas between panels.

Deployment time: These panels require significant time to assemble. One manufacturer suggests a team of 10 to assemble 328 ft (100 m) in one hour. The marshaling of staff and equipment needed to transport and assemble them can be significant. Consult with the manufacturer about estimated deployment times during the selection process. A test should be conducted to understand the time, equipment, and staff necessary to properly assemble the walls once delivered.

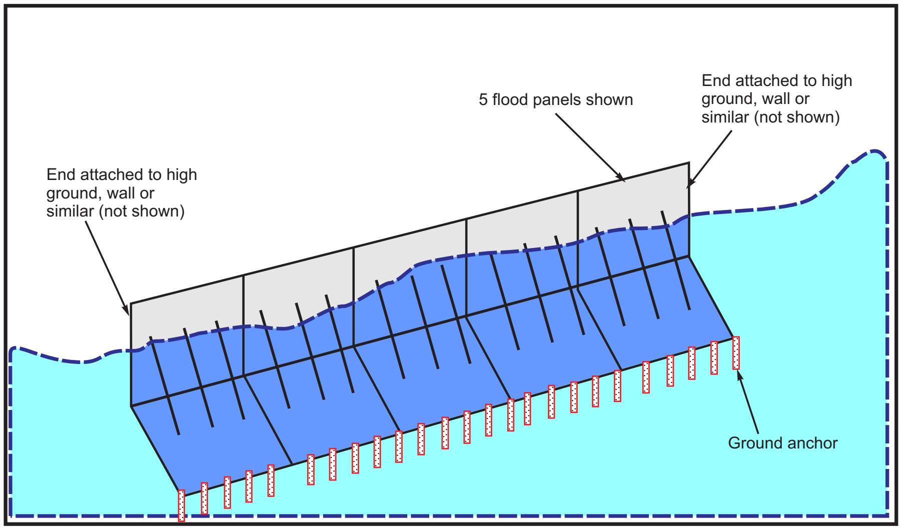


Fig. 3.7.8.1-1. Deployable flood walls without foundations

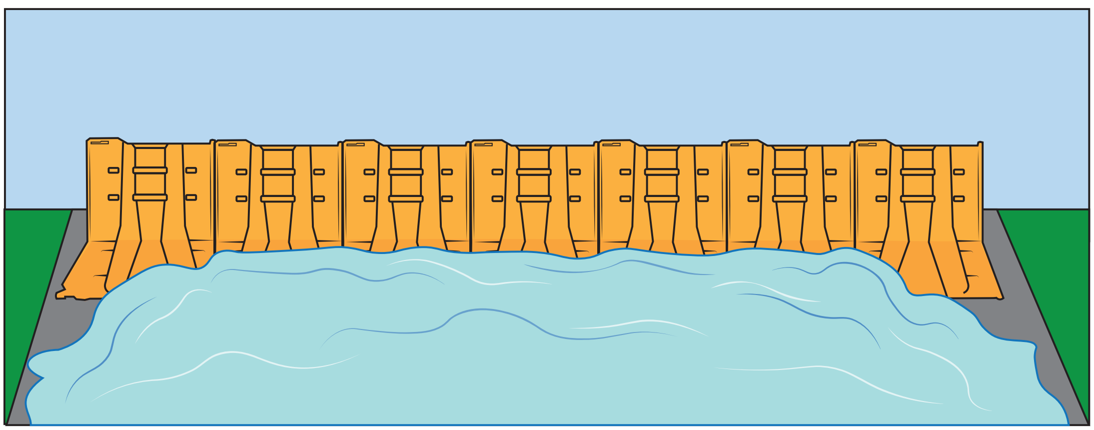


Fig. 3.7.8.1-2. Plastic L shaped panels interlocked, water portion of panel parallel with ground. Far end of image shows complete panels.

3.7.8.2 Rigid/Shaped Containers Filled with Water or Sand - Time of Use Manual Deployment

This type of flood protection uses a series of rigid and shaped containers that can be joined to form protection of any length. Some units require anchors to prevent movement. Follow the manufacturer's installation guidelines, as some manufacturers also utilize plastic sheeting to reduce leakage.

Ease of operation and training needed:

A. These devices require a trained workforce to assemble, per the manufacturer's installation guidelines. The workforce will need to be familiar with joining multiple sections, changing the direction, anchoring, repairing leaks, and the process to recreate the FM Approved assembly.

B. Multiple employees are needed for deployment.

C. Depending on product size, the weight of single units can be significant. Lifting equipment may be needed to stage multiple sections quickly.

D. Material handling equipment for loading the fill material will be needed.

E. A timed deployment test should be conducted, including both the transportation of panels and assembly equipment to the opening and the coordination of personnel required to properly assemble the system.

Deployment time: These panels require significant time to assemble. The marshalling of staff and equipment needed to transport and assemble them can be significant, even with proper pre-planning. Consult with the manufacturer about estimated deployment times during the selection process.

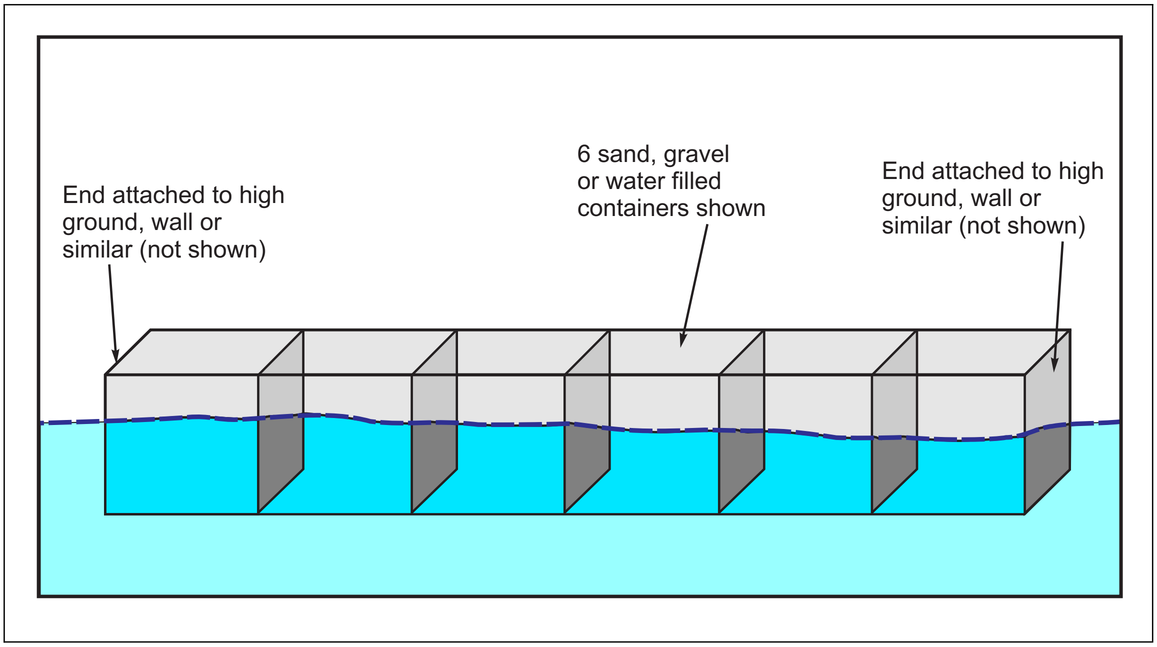


Fig. 3.7.8.2-1. Rigid/shaped containers filled with water or sand

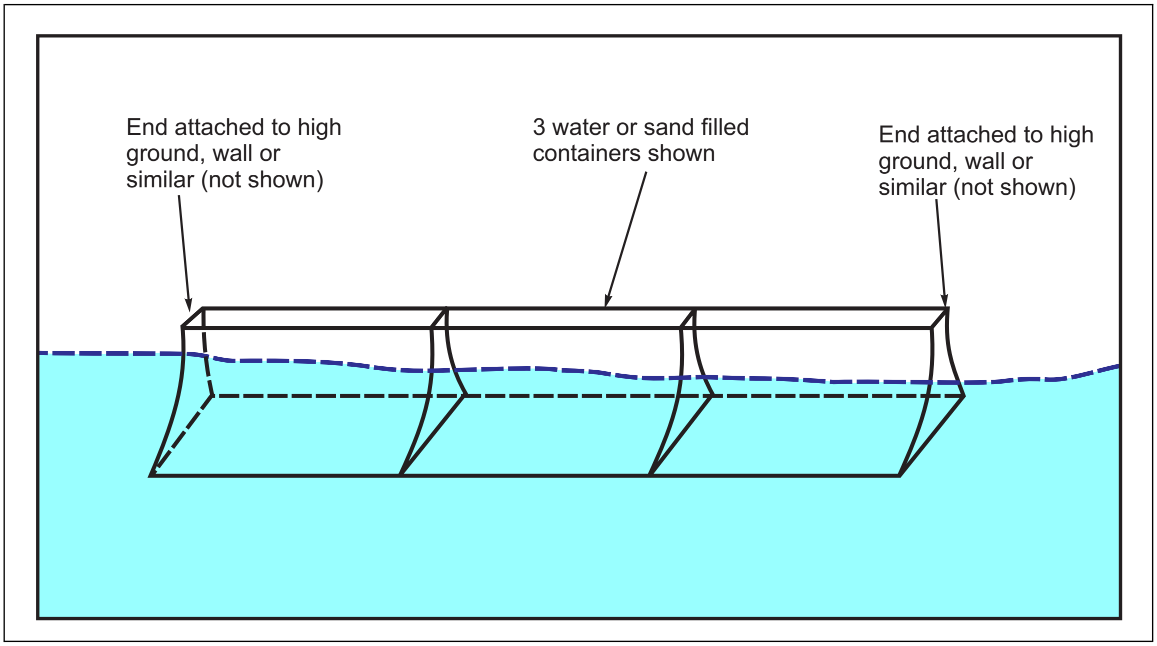


Fig. 3.7.8.2-2. Rigid/shaped containers filled with water or sand

3.7.8.3 Flexible Containers Filled with Water or Sand - Time of Use Manual Deployment

Flexible containers may be constructed with either a rigid wire or wooden frame and a waterproof membrane. The waterproof membrane or plastic sheeting may be deployed in front containers to reduce leakage. These containers will leak at various rates based upon design and installation. Careful planning is needed to ensure the flood abatement pumps can keep up with the anticipated leakage.

Ease of operation and training needed:

A. These containers typically are lighter than rigid containers, so they may not require lifting equipment to position.

B. Material handling equipment will be needed for loading the fill material. Proper filling ensures no voids are present in the fill.

C. Annual training/assembly is needed. The crew must be prepared to follow the manufacturer's installation instructions. Installation methods will vary and may include anchoring the units to the ground and interlocking the units together.

D. The crew will need to repair punctures, particularly between each section.

Deployment time: These devices require significant time to deploy. The marshaling of staff and equipment needed to transport and fill them can be significant. Consult with the manufacturer about estimated deployment times during the selection process. A timed deployment test should be conducted, including both the transportation of panels and assembly equipment to the opening and the coordination of personnel required to properly assemble the system.

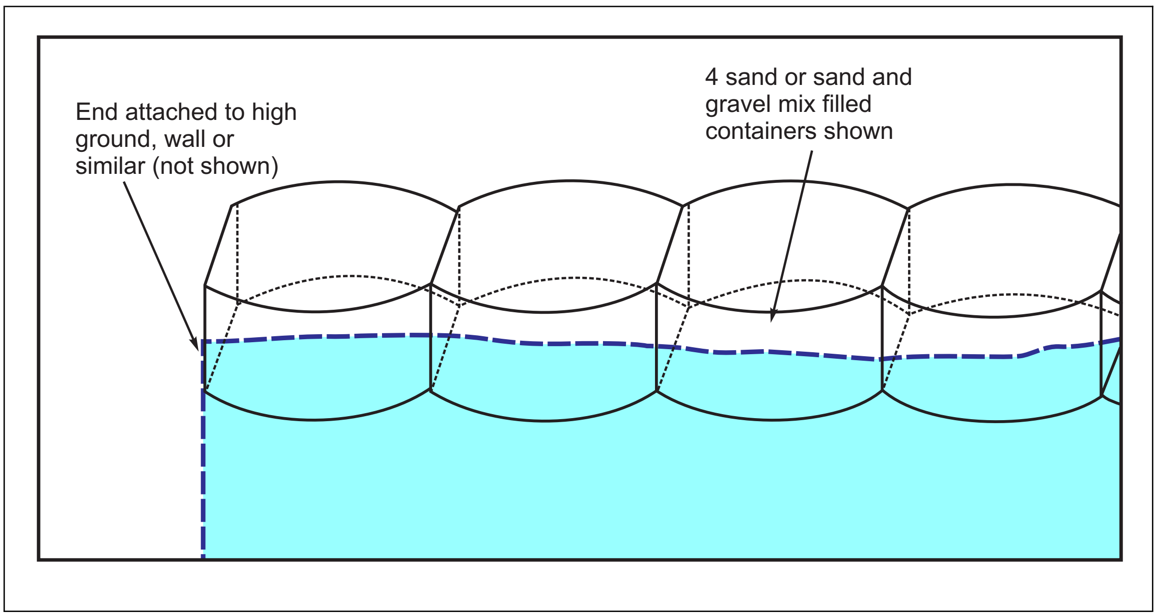


Fig. 3.7.8.3. Flexible containers filled with gravel or sand

3.7.8.4 Bladders Filled with Water - Time of Use Manual Deployment

This type of flood protection uses tubing made of durable, impermeable material; typical materials include polyester-coated fabric, nylon and PVC. The tubes are placed in an area that is free of debris or sharp objects. The tubes are anchored to the ground with anchoring straps to prevent floating or movement from water velocity. The location and spacing of anchors will vary based upon product and soil conditions. Engineering analysis is required to evaluate soil conditions and determine anchoring requirements. In certain instances (installations on grassy/loose soil), concrete pads are recommended for attachment of anchoring devices. The anchors are either permanent or installed when the tube is deployed. The anchoring straps are needed to prevent rolling, floating and movement due to waves or water velocity. The manufacturer may also recommend sandbagging to prevent rolling. Some manufacturers cover the tubes with plastic sheeting adhered to solid surfaces to reduce leakage. They cannot be deployed on hills, but can tolerate minor ground roughness.

Ease of operation and training needed:

A. These devices need a trained workforce to assemble, per the manufacturer's installation guidelines. The workforce will need to be familiar with joining multiple sections, changing the direction, anchoring, repairing leaks, and the process to recreate the FM Approved assembly.

B. Multiple employees are needed for deployment.

C. Depending on nominal size, the weight of the empty tubes can be significant. Lifting equipment may be needed to stage multiple sections quickly.

D. The tubes will also need to be filled via a water pump or another water source.

E. A timed deployment test should be conducted, including both the transportation of panels and assembly equipment to the opening and the coordination of personnel required to properly assemble the system.

Deployment time: These tubes require significant time to assemble. The marshaling of staff and equipment needed to transport and assemble them can be significant. Consult with the manufacturer about estimated deployment times during the selection process.

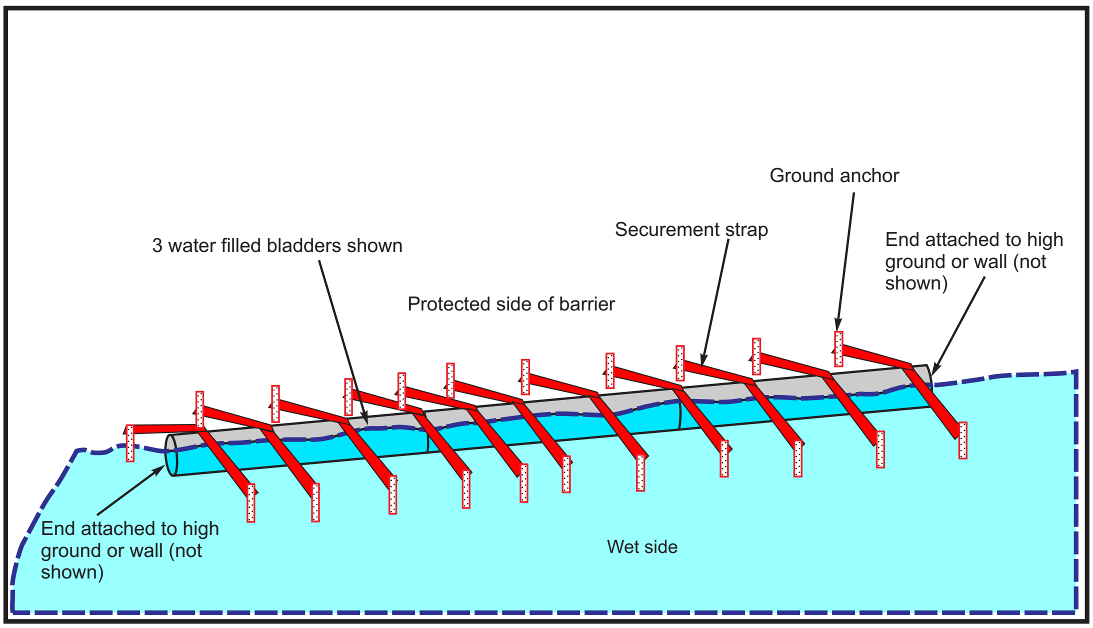


Fig. 3.7.8.4. Bladders filled with water; plastic sheeting may also be needed

3.7.8.5 Waterproof Fabric Cofferdams - Time of Use Manual Deployment

Fabric cofferdams are available in two types. The first is a temporary perimeter barrier designed to be rolled out and secured to the ground by use of anchors or sandbags. This design relies on the water to help fully deploy in terms of height, sealing along the ground and positioning. Successful deployment may require the use of dowels or other items to create a sail area for collecting the flood water at the beginning of the flooding.

Another design uses a rigid frame, and the waterproof fabric is attached to the frame.

Ease of operation and training needed:

A. The cofferdam without the rigid frame is easy to deploy with no specialist material handling or lift equipment. The cofferdam with the rigid frame may require material handling equipment.

B. Annual training is recommended.

Deployment time: Deployment time is quick, 15 minutes or less for a well-trained responder, once the materials are brought to the area where they will be deployed.

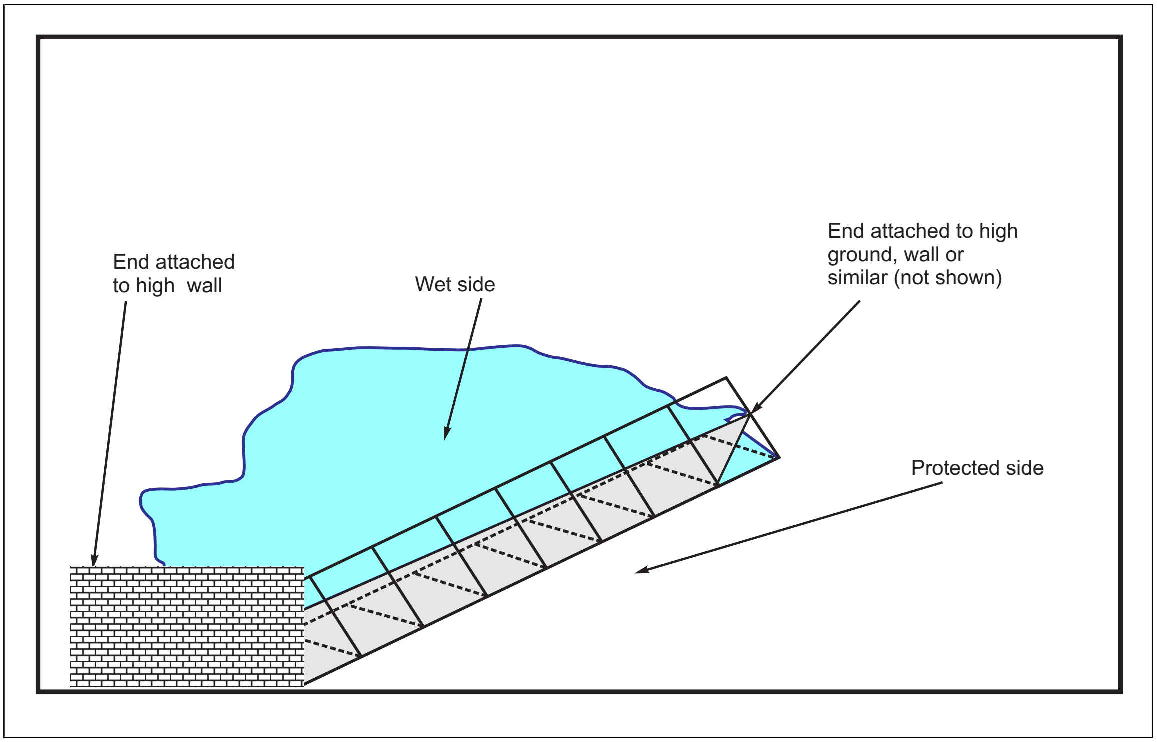


Fig. 3.7.8.5-1. Waterproof fabric cofferdams without rigid frame; water holds fabric open

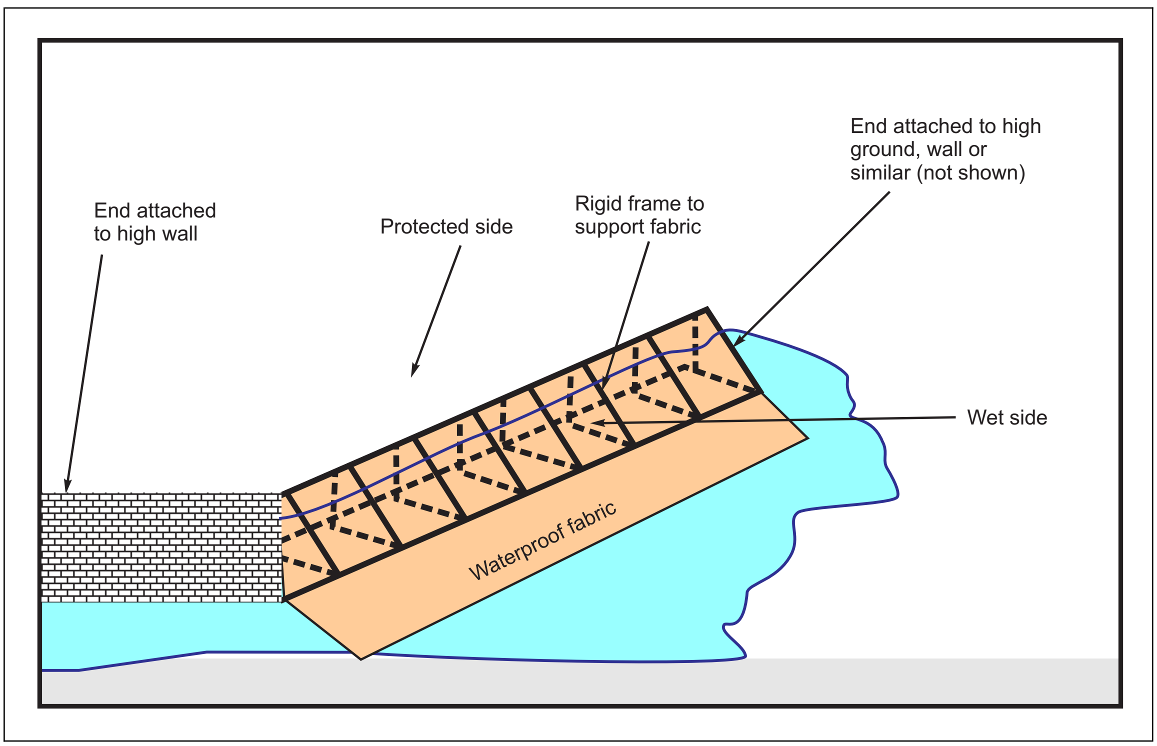


Fig. 3.7.8.5-2. Waterproof fabric cofferdams with rigid frame

3.7.9 Building and Perimeter – Pumps - Flood Solutions

3.7.9.1 Advanced Installed Solution - Flood Mitigation Pumps - Automatic

In this application, the flood mitigation pumps are permanently installed in a water collection pit. The flood water is pumped away via a rigid drain line. Common product styles include designs where the whole pump or only the wet end are submerged in the sump, and self-priming pumps that have only the suction line submerged in the sump. Installation considerations include connection to a reliable power supply (with alternate power as applicable), required electrical enclosure ratings, and screening to prevent clogging from debris in the water, in addition to the normal sizing for flow rate and discharge head.

Ease of operation and training needed:

A. When paired with a float switch or sensor that trips in the presence of water, these pumps will operate automatically.

B. Periodic inspection of suction screens and sump is needed to remove collected debris.

Deployment time: Once installed, no additional deployment effort is needed.

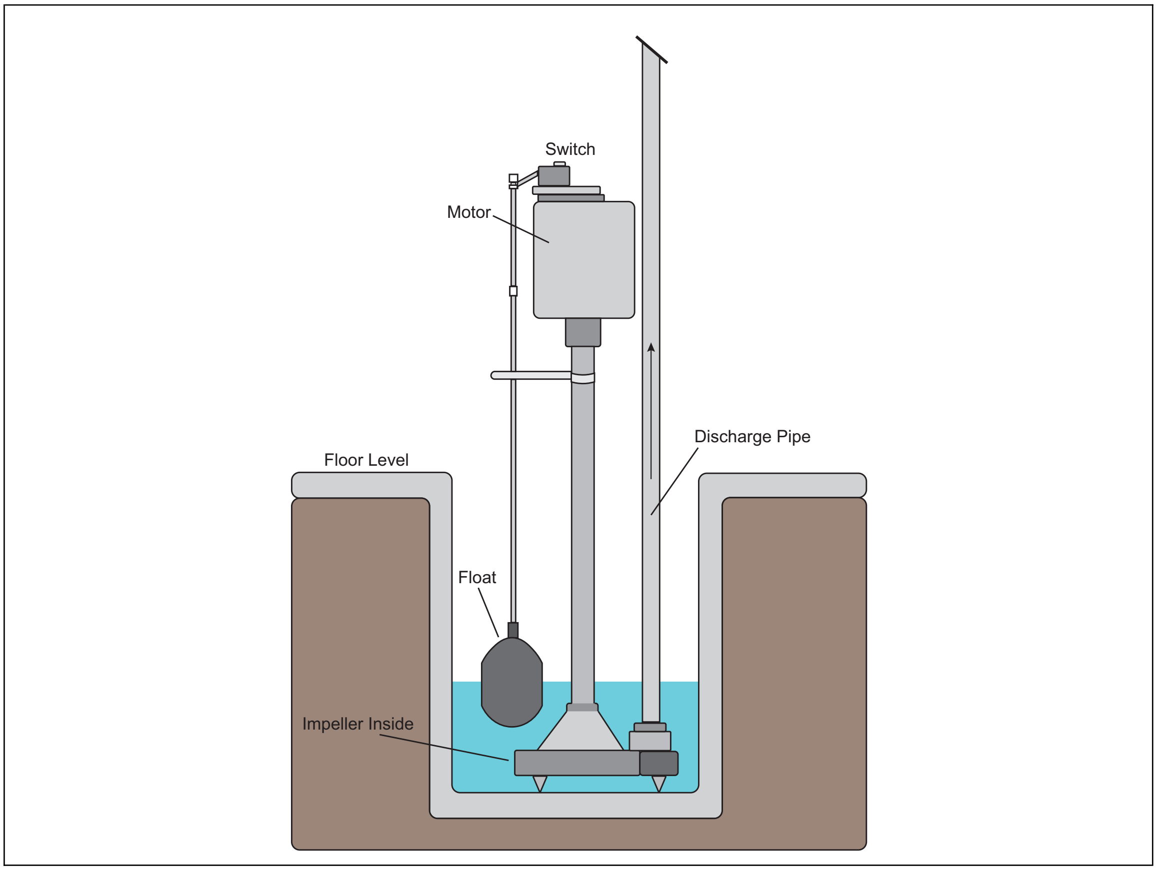


Fig. 3.7.9.1-1. Pedestal-type flood mitigation pump

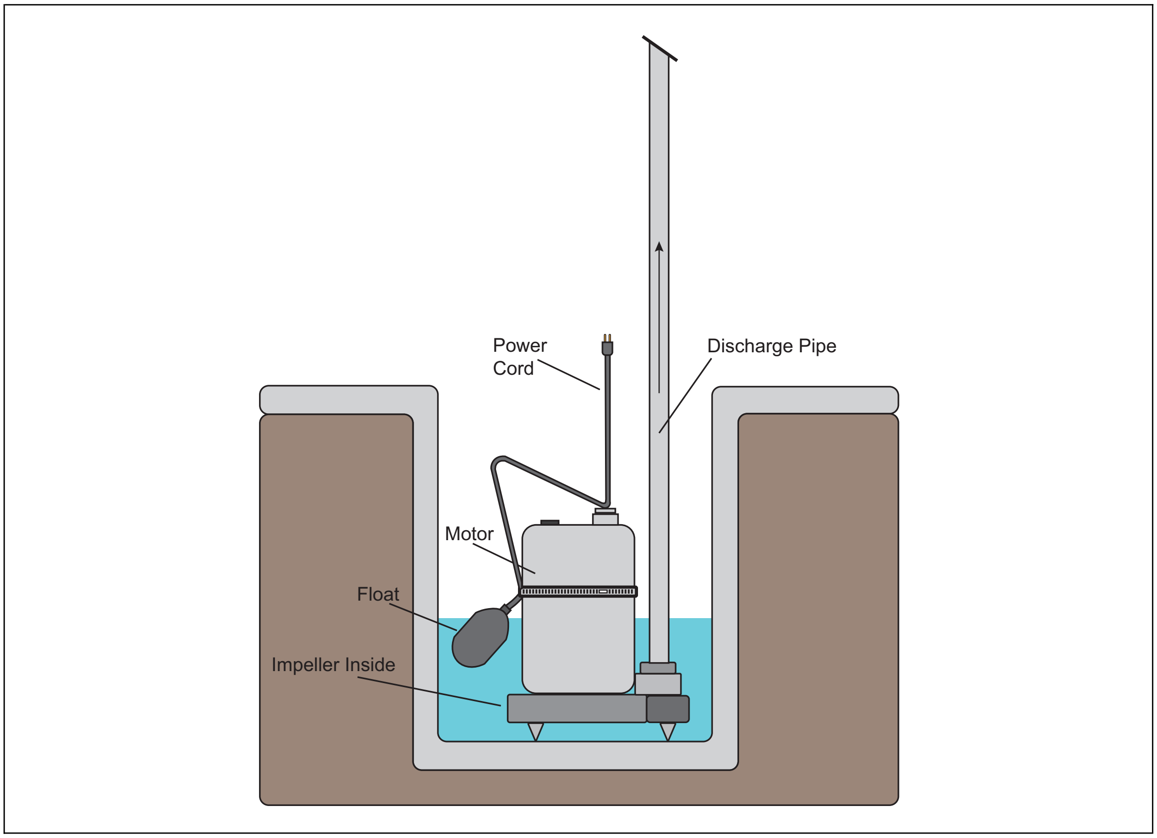


Fig. 3.7.9.1-2. Submersible-type flood mitigation pump

3.7.9.2 Semi-Permanent Flood Mitigation Pumps - Time of Use Manual Deployment

These pumps are brought to the application area and then connected to previously installed rigid or flexible lines.

Ease of operation and training needed:

A. Training for connection to rigid piping and for manual operation of the pump set will be required.

B. Periodic inspection of suction screens and sump is needed to remove collected debris.

C. If the pump set is engine driven, then maintenance of the driver should be followed, per the manufacturer's recommendations.

D. Routine operation of the equipment will maintain reliability and provide opportunities for regular service.

E. Based on the size of the temporary pump, equipment may be needed to transport it from the storage location to the deployment point.

Deployment time: Deployment time will vary based on proximity of the temporary pump to the rigid piping locations and the availability of trained workforce to deploy.

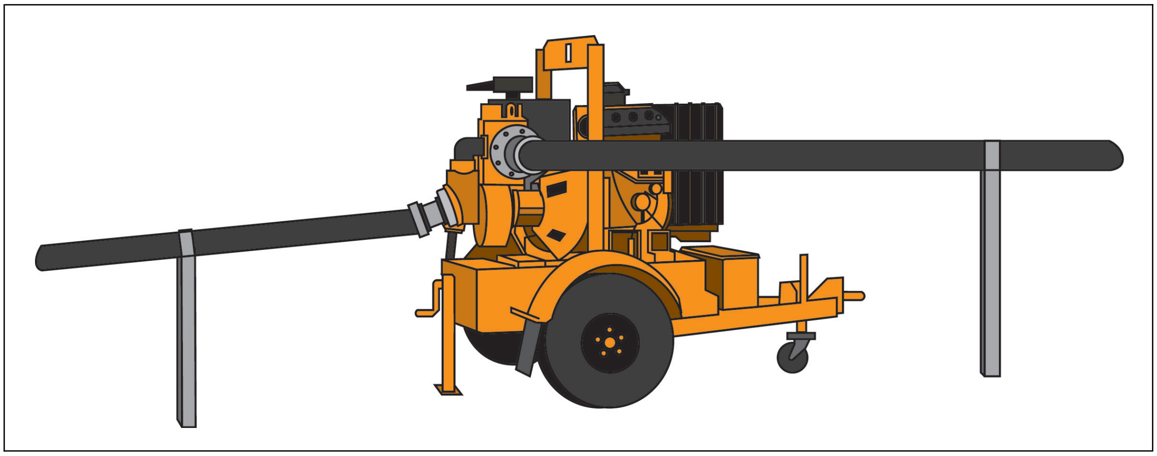


Fig. 3.7.9.2. Self-priming flood mitigation pump arrangement on a trailer connected to rigid piping

3.7.9.3 Temporary Flood Pumps - Time of Use Manual Deployment

Common applications for this style of flood protection will be to clean up seepage that gets past barriers into the protected area or to collect flood waters from the facility and discharge to a drain for removal from the site after the event. Typically, self-priming pumps are used in these applications. These flood pumps are designed to be brought to a site as needed by towing, on a truck or by other methods. Connection to the suction outlet is made with semi-rigid hose with the opposite (free) end fitted with a suction strainer. The discharge connection may use rigid, semi-rigid or lay flat hose and either be connected to the facility drain, or discharge openly in a location that will not return to the site. Installation considerations include connection to a reliable power supply (with alternate power as applicable) if electric motor driven, ability to exhaust (if engine driven), and screening to prevent clogging from debris in the water, in addition to the normal sizing for flow rate and discharge head.

Ease of operation and training needed:

A. Training will be required for connection to suction and discharge outlets and manual operation of the pump set.

B. If the pump set is engine driven, then maintenance of the driver should be followed, per the manufacturer’s recommendations.

C. Routine operation of the equipment will maintain reliability and provide an opportunity for regular service.

D. Based on the size of the temporary pump, equipment may be needed to transport it from the storage location to the deployment point.

Deployment time: Deployment time will vary based on proximity of the temporary pump to the rigid piping locations and availability of trained workforce to deploy.

4.0 REFERENCES

4.1 FM

Data Sheet 10-1, *Pre-Incident and Emergency Response Planning*

4.2 Other

American Concrete Institute. ACI 318, *Building Code Requirements for Structural Concrete.*

American Concrete Institute. ACI 423, *Recommendations for Concrete Members Prestressed with Unbonded Tendons.*

Federal Emergency Management Agency. FEMA Technical Bulletin 1-93, *Openings in Foundation Walls.*

Federal Emergency Management Agency. FEMA Technical Bulletin 8-96, *Corrosion Protection for Metal Connectors in Coastal Areas.*

International Code Council. *International Building Code.* Operating Standard 7-88, Ignitable Liquid Storage Tanks

4.2.1 Some Nationally Recognized Levee and Floodwall Standards

Construction Industry Research and Information Association (CIRIA). *The International Levee Handbook.* ISBN 978-0-86017-734-0.

US Army Corps of Engineers (USACE). *Design, Construction, and Maintenance of Relief Wells.* USACE Engineering Manual No. 1110-2-1914.

US Army Corps of Engineers (USACE). *Engineering and Design, Design and Construction of Levees.* USACE Engineering Manual No. 1110-2-1913.

US Army Corps of Engineers (USACE). *Engineering and Design, Retaining and Flood Walls.* USACE Engineering Manual 1110-2-2502.

US Army Corps of Engineers (USACE). *Guidelines For Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures.* USACE Technical Letter 111-2-571.

US Army Corps of Engineers (USACE). *Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams and Appurtenant Structures.* USACE Manual No. 1110-2-53.

US Army Corps of Engineers (USACE). *Mechanical And Electrical Design of Pumping Stations.* USACE Manual EM1110-2-3105.

APPENDIX A GLOSSARY OF TERMS

0.2-Percent-Annual-Chance Flood: A flood that has a 0.2-percent chance of being equaled or exceeded in any given year.

1-Percent-Annual-Chance Flood: A flood that has a 1-percent chance of being equaled or exceeded in any given year.

100-Year Flood: See 1-Percent-Annual-Chance Flood.

500-Year Flood: See 0.2-Percent-Annual-Chance Flood

Above-grade floor: A floor with a finished elevation above the surrounding grade on all sides.

Acre-foot (ac-ft, AC-FT): The quantity of water required to cover 1 acre to a depth of 1 foot, equivalent to 43,560 cu ft, or 326,000 gal or 1,233 m^3.

Alluvial fan: A cone-shaped deposit of alluvium where a stream leaves a narrow canyon, typically lacking topographical features except that of slope.

Alluvial fan flooding: Flooding in a cone shaped region, marked by deposits of alluvium, where a stream leaves a narrow canyon. In the United States, alluvial fans occur mostly along the base of the mountains in the western states. An estimated 15-25% of the arid west, including Los Angeles and Las Vegas, is covered by alluvial fans.

Alluvial plain: A nearly flat or gently sloping deposit of alluvium, typically lacking topographical features.

Apex: The canyon outlet in an alluvial fan, and the highest elevation on the fan. Flow leaving the apex spreads onto the uppermost portion of the alluvial fan via a single high-velocity channel that can change in location from event to event.

Approximate area occasionally flooded: A type of flood zone shown on USGS flood maps that provides no information on frequency, depth or duration, although it often refers to the 25–50-year flood (older term).

Aseptic formulations: Pharmaceutical products that are manufactured using processing techniques to ensure they are completely free from microbial contamination. This purity is especially critical for injectable drugs and other sterile products that are introduced directly into the body, where contamination could lead to serious infections.

The key characteristics of aseptic formulations include:

A. Active ingredients, excipients, containers, and closures are sterilized separately before being combined in a sterile environment.

B. Production occurs in cleanrooms equipped with airflow hoods, isolators and sterilizing fillers to minimize particle generation and microbial ingress.

C. Unlike some products that are sterilized after packaging, aseptic formulations rely on maintaining sterility throughout the process; as many drugs cannot withstand terminal sterilization methods like heat or radiation.

D. Continuous monitoring of air quality, temperature, humidity and microbial levels ensures the integrity of the aseptic process.

Bankfull stage: At a stream gauging station, the height above which extensive overflows occur on one or both banks.

Bare earth model: See DTM

Base flood: A term used by the Federal Insurance Administration (FIA) for the flood having a 1-percent probability of being equaled or exceeded in any given year; also referred to as the 100-year flood.

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

Basement: Any floor area partially or entirely below grade, regardless of occupancy or degree of interior finish.

Below-grade floor: See Basement.

Bench mark (BM): A permanent monument established by any Federal, State, or local agency, whose elevation and description are well documented and referenced to a recognized vertical datum.

Berms: Horizontal strips or shelves of material built contiguous to the base of either side of levee embankments for the purpose of providing protection from underseepage and erosion, thereby increasing the stability of the embankment or reducing seepage. Berms can be located on either side of levees, depending upon their purpose.

Breakwater: A structure built offshore to protect a coast or harbor from the force of waves.

By-pass system: An auxiliary or diversion channel, natural or man-made, used to pass flood waters that exceed the capacity of a river. The bypass is usually provided with levees and carries water only when the normal stream channel capacity is exceeded.

Canal: Any man-made channel built to route water to sites remote from a water source. Canals are usually operated by a single public utility and used for process water, power generation or navigation.

Catchment Area: An area of land where water from precipitation and/or snowmelt converges and drains to a common outlet such as a stream, river, lake or ocean. This area is also known as a watershed.

Closed conveyance: An enclosed structure, such as an underground pipe or culvert, not subject to overflowing.

Closure devices: Any movable and essentially watertight barrier, used in flood periods to close an opening in a levee, securing but not increasing the levee design level of protection.

Coastal flooding: Flooding created by wind on tide causing water to flow out of its normal boundary.

Coastal flood hazard area: An area of special flood hazards extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to storm surge and high-velocity wave action from storms or seismic sources. Sometimes referred to as a coastal high-hazard area or V-zone.

Combined sewer: A sewer designed to convey both sewage and stormwater within the same piping network.

Contour lines: A map feature (line) connecting points of equal elevation.

Conveyance: The ability of a pipe or stream to carry water. When the conveyance of the pipe or stream is exceeded, overflow of manholes or the stream banks will occur.

Conveyance system: All or part of a network of structures designed to convey stormwater from one location to another.

Critical flood depth: The inundation above the finished floor elevation at which important equipment, raw material, final product or operational integrity is affected by flooding, causing a significant increase in damage. Passing of the critical depth causes a step change in the depth-loss curve. Multiple critical depths can exist, depending upon the occupancy, construction and processes being carried out at a site. For example, in a pharmaceutical plant, only an inch of flooding can affect its operational integrity. FDA regulations impose a re-certification of the process and repair work at the property to remove mold. As another example, in a workshop, the critical depth of 2 ft (0.6 m) is reached when key controls of the production line start to be affected.

A few inches of water for sites with below grade spaces or tunnels, sensitive occupancies, or locations with utilities impacted by flood waters could significantly increase the loss.

Critical rainfall duration: The 100-year rainfall duration that maximizes flooding at key buildings and infrastructure of a site.

Datum: The reference specifications of a measurement system, usually a system of coordinate positions on a surface (a horizontal datum) or heights above or below a surface (a vertical datum see National Geodetic Vertical Datum).

Debris dam: A concrete or timber structure built across steep mountain valleys to trap high velocity water containing both large and small stony material. The dam slows the water velocity, forcing the deposit of alluvium and debris into the basin. Debris dams must be cleaned out periodically, as they become ineffective when full. They are common in some arid regions.

Debris basin: The area behind a small earth or concrete wall across a mountain stream that traps material that may have passed over upstream debris dams. These normally fill up with alluvium and must be periodically cleaned out to remain effective.

Design rainfall event: The physical parameters used as the basis for determining the runoff discharge. The event will have a frequency or a frequency and duration.

Design storm: A theoretical storm of specific frequency and duration developed empirically to simulate actual storms (e.g., Chicago design storm, Illinois State Water Survey design storm).

Detention: Holding surface water in a structure that will release it to receiving waters or a conveyance system over time. Detention structures can be in-line or off-line. In-line detention is the use of storage structures connected in-line to the conveyance system. An example is excess capacity in the pipe network of the conveyance system. Off-line detention refers to storage capacity where the flow has been diverted from the conveyance system to a storage structure.

Digital surface model (DSM): A representation of the elevation of the highest surfaces at a given location. This model includes all natural and manmade features. Often referred to as the ″first reflected surface,″ a DSM captures the elevation of objects like rooftops, mechanical equipment, parked cars, and the tops of trees or vegetation.

Digital terrain model (DTM): A representation of the ground's elevation, excluding trees, buildings and other surface objects. This model can also be referred to as a bare earth model.

Dikes: Embankments constructed of earth or other suitable materials to protect land from overflows or to regulate water.

Discharge: The quantity of stream, pipe, or sheet flow at any given time and place, usually measured in cubic feet per second (ft^3/s) or cubic meters per second (m^3/s).

Drainage area: The total land area where surface water runs off, is collected, and is directed into a stream or storm drain system.

Drainage divide: The line that separates one drainage area from another drainage area; precipitation that falls on one side of the divide stays in that particular drainage area.

Effective map: Latest flood map issued by FEMA, which is in effect as of the date shown in the title box of the flood map as: Effective Date; Revised Date; Map Revised.

EGM: An Earth Gravitational Model (EGM) is set of geopotential coefficients used in a spherical harmonic expansion to create a global potential surface that coincides with Mean Sea Level (MSL).

EGM2008: EGM2008 is a geopotential model of the Earth. It represents a milestone in global gravity field modeling and is used as the geoid reference in the World Geodetic System. Developed using accurate and detailed gravimetric data, EGM2008 satisfies a wide range of applications.

Elevation: The vertical distance of a point above sea level. It is commonly used in geography to describe the altitude of a location, such as a mountain or a city. The flood map vertical datum must be the same as and the city, site or plan vertical datum for analysis.

Encroachment: Any fill, structure, building, use, accessory use or development in the floodway or floodplain.

FMEA's area of minimal wave action (MiWA): The lower-hazard area expected to receive breaking waves that are 1.5 feet or less during the 1-percent annual chance flood.

FEMA's area of moderate wave action (MoWA): The higher-hazard area expected to receive breaking waves that are 1.5–3 feet during the 1-percent annual chance flood.

Flash flood: A flood that rises within hours, stays a short while and rapidly dissipates. It is usually characteristic of a small stream reacting to a single, severe storm.

Flood: The overflow, breaking, or breaching of natural or man-made stream channels, bodies of water or places where water is expected to be, including water from waves, tides or tsunamis.

Flood boundary and floodway map: Floodplain management map issued by FEMA that shows, based on detailed and approximate analyses, the boundaries of the 100-year and 500-year floodplains and 100-year floodway.

Flood crest: The maximum stage, height or elevation (normally in feet and inches or meters) reached by the flood waters at a given location.

Flood flow-frequency curve: A graph showing the number of times per year on the average that floods of certain magnitudes are equaled or exceeded.

Flood frequency: See Recurrence Interval.

Flood hazard area, floodplain, flood-prone area: Land area subject to inundation by water from any flooding source.

Flood hazard boundary map (FHBM): Initial map issued by FEMA that identifies approximate areas of 100-year flood hazard in a community. Contour lines and BFEs are not normally shown.

Flood hydrograph: A graph or curve representing water elevation or discharge at a particular location on a stream, plotted against the level above an arbitrary gauge datum or above MSL, (discharge in cu ft/s [cu m /s] and time in hours or days).

Flood insurance rate map (FIRM): Insurance and floodplain management map issued by FEMA that identifies areas of 100-year flood hazard in a community. It often refines and supersedes the FHBM. In some areas, the map also shows base flood elevations and 500-year floodplain boundaries and, occasionally, regulatory floodway boundaries.

Flood insurance study (FIS): Engineering study performed by FEMA to identify flood hazard areas, flood insurance risk zones and other flood data in a community. It often covers the significant water courses within the boundaries of a particular community. These studies contain flood profiles, narrative material on the extent and depth of past floods and similar data on 100-year and 500-year floods. A flood insurance rate map (FIRM) is separately issued to be used with the FIS.

Flood peak: The maximum instantaneous discharge of a flood (normally in cu ft/s or cu m/s) at a given location. It usually occurs at or near the time of the flood crest.

Flood-plain: The relatively flat area or lowlands adjoining or extending from the channel of a river, stream or water course, ocean, lake, or other body of standing water which have been or may be covered by flood water. The area may be at some distance from the actual exposing body of water.

Flood-plain anagement: The operation of a program of corrective and preventative measures for mitigating flood damage, including, but not limited to, emergency preparedness plans, flood-control works, and floodplain management regulations.

Flood-plain management regulations: Zoning ordinances, subdivision regulations, building codes, health regulations, special-purpose ordinances, and other applications of enforcement for mitigation of flood damage.

Flood-prone area: A term used by USGS for areas subject to flooding when upstream drainage area exceeds 250 sq mi (648 sq km) in semi-arid regions, or 100 sq mi (259 sq km) in rural areas, or 25 sq mi (65 sq km) in urban areas. A 100-year flood plain is normally delineated on the map unless another level is specifically designated.

Flood profile: A term used by the U. S. Army Corps of Engineers and FEMA. The graph depicts a longitudinal section of a stream, where stream bed, normal water, 100-year and other flood levels are shown, with elevations related to MSL. Flood profiles are an important part of the data presentations in Flood Plain Information Studies and Flood Insurance Studies.

Flood season: The time of year of historically highest river flows. In most areas, this is caused by the snow melting in the spring. Small creeks may be most affected by cloudbursts, usually in summer. Hurricanes may cause massive rains during summer and fall.

Flood stage: The stage or elevation at which overflow of the natural banks of a stream or body of water begins in the area in which the elevation is measured. It is also defined as the level at which flood damage begins. This term has been used by the National Weather Service, and is essentially the same as bankfull stage.

Flood wall: A concrete wall used above ground to confine water to a channel. The term is also used for a levee or dike, particularly if the water side is concrete.

Flood zone: The designation given to an area that indicates the magnitude of the flood hazard within the specific area.

Floodway: The channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.

Flow path: The path a particle of water would take starting from the drainage divide following along the natural ground slope toward the point of interest. The flow path will generally have three types of flow. These are sheet flow, shallow concentrated flow, and open channel flow.

Fluvial flooding: Flooding caused by the rise of water levels in rivers, lakes, or streams.

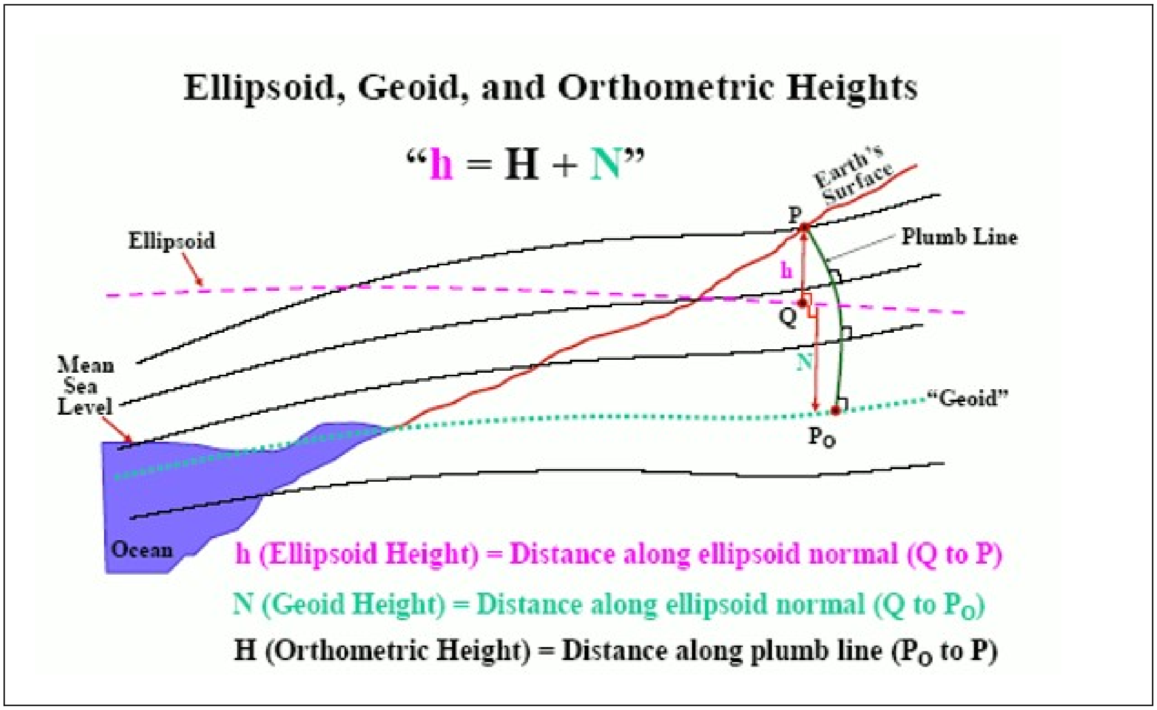
Freeboard: The vertical distance from the design water surface to the top of the channel wall, levee or dam. It is provided to protect against unaccounted factors such as future upstream development, accumulation of silt and debris, etc.

Gauging station: A location on a river or stream where water elevations are monitored and recorded using a gage. The gage height (ft, m) can be translated into river discharge (cfs, cms).

Geocoding: The process of associating geographic coordinates or grid cell identifiers to data, points, lines, and shapes.

Geographic information system (GIS): A system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems.

Geoid: An imaginary surface that closely approximates the shape of the Earth, taking into account irregularities in the distribution of mass within the Earth. It is the shape that the ocean's surface would take under the influence of Earth's gravity, including gravitational attraction and Earth's rotation, if other influences such as winds and tides were absent.



Gravity outlets: Culverts, conduits, or other similar conveyance openings through the line-of-protection that permit discharge of interior floodwaters through the line-of-protection by gravity when the exterior stages are relatively low. Gravity outlets are equipped with gates to prevent river flows from entering the protected area during time of high exterior stages.

Horizontal control: A network of stations of known geographic or grid positions referred to a common horizontal datum, which control the horizontal positions of mapped features with respect to parallels and meridians, or northing and easting grid lines shown on the map.

Hydraulic analysis: An engineering analysis of a flooding source carried out to provide estimates of the elevations of floods of selected recurrence intervals.

Hydraulic computer model: A computer program that uses flood discharge values and floodplain characteristic data to simulate flow conditions and determine flood elevations.

Hydraulic filled dam: A type of earth-filled dam in which a homogeneous earth bank is laid in place by pumping mud slurry to the construction side. This type of dam is not well consolidated, and holds a higher moisture content, as mechanical compaction is not normally used. This is the weakest method of dam construction and has a high collapse rate. Earthquake damage is common.

Hydraulic methodology: Analytical methodology used for assessing the movement and behavior of floodwaters and determining flood elevations and regulatory floodway data.

Hydrograph: A graph showing stage, flow, velocity, or other properties of water with respect to time.

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

Hydrology: The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground.

Hydrologic unit code: An eight-digit code identifying four levels of subdivisions. The code identifies geographic areas of the United States. The geographic areas define drainage regions based on surface topography. The first level (two digits) defines the region as one of 22 regions in the US. The second level defines a sub-region that is drained by a river system, a reach of a river, a closed basin, or a group of streams.

The third level subdivides the sub-regions into accounting units. The fourth level is the cataloging unit. A cataloging unit is a geographic area representing all or part of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature.

Hyetograph: A chart showing the distribution of rainfall over a particular period of time or a particular area.

Ice jam: An accumulation of ice in a stream that reduces the cross-sectional area available to carry streamflow and increases the water-surface elevation of the stream.

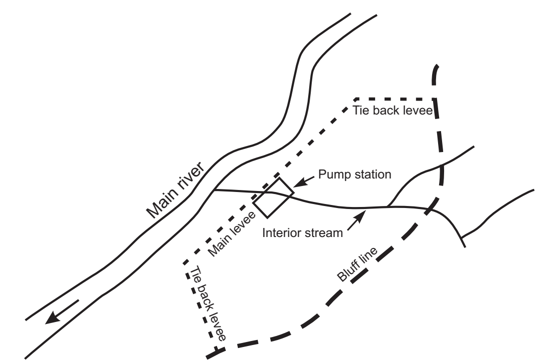
Inlet structure: An opening to a conveyance (e.g., storm sewer) which acts as a collection point for stormwater runoff. Examples include catch basins, curb openings, and grate inlets.

Interior drainage systems: Systems associated with levee systems that usually include storage areas, gravity outlets, pumping stations, or a combination thereof.

Intensity-duration-frequency curve: A series of curves that relate the rainfall intensity, duration of a storm and the recurrence interval for a specific location.

Jetty: A structure that projects from the land out into a body of water, typically built to influence the current or tide, or to protect a harbor or shoreline from erosion.

Levee systems: A bank of earth placed parallel to a river channel setback. Levees may be unlined or lined with some material such as stone rip-rap or concrete. Flood protection systems also include structures, such as closure and drainage devices, which are constructed and operated in accordance with sound engineering practices.



Plan view schematic

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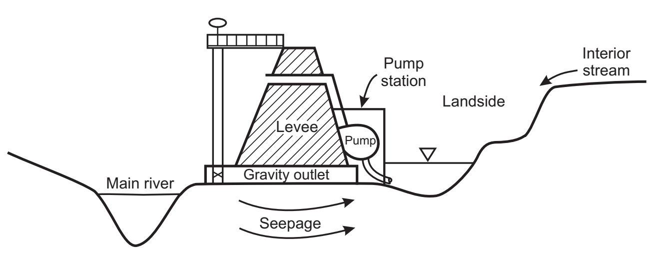

Sectional view schematic

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Light detection and ranging (LIDAR) system: An airborne laser system, flown aboard rotary or fixed-wing aircraft, that is used to acquire x, y, and z coordinates of terrain and terrain features that are both manmade and naturally occurring. LIDAR systems consist of an airborne Global Positioning System with attendant base station(s), inertial measuring unit, and light-emitting scanning laser. Ground elevation data points are then created that can be imported into various tools to develop point source data, ground elevation profiles or 3D maps. LiDAR data can be processed to create DTM and DSM.

Lines-of-protection: Locations of levees or walls that prevent floodwaters from entering an area.

Local area fixed protection (LAFP): Flood-control works (levees, flood walls, etc.) that help control the level of water in the exposure (river, lake, stream, etc.) or provide protection against a particular water level.

Local mean sea level: The average sea level between high and low tide at a specific location.

Mean annual flood: The average of the annual peak river discharges.

Mean recurrence interval (MRI): Also called frequency. Refers to the statistical average time between events for a given set of parameters (e.g., rainfall intensity, duration). For example, a rainfall intensity having a recurrence interval of 10 years will occur on an average of once every 10 years, or on an average of 10 times in 100 years. It also may be referred to as having a 10% probability of exceedance, as there is a 10% chance of it occurring in any one year. It does not occur at regular ten-year intervals. For instance, it may not occur for 40 years, then occur several times in successive months.

Mean sea level (MSL): The standard datum (base) for reporting topographic land elevations. It is also known as the National Geodetic Vertical Datum (NGVD) of 1929. It does not necessarily equal Local Mean Sea Level.

National Geodetic Vertical Datum of 1929 (NGVD): Datum established in 1929 as a basis for measuring flood, ground, and structural elevations.

North American Vertical Datum (NAVD): The successor to the National Geodetic Vertical Datum of 1929, established in 1988.

North American-Pacific Geopotential Datum of 2022 (NAPGD2022): The geopotential reference framework for vertical and gravity-related measurements in the U.S. and its territories. It replaces older vertical datums like NAVD 88.

Open channel flow: The point at which shallow concentrated flow enters a clearly defined waterway.

Open conveyance: A structure, such as a ditch or swale, that can overflow to surrounding terrain.

Opening: Any doorway, operable window, passageway, or open conveyance system in a building wall.

Outlet structure: The structure at the termination of a conveyance system where the collected runoff is deposited into receiving waters.

Penetration: Any pipe, cable, wire, or closed conveyance system that passes through a building wall.

Pluvial flooding: Flooding from an extreme rainfall event. Can be independent of an overflowing water body. Also called surface water or stormwater runoff.

Ponding: The result of runoff or flows collecting in a depression that may have no outlet, subterranean outlets, rim outlets, or manmade outlets such as culverts or pumping stations. Impoundments behind manmade obstructions are included in this type of shallow flooding as long as they are not backwater from a defined channel or do not exceed 3.0 feet in depth.

Precipitation: A general term that includes rain, snow, sleet, hail, etc. For the purposes of this document it refers to rainfall; the total amount of rain that falls during a specific event, or a rate of rainfall over a given duration.

Probable maximum flood (PMF): A hypothetical flood representing the worst combination of historically known weather circumstances. There is no frequency assigned to this flood. It is considered beyond a reasonable level of flood design and is generally not used as a design criterion, except by the Corps of Engineers for design of flood-control dam spillways.

Pumping stations: Pumps located at or near the line-of-protection to discharge interior flows over or through the levees or floodwalls (or through pressure lines) when free outflow through gravity outlets is prevented by high exterior stages.

Rainfall intensity: The rate of rainfall expressed in depth per unit of time.

Rating curve: A graph of river stage (gage height) vs. river flow (discharge). It shows the relationship between the water level and the flow rate at the river gage location.

Rating table: A table prepared for a specific point on a stream (normally a USGS gaging station) that shows the relationship between gage height (or water level) and stream discharge. Normally, gage height is shown in tenths of a foot and discharge in cubic feet per second.

Receiving water: The lake, ocean, pond, river, canal or other body of water into which the stormwater drainage system deposits collected runoff.

Recurrence interval: Also called flood frequency. Refers to the statistical average time between floods of a specified discharge. For example, a flood having a recurrence interval of 10 years will occur on an average of once every 10 years, or on an average of 10 times in 100 years. It may also be referred to as the 10% flood, as there is a 10% chance of it occurring in any one year. It does not occur at regular ten year intervals. For instance, it may not occur for 40 years, then occur several times in successive months. Similarly, a 50-year flood would be expected twice in a century, and may be referred to as the 2% flood, as there is a 2% chance of it occurring in any one year. The commonly used term 100-year flood is expected to average only once a century as it has a 1% chance in any one year. Examples of such floods happening twice a decade, however, are common.

Regulatory floodway: The area defined as the channel of a stream and the adjacent land areas reserved to discharge the 100-year flood without cumulatively increasing the elevation of the 100-year flood more than a designated height.

Reservoir: A body of water contained by a dam for the purpose of providing a water supply to an area or municipality. While a reservoir may have some reserve-holding capacity during flood time, the flood-inhibiting characteristics are often negligible. The reservoir may expose the downstream area to overtopping, rupture or excessive discharges.

Retention: Retaining surface water in a structure and not releasing it to receiving waters or conveyances. The accumulation of water is released only through evapotranspiration, infiltration, or percolation.

Ring levees: Levees that completely encircle or ″ring″ an area subject to inundation from all directions.

Rip-rap: A foundation or sustaining wall of stones randomly placed without mortar. Rip-rap is used primarily for channel improvement and stabilization.

River flooding/Riverine flood hazard area: Flooding that results from a river or stream overflowing its normal boundaries. For flood type in Horizon/Polaris river flooding includes all flooding from flood waters overflowing its normal boundaries, except coastal flooding.

Runoff: See surface water.

Safe Water Level: Refers to the highest flood level for which reasonable assurance can be made that the levee system will not fail (with no emergency remedial measures taken). This is further defined as the river stage at which only normal surveillance and minor remedial work would be required during normal flood periods, and close surveillance of the system is required only during extended flood periods.

Sanitary sewer: Sewers that carry domestic waste and possibly some industrial waste.

Sea wall: A protective structure of stone or concrete that extends from the shore into the water to prevent a beach from washing away.

Seiche (pronounced “saysh”): An oscillation of the water surface in a lake, bay, etc., caused by seismic disturbances, winds, waves, or abrupt, unusual changes in atmospheric pressure.

Setback levees: Levees that are built on the land side of existing levees, usually because the existing levees have suffered distress or are in some way endangered, as by river migration.

Shallow concentrated flow: After 100 to 300 ft (30 to 90 m) of sheet flow, the water gets somewhat deeper and channeled and is referred to as shallow concentrated flow.

Shallow flooding: Unconfined flows over broad, relatively low relief areas, such as alluvial plains; intermittent flows in arid regions that have not developed a system of well-defined channels; overbank flows that remain unconfined, such as on delta formations; overland flow in urban areas; and flows collecting in depressions to form ponding areas. For National Flood Insurance Program purposes, shallow flooding conditions are defined as flooding that is limited to 3.0 feet or less in depth where no defined channel exists.

Sheet flow: A type of flooding characterized by a broad, relatively unconfined down slope movement of water across sloping terrain. Sheet flow is usually no more than 1-2 ft (0.3-0.6 m) deep.

Sheet runoff: The broad, relatively unconfined downslope movement of water across sloping terrain that results from many sources, including intense rainfall and/or snowmelt, overflow from a channel that crosses a drainage divide, and overflow from a perched channel onto deltas or plains of lower elevation. Sheet runoff is typical in areas of low topographic relief and poorly established drainage systems.

Special flood hazard area (SFHA): Land area subject to inundation by a flood having a 1-percent or greater probability of being equaled or exceeded during any given year (base, or 100-year, flood).

Spur levees: Levees that project from the main levee and serve to protect the main levee from the erosive action of stream currents. Spur levees are not true levees; they are training dikes.

Stage: The height of the water surface above a reference elevation.

Standard project flood (SPF): Is the most severe combination of hydrological and meteorological factors considered reasonably characteristic of the region. It is computed using the Standard Project Storm (SPS). This definition does not include frequency of occurrence, yet it will generally be more severe than a 100-year flood. It is a flood level often used by the Army Corps of Engineers when designing flood-control works.

Standard project storm (SPS): It is a theoretical model used to estimate the most severe rainstorm that could reasonably occur in a specific area. It represents the relationship between precipitation and time, defining how rainfall intensity varies throughout the duration of the storm. The SPS aims to capture the typical pattern of precipitation for major storms in the locality.

Steriles production: The process of producing pharmaceutical or medical products in an environment that is completely free from viable microorganisms and other contaminants. This process is essential for products that are introduced directly into sterile areas of the body, such as injectable drugs, ophthalmic solutions, and implantable devices.

Stillwater flood elevation (SWEL): Projected elevation that flood waters would assume, referenced to National Geodetic Vertical Datum of 1929, North American Vertical Datum of 1988, or other datum, in the absence of waves resulting from wind or seismic effects.

Stillwater flood level (SWFL): Rise in the water surface above normal water level on the open coast due to the action of wind stress and atmospheric pressure on the water surface.

Stop logs: Logs, planks, cut timber, steel, or concrete beams fitting into end guides between walls or piers to close openings in levees, floodwalls, dams, or other hydraulic structures. The stop logs are usually handled or placed one at a time.

Storage facility A detention or retention structure as part of a stormwater management system.

Storm sewer: A sewer designed specifically to carry stormwater, street wash, and other surface water to disposal points.

Storm surge: The wall of water that precedes the leading edge of the eye of a hurricane during landfall. It is generally caused by the low atmospheric pressure in the eye of a hurricane, high winds and waves.

Stormwater flooding: Flooding from rainfall or melting snow before the runoff reaches a body of water or channel where water is normally held or transported.

Stormwater management or stormwater management system: Terms used to describe a system developed to collect and manage stormwater runoff safely and effectively. A collection of pipes, channels, detention/retention elements and collection system (catch basin, grates, etc.) designed to remove rainfall runoff flowing and accumulating in an urbanized area. Terrain/landscaping includes the layout and elevation of roads, ground, buildings, etc. within an urbanized area for the purpose of collecting and directing rainfall runoff into the stormwater system.

Stream flow: The portion of flowing water from a flood or surface-water event that is in a defined channel.

Street gates: Closure gates used during flood periods to close roadway openings through levees or floodwalls.

Stormwater rational method: This method predicts the peak runoff using the formula Q=CiA, where:

Q represents the peak runoff flow.
C is the runoff coefficient, which varies based on surface characteristics.
i is the rainfall intensity, typically measured in inches per hour or millimeters per hour.
A is the area contributing to the runoff.

The rainfall intensity (i) is determined based on the time of concentration, which is the time it takes for water to travel from the most distant point in the watershed to the point of interest. This method is widely used in hydrology and civil engineering to design stormwater management systems.

Sublevees: Levees built for the purpose of under seepage control. Sublevees encircle areas behind main levees, which are subject, during high-water stages, to high uplift pressures and possibly the development of sand boils. Sublevees normally tie into the main levees, thus providing a basin that can be flooded during high-water stages, thereby counterbalancing excess head beneath the top stratum within the basin. Sublevees are rarely employed as the use of relief wells or seepage berms make them unnecessary except in emergencies.

Surface water: Melting snow or rain water while collecting and/or flowing over the ground surface on its way to natural or man-made drainage channels or ground infiltration. Same as surface runoff.

Swale: A shallow, trough-like depression that carries water during rainstorms or snow melts.

Tides: The regular rise and fall of sea levels caused by the gravitational interactions between the Earth, the Moon, and the Sun. These movements result in periodic changes in water level along coastlines and are influenced by the relative positions and distances of these celestial bodies.

Specific types of tides based on alignment, distance and timing are derived from this general concept:

Spring Tide – strongest tidal range (Moon and Sun aligned)
Neap Tide – weakest tidal range (Moon and Sun at right angles)
King Tide – highest predicted tide of the year (spring tide + perigee)
Perigean Spring Tide – spring tide during Moon's closest approach
Apogean Tide – smaller tides during Moon's farthest point

Tie back levees: Levees that extend from the main levees along rivers, lakes, or coasts to bluff lines (high ground) and are part of the line-of-protection.

Time of concentration: The time required for water to flow from the most distant point of a drainage area to the point of concern (e.g., a catch basin). The time of concentration is specific for each location in a drainage area and can consist of overland flow time, open channel flow time, and pipe flow time. Assuming a constant rainfall intensity, the time of concentration will be the time at which all of the drainage area is contributing to the runoff and thus the time of peak runoff volume.

Topographical map: Any map on which terrain relief is indicated by contour lines. The most commonly available topographical map is the series produced by the USGS on a scale of 1:24,000 which show 7-½ minutes of longitude and latitude. These are in color and show all significant natural or man-modified areas. Ninety percent of elevations are accurate within one-half of the contour interval. The 7-½ minute map is also the basis for the flood map produced by the USGS. Some of the new USGS maps use SI units and are Z-fold maps. They cover 7-½ minutes latitude and 15 minutes longitude.

Transect: Cross section taken perpendicular to the shoreline to represent a segment of coast with similar characteristics.

Travel time: the time it takes water to travel from one location to another in a watershed along a flow path.

Tsunami/seismic sea wave: An ocean wave front of seismic origin, generated principally by undersea earthquakes of magnitudes greater that 6.5 on the Richter Scale with focal depths less than 30 miles (48 kilometers). They are long period waves (5 minutes to several hours), of low height when in deep oceans. Even though propagating at more than 500 mph (223 m/s), they are not discernible in the deep ocean and go unnoticed by ships. Only when the wave approaches a coastal region, do refraction, shoaling and harbor resonance become important and produce the typical great wave heights. Most tsunamis occur in the Pacific Ocean. Run-up elevations for the 100- and 500-year event for the U.S. Pacific Coast and Hawaii have been published by the Army Corps of Engineers.

Undeveloped coastal barrier: An area, adjacent to the Atlantic or Pacific Oceans, the Gulf of Mexico, or the Great Lakes, where flood insurance will not be available for substantially improved structures or new construction. These areas are protected by law to discourage development in an attempt to preserve dunes, beaches, and wildlife habitats.

Unit hydrograph: The hydrograph of direct runoff from a storm uniformly distributed over a drainage basin during a specified unit of time.

Wave action: Refers to the impact of waves on structures and shorelines, particularly during coastal flooding events. It encompasses the forces exerted by waves, including their height, frequency, and energy, which can lead to erosion, structural damage and increased flood levels.

Watershed: An area of land where water from precipitation and snowmelt drains to a common point, such as a stream, river, lake or ocean. Also referred to as a catchment area.

Water-surface elevations (WSELs): The heights of floods of various magnitudes and frequencies in floodplains of coastal or riverine areas, in relation to a specified vertical datum.

Wave breaking: The process where a wave becomes unstable due to increasing steepness and collapses forward, dissipating energy. Typically occurs as waves travel into more shallow water where the wave base slows down due to friction with the seabed, causing the crest to outrun the base and the wave to break.

A common rule of thumb is that a wave will break when the wave height (H) reaches approximately 0.78 times the local water depth (d): $H_{break} \approx 0.78 \cdot d$.

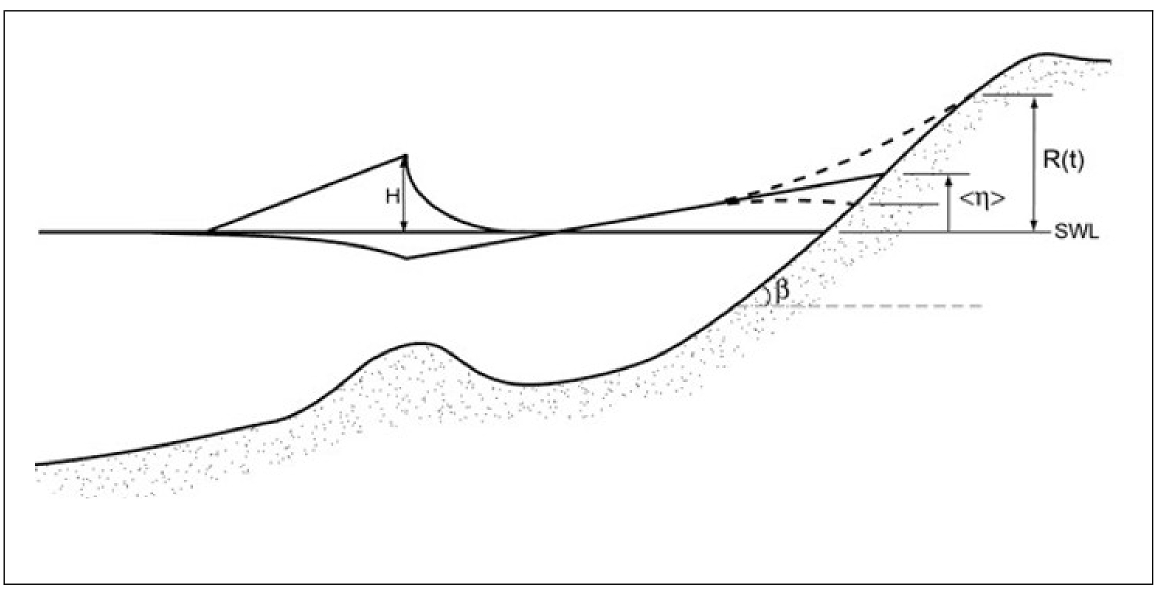
Wave height: The vertical distance between the crest (highest point) and the trough (lowest point) of a wave.

Wave overtopping: The process by which water from waves flows over the top of a coastal structure—such as a seawall, breakwater, or revetment—when the wave run-up exceeds the crest height of the structure. This phenomenon can lead to flooding, erosion or damage to infrastructure behind the structure.

Formally, wave overtopping is quantified as the discharge of water per unit time per unit length of the structure, typically expressed in gallons per second per foot (gal/s/ft) (liters per second per meter [l/s/m]) or cubic feet per second per foot (ft^3/s/ft) (cubic meters per second per meter [m^3/s/m].) The overtopping rate depends on factors such as wave height and period, water level, structure geometry and wave direction.

Wave period: The time it takes for two successive wave crests (or troughs) to pass a fixed point (see Wavelength).

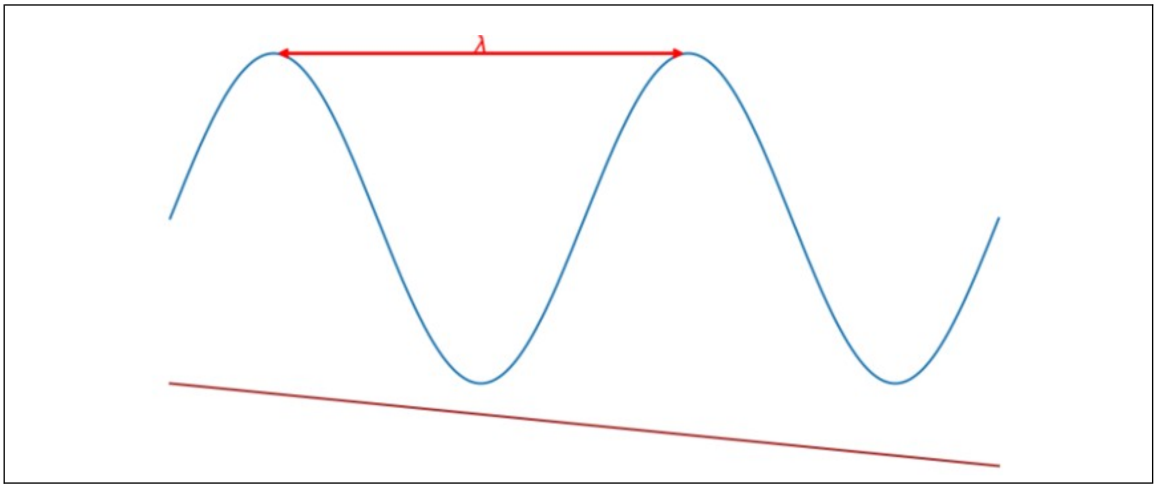
Wave runup: The maximum vertical extent of wave uprush on a beach or coastal structure above the still water level. It includes both the wave setup and the swash (the rush of water up the slope due to individual waves).



From USGS: Wave runup (R) is the time-varying elevation of water level at the shoreline, measured here in reference to the still water level (SWL). The schematic shows wave runup (R), and its components, time-averaged wave setup (η) and time-varying swash (dashed lines), as a function of wave height (H) and beach slope (β).

Wave setup: The sustained increase in mean water level at the shoreline caused by the momentum transfer from breaking waves. It results in a higher baseline water level, independent of individual wave crests.

Wavelength: The horizontal distance (λ) between the two successive wave crests (or troughs) in a wave pattern.



Wind setup: The tilting of the surface of a body of water caused by the movement of the surface water toward the leeward shore under the action of the wind. Wind setup is generally larger in shallow basins with rough bottoms.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version). l

October 2025. Interim revision. The following changes are included:

A. Section 2.2.2, Stormwater Runoff and Terrain Management was completely rewritten to improve wording. The technical intent was not changed.

B. Section 3.6.1, Freeboard is a Key Design Consideration, was rewritten.

April 2025. Interim revision. Minor editorial changes were made.

July 2023. Interim revision. Minor editorial changes were made.

October 2019. Interim revision. Minor editorial changes were made.

April 2019. Interim revision. Minor editorial changes were made.

October 2018. Interim revision. Added support information to Section 3.2 Flood Maps and Data, and Section 3.4 Understanding Flood Sources and Their Characteristics, covering historical flood data, floodway constrictions, and flood control dams.

October 2016. The following major changes were made:

A. Expanded the document to better address solutions for existing buildings. Rewrote parts of the data sheet to better emphasize flood prevention and mitigation, which is an approach that relies on permanent solutions and emergency actions.

B. Added new recommendations on lessening damage for existing buildings and equipment (Section 2.2.6). Topics in this section include the following: Permanent Site Flood Protection Systems, Complete and Partial Building Protection, Protection or Relocation of Equipment, Production Lines or Storage, and Temporary Perimeter Flood Protection Systems.

C. Added three recommendations (2.2.2.11, 2.2.2.12, and 2.2.2.13) to Section 2.2.2, Stormwater Runoff and Terrain Management. These recommendations cover stormwater systems with a history of flooding, desert storm systems, and basement pumped drainage systems.

D. Revised Section 3.0, Support for Recommendations, to help the building owner better understand the flood scenario and select an appropriate solution to retrofit buildings. Added or expanded information on the following topics: flood maps and data, site-specific flood studies, flood protection breach studies, understanding the flood potential, understanding flood sources and their characteristics, understanding the impact, and building or retrofitting in a flood-prone area. Added examples on opening-protection solutions, and a section on temporary perimeter protection.

October 2014. Interim revision. Minor editorial changes were made.

July 2014. Interim revision. Minor editorial changes were made.

July 2012. The following changes were made:

- Sections 2.2.6 and 3.7 have been added to the data sheet.

September 2010. Minor editorial changes were made.

February 2010. Minor editorial changes were made.

October 2007. Minor editorial changes were made for this revision.

March 2007. This data sheet has been completely rewritten and incorporates material formerly contained in Data Sheets 9-13, *Evaluation of Flood Exposure*, and 9-2, *Surface Water*, which are now obsolete.