D 4.3: Technologies for flood-proofing "hotspot" buildings

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Task Leader: Dura Vermeer

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Lead Author	Rutger de Graaf
Contributors	Bart Roeffen, Wenneke Lindemans, Karina Czapiewska, Peter de Jong, Barbara Dal Bo Zanon
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Summary

Urban systems contain assets of high value, complex and interdependent infrastructure networks. These infrastructure networks are critical for the continuity of economic activities as well as for the people's basic living needs (Van Ree et al., 2011). Hotspot buildings are defined in this research as essential nodes in critical infrastructure on which urban areas depend for their functioning. Examples of critical infrastructure are technological networks such as energy supply, transport services, water supply, information and communication services (Herder & Thissen, 2003). Hotspot buildings within these networks include power stations, water treatment plants, control centres of public transport, waste water treatment plants, fire fighting stations and hospitals. The availability and functioning of hotspot buildings is needed to maintain daily life as normal as possible during floods but is also required for fast and effective recovery after flood disasters. The flood vulnerability therefore largely depends on the degree in which both high value assets and critical urban infrastructure are affected, either directly or indirectly.

Failures of hotspots can cause major damage to society and the economy: hence, the need is urgent to identify these risk hotspots and develop potential protection technologies. Flood proofing is a building method to construct or reconstruct buildings to make them resilient against flooding. This can be done by avoiding contact with floodwater or by making the building resistant to potential damage caused by floods. In literature, (FEMA, 1999; Zevenbergen et al., 2010) various technical flood proofing concepts have been discussed. This article includes wet flood proofing, dry flood proofing, elevating structures, floating structures, amphibious structures, temporary flood barriers and permanent flood barriers.

In this research guidelines on flood proofing technologies and concepts for retrofitting of non-residential buildings are formulated. These guidelines are presented in three tools that are incorporated into an excel model. This tools can be used by designers and decision makers to select and evaluate flood proofing concepts for flood proofing hotspot buildings in different stages of the urban development process. In the beginning of such a process when options are explored, a general overview is presented on the most suitable flood proofing concepts based on flood depth and flood duration. In this phase the relevance map gives an indication on the relative importance of flood proofing a particular hotspot building based on flood impacts and the service area of a particular hotspot building. Both tools require only a small amount of data and specific information. In the next phase of the urban development process, when possible measures for flood-proofing are selected, the selection tool gives insight which flood proofing concepts could be feasible based on information on location characteristics and hotspot characteristics. The selection tool requires a small amount of information, although more data should be available than in the first phase. In the decision making phase, the evaluation tool provides detailed information about the costs of several possible options for flood proofing a specific hotspot. Relatively detailed information on the hotspot, flood characteristics and location characteristics should be available for applying this tool.

The tools presented in this article are expected to be useful primarily for decision makers and designers, to quickly limit the large amount of available options for flood proofing hotspot buildings. Therefore the tools have the potential to contribute to make cities more flood resilient by better protecting vulnerable hotspot buildings in critical infrastructure.

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1 Introduction

Recent floods across Europe the past decades, and especially the recent floods in the United Kingdom and Ireland in 2007 and 2009, made clear that if the most vital buildings and assets are hit by floods it may have far-reaching consequences, even for people well outside the flood-prone areas. Larger public utilities may serve up to hundreds of thousands of people and losing operation for only days may result in catastrophic events. Flood-proofing measures are an effective strategy for reducing flood risk in individual buildings. By providing additional protection to the most vital buildings in a city or region the risk can be greatly reduced by relatively small interventions. Being able to save a vital node in a power or communications grid by applying relatively simple measures, such as raising the structure or erecting a wall around it, may well prove to be a good investment. Aside from reducing the risk for all the people that rely on the services, it will likely be a economically justifiable investment. Costs incurred by Yorkshire Water from a single flooded sewage treatment plant in 2007 were estimated at £50 million and flooding of the Mythe Water Treatment Works cost about £30 million. With a flood probability of 1/200 this would translate to costs of respectively £250k and £150k per year. At the same time flood proofing measures are often scalable and faster to implement than the robust measures that are necessary in order to protect complete districts, cities or regions.

This report provides integrative research and guidance on the application of flood-proofing measures to the most vital buildings and services, which are referred to in this report as 'hotspots'. The current best practices and state of the art of flood-proof hotspot buildings have been investigated to find out which gaps in knowledge are to be addressed in this report.

1.1 State of the art

A desk study was conducted in order to make an overview and categorise international best practices and guidelines on flood proofing measures to hotspot buildings and to find gaps in knowledge. Data was collected from previous research projects and by sending out questionnaires to recognized experts. These experts were identified by peer recommendation of FloodProBE partners. In addition, the online database of FloodProbe that is used by FloodProBE partners to collect and store useful literature, was used to compile information. The state of the art and list of floodproof projects were discussed in FloodProBE project meetings in order to improve the quality and scope. A broad, but by no means exhaustive, list of international examples has been assembled and analysed (found in Appendix 1).

1.2 Gaps in knowledge

While, there are already guidelines and best practices on floodproofing several types of buildings (mostly residential), there is currently few research specifically aimed at flood proofing hotspot buildings. For most hotspot types examples of flood proofing by retrofitting have been found. Most projects that were found were retrofitted after a flood disaster and only few examples of preventive retrofitting were found. What is lacking is a more structured approach of when and how these flood-proofing technologies can be applied to reduce the risk in the most vital facilities and assets.

Gap 1: *Integrated and structured guidance on flood-proofing hotspots and the connection to vital infrastructures during flooding to secure their functioning.*

Most guidelines on flood-proofing that were found in the literature survey mainly focused on new buildings and not retrofitted ones. An example is CIRIA (2007). FEMA (1999) does have a publication that includes retrofitting, however this book is on flood-proofing of building utilities and not about flood-proofing the building itself. FEMA (2009) is restricted to flood-proofing residential buildings. The Dutch guidelines are broad in scope, but mainly present design concepts and do not focus on the in depth application and evaluation of flood proofing technologies. German guidelines are comprehensive and provide useful information about the applicability of building materials in flood prone areas, but again primarily focus on residential buildings. Based on this literature survey, the following knowledge gap can be defined:

Gap 2: *Guidelines on flood proofing building technologies and concepts for retrofitting non-residential buildings.*

1.3 Objectives

This report will focus on providing guidance on flood-proofing hotspots, based on integrated and structured knowledge on flood-proofing techniques and their application to specific types of buildings and utilities. A set of design guidance tools are developed that can assist both researchers, designers and policy makers in the decision process with regard to protecting vital buildings and utilities. The tools are tested and illustrated with various case studies, and will then be applied to a FloodProBE pilot project. The outcome will be used in the final design in order to demonstrate how the results are interpreted and applied.

1.4 Structure of this report

The structure and underlying methodology of the report is elaborated in figure 1.1. In the second chapter of this document the different methods of flood proofing are described and catalogued. In the third chapter an overview of the hotspot buildings is made with a direct link to the possibilities and impossibilities of applying flood proofing methods. The data from the state of the art, the functional requirements, flood characteristics and hotspot data were used to create a design guidance tool on the application of flood proofing measures to hotspot buildings. This is reported on in chapter 4. The tool can be used to support and provide guidance for decision makers and designers to shortlist flood proofing methods. The tool consists of three parts: the relevance maps, the selection tool and the evaluation tool. In the fifth chapter several case studies are presented to evaluate and illustrate how the tool can be applied. The results of this have been used to fine-tune the tools. The last chapter is an application of the tool to one of the FloodProBE pilot sites, which entails in a design of a new flood-proof building.

1.5 Implementation

The technology and tools that are presented within this report can be used to develop and evaluate strategies that reduce flood risk in hotspot buildings. A generic scheme of the workflow is provided in the WP5 umbrella document, which outlines the different steps that need to be taken in order to select, design and implement an intervention. The structure of this report fits within the workflow of the scheme: chapter 2 serves as a catalogue of floodproofing measures; chapter 3 gives examples on how to formulate relevant requirements; chapter 4 and 5 provide guidance on how to use the tools for evaluation of floodproofing measures and chapter 6 and 7 illustrate how to use the results.

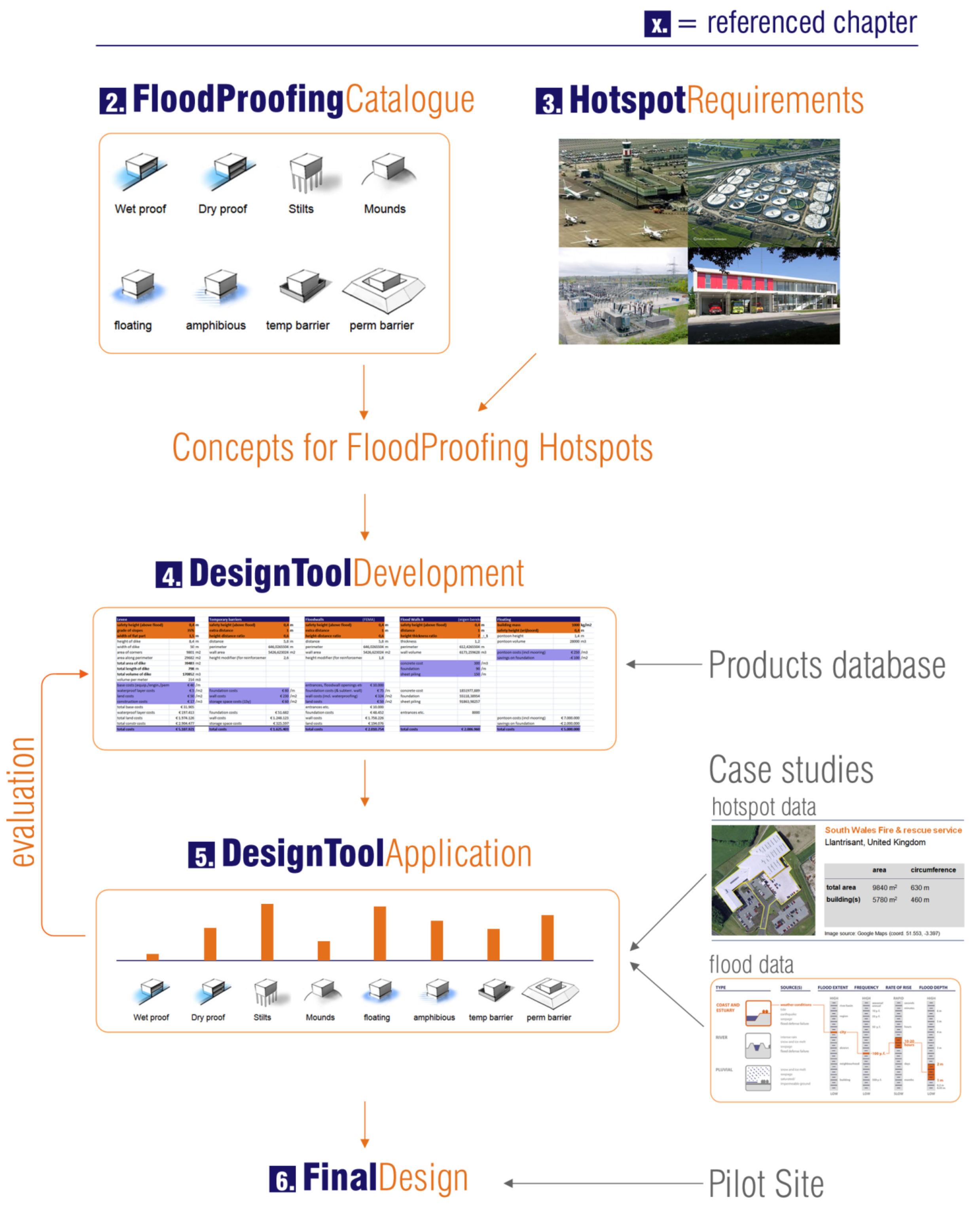


Figure 1.1 Structure of this report

2 Catalogue of flood proofing concepts

Flood proofing is a way of constructing buildings to make them resilient against flooding. This can be done by avoiding contact with floodwater or by making the building resistant to potential damage caused by floodwaters. Both *Urban Flood Management* (Zevenbergen et al., 2010) and *Engineering Principles and Practices of retrofitting flood-prone residential structures* (FEMA, 2012) distinguish similar methods of flood proofing. FEMA (2012) focuses mainly on retrofitting and doesn't include floating and amphibious options. Zevenbergen (2010) does include these measures, but regards urban flood barriers as a separate theme. FEMA includes floodwalls and levees, but not temporary defences. These are however discussed in FEMA (2007). Considering that 'relocation' or 'moving' of a structure is not a building technique, this method will not be taken into account in this research.

The selected methods, that will be described in the following paragraphs, are:

- Wet flood proofing
- Dry flood proofing
- Elevation
- Floating and amphibious structures
- Temporary and demountable flood defences
- Permanent flood defences

An important factor in deciding upon the measure(s) to apply, is whether a new hotspot building is to be realized or an existing building is retrofitted with floodproofing measures. The methods of creating floating, amphibious or elevated structures (on a mound or stilts) usually cannot be applied to existing hotspot buildings, because it is an integral part of the building structure. A small number of examples do exist, where buildings were retrofitted with one of these methods. In the U.S. wood-framed structure houses are sometimes relocated or lifted to reduce flood risk. Considering that these applications are very specific to the type of structure and foundation, they were excluded as generally feasible options for retrofitting. In some cases it may be worth investigating whether a new floodproof facility or building may be a better solution, than retrofitting an existing one. General guidance on the subject is provided in FloodProBE deliverable 5.3.

2.1 Wet flood proofing

Wet flood proofing or wet proof construction is a building method that allows temporary flooding of the lower parts of the building. To prevent damage, preferably water resistant building materials are applied. As an alternative, materials can be used that can be easily repaired or replaced. Another important design aspect is the location of electrical lines and delivery points above the expected flood level. Construction parts have to be designed in such a way that they can easily be dried after the flood.

Design considerations

Because (part of) the ground floor is not useable during a flood, this method is commonly used for parking spaces, sheds, basements, building access areas and similar functions. It is usually not employed in spaces where residential or commercial activities take place (Zevenbergen et al., 2010). These activities would be extremely hindered by the water in the building. During a flood there are two options for entering the building. People can use the existing entrance that is in the flooded area. Secondly an additional entrance can be designed above the expected flood level to be used during the flood. The footprint of the building is preferably small to minimise damage. Wet proofing can be used to protect new as well as existing buildings. Because the building gets flooded and needs to be repaired afterwards, this solution is most suitable when flooding does not occur frequently.

Wet proofing is especially suitable when short periods of floods are expected. The expected flood level is preferably between one meter and one floor. In that case the higher floors of the building can still be used. For flood levels lower than 1 meter, dry flood proofing is the preferred option because in that case relatively small measures are needed to keep the water out.

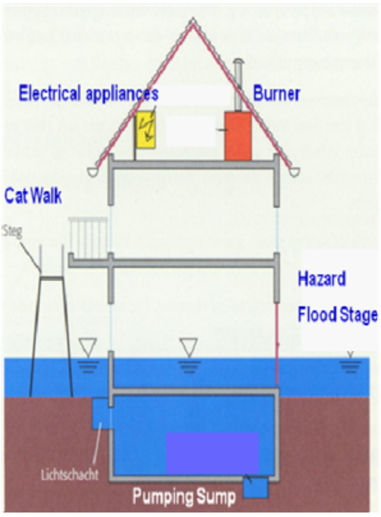


Figure 2.1 Wet proof method scheme with temporary escape ways (Pasche, E., 2008).

Figure 2.2 Combination of mobile walls and cat walks in Hamburg, Germany (Pasche, E., 2008).

2.2 Dry flood proofing

With dry flood proofing or dry proofing, the water is prevented to enter the building. The building is made waterproof by treating the facades with coatings, using resistant materials or building materials with a low permeability. In addition, building materials should have a good drying ability. Openings in the facades can be closed with flood shields, panels or doors, which are permanent features. The difference with temporary barriers is that dry proofing measures are an integrated part of the building, whereas temporary barriers are additions located outside the building.

Design considerations

Dry proofing is a useful method to flood proof buildings. Because entrances on the ground floor are not accessible during a flood, it is important that in the design a second entrance is created above the expected flood line. This can be either the regular entrance or an emergency entrance only. Dry proofing is most efficient when the building footprint or circumference of the building is small. Dry proofing is often applied on the facade. In case of a large circumference due to a complicated building shape, a temporary or permanent barrier could be easier and cheaper to apply. Dry proofing can be used to flood proof new and existing buildings.

Point of attention is the accessibility of the building during the flood. Dry flood proofing is a suitable option for relatively low flood levels (< 1meter). There are known examples, for instance Hamburg Hafen city, where the entire ground floor is dry proofed. With higher flood levels the water pressure to the walls requires additional construction measures to resist the load on the walls and floors. Therefore it is recommended that it is not used with expected floods above 1 floor. If connections to roads and other infrastructure is protected against flooding, flood duration is not a limitation.

Figure 2.3 Dry proofing, Hamburg, Germany (Pasche, E., 2008).

Figure 2.4 Pohkit Goh: 'Flood House' (Architecture.com, 2011).

Figure 2.5 Door barrier (Leven met water, 2008).

Figure 2.6 Hof van Waterrijk (Nieuwbouwwijzer.nl, 2011).

2.3 Elevating structures

Another method to protect a building from floods is to elevate the entire building above the expected flood level in order to prevent damage. To enable the continuing functioning of such a building, the connection to infrastructure is to be secured against flooding as well. An example is an access road that is also elevated. There are several ways to construct such a building. In this research project the focus is on two alternatives. They will be discussed separately.

2.3.1 Building on stilts

Buildings on stilts are founded on stilts that extend above the ground. The building is ‘lifted’ above the ground and can be built above land or water. It enables multifunctional use of space; for example parking and water retention. With this type of construction, points of attention are the spatial quality under the building and the access during a flood. The type of stilts can be organized in three groups: elevation on piers, elevation on posts or columns and elevation on pilings.

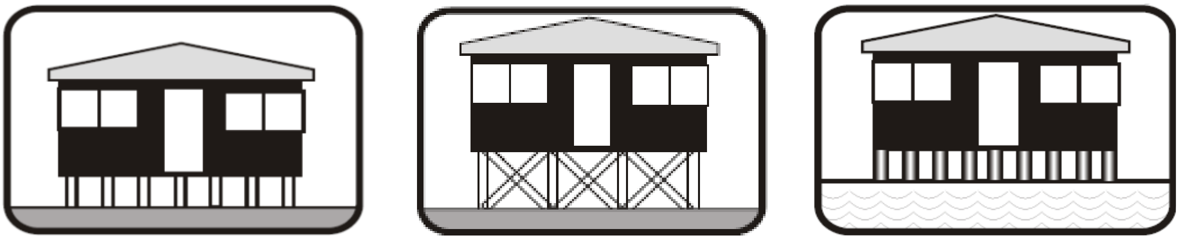


Figure 2.7 Raised structures: on piers, posts or columns and pilings (Pinellas County Building Department, 2004).

Design considerations

When buildings have a large space demand, the area underneath the building can become a dark and unpleasant space. This is not the case when the building is above permanent water or when the building is elevated very high (as shown in figure 2.7). For the elevation of heavy buildings special constructional reinforcements are needed.Therefore, this method could be applied on buildings with a relatively low weight. Building on stilts above land is preferable when the expected flood levels are considerably high If the expected flood level is 2 meters or higher, the space underneath the building can be used for activities such as parking, storage or other purposes during normal operation. In case of a high expected flood level is high and a slow to moderate flow velocity, elevation on posts is commonly used. The construction constist of wood, steel or concrete and is fixed in pre-dug holes and braced together. If the flood depth is shallow with a slow velocity, the building can be set on a low foundation constructed of reinforced masonary block or reinforced concrete.

Above water, building on stilts can also be applied for lower expected flood levels. The expected flood duration can be months, or in case of building on stilts above water, even permanent. The building can be built on piers when the expected flow velocity is high such as in coastal areas. It is also suitable for high flood depthse or poor soil conditions. The buiding is set on tall foundation pilings that have been driven into the ground.

Figure 2.8 Office building on stilts in Amsterdam, The Netherlands (Groene.nl, 2010).

Figure 2.9 Office Buildings on stilts in Trondheim, Norway (Allshesaysis. blogspot.com, 2010).

Figure 2.10 Housing on posts Yawnghwe Burma (Wikipedia.org, 2012a).

Figure 2.11 Synagogue on mound in Sliedrecht, NL (Verdouw, G., 2011).

2.3.2 Building on mounds

A mound is an artificial hill. In the Netherlands this is a traditional way of protecting buildings and areas that are vulnerable for flood. They were first designed to act as safe havens but changed over time into places where people permanently lived. Even entire villages were constructed on these mounds. They can still be seen in the northern part of the Netherlands. Similar constructions are known in Germany and Denmark.

In the modern use of a mound, the building is raised from the ground level by an artificial hill. The benefits of these methods are that gardens or surrounding grounds are also protected from the flood and that multiple buildings could be built on the mound, assuming the mound is large enough. A disadvantage of this method is that extensive earth works are needed to build the mound.

Best Practice: New mounds in the Netherlands

After heavy flooding in 1993 and 1995 the programme '*Ruimte voor de Rivier*' was initiated in the Netherlands. The aim of this programme is to safeguard cities and villages along the rivers from future flooding. The programme consists of 39 measures to be implemented in the Dutch basin of the river Rhine and the lower reaches of the river Meuse (Bergsche Maas). The *Overdiepse* polder is one of these projects. By lowering the dike, the river will enter the polder with high water on an average of once every 25 years. This will result in a lowering of the water level in the river of 27 cm. This will protect cities, such as 's-Hertogenbosch, that are located further downstream.

The farmers who live in the polder took the initiative to create eight mounds along the new winter dike. The other farmers will move and start their businesses elsewhere. The new farms and barns will be built on the mounds. The connection to the dike will ensure an access to the dwellings in times of flooding. It will be elevated 6 meters above the ground. The projected total project costs amount to 111 million euro and the project will be realised from 2010 till 2015. The mounds are constructed from several layers of sand and clay. The layers will be compressed by bulldozers and vibrating rollers. This will increase the stability and prevent the sand from sliding. For the construction of the eight mounds and the new winter dike, 2 million cubic meters of sand and clay are needed. The sand will come out of the sand depot in the polder or will be transported into the area through the river Oude Maasje. Besides, recycled sand from the excavated dike will be used (Waterschap Brabantse Delta, 2010, 2011).

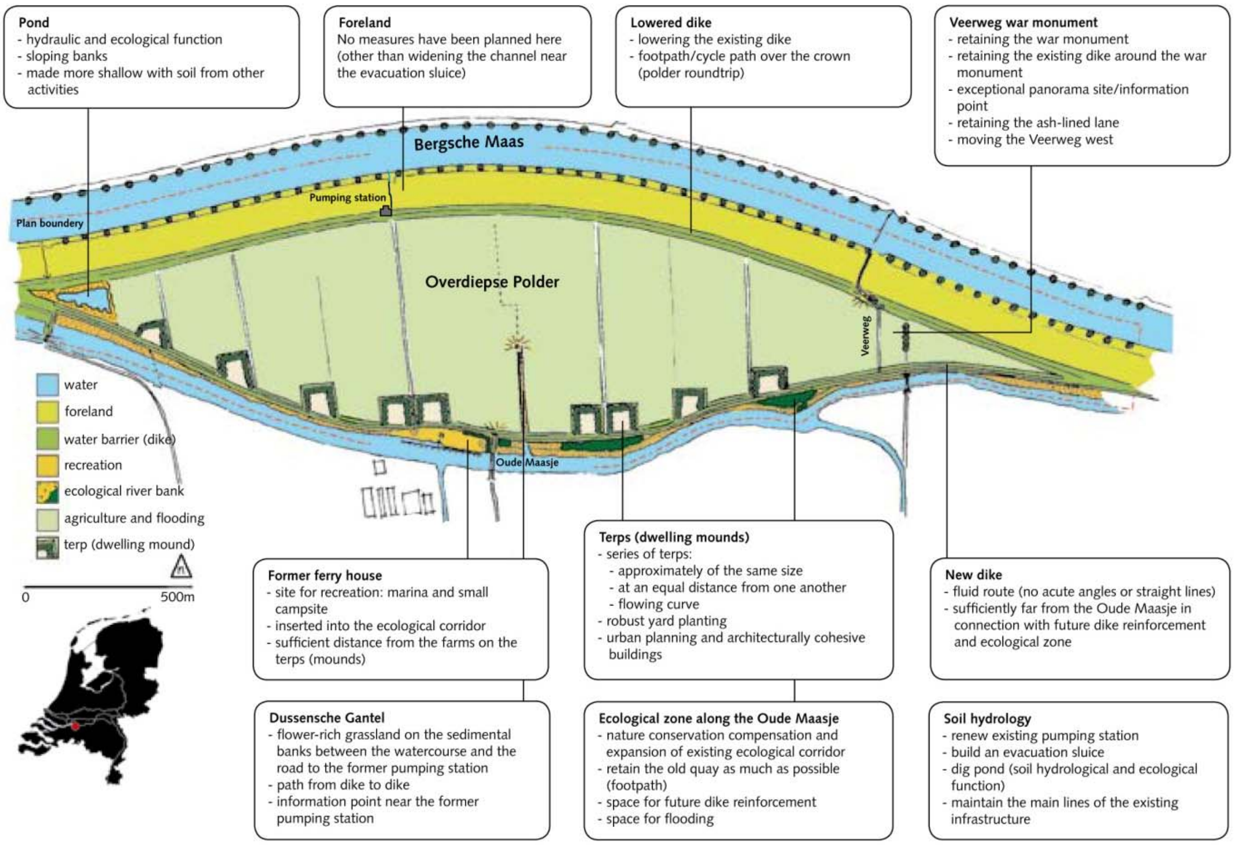


Figure 2.12 Overview of Overdiepse Polder, The Netherlands (Waterschap Brabantse Delta, 2010).

Design considerations

A mound is a landscaping element and therefore building on mounds can be a remarkable addition to the surrounding landscape. It is often used near a new or existing dike to ensure the accessibility of the mound during a flood. On the other hand excessive ground displacement is needed to create the mounds. This method is not applicable for the renovation of buildings. Compared to building on stilts, building on mounds is preferable with expected flood levels that are lower than 3 meters. For higher levels, much ground displacement is required, also due to the required slope around the mound. The expected flood duration can be weeks or even months as long as there are functioning connections.

2.4 Floating and amphibious structures

Floating an amphibious structures allow the vertical building movement with the water level while fixing the building at a certain location.

2.4.1 Floating structures

A floating building is a building that is founded on a floating structure that is permanently located in the water. The building has to be fixed to a location while allowing a certain vertical movement by the application of mooring posts. Because of the water fluctuation, a flexible connection to the land is needed. Floating structures allow the possibility of moving the building and moor it somewhere else. It is a flexible and reversible mode of construction and therefore responds to the societal objective to increase the capacity to adapt the built environment to the expected impacts of climate change. Houseboats are the oldest examples of floating structures in the Netherlands. Recently, a new trend has emerged in the Netherlands, and also in other countries. New floating houses and buildings are constructed that look like modern houses and have no similarity to the traditional houseboats or barges.

In the Netherlands, most floating houses are constructed on a hollow concrete foundation. This system is relatively cheap and technically robust. Concrete segments can be connected to realise large platforms. The largest building in the Netherlands that was built on this type of platform is a prison in Zaandam. The floating foundation is 100 meters long and 22 meter wide. Disadvantages of this system are the required depth which is usually about 1.5 meters for a single house. In Canada and the USA an Expanded Polystyrene (EPS) and concrete combination is the most used technique. The polystyrene decreases the density of the floating construction which provides higher buoyancy. Advantages of this system are a lower required depth of the surface water. In addition the system is unsinkable and enables the construction of larger platforms. The system is more suitable for shallow surface water. A depth of 1.0 meter can be sufficient. However, the material costs are higher than the concrete system.

Figure 2.13 Floating prison in Zaandam, The Netherlands (De Volkskrant, 2007).

Figure 2.14 Floating Pavilion in Rotterdam, The Netherlands (Deltasync, 2010).

Design Considerations

Because floating structures need permanent water, it is preferable to use this method in locations where there is already existing water or where additional water retention is needed. This technology is especially interesting in cities where space on land is lacking. Stability is an important aspect of floating construction. Therefore it is important that the floor space to volume ratio is high. For instance high rise buildings could experience stability problems if they are constructed as a floating building. Also the building mass should be evenly distributed over the floating construction to prevent leaning. When planning hotspot buildings with a high mass, it is important to take in account that to make such a building float, much buoyancy is needed. This can either be done by creating a large platform or by creating a high depth under the waterline. Floating can only be applied to new buildings. Floating structures are preferable for relatively large water level fluctuations (>3 meters). In that case constructing a barrier is a costly option. The building will adapt to any water level as long as the mooring posts are long enough. The area can be permanently flooded because the building is located in the water.

2.4.2 Amphibious structures

An amphibious structure usually has a traditional foundation combined with a floating foundation. The building is situated on the ground during normal operation and will start to float when a flood occurs. The building is fixed by mooring posts to prevent horizontal displacement. An example of amphibious housing is Maasbommel where 32 amphibious houses have been constructed.

Figure 2.15 Amphibious dwellings in Maasbommel, The Netherlands (Leven met water, 2008).

Figure 2.16 Amphibious house in New Orleans, Louisiana, USA (Donsky, A., 2009).

Design Considerations

Amphibious construction is only possible for new buildings. In particular in floodplains where floods frequently occur and in emergency water retention basins, this construction method can be applied. For planning hotspot buildings with a high mass it is important to take in account that high buoyancy is needed to make such a building float. Floating of the amphibious building will only take place if the flood level is higher than the depth of the building in a floating situation. Amphibious constructions can only be applied to new buildings. A flood level of higher than 1 meter is needed for the building to start floating. For higher flood levels than one floor the method can be preferable compared to the construction of barriers and dry flood proofing. The costs of amphibious structures are high because both a ground foundation and a floating foundation are required. Long flood duration are not an issue, as long as accessibility of the building is secured.

2.5 Temporary and demountable flood defences

2.5.1 Temporary flood defence

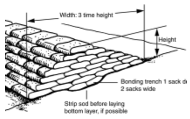
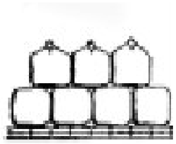
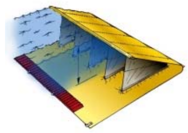
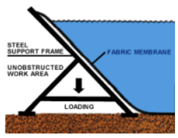
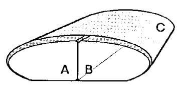
An temporary flood protection system: "*is formed by removable flood protection products that are wholly installed during a flood event and removed completely when levels have receded, its connection with the underlying surface, and the end connections*" (Environmental Agency, 2011). For the flood protection system the integral cohesion between the barrier components and the operational system in the food area are most vital. All flood barriers consist of components such as the superstructure, the foundation or bedding structure, the seepage cut-off (if applicable), the seals, joints and interactions within the structure and with the adjacent structures and subsoil. Important aspects of this flood protection system are the forecasting systems and methods, flood alert systems and monitoring, mobilisation of equipment and manpower and materials and closure of the defence system. The influence of these aspects greatly differs per type of system. Some can be applied in areas that are already flooded and can be installed within 3 hours by two men, others require a completely dry site or use a complete workforce with forklift trucks.

2.5.2 Demountable flood defence

A demountable barrier is partly temporary and partly permanent. moveable flood protection system that is fully pre-installed and requires operation during a flood event, or a system that requires part-installation into pre-installed guides or sockets within a pre-constructed foundation. The protection of the barrier functions well when closed and consists of the temporary and elements, the foundation, seals and joints within the structure, the end connections and the connections between the structure and the surface. The types of temporary flood proofing systems, including demountable systems, are categorized in the following table.

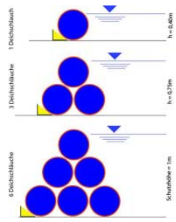
Design considerations

The temporary systems are placed on whatever surface or foundation available. The bedding surface therefore needs to be more or less appropriate and adequately prepared to prevent seepage. The demountable systems are often applied as additional flood proofing strategy next to permanent flood protection, for example on along rivers. Reasons for the need of this additional system can be the need of access to area when it's not flooded, for the view, unaccepted environmental impact if it was permanent. Temporary barriers are applied in places where the space to construct a permanent barrier is lacking and short floods of days or weeks occur. An example is the city of Prague where the historical city centre had to be protected against the floods from the river Vltava. In this case, temporary barriers are built up in one day to protect the city centre. Temporary barriers require some space around the hotspot building.

Temporary barrier type illustration	Cost formula(€/m)	Width (m)	Max height (m)
Sandbags  	$124x^2 + 2x + 0,5$	3*h 	2,5
Containers / gabions  	$34x^2 + 57x - 3$	1*h 	3,5
Flexible freestanding (fold-out)  	$380x^2 - 120x + 110$	4*h 	2
Rigid frame  	550x + 50	2*h 	2,5
Flexible frame  	55x2 + 61x + 76	2*h 	2,5
Geotech Tube  	87x2 + 37x + 2	2,5*h 	3,25

Tube	$364x^2 - 49x + 18$	2*h	2,5





Demountable	$150x^2 + 1000x$	<1*h	5


Preinstalled (self-closing)	$500x^2 + 250x + 2250$	<1*h	2,5


Image sources:

http://standeyo.com/NEWS/08_Earth_Changes/08_Earth_Changes_pics/080617.sandbagging.jpg
http://4.bp.blogspot.com/-vXrWvj12JUg/Tl0hpy5N3XI/AAAAAAAARM0/C8pfZ73LWEw/s1600/01.JPG
http://www.hydroresponse.com/image/watergate36lg.jpg
http://specialtyfabricsreview.com/repository/1/498/large_1008_ft2_1.jpg
http://www.hesco-usa.com/images/projects/fargo_lg.jpg
http://www.wbrz.com/images/news/2011-05-06/HESCObaskets.jpg
http://www.hydroresponse.com/image/geo121lg.jpg
http://www.hydroresponse.com/image/geo19lg.jpg
http://georgewashington2.blogspot.com/2011/06/fort-calhoun-nuclear-plant-flooded.html
http://a8.sphotos.ak.fbcdn.net/hphotos-ak-snc3/s320x320/23533_304361832967_232689647967_3474003_601851_n.jpg
http://www.4stav.cz/img-foto/002/5820_m.jpg
http://www.eu-floodcontrol.eu/tigerdam/pic/produktbeschreibung/foto_usa_1.jpg
http://web.sbe.hw.ac.uk/staffprofiles/bdgsa/Sustainable_Flood_Management/
http://www.floodcontrolinternational.com/PRODUCTS/FLOOD-BARRIERS/Resources/gallery1.jpg
http://www.blobel.com/images/BL-HWS-K-Open.jpg

2.6 Permanent flood defences

Permanent barriers are permanently in place. They are used both in situations where permanent water protection is needed and situations with occasional floods. Permanent flood barriers can be either a dike around the hotspot itself or an integrated flood defence in the surrounding area of the hotspot, including walls, gates or other structures. A dike, levee or embankment consists of an artificial barrier that is built on sea shores or river banks, for permanently protection from high water levels (figure 2.17) or for areas where flooding occurs frequently (figure 2.18). This type of barrier requires much space because of the slope, therefore it may not be feasible in dense urban areas or for relatively small areas.

Figure 2.17 Dutch dike between Kesteren and Opheusend (Wikipedia.org, 2012b).

Figure 2.18 House with dike in Vicksburg, Mississippi, USA (Hadhazy, A., 2011).

Figure 2.19 Floodwall and gate in Parkersburg Virginia, USA. (Radka, L. B., 2012).

Figure 2.20 Floodwall in Perth, Australia (Rickard, C. E., 2009).

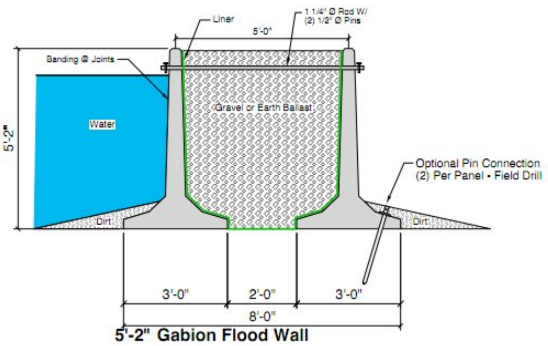


Figure 2.21 Example of floodwall (Mader, S., 2011).

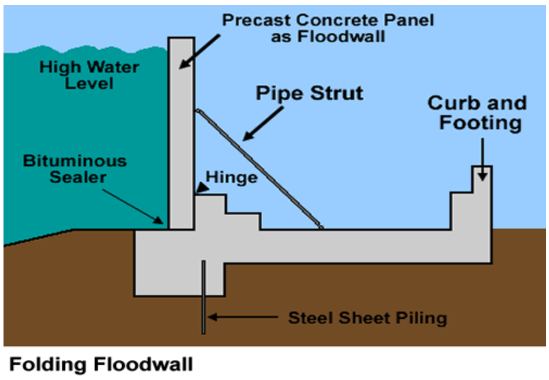


Figure 2.22 Example of floodwall (Management Measures Digital Library, 2011).

Design considerations

The primary function of a wall or embankment is flood defence. Often a secondary function can be added such as ecological functions or improving the amenity or both. A floodwall can be constructed from brick, masonry, concrete, sheet piling or a combination of these materials. Steel is the most common material for sheet piles, though the alternative of plastic should not be overlooked for situations where the lower inherent strength is acceptable. A flood embankment is constructed from earth, and may include a clay core to reduce seepage through the embankment. Both floodwalls and flood embankments may require a cut off to limit seepage through the foundations. Other design considerations are stated in the overview of table 2.1.

Table 2.1 Comparison between a flood wall and a dike (Rickard, C. E., 2009).

Factor	Wall	Dike
Space	Ideal for situations where space for the defence is limited	Takes up a lot of space. A 2.5 m high dike typically requires a footprint at least 15m wide.
Environment	Ideal for urban situations where the defence can be designed to blend into the local infrastructure.	Ideal for rural setting, but can be used in an urban environment if space permits (for example, in a riverside park).
Cost	Depends on the materials used (especially cladding), access for construction and foundation conditions.	Cost mainly depends on the source of fill material. Use of locally obtained material can significantly reduce costs and the overall environmental impact.
Foundations	Walls and embankments can both be complicated by the presence of weak or permeable foundations.	
Asset management	Generally require minimal maintenance, but the design should address the need for inspection of critical elements to ensure continued functionality.	Require regular inspection and maintenance, including grass cutting, control of unwanted vegetation, repair of damage by cattle and dealing with infestation by burrowing animals
Under-seepage	Walls are likely to require a cutoff against seepage when constructed on permeable soils.	Dikes may require a cutoff against seepage on permeable soils, but the longer seepage path often makes this less of an issue that with a wall.

2.7 Conclusion

Whether flood proofing concepts are applicable to certain types of hotspot buildings, will depend on the characteristics of the hotspot, the location and the specific flooding scenarios. In this chapter the flood characteristics, location characteristics and design characteristics that influence the choice of flood proofing method will be explained. This will form the framework for the application of flood proofing measures for the different hotspot typologies, described in chapter 3.

2.7.1 Flood characteristics

Low flood level

For floods with a low flood level (less than 1 meter), wet proofing, dry proofing, stilts, mounds or temporary barriers are the most suitable solutions. Dry flood proofing is an option because in that case only the lowest 1 meter of the building has to be made flood proof. The duration of the flood is of no influence on the performance of dry proofing. Temporary barriers are only useful if the flood can be predicted. Temporary barriers are most suitable for short floods, for instance with a duration of days or weeks. A mound is a good solution for low flood levels, because in that case the building can still function and the costs for ground displacement are relatively low. This solution is most suited for a flood with duration of weeks or months. Stilts can in this situation be applied when the area is flooded frequently or for a long time.

Medium to high flood level

Flood level up to 3 meters. Wet proofing is a good solution when short periods of floods are expected and the expected frequency of flooding is comparably low. Elevation on stilts creates multiple use of space and is therefore more interesting if the expected flood levels are from 1 floor or higher. Because it is a permanent solution, it is recommended for an expected flood duration of weeks or months. Permanent barriers may be a good strategy when flood levels lower than one floor occurs frequently. Also in case floods cannot be predicted permanent barriers can be a preferable option. The duration of the flood is not of influence on this method.

High flood level

For high flood levels that exceed of 3 meters, floating and amphibious constructions are the most obvious options. With stilts it is quite simple to design and construct a building that is elevated high enough to not be threatened by a flood. If in a location extreme floods are known or expected, this should be considered in the design of the building. Because building on stilts is a permanent solution, it is recommended for expected flood durations of weeks up to months. Floating and amphibious building can adjust easily to changing water levels. If the expected flood will be for weeks of months floating is the most preferable solution. With this technology the double foundation of the amphibious building is not required. Whether or not a flood proofing method is suitable for a specific building, depends on the expected flood level, the duration, the flooding frequency and the predictability of the flood (see table 2.2).

Table 2.2 Overview of flood proofing concepts according to flood level and flood duration

Expected flood duration	0–1	1–3	3–5m
Longer period	dry floodproofing stilts mounds permanent barriers	dry floodproofing stilts mounds floating permanent barriers	stilts floating amphibious permanent barriers
Several days	wet floodproofing dry floodproofing stilts temporary barriers permanent barriers	wet floodproofing dry floodproofing stilts floating temporary barriers permanent barriers	stilts floating amphibious permanent barriers

Expected flood depth: 0, 1, 3, 5m

2.7.2 Location characteristics

For a selection of a location for a new building, flood characteristics have to be taken into account. Preferably the building will be located above sea level or on terrain where no floods will occur. However if this is not possible, choosing the right flood proof method is crucial. For deciding on what flood proofing method to apply two location-specific crucial aspects should be taken into account; the availability of permanent water and the amount of space around the hotspot. In case there is no permanent water, floating is not an option. If permanent water is available, wet proofing, dry proofing, amphibious and temporary barriers are not a preferred option. When there is little or no space around the location temporary and permanent barriers are not feasible.

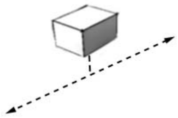
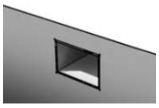
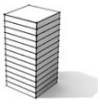
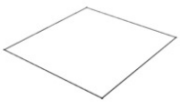
Table 2.3 Location characteristics that exclude certain flood proofing options.

Location-specific	Wet proof	Dry proof	Stilts	Mounds	floating	amphibious	temp barrier	perm barrier
Permanent water	✗	✗				✗	✗	
Insufficient space around hotstpot				✗			✗	✗

2.7.3 Design characteristics

Similar to flood characteristics and location characteristics, the design characteristics influences the applicability of flood proofing options. In general, the building circumference and area influence the flood proofing method and its dimensions and many hotspots have specific design characteristics that enable their functionality. Table 2.4 presents an overview of the hotspot characteristics and the feasibility of flood proofing options.

Table 2.4 Design characteristics and the feasibility of flood proofing options

 Underground infrastructure	Some hotspots require a connection with the underground infrastructure for their functioning. Examples: are electricity, waste water and drinking water connection. When applying **floating** or **amphibious** flood proofing this connection has to be flexible and with piles the connection should be protected.
 Vital road connection	Hotspots that are dependent of the road network to maintain their function are for instance: fire stations and police stations. Flood proofing methods that interrupt the road connection are not possible or less suitable. Examples are **wet proofing** and **dry proofing**.
 Vital track connection	Hotspots that require a rail connection to maintain their function (e.g. train station). Trains are extremely heavy vehicles and they cause an eccentric load when they move. For this reason **floating** and **amphibious** methods are not suitable. In addition, **wet** / **dry proofing**, **temporary** and **permanent barriers** are not feasible, because they interrupt access of the train to the building. Underground tracks are an exception. In this case please refer to ‘subterranean’
 Subterranean	A hotspot located underground is basically protected from floods. The connection with the ground level, usually the entrance has to be protected. Because the connection with the underground hotspot is vital, methods that do not support such a connection are not suitable. Building on **stilts**, **floating** or **amphibious** are therefore not applicable. **Wet proofing** is not suitable because if the entrance is allowed to be flooded, the underground hotspot will not be protected.
 High building	High buildings need special attention for stability in case **floating** and **amphibious** structures are applied. The optimal form for high floating buildings is a pyramid because of the low centre of gravity and equal division of forces. Usually a height of 4 storeys is seen as the maximum.
 High or uneven vertical load	Buildings with high or uneven vertical load need special attention on stability when applying **floating** or **amphibious** structures
 Heavy building	Hotspot buildings with al lot of machinery or fluids are considered heavy. This has to be taken into account when calculating the buoyancy for **floating** or **amphibious** structures.
 Non-building	The hotspot does not consist of one more buildings but is an open field with objects for example a surface electricity substation. **Wet** and **dry proofing** are solutions applied directly onto buildings and therefore not applicable.
 Vital functions on ground level	Many hotspots have important functions on the ground level. Or floodwaters entering the hotspot may contaminate it or be contaminated by it. In this case **wet proofing** is not an option.
Retrofitting	When retrofitting an existing building is being protected. Flood proofing methods that are usually too costly or not suitable for retrofitting are: amphibious, floating, stilts and mounds.
New building	All of the systems can be applied on new buildings

3 Functional requirements for flood proofing hotspots

Hotspot buildings are high value nodes in critical infrastructure. These infrastructures are of vital importance to the society. Examples of critical infrastructures are technological networks like energy supply, transport services, water supply, information and communication services. Failures of hotspots can cause major damage to society and economy: Hence, the need is urgent to identify these “risk hotspots” and develop potential protection concepts and technologies. Flood proofing these facilities secures the functioning and welfare of urban areas during flooding. In this chapter the different types of hotspots are described and guidance is provided how to protect them with flood proof construction methods. A list of hotspots was determined through expert consultation among the members of Work Package 4. The following hotspot buildings are selected: drinking water and sewage treatment plants, electricity substations, energy storage, hospitals, fire stations, police stations, communication centres, food distribution, train, metro and bus stations, airports and financial buildings.

Importance of critical infrastructures for the functioning of hotspots

Hotspot buildings are high value point elements in the urban system. They can only provide this value to the urban system by connection to this system. A flood proof and functioning power station has no significance to an urban area if all the power lines are broken and the energy cannot be delivered to the city and a flood proof hospital can only function if it can be reached by patients, staff and suppliers. Therefore, flood protection of hotspot buildings should not be considered in isolation. Both the protection of the building against the effects of flooding and the protection of the connections to the hotspot building to ensure supplies and delivery are of importance.

For the different hotpots, different types of critical requirements are needed secure the function of the hotspot during floods. These requirements are considered per hotspot. The following table (adapted from Escarameia, HR Wallingford) shows examples of hotspot buildings and critical requirement that are needed to secure their functioning during floods.

Table 3.1 Overview of critical requirements.

	Ensure supplies for production	Access to site by workers	Ensure water and sanitation	Ensure energy supply	Ensure food supply	Ensure flood safety	Ensure waste collection	Indoor climate control	Connection to network vital to deliver critical function
Water treatment	✓	✓	✓	✓		✓	✓		
Sewage treatment	✓	✓	✓	✓		✓	✓		✓
Electr.substations		✓		✓		✓			✓
Energy storage	✓	✓		✓		✓			
Hospitals	✓	✓	✓	✓	✓	✓	✓	✓	
Fire stations		✓	✓	✓	✓	✓	✓		✓
Police stations		✓	✓	✓	✓	✓	✓		✓
Communications		✓		✓		✓		✓	
Food distribution	✓	✓	✓	✓	✓	✓	✓	✓	
Financial centres	✓	✓		✓		✓			
Airports	✓	✓		✓		✓			
Bus stations	✓	✓				✓			✓
Train stations		✓		✓		✓			✓
Metro stations		✓		✓		✓		✓	✓

3.1 Drinking water treatment works

Drinking water treatment works treat water to potable standards, in order to deliver safe and clean water to users. Users include industries and households. In the European Union there are two main types of drinking water treatment plants; groundwater based treatment plants that are mostly based on higher grounds, and surface water treatment plants that are mostly based along rivers and lakes. The second category is more vulnerable to flooding and usually serves a much larger supply areas than groundwater based treatment plants. Therefore, in this report a surface water drinking water treatment work will be used as an example. During floods, the drinking water supply should continue to function because water supply is vital to the continuing operation of a city.

Surface water treatment plants generally consist of a storage basin, a building where the purification process takes place, and the clear water tanks. These components should be protected against floodwater to enable their functioning during a flood. The electrical components and the buildings are most vulnerable to flooding (Ciria, 2010).

Figure 3.1 Beerenplaat Drinking Water Production plant of Rotterdam, The Netherlands (Van Dijk, 2008).

Figure 3.2 Kralingen Drinking Water Production plant of Rotterdam, The Netherlands (Van Dijk, 2008).

These hotspots consist of a collection of buildings, tanks and basins. These installations are individual buildings that stand apart from each other. Therefore these hotspots generally have a large area that needs to be protected. The service lines that connect them to the individual houses and offices in a city are all below grade level. Therefore it is assumed that during a flood, these are not threatened. In case of emergency they have to be reachable for operation, maintenance and repair. This can be easily achieved for example by boat or helicopter. To make this possible, a docking station or helicopter platform would be needed.

For flood proofing this type of hotspot a choice has to be made whether to protect the entire plant or flood proofing each building. An advantage of flood proofing the entire plant is that the whole area is protected. This makes the internal logistics easier during a flood. Additionally, the hotspot could be used as a shelter or safe haven.

Feasibility of flood proofing concepts

Drinking water plants have a large space demand and are heavy buildings due to the large water tanks. **Wet proofing**, is not a feasible options because of the vital function and the risk of contaminating drinking water with floodwater. For both new as the retrofitting situation d**ry proofing** is a possible solution. By preventing the access of flood water to the installations and buildings the continuing functioning of the water treatment plant is secured. Building on **stilts** is not possible because of the enormous area beneath the hotspot that would be created. Building on a **mound** is possible, although much ground displacement will be needed. Building on **stilts** is not possible due to the heavy weight of the buildings. **Floating** can be applied. An equal division of weight should be guaranteed. It could be a good option if space for a new drinking water treatment plant on land is lacking and the water is already available on the site. **Amphibious** construction is possible. However, the expected flood level should be higher than the depth of the building. Because of the fact that the objects are interconnected with the underground infrastructure, floating or amphibious building is complicated. **Temporary or permanent barriers** can be placed around the plant to prevent flooding of the installations and the buildings.

Table 3.2 Possible solutions Drinking water treatment works.

	Limitations	*Wet proof*	*Dry proof*	*Stilts*	*Mound*	*Floating*	*Amphibious*	*Temporary Barriers*	*Permanent Barriers*
New		✗	✓	✗	✓	✓	✓	✓	✓
Retrofit		✗	✓	✗	✗	✗	✗	✓	✓

3.2 Sewage treatment works

Sewage or wastewater treatment works treat municipal wastewater to improve water quality standards in order to protect the water quality of receiving waterways. Sewage treatment works are mostly based along canals, rivers and lakes. Consequently, they are vulnerable to flooding. The continuing functioning of sewage treatment works during flooding is vital to prevent accumulation of waste in houses and to prevent the spreading of pathogens during floods in order to prevent epidemic during or after the flood.

Sewage treatment generally consists of a number of treatment steps. These treatment steps are usually located in a number of buildings that contain one or more of the treatment steps: Pre-treatment (screening, removal of grit, fat and grease); primary treatment (sedimentation, settling of sludge); secondary treatment (degradation of biological content by activated sludge); tertiary treatment (additional removal of nutrients or disinfection). In addition there are buildings with a control room, chemicals storage and pumps. These facilities should be protected against floodwater to enable their functioning during a flood. Similar to water treatment works the buildings and electrical components are most vulnerable to floods.

For flood proofing this type of hotspot a choice has to be made whether to protect the entire plant or flood proofing each building. An advantage of flood proofing the entire plant is that the entire area is protected. This makes the internal logistics easier during a flood and because it is a large area that is protected, it could also be arranged as a shelter or safe haven.

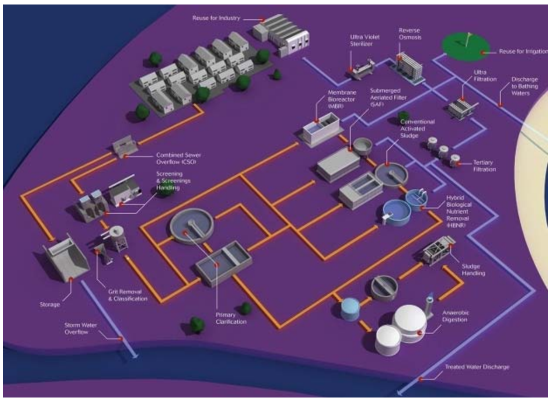


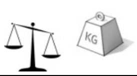
Figure 3.3 Possible components in wastewater treatment (Ovivo Water, 2011).

Figure 3.4 Wastewater treatment Harnaschpolder Delft, The Netherlands (Nexans.nl, 2006).

Feasibility of flood proofing concepts

Sewage treatment works are low rise buildings with a large space demand. Like drink water treatment works the buildings are heavy due to the water tanks. **Floating** can be applied if an equal division of weight is guaranteed. It could be a good option if space for a new waste water treatment plant on land is lacking and the water is already available on the site. **Amphibious** construction is possible. However, the expected flood level should be higher than the depth of the building. Because of the fact that the objects are interconnected with the underground infrastructure, floating or amphibious building is complicated. For both floating and amphibious flood proofing the connection with the underground infrastructure is a big challenge. This is in particular the case, if the expected flood height is more than one meter. **Wet proofing** is not possible because waste water should not be mixed with floodwater. This may cause water pollution and the distribution of pathogens in the flood area. Also the chemicals and electrical appliances that are used for wastewater treatment should be protected against the water. Building on a **mound** is possible, although much ground displacement will be needed. Building on **stilts** is not possible due to the heavy weight. Moreover an enormous area beneath the hotspot would be created. For both new as retrofitting **dry proofing** is a possible option to prevent the water from entering buildings and the treatment tanks. The treatment tanks already consist of water resistant material. As a result, with a relatively low effort these tanks can be made flood proof. However, if the expected flood level is higher than the height of tanks, water will still enter the treatment tanks. **Temporary or permanent barriers** can be placed around the sewage treatment plant to prevent flooding of the installations and the buildings.

Table 3.3 Possible solutions sewage treatment works.

	Limitations	*Wet proof*	*Dry proof*	*Stilts*	*Mound*	*Floating*	*Amphibious*	*Temporary Barriers*	*Permanent Barriers*
New		✗	✓	✗	✓	✓	✓	✓	✓
Retrofit		✗	✓	✗	✗	✗	✗	✓	✓

3.3 Electricity substations and transformer stations

A substation is a part of an electricity network. The electricity network can be subdivided into the transmission system and the distribution system. Transmission substations are used to connect different transmission lines. Distribution substations transform energy to a lower voltage level to make it fit for (local) distribution. Electricity is vital to the functioning of a modern city. Home appliances, lighting, security systems, communication all depend on the electricity network. Substations can be divided in three groups: substations that are located on the surface enclosed by a fence, underground substations, or substations located in special-purpose buildings. This last option is usually found in urban areas, in order to reduce noise. Electricity substations may consist of transmission and distribution buses, transformers, a disconnect switch and/or a circuit breaker and a control building. All elements are considered vulnerable to water. Substations need to be connected to land based infrastructure.

Figure 3.5 Surface substation (Geograph.org.uk, 2011).

Figure 3.6 Underground substation (Fujian Headspring Mining Investment Co., Ltd. , 2011)

Figure 3.7 Substation building (Banff Lodging Company, 2011).

Feasibility of flood proofing concepts

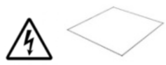
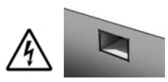
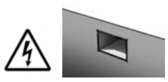
Surface substations have a large space demand and are located outdoor. Therefore **wet and dry proofing**, are not feasible options. Wet proofing is not a suitable solution because all elements that make up a substation are considered vulnerable to water. Because this hotspot is not a buildings dry proofing cannot be applied. New surface substations could be elevated on **stilts or a mound. Floating** and **amphibious** can be applied but the flexibility of electricity connections should be taken into account especially in cases when high flood levels are expected. For substations confined within a building, the possibilities are the same as for surface substation. The only difference is that **dry proofing** can now be applied. For new underground substations the entrances can be **dry proofed**. All other techniques except for the barriers cannot be applied because the building is underground. For retrofitting and new surface substations, substation buildings and underground substations temporary or permanent barriers can be applied. In the example below this is described how this is applied in practise. The entry points are either vehicle or pedestrian access points. The vehicle entrances are protected with lift hinge flood gates. Pedestrian entrances are protected by swing hinge flood gates.

Figure 3.8 Elevated transformer substation in floodplain, Nijmegen, Netherlands (De Graaf, R.E., 2010).

Figure 3.9 Kerang substation, Victoria, Australia (Savage, J., Williams, F. 2011).

Figure 3.10 Floodwalls around electricity substations (Flood Control Limited, 2010).

Table 3.4 Possible solutions electricity substations and transformer stations.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New Substation surface		✗	✗	✓	✓	✓	✓	✓	✓
Retrofit Substation surface		✗	✗	✗	✗	✗	✗	✓	✓
New Substation building		✗	✓	✓	✓	✓	✓	✓	✓
Retrofit Substations building		✗	✓	✗	✗	✗	✗	✓	✓
New Substations, underground		✗	✓	✗	✗	✗	✗	✓	✓
Retrofit Substations underground		✗	✓	✗	✗	✗	✗	✓	✓

3.4 Energy storage

Energy Storage can be categorized in a variety of types; from natural storage to the more commercial types such as mechanical, electrical, chemical, biological and thermal storage. Examples are; growing crops, conversion of solar energy into electricity, water reservoirs & dams, but also all types of fuels. Chemical fuels are the most dominant form of energy storage. The vast majority of the transportation sector relies on these fuels. Therefore, in this report the example of chemical energy storage will be elaborated.

Big storage tanks exist in almost all port areas in Europe. They preserve oil, chemicals, bio fuel, and gas. The storage locations are all based along rivers and in port areas. These storage areas usually consist of large amounts of tanks or a few individual tanks. For example the storage units of Maasvlakte Oil Terminal have 36 tanks that all have a capacity of 114.000 m^3 with a height of 22 meters. The terminal is connected by pipelines to several refineries. The longest connection is 140 km long. Usually the area of tanks is situated on a mound or is protected by a dike to prevent the fuels from leaking to the sea if a leakage occurs. Other storage units have local dikes around them that can hold the total capacity of the tanks if the leakage occurs from the inside out. The tank itself also functions as a dry proof building. During a flood, fuel supply should continue to function because fuel is vital for transportation of people, goods and emergency services. Also, emergency services like such as trucks, ambulances and all kinds of water emergency services should be able to reach critical locations, shelters and hotspots.

For flood proofing this type of hotspot a choice has to be made whether the entire plant will be flood protected or that the individual buildings will be flood proofed. An advantage of flood proofing the entire plant is that the entire area is protected. This makes the internal logistics easier during a flood and it also protects the numerous pipelines in that area.

Figure 3.11 Oil storage Rotterdam, The Netherlands (Odfjell.com, 2011).

Figure 3.12 Oil tanks VOPAK (Skyscrapercity.com, 2006).

Feasibility of flood proofing concepts

The storage tanks for oil and fuels are well protected from flooding because of the high risk safety requirements. This means that many flood proofing methods are already applied in the building and building site. **Wet proofing** is not a realistic option because it would be an environmental disaster if flood waters would mix with oil. The tanks are already **dry proof** because of their function. By keeping the tanks from leaking, it also is protected from the water from the other side. The connection pipelines from and to the ships and truck could still be a point of attention. Elevating the object or area is demanded by some of the oil storage companies, so some of these areas are already situated on higher grounds than the surrounding area, this is similar to a **mound**. Building on **stilts** is not possible due to the heavy weight. **Floating** and **amphibious** construction is possible. While floating seems a feasible option, considering the oil tankers that are already in use, this would require precaution measures, to prevent oil leakage in the water. Also the connection to the mainland with flexible pipelines is a point of attention. The tanks are already protected by a surrounding dike around the whole area as well as around the tanks themselves. These **permanent barriers** are needed because of the high risk when one of the fuels would leak. Because of this, **temporary barriers are** not an obvious choice.

Figure 3.13 Dikes around oil storage tanks, Maasvlakte (Rotterdam), The Netherlands (Skyscrapercity.com, 2009).

Table 3.5 Possible solutions Energy storage.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New		✗	✓	✗	✓	✓	✓	✓	✓
Retrofit		✗	✓	✗	✗	✗	✗	✓	✓

3.5 Emergency services: Hospitals

Medical institutions or hospitals provide treatment and care for the injured and the sick. They are mostly located in urban areas. Hospitals differ in number of specialism, size of specialist departments and treatment facilities. There are three types of hospitals; general hospitals, specialist hospitals and university hospitals. University hospitals have extensive diagnostic and therapeutic facilities and carry out research and teaching (Neufert, 2000).

Some people need special care constantly. If this cannot be given during a flood, there will be many victims. During a flood, often also many people will be injured. The hospital will have to be able to give emergency care. Therefore it is important that a hospital stays functional during a flood. During a flood not all functions are vital to keep the hospital functioning. The functions that are the most important during a flood are: emergency room, intensive care, surgery, cardiology, radiology, wards and pharmacy. Laboratories, GP and the mortuary are vital but can be located outside the hospital provided that transportation between these facilities and the hospital is possible.

Figure 3.14 Erasmus MC, Rotterdam, The Netherlands (Nieuwslog.nl, 2010).

Figure 3.15 Oslo University Hospital, Oslo, Norway (Panoramio.com, 2011).

Table 3.6 Critical requirements Hospitals.

	1. Supplies	2. Access	3. Water sanitation	4. Energy	5. Food	6. Safety	7. Waste	8. Climate	9. Network connection
Critical requirements	✓	✓	✓	✓	✓	✓	✓	✓	

Feasibility of flood proofing concepts

Most often hospitals are large buildings in an urban area. They often consist of a combination of low and high-rise buildings. When the hospital has a small footprint and no important functions are situated at ground level, **wet proof** construction is not possible. Flood water should be kept outside the hospital to secure public health.

Dry proof construction is feasible only when the surface of the building in comparison with the floor plan is relatively small. **Amphibious** construction and **floating** construction are options if the building height is not to large. The **mound** is a possible solution when the hospital has a relative small footprint. There are examples of (partly) raised hospitals on **stilts**. The first example is

Medical University of South Carolina. The ground floor of this hospital is mainly used for parking. All the vital elements, such as generators, pumps etc, are located on the floors above. The hospital's entrance is located on the second floor, which can be reached by a ramp and stepped walkways. The elements that had to be located on the ground floor (elevator lobbies and storage rooms) are protected by floodgates and doors (Crumrine, R. G., 2008).

Figure 3.16 Medical University of South Carolina on stilts (Crumrine, R.G., 2008).

Figure 3.17 Memorial Hermann Baptist Hospital in Beaumont (Horton Drywall Co., 2011).

A second example is the Memorial Hermann Baptist Hospital in Beaumont (Texas). It was damaged by flooding as a result of the tropical storm Allison in June 2001. After that, a number of measures were taken to protect the hospital. To decrease the vulnerability and enables the hospital to keep functioning in case of a flood, a new building was erected next to it in 2004. In this building all critical mechanical, electrical and plumbing equipment is placed at an elevated floor level (FEMA, 2008).

Two other options are temporary and permanent barriers. **Temporary barriers** are generally not the preferred option because the accessibility of the hospital for ambulances is significantly reduced. However, it could be an option if the access is located on a higher level. **Permanent barriers** are sometimes used as a flood defence for hospitals. An example of this measure is the 'VieCuri Medisch Centrum'. It is a hospital in the Netherlands that has been built in the floodplain of the river Meuse. On several occasions the hospital inundated. In a recent flooding of June 2009, elevators went offline and several wards inundated and had to close down. To prevent future flooding hazards a dyke has been built between the river Meuse and the hospital, it has an emergency storage facility and vital installations are placed in higher parts of the building (Deltares and Grontmij, 2010). Accessibility of the hospital has to be taken into account. During a flood it is also important that patients can reach the hospital, this can be provided in other ways than normal, for example with boats. Therefore (emergency) docking stations for boats should be provided.

Table 3.7 Possible solutions Hospitals.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New	⚠	✗	✓	✓	✓	✓	✓	✓	✓
Retrofit		✗	✓	✗	✗	✗	✗	✓	✓

3.6 Emergency services: Fire stations

A fire station is a structure used to station fire fighting equipment, vehicles, crew and supplies. It is usually located in urban areas. Fire is usually the next hazard after a major flooding event. Gas leaks or electric short-circuiting may easily start fires. Apart from eliminating fire hazards the fire department also acts as an emergency service: rescuing people, clearing road blocks, setting up communications, maintaining flood control etc. Fire stations come in various sizes and layouts and may be manned by full-time career fire fighters, part-timers or volunteers / paid on call. A typical layout consists of 1) an 'apparatus bay', where fire fighting and emergency response vehicles are stored; 2) administrative and training areas and 3) optionally residential areas with dorms and support areas (kitchen/bathroom). The most essential part, for a fire station to be able to continue operations during flood hazards, is the access to an operational/functional traffic network. Some (specialized) fire stations may employ other types of fire fighting vehicles that may come in handy during flood events, such as ships, planes or helicopters.

Figure 3.18 Fire Station in Houten, The Netherlands (Joostdevree.nl, 2011).

Figure 3.19 18th Fire Station, Santiago, Chile (2011, Architectureweek.com,).

Figure 3.20 Corning Fire Department on a mound, NY, USA (Blogspot.com, 2011a).

Feasibility of flood proofing concepts

The accessibility of fire trucks is vital for the functioning of this hotspot and needs to remain operational during a flood. Since they are situated on the ground floor, **wet proofing** and **dry proofing** is not a feasible option, because of the essential access to roads. **Amphibious and floating construction** are only feasible in combination with amphibious (or temporary floating) roads. Building on mounds is not a preferable solution for densely built areas because it requires a lot of space. However there are examples of fire stations on mounds. **Stilts** are also a solution. In general it is good practice to (re)located fire stations to higher ground. **Temporary barriers** or **permanent barriers** are not feasible if it would block access to fire trucks. Combination of the permanent barrier with a slope is also possible. This is illustrated by a flood defence initiative in York. In 2010 flood defence walls were erected to protect York's fire station on Peckitt Street and several nearby properties against flooding when the River Ouse rises above normal levels (Bbc.co.uk, 2011). In 2011 the fire department moved to another location. Apparently one of the reasons for moving was that the building was still prone to flooding (Bbc.co.uk, 2011b). This would be the only retrofitting possibility in this situation.

Table 3.8 Possible solutions Fire stations.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New		✗	✗	✓	✓	✓	✓	✗	✓
Retrofit		✗	✗	✗	✗	✗	✗	✗	✓

3.7 Emergency services: Police stations

A police station is a building which accommodates police officers and other staff. The building contains a front office and a back office, temporary holding cells, interview and interrogation rooms. It also offers accommodation for vehicles along with personnel facilities. Some big police stations have stables for horses as well. Police stations are mostly located in city centres with smaller divisions in neighbourhoods. When a flood would occur, police forces are needed to maintain order, save people and protect shops and other buildings. Because of this, police stations are hotspot buildings. To ensure the needed functions, the continuity of the communication room and the vehicle accessibility has to be maintained.

Figure 3.21 Police station Rotterdam, The Netherlands (RNW, 2009).

Figure 3.22 Mostowski Police Station in Warsaw, Poland (Wikipedia.org, 2012c).

Feasibility of flood proofing concepts

Police vehicles are a vital part of this hotspot and need to remain operational during a flood. Since they are situated on the ground floor, **wet proofing** and **dry proofing** is not a feasible option. For the total building area m**ounds** and **stilts** are feasible solutions. Mounds are not the most preferable option because police stations are often located in city centres or in densely built-up areas. A mound needs an area that is larger than the building footprint because of the required slopes.. **Amphibious and floating constructions** are only feasible in combination with amphibious or (temporary) floating roads, which may be quite an difficult and expensive solution. Floating could be an option if a new police station has to be build in a centre where there is no more space on land or when more water retention is needed. **Temporary barriers** are not feasible because they completely close off the police station and make it impossible for police vehicles to enter or exit the premises. **Permanent barriers** can be applied if the barrier can be crossed by a bridge or slope.

Table 3.9 Possible solutions Police stations

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New		✗	✗	✓	✓	✓	✓	✗	✓
Retrofit		✗	✗	✗	✗	✗	✗	✗	✓

3.8 Communications buildings

There are different definitions of a communication building or centre. First, it can be a facility that serves as a hub for communications network, for example in the military. In this function it is equipped for technical control and maintenance of the circuits and the communications networks. Furthermore, responsible communication building can have the function of transmission, receipt, processing and distribution of incoming and outgoing messages (Wikipedia.org, 2011).

Second there are Network Operation centres (NOC). Here control is exercised on computer, television broadcast or telecommunication networks. The term is generally used to refer to telecommunication providers. The housing of a NOC may contain servers and other equipment essential to running the network. The employees of a NOC monitor the networks performance and look for alarms or conditions that need special attention. With telecommunication for example this includes power failures, communication line alarms (such as bit errors, framing errors, line coding errors, and circuits down) and other performance issues that may affect the network (Wikipedia.org, 2011).

Third the term communication centre can refer to a data centre. This is a facility that houses computer systems and associated components. A data centre has multiple functions; on the one hand it provides storage of the data of one or more companies. On the other hand it operates the one or more companies' network. A data centre can be housed inside a company's building but can also be a separate building. The latter will provide network and communication services to multiple companies.

Finally, one could consider a telephone exchange or switching centre as (a part of) a communication centre. A switch room requires room for the digital exchanges, which are essential for the telephone network to operate.

Most data centres are located in or near urban areas. Communication is vital during a flood. Without communication humanitarian and governmental organizations cannot plan and execute aid and evacuation programmes. It is also important the data that is stored in the data centres, is safe guarded from the flooding. In this report the focus will be on data centres. Critical functions of a communication centre, that need to be operational during a flood, are: Storage systems, Network operating systems, Climate control such as air conditioning, Energy supply, generators, backup systems, Transmitters, cables and antennae and the Control systems.

Figure 3.23 In house data centre (Wikipedia.org, 2007).

Figure 3.24 Cooling towers and data centre, St. Louis, US (Flickr, 2007)

Figure 3.25 Technicians in a NOC (Wikipedia.org, 2011).

Feasibility of flood proofing concepts

With this type of hotspot it is important that the data centre building or part of the office building where the data centre is located does not get flooded. **Wet proofing** could be used only under two conditions: first, only part of the building is used as a data centre, and second the equipment should not be located on the ground floor**.** Many data centres have already taken precautions against flooding. Some are built above sea level, other are located on higher floors in a building. Some are also equipped with raised floors and water or moisture detection.

Dry proofing is a good method to make a data centre flood resistant. An example is the new data centre of the Decatur Memorial Hospital. The new data centre is a steel reinforced concrete bunker, which uses the data centre as well as generator and mechanical areas. It is also equipped with sump pumps (Decatur Memorial Hospital, 2009).

Amphibious and **floating construction** is possible. Point of attention is the weight of the total building**.** In case the data centre is full with heavy equipment, high buoyancy is needed. Elevating the communication centre by application of **stilts or a mound** is also an option. An example of this kind of building is the Hermann Hospital in Houston, Texas. In the mid 1990's, a new communication centre was realized in the Hermann Hospital and Hermann Children's Hospital. A new voice communications network was implemented, which included a new campus-wide cable plant, a new telephone switch room and new wiring closets. The new telephone switch room was located in the basement of the hospital. The switch room was designed with a raised floor and all of the cabling, both voice and electrical, was fed into the room through the use of overhead racks. As an additional waterproofing step, a concrete curb was installed under the raised floor.

"*During Tropical Storm Allison in 2001, Hermann Hospital was forced to close and transfer all of their patients to other facilities due to the enormous flooding and loss of commercial power; however, the concrete curb and the 18" raised floor kept the telephone system and its batteries and rectifiers dry. The system provided vital communications within the hospital and to the outside world and ran until the batteries were drained. When commercial power was restored - the telephone system rebooted and worked - one of the few telephone systems within the Texas Medical Centre that did not sustain significant damage*" (Trilliant Technology Group, 2011).

Temporary or **permanent barriers** can only be used if there is sufficient area around the building to build a barrier. Most of the communication centres will be located in urban areas. Therefore it will not be possible to use this method most of the time.

Table 3.10 Possible solutions Communication centres.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New		✓	✓	✓	✓	✓	✓	✓	✓
Retrofit		✓	✓	✗	✗	✗	✗	✓	✓

3.9 Food distribution centres

Food distribution centres are logistic hubs with storage of food products before distribution to supermarkets. They are mostly located directly along the highway and outside cities due to their large space demand. There are national and regional food distribution centres, general (all sorts of food products) or specialized (for example frozen foods only). Food distribution centres are generally large low rise buildings with doors to facilitate easy access for trucks. The interior is mostly used for storage space, including refrigerated storage space. Because supermarkets no longer have much storage space, generally only for a couple of days of operation, the food supply of cities is completely dependent on food distribution centres. Consequently these centres should be protected against flooding. For continuing functioning they require the access of trucks or other forms of transportation, and the continuing use of climate control and refrigerators.

Figure 3.26 National food distribution centre, Coventy, UK (Co-op Food Supply Chain Logistics, 2009a).

Figure 3.27 Food distribution centre, West Thurrock, United Kingdom (Co-op Food Supply Chain Logistics, 2009b).

Feasibility of flood proofing concepts

Food distributions centres are low rise buildings with a large space demand. Because of this **stilts, mounds, floating or amphibious structures**, although an option, will usually incur relatively high costs. However, there are several large superstores that are built on stilts (e.g. Tesco in Long Eaton). All options except mounds may have accessibility issues. Ramps, floating or flexible road connections are necessary to maintain the distribution function, also during floods. Alternatively, distribution may be organised over water during a flood. Wet proofing is not recommended, because of the risk of contamination by the flood water. For both new and retrofitting **dry proofing** is an option and if sufficient space around the building is available **Permanent** or **Temporary barriers** can be erected. If operation during floods is vital, access for trucks needs attention. Elevated ramps are an option. If large parts of the region and roads are flooded, alternative modes of transportation, such as distribution by boat or helicopter, can be considered.

Table 3.11 Possible solutions Food distribution centres.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New	⚠	✗	✓	✗	✗	✓	✓	✓	✓
Retrofit		✗	✓	✗	✗	✗	✗	✓	✓

3.10 Financial buildings

The term ‘financial building’ is used to denote financial institutions and businesses. Mainly banks, but it also includes non-bank financial institutions (NBFI’s) and companies (NBFC’s) that are vital to the local and regional economy (e.g. stock exchanges). Financial buildings are predominantly located in urban areas. Recent events show that failure to operate during floods may severely affect daily life. The vault security of a Japanese bank, hit by the 2011 tsunami, was crippled and $500.000 was robbed (CTV NEWS, 2011). During a Mississippi flood, the safe deposit vault got swamped, affecting 1200 of the 4000 deposit boxes (McGuin, D.P., 2006). Even if the vaults are truly flood proof, flooding events may still seriously hamper daily operation and cause financial issues for clients and (local) residents. Lack of financial resources may even hamper voluntary evacuation, as was proven during Hurricane Katrina (McGuin, D.P., 2006). If bigger financial buildings are hit, it may seriously harm nationwide economy.

Figure 3.28 Bank of England, London, UK (Wordpress.com, 2011).

Figure 3.29 Commerce Bank, Pennsylvania, USA (Global Flood Defence Systems, 2012).

Table 3.12 Critical requirements Financial buildings.

	1. Supplies	2. Access	3. Sanitation	4. Energy	5. Food	6. Safety	7. Waste	8. Climate	9. Connection
Critical functions	✓	✓		✓		✓			

Feasibility of flood proofing concepts

Financial buildings are extremely heavy buildings. Vaults need heavy armoured walls to prevent robbery and fire risk. **Floating** and **amphibious** construction are therefore not suitable. Considering that the ground floor has an important funcion to facilitate customers and visitors, w**et proofing** is not suitable. **Stilts or mounds** are suitable methods, however there are some points of attention. Accessibility may be influenced negatively when constructed on stilts. Mounds need sufficient space around the building, which in urban areas is not always available. For new as well as retrofitting d**ry proofing** could be applied, as long as the building remains accessible and electricity and communications can be maintained. **Permanent barriers** are a common used solution. The Commerce Bank in Pennsylvania has been fitted with a self-closing flood barrier that protects the entrance from flooding (Global Flood Defence Systems, 2012).**Temporary barriers** are quite similar to permanent barriers which have already been applied to banks (figure 3.29).

Table 3.13 Possible solutions Financial buildings.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New	⚠ ⚖	✗	✓	✓	✓	✗	✗	✓	✓
Retrofit		✗	✓	✗	✗	✗	✗	✓	✓

3.11 Transportation hubs: Airports

An airport is a location where aircrafts can take off and land. It consists of a collection of buildings including a terminal, hangars, a control tower and one or several runways. Airports are usually situated near urban areas, but not too close to prevent safety or noise issues. Airports may serve an important role in a flood crisis situation. Transportation of relief goods, such as food and water, are essential and airports make a strategic location for emergency shelter and evacuation missions. During a flood at least one runway and a control tower need to remain in operation. Because of their elevation control towers can easily be constructed as a flood proof building; as long as access remains free of water and electricity and communication lines remain intact.

Figure 3.30 Rotterdam The Hague Airport, The Netherlands (Vliegveldinfo.com, 2011).

Figure 3.31 Charles de Gaulle Airport, Paris, France (Blogspot.com, 2011b).

Airports are not dependent on a specific physical network. When the connections to land can no longer be used due to flooding, the airport can still be reached by boats or airplanes. Emergency or evacuation routes with boats can be established to transport people to the airport and from there to safer places. In the same time rescue teams and supplies can be flown into the affected area. From there it could be distributed by boats. Therefore it is not crucial to protect the land connection of the airport. The functional scheme of the terminal building shows that a connection between terminal building and runway is of great importance. Passengers need to be transported safely from the terminal building to the planes. In large airports these connection are physical, but they can also be established by vehicles. During a flood this connection has to be protected.

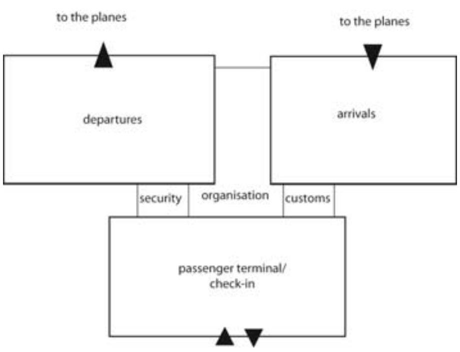


Figure 3.32 Organization scheme (based on: Rotterdamairport.nl, 2011 and Paris.com, 2011).

Figure 3.33 Madeira Airport, Portugal (Hubpages.com, 2011).

Feasibility of flood proofing concepts

Flood-proofing an airport can either be done by protecting the different elements, or by protecting the entire area. The second option has a larger area that needs to be protected, but this extra space may double as a shelter. **Wet and dry proofing** are solely used on buildings and are not viable measures for runways. Building on higher ground is a solution. Runways are normally not founded on **stilts** due to safety requirements, but it is possible in extreme situations. E.g. the Madeira Airport is built out over the ocean on 180 columns of approx. 70 m high. **Mounds** are also a possible option. **Floating** airports have been tested at small scale in Japan. The outcome of the research was that a full scale floating airport may reduce about 33% of the costs compared to one on reclaimed land. Several concepts for floating airports were developed. In 2000 a 1km floating runway in Tokyo Bay, called the Mega-Float, was constructed and tested with sponsorship of the Japanese Ministry of Land, Infrastructure, and Transport (Mlit.go.jp, 2011). After the tests were finished, the airport was dismantled (Bimco.org, 2011). The Pneumatic Stabilized Platform (PSP) was another concept for floating airports, designed for San Diego. It was rejected in 2003 due to high cost and complicated access for passengers, transport and utilities (Blood, H. and Innis, D., 1995). Constructing **amphibious** runways is an even bigger challenge than floating runways. The surface beneath the runway should be well prepared (very smooth) to reduce risk of breaking and in combination with the floating platform this solution may not be financially feasible. For new and retrofitting **temporary barriers** are a feasible option if the entire airport is enclosed. In 2009 a $24 million system has been implemented at the downtown airport of Saint Paul (USA). It is 1km long and takes about 48 hours to install. It has already operated a couple of times (Finance-commerce.com, 2011). **Permanent barriers** are also an option if the entire airport is to be enclosed by the barrier. The Kansai International Airport is built on a man-made island in the Bay of Osaka. Due to large settlements of the ground, a dike has been constructed surrounding the airport. Some hybrid options, using different measures for the runway and the buildings, may also be worth investigating and alternatively, only the most vital areas can be flood-proofed.

Figure 3.34 Mega-Float, Tokyo Bay, Japan (concept) (Mlit.go.jp, 2011).

Figure 3.35 Temporary barrier at St. Paul's Airport, USA (Johnson, B., 2010).

Table 3.14 Possible solutions Airports.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New		✗	✗	✓	✓	✓	✓	✓	✓
Retrofit		✗	✗	✗	✗	✗	✗	✓	✓

3.12 Transportation Hubs: Bus stations

A bus station is a cluster of bus stops where different bus routes meet; mostly located in cities and near other means of transportation, such as train stations or airports. Mobility and public transport are an important part of daily life and therefore vital during a flood. Bus transportation can also be used to evacuate or shelter people. A bus stations consists of platforms, waiting rooms, ticket office, and restrooms and waiting rooms for drivers. Optional are shops, offices and a workshop or maintenance area for the busses. In the floor plan of the bus station Sloterdijk (Gvb.nl, 2011) there are multiple platforms (A till M). The ticket offices and other facilities are located in the train station Sloterdijk, which is located next to the bus station. There are two types of bus stations: fixed and dynamic stations. In a fixed station every bus route has its own fixed bus stop. In a dynamic bus station the bus platforms assigned to a bus route can vary. This results in more flexibility and space reduction. Info panels are needed to inform passengers about their departure time and stop.

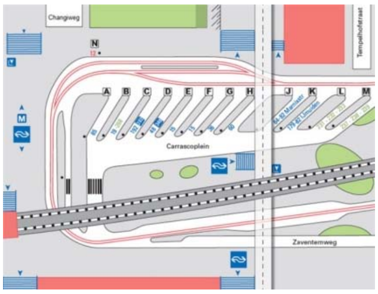


Figure 3.36 Bus station Sloterdijk, Amsterdam, The Netherlands (Gvb.nl, 2011).

Figure 3.37 Heathrow central bus station, London, United Kingdom (Wikipedia.org, 2012d).

Figure 3.38 The raised bus station of Hoofddorp, The Netherlands (Skyscrapercity.com, 2011).

Feasibility of flood proofing concepts

For a bus station to function during a flood, it is important that the platforms maintain accessible for the vehicles. Because the platforms are not buildings **wet proofing** and **dry proofing** are not applicable methods. They could however be used for the station buildings. In addition, the connecting roads should be accessible in order for the bus station to fulfil its function. **Stilts:** There are bus stations, for example in Hoofddorp en Den Haag (the Netherlands) that are elevated. In Hoofddorp the station is located on a viaduct, in Den Haag it is on the second floor of the train station. By combining the station with another function and thus raising it, the station becomes automatically flood proof. A station on a **mound** is also possible, but will be more costly because of the large area of space that needs to be raised. A **floating or amphibious** bus station is possible. Point of attention is the requirement of a flexible connection to the road network during a flood**.** For new and retrofitting, temporary barriers are not a feasible solution because they close the station from the road network. **Permanent barrier** are only possible if the platform is connected to the road network by a slope or bridge.

Table 3.15 Possible solutions Bus stations

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New		✗	✗	✓	✓	✓	✓	✗	✓
Retrofit		✗	✗	✗	✗	✗	✗	✗	✓

3.13 Transportation Hubs: Train stations

A train station or rail station is a train facility where trains regularly stop to load and unload passengers or goods. It generally consists of a platform next to tracks, called a stop. Often a station building includes stores, restaurants, tickets services and waiting rooms. Some big stations have a train depot; an open rail car stabling area, combined with shunting, train formation and maintenance. In the table, the focus is mainly on the platform and the tracks.

Figure 3.39 St. Ives Cornwall, United Kingdom (Wikipedia.org, 2012e).

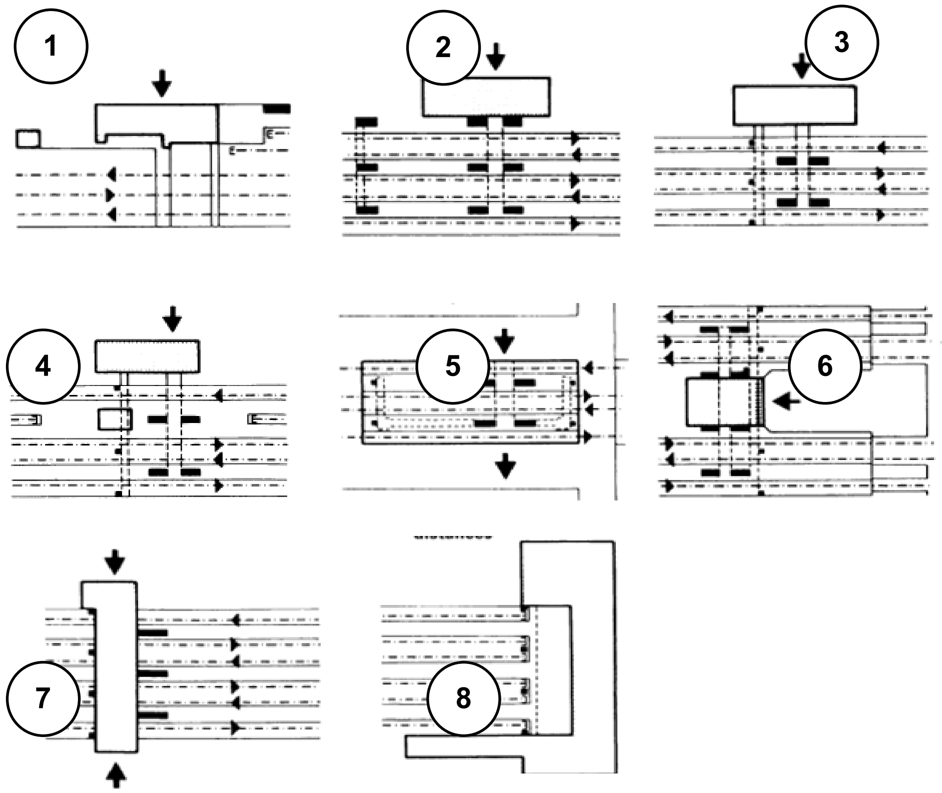
Figure 3.40 Prague train station, Czech Republic (Hickerphoto.com, 2011).

Table 3.16 Critical requirements Train stations.

	1. Supplies	2. Access	3. Water sanitation	4. Energy	5. Food	6. Safety	7. Waste	8. Climate	9. Network connection
Critical requirements		✓		✓		✓			✓

Feasibility of flood proofing concepts

There are eight general configurations of railway stations (see fig. 3.41). These have an influence on the flood proofing measures. The station can be divided into the platform, that runs parallel to the tracks and is used to reach the trains and the station building. The station building is either at the same level of the tracks, under the tracks in a tunnel, or above the tracks in a bridge structure. Because the tracks are not a building, **wet proofing** and **dry proofing** do not apply. A possible method to protect the tracks is to raise them on **stilts** or **mounds** or have a **permanent barrier** around them. A **temporary barrier** is not possible for the tracks and the platform, because the tracks would no longer function. It may be a solution for the train station building. The platforms and the building are in most train station configurations are already elevated (figure 3.41 nr.3 - 7). As a result, **stilts** or **mounds** are good options for both tracks and buildings. For the building, w**et proofing** could be possible as long as the primary functions for power supply are protected so they can work properly. **Dry proofing** can be a feasible option both in the case of a new and retrofitting situation. **Wet proofing** and **dry proofing** of the platform is not possible for this is not a building. **Floating** and **amphibious** rail stations are not feasible, because of the rigid connections of the tracks. **Permanent barriers** are only possible if they would stretch out along the tracks as well. Configuration 3-6 is most suitable. In that case tracks are higher than the building and only the station needs to be made flood proof, e.g. by temporary barriers or dry proofing.



1. Station building at one side on ground level, passengers must cross tracks to go to the other side. Station building detached from the tracks.
2. Like number one only with tunnel to access the tracks, staircase for access to platforms.
3. Building on one side, below track level. Tunnel for crossing the tracks, staircase and lift for access to platform.
4. Building on one side below track height, between tracks waiting rooms (interchange stations).
5. Building in the middle, underneath the tracks, short walking distances.
6. Building in the middle, underneath the tracks spacious access via forecourt and short walking distance.
7. Building over the tracks, acts like a bridge for passengers.
8. Station at end of track, where possible at track height.

Figure 3.41 Configurations train stations (Neufert, 2000).

Table 3.17 Possible solutions Train stations

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New:		✗	✗	✓	✓	✗	✗	✗	✓
Retrofit:		✗	✗	✗	✗	✗	✗	✗	✓

3.14 Transportation Hubs: Metro stations

A rapid transit, metro, subway or underground station is a hub where trains stop to allow passengers to board and disembark the vehicle. It is a transport system with high capacity and frequency, therefore a large number of passengers will use a station during the day. In city centres metro stations are mostly underground and can be accessed by multiple entrances. Sometimes it is connected to a shopping mall or commercial building. In the suburbs the metro is mostly above ground, sometimes on a viaduct or dike. In particular large cities depend on mobility and public transport. Therefore it is vital that the system stays operational during a flood. A metro station consists of tracks and platforms, access to the platforms, payment units and ticket windows. The possibility for the trains to use the tracks and transport people is an essential feature, which should function also during a flood.

Figure 3.42 Subway entrance, NY, USA (Wikipedia.org, 2012f).

Figure 3.43 Metro station, Prague, Czech Republic (Blogez.com, 2011).

Table 3.18 Critical requirements Metro stations.

	1. Supplies	2. Access	3. Water sanitation	4. Energy	5. Food	6. Safety	7. Waste	8. Climate	9. Network connection
Critical requirements		✓		✓		✓		✓	✓

Feasibility of flood proofing concepts

The main purpose for flood proofing metro stations is to prevent the water from entering the entrances of the stations. Therefore **wet proofing** is not feasible for this kind of hotspot. When the entrance to the station is situated in or under a building, **dry proofing** could be a possible solution for both new station and retrofit.

Figure 3.44 Elevated metro track in Paris, France (Denunciando.com, 2011).

Figure 3.45 Temporary barriers or floodgates at metro station in Tokyo, Japan (TU Delft, 2011).

Because a connection with the underground platforms is necessary, **floating** or **amphibious** constructions are not feasible option. **Stilts**: Some metro tracks are elevated above the ground. Here the stations are also raised. These buildings are protected against floods**.** For new metro lines and stations this solution can be applied. For underground tracks this is not a viable option. The underground station's entrance building could be placed on a **mound.** What can be applied in new and retrofitting situations are **Temporary barriers**. This method is already in use in Tokyo, Japan. **Permanent barriers** in front of a metro station entrance are possible but use a large space and wouldn't be very suitable in city centres, especially when retrofitting. In the table (and in the model in chapter 4) we are only considering the underground metro stations.

Table 3.19 Possible solutions Metro stations.

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
New: underground station		✗	✓	✗	✓	✗	✗	✓	✓
Retrofit: underground station		✗	✓	✗	✗	✗	✗	✓	✓

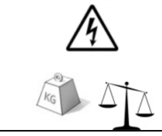
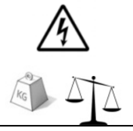
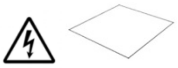
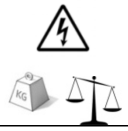
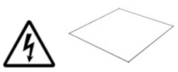
3.15 Conclusion

In this chapter, an overview of hotspots has been presented. These hotspots have been combined with the flood proofing concepts of chapter 2. The result is presented in two overview table that show feasible and unfeasible flood proofing strategies for different hotspot buildings. One table is for new hotspot building, the other one is for retrofit hotspot buildings.

For some hotspots a link with a transportation network is critical for its functioning. Examples are sewage treatment works, bus stations, train stations, metro stations, police stations and fire stations. If these hotspots are not linked to the network they are part of, they simply cannot function. Other hotspots also need a connection to a network but they can temporarily use other modes of transportation during a flood. Drinking water, hospitals and food distribution could use an alternative distribution system with transport by boats. As long as the hospital itself is protected, the connection to the network is less important.

Table 3.20 shows that in most cases wet proofing is not a feasible method for flood proofing hotspots. The only hotspots where wet proofing could be an option are communication centres.

Table 3.20 Overview of flood proofing concepts for hotspots (R = can be retrofitted).

	Limitations	Wet proof	Dry proof	Stilts	Mound	Floating	Amphibious	Temporary Barriers	Permanent Barriers
Drinking water treatment		✗	✓ R	✗	✓	✓	✓	✓ R	✓ R
Sewage water treatment		✗	✓ R	✗	✓	✓	✓	✓ R	✓ R
Substations, surface		✗	✗	✓	✓	✓	✓	✓ R	✓ R
Substations, building		✗	✓ R	✓	✓	✓	✓	✓ R	✓ R
Substations, underground		✗	✓ R	✗	✗	✗	✗	✓ R	✓ R
Energy storage		✗	✓ R	✗	✓	✓	✓	✓ R	✓ R
Hospitals		✗	✓ R	✓	✓	✓	✓	✓ R	✓ R
Fire stations		✗	✗	✓	✓	✓	✓	✗	✓ R
Police stations		✗	✗	✓	✓	✓	✓	✗	✓ R
Communication centres		✓ R	✓ R	✓	✓	✓	✓	✓ R	✓ R
Food distribution		✗	✓ R	✓	✓	✓	✓	✓ R	✓ R
Financial buildings		✗	✓ R	✓	✓	✗	✗	✓ R	✓ R
Airports		✗	✗	✓	✓	✓	✓	✓ R	✓ R
Bus station		✗	✗	✓	✓	✓	✓	✗	✓ R
Train station platform and tracks		✗	✗	✓	✓	✗	✗	✗	✗
Metro station underground		✗	✓ R	✗	✗	✗	✗	✓ R	✓ R

4 Development of design tools

An interactive flood proofing design tool has been developed that allows policy makers, decision makers and designers to narrow down the range of possibilities of flood proofing methods for hotspot buildings in their own projects. The design tool provides insights into the requirements and economical consequences of the different flood proofing options. The tool consists of three stages: the *Relevance Map*, the *Selection Tool* and the *Evaluation Tool*. The *Relevance Map* provides a first check to evaluate the level of relevance of applying flood-proofing measures. The *Selection Tool* is used to select the applicable flood-proofing measures based on the type of hotspot and other qualitative aspects. The *Evaluation Tool* provides quantitative data, such as cost estimates and application ranges, and it is used to find the most optimal flood-proofing methods for a given situation.

4.1 Relevance Map

In order to assess the broader local or regional relevance of flood proofing a hotspot building, two factors are of importance: the service area of the hotspot (how many people rely on this service) and the magnitude of the anticipated flood scenario (how many people will be affected by the flood).

The amount of people that depend on the hotspot is referred to here as the '*hotspot service area*'. The hotspot types have been clustered into three levels in terms of their service area: district, city and region (table below has been added for reference). Hotspots with regional or larger importance serve a significant support area and a high economic value. For example airports and food distribution centres are generally large scale facilities that serve many people. If an airport would flood, this would have huge effects on the economy of that region. If a food distribution centre would flood, it would affect the stores in a very large area. On the other hand, the flooding of a district bus station would not affect that many people and would have less regional impact on the economy.

Table 4.1 Hotspots by importance.

Service area	Hotspot
Regional or larger	Airports, Train station, Energy storage, Food distribution centre Communication building (network operations / data / telecomm.) Hospital (specialized / regional hospital) Financial center (stock exchange, central bank)
City	Metro station, Electricity substation (transmission substation) Communication building (data center), Drinking water treatment, Sewage treatment, Hospital (general hospital), Financial (city bank)
District	Bus station, Electricity substation (distribution/transformation) Police station, Fire station, Financial building (branch office) Hospital (clinic)

Secondly, the magnitude of the (anticipated) flood event is relevant. This can be defined as the amount of people that are affected by the flood and it is referred to as '*flood impact'*. If a hotspot that only has a local importance is hit by a small scale local flood, the impact is low. People that normally rely on this hotspot can easily find similar hotspot that has not been flooded at a small distance. On the other hand, if an international airport is flooded, the impact of flood proofing on the broader economy it is high, even if the flood would only be limited to a small region. In case both the *hotspot importance* is high and the *flood impact is high*, flood proofing of the hotspot would be necessary to improve urban flood resilience. Both factors have been combined in figure 4.1. It gives a general idea about the relevance of flood proofing a particular type of function designated as a hotspot.

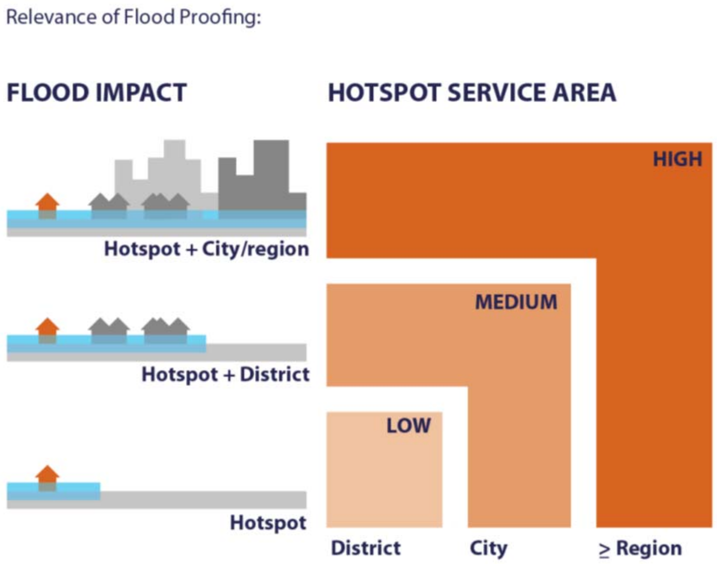


Figure 4.1 Flood proofing hotspot relevance map.

4.2 Selection Tool

The Selection Tool narrows down the number of feasible flood proofing measures for each type of hotspot. Building-specific and location-specific limitations will exclude certain flood proofing options. For example, if there is no possibility of creating water or using existing water, **floating** is not an option and if a metro station is created underground, **stilts** or **wet proofing** cannot be applied. Such qualitative advantages and disadvantages, most of which have already been discussed for the individual hotspot types, have been used as a base for the selection tool. An overview of the analysis of these aspects, that forms the basis for the tool, is found in Appendix 1.

In the selection tool the different characteristics of hotspot typologies have been converted into a series of simple Yes or No questions. Based on the answers several flood proofing types can be excluded. An example of a question is:

Does the hotspot contain fluid storage with considerable weight?

Hotspots like water purification plants, waste water purification plants and energy storage comprise numeral buildings filled with fluids. Because of this the buildings are very heavy. This poses a limit on the usage of stilts. Also with floating an amphibious flood proofing weight has to be taken into account, but considering that fluids are (nearly) weightless in water this they will not be excluded.

Flood proofing selection tool

Questions:	ANSWER: 0 = no 1 = yes
Are you retrofitting an existing hotspot?	0
Does the area around hotspot needs flood protection?	0
Does the hotspot contain fluid storage with considerable weight?	0
Does the hotspot consist of installations instead of buildings?	0
Is there a possibility for or availability of permanent water?	1
Does the ground floor needs to contain vital functions?	1
Is space around the hotspot permanently available?	1
Is space around the hotspot available in case of flooding?	1
Is vehicle access vital during flood?	0
Hotspot with permanent rail connection above ground level?	0
Is the hotspot situated underground?	1

Flood proof measures to choose from:

Dry proofing, Mound, Flood wall, Dike, Temp barrier.

Dry proofing, : POA Emergency entrance has to be elevated during flood. Openings such as windows and doors are a point of attention.

Mound, : POA Ground displacement is needed, the solution needs a large perimeter because of the slope.

Flood wall, : Emergency entrance has to be elevated . The solution can be integrated with a customary fence.

Dike, : POA Ground displacement is needed, the solution needs a large perimeter because of the slope.

Temp barrier. : POA Manpower and time is needed for build-up, the hotspot needs a fence or wall for normal security; the solution is additional. Emergency entrance has to be elevated during the flood.

Figure 4.2 Overview of questions used as input for the hotspot selection tool.

After answering all the questions, one or several possible flood proofing measures will appear on the screen. In addition, the most important points of attention will be shown for each flood proofing measure. This list narrows down the amount of available flood proofing methods for the decision maker or the designer. With this short list of qualitative aspects, the quantitative characteristics of the hotspot, like circumference and expected can be applied in third part of the design tool, the Evaluation Tool. The first two tools provide insight in the relevance of flood proofing a particular hotspot and the available flood proofing measures in a specific situation.

4.3 Evaluation Tool

It is a complicated task to find the most optimal and cost effective flood proofing solution for a particular hotspot building. Many factors play a role in the decision making. These factors are both related to the properties of the hotspot (e.g. area, perimeter, height and service area), and to the type of flood that is to be expected (e.g. flood level, frequency, onset time and impact). The objective of the Evaluation Tool is to serve as a guide in this process. Based on the hotspot properties and the expected flood type, the available flood proofing measures for that specific situation are selected and can be compared on costs and efficiency. Contrary to the Selection Tool which has a quantitative character, the Evaluation Tool provides a quantitative comparison.

The tool is based on a database of reference flood proofing products, which is built of data from different sources: research publications, data from governmental agencies, such as the UK Environmental Agency and FEMA, and data provided by the many suppliers of flood proofing products.

The most relevant components of the design tool are briefly described below.

Area requirement

Particular types of hotspots are often located in an urban context, where space for external flood-proofing measures is scarce. The available area around the hotspots will influence what types of measures are options. **Flexible free-standing barriers**, **levees** and **sandbags** are most space demanding. Several measures, such as **floating** or **stilts**, do not demand additional space.

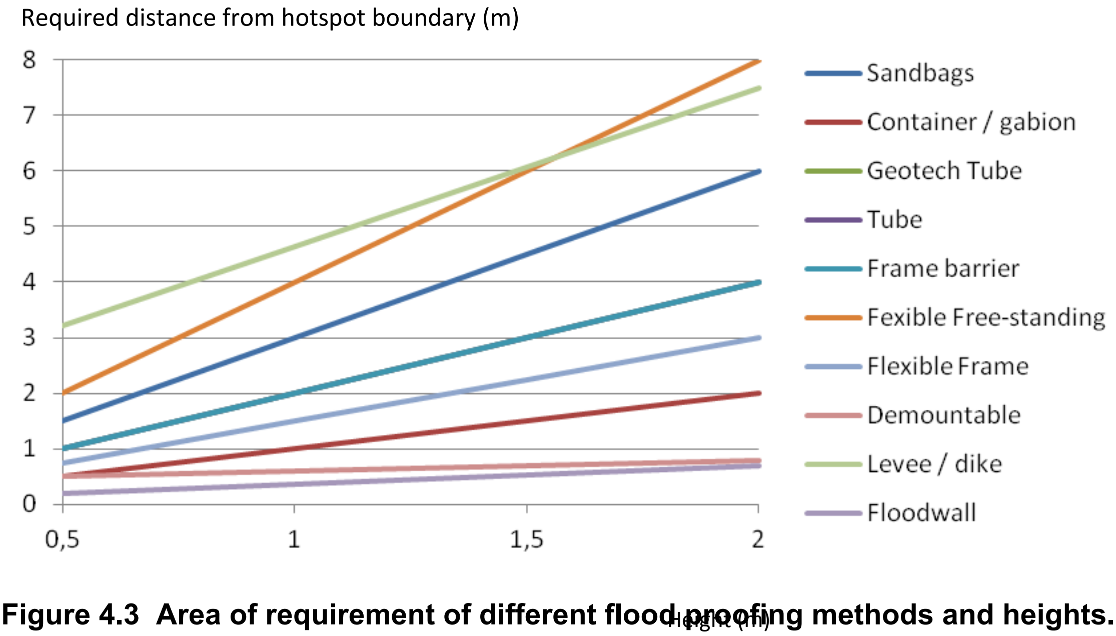


Figure 4.3 Area of requirement of different flood proofing methods and heights.

Installation time

The amount of time required to install a temporary barrier, is of great importance in relation to the prediction time of the flood. Based on various sources, the amount of time to install the systems has been estimated. Most systems are quick to set up, with **flexible free-standing** barriers requiring the least amount of time. Three systems may present obstacles if rapid erection is required. They are discussed below.

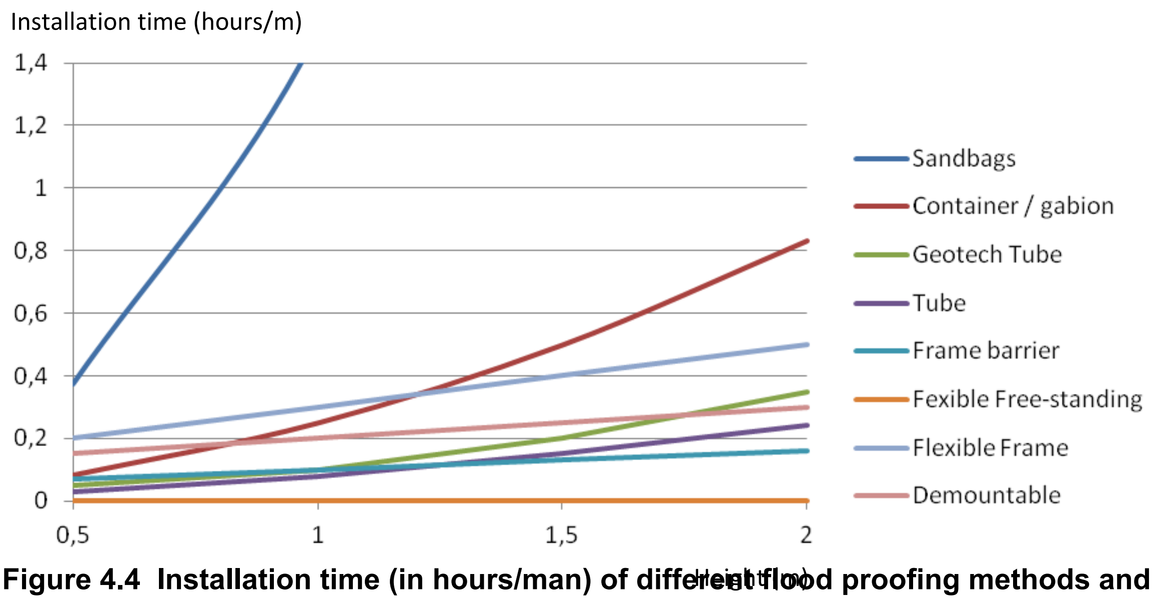


Figure 4.4 Installation time (in hours/man) of different flood proofing methods and heights.

The graph shows that **sandbags** are very labor intensive, especially at higher flood levels. **Container/gabion** systems require heavy equipment such as a front-loaders and lorries that deliver the metal gabions and sand. While the installation time is limited, installing this system is a considerable logistic challenge. **Flexible frames** are complex to install and require a relatively high level of skill. As a result, on larger projects lack of enough skilled personnel will cause longer installation times.

Height range

Flood proofing products have a limited height range. Most products have a maximum height between 2,5 m and 3 m. For **Flexible free-standing** barriers the maximum height is even less, up to 2 m. Generally, the permanent barriers and demountable systems have a higher maximum range.

Cost estimation

Costs are an essential part of the assessment of flood defense measures. Some systems are more cost effective for lower flood depths, but get very expensive as soon as they are applied for high flood depths. Both sandbags, tubes and containers are exponentially more expensive at a bigger height, because of the pyramid style stacking of the elements. Some systems only have a limited life span of one or two application cycles. Both sandbags and container/gabion systems are difficult to reuse. This will have a considerable influence on the investment over longer periods. The costs may also depend on the flood frequency, especially temporary measures that take manpower and resources to be installed.

For each type of flood proofing measure, cost data in relation to the protection height level was gathered from a large number sources. These two variables (costs per meter and protection height) were plotted into scatter graph and polynomial trend estimation was established for each data set. As an example, the scatter plot of the **container/gabion** data set is displayed in figure 4.5. The formula's of each of the graphs were then inserted into the evaluation tool. A detailed overview of this process can be found in appendix 3.

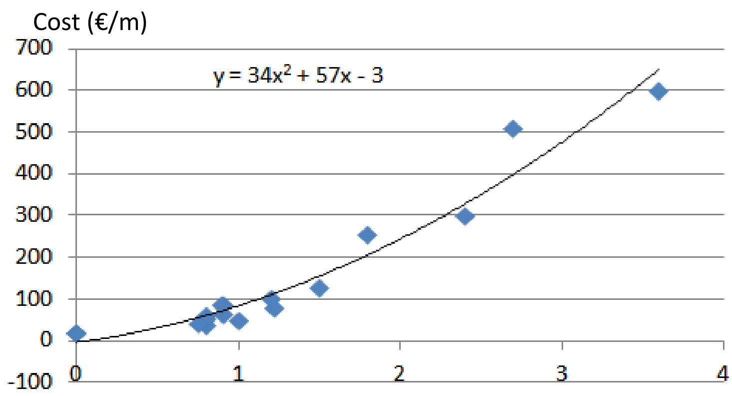


Figure 4.5 Scatter plot of container/gabion data

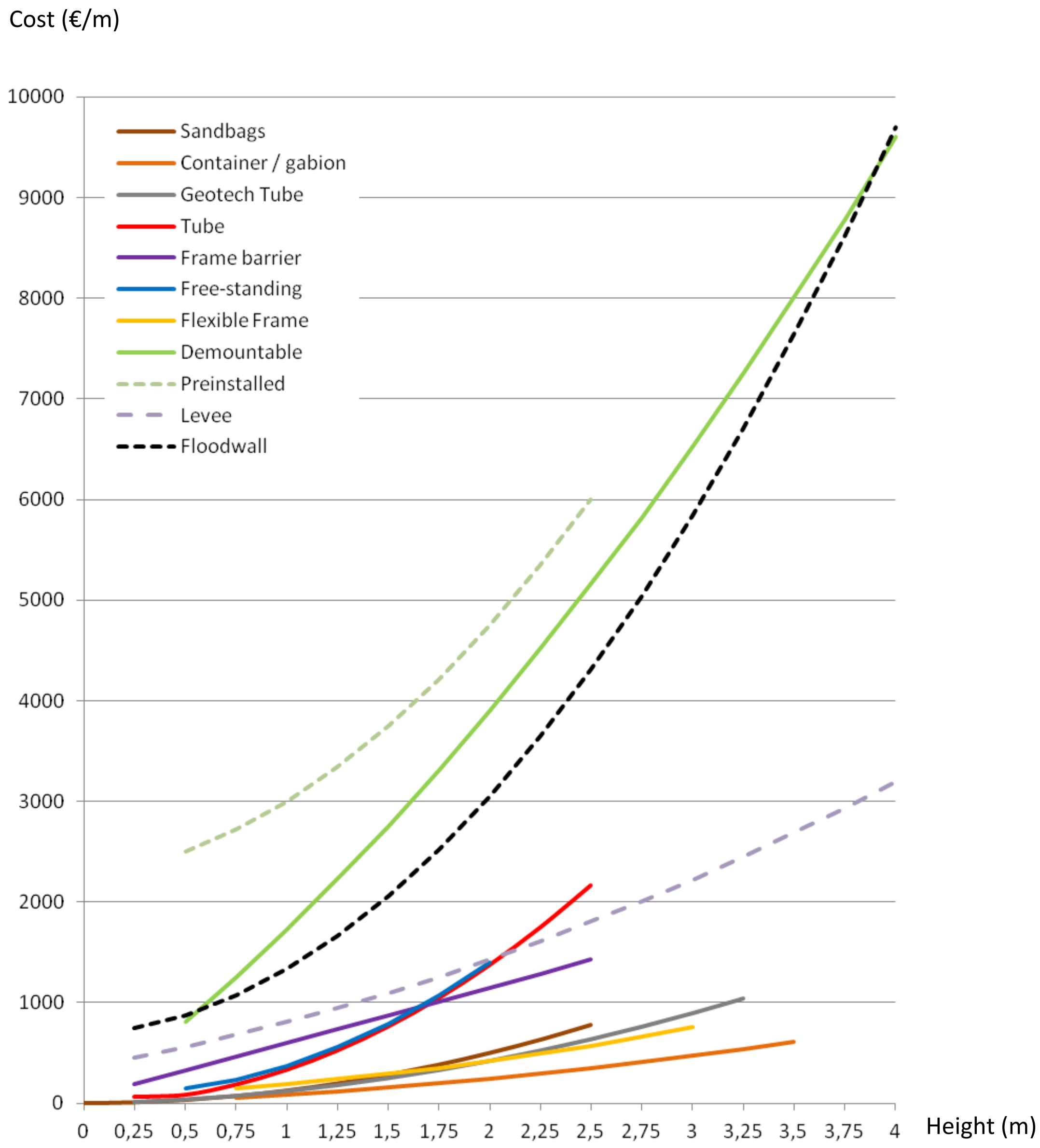


Figure 4.6 Cost estimate data (in €/m) and height ranges for barrier-type flood proofing methods.

4.4 Example of using the Evaluation Tool

After using the 'Selection Tool', the 'Evaluation Tool' can be used to evaluate the selected flood proofing options. The options are evaluated on relative costs, space demand, installation time and the available height range of the systems. In order to use the tool some basic input data is needed with regard to the hotspot building and the characteristics of the expected flood. They are described below.

Site area/perimeter: area and perimeter of the complete site. When the hotspot consists of several buildings, methods such as floodwalls and levees will be applied to the entire site rather than flood proofing the perimeter of each individual building.

Building area/perimeter: area and perimeter of the hotspot building. Methods such as dry and wet flood proofing are applied to the individual buildings.

Land cost: several flood proofing options demand additional space (e.g. a levee). The costs of this area are taken into account in the calculations. Urban areas will be more expensive than rural areas. If the area around the hotspot is already part of the property (and has no function) the parameter is set to 0.

Available perimeter width: amount of area available around the perimeter of the hotspot. This is compared to the space demand of the (temporary) barriers.

Flood height and frequency: anticipated maximum flood level and chance it will occur.

Flood onset time: time between a flood warning and the flood event. This is the time available for installing temporary barriers. Flash floods will have very rapid onset times and little time for preparations.

HOTSPOT	**site area**	38000	m2
DATA	**site perimeter**	960,0	m
	building area	23000,0	m2
	building perimeter	1450,0	m
	Building mass	1200	kg/m2
	Land cost	€ 50,00	/m2
	Available perimeter width	10,0	m
FLOOD	**flood height**	3,5	m
DATA	**flood frequency**	1/100	
	Flood onset time	20,0	h

		cost	#appl	lifetime cost	width(m)	inst. time	h min	h max	min length
FLOOD	**Sandbags**	€ 1.465.440	1	€ 1.465.440	10,5	1764	0	2,5	1
PROOFING	**Container / gabion**	€ 588.480	1	€ 588.480	3,5	196	0,75	3,5	1
OPTIONS	**Geotech Tube**	€ 1.149.360	6	€ 1.149.360	7,0	117	0,25	3,25	30
	Tube	€ 4.133.280	4	€ 4.133.280	7,0	47	0,25	2,5	15
	Frame barrier	€ 1.896.000	10	€ 1.896.000	7,0	20	0,25	2,5	1
	Flexible Free-standing	€ 4.179.840	5	€ 4.179.840	14,0	0	0,5	2	5
	Flexible Frame	€ 924.720	hire	€ 924.720	5,3	67	0,75	2,5	1
	Demountable	€ 5.124.000	50y	€ 5.124.000	0,5	34	0,5	5	5
	Preinstalled	€ 8.880.000	50y	€ 8.880.000	0,5	na	0,5	2,5	1
	Levee / dike	€ 2.133.486	50y	€ 2.133.486	11,8	na	0	10	
	Floodwall	€ 7.329.120	50y	€ 7.329.120	1,2	na	0	10	
	Wet proofing	€ 4.102.888	5	€ 410.289	0,0	na	0	4	
	Dry proofing	€ 1.816.650	50y	€ 1.816.650	0,0	na	0	3	1
	Floating	€ 3.387.500	50y	€ 3.387.500	0,0	na	0	10	
	Amphibious	€ 8.050.000	50y	€ 8.050.000	0,0	na	0	10	
	Stilts	€ 2.675.000	50y	€ 2.675.000	0,0	na	0	10	
	Mounds	€ 1.418.659	50y	€ 1.418.659	0,0	na	0	10	

Figure 4.7 Example dataset of the Evaluation Tool.

After filling in the hotspot and flood data, the results of the Evaluation Tool can now be assessed. An example data set is shown in Figure 4.8. If the width demand of particular methods is an issue, they will be highlighted in red. If the maximum barrier height is not sufficient for the anticipated flood depth, it will also be highlighted. The installation time, given in hours, is based on a crew of 10 people (or equivalent amount of equipment, such as pumps, lorries and front-loaders). It can be multiplied if sufficient personnel are available. However, it should be noted that the amount of equipment will also increase in that case. The lifetime costs of the temporary flood barriers is estimated, based on the maximum number of applications (before it needs to be renewed) and the anticipated number of flood events during a 50 year period.

Customization

Within the Evaluation Tool there is a large amount of default data that can be further customized for each project. As an example, the levee calculation is based on many factors, such as the grade of slope, the width of the top part (that is sometimes used as a road) and the safety margin to take into account local water fluctuations or waves.

Levee		
safety height (above flood)	0,1	m
grade of slopes	35%	
width of flat part	1,5	m
height of dike	3,6	m
width of dike	22,1	m
area of corners	1949	m2
area along perimeter	21189	m2
total area of dike	**23137**	m2
total length of dike	**1048**	m
total volume of dike	**44477**	m3
volume per meter	42	m3
base costs (equip./engin./perm	€ 100	/m
waterproof layer costs	€ 5	/m2
land costs	€ 50	/m2
construction costs	€ 17	/m3
total base costs	€ 104.829	
waterproof layer costs	€ 115.686	
total land costs	€ 1.156.858	
total constr costs	€ 756.114	
total costs	**€ 2.133.486**	

Figure 4.8 Example customizable parameters of the Evaluation Tool.

Can we integrate these questions in the excel model as assistance to the user? Then we can remove it here

Are you retrofitting an existing building?

If the measure is going to be applied on an existing building, group of buildings or area the answer to this is YES. If a new building or site developing is to be developed the answer is NO. When retrofitting, measures as floating, amphibious, stilts and mounds are not applied because of the cumbersome interventions.

Does the area around the hotspot need flood protection?

When there is a dry area needed between the buildings a larger area has to be made flood proof. For the continuation of the processes in the area or building and maintenance of it, this is sometimes necessary. It could also be the case when the area is used as a big shelter where a lot of space is needed for transportation of means and good. A connection between buildings can also be made by elevating circulation areas to a first or second floor. When this is the case (YES) dry proofing and wet proofing is not a suitable solution.

Does the hotspot contain fluid storage with considerable weight?

Hotspots like water purification plants, waste water purification plants and energy storage comprise numeral buildings filled with fluids. Because of this the buildings are very heavy. This poses a limit on the usage of stilts. Also with floating an amphibious flood proofing this weight has to be taken into account.

Does the hotspot consist of installations instead of buildings?

The hotspot is not a building or group of buildings but installations, like in the example of the electricity surface station. Flood proof methods exclusively applicable on buildings namely wet and dry flood proofing, are excluded.

Is there a possibility for, or availability of permanent water?

For a floating construction, permanent water is needed, if permanent water is not possible this method will be excluded. And important point of attention is the depth of the floating construction and the availability of or possibility for that depth. When velocity of the flood is high, special attention has to be made to the anchoring of the floating construction. When the flood level is high, the flexible connections, as needed among others for the water purification plant, between the building and the underground infrastructure can be challenging. If access roads are connected to the floating construction this is also an important point of attention.

Does the ground floor need to contain vital functions?

When vital functions are situated on the ground floor, the method of wet proofing is not possible. Almost all the hotspots have vital functions on the ground floor. Actually only the communication centre could be wet proofed if data storage is not situated on the ground floor.

Is space around the hotspot permanently available?

If flood barriers are to be applied, space is needed for the construction of the barriers. If the answer is NO, than barriers are not a viable option. A dike or levee needs the most space because of the slope a flood wall the least. The height, force and period of the flood influence the height and width of the flood defence. (The size of the barriers will be calculated in the Evaluation Tool).

Is space around the hotspot available during flood events?

When no permanent space around the hotspot is available, temporary space still can be available. Temporary barriers can be placed on for example pavements or roads. Space is needed for the construction of the barrier as for the material of the barrier. If the answer is NO, than barriers are not a viable option. If there is not space that can be used, temporary barriers are also excluded.

Is vehicle access vital during flood?

This question is mainly aiming for the logistics part of the process in the building: access roads and entrances stay the same if the flood proof measure is one of the following: a permanent barrier dike, mounds, amphibious or floating. Because the entrance road is already elevated if will not change in time of flood. With stilts, the area used beneath the building, usually for parking space, cannot be used. If the amphibious or floating measure is applied, the height between the access road and the building will change, unless the road is also amphibious or floating. In the case of wet proofing, the ground floor (and cellar) will be flooded. If a temporary barrier or a flood wall is applied, the hotspot is not accessible for vehicles during a flood because the flood wall will be closed as will the temporary barrier be. For hotspot functions as a fire station and police station the vehicle accessibility is vital.

Hotspot with permanent rail connection above ground level?

When the hotspot has a permanent rail connection, like a train station or a metro station (not underground) dry flood proofing, wet flood proofing, amphibious and floating constructions are not possible.

Is the hotspot situated underground?

Hotspots situated underground usually are already flood proof, protected from the ground water. During floods the crucial elements are the entrance buildings and ventilation shafts. For this hotspot the focus is mainly on the entrance. This entrance can be situated on higher grounds as a mound, be dry proofed or protected using a barrier.

5 Applying design tools to case studies

In this chapter the flood-proofing design tools are applied to case studies, in order to test, validate and illustrate the principles. Each case study consists of a flood event and a hotspot building that was at risk. Five case studies have been considered and the three most interesting cases have been further evaluated with the help of the flood-proofing tools. Data has been collected on both the flood event and the hotspot, and was used as input. Once the tool has been tested and validated with existing buildings and historic flood events, it can then be applied in a similar way to other cities and hotspots.

Case study overview description

Floods can be classified in different types, according to their characteristics, to their sources or to the context were they occur. Floods can be broadly classified in three main types:

- coastal and estuarine floods;
- river floods;
- pluvial floods.

Each case study overview contains a flood context description and the main parameters that describe the event. The parameters that have been included are:

- Extent: flood extension for a specific event or scenario (for example for return periods of 10, 50 or 100 years). If a large area is flooded there can be more damage costs and higher environmental risk.
- Frequency: is the probable frequency of occurrence of a certain flood. Some floods can occur seasonally, other ones, usually more severe, occur less frequently. The probability that a certain event occurs is usually estimated as an average return period such as T= 10, 25, 50, 100, 500 years or even more. For each event, the predicted area of inundation can be mapped out.
- Depth: measures the water level height in a flooded area. In general, a higher flood level causes damage.
- Rate of rise: describes how fast the water increases during a flood. This parameter influences flood fighting arrangement measures and evacuation times.

(Sources: European Parliament and Council of the European Union, 2007; Mavrova-Guirginova, M. et al., 2010)

The amount time the area remains flooded (*duration)* and the speed of the water during flooding *(flow velocity)* were not included as parameters. Although these factors are highly relevant in estimating the damage to buildings and infrastructure, the number of casualties, social inconvenience, and environmental risk, the effects on the different flood-proofing technologies needs further research before it can be implemented.

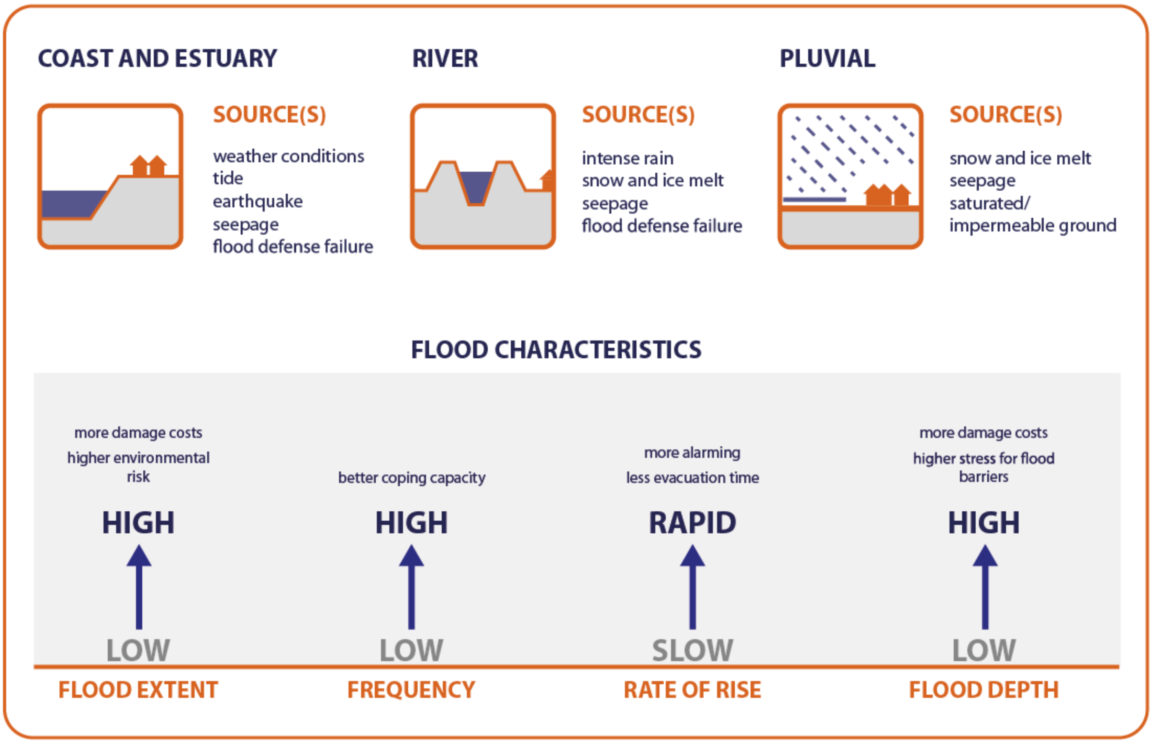


Figure 5.1 Flood types, sources and characteristics.

The case studies are selected to each have at least one extreme flood parameter and a different flood 'source'. For New Orleans the flood depth was extreme and the type was a coastal flood. Venice has a seasonal frequency and has coastal flooding. For Warsaw the frequency is annual and the rate of rise is high and the source is pluvial. In UK the flood source is riverine, with a high extent and a rapid rate of rise. After evaluating the data on the various cases, Warsaw was eliminated because there were either no hotspots at risk or no information on this matter. In New Orleans the hotspot with the largest flood height was selected, because the other cases already featured lower flood heights.

The section below reports on the application of the guidance tools in each of the three case studies. Elaborate information on the case studies, including the ones that were considered but not used in this evaluation, can be found in appendix 4. At the end of the chapter additional information is provided on how to apply the tools to other hotspot buildings.

5.1 Memorial Medical Center, New Orleans

Hotspot description

The Memorial Medical Center, today known as Ochsner Baptist Medical Center, was founded in 1926 by the Southern Baptist Convention. This hotspot building is situated in Uptown New Orleans, in an area that is around 1 meter below sea level. In the aftermath of Hurricane Katrina in 2005 the hospital was submerged in 3-3.5 meters of water. "*About 2,000 patients, medical workers and other staff were stranded at Memorial. Officials eventually recovered 45 bodies from Memorial, many of whom were said to have died from dehydration during the four-day wait for rescuers*" (Foster, M., 2011).

Data collection

Data on the flood event (figure 5.2) and hotspot (figure 5.3) have been collected and analysed. A detailed study including sources can be found in appendix 3 and 4. The data has been used as input for the design guidance tools.

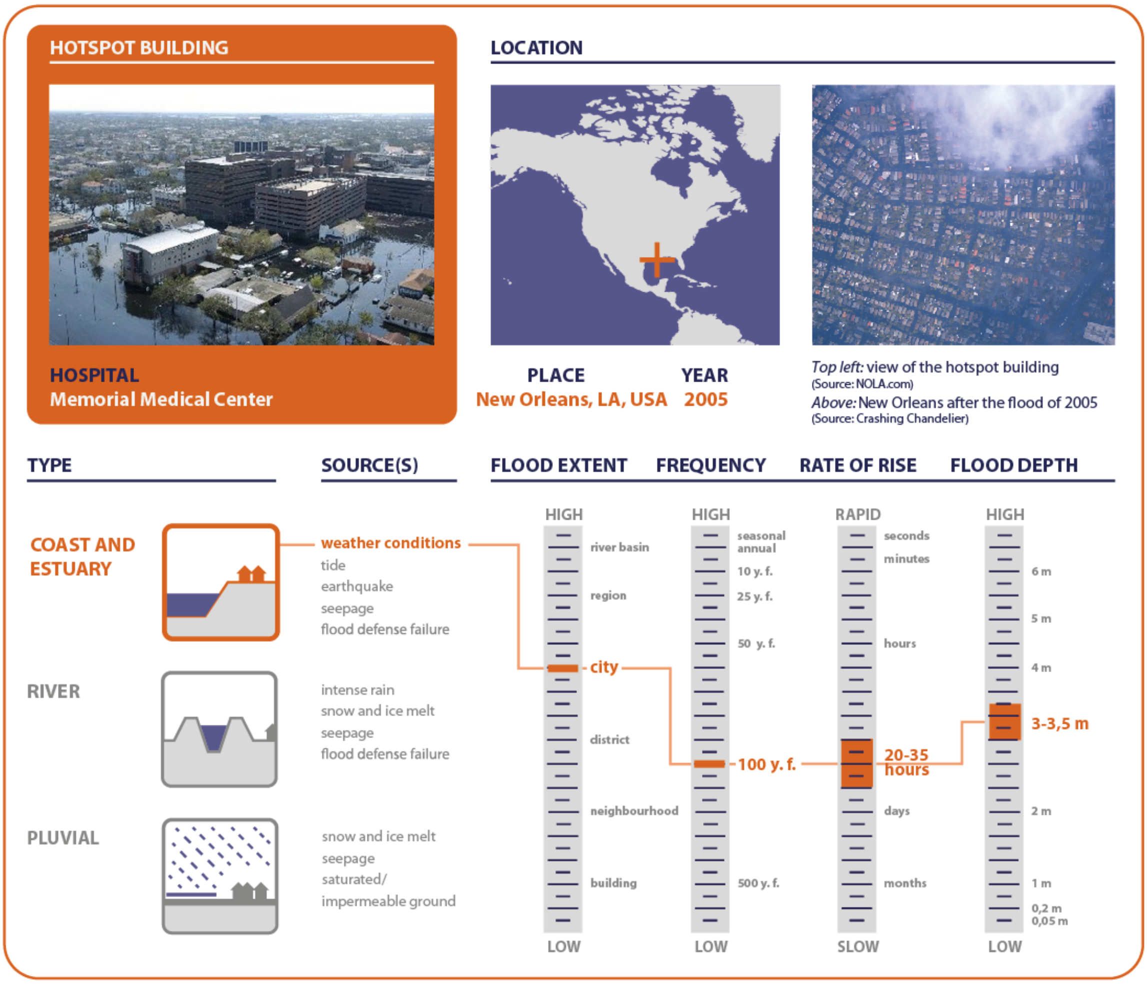


Figure 5.2 Flood data

HOSPITAL: Memorial Medical Center

New Orleans, Lousiana, USA

	area	perimeter
site	38000 m^2	960 m
building(s)	23110 m^2	1450 m

Images sources: Google Maps (coord. 29.937, -90.103)

Figure 5.3 Hotspot data

Relevance Map

The Memorial Medical Centre (now renamed Ochsner Baptist Medical Center) is a general medical and surgical hospital. A hospital with a regional function. Flood impact was at city/region level. Therefore the medical centre is in the highest category of flood proofing relevance.

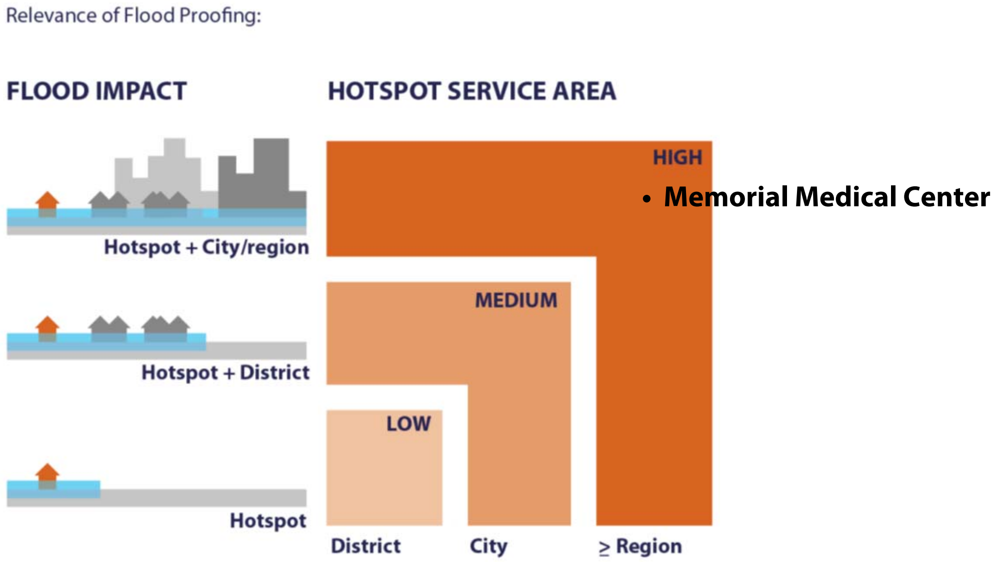


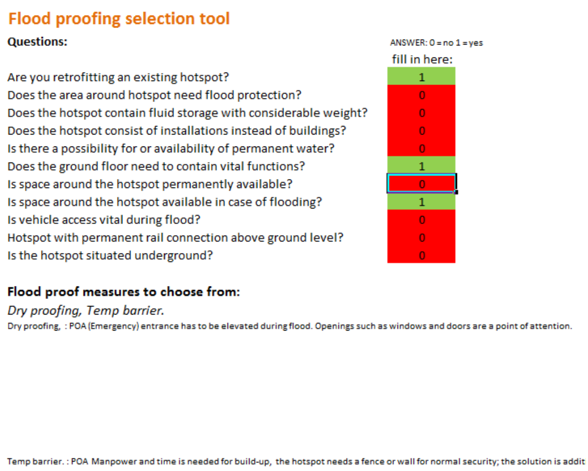
Figure 5.4 Relevance map of flood proofing the hospital.

Selection Tool

According to the *Selection Tool* the following flood proof methods available are:

- Dry proofing
- Temporary barriers

When rebuilding the complete hospital is an option, all flood proof methods are available, except for wet proofing.



Flood proofing selection tool

Questions:

Questions	ANSWER: 0 = no 1 = yes fill in here:
Are you retrofitting an existing hotspot?	1
Does the area around hotspot need flood protection?	0
Does the hotspot contain fluid storage with considerable weight?	0
Does the hotspot consist of installations instead of buildings?	0
Is there a possibility for or availability of permanent water?	0
Does the ground floor need to contain vital functions?	1
Is space around the hotspot permanently available?	0
Is space around the hotspot available in case of flooding?	1
Is vehicle access vital during flood?	0
Hotspot with permanent rail connection above ground level?	0
Is the hotspot situated underground?	0

Flood proof measures to choose from:

Dry proofing, Temp barrier.

Dry proofing, : POA (Emergency) entrance has to be elevated during flood. Openings such as windows and doors are a point of attention.

Temp barrier. : POA Manpower and time is needed for build-up, the hotspot needs a fence or wall for normal security; the solution is addit

Evaluation Tool

An important factor in this case is the high flood level. Results from the flood proofing evaluation tool show that dry proofing and many temporary flood measures are not suitable for such a high flood level. Actually none of the retrofitted flood proofing measures is possible. The number of men available to set up temporary barriers is unknown and set to 25. When this amount would be increased to a 100 the **container / gabion system** and **demountable system** would be an option. The Tube and the Frame barriers are too low to be applied. There is no space available for levees or flood walls and it would block the entrance to the hospital.

For a new hotspot building on this particular location, stilts of about 2,5 to 3m have the best results with regard to costs. The space underneath the building may be used as parking space and outside storage. Currently a multi-storey car park is used. In case of retrofitting the best option would be demountable barriers. Although dry proofing is usually not feasible above 3 meters, it may be calculated if the structure can withstand hydrostatic pressure of 3,5 m of water, possibly by making small structural modifications.

Flood proofing evaluation tool

Hotspot data

	fill in here:	
Site area	38000	m2
Site perimeter	960	m
Building area	23000	m2
Building perimeter	1450	m
Building mass	1200	kg/m2
Land cost	€ 50.00	/m2
Available perimeter width	12.0	m

Flood data

	fill in here:	
Flood height	3.5	m
Flood frequency	1/100	
Flood onset time	20.0	h

Number of people available for help

	fill in here:
Men	25

Flood proofing options

	cost EUR *1000	appl*	lifetime cost EUR*100 50 y	width m	inst. time hrs. w/men	h min m	h max m	min length m
Sandbags	€ 1,465	1	€ 1,465	10.5	706	0	2.5	1
Container / gabion	€ 588	1	€ 588	3.5	79	0.75	3.5	1
Geotech Tube	€ 1,149	6	€ 1,149	7.0	47	0.25	3.25	30
Tube	€ 4,133	4	€ 4,133	7.0	19	0.25	2.5	15
Frame barrier	€ 1,896	10	€ 1,896	7.0	8	0.25	2.5	1
Flexible Free-standing	€ 4,180	5	€ 4,180	14.0	0	0.5	2	9
Flexible Frame	€ 925	hire	€ 925	5.3	27	0.75	2.5	1
Demountable	€ 5,124	50y	€ 5,124	0.5	84	0.5	5	3
Preinstalled	€ 8,880	50y	€ 8,880	0.5	0	0.5	2.5	1
Levee / dike	€ 3,924	50y	€ 3,924	11.8	0	0	10	22.1
Floodwall	€ 7,329	50y	€ 7,329	1.2	0	0	10	
Wet proofing	€ 4,103	5	€ 4,103	0.0	0	0	4	
Dry proofing	€ 1,817	50y	€ 1,817	0.0	0	0	3	
Floating	€ 3,388	50y	€ 3,388	0.0	0	0	10	
Amphibious	€ 8,050	50y	€ 8,050	0.0	0	0	10	
Stilts	€ 2,675	50y	€ 2,675	0.0	0	0	10	
Mounds	€ 3,343	50y	€ 3,343	5.6	0	0	10	

appl * = number of applications or lifespan

Figure 5.5 Evaluation tool output for a new hotspot (not feasible options shown in red)

5.2 Cassa di Risparmio di Venezia, Venice

Palazzo Nervi-Scattolin is the base of Venice Savings Bank headquarters. The building replaced a previous one, dated back to 1883, and was designed by the engineer Pier Luigi Nervi and the architect Angelo Scattolin in 1970. It is situated in S. Marco district, one of the lowest and most vulnerable areas to flooding. Because it was built only a few years after the great flood of 1966, measures were taken to protect it from floods. Therefore it may serve as a flood-proofing example rather than a vulnerable hotspot.

Data collection

Data on the flood event (figure 5.6) and hotspot (figure 5.7) have been collected and analysed. A detailed study including sources can be found in appendix 3 and 4. The data has been used as input for the design guidance tools.

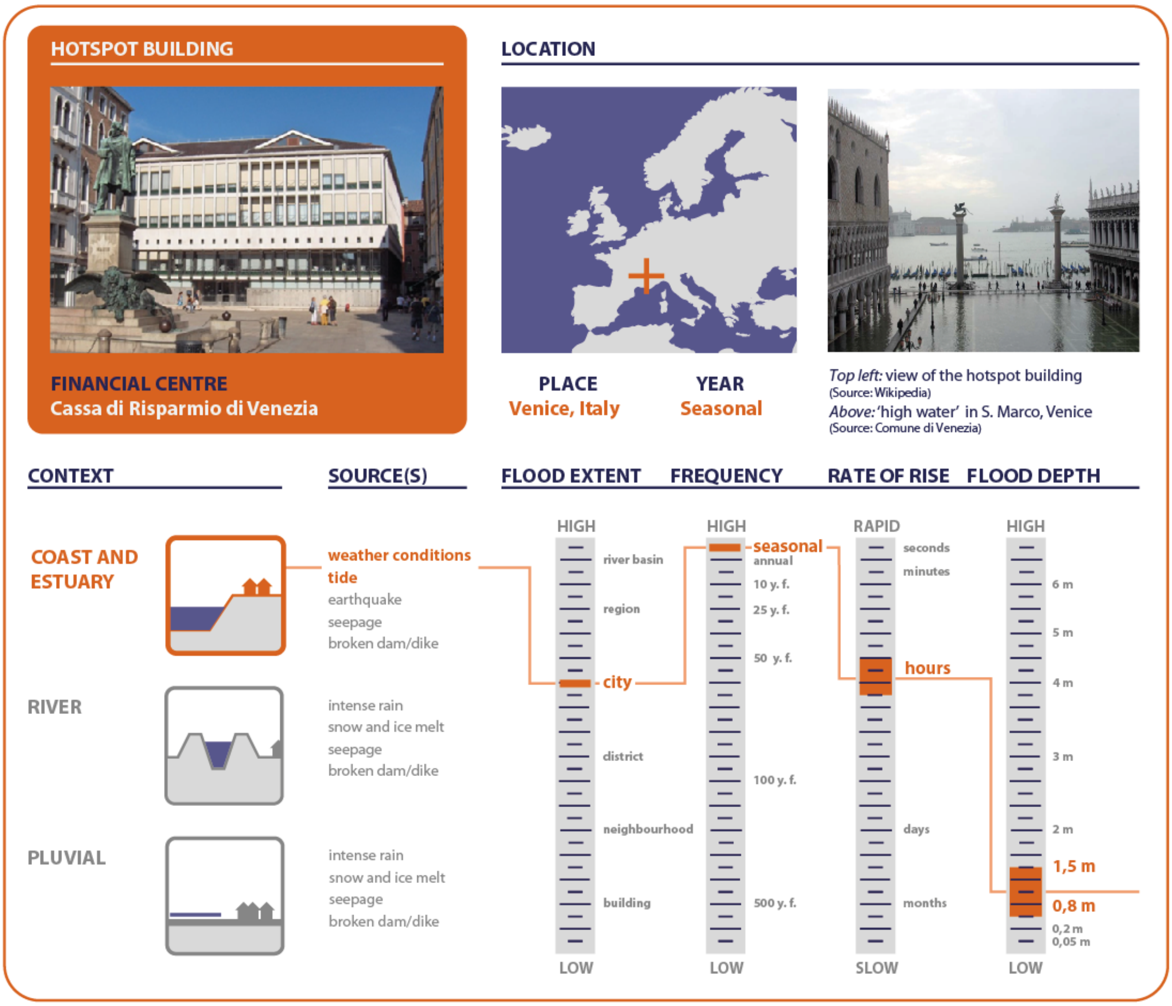


Figure 5.6 Flood data.

FINANCIAL CTR: Cassa di Risparmio di Venezia

Venice, Italy

	area	perimeter
site	1350 m^2	150 m
building(s)	1350 m^2	150 m

Images source: Google Maps (coord. 45.435, 12.334)

Figure 5.7 Flood data

Relevance Map

Cassa di Risparmio di Venezia is a city bank. Flood impact is at city/region level (90%).

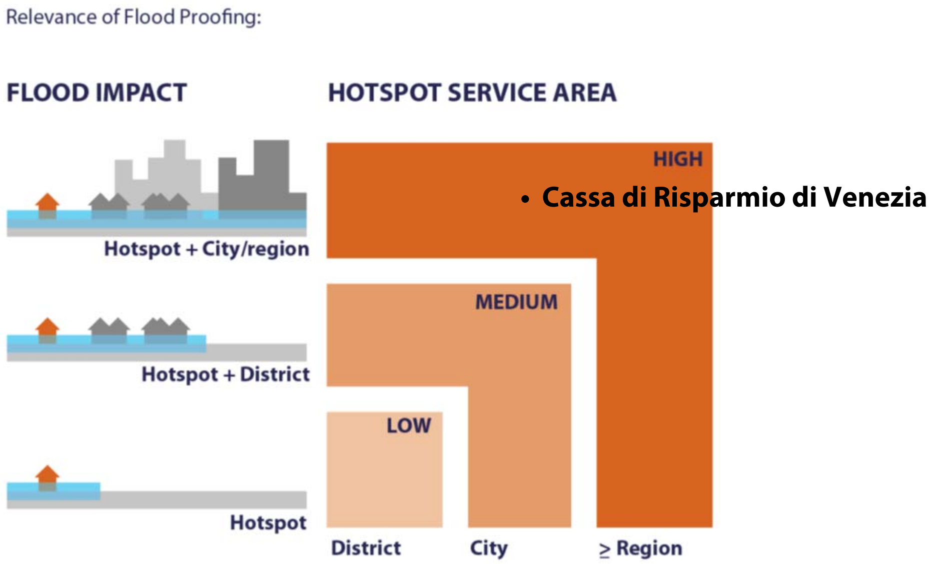


Figure 5.8 Relevance map of flood proofing the bank.

Selection Tool

According to the Selection Tool, the following flood proof methods are available:

- Dry flood proofing
- Temporary barriers

Wet flood proofing, **floating** and **amphibious** methods are not available to financial centers.

Levee / **dikes** and **floodwalls** are unavailable because there is no permanent space available around the hotspot.

Evaluation Tool

In the current situation the building has been protected by dry flood proofing measures: the perimeter of the building is protected by a 2 meter high closed facade and only the entrances are more vulnerable. It is likely they may be closed when 'acqua alta' occurs. The results for the evaluation tool indicate that the most effective options are dry proofing and stilts. Temporary barriers, such as tubes or frame barriers, also come up as a solution, but some care must be taken interpreting this data. Temporary measures are not common in Venice, because floods will occur very often (seasonally). At the same time acqua alta is very hard to predict, leaving a small amount of time to set up protection measures. Amphibious is not an option because of the costs involved to make such a heavy building buoyant.

Flood proofing evaluation tool

Hotspot data

	fill in here:	
Site area	1350	m2
Site perimeter	150	m
Building area	1350	m2
Building perimeter	150	m
Building mass	4000	kg/m2
Land cost	€ 1.000	/m2
Available perimeter width	4,0	m

Flood data

	fill in here:	
Flood height	1,5	m
Flood frequency	1/11	
Flood onset time	3,0	h

Number of people available for help

	fill in here:
Men	10

Flood proofing options

	cost EUR *1000	appl*	lifetime cost EUR*100 50 y	width m	inst. time hrs. w/ men	h min m	h max m	min length m
Sandbags	€ 42	1	€ 193	4,5	51	0	2,5	1
Container / gabion	€ 24	1	€ 108	1,5	6	0,75	3,5	1
Geotech Tube	€ 38	6	€ 38	3,0	3	0,25	3,25	30
Tube	€ 115	4	€ 130	3,0	1	0,25	2,5	15
Frame barrier	€ 131	10	€ 131	3,0	1	0,25	2,5	1
Flexible Free-standing	€ 119	5	€ 119	6,0	0	0,5	2	9
Flexible Frame	€ 44	1	€ 199	2,3	5	0,75	2,5	1
Demountable	€ 276	50y	€ 401	0,5	2	0,5	5	3
Preinstalled	€ 563	50y	€ 563	0,5	0	0,5	2,5	1
Levee / dike	€ 5.616	50y	€ 5.616	6,1	0	0	10	10,6
Floodwall	€ 416	50y	€ 416	0,5	0	0	10	
Wet proofing	€ 65	5	€ 65	0,0	0	0	4	
Dry proofing	€ 94	50y	€ 94	0,0	0	0	3	
Floating	€ 1.299	50y	€ 1.299	0,0	0	0	10	
Amphibious	€ 1.607	50y	€ 1.607	0,0	0	0	10	
Stilts	€ 56	50y	€ 56	0,0	0	0	10	
Mounds	€ 932	50y	€ 932	2,8	0	0	10	

appl * = number of applications or lifespan

Figure 5.9 Evaluation tool output for a retrofit hotspot (not feasible options shown in grey)

5.3 Walham substation

Walham substation, near Gloucester (UK), supplies electricity to 600,000 people in Gloucestershire, South Midlands and South Wales. On July 22 in 2007 intense rain flooded the River Severn; unexpectedly because this area is usually not under threat. Catastrophe was averted by raising emergency barriers to protect the electricity substation, using civil and military personnel.

Data collection

Data on the flood event (figure 5.10) and hotspot (figure 5.11) have been collected and analysed. A detailed study including sources can be found in appendix 3 and 4. The data has been used as input for the design guidance tools.

Figure 5.10 Flood data.

SUBSTATION: Walham Substation

Walham, United Kingdom

	area	perimeter
site	21000 m^2	600 m
building(s)	n.a.	n.a.

Image source: Google Maps. (coord. 51.879, -2.254)

Figure 5.11 Hotspot data.

Relevance Map

Walham Sub-station provides power to half a million homes and is reported to provide electricity to Government Communications Headquarters (GCHQ) and a nuclear establishment. (MCMASTER, R. and BABER, C., 2008) The UK floods impact is at city/region level.

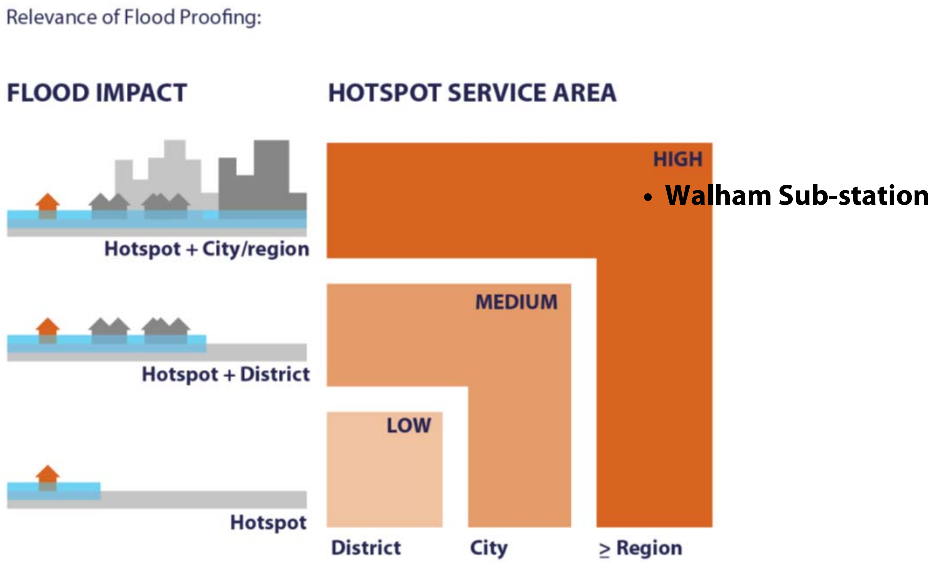


Figure 5.12 Relevance map of flood proofing the substation.

Selection Tool

According to the tool, all flood proofing methods are available, except for:

- Dry flood proofing
- Wet flood proofing

Evaluation Tool

Because of the low frequency of such large-scale flood events (T=100 y), temporary barriers are a cost effective solution. One or two of such systems could serve as a backup for many different sites in the area. However, because the lead time of the flash floods was only short (about 6 hours in Walham), and roads were grid-locked, there was not much time for installing temporary measures. In order to secure a 600 meter perimeter with 25000 to 30000 sandbags, 150 people would need to work for up to 10 hours. A container/gabion based flood wall would also take a lot of time. In this specific case, such barriers were applied directly after the water receded as a more permanent solution, it was installed in about 19 hours (Hesco, 2007). In the first instance a frame barrier was deployed, because the installation time of this system is much lower. In good conditions 10-15 people would finish a job of this size in 3 hours. Although at Walham the conditions were far from ideal with water levels already rising, about 200 people (navy personnel) were assisting to fight the floods and deploy the temporary barrier. Tubes would also be a good alternative on this location and considering the importance of Walham sub-station, it is worth evaluating more permanent measures. Judging from the results of the Evaluation Tool, a permanent levee or wall would be a cost effective measure. In response to the recent widespread floods in the UK—such as in spring 1998, autumn 2000, winter 2003 and summer 2007, such protection measures have been implemented at many similar sites. The Mirfield site was protected by reinforced concrete flood walls with access barriers and gates. Western Power sites in Wales were fitted with recycled floodscreens (Task Green, 2011).

Flood proofing evaluation tool

Hotspot data

	fill in here:	
Site area	21000	m2
Site perimeter	600	m
Building area	21000	m2
Building perimeter	600	m
Building mass	1200	kg/m2
Land cost	€ 50.00	/m2
Available perimeter width	4.0	m

Flood data

	fill in here:	
Flood height	1.5	m
Flood frequency	1/100	
Flood onset time	6.0	h

Number of people available for help

	fill in here:
Men	25

Flood proofing options

	cost EUR *1000	appl*	lifetime cost EUR*100 50 y	width m	inst. time hrs. w/ men	h min m	h max m	min length m
Sandbags	€ 169.5	1	€ 170	4.5	81	0	2.5	1
Container / gabion	€ 95.4	1	€ 95	1.5	9	0.75	3.5	1
Geotech Tube	€ 152.0	6	€ 152	3.0	5	0.25	3.25	30
Tube	€ 458.1	4	€ 458	3.0	2	0.25	2.5	15
Frame barrier	€ 525.0	10	€ 525	3.0	2	0.25	2.5	1
Flexible Free-standing	€ 474.0	5	€ 474	6.0	0	0.5	2	9
Flexible Frame	€ 174.8	hire	€ 175	2.3	7	0.75	2.5	1
Demountable	€ 1,102.5	50y	€ 1,103	0.5	23	0.5	5	3
Preinstalled	€ 2,250.0	50y	€ 2,250	0.5	0	0.5	2.5	1
Levee / dike	€ 1,454.1	50y	€ 1,454	6.1	0	0	10	10.6
Floodwall	€ 1,235.1	50y	€ 1,235	0.5	0	0	10	
Wet proofing	€ 1,004.5	5	€ 1,005	0.0	0	0	4	
Dry proofing	€ 844.2	50y	€ 844	0.0	0	0	3	
Floating	€ 4,462.5	50y	€ 4,463	0.0	0	0	10	
Amphibious	€ 7,350.0	50y	€ 7,350	0.0	0	0	10	
Stilts	€ 868.0	50y	€ 868	0.0	0	0	10	
Mounds	€ 847.3	50y	€ 847	2.8	0	0	10	

appl * = number of applications or lifespan

Figure 5.13 Evaluation tool output for a retrofit hotspot (not feasible options shown in red)

5.4 General characteristics

Characteristic data about hotspot buildings have been collected to be used as generic input in the design tools. For every hotspot type the area and perimeter have been determined (table 5.1) for both the built area and the complete site. This distinction is made because many measures are either applied to buildings or to the site. The generic data is based on an overview of references, listed in appendix 4. This overview can also be used as inspiration or reference for decision makers to have a general idea of the appearance of this type of hotspot. The examples were selected on one or more of the following criteria;

- from the chapter state-of-the-art
- large scale and small scale buildings
- an inner-city example and an village or suburb example
- location in one of the contributing countries of this research
- a higher flood risk location
- locations near the water

The average of the hotspot examples, listed below, can be used as default input in the design tool.

Table 5.1 Average area and perimeter of the fourteen hotspots.

		area	perimeter
Fire stations	site	4340 m^2	310 m
	building(s)	2460 m^2	230 m
Bus stations	site	8500 m^2	650 m
Police stations	site	3080 m^2	270 m
	building(s)	3080 m^2	270 m
Train stations	site	7630 m^2	560 m
	building(s)	7630 m^2	560 m
Metro stations	site	510 m^2	130 m
	building(s)	220 m^2	60 m
Hospitals	site	55930 m^2	930 m
	building(s)	28540 m^2	1120 m
Drinking water production	site	427800 m^2	2360 m
	building(s)	334930 m^2	3960 m
Waste water treatment plants	site	111030 m^2	1530 m
	building(s)	201460 m^2	6550 m
Food distribution centres	site	80000 m^2	1200 m
	building(s)	45000 m^2	1200 m
Electricity substations	site	10 /1000 /35000 m^2	13 /150 /600 m
	building(s)	10 /100 /700 m^2	13 /50 /150 m
Airports	site	10-15 km^2	15-20 km
Financial buildings	site	6800 m^2	320 m
	building(s)	6800 m^2	320 m
Communication centres	site	4490 m^2	270 m
	building(s)	4490 m^2	270 m
Energy storage	site	483340 m^2	3960 m
	building(s)	131860 m^2	13540 m

6 Pilot project: St. Francis Hospital, Rotterdam

One of the case studies of FloodProBE is the Rotterdam Airport area. Plans are being developed to create the Rotterdam Emergency Airport (REA). In a stakeholder meeting of the REA a survey was held under the stakeholders. Stakeholders from the municipality of Rotterdam, building companies, consultancy companies and Rijkswaterstaat were present. The question asked was which hotspot was the most important to develop flood proof concepts for. The stake holders could rate the hotspots from 1 to 5. Afterwards the totals were calculated and divided by the number of voters to come to a score.

Table 6.1 Results of survey.

Hotspot building	Score
Hospital	4.71
Rescue equipment storage*	4.43
Food distribution centre	4.29
Mortuary*	4.17
Communications centre	4
Substations	4
Drinking water treatment works	3.88
Energy storage	3.75
Fire station	3.71
Police station	3.43
Sewage water treatment works	3.43
Financial centre	2.25

*These hotspots were added by the stakeholders themselves. In the research FloodproBE these are not part of the hotspot list and therefore will not be included in the research.

The results above show that a flood proof hospital is in this situation considered to be the most important hotspot. Therefore a concept for this type of hotspot is developed. In this chapter the flood proof hospital and the concepts will be described.

The planning of the Rotterdam Emergency Airport (REA) is that it will be realized in 25 to 30 years from now. The closest hospital to the REA is the St. Francis Hospital built in 1975. The lifespan of hospitals is generally 50 years (Collegebouw ziekenhuizen, 2010). Modernisation of methods and medicines change the building requirements of the hospital. Also the number of patients changes regularly. The new building of the St. Francis Hospital will be needed at the same time the REA will be realized, therefore the St. Francis Hospital is suitable as a case study in this research. Because the current location of the hospital is too far from the REA to serve as an emergency hospital, the new building in this case study will be realized on the site of the REA.

The St. Francis Hospital is a general hospital. It serves a population of around 200,000 people. This population inhabits neighbourhoods of Rotterdam: Lansingerland, Rotterdam North, Hillegersberg, Schiebroek, Overschie, Stadscentrum, Prins-Alexanderpolder, Krallingen, Crooswijk, Delfshaven, Prinsenland, Zevenkamp, Capelle aan den IJssel, Vlaardingen, Schiedam, Ommoord en Pijnacker-Nootdorp. In the tables below general information on the hospital and its size are shown.

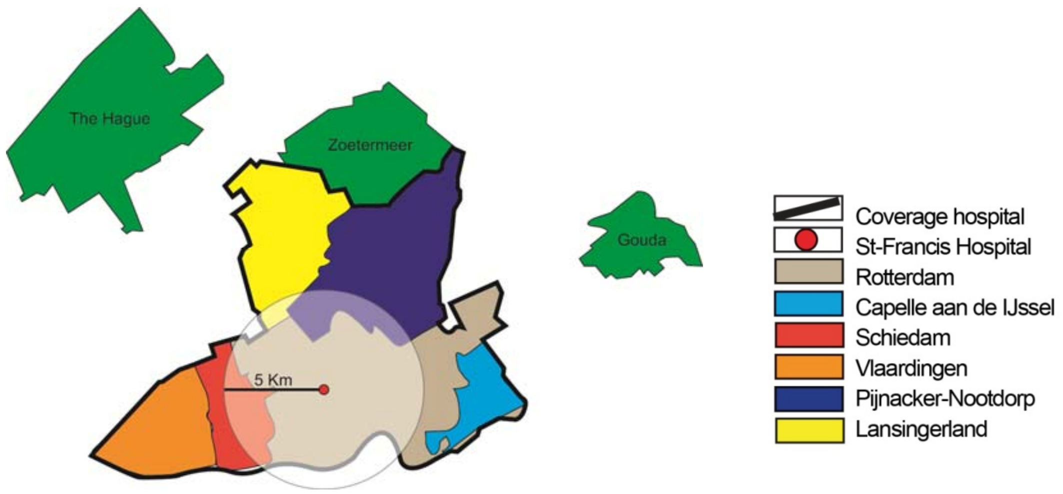


Figure 6.1 Coverage area St Francis Hospital.

Table 6.2 Size of the hospital, number of employees (St-Franciscus Gasthuis, 2010)

Total number of employees	2,237
Number of specialists	136

Table 6.3 Number of treatments, 2009 (St-Franciscus Gasthuis, 2010)

Treatment at specialist department	335,904
Surgical operations	52,115
Clinical hospitalisation	22,770

Table 6.4 Number of beds, 2009 (Sint-Franciscus Gasthuis, 2010)

Total number of beds	449
Beds with hart monitors	10
IC beds with artificial respiration	12
IC beds without artificial respiration	4

6.1 Flood scenario

In the Rotterdam area the most significant flood threat is a flooding of the river Meuse. At the mouth of the river, the Maeslant storm surge barrier has been constructed in the nineties. During high water levels, two gates can close the river mouth. This will happen if the water level reaches 3 meter above MSL. In case of a storm surge barrier failure, the dike ring along the Nieuwe Waterweg and the Meuse is a second line of defence. The water level can reach up to 5 meters MSL, before the dike failure occurs. In the climate report of the municipality of Rotterdam and the water board is stated that the dikes in 2050 have to be able to withstand a water level of 7 meters MSL (Van Veelen et al., 2010). This is 2 meters higher than the current situation.

Figure 6.2 Flood defence around Rotterdam.

In the studied scenario the Maeslant storm surge barrier will fail and the dikes will fail. This will mean that the hinterland of Rotterdam will be flooded, as well as the location of the REA, polder Zestienhoven. The entire location is located below MSL. The heights differ between -2 and -6 meter MSL. In the current situation the estimated water level in the polder will be 1.5 to 2 meter. With the expected water level increase of 2 meter in the future, the maximum water level at the location will be 3 to 4 meters above ground level. This means that the two lowest floors of the hospital will be flooded. In this research an expected water level of 3 metres will be used or one floor.

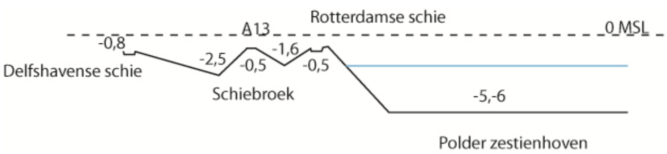


Figure 6.3: Section location

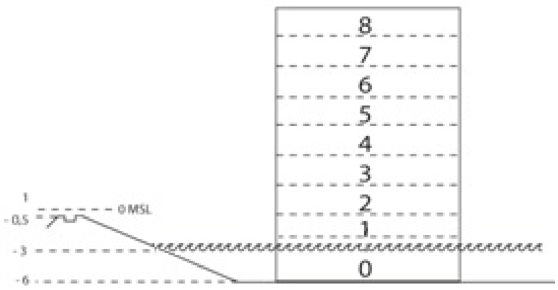


Figure 6.4: Flooding of hospital in polder Zestienhoven.

During a Maeslant storm surge barrier failure, the project location will not flood immediately. For two reasons it will take a longer time before flooding occurs: first the water has to cross the land between the river and the project location. Secondly, there are several barriers such as dikes and higher roads in between which will slow down the water flow. Consequently, it will take several hours to reach and flood polder Zestienhoven. Other disasters showed that in the first six hours after a flood mainly people with minor injuries come to the hospital. After six hours, people with serious injuries find their way to the hospital (Doctorswithoutborders, 2010).

6.2 Functional requirements

The St. Francis Hospital has a number of specialist departments and outdoor patient clinics. They are listed in Appendix 2. Also the St Francis Hospital has a dialysis centre, medical and/or GP laboratory and its own pharmacy (Sint-Franciscus Gasthuis, 2010). Apart from that a hospital has a number of medical departments such as an accident and emergency (A&E), intensive care, operating rooms and nursing wards. Finally reception areas, security, management, technical services, shops and restaurants all are part of the intricate spatial organisation of a hospital. An organisation scheme has been drafted for the St. Francis Hospital (figure 6.5). This is based on the functional organisation of other hospitals.

When a flood occurs a hospital will need to provide emergency response. Hospitals are expected to provide care and treatment for those who are already in the hospital. Secondly, many people will be injured during the flood. This causes an additional number of patients who need medical attention. During a flood, the St Francis Hospital will have the same coverage area as in a normal situation. However, the number of patients will increase. In the development of a flood proof concept for this hospital, an increase of 20% of floor space for the essential functions such as A&E will be assumed.

During the first days of a flood, the activities of the hospital will be focused on the emergency health care. When the flood remains for weeks or months, it will be essential that the entire hospital will function in an optimal way. Not all of the departments and facilities are essential during the first stage of a flood. A division can be made between essential functions and functions that are temporarily not necessary. The space that is saved can be used for other purposes. To do this, the non critical functions have to be placed strategically in the hospital, to enable a flexible use of space to expand essential functions during a flood. The functions of the hospital are divided into four groups:

- Group 1: Essential functions and facilities during a flood
- Group 2: Essential functions that can be located elsewhere
- Group 3: Functions that can be used as extra wards during a flood
- Group 4: Functions that can be used as extra A&E and first aid during a flood

In table 8.5 is shown which areas of the hospital can be used differently during a flood. In table 8.6 the required area needed for the new St. Francis hospital is divided over the four groups. The numbers for de area needed are derived from data from the Meander Medisch Centrum in Amersfoort (Meander Medisch Centrum, 2005, 2006). It shows that the total area needed for group 1 and 2 is 26.100 m2. During a flood this will have to be increased with 20%. This means that 5220 m^2 of the hospital will have to be transformed. Because the ratio between group 3 and 4 is 2:1 (table 8.7), this resolves in 3480 m2 extra wards and 1740 m^2 extra accident and emergency and first aid facilities.

Table 6.5 Possibilities alternative use of space during a flood.

Group 1: Functions and facilities that are necessary during a flood	
Accident & Emergency	This is the most dynamic department and should be easily accessible. During flood more A&E patients are expected. Therefore A&E should be enlarged.
Surgery, Operating rooms	To provide A&E care sufficient operating rooms are needed. During a flood these facilities should be enlarged.
Cardiology/C.C.U.	Patients with coronary problems have to be looked after at all times, also during a flood.
Intensive care	Patients on the I.C. have to be looked after always, also during a flood.
Radiology	The correct analysis and diagnosis is very important to treat patients. Therefore it is vital that radiological services are maintained.
Laboratories	The correct analysis and diagnosis is very important to treat patients
Observatory	In an early stage of the flood this facility is less urgent. When the flood stays and the number of patients grows, this becomes more important.
Wards/ Gynaecology/ Obstetrics/ Paediatrics	Patients cannot be sent away during a flood. Babies will have to be delivered. Therefore the hospital should maintain these functions.
Plaster room	Minor injuries will include a lot of broken limbs. Plaster room is vital.
Pharmacy	Preparation and storage of medication is vital, also during a flood.
Mortuary	To prevent epidemics, remains of deceased should be handled properly.
Security	It is important that care can be provided in a secure and calm way. Security can prevent disturbances.
General & techn. services/ Storage	(medical) supplies have to be supervised and controlled.
Locker rooms personnel	To facilitate personnel, locker rooms and other personnel areas are essential.
Group 2: Important functions that can be located outside hospital (e.g. in a shelter)	
GP post	GP Post can take care of the minor injuries. When this is located close to a (temporary) shelter, a lot of patients do not have to go to the hospital.
Pharmacy	An annex can be situated near shelter/GP Post to provide care for minor injured.
Group 3: Functions that can be used as extra wards	
Consulting centre/ Training rooms/Therapy room	These kind of facilities are used for not life threatening injuries and illnesses. Regular appointments will be rescheduled after the flood.
Management department/Offices	Offices, conference rooms etc can be used for other purposes during a flood.
Day wards	Because focus during floods is on emergency care, regular appointments will be rescheduled. The day wards can thus be used for flood injured.
Shop, restaurant, health insurance companies (general facilities)	These supporting facilities are mainly for visitors and therefore not necessary during a flood.
Group 4: Functions that can be turned into extra A&E and first aid	
Reception	
Outdoor patient clinics/ Clinical departments/Psychiatry	A lot of room, specialists and equipment of the outdoor patient clinics can be used to extend the A&E services.

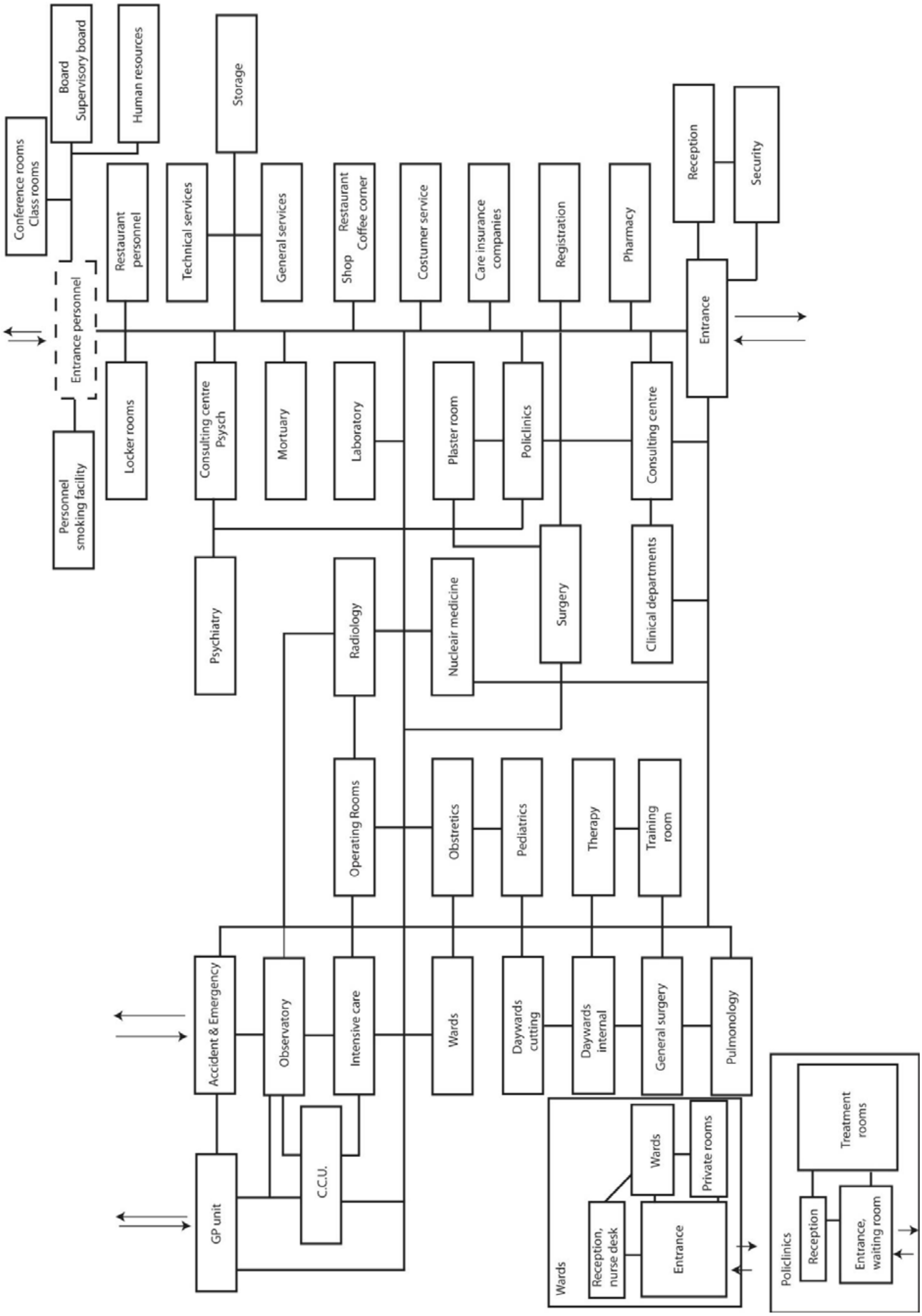


Figure 6.5 Organisation scheme of the hospital.

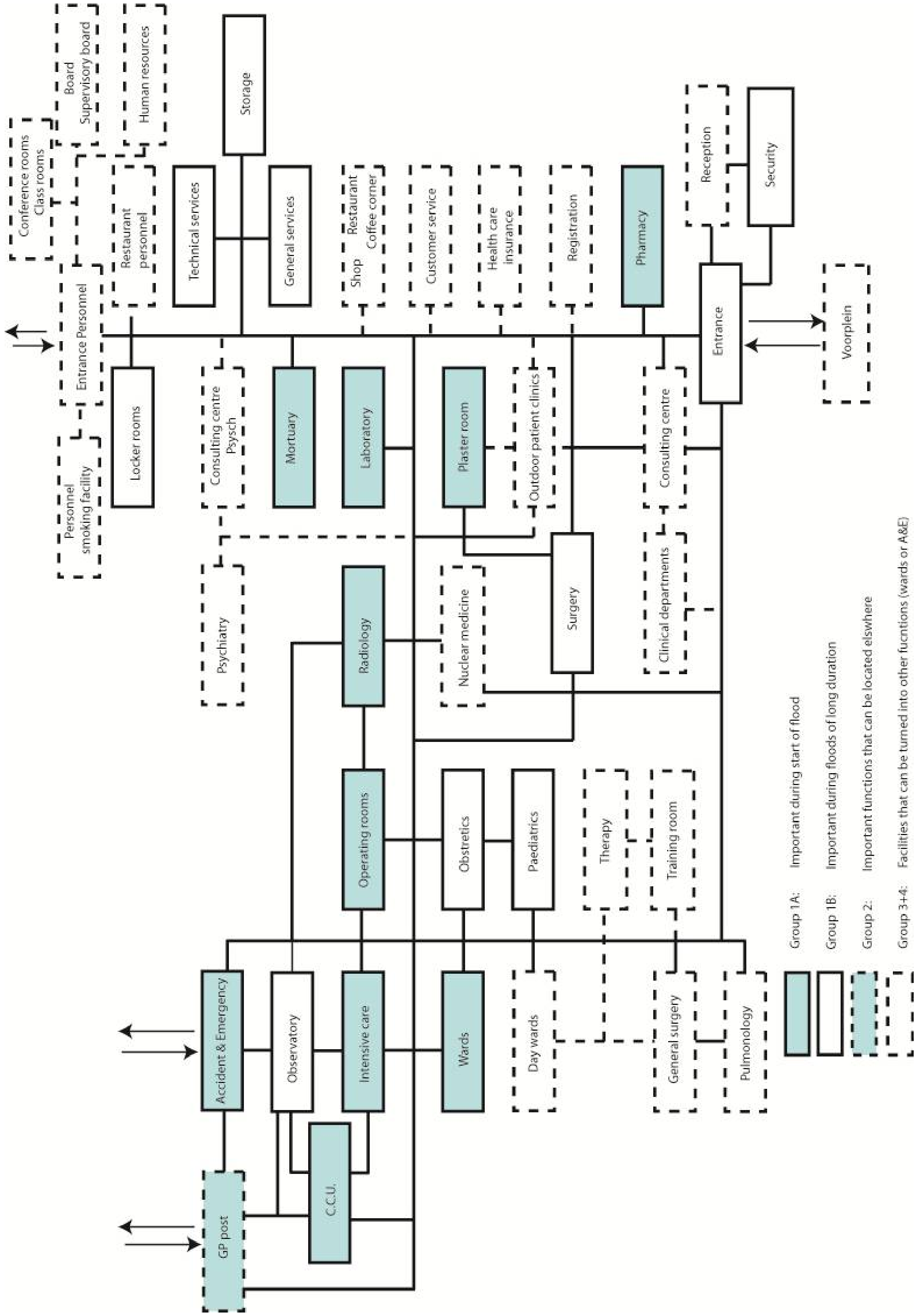


Figure 6.6 Organisation scheme of the hospital during a flood, distinction is made in four functional groups.

Table 6.6 Area use of St Francis Hospital (Meander Medisch Centrum, 2005, 2006)

Functions	Hospital (total) M^2 GFI	Group 1+2 M^2 GFI	Group 3 M^2 GFI	Group 4 M^2 GFI
GP Post, A&E, Observatory	1.300	1.300	0	0
Consultancy centres	6.500	0	6.500	0
Outdoor patient clinics, Radiology, General surgery	5.900	500	0	5.400
Day wards	2.400	0	2.400	0
Operating rooms, IC, CCU	4.400	4.400	0	0
Wards, Gynaecology, Obstetrics	11.500	11.500	0	0
Pharmacy, mortuary, laboratories	5.200	5.200	0	0
Office space, conference rooms etc	3.000	0	3.000	0
Management dept: Board rooms, secretary, HR, Finance, Communication	2.300	0	2.300	0
General services	3.200	3.200	0	0
Hall Functions: reception, shops, restaurants	0	0	1.000	1.700
Total	**48.400**	**26.100**	**15.200**	**7.100**
Technical services and logistics	8.537		8.537	
TOTAL AREA	**56.937**		**56.937**	

*NB GFI stands for Gross Floor Index

Table 6.7 Percentage of used area

	Area (m^2)	Percentage (%)
Group 1+2	26.100	54
Group 3	15.200	31
Group 4	7.100	15
TOTAL	**48.400**	**100**

6.3 Hospital typology

There are several hospital typologies in the Netherlands. The typologies that are most often used are: the Breitfuß structure, double comb structure, passage structure, cross structure, branch structure, linear structure and the pavilion structure will be discussed in this research (College bouw ziekenhuisvoorzieningen, 2002).

The Breitfuß structure consists of a compact high rise part that most often contains the wards on top of a low rise part that accommodates the treatment and outdoor patient clinics. The low rise serves as a kind of pedestal for the high rise. This structure results in a compact building volume with short walking distances. However space is needed for the vertical transport and extension is only possible in the lower part of the building.

The double comb structure consists of a logistic route in the heart of the building. Building sections are placed on the opposite sides, similar to a comb. Extension of the building is easy, which makes the building quite flexible. Departments that are related to each other can be easily clustered. Due of the layout of the building also long walking distances can occur and there is no clear division between logistic flows and visitor flows.

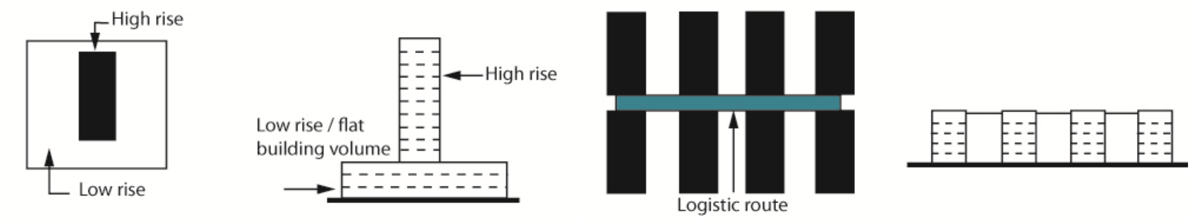


Figure 6.7 Breitfuß structure (left) and double comb structure (right).

In the passage structure the different departments are positioned alongside a passage. This is the main entrance to the hospital and facilities such as restaurants and shops are located here. From this passage all the departments have visual contact with each other and the patients. The structure is comparable to the double comb structure and therefore easy to extend. Long walking distances and mixed flows of people are disadvantages of this typology.

The cross structure consists of a floor plan that resembles two crosses. In between is a covered hall where the entrance and general facilities are located. This design makes it possible for a large hospital to have a compact building form. The typology provides much daylight to the building.

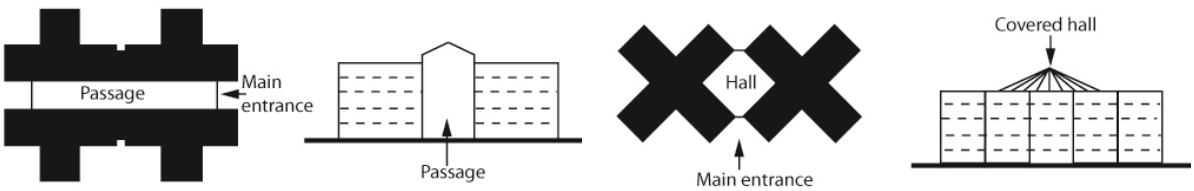


Figure 6.8 Passage structure (left) and cross structure (right).

A central hall is the most important part of the branch structure. Here the entrance and the general facilities are located. The departments and clinics are positioned around this hall and are located in branches. The typology is mostly applied in low rise hospitals. Outdoor patient clinics can have their own entrance and because of the branches almost all the departments have views of the surroundings. The building can easily be extended. Because of its structure the hospital has a large space demand and the walking distances are rather long.

A building shaped like a ribbon or tape is considered a linear structure. The building most often consists of a couple of bends, to decrease space demand and to create a courtyard. A hall can connect the different parts of the building to minimise the walking distances. This typology can easily be extended. A disadvantage is that the logistic and visitors flow cannot be separated.

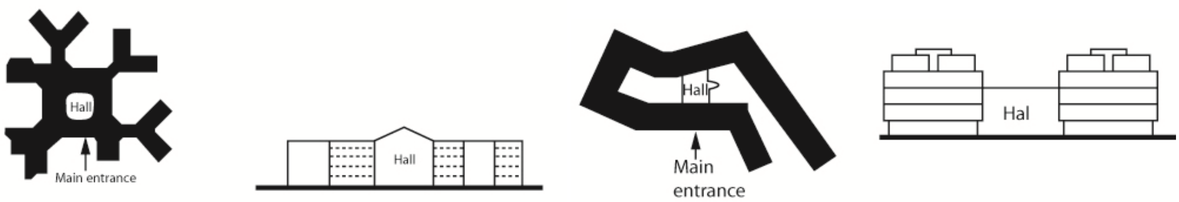


Figure 6.9 Branch structure (left), and linear structure (right).

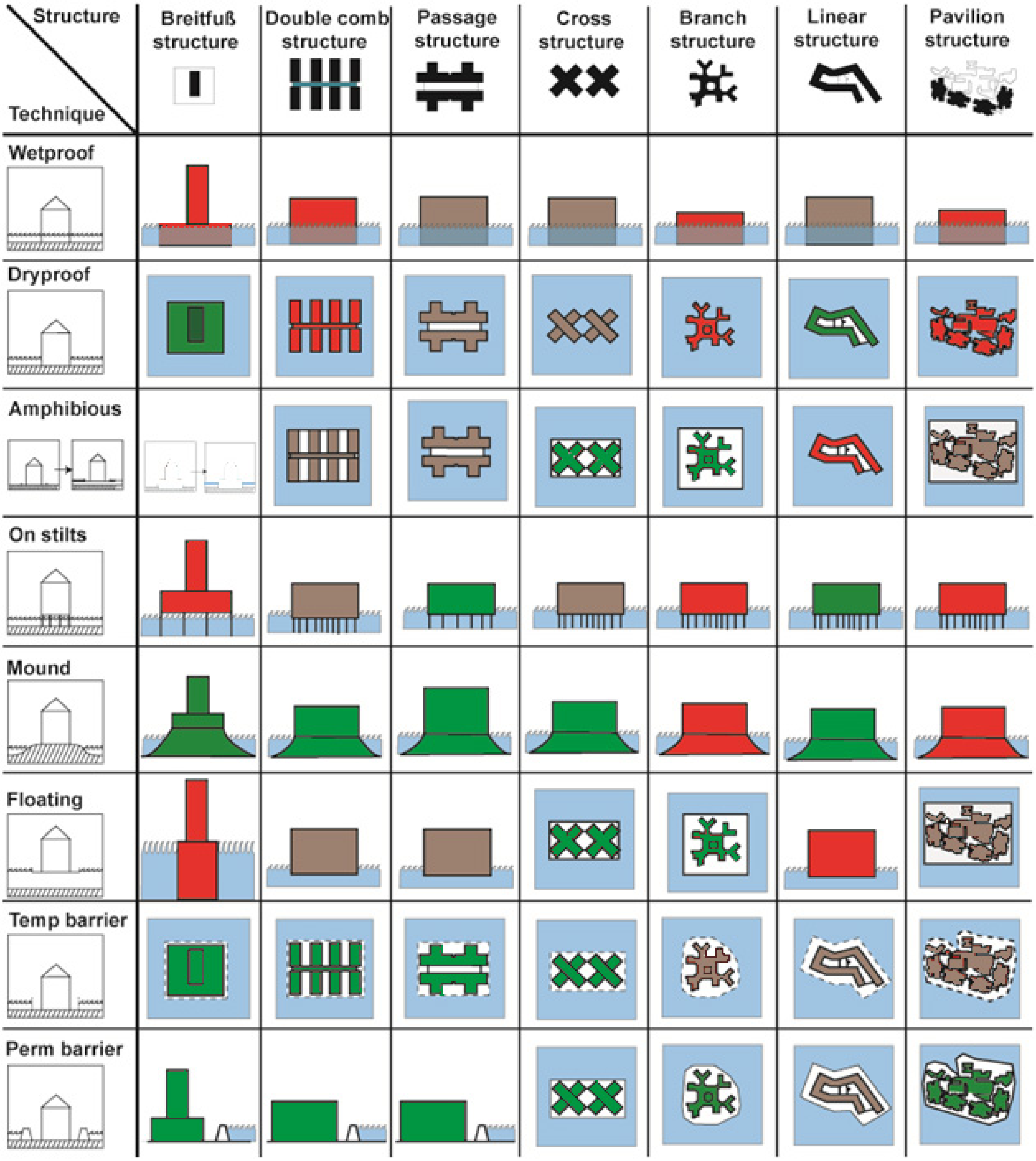
With the pavilion structure, departments that have overlap or similarities can be clustered together. All the clusters are located in separate pavilions. These are linked by a hall where the main entrance is situated. This typology is used mostly for low rise hospitals. It is not very easy to change the internal configuration of this typology, however it is possible to extend the hospital with more pavilions. This typology has a large space demand.

Figure 6.10 Pavillion structure.

Not all of these typologies can be combined with the different methods to flood proof a building. In figure 6.11 a comparison of the different combinations is made. The green icons are considered good combinations, the red ones are combinations that are less likely. The grey combinations are possible, but mostly not preferable. As an example, the Breitfuß structure is not suitable for floating due to the high rise structure. Low rise buildings with a large space demand are good candidates for floating construction, but typologies with an irregular floor plan will have an uneven mass distribution. Therefore the branch, linear and pavilion structure are considered not suitable. The double comb and cross could be constructed floating or amphibious, but it is not preferable. Temporary barriers are no preferred option because the accessibility of the hospital for ambulances is significantly reduced by them. The branch and pavilion structure in particularly are not suitable for temporary barriers because the perimeter of these types are rather large.

Table 6.8 Advantages and disadvantages of typologies

Typology	Advantages	Disadvantages
Breitfuß structure	- Compact building volume - Short connections/ distances - On top of low rise possibility for extra connection to logistics network	- Less possibilities for extension - Space needed for vertical transport
Double comb structure	- High degree of flexibility - Clustering of functions possible - Good possibilities for extension - A lot of façade area with much daylight entering	- Long connections/ distances - No clear division between logistic and visitor flows.
Passage structure	- Distinct entrance - Clustering of functions possible - Good possibilities for extension - Compact building volume	- Long connections/ distances - No clear division between logistic and visitor flows.
Cross structure	- Big spaces with much daylight - Compact volume with the possibility of divisions - Good possibilities for extension	- No clear overview layout
Branch structure	- Good possibilities for extension - A lot of façade area with much daylight entering	- Has a large space demand - Long connections/distances - Looks/feels chaotic
Linear structure	- Short connections/ distances - Clustering of functions possible - Good possibilities for extension - A lot of façade area with much daylight entering	- No clear division between logistic and visitor flows.
Pavilion structure	- Obvious division departments - Obvious visitor flows - Multiple entrances possible - Possibilities for extension	- Has a large space demand - Departments are spread



Green: good solution, grey: possible solution, red: no solution

Figure 6.11 Combinations of typologies and flood proofing methods.

Wet proofing in general is not feasible for hospital due to health concerns. Dry proofing could be a useful option for the Breitfuß structure because only a relatively small part of this high rise building has to be dry proofed. Dry proofing is also a good solution for the linear structure, because the courtyard ensures logistic routes and the entering of daylight. Low rise, wide spread buildings, like the branch, double comb and pavilion types, are not appropriate for dry proofing because a large part of the hospital needs to be protected.

Stilts are less suitable for most of the typologies because due to their shapes, they will require many foundation piles. Mounds are more favourable it will require a lot of ground displacement. Therefore permanent and temporary barriers are most suitable for typologies with a large space demand, branch and pavilion structures. Permanent barriers are possible with all the other typologies, but other methods may be more effective. When the perimeter is too large like the pavilion or branch structure, temporary barriers would take too long to set up.

For this project the most suitable combination is dry proofing on a linear structure. Both in the normal situation and during a flood, the entire hospital can stay operational. Because not all the functions are essential during a flood, a large part of the hospital can be used to enlarge the accident and emergency facilities. Moreover it has a relatively small perimeter and the courtyard ensures the provision of daylight in the building. During a flood the courtyard can be used for other purposes; for example it can be transformed into a shelter for temporary housing of evacuees. In this research a design concept for this combination will be presented.

6.4 Application of the Evaluation Tool

The service area of the hospital is a city level. During the flood it will probably be extended to a regional function because it is going to serve as an emergency hospital. For this the relevance of the flood proofing measure is high.

Relevance map

Questions:	ANSWER: 0 = no 1 = yes
What is the size of the service area (please choose one - 1)	
a. district	0
b. city	0
c. regional or larger	1
	ok
What is the projected scale of the flood scenario	
a. only the hotspot is affected	0
b. the district or neighborhood is affected	0
c. city	1
	ok
Relevance of flood proofing measure is:	**HIGH**

Figure 6.12 Relevance map results.

After applying the flood proofing selection tool; *Dry proofing, Floating, Amphibious, Stilts, Mound, Flood wall, Dike, Temp barrier* can be used as protection. The building is a new building, the answer on the first question is no (= 0). The area around it does not need protection and the hospital does not mainly exist out of fluid storage so floating an amphibious are still possible. The location of the future hospital could have permanent water available so floating is still possible and the ground floor contains vital functions this eliminates wet proofing. Space around the hotspot is available because this will be a new project in a location with a large open space so temporary barriers and permanent barriers could be installed. To the question if vehicle access is vital during flood is answered no. This is because of the assumption that emergency transport can also be provided by boat. If this would not be possible, dry proofing, flood walls and temporary barriers would not be a suitable solution because they block the accessibility for vehicles. Moreover the hospital does not need a rail connection and is not situated underground.

Flood proofing selection tool

Questions:	ANSWER: 0 = no 1 = yes fill in here:
Are you retrofitting an existing hotspot?	0
Does the area around hotspot need flood protection?	0
Does the hotspot contain fluid storage with considerable weight?	0
Does the hotspot consist of installations instead of buildings?	0
Is there a possibility for or availability of permanent water?	1
Does the ground floor need to contain vital functions?	1
Is space around the hotspot permanently available?	1
Is space around the hotspot available in case of flooding?	1
Is vehicle access vital during flood?	0
Hotspot with permanent rail connection above ground level?	0
Is the hotspot situated underground?	0

Flood proof measures to choose from:

Dry proofing, Floating, Amphibious, Stilts, Mound, Flood wall, Dike, Temp barrier.

Dry proofing: (Emergency) entrance has to be elevated during flood. Openings such as windows and doors are a point of attention.

Floating: Connections to land and between buildings have to be flexible. A large floating construction is needed. A way of anchoring the construction is needed.

Amphibious: Connections to land and between buildings have to be flexible. A large floating construction is needed. A way of anchoring the construction is needed.

Stilts: (Emergency) entrance has to be elevated. Build up time and manpower needed. The hotspot needs a fence or wall for normal security; the solution is additional.

Mound: Ground displacement is needed; the solution needs a large perimeter because of the slope.

Flood wall: Emergency entrance has to be elevated. The solution can be integrated with a customary fence.

Dike: Ground displacement is needed; the solution needs a large perimeter because of the slope.

Temp barrier: Manpower and time is needed for build-up, the hotspot needs a fence or wall for normal security; the solution is additional. Emergency entrance has to be elevated during the flood.

Figure 6.13 Selection tool results.

For the application of the evaluation tool, the site perimeter and site area and building mass have been estimated on respectively 15000 m², 1100m² and 2000 kg/m². The land cost for a levee is estimated on € 150 /m², this is lower than the regular land cost for real estate. The available perimeter width, the smallest distance between the perimeter of the building and the perimeter of the site.

Flood proofing evaluation tool

Hotspot data

	fill in here:	
Site area	15000	m2
Site perimeter	1100	m
Building area	9200	m2
Building perimeter	560	m
Building mass	2000	kg/m2
Land cost	€ 150.00	/m2
Available perimeter width	12.0	m

Flood data

	fill in here:	
Flood height	3	m
Flood frequency	1/100	
Flood onset time	12.0	h

Number of people available for help

	fill in here:
Men	25

Flood proofing options	cost EUR *1000	appl*	lifetime cost EUR*100 50 y	width m	inst. time hrs. w/ men	h min m	h max m	min length m
Sandbags	€ 1,235	1	€ 1,235	9.0	594	0	2.5	1
Container / gabion	€ 521	1	€ 521	3.0	66	0.75	3.5	1
Geotech Tube	€ 986	6	€ 986	6.0	40	0.25	3.25	30
Tube	€ 3,462	4	€ 3,462	6.0	16	0.25	2.5	15
Frame barrier	€ 1,870	10	€ 1,870	6.0	8	0.25	2.5	1
Flexible Free-standing	€ 3,496	5	€ 3,496	12.0	0	0.5	2	9
Flexible Frame	€ 829	hire	€ 829	4.5	26	0.75	2.5	1
Demountable	€ 4,785	50y	€ 4,785	0.5	83	0.5	5	3
Preinstalled	€ 8,250	50y	€ 8,250	0.5	0	0.5	2.5	1
Levee / dike	€ 6,829	50y	€ 6,829	10.4	0	0	10	19.2
Floodwall	€ 6,424	50y	€ 6,424	1.0	0	0	10	
Wet proofing	€ 1,675	5	€ 1,675	0.0	0	0	4	
Dry proofing	€ 724	50y	€ 724	0.0	0	0	3	
Floating	€2,313	50y	€2,313	0.0	0	0	10	
Amphibious	€ 4,270	50y	€ 4,270	0.0	0	0	10	
Stilts	€ 1,062	50y	€ 1,062	0.0	0	0	10	
Mounds	€ 2,828	50y	€ 2,828	4.9	0	0	10	

appl * = number of applications or lifespan

Figure 6.14 Evaluation tool results.

Concluding from the calculation, dry proofing is the cheapest option for this hospital. Because of the high water level, and the duration of flood the construction of the entire first floor should be reinforced with a stronger construction. The costs for this are not accounted for in this model. Therefore option two (stilts) or option three (floating) could be more interesting depending on the higher cost of this intervention. Moreover because of closure of the two facades creating two courtyards on the inside of the building, the perimeter is limited because the facades facing the courtyard are not calculated in the model.

6.5 Location: Rotterdam Emergency Airport

Figure 6.15 Possible locations in polder Zestienhoven.

On the REA four possible locations for a new hospital are appointed. From these locations 2 is the most favourable because this location is relatively good to connect to the public transport network in Rotterdam. Furthermore it is located on the road in the area and close to higher grounds. The noise from the airport is low and the location is surrounded by a green landscape. Hospitals are commonly located in green areas to promote a fast recovery (De Jong, 2010).

In a normal situation the hospital is easy to reach by car using the existing roads. There is already a bus connection, and maybe in the future the shuttle service of the airport and the subway will have a stop close by. Then the hospital will also be easy accessible by public transport. During a flood the hospital will still be easy to reach by the dike in the direct vicinity of the hospital. Also if a floating road is constructed to the hospital, people can still reach the hospital through this way. The entrance of the A&E is above the expected water level and an amphibious ramp connects it to the ground. During a flood boats can moor here to bring patients to the hospital. Also a connection with the airport is a possibility. It will also be possible to reach the hospital with a helicopter.

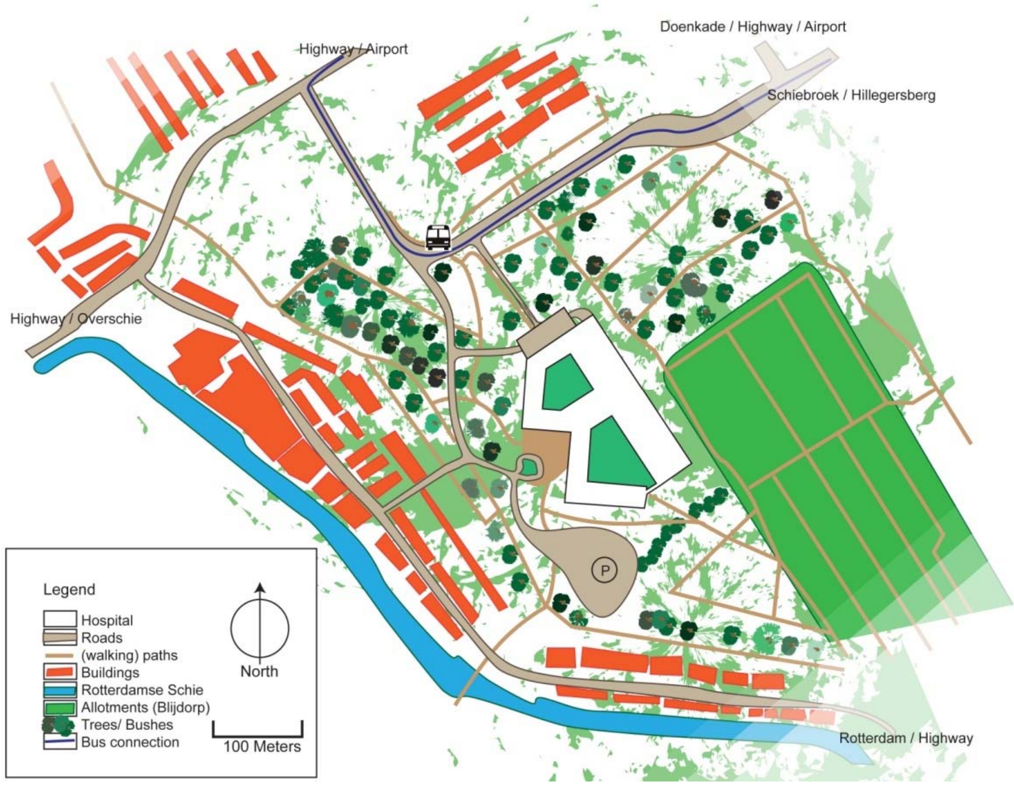


Figure 6.16 Accessibility of the St Francis Hospital in a normal situation.

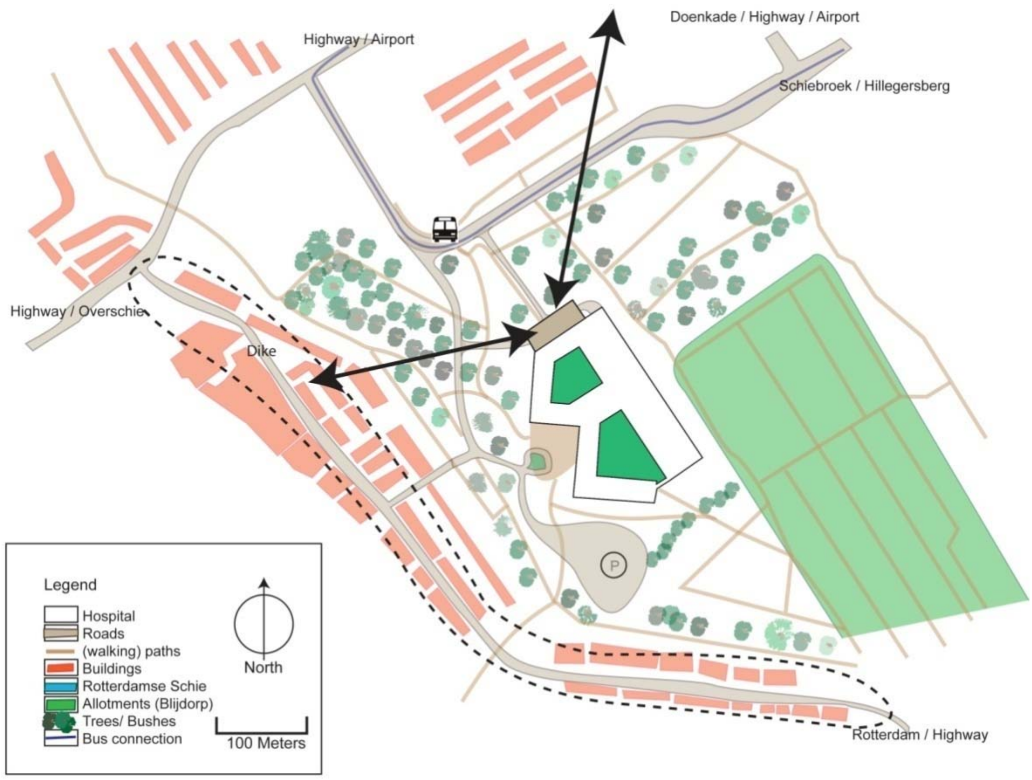


Figure 6.17 Accessibility of the St Francis Hospital during a flood.

6.6 Design Concept

The spatial requirements as described in chapter 6.2 and 6.3 are used to make the design concept. The new building for the St Francis Hospital is designed as a rectangular shape which is dented on the south side. Because of the dry proofing method, the outer façade has no openings on the ground floor. By choosing the dented form, the amount of inner façade facing the north is minimised to ensure the maximum entrance of daylight in the building. De curves in the building also make it possible to make a connection in the centre of the building and shorten the walking distances. The main entrance is situated on the front of the building, in the bent of the façade. It opens into a central hall and the entrance is clearly visible for all visitors. The entrance for the A&E and the GP post is situated on the second floor, above the expected water level. In times of flooding, an amphibious ramp can be connected to the platform to allow boats to moor.

Figure 6.18 Floor plan design concept of St Francis Hospital.

The hospital has a total gross floor area of 55.200 m2 divided over six floors. The floor area of every floor is 9,200 m2. During a flood parts of the building will be transformed to allow emergency functions to expand. Functions that need an easy access for patients and visitors, such as shops, restaurants and the pharmacy, are located on the ground floor. Also the general services are located here. Functions that are visited by patients on appointment or just for one day, such as the outdoor patient clinics, consultancy room and day wards, are located on the ground, first and second floor. On the second floor are the GP post, A&E, operating rooms and ICU and CCU services. The wards are mainly on the third and fourth floor. The rest of the fourth and the fifth floor is used by laboratories, class rooms, management department, offices and supporting services. In the appendix the detailed organisation of every floor is shown.

Figure 6.19 Organisation of the hospital in functional groups.

As is shown in figure 6.19 approximately half of the hospital is needed to function during a flood. The other parts of the hospital can be used to extend the wards and the A&E. In figure 6.19 is shown which parts of group 3 and 4 need to be converted to create the needed addition of 20% for emergency functions. The wards need 3480 m^2 extra and the A&E 1740 m^2. In the figure the blue circled parts are transformed in extra wards. On the first floor 2400 m^2 is created and on the second floor 1600 m^2. The black circled parts in figure 6.20 are extra A&E facilities. The spaces used are mostly outdoor patient clinics because they already have (part of) the equipment needed. On the first floor 800 m^2 is created and on the second floor 1200 m^2.

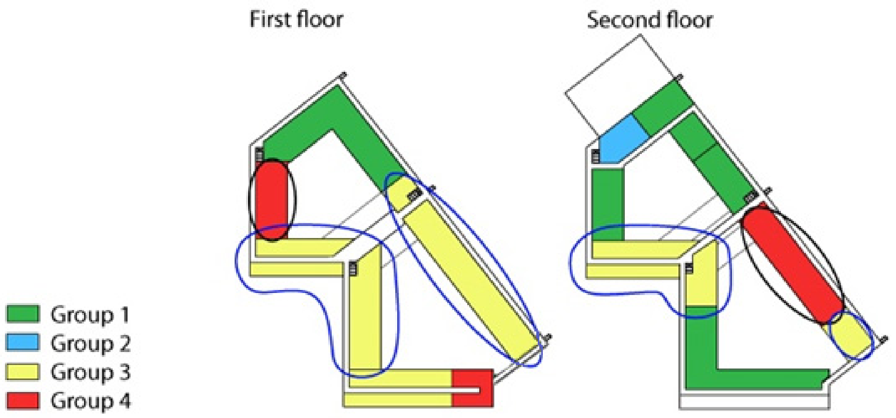


Figure 6.20 First and second floor during a flood, circled parts are converted in emergency functions during a flood.

6.7 Design Elaborations

After determining the general shape and organisation of the hospital, certain parts have been designed in more detail, to illustrate the differences between normal situations and during floods.

Consulting centre: This centre consists of small rooms where patients are consulted. In this example the consulting rooms are clustered together, with waiting rooms and reception desk located in between the clusters. The layout is indicated in figure 6.21. During a flood the consulting rooms can be easily transformed into extra patient wards. The internal walls will be constructed in such a way, that they can slide away to create emergency wards of different sizes.

Figure 6.21: Consulting centre during normal and flood situation.

Daylight entry: Because the building will be dry proofed, the entry of daylight on the lower floors is a point of attention. There a several methods that can be used. They are illustrated in figure 6.22.

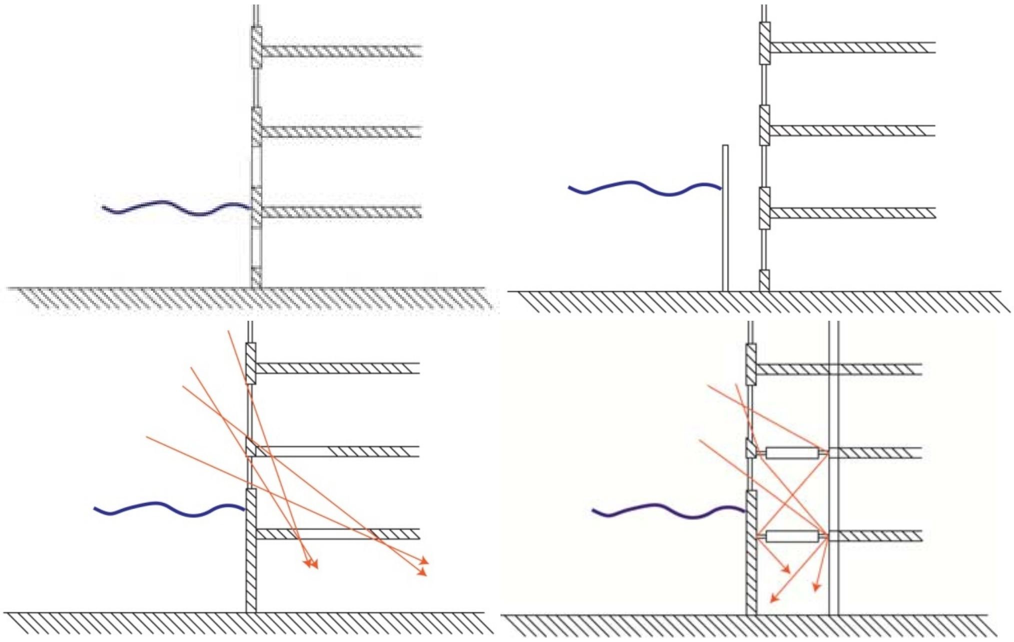


Figure 6.22 Possible ways to provide daylight on lower floors.

7 Conclusions, discussion and future directions

7.1 Using the design guidance tools

The tools presented in this report can be used by designers and decision makers to select and evaluate flood proofing concepts for the protection of hotspot buildings, during different stages of the urban development process. In the beginning of such a process when option are explored, the flood proofing catalogue gives a general overview on flood proofing concepts. The basic considerations for their application can be found at the end of the chapter. The relevance map can be used as a first indicator on the relevance of flood proofing a particular hotspot, based on the probable flood impact and the service area of the hotspot building. Both of these aids require only a small amount of data or specific information.

In the next phase of the development process, when possible measures for flood-proofing are selected, the selection tool gives insight which flood proofing concepts could be feasible based on information on location characteristics and hotspot characteristics. The selection tool requires a small amount of information, although more data should be available than in the first phase.

In the decision making phase, the evaluation tool provides detailed information about the costs of several possible options for flood proofing a specific hotspot. Relatively detailed information on the hotspot, flood characteristics and location characteristics should be available for applying this tool.

It is demonstrated that the tools presented in this article can be useful for decision makers and designers to quickly limit the large amount of available options for flood proofing hotspot buildings. Therefore the tools have the potential to contribute to make cities more flood resilient by better protecting vulnerable hotspot buildings in critical infrastructure.

7.2 Effectiveness of floodproofing hotspots

If information is available on estimated damage from certain flood scenarios, the evaluation tool can also be utilized to help make a cost-benefit analysis (CBA). For instance, costs incurred by Yorkshire Water from a single flooded sewage treatment plant in 2007 were estimated at £50 million and the flooded Mythe Water Treatment Works had about £30 million damage. With a flood probability of 1/200 this translates to costs of respectively £250k and £150k per year. If these annual costs are multiplied by the lifetime of the flood defense system, for example with a 50 year design life, costs would amount to respectively £12,5M and £7,5M. Recently a £5.5M programme, including a permanent flood barrier, has been finished at Mythe Water Treatment Works (Costain, 2010).

7.3 Limitations

Currently, the design tool is limited to 14 hotspots, that were selected collectively throughout the research programme. Additional hotspots like cultural heritage centres, waste handling facilities and pumping stations could also be considered. The current approach makes implementation of additional hotspot functions relatively easy and straightforward.

Another important limitation is that critical infrastructure and networks, including roads, bridges, power lines, tubes and pipes, were not the focus of this research. Although the infrastructural connections with the hotspots were an important area of study, it is of major importance that the whole circuit is protected from floods; e.g. when a hospital cannot be reached, it loses an important part of its function.

Additional flood data parameters, such as flood velocity and duration, may be implemented. Currently, they are not taken into account in the model. When the velocity of the expected flood is very high, it will have more destructive force and some of the flood proofing measures can be insufficient or need to be reinforced. A long duration may also restrict the application of certain flood-proofing measures. Examples of flood-proofing measures that can only be applied if floods have a limited duration are dry proofing and several types of temporary barriers.

7.4 Future directions

In the perspective of the EU Flood Directive the hotspot evaluation tool can be used for the third step. The implementation of the EU Flood Directive consists of three steps:

1. A preliminary flood risk assessment, finished by 2011
2. Flood risk and flood hazard maps, finished by 2013
3. Flood risk management plans, finished by 2015

The aim of the ‘flood risk management plans’ is to reduce the likelihood and/or the impact of floods. One of the elements stated by the EU is Protection***:*** *taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location*[1]*.* The application of the hotspot tool could be used to reduce the impact by targeting the vital hotspots and flood-proofing them. Information about the flood risk and flood hazards, which is to be prepared in step 2, may be used as input to the design tool.

The intended direction with the guidance tools developed in this programme is to apply them to more pilot sites in the near future. The data of each of the sites and hotspots will be used to expand the database and optimize the results of the design tools.

[1] http://ec.europa.eu/environment/water/flood_risk/flood_risk.htm

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Appendix 1 | State of the Art data

A desk study was conducted in order to make an overview and categorise international best practices in retrofitting flood proofing measures to hotspot buildings. A broad, but by no means exhaustive, list of international examples has been assembled and analysed. In the following overview, the focus is on hotspot buildings retrofitted to be flood-proof. A list that also includes other categories is provided at the end of this chapter.

<u>2.2 Electricity stations</u>

Yorkshire Energy Distribution (UK)

Yorkshire Energy Distribution Limited (YEDL) is responsible for distributing electricity throughout much of Northern England from Northumberland through to North Lincolnshire, they operate and maintain a distribution network that delivers electricity to more than 3.6 million premises.

As many of the primary sub-stations have been built in what have now become flood risk areas, YEDL embarked on a multi-million pound programme to provide permanently-ready flood protection that would not restrict access to the sites and could be easily operated by one person.

Figure 1.1-1.3: Floodwalls around electricity substations (Flood Control Limited, 2010)

The general principle of the defence consists of a flood wall around the perimeter and entry points protected with flood gates or demountable flood barriers. All cable ducts passing through the defence perimeter were sealed and drains were protected by backflow prevention valves. An internal drainage network with sump and pump facilities ejects rising groundwater and rainfall accumulation from the site.(Flood Control Limited, 2010)

The entry points are either vehicle or pedestrian access points. The vehical entrances are protected with lift hinge flood gates. These present a completely flush threshold and are easy to handle by one person. They are virtually maintenance free and have a life expectancy of 50 years. Pedestrian entrances are protected by swing hinge flood gates.

Type of flood proofing:	Dry proof
Year:	2002

2.3 Cultural Heritage

National Archives Building (Washington, DC, USA)

The June 2006 Flooding in Washington shut down operations at four key federal office buildings, including the National Archives Building which holds treasures such as the original Declaration of Independence and Bill of Rights. Rainwater flooded two transformer vaults and the subbasement areas. The National Archives' electrical power went out immediately, but the sprinkler and security systems remained operational. Sump pumps continued to operate because of the emergency generator, but they were overwhelmed and had no place to pump the water. Fortunately, no original records were affected by the flood.

In 2009 two 'Self Closing' Flood Barriers were installed. This pioneering flood defence system consists of a polyester entrenched wall. When the water rises, the wall will automatically rises like a floating wall. No power source is required and it doesn't need manual operation. When the basin of the wall is filled, the barrier will be locked waterproof. When waters recede, it automatically sinks back. (NCPC, 2010)(UKFloodbarriers.co.uk, 2010)

Figure 1.4: Installation of the Self Closing Flood Barrier (Floodbarrier.nl, 2010)

Figure 1.5: National Archives Building (Floodbarrier.nl, 2010)

Type of flood proofing: Dry proof

Year: 2009

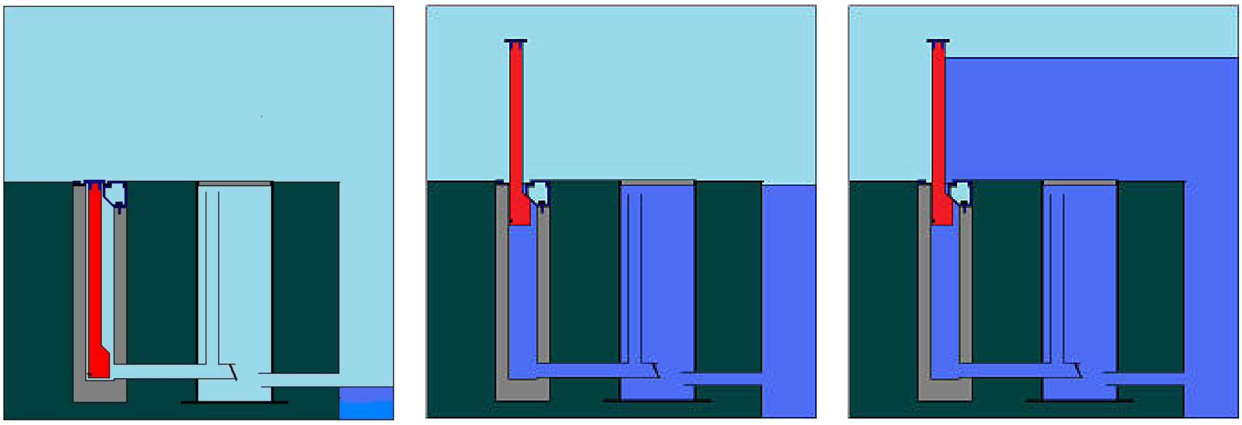


Figure 1.6-1.8: Functioning of the Self Closing Flood Barrier (Floodbarrier.nl, 2010)

Albertinum (Dresden, Germany)

Figure 1.9: the Albertinum museum
(SKD, 2010)

The Albertinum museum in Dresden is a center of art from the Romantic period to the present. The museum is situated on the south bank of the river Elbe. The building was damaged when the Elbe flooded in 2002. The collection, including paintings of Canaletto, Vermeer and Degas, was barely rescued from the floods by the use of emergency pumps that emptied water from the building at the rate of 7,000 liters a minute.

After the flood a new storage depot was built in a bridge construction that spans the building's courtyard. Placed at the roof level, this depot is extremely flood proof and can serve as an emergency storage for the art collection of the museum. (Bloomberg.com, 2010)(SKD, 2010)

Type of flood proofing:	elevated construction
Year:	2002

Isabella Steward Gardner Museum (Boston, MA, USA)

Figure 1.10: the Isabella Steward Gardner museum
(Meganandmurray.com, 2011)

The Isabella Steward Gardner Museum in Boston houses the extensive private art collection of Isabella Steward Gardner. Flood waters and sewage damaged the basement areas of the museum in 1996. Damage included the air-handling system that keeps the museum and the art works at constant humidity levels. The large art collection is a valuable piece of cultural heritage, and the museum and its collection are therefore seen as a flood proofing hotspot.

After the flood incident the museum was fitted with four sumps and pumps in the basement of the building. During a flooding event the sumps fill and the pumps eject floodwaters into the city's storm drains. The system is equipped with an emergency power generator. (FEMA, 2010)

Type of flood proofing:	installation of sumps and pumps
Year:	1996-1998

Punta Della Dogana (Venice, Italy)

The Punta della Dogana, the former customs house in Venice, was redesigned by Tadao Ando into a new contemporary art centre. The renovation work included large measures to increase the protection against water. The base of the building was raised to 1.5 m above sea level and in order to improve the building's overall waterproofing, a protective shell was installed. This shell, combined with watertight bulkheads along the entire perimeter and mobile protections for the doors, create a 2,500 sq. m. water hold-up tank which ensures protection against high water up to 2.10 m above sea level. (Designboom.com, 2010)

Figure 1.11: the Punta della Dogana (Designboom, 2010)

Type of flood proofing: elevated construction/dryproof

Year: 2009

Rijksmuseum (Amsterdam, the Netherlands)

As a key cultural institution hosting Dutch Masterpieces of the Golden Age, the Rijksmuseum is a vital hotspot which is well protected against pluvial flooding. The main storage area located underground were made watertight and fitted with storm doors. Works of art are placed at a distance from the perimeter walls, so that incidental moisture wouldn't affect it. A detection system was installed and connected to the building's alarm system. The system also monitored the ground water level. Rain water was collected and pumped out to the sewage system. Besides these technical measures, an emergency plan with guidelines in case of a flood risk was in effect.

Figure 1.12: the Rijksmuseum (Deltares and Grontmij, 2010)

The building, designed by Pierre Cuypers (1876-1885), is currently undergoing extensive renovation. The future situation of the museum in terms of flood proofing measures is unknown to the author. (Deltares and Grontmij, 2010)(

Type of flood proofing: dryproof

Year: 2010-2013

2.4 Hospitals

Memorial Hermann Baptist Hospital (Beaumont, TX, USA)

The Memorial Hermann Baptist Hospital in Beaumont, Texas in the USA was damaged by flooding as a result of the tropical storm Allison in June 2001. After that, a number of measures were taken to protect the hospital.

The hospital is located in the Texas Medical Center Complex, close to the city center of Houston, where a large number of medical services are concentrated. As a large healthcare complex close to a large city, the Memorial Hermann Baptist Hospital is seen as a hotspot building.

Figure 1.13: Memorial Hermann Baptist Hospital (FEMA, 2010)

To decrease the vulnerability of the hospital, a new building was erected next to the hospital in 2004. In this building all critical mechanical, electrical and plumbing equipment is placed at an elevated floor level. This enables the hospital to keep functioning in case of a flood. In 2005, two of the existing hospital buildings were retrofitted with hurricane shutters and a water well. The exterior walls were waterproofed and provided with a new roof. After hurricane Rita in 2005, the hospital was equipped with large power generators. (FEMA, 2010)

Type of flood proofing: elevated construction

Year: 2004-2005

VieCuri hospital (Venlo, the Netherlands)

The 'VieCuri Medisch Centrum' is a hospital that has been built in the floodplain of the river Maas. On several occasions the hospital inundated. In a recent flooding of June 2009, elevators went offline and several wards inundated and had to close down.

To prevent future flooding hazards a dyke has been built between the river Meuse and the hospital, it has an emergency storage facility and vital installations are placed in higher parts of the building (Deltares and Grontmij, 2010).

Type of flood proofing: dyke, raised construction

Year: 2009

2.5 Water treatment works

Emergency water supply bases (Tokyo, Japan)

The Waterworks Bureau of the Tokyo Metropolitan Government has established an emergency water supply system. In order to improve the Tokyo's coping capacity in case of disasters such as droughts, 195 emergency water supply bases have been realized. This ensures that each resident has a supply within close proximity of two kilometers. These emergency bases can supply three liters of drinking water to 12 million people during four weeks. The emergency water tanks constantly reserve fresh water from the main distribution network (Waterworks Bureau, 2005).

Type of flood proofing:	emergency water supply
Year:	unknown

2.6 Transportation hubs

Emergency transportation lock gate (Tokyo, Japan)

Lock gates have been constructed in the Tokyo urban polders that allow rapid shipments of disaster relief goods. This is important because the accessibility over land can be limited after a disaster. An example is the lock along the Arakawa, designed to enable the transport of goods into the central area of Tokyo after a disaster. This can contribute to the functioning of hotspots. (De Graaf, R.E., and J. Matsushita, 2008)

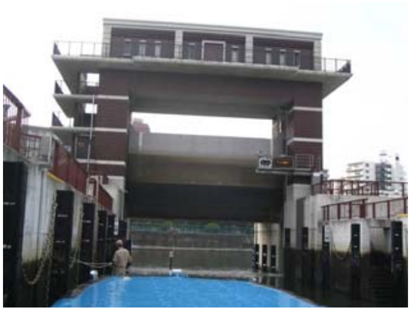


Figure 1.14: Emergency lock gate (De Graaf, R.E., and J. Matsushita, 2008)

List of reviewed projects

	name	*location*	*country*	*building type*	*hotspot function*	*new / retrofit*	*year*	*floodproofing type*
1.	NBBJ Hospital	Charleston, SC	USA	hospital	healthcare	new	2008	elevation
2.	Community Complex	St. Mary's, WV	USA	community	-	retrof.	2004	wet floodproofing
3.	Peterborough Senior Center	Fenway, Massachusetts	USA	elderly home	shelter?	retrof.	1998	wet floodproofing
4.	Firehouse No. 1	Port Charlotte, Florida	USA	fire department	fire-fighting	new	2004	elevation
5.	Memorial Hermann Bapt. Hospital	Beaumont, TX	USA	hospital	healthcare	retrof.	2005	dry floodproofing
6.	Memorial Hermann Bapt. Hospital	Beaumont, TX	USA	hospital	healthcare	new	2004	relocation
7.	Public library	Sanibel, Florida	USA	library	library	new	2004	elevation
8.	Highway Shop	Crawford County, WI	USA	commercial	-	new	2003	relocation
9.	Isabella Steward Gardner Museum	Boston, Massachusetts	USA	museum	cultural	retrof.	1997	wet floodproofing
10.	Pump Station	Luzerne County, PA	USA	pump station	wastewater	retrof.	1996	elevation
11.	Sanitary lift station	Drayton, North Dakota	USA	pump station	wastewater	new	2000	relocation
12.	Pump Station	Albany, New York	USA	pump station	wastewater	retrof.	2006	elevation
13.	Duval Beach Club	Key West, Florida	USA	restaurant	-	retrof.	1998	wet floodproofing
14.	Private homes	Snoqualmie, WA	USA	residential	-	both	2006	elevation / relocation
15.	Orleans Parish pump station	New Orleans, LA	USA	pump station	wastewater	retrof.	2009	dry floodproofing
16.	Private home	Stinson Beach, CA	USA	residential	-	new	2005	elevation
17.	Hafen City	Hamburg	Ger.	mixed	several	new	ongoing	elevation; dry proofing
18.	Yamanouchi pharmaceutical ind.	Meppel	NL	industrial	-	new	?	dry floodproofing
19.	National Archives Building	Washington D.C.	USA	archive	cultural	retrof.	?	dry floodproofing
20.		Tokyo	Japan	highway	transportation	new	?	elevation
21.	Yokohama Stadium	Yokohama	Japan	stadium	shelter	new		elevation
22.	Arakawa Lock	Tokyo	Japan	ship lock	transportation	new		wet floodproofing
23.	Emergency Water Supply Bases	Tokyo	Japan	water supply	water supply	new	in operation	dry floodproofing
24.	Hospital	Venlo	NL	hospital	healthcare	retrof.	2009 / 2010	dry proofing / elevation
25.	Meander Hospital	Amersfoort	NL	hospital	healthcare	new	design	elevation
26.	Rijksmuseum	Amsterdam	NL	museum	cultural	retrof.	?	dry floodproofing
27.	Albertinum	Dresden	Ger.	museum	cultural	retrof.	2002	elevation
28.	Punta della Dogana	Venice	Italy	museum	cultural	retrof.	2009	dry floodproofing
29.	Pynes WTW	Upton Pyne	UK	water treatment	waste supply	retrof.	> 2012	dry floodproofing
30.	Mythe WTW	Tewkesbury	UK	water treatment	waste supply	retrof.	> 2012	dry floodproofing
31.	London Underground	London	UK	metro/tube	transportation	retrof.	?	dry floodproofing
32.	Yorkshire Energy Distrib. (YEDL)	Yorkshire, Lincolnshire	UK	sub-stations	energy supply	retrof.	2002-2009	dry floodproofing
33.	Northern Energy Distrib.(NEDL)	Yorkshire	UK	sub-stations	energy supply	retrof.	2003-2009	dry floodproofing
34.	EDF Energy	South East Engl/London	UK	sub-stations	energy supply	retrof.	2003-2009	dry floodproofing

measures	*reference*
elevation of critical equipment and main entrance	www.healthcaredesignmagazine.com
electrical equipment protection; water resistant materials; water heaters relocation; removable equipment	FEMA (www.fema.gov)
pump in elevator sump; water / sewer lines: backflow protection	FEMA
elevation of critical spaces; electrical equipment: protection	FEMA
hurricane shutters; water well; water resistant materials	FEMA
new (elevated) building for critical mechanical, electrical, plumbing equipment	FEMA
raised floor level; installation of generator	FEMA
relocation to higher ground	FEMA
installation of sumps and pumps; emergency generator	FEMA
elevation of electrical motor control center and power panels; submersible pumps	FEMA
relocation to safer ground	FEMA
extension of manhole collar	FEMA
wet floodproofing	FEMA
elevation of existing houses; relocation to new houses	FEMA
water proofing perimeter wall; storm doors; pump; relocation of electrical equipment; backup cooling water	USACE (www.nolaenvironmental.gov)
floating' concrete foundation, elevation of living space	www.dwell.com/articles/prince-of-tides.html
elevation of all living spaces and road system; storm doors in lower concrete perimeter walls	www.maakruimtevoorklimaat.nl/klimaatadaptatie/helpdesk-waterwo
self closing flood barrier	www.floodbarrier.nl
self closing flood barrier	www.floodbarrier.nl
elevating stretches of highways to prevent flooding	Graaf, R. de, et al. (2008)
elevation of entire building	Graaf, R. de, et al. (2008)
lock for emergency ships in case of disaster	Graaf, R. de, et al. (2008)
constant water supply in case of disaster, emergency cutoff valves; local power generation	www.waterworks.metro.tokyo.jp/eng/supply/05.pdf
dyke protecting hospital; emergency storage; elevation of vital elements	Provincie Utrecht (2010)
elevation of main entrance, vital elements and emergency electricity supply	Provincie Utrecht (2010)
proofing walls; storm doors; placement of valuable items off perimeter walls; water detection system	Provincie Utrecht (2010)
roof space emergency storage	www.bloomberg.com/news/2010-06-27/flood-hit-albertinum-reopens
protective shell in building; storm doors	www.designboom.com/weblog/cat/9/view/6656/tadao-ando-punta-d
600-metre long steel sheet piled wall	
permanent flood barrier (5.5M pound project)	
Demountable flood defenses, flood gates, other flood resistant/resilient/repairable building measures	ARUP - Flood resilience and resistance for critical infrastructure
Demountable flood barriers, flood gates, backflow prevention	Flood Protection Association (2010)
Demountable flood barriers, flood gates, backflow prevention	Flood Protection Association (2010)
Demountable flood barriers, flood gates, backflow prevention	Flood Protection Association (2010)

Appendix 2 - General Design considerations

The findings of the previous chapters are used to set up a general set of design considerations. They are used to describe the considerations for each hotspot type on the next page.

These are used for building the model:

A	This is possible as new and retro-fit solution
B	It is constructed around the external perimeter; the whole group is protected
C	The solution is used on the individual buildings
D	This solution is only applicable for new hotspot buildings
E	Permanent water is needed
F	Connections between buildings possible
G	Access route can be elevated or on higher grounds; the hotspot is always accessible
H	It could double function as a shelter/safe haven
I	The hotspot is easy to enlarge; the hotspot can easily adapt future use
J	Ground displacement is needed
K	It is not easy to enlarge the hotspot without (momentarily) increasing the flood risk
L	Area around the hotspot has to be available to construct the flood proof measure.
M	Point of attention: A (emergency) entrance has to be elevated during a flood.
N	The connections between the buildings are a point of attention. Alternative measures are needed to create connections.
O	Openings such as windows and doors are a point of attention
P	The connection to land is a point of attention; it has to be flexible.
Q	A way of anchoring the construction is needed.
R	Connections with the underground infrastructure have to be flexible
S	Connections between the platforms are needed.
T	The hotspot will function the same during flood as during a normal situation
U	Point of Attention: Build up time and man power needed
V	Space below the hotspot can be used for other functions; for example parking or a playground.
W	The solution can be combined/integrated with the customary fence
X	The hotspot needs a fence or wall for normal security; the solution is additional.
Y	This solution could have large perimeter due to the slope of the dike or mound.
Z	Only in case of individual building or parts of the area clustered together on stilts
A1	Flood hazard from one side and the egress routes are on the opposite side.
B1	No important functions on ground floor.

Table II.1 Comparison alternative concepts Cluster 1: Water treatment, sewage water treatment, energy storage.

General comments	Advantages	Disadvantages
Dry proofing		
- A - C	- This solution has the smallest perimeter (only the facades)	- O - M - N
Floating: one platform		
- D - B - E	- F	- A large floating construction is needed - P - Q - R
Floating: different platforms		
- D - C - E	- Less construction is needed in comparison with one platform	- P - Q - R - S
Mounds		
- B - D	- F - G	- J - K - T - Y
Temporary barrier: External wall		
- A - B	- F	- U - L - X
Temporary barrier: Individual buildings		
- A - C	- I	- N - L - U - Perimeter will be larger than external wall
Permanent barrier: Dike		
- A - B	- F - G	- Y - J - K - L
Permanent barrier: Flood Wall		
- A - B	- Wall can be constructed closer to buildings: it has a smaller perimeter than the a dike - F	- M - W - K - L

Table II.2 Comparison alternative concepts Vehicle cluster: Fire station, police station, bus station.

General comments	Advantages	Disadvantages
Stilts		
- D - Vehicle bay has to be above flood level	- V: carwash or storage (fire/police) or other functions (bus) - T: when V is the case the function will change during flood	- Connection to road network - The internal logistics and emergency response become more difficult (fire)
Mound		
- D	- G - Internal logistics of station are not compromised - T	- J - L
Amphibious: One platform		
- D - B - Station floats only during flood	- In normal situation: functioning normally, only during flood adaptation - T	- Floating access roads needed/connection to higher grounds - R - P - Q
Floating: One platform		
- D - B - E	- T	- P - Q
Floating: Vehicle bay on own platform		
- D - C - E	- Apparatus bay is movable - Can be used by emergencies further away: range of station is bigger (police/fire)	- R - P - Q
Temporary barrier		
- A - B	- G - I - Internal logistics of station are not compromised - T	- L - U - A1
Permanent barrier: Dike		
- A - B	- G - Internal logistics of station are not compromised - T	- Y - J - K - L - Additional area is needed for access ramps
Permanent barrier: Flood Wall		
- A - B	- G - Internal logistics of station are not compromised - T	- L - K - Additional area is needed for access ramps

Table II.3 Train stations: station building and platform

General comments	Advantages	Disadvantages
Stilts - both		
- D	- V - T: when V is the case the function will change during flood)	
Mound - both		
- D	- T	- J - L - K - Y
Permanent barrier: Dike – both together		
- A - B	- G - Internal logistics of station are not compromised - T	- Y - J - K - L - A1 - Additional area is needed for access ramps

Table II.4 Metro station

General comments	Advantages	Disadvantages
Dry proofing		
- A - C	- Especially suited for urban areas - It uses a minimum of land area	- O - If one hotspot fails, the whole network can compromised (underground)
Mound		
- D	- T	- J - L - Y
Temporary barrier: External Wall		
- A - B	-	- L - U
Permanent barrier		
- A - B	- G - T	- Y - J - L

Table II.5 Cluster 3: Hospitals, communication centres, financial buildings

General comments	Advantages	Disadvantages
Wet proofing		
- A - C		- M - B1 - Not all lifts can run to the lower floors; this to ensure use of elevators during flood. - Only part of the data centre is used for storage - Not suitable for hospitals.
Dry proofing		
- A - C		- M - O
Floating		
- D - B	- T	- P - Q - For communication centres the weight is a point of attention - Not possible for financial centres
Amphibious		
- D	- T	- Q - P - For communication centres the weight is a point of attention - Not possible for financial centres
Stilts		
- D	- V	- When it is a large hospital, the space underneath it will become uninviting. This is not the case when building above water. - M
Mounds		
- D	- G - T	- J - L
Temporary barrier		
- A - B	- Less area is needed in comparison with a mound or a dike	- U - M - L - I
Permanent barrier: Dike		
- A - B	- G - T	- L - K - J

Table II.6 Food distribution

General comments	Advantages	Disadvantages
Dry proofing		
- A - C		- M - O
Floating		
- D	- T	- P - Q
Amphibious		
- D	- T	- P - Q
Temporary barrier		
- A - B	- Less area is needed in comparison with a mound or a dike	- U - M - L - I
Permanent barrier: Dike		
- A - B	- G - T	- L - J - K

Table II.7 Airports

General comments	Advantages	Disadvantages
Stilts		
- D	- V - T: when V is the case the function will change during flood	- M - Because of the large area the space underneath is a point of attention
Mound		
- D - C or B	- F - G - T	- J - L - Elevated connection between terminal and airplane needed
Floating: one platform		
- B - D - E	- F - T	- A very large platform is needed - K - P - Q
Amphibious		
- B - D - E	- F - T	- A very large platform is needed - K - P - Q

Temporary barrier		
- A - B	- F	- I - L - X
Permanent barrier: Dike		
- À - B	- F - G - T	- Y - J - K - L - Due to safety measures a large area must be protected
Permanent barrier: External Wall		
- A - B	- The perimeter is smaller than with a dike - F	- K - L - M - W

Table II.8 Electricity substation building

General comments	Advantages	Disadvantages
Dry proofing		
- A - C	- Less area is needed in comparison with other solutions	- M - B1 Ventilation openings have to be positioned above the expected water level.
Stilts		
- D - C - Not possible for underground substation	- V - T: when V is the case the function will change during flood	- M - Stability measures in the stilt construction are a point of attention
Mounds		
- D - C - Not suitable for underground substation	- G	- J - L
Floating		
- D - Not possible for underground substation	- T	- P - Q - R
Amphibious		
- D - Not possible for underground substation	- T	- P - Q - R

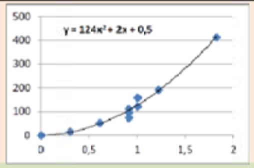
Temporary barrier		
- À - B		- U - M - L
Permanent barrier: Dike		
- A - B	- G	- J - L - Y The substation is fairly small, dike is probably not most suitable
Permanent barrier: External Wall		
- A - B		- L - M

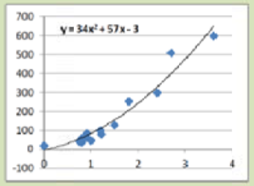
Table II.9 Comparison alternative concepts Electricity surface substation

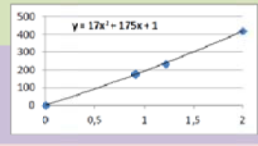
General comments	Advantages	Disadvantages
Stilts		
- D - C	- V - T: when V is the case the function will change during flood	- M
Mound		
- D - C	- G	- J - L
Temporary barrier		
- A - B		- X - L - M
Permanent barrier: Dike		
- A - B	- G - F	- J - K - L
Permanent barrier: External Wall		
- A - B	- F	- L - W - M

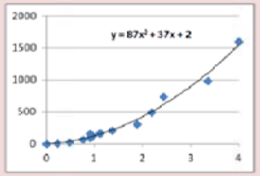
Appendix 3 | Data on flood proofing measures

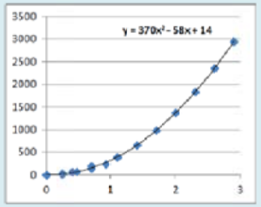
measure	type	data	prot. height (m)	price $	prot. height (m)	€/m	in-/excl.	link
Sandbags	BAG/GABION	$39/linear foot 3' high @ $0.25/bag	0,91		0,91	96		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		h = 1 foot; d = 100 feet	0,3	$600	0,3	15		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		h = 2 foot; d = 100 feet	0,61	$2.100	0,61	52		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		h = 3 foot; d = 100 feet	0,91	$4.500	0,91	111		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		h = 4 foot; d = 100 feet	1,22	$7.800	1,22	192		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		1000 feet	0,91	$30.000	0,91	74	+workers and filling	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		Woven Polypropylene Bags	1,0?	£10.100	1	121		evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC080019_report_sflb.ashx
		UV Stabilised Woven Polypropylene	1,0?	£13.200	1	158		evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC080019_report_sflb.ashx
					0	0		
		multiplication	1,82		1,82	413		
HESCO Bastion concertainer	BAG/GABION	$35/linear foot 3' high	0,91		0,91	86		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		Mil 38: L=30,5m W=1m H=1	0,8	$1.600	0,8	39	+filling	publications.gc.ca/collections/Collection/D82-46-1999E.pdf
		Mil 48: L=30,5m W=1,5m H=1	0,8	$2.400	0,8	59	+filling	publications.gc.ca/collections/Collection/D82-46-1999E.pdf
		$394 per 3'x3'x15' unit; 1000 feet =	0,91	$26.398	0,91	65	+workers and filling	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		P-4315 (4ft x 3ft x 15ft); 5000 feet =	1,22	$163.968	1,22	81	+workers and filling	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		L=100m H=1m	1,00 ?	£ 4.000	1	48		interpolation/multiplication
		1 layer 85 EUR/m (at 90cm)	0,9		0,9	85		interpolation/multiplication
		2 layers 255 EUR/m (1,80 m)	1,8		1,8	255		interpolation/multiplication
		3 layers 510 EUR/m (2,70 m)	2,7		2,7	510		interpolation/multiplication
		1 layer 100 EUR/m (at 1,20 m)	1,2		1,2	100		interpolation/multiplication
		2 layers 300 EUR/m (2,40 m)	2,4		2,4	300		interpolation/multiplication
		3 layers 600 EUR/m (3,60 m)	3,6		3,6	600		interpolation/multiplication
					0	20		
					0	20		
Maccaferri Flex Mac	BAG/GABION	L=30,5m W=1m H=1	0,8	$2.100	0,8	52	+filling	publications.gc.ca/collections/Collection/D82-46-1999E.pdf
Harbeck Big Bag	BAG/GABION	L=100m H=0,75m	0,75 ?	£3.600	0,75	43		evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC080019_report_sflb.ashx
		L=100m H=1,5m	1,50 ?	£10.800	1,5	130		evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC080019_report_sflb.ashx
Big Bags USA	BAG/GABION	$395 per unit (3' 3' 15')				70	?	bigbagsusa.com/cost%20and%20savings.htm
Rapid Deployment Flood Wall (F	BAG/GABION	$159/linear foot 3' high	0,91		0,91	391		oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		$95/4'x4'x8" unit; 1000 feet =	0,91	$151.525	0,91	373	+workers and filling	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		4ft x 4 ft x 8 in units; 5000 ft =	1,22	$826.500	1,22	407	+workers and filling	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		1,000-foot wall, 4' h, 1,740 RDFW units	1,22	$194.985	1,22	480		www.geocellsystems.com/brochures/pdfs/True_Cost_of_Sandbags.pdf
Portadam	FLEX FRAME	$73/linear foot 3' high	0,91		0,91	180	(hire?)	oregonapwa.org/conference/spring09/Presentations/Flood%20Fight%20Methods%20Technologies.pdf
		$71,30/linear foot 3' high; 1000 ft =	0,91	$71.300	0,91	175	(hire?) +workers	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		4ft frames, liner, hardware; 5000 ft =	1,22	$473.595	1,22	233	(hire?) +workers	chl.erdc.usace.army.mil/Media/6/8/1/ffs_ProductCost.pdf
		£ 350 per meter for l=100 m, up to 2m	2	£ 350/m	2	420	(hire)	bfw.ac.at/rue_documents/pjr_310_413.pdf
					0	0		
					0	0		
Aqua Barrier	GEOTEXTILE TUBE	double baffle L=30,5m W=3,2m H=1,22	0,91	$6.800	0,91	167		publications.gc.ca/collections/Collection/D82-46-1999E.pdf
		single baffle L=30,5m W=3,2m H=1,22	0,91	$6.400	0,91	157		publications.gc.ca/collections/Collection/D82-46-1999E.pdf
Aqua Dam (AD04)	GEOTEXTILE TUBE	L=30,5m W=3,6m H=1,2	0,96	$5.200	0,96	128		publications.gc.ca/collections/Collection/D82-46-1999E.pdf
		h=1 ft; 9 inch protected - per ft:	0,23	$4	0,23	9		www.aquadam.net/Pricing/standard_pricing.html
		h=2 ft; 19 inch protected - per ft:	0,48	$10	0,48	25		www.aquadam.net/Pricing/standard_pricing.html
		h=3 ft; 30 inch protected - per ft:	0,76	$28	0,76	69		www.aquadam.net/Pricing/standard_pricing.html
		h=4 ft; 38 inch protected - per ft:	0,97	$48	0,97	118		www.aquadam.net/Pricing/standard_pricing.html
		h=5 ft; 44 inch protected - per ft:	1,12	$69	1,12	169		www.aquadam.net/Pricing/standard_pricing.html
		h=6 ft; 54 inch protected - per ft:	1,37	$85	1,37	209		www.aquadam.net/Pricing/standard_pricing.html
		h=8 ft; 74 inch protected - per ft:	1,88	$125	1,88	308		www.aquadam.net/Pricing/standard_pricing.html
		h=10 ft; 86 inch protected - per ft:	2,18	$200	2,18	492		www.aquadam.net/Pricing/standard_pricing.html
		h=12 ft; 96 inch protected - per ft:	2,44	$300	2,44	738		www.aquadam.net/Pricing/standard_pricing.html
		h=16 ft; 132 inch protected - per ft:	3,35	$400	3,35	984		www.aquadam.net/Pricing/standard_pricing.html
					0,00	0		
					4,00	1600		
Water Structures (Aqua Dam W	GEOTEXTILE TUBE	L=30,5m W=3,05m H=1,22	0,91	$3.900	0,91	96		publications.gc.ca/collections/Collection/D82-46-1999E.pdf
Clement (3 levels)	TUBE	L=30,5m	0,91	$5k-9k	0,91	150-225		publications.gc.ca/collections/Collection/D82-46-1999E.pdf
NOAQ Tube Wall	TUBE (air)	L=100m H=1m	1,00 ?	£ 31800	1	381,6		evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC080019_report_sflb.ashx
Tiger Dams	TUBE	L=100m H=1m	1,00 ?	£ 29000	1	348		evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC080019_report_sflb.ashx
			0,4		0,4	65		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			0,7		0,7	196		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			1,1		1,1	393		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			1,4		1,4	655		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			1,7		1,7	982		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			2		2	1375		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			2,3		2,3	1833		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			2,6		2,6	2356		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			2,9		2,9	2945		rickersmith.wordpress.com/2009/04/15/petite-woman-from-nevada-shows-sturdy-public-works-crews-how-simple-it-is-to-set-up-tiger-dam-tempor
			0		0	0		
HydraBarrier	TUBE				0,25	24		www.hydrabarrier.com/order_supreme.htm
					0,475	72		www.hydrabarrier.com/order_supreme.htm
					0,7	144		www.hydrabarrier.com/order_supreme.htm
					0,925	240		www.hydrabarrier.com/order_supreme.htm











Appendix 4 | Flood data

7.5 Great New Orleans Flood, 2005 – Mid-City

Figure IV.1 New Orleans flood overview, Mid-City.

7.5.1 General information

Description of events

The day before Katrina hit New Orleans, high tides created by the storm's outer bands engulfed low-lying wetlands and communities outside the levee system (Lake Borgne, Lake Pontchartrain). In the early morning of August 29th, rising water in the Industrial Canal leaked through damaged gates, flooding the near neighbourhood. Then the first east line of defence (MR-GO levee) crumbled and Lake Borgne advanced into wetlands. Soon all the levees protecting East New Orleans were overtopped and breached in succession. Levee wall panels on the west side of the Industrial Canal breached, then the ones on the east side. Lake Borgne advanced to St. Bernard Parish second line of defence, filling all the area between the levee and the Mississippi River. In the end of August 29th the hurricane was moving away, but Lake Pontchartrain remained swollen, while water continued bleeding into the city until the lake level equalized with the floodwaters (1st September). (NOLA, 2006)

Duration

The majority of the city remained under water for days, in many places for weeks. In total the flood lasted for fifty-seven days (Blakely E.J., 2011).

Causes

- Tremendous rainfall preceded the storm surge arrival;
- levees failure;
- land below sea level.

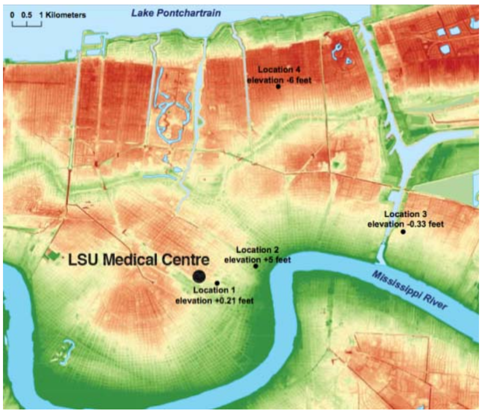
7.5.2 Hotspot building: LSU Medical Center University Hospital, New Orleans

The hotspot building chosen is the LSU Medical Center University Hospital in New Orleans. In consequence of the great flood of 2005, the building underwent severe flood damage (Louisiana Medical News, 2008) and was reopened only in November 2006 (Medical Center of Louisiana at New Orleans, 2007). LSU Health Sciences Center regularly updates about hurricane Katrina recovery actions and works (facilities updates available on the website www.lsuhsc.edu) describing the damages and the work that was required to restore LSUHSC-NO campus to full operation and the main flood issues in this area.

Figure IV.2 Satellite view of the hospital (Google Maps, 2012).

Figure IV.3 Bird's eye view of the hospital (Bing Maps, 2012).

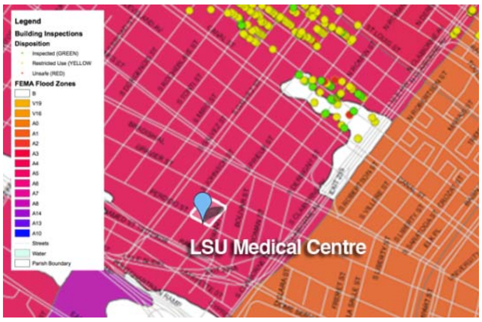
Flood data



Topography of New Orleans

As shown from the map, the LSU Medical Center University Hospital is situated in an area between -1 and 0 meters below the sea level.

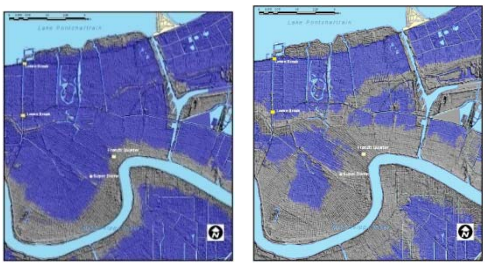
Elevation map of New Orleans (GROSSI, P. and MUIR-WOOD, R., 2006).



FEMA flood zone classification

According to FEMA flood zones classification, the area is situated in flood zone A, which means that the area is at high risk of flooding (inundated by a T= 100 year flooding). As shown from the satellite map on the right, the Medical Centre is very close to the Super Dome (the big circular building near the highway intersection).

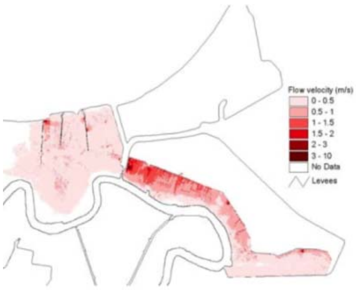
FEMA flood zones of the area (FEMA 2005)



Flood depth maps

The first map on the left shows the maximum flood height reached on the 30th August 2005 (+3 feet above sea level, USGS data). The second map shows the flood level at sea level. Considering that the area is situated between -1 and 0 meters below the sea level, the flood depth was between 1m and 2m.

On the left: +3 feet above sea level flood height. *On the right*: flood level at sea level (Chubb Custom Cartography, 2006).



Flow velocity

From simulations, the flow velocity in the area was estimated between 0- 0.5 m/s (slow).

Overview of flow velocity and arrival time of the floodwater after breaching from flood simulations (Jonkman, S.N. et al., 2008).

Hotspot issues

- Most of the key electrical, mechanical and communications equipment situated on the basements and on 1st floor was impacted by the waters;
- Refrigeration was lost as soon as the generators ran out of fuel;
- Heat and humidity affected more sensitive items in upper floors;
- Perishable items stored in refrigerators, freezers, etc. spoiled.

(Smith, R., 2005)

Flood characteristics overview

Flood extent	80% of New Orleans was flooded (The Guardian, 2011).
Frequency	1 in 100 year flood
Duration	weeks (total flood duration: 57 days)
Rate of rise	flood arrival time in the area: between 20-35 hours
Flow velocity	between 0 – 0,5 m/s
Flood depth	between 1 and 2 meters

SOURCES: The Guardian, 2011; Jonkman, S.N. et al., 2008; FEMA, 2005.

7.6 Great New Orleans Flood, 2005 – Uptown

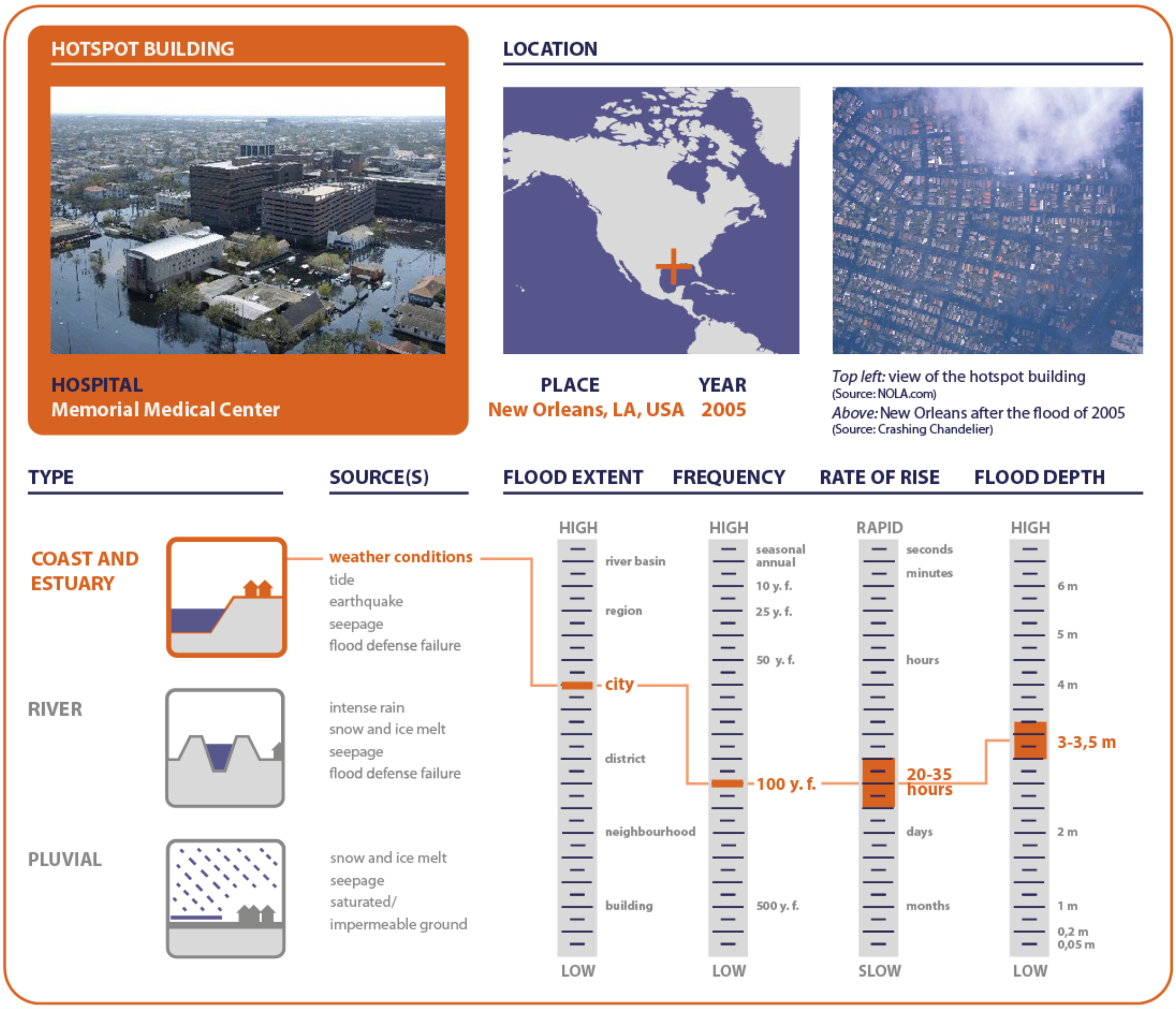


Figure IV.4 New Orleans flood overview, Uptown.

7.6.1 General information

Description of events

See the previous case study.

Duration

See the previous case study.

Causes

See the previous case study.

7.6.2 Hotspot building: Memorial Medical Center, New Orleans

The Memorial Medical Center, today known as Ochsner Baptist Medical Center, was founded in 1926 by the Southern Baptist Convention. This hotspot building is situated in Uptown New Orleans, in an area that is around 1 meter below sea level. In the aftermath of Hurricane Katrina in 2005 the hospital was submerged in 3-3.5 meters of water. "*About 2,000 patients, medical workers and other staff were stranded at Memorial. Officials eventually recovered 45 bodies from Memorial, many of whom were said to have died from dehydration during the four-day wait for rescuers*" (Foster, M., 2011).

Figure IV.5 Aerial view of the Memorial Medical Center (Bing Maps, 1012).

Figure IV.6 Picture of the hospital (Wikipedia, 2006).

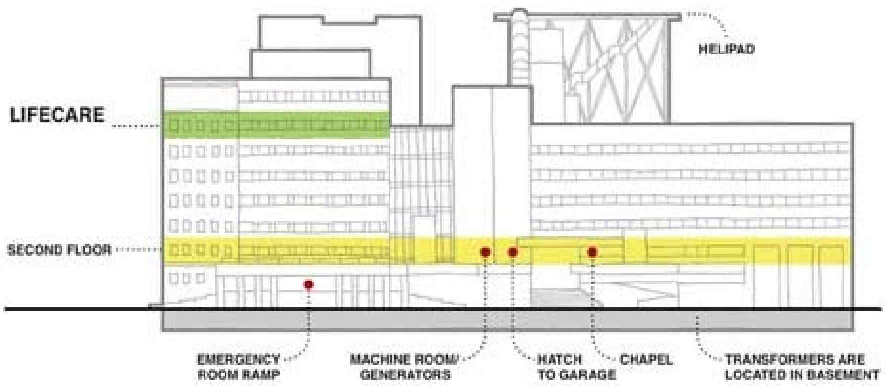
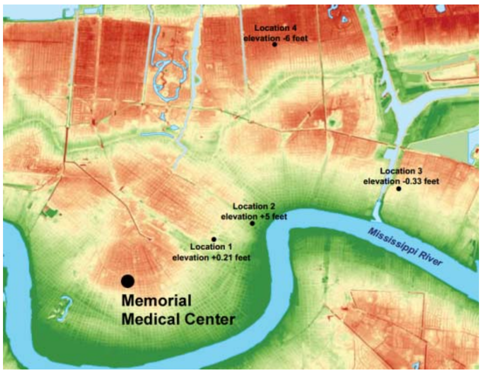


Figure IV.7 Hospital section (Fink, S., 2009).

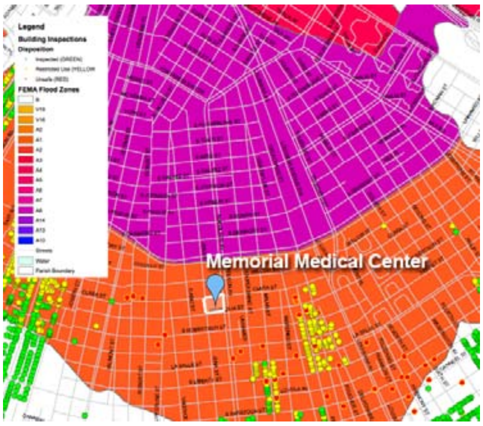
Flood data



Topography of New Orleans

As shown from the map, the Memorial Medical Center is situated in an area 1 meter below the sea level.

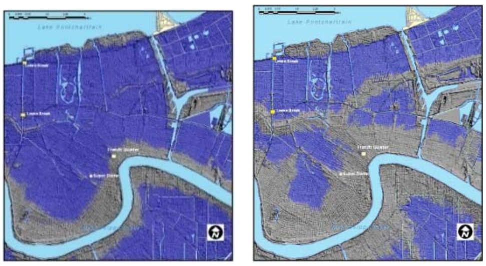
Elevation map of New Orleans (GROSSI, P. and MUIR-WOOD, R., 2006).



FEMA flood zone classification

According to FEMA flood zones classification, the area is situated in flood zone A, which means that the area is at high risk of flooding (inundated by a T= 100 year flooding).

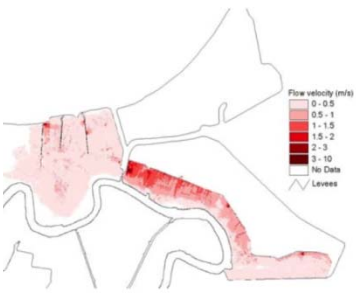
FEMA flood zones of the area (FEMA 2005)



Flood depth maps

The first map on the left shows the maximum flood height reached on the 30th August 2005 (+3 feet above sea level, USGS data). According to sources (Foster, M., 2011) the hospital was submerged in 3-3.5 meters of water.

On the left: +3 feet above sea level flood height. *On the right*: flood level at sea level (Chubb Custom Cartography, 2006).



Flow velocity

From simulations, the flow velocity in the area was estimated between 0- 0.5 m/s (slow).

Overview of flow velocity and arrival time of the floodwater after breaching from flood simulations (Jonkman, S.N. et al., 2008).

Hotspot’s issues

- Emergency generators failed because they were located in the hospital's flooded basement;
- Communications failed;
- Temperatures inside the building soared above 100 degrees (38 °C);
- The building was contaminated with sewage and chemicals;
- Backed up toilets and no running water;
- Administrators were worried that intruders might loot the hospital for drugs and valuables.

(Foster, M., 2011; Creelman, K., 2009; Roberson, J., 2011)

Flood characteristics overview

Flood extent	80% of New Orleans was flooded (The Guardian, 2011).
Frequency	1 in 100 year flood
Duration	weeks (total flood duration: 57 days)
Rate of rise	flood arrival time in the area: between 20-35 hours
Flow velocity	between 0 – 0,5 m/s
Flood depth	between 3 and 3,5 meters

SOURCES: The Guardian, 2011; Jonkman, S.N. et al., 2008; Foster, M., 2011.

7.7 Venice "high water" phenomenon

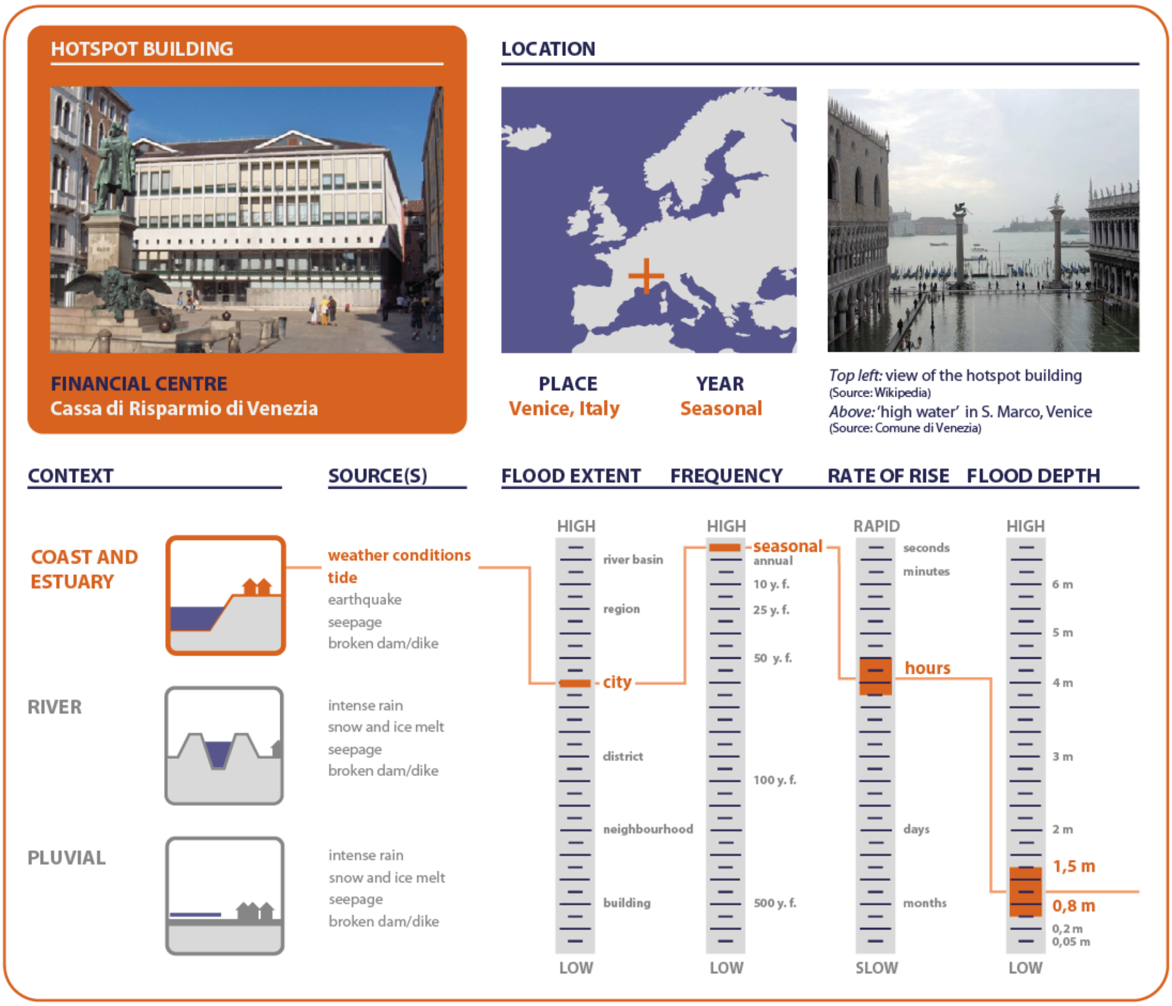


Figure IV.8 Venice "high water" phenomenon overview.

7.7.1 General information

Description of events

The term "Acqua alta" is used in Venice to define exceptional tide peaks (80 cm above the mareographic zero reference point of Punta della Salute) that occur periodically in the northern part of the Adriatic Sea. The high tide may cause flooding in many areas around the northern Adriatic, especially in the Venice Lagoon, where the astronomical tides are amplified by seasonal winds (Bora and Scirocco) and by the atmospheric pressure, raising the water level and causing frequent floods in the city of Venice. In the last century the number of these events is increased, due to lagoon morphology modifications, sea level rise and subsidence. To ensure the protection of Venice from medium-high water, the Ministry of Infrastructure and Consorzio Venezia Nuova have initiated a general plan of action for the safeguard of Venice, which includes the construction of hollow gates at the inlets (MOSE) to isolate temporally the Lagoon from the Adriatic Sea during the high tides.

Duration

Venice is exposed to flooding tides. High waters occur mainly in autumn and winter, usually flooding large part of the city for some hours (2-5 hours, depending on their height relative to the mareographic zero).

Causes

- Astronomical tides amplified by winds and atmospheric pressure;
- Land subsidence;
- Lagoon morphology modifications;
- Sea level rise.

7.7.2 Hotspot building: Cassa di Risparmio di Venezia (Palazzo Nervi – Scattolin)

Palazzo Nervi-Scattolin, situated in Campo Manin, is the base of Venice Savings Bank headquarters. The building replaced a previous one, dated back to 1883, and was designed by the engineer Pier Luigi Nervi and the architect Angelo Scattolin in 1970.

Figure IV.9 Satellite views of the building (Bing Maps, 2012).

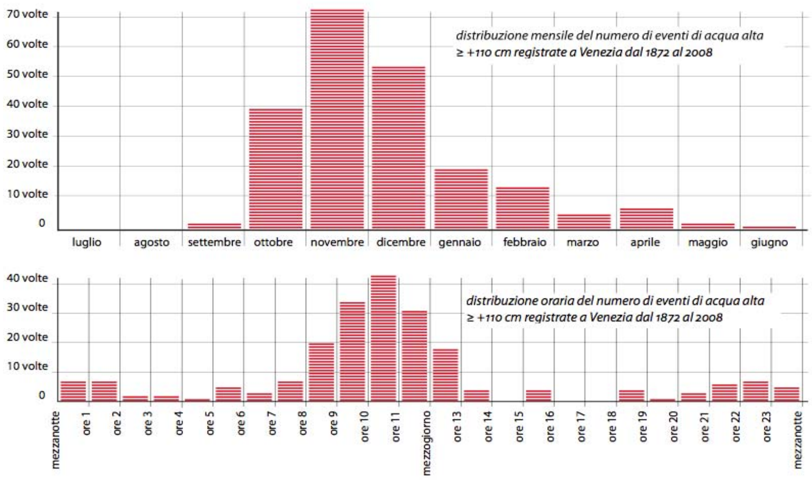
Figure IV.10 View of the building from Campo Manin (Wikipedia.org, 2011).

Flood data

Elevation map

The considered building is situated in S. Marco district, one of the lowest and most vulnerable areas to flooding.

Elevation map and satellite view of the area (INSULA SPA, 2011; Google Maps).



High water trend

The graphs show the high water trend during a year and during a day, obtained from data registered in Venice from 1872 to 2008.

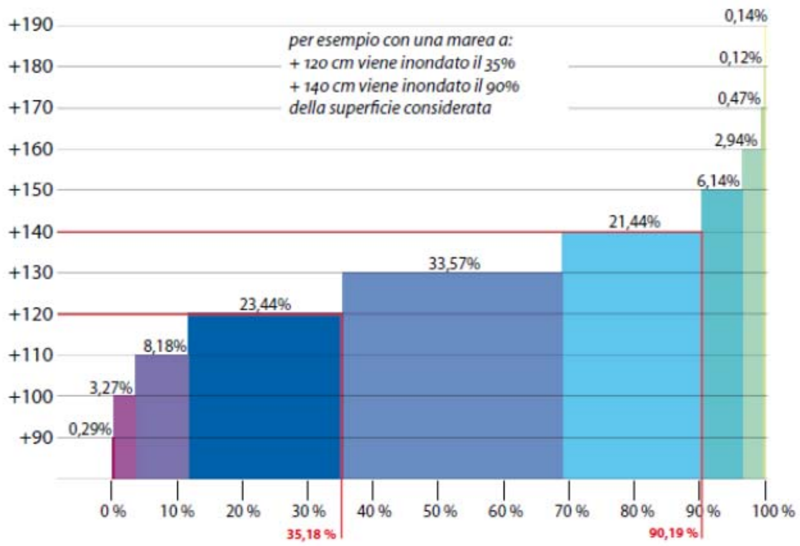
High water trend (numbers of events higher or equal to 110 cm) during a year and during one day. Data from 1872 to 2008 (Comune di Venezia, 2009).

livelli di marea	permanenza ore/min	numero casi	durata media ore / min	frequenza casi / anno
≥ 190 cm	0 10	1	0 10	1 / 44
≥ 180 cm	1 30	1	1 30	1 / 44
≥ 170 cm	5 50	1	5 50	1 / 44
≥ 160 cm	9 20	2	4 40	1 / 22
≥ 150 cm	17 40	4	4 25	1 / 11
≥ 140 cm	33 45	11	3 04	1 / 4
≥ 130 cm	73 35	30	2 27	1 / 1.5
≥ 120 cm	175 15	70	2 30	1.6
≥ 110 cm	420 10	170	2 28	3.9
≥ 100 cm	995 35	420	2 22	9.5
≥ 90 cm	2471 15	985	2 31	22.4
≥ 80 cm	6288 45	2452	2 34	55.7
≥ 70 cm	15741 55	5847	2 42	132.9
≥ 60 cm	33633 00	11470	3 05	260.7

Tide permanence

The chart shows the tide permanence and number of events from 1966 to 2009. Data in the last two columns refer to the average duration of a specific tide level phenomenon and its annual frequency.

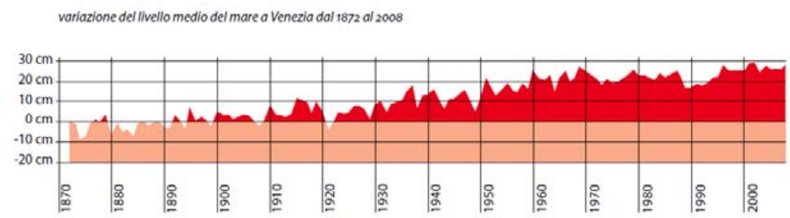
Tide permanence (Comune di Venezia, 2010).



Flood extent

From the altimetry data is possible to calculate the percentage of the city area that is flooded for a specific tide level. With a water level of 120cm the 35% of Venice is flooded, while with a 140cm tide the value reaches the 90% (Tronchetto, train station, Giudecca island and S. Elena island excluded).

Graph showing the percentage of the flooded area for each tide level (Comune di Venezia, 2009).



High water events frequency

As from the charts, the number of medium and high tides (90-120cm) has increased in the past 60 years. IPCC scenarios forecast, with large margins of uncertainty, that the frequency of high water will vary from 20 to 250 in one year.

Graphs showing the average sea level and the annual distribution of the tides above 110 cm in Venice from 1972 to 2008 (COMUNE DI VENEZIA, 2009).

Hotspot's issues

- Pedestrian circulation inconvenience, solved partially using temporary wooden walkways (passerelle);
- Damages to the groundfloor of the building;
- Damages to economical activity.

(Comune di Venezia, 2009)

Flood characteristics overview

Flood extent	with a water level of 120cm the 35% of Venice is flooded, while with a 140cm tide the value reaches the 90%
Frequency	flooding in general occurs on average 4 times per year (T=0.25 years) (Estimated flood frequency of a 1,5m flood is 1 in 11 years)
Duration	from 2 to 6 hours (average)
Rate of rise	the period from the lower tide peak to the higher is 6 hours. Because severity is influenced by wind and rain it is hard to predict. A value of 3h has been used.
Flow velocity	very low
Flood depth	between 0,8 – 1,5m (for 1/11 y flood)

SOURCES: INSULA SPA, 2011; Comune di Venezia, 2009-2010.

7.8 Flash flood in Warsaw, Poland (2010)

Figure IV.11 Warsaw flood overview.

7.8.1 General information

Description of events

Precipitation exceeded 200 mm in certain places. This led to a flood wave in the Upper Vistula and Odra Basin on 15-17 May 2010. Rapid growth of the water level in the Upper Vistula and Odra tributaries characterized the first phase. After a couple of days high water levels also occurred on the Vistula and Odra rivers. The flood moved to the Northern part of Poland in the third week of May. Flood embankments were destroyed due to high water levels and high flow velocities. A number of cities were damaged and several thousand people were forced to evacuate.

The second exceptional rain event started on 1 June to 3 June 2010 – the total precipitation on the Upper Vistula basin was higher than 100mm. Because the river basin was still largely saturated, the water levels rose faster than during the first rain event. Flood damage was once again recorded. The two flood waves caused enormous damage to the population, environment, infrastructure and industry. Rescue operations and humanitarian assistance for the population were conducted in approximately 1350 places. Due to the floods there were 29 victims" (European Community Civil Protection Mechanism - Operations Field Reporting Tool, 2010).

Duration

Some days before the severe storm that hit Warsaw on the 2nd of July, some metro stations in Warsaw were flooded because of the intense rain. In Warsaw, flooding occurred for some hours.

Causes

Tremendous rainfall caused a flash flood in the city of Warsaw.

7.8.2 Hotspot building: metro station Wawrzyszew

Bad weather conditions were affecting Poland since the end of May 2010. Some days before the severe storm that hit Warsaw on the 2nd of July, some metro stations in Warsaw were flooded because of the intense rain. One of them, Wawrzyszew metro station, was still operational after the water flew into the station, but firemen had to pump out the water from it for several minutes (TVNWarszawa.pl. 2010).

Figure IV.12 Satellite image of the area (Google Maps, 2012).

Figure IV.13 View of one of the metro station access buildings (Panoramio.com, 2009).

Hotspot's issues

- Water entered the metro station and some tracks and platform were inundated
- One entrance was closed to let the firemen pump out the water from the station.

Flood characteristics overview

Flood extent	city of Warsaw and other parts of the country
Frequency	nearly once a year, during severe storms
Duration	some hours
Rate of rise	two hours
Flow velocity	between 0 – 0,5 m/s
Flood depth	between 0 and 0,3 meters

SOURCES: TVN24.pl, 2010; TVNWarszawa.PL, 2010; Lupikasza, E. and Bielec-Bakowska, Z., 2009.

7.9 UK floods in summer 2007

Figure IV.14 Walham (Gloucester) flood overview.

7.9.1 General information

Description of events

In May 2007, exceptionally wet weather began and continued throughout the summer, with record-breaking rainfall totals in June and July. Two exceptionally intense rainstorms on June 25 and July 20 caused severe flash flooding in many areas across the U.K. In both events the flooding had three relatively distinct phases as summarized by Centre for Ecology and Hydrology (CEH):

- Localized flash flooding with surface runoff very common (even in permeable catchments) and landslides;
- Extremely high flows in small responsive catchments (e.g. the River Teme);
- Subsequently extensive and long duration floodplain inundations as the runoff concentrated in the major river basins (Trent, Great Ouse, Thames) (Lower Severn Community Flood Information Network, 2011).

As a result of the floods several critical public utilities were at risk. Flooded Tewkesbury's Mythe Water Treatment Works left 140,000 people without drinking water for up to 17 days and 42,000 homes in Gloucestershire were left without electricity after a major electricity substation in Castle Meads was turned off due to the flood (Environment Agency, 2009). Elsewhere, Neepsend (Sheffield) electricity sub-station was shut down with a loss of power to 40,000 people and there were further power failures in Hillsborough. (Pitt, M. 2007). Walham electricity substation in Gloucester supplying half a million people narrowly escaped flooding with the help of military and civil emergency services and Osney Mead substation, which supplies power to Oxford, was threatened but did not flood. (Edwards, R., 2007; Pitt, M. 2007)

Duration

In May 2007 the wet weather began and continued throughout the summer, with the most intense rainstorms on June 25 and July 20. Floods lasted one to several days (Peck, S. et al., 2007).

Causes

The cause of the UK summer floods of 2007 have been explained in great detail in the 2007 RMS report “U.K. Summer 2007 Floods”. May to July 2007 was the wettest summer in England and Wales ever recorded (since 1766). During the above average rainfall in May, soil moisture levels increased. An additional consequence was that the amount of sunshine was below average, which greatly reduced evaporation rates. Extreme rainfall events on June 25th and July 20th, were caused by stationary or slow-moving low pressure systems, influenced by unusual summer cyclonic activity (Blackburn, M. et al., 2008). Many locations recorded well above (and up to four times) the monthly average of rainfall accumulation in a single day (Stuart-Menteth, A., 2007).

7.9.2 Hotspot building: Walham substation, Walham

The hotspot building chosen is a substation in Walham, near Gloucester, United Kingdom. This substation “supplies electricity from the National Grid to 600,000 people in Gloucestershire, effectively the entire County, as well as to areas in the South Midlands and South Wales. Alternative supplies could have been found for South Wales but not for Gloucestershire” (Gloucestershire Constabulary, 2007). On July 22nd 2007 because of the intense rain, the River Severn flooded unexpectedly this area, which usually is not under threat. Emergency barriers reinforced by sandbags were constructed to protect the electricity substation, using civil and military personnel.

Figure IV.15 Aerial view of the substation after the flood (This is London, 2007)

Figure IV.16 View of the 275kV busbars (Flickr.com, 2009).

Flood data

Flood frequency

The UK 2007 floods were extreme events with an estimated return probability of about 1 in 200 years (Environment Agency, 2010).

Flood level

According to the municipality of Gloucestershire flood levels reached up to 7 feet (over 2 meters) in some vulnerable areas (Gloucestershire County Council, 2012). In a channel 4 News interview one of the people on-site reported that the flood height was up to 2 or 3 feet (60 to 90 cm) (Channel 4, 2007). Reports from National Grid's site staff indicated that the floodwaters inside a similar facility at Neepsend had reached a depth of 1.2-1.5 m (National Grid, 2007)

Flow velocity

YSI Hydrodata recorded in-water velocities of over 2.5m/s and flow rates of 258 cubic meters/sec, during the UK floods of 2007 (YSI Hydrodata, 2009). At the Walham substation rates were presumably lower. The HFIDTC report (2008) states that "floodwater was not very deep or fast flowing", but that there was still a big risk for personnel if flood barriers would suddenly collapse (MCMaster, R. et al., 2008).

Risk

The potential risk has been evaluated in a memorandum of the EFRA (2007) (Gloucestershire Constabulary, 2007) "loss of electricity would have meant that households could not have boiled water, cooked food, including baby food, and provide basic heating. Furthermore, essential services within the County would have been reliant on generators and sewage would not have been pumped. Street and domestic lighting would have been lost for the duration of the emergency. It was anticipated that the loss of electricity could be for up to 3 weeks."

Hotspot's issues

The main threat for the substation was a riverine (fluvial) flood, resulting from accumulated rainwater runoff, in combination with the regular tidal surges of the Severn River (MCMaster, R. et al., 2008). The most vital part of the substation was the switching room. EFRA 2007 notes that "the critical risk to the sub-station came from an internal threat from rising flood water which came through the ground as a result of saturation and the rising water table, and not as a result of the external Hesco barriers being overwhelmed by flood water" (Gloucestershire Constabulary, 2007). Hesco emergency barriers were erected, provided from the Bristol / Bath area by the Environment Agency (EA) and reinforced by sandbags. A major pumping operation was undertaken, aimed to protect the switching gear from the rising water, using nationally supplied equipment.

Flood characteristics overview

Flood extent	large parts of North and West England, Wales and Northern Ireland were flooded
Frequency	1 in 200 year flood
Duration	one to several days (total flood period over 2 months)
Rate of rise	local pluvial flash floods followed by slower fluvial floods
Flow velocity	between 0 – 2,5 m/s, at Walham presumably lower than 2,5m/s
Flood depth	between 1 and 2 meters.

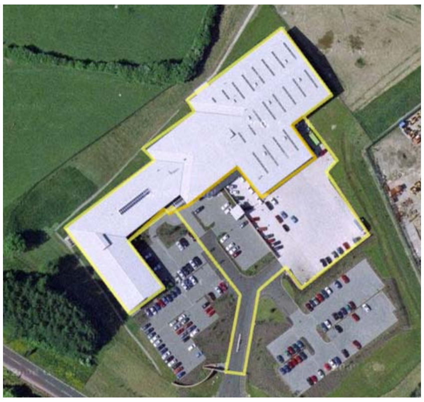
SOURCES: Gloucestershire County Council, 2012; YSI Hydrodata, 2009; Environment Agency, 2010; PECK, S. et al., 2007.

Appendix 5 | Functional requirements

7.10 Fire stations

One of the most essential aspects of the fire station functioning is the accessibility of fire trucks. For this reason it is important to provide the necessary space to access and manoeuvre the fire trucks. The data therefore refer not only to the building, but also to the open area that includes manoeuvre spaces and accesses.

Table V.1 Fire stations examples



South Wales Fire & rescue service

Llantrisant, United Kingdom

	area	perimeter
site	9840 m^2	630 m
building(s)	5780 m^2	460 m

Image source: Google Maps (coord. 51.553, -3.397)

Vrijwillige Brandweer Schalkwijk en Tull en ‘t wall

Houten, the Netherlands

	area	perimeter
site	3750 m^2	260 m
building(s)	1080 m^2	140 m

Images sources: Google Maps, Joostdevree.nl, 2011 (coord. 52.023, 5.159)

Parc de Bombers Eixample

Barcelona, Spain

	area	perimeter
site	4330 m^2	290 m
building(s)	4330 m^2	290 m

Images sources: Google Maps, Bing Maps (coord. 41.388, 2.153)

Freiwillige Feuerwehr

Thondorf, Austria

	area	perimeter
site	730 m^2	130 m
building(s)	320 m^2	80 m

Image source: Google Maps (coord. 47.012, 15.475)

Stasjon 1 – Briskeby brannstasjon

Oslo, Norway

	area	perimeter
site	3070 m^2	240 m
building(s)	790 m^2	190 m

Images sources: Google Maps, Wikipedia.org (coord. 59.922, 10.716)

AVERAGE

	area	perimeter
site	**4340 m^2**	**310 m**
building(s)	**2460 m^2**	**230 m**

7.11 Bus stations

The previous chapter demonstrated that the most important components of bus stations are the platforms. For this reason the data about bus stations include platforms, accesses, manoeuvre and stop areas.

Table V.2 Bus stations examples

Bussterminalen

Oslo, Norway

	area	perimeter
site	6480 m^2	750 m

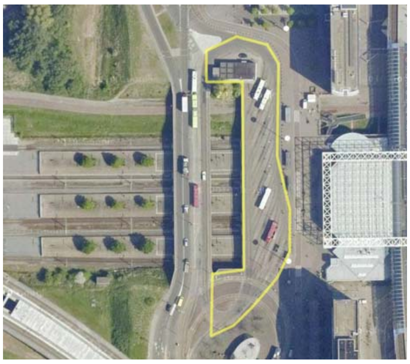
Image source: Google Maps (coord. 59.911, 10.758)

Florenc Bus Terminal

Prague, Czech Republic

	area	perimeter
site	14910 m^2	690 m

Images sources: Google Maps, panoramio.com
(coord. 50.089, 14.441)

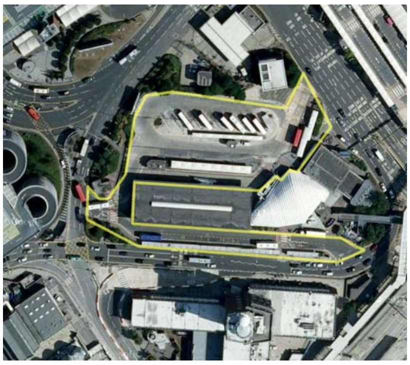


Bus Station Sloterdijk

Amsterdam, The Netherlands

	area	perimeter
site	3770 m^2	400 m

Image source: Google Maps (coord. 52.389, 4.836)



Heathrow Central Bus Station

London. United Kingdom

	area	perimeter
site	6810 m^2	660 m

Images sources: Google Maps, Wikipedia.org, 2011e (coord. 51.471, -0.453)

Leeds City Bus Station

Leeds, United Kingdom

	area	perimeter
site	10510 m^2	740 m

Images sources: Google Maps, flickr.com (coord. 53.797, -1.535)

AVERAGE

	area	perimeter
site	**8500 m^2**	**650 m**

7.12 Police stations

For the data analysis of police stations examples were collected from the Netherlands, Poland, Norway and the UK. Table 5.3 presents an overview.

Table V.3 Police stations examples

Hoofdbureau van Politie

Rotterdam, The Netherlands

	area	perimeter
site	4190 m^2	440 m
building(s)	4190 m^2	440 m

Images sources: Google Maps, www.architectuurgids.nl
(coord. 51.923, 4.480)

Komenda Stołeczna Policji

Warsaw, Poland

	area	perimeter
site	6710 m^2	370 m
building(s)	6710 m^2	370 m

Images sources: Google Maps, Wikipedia.org, 2011
(coord. 52.246, 20.998)

Politistasjon

Hamar, Norway

	area	perimeter
site	2140 m^2	200 m
building(s)	2140 m^2	200 m

Images sources: Google Maps, www10.aeccafe.com
(coord. 60.795, 11.094)

Police Station Liverpool

Liverpool, United Kingdom

	area	perimeter
site	1300 m^2	150 m
building(s)	1300 m^2	150 m

Images sources: Google Maps, Google Streetview
(coord. 53.383, -2.907)

Police Station Boxtel

Boxtel, The Netherlands

	area	perimeter
site	900 m^2	190 m
building(s)	900 m^2	190 m

Images sources: Google Maps, www.e-architect.co.uk
(coord. 51.602, 5.322)

AVERAGE

	area	perimeter
site	**3080 m^2**	**270 m**
building(s)	**3080 m^2**	**270 m**

7.13 Metro stations

For the data analysis of metro stations examples were collected from the Netherlands, Poland, Norway and other countries. Table 5.4presents an overview.

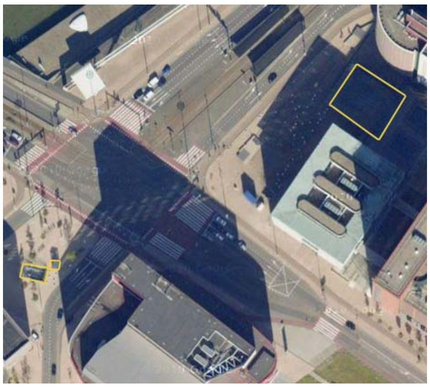
Table V.4 Metro stations examples

Wawrzyszew Metro Station

Warsaw, Poland

	area	perimeter
site	1610 m^2	260 m
building(s)	1030 m^2	140 m
	540 m^2	90 m
	50 m^2	30 m

Images sources: Google Maps, Panoramio.com
(coord. 52.286, 20.939)



Wilhelminaplein Metro Station

Rotterdam, The Netherlands

	area	perimeter
site	520 m^2	140 m
building(s)	70 m^2	50 m
	440 m^2	80 m

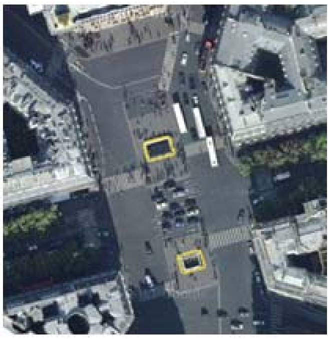
Images sources: Google Maps, Google Streetview
(coord. 51.907, 4.490)

Plac Wilsona Metro Station

Warsaw, Poland

	area	perimeter
site	430 m^2	110 m
building(s)	210 m^2	60 m
	210 m^2	60 m

Images sources: Google Maps, openbuildings.com
(coord. 52.268, 20.985)

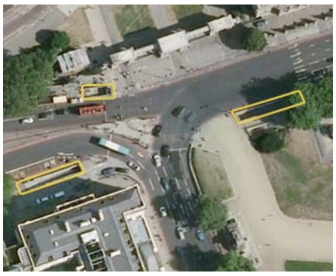


Opéra Metro Station

Paris, France

	area	perimeter
site	140 m^2	70 m
building(s)	60 m^2	30 m
	80 m^2	40 m

Images sources: Google Maps, Google Streetview
(coord. 48.870, 2.332)



Hyde Park Corner Metro Station

London, United Kingdom

	area	perimeter
site	210 m^2	130 m
building(s)	40 m^2	30 m
	80 m^2	50 m
	100 m^2	60 m

Image source: Google Maps, Google Streetview
(coord. 51.503, -0.1512)

Cavour Metro Station

Rome, Italy

	area	perimeter
site	160 m^2	80 m
building(s)	60 m^2	40 m
	100 m^2	40 m

Images sources: Google Maps, www.flickr.com
(coord. 41.894, 12.493)

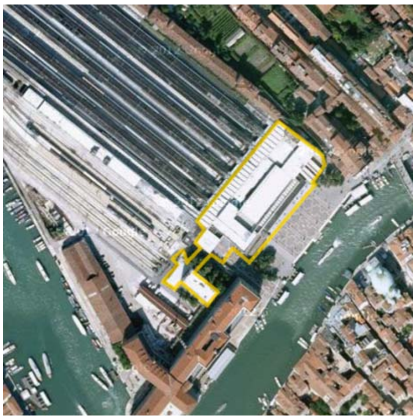
AVERAGE

	area	perimeter
site	**510 m^2**	**130 m**
building(s)	**220 m^2**	**60 m**

7.14 Train stations

Train stations from Italy, Czech Republic and three other countries were used to collect data for this type of hotspot. Table 5.5 presents an overview.

Table V.5 Train stations examples

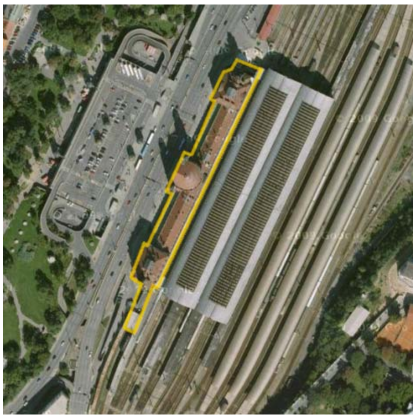


Venezia S. Lucia

Venice, Italy

	area	perimeter
site	8940 m^2	570 m
building(s)	8940 m^2	570 m

Images sources: Google Maps, cruises.about.com
(coord. 45.440, 12.320)



Praha Hlavní nádraží

Prague, Czech Republic

	area	perimeter
site	6800 m^2	620 m
building(s)	6800 m^2	620 m

Images sources: Google Maps, 3.bp.blogspot.com
(coord. 50.083, 14.435)

Amsterdam Centraal

Amsterdam, The Netherlands

	area	perimeter
site	5400 m^2	440 m
building(s)	5400 m^2	440 m

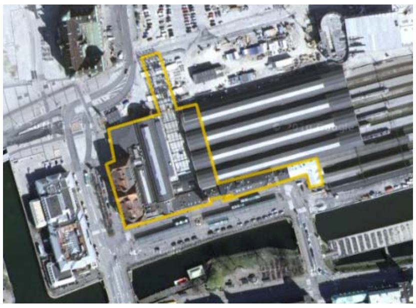
Images sources: Google Maps, tripadvisor.com
(coord. 52.378, 4.900)

Heidelberg Hauptbahnhof

Heidelberg, Germany

	area	perimeter
site	7020 m^2	480 m
building(s)	7020 m^2	480 m

Images sources: Google Maps, Wikipedia.org
(coord. 49.404, 8.675)



Malmö centralstation

Malmö, Sweden

	area	perimeter
site	10010 m^2	690 m
building(s)	10010 m^2	690 m

Image source: Google Maps (coord. 55.609, 12.999)

AVERAGE

	area	perimeter
site	**7630 m^2**	**560 m**
building(s)	**7630 m^2**	**560 m**

7.15 Hospitals

Hospital examples from the USA, Poland, the Netherlands and other counties were used. Table 5.6 presents the results.

Table V.6 Hospitals examples

Memorial Medical Center

New Orleans, Lousiana, USA

	area	perimeter
site	38000 m^2	960 m
building(s)	23110 m^2	1450 m
	(2506 m², 12410 m², 8193 m²)	(201 m, 645 m, 602 m)

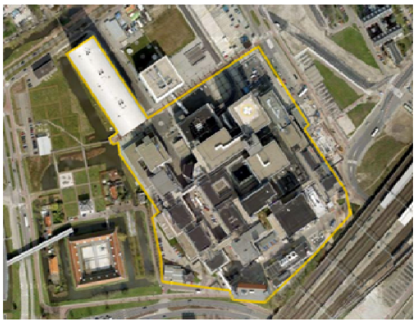
Images sources: Google Maps, Bing Maps
(coord. 29.937, -90.103)

Carolina Medical Centre

Warsaw, Poland

	area	perimeter
site	9430 m^2	500 m
building(s)	6437 m^2	470 m

Images sources: Google Maps, medicaltraveleurope.com
(coord. 52.189, 21.045)



Leids Universitair Medisch Centrum

Leiden, The Netherlands

	area	perimeter
site	77210 m^2	1140 m
building(s)	61450 m^2	1203 m

Images sources: Google Maps, parool.nl (coord. 52.165, 4.477)

Memorial Hermann Baptist Hospital

Beaumont, Texas, USA

	area	perimeter
site	39970 m^2	840 m
building(s)	22860 m^2	1060 m

Images sources: Google Maps, redwingaerials.com (coord. 30.070, -94.120)

Norfolk and Norwich University Hospital

Norwich, United Kingdom

	area	perimeter
site	77660 m^2	1300 m
building(s)	48770 m^2	2006 m

Images sources: Google Maps, www.edp24.co.uk (coord. 52.617, 1.220)

LSU Medical Center University Hospital

New Orleans, Lousiana, USA

	area	perimeter
site	14220 m^2	350 m
building(s)	8640 m^2	510 m

Images sources: Google Maps, Bing Maps
(coord. 29.956, -90.085)

AVERAGE

	area	perimeter
site	**55930 m^2**	**930 m**
building(s)	**28540 m^2**	**1120 m**

7.16 Drinking water production plants

Drinking water supply is vital during a flood. Water treatment plants usually consist of storage basins, clear water tanks and a collection of buildings. When flood proofing this type of hotspot it is possible to chose whether floodproofing the entire plant or each building. For this reason drinking water production plants data include measures about the total area and about each building inside the production plant.Table 5.7 presents the results.

Table V.7 Drinking water production plants examples

Beerenplaat

Spijkenisse, The Netherlands

	area	perimeter
site	1702020 m^2	5550 m
building(s)	1482850 m^2	9030 m
	(1424478 m^2, 3431 m^2, 361 m^2, 5105 m^2, 1640 m^2, 5647 m^2, 5647 m^2, 2202 m^2, 13932 m^2, 1423 m^2, 99 m^2, 72 m^2, 72 m^2, 99 m^2, 741 m^2, 5321 m^2, 5321 m^2, 2892 m^2, 984 m^2, 984 m^2, 984 m^2, 984 m^2, 430 m^2)	(4854 m, 340 m, 70 m, 308 m, 225 m, 270 m, 270 m, 187 m, 479 m, 162 m, 43 m, 32 m, 32 m, 43 m, 108 m, 334 m, 334 m, 278 m, 144 m, 144 m, 144 m, 144 m, 85 m)

Images sources: Google Maps, panoramio.com
(coord. 51.834, 4.411)

Waterbedrijf Europoort

Rotterdam, The Netherlands

	area	perimeter
site	311160 m^2	3460 m
building(s)	141750 m^2	6020 m
	(71080 m^2, 1877 m^2, 8733 m^2, 3514 m^2, 3514 m^2, 8143 m^2, 1134 m^2, 5728 m^2, 3628 m^2, 733 m^2, 415 m^2, 2327 m^2, 2321 m^2, 2321 m^2, 2321 m^2, 2321 m^2, 2321 m^2, 2321 m^2, 2321 m^2, 4354 m^2, 8944 m^2, 1375 m^2)	(1313 m, 203 m, 403 m, 211 m, 211 m, 441 m, 137 m, 312 m, 229 m, 109 m, 95 m,175 m, 175 m,175 m, 175 m, 175 m, 175 m, 175 m, 175 m, 346 m, 404 m, 199 m)

Images sources: Google Maps, Bing Maps
(coord. 51.907, 4.539)

W.J. Hooper Water Production Plant

Stockbridge, Georgia, USA

	area	perimeter
site	39560 m²	970 m
building(s)	12420 m²	1540 m
	(393 m2, 545 m², 483 m², 201 m², 761 m², 5150 m², 277 m², 530 m², 113 m², 3592 m², 248 m², 125 m²)	(85 m, 100 m, 80 m, 51 m, 98 m, 458 m, 112 m, 158 m, 43 m, 232 m, 70 m, 49 m)

Images sources: Google Maps, Bing Maps (coord. 33.528, - 84.177)

Al Wahda Water Treatment Plant

Baghdad, Iraq

	area	perimeter
site	23320 m²	690 m
building(s)	11770 m²	1460 m
	(240 m2, 2727 m², 893 m², 901 m², 536 m², 730 m², 388 m², 4958 m², 393 m²)	(67 m, 242 m,113 m, 121 m,106 m, 155 m, 108 m, 461 m, 84 m)

Image source: Google Maps (coord. 33.357, 44.356)

Water Plant Olympia Drive

Pittsburg, California, USA

	area	perimeter
site	62910 m²	1110 m
building(s)	25880 m²	1650 m
	(240 m², 331 m², 98 m², 66 m², 84 m², 192 m², 257 m², 383 m²)	(1882 m, 5896 m, 488 m, 235 m, 527 m, 2852 m, 3797 m, 10199m)

Image source: Google Maps (coord. 38.006, -121.904)

AVERAGE

	area	perimeter
site	427800 m²	2360 m
building(s)	334930 m²	3960 m

7.17 Wastewater treatment plants

Sewage treatment works consist of multiple tanks, basins and buildings where the wastewater is treated to protect the water quality of receiving waterways. In the same way as drinking water treatment plants, when flood proofing this type of hotspot it is possible to chose whether floodproofing the entire plant or each building. Results can be found in table 5.8.

Table V.8 Wastewater treatment plants examples

WWTP Harnaschpolder

Delft, The Netherlands

	area	perimeter
site	271340 m^2	2020 m
building(s)	87020 m^2	7350 m
	(2374 m^2, 3253 m^2, 3253 m2, 3253 m^2, 3253 m^2, 11558 m^2, 11558m^2, 11558m^2, 11558m^2, 12871m^2, 1508 m^2, 305 m^2, 305 m^2, 305 m^2, 3621 m^2, 3621 m^2, 603 m^2, 522 m^2, 310 m^2, 1430 m^2)	(209 m, 149 m, 149 m, 149 m, 149 m, 69 m, 141 m, 709 m, 404 m, 404 m, 1440 m, 66 m, 66 m, 777 m, 777 m, 203 m, 203 m, 203 m, 203 m, 880 m)

Images sources: Google Maps, www.waterdokter.nl
(coord. 52.015, 4.318)

RWZI Antwerpen Zuid

Antwerpen, Belgium

	area	perimeter
site	141510 m^2	1960 m
building(s)	64740 m^2	3970 m
	(36908 m^2, 10161 m^2, 11230 m^2, 2966 m^2, 715 m^2, 2759 m^2)	(1684 m, 1116 m, 431 m, 311 m, 169 m, 263 m)

Images sources: Google Maps, Wikipedia.org
(coord. 51.195, 4.369)

RWZI Den Haag

Den Haag, The Netherlands

	area	perimeter
site	40270 m^2	900 m
building(s)	29210 m^2	2040 m
	(2579 m^2, 3845 m^2, 1360 m^2, 378 m^2, 8380 m^2, 12668 m^2)	(409 m, 254 m, 167 m, 93 m, 382 m, 733 m)

Image source: Google Maps (coord. 52.088, 4.266)

Oceanside Wastewater Treatment Plant

S. Francisco, California, USA

	area	perimeter
site	77040 m^2	1350 m
building(s)	18860 m^2	n.a.

Image source: Google Maps (coord. 37.727, -122.503)

Everett Water Pollution Control Facility

Everett, Washington, USA

	area	perimeter
site	50400 m^2	1620 m
building(s)	830320 m^2	6150 m
	(2077 m^2, 1339 m^2, 1671 m^2, 2309 m^2, 685612 m^2, 137307 m^2)	(212m, 140m, 209 m, 258 m, 3796 m, 1537 m)

Image source: Google Maps (coord. 47.996, -122.17)

AVERAGE

	area	perimeter
site	**111030 m^2**	**1530 m**
building(s)	**201460 m^2**	**6550 m**

7.18 Food distribution centres

Food distribution centres data from multiple countries were collected and summarized in table 5.9.

Table V.9 Food distribution centres examples

Co-operative distribution centre

Avonmouth, Bristol, United Kingdom

	area	perimeter
site	76000 m^2	1150 m
building(s)	50000 m^2	950 m

Image source: Bing Maps (coord. 51.547,-2.642)

Southeast Food Distribution Center

Medley, Miami, FL, USA

	area	perimeter
site	48500 m^2	950 m
building(s)	27500 m^2	700 m

Images sources: Bing Maps (coord. 25.858, -80.375)

Albert Heijn Distribution Centre

Zaandam, Netherlands

	area	perimeter
site	120000 m^2	1500 m
building(s)	60000 m^2	1350 m

Image sources: Bing Maps (coord. 52.426,4.804)

Centro Emerald Market (shopping centre)

Emerald, Australia

	area	perimeter
site	20000 m^2	650 m
building(s)	11000 m^2	600 m

Image sources: www.wesfarmers.com.au, Bing Maps (coord. -23.527, 148.164)

ASKO Sentrallager

Vestby, Norway

	area	perimeter
site	140000 m^2	1600 m
building(s)	80000 m^2	2200 m

Image sources: Bing Maps, www.supplychainoutpost.com (coord. 59.588,10.742)

AVERAGE

	area	perimeter
site	**80000 m^2**	**1200 m**
building(s)	**45000 m^2**	**1200 m**

7.19 Electricity substations

Electricity substations examples from the UK, Australia, Japan and other counties were used to compile the data for this type of hotspot. Table 5.10 presents the results.

Table V.10 Electricity substations examples

Walham Substation

Walham, United Kingdom

	area	perimeter
site	21000 m^2	600 m
building(s)	n.a.	n.a.

Image source: Google Maps. (coord. 51.879, -2.254)

Llanarth Substation

Llanarth, United Kingdom

	area	perimeter
site	(750+550) 1300 m^2	200 m
building(s)	50 m^2	30 m

Images sources: Google Maps, local.upmystreet.com (coord. 52.188,-4.321)

Kerang sub-station

Victoria, Australia

	area	perimeter
site	40000 m^2	620 m
building(s)	750 m^2	150 m

Images sources: Google Maps, media.bmt.org (coord. -35.771,143.933)

Shin-toyosu Underground Substation (500 kV)

Tokyo, Japan

	area	perimeter
site	20000 m^2	450 m
building(s)	20000 m^2	450 m

Images sources: Google Maps, www.cmd2010.org
(coord. 35.647,139.790)

BPA Arlington Substation (wind power)

Arlington, Oregon, USA

	area	perimeter
site	50000 m^2	900 m
building(s)	850 m^2	300 m

Image source: Google Maps (coord. 45.675, -120.215)

Distribution substations (transformer vaults)

Various locations

	area	perimeter
built area	4-20 m^2	8-20 m
average	10 m^2	13 m

Images sources: Wikipedia.org, www.ubbergen.nl, www.roberthenrycorp.com

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	area (S/M/L)	perimeter(S/M/L)
site	**10 /1000 /35000 m^2**	**13 /150 /600 m**
built area	**10 /100 /700 m^2**	**13 /50 /150 m**

7.20 Airports

Airports consist of one or several runways, control towers, terminal buildings and hangars. During a flood is essential that runways and control towers stay functional. In many cases airport buildings are situated between the runways. For this reason the airports data include measures of the whole airports area. Table 5.11 presents the data on airports.

Table V.11 Airports examples

Aéroport Paris-Charles de Gaulle

Roissy-en-France, France

	area	perimeter
site	22 km^2	20 km
building(s)		

Image source: Google Maps, www.airport-data.com (coord. 49.010, 2.545)

Heathrow Airport London

Hounslow, United Kingdom

	area	perimeter
site	10 km^2	14 km
building(s)		

Images sources: Google Maps, www.heathrowterminal4.co.uk (coord.51.473, -0.459)

Schiphol Airport

Amsterdam, Netherlands

	area	perimeter
site	20 km^2	26 km
building(s)		

Images sources: Google Maps, www.aerophoto-schiphol.nl (coord.52.310, 4.766)

Rotterdam the Hague Airport

Rotterdam, Netherlands

	area	perimeter
site	3 km^2	7 km
building(s)		

Images sources: Google Maps, Wikipedia.org
(coord. 51.954, 4.436)

Hartsfield-Jackson Atlanta International Airport

Atlanta, Georgia, USA

	area	perimeter
site	14 km^2	16 km
building(s)		

Image source: Google Maps, (coord. 33.639, -84.432)

AVERAGE

	area	perimeter
site	**10-15 km^2**	**15-20 km**
built area		

7.21 Financial buildings

For the data analysis of financial buildings, examples were collected from Italy, the Netherlands, the UK and other countries. Table 5.12 presents an overview.

Table V.12 Financial buildings examples

Cassa di Risparmio di Venezia

Venice, Italy

	area	perimeter
site	1350 m^2	150 m
building(s)	1350 m^2	150 m

Images sources: Google Maps, Wikipedia.org
(coord. 45.435, 12.334)

De Nederlansche Bank

Amsterdam, the Netherlands

	area	perimeter
site	13130 m^2	460 m
building(s)	13130 m^2	460 m

Images sources: Google Maps, www.beste-werkgevers.nl
(coord. 53.358, 4.900)

Bank of England

London, United Kingdom

	area	perimeter
site	11760 m^2	440 m
building(s)	11760 m^2	440 m

Images sources: Google Maps, Wordpress.com, 2011
(coord. 51.514, -0.088)

Oesterreichischen Nationalbank

Wien, Austria

	area	perimeter
site	4310 m^2	270 m
building(s)	4310 m^2	270 m

Images sources: Google Maps, Panoramio
(coord. 48.216, 16.354)

Deutsch Bundesbank

Köln, Germany

	area	perimeter
site	3470 m^2	270 m
building(s)	3470 m^2	270 m

Images sources: Google Maps, Bing Maps
(coord. 50.911, 6.973)

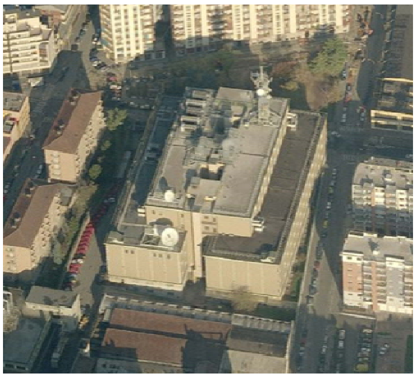
AVERAGE

	area	perimeter
site	**6800 m^2**	**320 m**
building(s)	**6800 m^2**	**320 m**

7.22 Communication centres

For the data analysis of communication centres, examples from several countries were collected. Table 5.13 shows the results.

Table V.13 Communication centres examples



Telecom Internet Data Centre

Torino, Italy

	area	perimeter
site	5510 m^2	300 m
building(s)	5510 m^2	300 m

Image source: Google Maps, Bing Maps
(coord. 45.060, 7.639)

Vodafone NOC

Newbury, United Kingdom

	area	perimeter
site	2070 m^2	200 m
building(s)	2070 m^2	200 m

Images sources: Google Maps, Bing Maps
(coord.51.416, -1.319)

Nap of Amsterdam

Amsterdam, Netherlands

	area	perimeter
site	7760 m^2	260 m
building(s)	7760 m^2	260 m

Images sources: Google Maps, Bing Maps (coord.52.322, 4.801)

Cybercon Data Center

St. Louis, Missouri, USA

	area	perimeter
site	2160 m^2	210 m
building(s)	2160 m^2	210 m

Images sources: Google Maps, Cybercon.com
(coord. 38.629, -90.197)

TelecityGroup Data Center

Dublin, Ireland

	area	perimeter
site	4970 m^2	400 m
building(s)	4970 m^2	400 m

Images sources: Google Maps, Bing Maps
(coord. 53.411, -6.346)

AVERAGE

	area	perimeter
site	**4490 m^2**	**270 m**
built area	**4490 m^2**	**270 m**

7.23 Energy storage

Table 5.13 shows the results of data collection of energy storage.

Table V.14 Energy storage

Vopak Terminal

Rotterdam, The Netherlands

	area	perimeter
site	141650 m^2	2512 m
building(s)	96370 m^2	6350 m
	(4921 m^2, 24646 m^2, 19875 m^2, 8128 m^2, 2612 m^2, 3792 m^2, 4316 m^2, 639 m^2, 3122 m^2, 23355 m^2, 968 m^2)	(1175 m, 684 m, 889 m, 403 m, 216 m, 376 m, 734 m,126 m, 391 m, 914 m, 446 m)

Images sources: Google Maps, www.vopak.nl
(coord. 51.902, 4.359)

Vopak Terminal

Södertälje, Sweden

	area	perimeter
site	155090 m^2	1840 m
building(s)	26930 m^2	3900 m
	(988 m^2, 653 m^2, 1917 m^2, 89 m^2, 174 m^2, 1019 m^2, 204 m^2, 366 m^2, 609 m^2, 893 m^2, 559 m^2, 1471 m^2, 575 m^2, 885 m^2, 729 m^2, 4048 m^2, 1258 m^2, 376 m^2, 599 m^2, 662 m^2, 1048 m^2, 228 m^2 491 m^2, 1957 m^2, 789 m^2, 907 m^2, 3430 m^2)	(173 m, 249 m, 174 m, 38 m, 63 m, 201 m, 78 m, 70 m, 155 m, 105 m, 97 m, 150 m, 105 m, 157 m, 98 m, 229 m, 290 m, 118 m, 90 m, 107 m, 119 m, 67 m, 94 m, 191 m, 255 m, 129 m, 298 m)

Images sources: Google Maps, Bing Maps
(coord. 59.169, 17.658)

Odfjell Terminals

Rotterdam, The Netherlands

	area	perimeter
site	615720 m^2	3090 m
building(s)	178850 m^2	29370 m
	(3256 m^2, 2326 m^2,	(233 m, 211 m,
	1826 m^2, 1098 m^2,	496 m, 362 m,
	908 m^2, 499 m^2,	342 m, 280 m,
	4212 m^2, 2337 m^2,	547 m, 324 m,
	2187 m^2, 1811 m^2,	3709 m, 451 m,
	9790 m^2, 7122 m^2,	1304 m, 711 m,
	748 m^2, 302 m^2,	244 m,168 m,
	596 m^2, 394 m^2,	177 m, 148 m,
	966 m^2, 114 m^2,	280 m, 54 m,
	743 m^2, 4017 m^2,	239 m, 681 m,
	3904 m^2, 792 m^2,	888 m, 201 m,
	8539 m^2, 10223 m^2,	1182 m, 1670 m,
	308 m^2, 2152 m^2,	104 m, 751 m,
	8100 m^2, 1090 m^2,	1209 m,171 m,
	972 m^2, 961 m^2,	125 m, 233 m,
	139 m^2, 263 m^2,	38 m, 117 m,
	1596 m^2, 458 m^2,	247 m, 101 m,
	140 m^2, 805 m^2,	48 m, 215 m,
	695 m^2, 622 m^2,	243 m, 150 m,
	6598 m^2, 26759 m^2,	1302 m, 2863 m,
	2304 m^2, 434 m^2,	169,653 m, 83 m,
	9356 m^2, 1031 m^2,	839 m, 172 m,
	824 m^2, 936 m^2,	189 m, 192 m,
	1707 m^2, 827 m^2,	160 m, 145 m,
	2090 m^2, 8944 m^2,	493 m, 1850 m,
	7672 m^2, 621 m^2,	1677 m, 179 m,
	2047 m^2)	403 m,)

Images sources: Google Maps, www.odfjell.com
(coord. 51.880, 4.315)

Murphy Oil Terminal

New Orleans, Louisiana, USA

	area	perimeter
site	717640 m^2	6640 m
building(s)	213350 m^2	14350 m
	(15108 m^2, 23230 m^2,	(813 m, 1375 m,
	11273 m^2, 6186 m^2,	1361 m, 648 m,
	3939 m^2, 17569 m^2,	324 m, 1037 m,
	785 m^2, 7145 m^2,	120 m, 492 m,
	5625 m^2, 476 m^2,	474 m, 82 m,
	5676 m^2, 10704 m^2,	411 m, 627 m,
	56258 m^2,34092 m^2,	2864 m, 1199 m,
	11279 m^2, 1381 m^2,	1706 m, 310 m,
	2625 m^2)	504 m)

Images sources: Google Maps (coord. 29.935, -89.939)

Vopak Sebarok Terminal

Pulau Sebarok, Malaysia

	area	perimeter
site	458340 m²	5710 m
building(s)	143780 m²	13720 m
	(11346 m², 33802 m², 816 m², 5970 m², 6061 m², 715 m², 4270 m², 10465 m², 9683 m², 3961 m², 5496 m², 3139 m², 1283 m², 607 m², 11413 m², 3376 m², 12417 m², 3166 m², 11277 m², 2696 m², 416 m², 1053 m², 350 m²)	(1130 m, 733 m, 146 m, 831 m, 637 m, 99 m, 488 m, 821 m, 1099 m, 218 m, 376 m, 421 m, 126 m, 84 m, 848 m, 447 m, 2449 m, 516 m, 1368 m, 430m, 147 m, 237 m, 67 m)

Images sources: Google Maps, www.vopak.nl
(coord. 1.2057,103.795)

AVERAGE

	area	perimeter
site	**483340 m²**	**3960 m**
building(s)	**131860 m²**	**13540 m**

Appendix 6 Departments and specialism St. Francis

Table VI.1 Departments and specialism St. Francis Hospital (Sint-Franciscus Gasthuis, 2010)

Special departments	
Anaesthetics	Neurosurgery
Cardio surgery	Nephrology
Cardiology	Nuclear medicine
Dermatology	Obstetrics
General surgery	Ophthalmology
Gynaecology	Orthopaedics
Haematology	Plastic Surgery
Internal Medicine	Pulmonology
Oral and maxillofacial surgery	Psychiatry
Ear, Nose, Throat department (ENT)	Psychology
Paediatrics	Radiology
Clinical chemistry	Radiotherapy
Clinical Genetics	Rheumatology
Clinical oncology	Rehabilitation
Clinical pathology	Thoracic surgery
Gastroenterology and Hepatology	Vascular surgery
Medical microbiology	Urology
Neurology	

Other medical facilities	
Dialysis centre	Pharmacy
Medical/ GP Laboratory	