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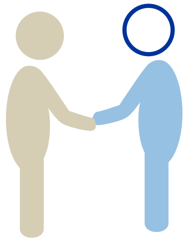
Designing flood resilience into new buildings

May 2019

The most cost-effective means of increasing resilience (irrespective of peril), is to plan and implement these measures at the earliest stage possible in the design process.

The objective of this document is to describe some design measures, which could be considered during the planning stage of a new building, to improve building resilience to flood.

Introduction



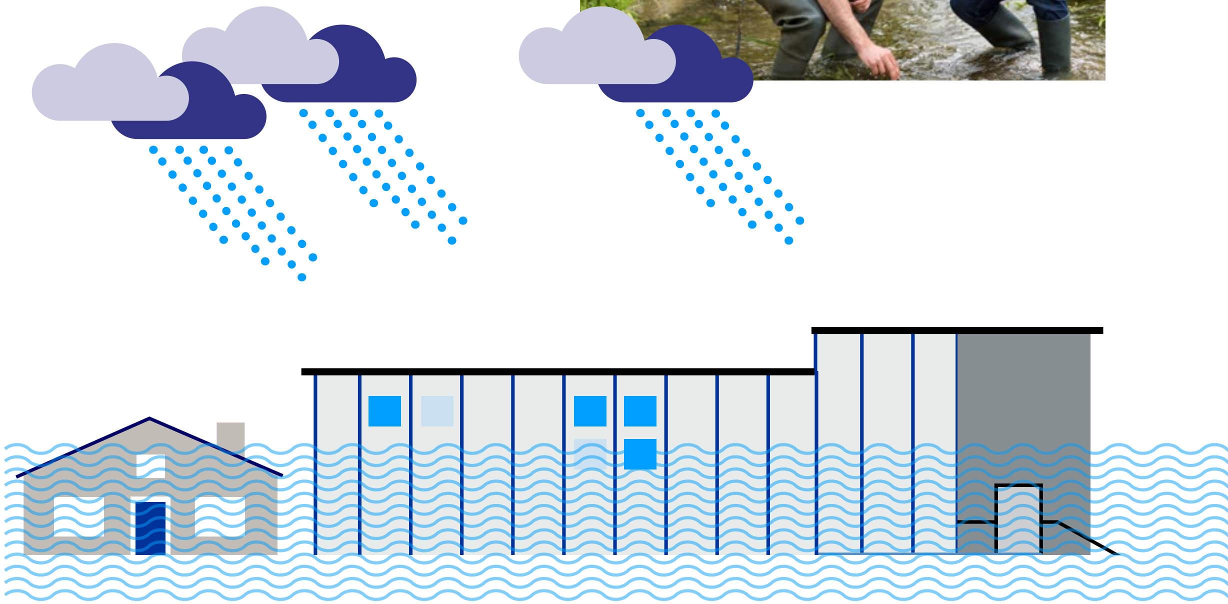
The proposed measures in this document aim to mitigate the impact of a flood event on a building and should be implemented in the planning or design stages.

These measures are to be considered as part of a comprehensive resilience strategy. Such a strategy would typically include several measures (both physical and organizational), to account for the uncertainties inherent in flood risk. Even with such measures in place, flood risk cannot be totally eliminated.

Since type, probability and intensity of flooding (e.g. floodwater depth and velocity) varies considerably within a very small geographic area, a site-level flood hazard analysis should be carried out in the planning phase to refine the recommendations provided in this document.

The guidance in this document is not exhaustive. It is based on observations from historical losses as well as the limited design guidelines and standards available in some countries (see Appendix for some examples).

For more information on different types of flooding go to Zurich's natural hazards site at ***www.zurich.com/en/knowledge/topics/natural-hazards***





Flood hazard level: Defining the "Design Flood"

In the limited number of flood design codes or standards available (see Appendix), the minimum level of protection for buildings in flood zones, whether riverine, pluvial, storm surge, etc., (depending on the code or standard) is defined with reference to a Design Flood Elevation (DFE), Flood Proofing Elevation (FPE) or a Base Flood Elevation (BFE). Various flood intensities, expressed in terms of return period, are referenced in these documents, which are based on national flood hazard maps. Such a design flood elevation often corresponds to some probability of occurrence, expressed as 100-year or 500-year return period flood, for example. Some design codes also allow for climate change effects. For drainage system design, i.e. rainfall protection, the duration of the event is also defined.

It is to be noted that the intensity of an event increases with the return period. In other words, the high return period events represent the high intensity, low probability floods, while low return periods represent high frequency (probability) floods of small intensity.

Definition: Return period vs probability of occurrence

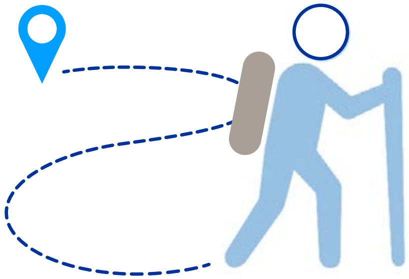
There is a wide misconception around the term "return period". A 100 year return period event (sometimes called a 1 in 100 year event), for example, does not mean it occurs once in 100 years. The return period is just another way to express probability of occurrence (or exceedance). It is the average (mean) number of times an event may occur over the indicated time period. It is based primarily on historical events, as well as statistical models. A "100 year return period" event can happen several times in a year. A more accurate way to express a hazard level is by means of "probability of occurrence within a certain time frame", e.g. an event can be expressed as "1% annual probability of occurrence" instead of a "100 year return period event". The same event can be expressed as a "26% probability of occurrence in a 30 year time period". The relationship between "return period" and "probability of occurrence in a time period" follows an exponential relationship (the Poisson model).

If regional or global flood hazard maps are used, determine the reliability of the resource. As a rule-of-thumb, the smaller the area covered by the hazard map, the more closely it will reflect local conditions, which influence the flood hazard. Other factors determining the reliability of a hazard map include (but are not limited to), year of issue, historical urban development in the catchment area (the area where all surface water, flows into the river or water body), water bodies included in the study, consideration of regional flood protection measures, and so on.

Irrespective of the availability of national flood hazard maps, the flood design level (intensity and probability) must be defined for the location as a basis for flood mitigation measures. This parameter should not be just based on the last flood event, which has impacted the region. Such an approach does not comply with sound engineering practice, which defines various safety factors that account for uncertainties and variability in flood intensity and performance of the protection system.

Ideally, the definition of a design flood should be based on a site-level flood hazard analysis. The study should include all potential sources of flooding, e.g. creeks and seasonal water bodies, surface runoff, intense rainfall, etc. and not only large rivers. It should also take into account the effect of flood protection systems that may reduce or increase flood intensity and probability at the location. Such a study should provide, as a minimum, the elevation (depth) of floodwater related to the design level (or to different return periods). Additional valuable design parameters include the floodwater velocity and duration of flooding.

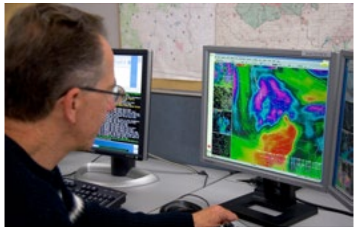
Guidance



Design criteria for protection measures

Once the characteristics of the design flood level have been identified (probability, geographic extent, depth, flow velocity, and duration of event), the associated protection measures can be designed and detailed.

Flood resilience measures can be generally classified into two categories: **physical and organizational**. Both should be defined at local (site, commercial or industrial park, suburb, etc.) as well as individual building levels. ***Since this document deals with the design of new buildings, physical measures only will be discussed here.***



The uncertainties and variability associated with flood hazard should be reflected in the design of the protection system. For example by increasing the height of flood barrier, the elevation of pipe penetration through the outside walls with respect the design flood depth, or by increasing the thickness of the flood protection wall.

As an example of how some standards deal with variability in flood hazard maps, Table 2.3.7 in the Australian standard "Construction of Buildings in Flood Hazard Areas" recommends increasing the flood hydrostatic pressure used in the design of structures in flood zones by a flood load factor, which is dependent on the length of flood records. For example, a 50% increase in the flood related actions is recommended when flood records are short (minimum 25 years). Some design codes also require a safety margin, often between 30cm to 60cm (1ft to 3ft) above the design flood depth, as the minimum height of flood protection depending on importance and occupancy of the building.

Flood resilience strategy

The level of protection provided at a location can be broadly classified into three categories[1], depending on the characteristics of the flood event, and criticality of the site.

Avoidance: Of course, the most effective means of protection is not to build in a flood zone in the first place. However, if the location is within a flood zone then the buildings are constructed in such a manner that they are above design flood levels. This can be achieved, for example, by constructing the building on an embankment, elevating the lowest floor levels, landscaping to divert floodwater away from the building and building flood walls along the site boundary.

Building-level protection: In this case (also known as the resistant protection strategy), the buildings are inside the flood zone, within the design flood depth. However, the design and detailing are such that water cannot penetrate into the building. This can be achieved by using impermeable construction materials that also dry and can be cleaned quickly and efficiently after a flood, ensuring penetrations, e.g. water pipes, and so on, are above the design flood level, providing waterproof and impact-resistant window and door frames, etc.

Water-entry strategy: In the "resilient protection strategy" water may enter the building, but impact is minimized. In other words, there is no damage to the structural (load-resisting) elements of the building as well as the critical equipment, stock, and machinery. Damage to non-structural elements, e.g. façade, cladding, internal finishes, is limited and to such an extent that site operations are not impacted.

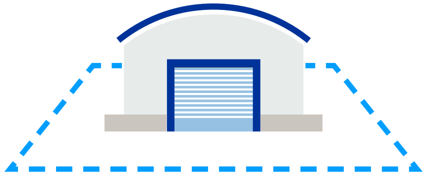
[1] "Improving the Flood Performance of New Buildings: Flood Resilient Construction", Department for Environment, Food, and Rural Affairs (DEFRA), May, 2007.

Physical flood resilience measures

The effectiveness and reliability of protection measures rely on correct implementation of design, detailing, installation, and maintenance of the system. Good project management and onsite supervision is essential to guarantee the **effectiveness** of any physical measures, i.e. that the designer specifications have actually been implemented by the contractor. The **reliability** of any protection measure is contingent upon maintenance measures, e.g. inspection of levees (vegetation management and animal burrow inspections), pump maintenance, inspection and testing of backflow prevention valves, etc.

The effectiveness and reliability of physical flood protection measures are increased by **incorporating them as early as possible** in the design and detailing processes.

Site perspective



These are all measures implemented between the site boundary and buildings, and can be considered as the first barrier that floodwater encounters as it approaches the site. Some of the main issues to be considered are listed below:

Fixed flood protection systems

These include (but are not limited to) levees, walls and flood gates at access roads, i.e. measures implemented at the site boundary.

Site boundary walls, if available, should be specifically designed as floodwater retaining structures. Foundation design must consider the impact of the flood duration on soil properties, e.g. resistance to hydrostatic forces considering bearing capacity of saturated soil and ground settlement due to flood (amongst other factors).

Levees must be designed based on a local (site-level) flood analysis, that includes not only design flood level depth, duration, and velocity, but also (saturated) soil conditions. Levee material must be carefully defined, as well as construction issues, e.g. number and heights of lifts (layers), compaction levels and testing, material type, etc. Type of vegetation on the levee must be carefully selected to increase and not compromise water tightness of the levee.

Site perspective

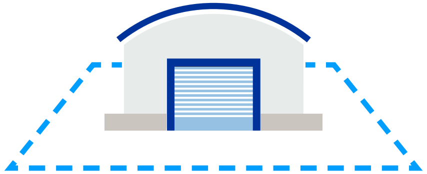


Figure 1:

A well-designed, detailed, and maintained levee.

Note (1) the maintenance road on the levee crest,

(2) precast concrete panels on the slope (photo is at bend of river) to protect the levee against erosion,

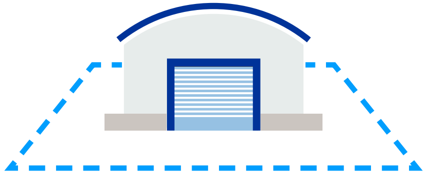
(3) well-maintained, specially selected short-rooted vegetation on the levee, and

(4) trees cut back to a suitable distance to prevent roots from affecting levee foundations.

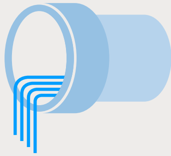
Figure 2:

The reliability and effectiveness of public protection systems must be considered when designing new buildings within areas that are supposedly flood protected. Poorly maintained levees are not reliable. In this image, the water-tightness of the levee is put at risk due to the roots of the vegetation on top of the levee and by the location of the trees, which are situated too close to the levee base.

Site perspective



Drainage systems



Drainage systems should be design according to local design standards, which define the design rainfall intensities, frequencies (return periods), and durations,

Issues such as discharge of floodwater from the parking areas and roads, backflow prevention (sewage, drainage system, below-grade fuel or septic tanks, etc.), interface with local (municipal) drainage systems, screening of discharge points to prevent debris blockage, etc. are to be considered during the planning stage. Compatibility with the interface to the public system (capacity, materials, etc.) should also be considered.

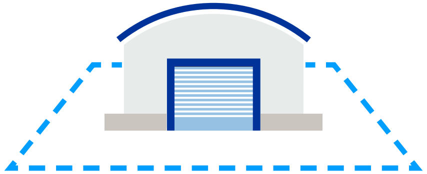
Drainage system should be adequate to cope with water accumulating on-site during flood event, when the site is isolated from the water behind the flood protection walls. Water pumps or retention basin are often needed to discharge rainwater (and sometimes process water) from the site. The water pumps should be connected to emergency generator as power cut often occur in flood events.

The interfaces between site drainage and public drainage systems must be carefully planned and detailed, e.g. relative elevations, sump pits and pumps, blockage prevention measures, etc.

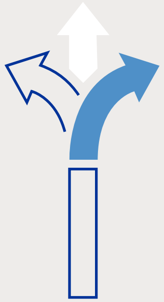
Figure 3:

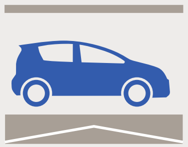
The pumps (1) are provided at the lowest point of the site, which is protected by an earth embankment (2) to evacuate rainwater. The pumps are automatically activated when the water level in the retention chamber below the pump attains a pre-defined level.

Site perspective



Access roads and parking lots (above ground)





Elevation of the access roads and parking lots can be defined to a lower design level, i.e. frequent, low intensity events. However, some issues to consider in the design and detailing are:

- Identify all possible access roads. Redundancies would be useful if local authorities cannot clear roads expeditiously.
- Alternative parking areas, e.g. on elevated ground, to be designated, to allow access to the site even before floodwater has fully drained.
- Provide additional measures to support road and parking drainage during a flood event, e.g. pumps to drain floodwater and discharge into the public system or to collect in a flood retention area.

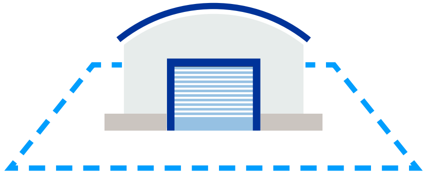
Capacity of local (municipal) drainage system must not be exceeded due to water pumped from the parking lot. This requires close collaboration with local authorities to ensure that the local drainage system capacity will not be exceeded or to identify areas where excess water c an be discharged.

Parking area may be used as flood retention area, but drainage to be designed accordingly. Such a measure must be carefully investigated and implemented with caution, as it depends on the local situation (topography, neighboring facilities etc. besides municipal drainage).

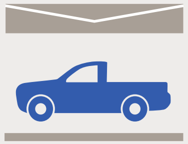
If possible, consider using surface material that allows water absorption or, ideally, permeable road surfaces that are part of a sustainable drainage system, e.g. ponds .

[2] Refer, for example, to the UK National Standards for Sustainable Drainage (https://www.susdrain.org/) (Construction Industry Research and Information Association, CIRIA).

Site perspective



Below ground levels (parking lots, basements, etc.)



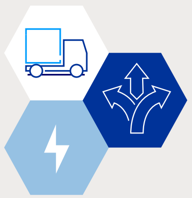
The underground area should be designed as a completely waterproofed system, e.g. concrete mix (waterproofing additives), construction joints, wall and floor slab thicknesses, etc. must be designed and detailed to sustain increased ground water levels (due to flooding) and associated hydrostatic pressure.

Besides structural criteria the drainage system, e.g. sump pits and pumps, must also be appropriately designed.

Temporary flood protection systems are to be considered at entry points to the underground floors, when access points are susceptible to water ingress, e.g. at same level or slightly higher than surrounding roads or pavement areas.

When selecting temporary flood protection systems, issues such as system approval, time available between flood warning and arrival to site, flood event duration, water depth, etc. must be considered. Please consult a qualified Zurich Risk Engineer for further guidance.

Infrastructure

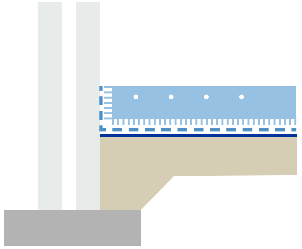


Determine critical infrastructure in the region that could be impacted by a flood event. In other words, the flood analysis should not only include the impact of the flood event at the site, but also the flood risk of the infrastructure, upon which the future site is dependent, e.g. wastewater treatment plants, bridges, power substations, etc.

Redundancies and emergency (backup) measures related to power supply (emergency generators), removal of wastewater by tanker trucks, access roads available during a flood event, etc. should be considered in the planning.

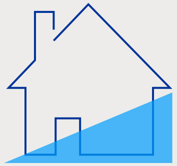
The impact of floodwater on below-ground infrastructure (tanks, piping, etc.) should be considered – not only in terms of uplift pressure but also leakage of content with consequent site contamination.

Building perspective



These factors relate to the buildings themselves in terms of architectural features, construction materials, and value distribution within the buildings.

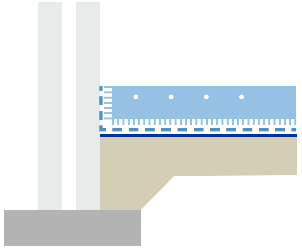
Elevations



Finished floor level of the lowest occupied floor should be above the design flood elevation.

Besides floor elevations, critical equipment and inventory with lone replacement time and/or high values, should also be installed above the design flood elevation. If this is not possible, the ground floor rooms should be waterproofed.

Building perspective



Openings

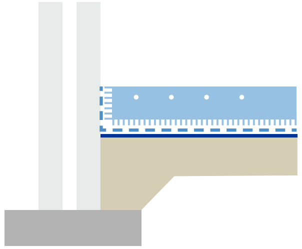
Finished floor level of the lowest occupied floor should be above the design flood elevation.

Besides floor elevations, critical equipment and inventory with lone replacement time and/or high values, should also be installed above the design flood elevation. If this is not possible, the ground floor rooms should be waterproofed.

Figure 4: Openings on the ground floor should be above "design level" flood and provided with impact-resistant glazing or doors against water-borne debris. Mobile flood protection may need to be considered for operations-critical areas.

Figure 5: Doors and glazing should be impact-resistant and water-tight. Mobile flood protection may need to be considered for operations-critical areas.

Building perspective



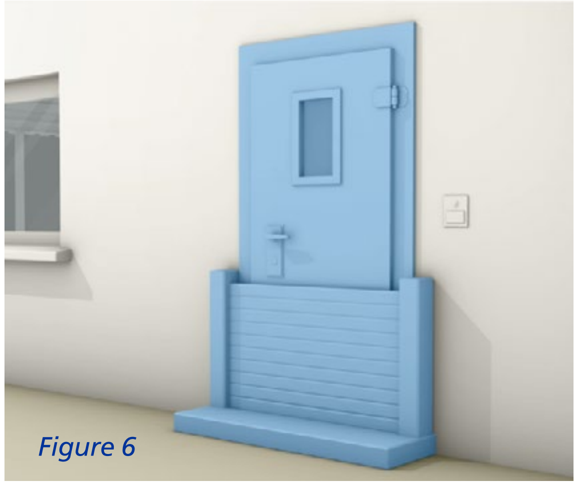


Figure 6

Figure 7

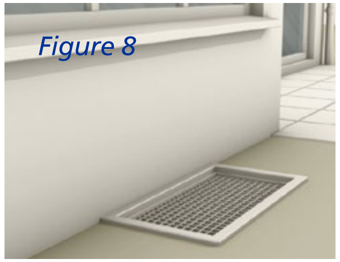


Figure 8

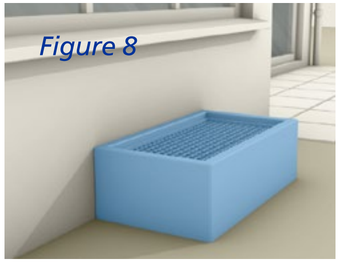


Figure 8

Figure 6: Hydrostatic pressure and water resistant flood door, elevated curb and temporary flood protection panels.

Figure 7: Impact resistance barriers for glazing.

Figure 8: Prevention of flood water ingress into the basement through the ventilation shaft.

Construction material:

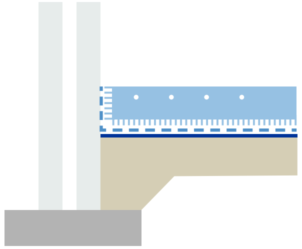
The building construction material for the levels within the design flood level should be designed for water-tightness, resistance to water pressure and velocity as well as impact from debris.

Selection of construction material below the design flood level should include ease of cleaning and drying as moisture in the wall can result in mold growth. When concrete is used, the mix (cement type, waterproofing additives, etc.) is to be designed accordingly.

Water-tightness of construction joints should be given special attention. Poor workmanship (installation) of these joints during the construction phase is a common cause of water ingress into the building.

It is important to consider uplift (buoyancy) pressures on the building foundation, as well as soil weakening due to saturation by flood water, and design accordingly.

Building perspective



Temporary flood protection systems

If it is decided to implement a temporary flood protection system[3] consider installing some parts of the system permanently in the structure. As an example, mounting frames of flood panels can be installed in the frames of doors, windows, or other openings (underground parking garage entrances).

Storage areas of temporary units should be onsite and easily accessible, not only for deployment, but also for maintenance and regular inspection).

Examples of onsite storage of temporary flood protection systems directly at areas of installation.

Left: folding type barrier.

Right: Sealants and elastomeric membranes stored in a box behind site access gate.

[3] Refer to pertinent Zurich Risk Engineering Risk Topic regarding selection criteria

Appendices

Examples of flood design requirements in some national guidelines and standards (list is indicative and not exhaustive):

Country/Standard	Main features
USA/ASCE 24-14	• Based on "Base Flood Elevation" (FIRM maps) or "Design Flood Elevation" (local design flood level). Typically, 100 year and 500 year return periods. • Design elevations are specified according to "Flood Design Class". Therefore, for non-critical classes (e.g. ordinary buildings), the minimum elevation of flood protection is the 100-year flood depth plus 1 ft. (30 cm) as safety margin, and it is 2 ft. above the 500-year return period flood elevation for critical Flood Design Classes (Class 4). • Criteria for design and detailing of fill embankments are defined, including slope (not steeper than 1:1.5). • Specifies a minimum of 12 hours to mobilize mobile flood protection units. • Specifies site, building and equipment elevation requirements. • Flood-resistant construction materials. • Equip fuel lines with float-activated automatic shutoff valves. • Anchor tanks that are below design flood elevation to 1.5 times the buoyancy forces. • Prevent elevator cabs from descending to flood level.
USA/FEMA 543	• Focus of this document is community-critical facilities, i.e. schools, health care facilities, fire and police stations, and emergency operation centers. • The document is intended as an introductory guideline and not a design standard. • Recommended to use the BFE (see above) or design flood designated by the community, whichever is higher (but not less than the BFE). The 500 year return period flood levels is strongly recommended. • Flood loads (on buildings and building elements) are described, e.g. hydrostatic loads (buoyancy), hydrodynamic loads, breaking wave loads (coastal areas), impact loads from debris, long-term erosion and scour.

Appendices

Australia/Construction of Buildings in Flood Hazard Areas (Australian Building and Construction)	Defines building requirements within Flood Hazard Areas (FHA), based on the Defined Flood Event (DFE), which is stipulated by the local authorities.
UK/BS 85500 (Flood resistant and resilient construction)	Flood depths of over 600 mm are considered to be „high“. Floods longer than 12 hours are assumed “long duration”. Recommended protection level is 30 cm above 100 year flood event.
UK/BS 8533 (Assessing and managing flood risk in development)	Buildings should be designed so that floor levels are situated 300 mm above the 1 % (1 in 100) fluvial flood level, or 0.5% (1 in 200) tidal flood level (whichever is higher) and include an allowance for climate change. Within Scotland, floor levels should be situated a minimum of 500 mm above the 0.5% (1 in 200) fluvial or tidal flood level (whichever is higher) and include an allowance for climate change. Within Northern Ireland, where climate change has not been calculated, floor levels should be situated 600 mm above the design flood level. Where it is not feasible to raise floor levels or development site ground levels above the flood level, buildings should be constructed using water-resistant materials.
Austria (Oberösterreich)	50 cm above 100 year return period flood level.

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