Construction technologies for flood-proofing buildings and infrastructures

Concepts and Technologies for Smart Shelters

Date: January 2013
Report Number: WP04-01-12-15
Version Number: 1_0_08

Deliverable Number:	D4.3
Due Date for Deliverable:	June 2012
Actual Submission date:	01/03/2013
Task Leader:	Edwin Blom, Dura Vermeer Business Development BV

FloodProBE is co-funded by the European Community
Seventh Framework Programme for European Research and Technological Development (2009-2013)
FloodProBE addresses "Technologies for Improved Safety of the Built Environment in Relation to Flood Events"
Start date: November 2009, duration: 4 Years

Document Dissemination Level PU

PU = **Public**

PP = **Restricted to other programme participants (including the Commission Services).**

RE = **Restricted to a group specified by the consortium (including the Commission Services).**

CO = **Confidential, only for members of the consortium (including the Commission Services).**

CL restricted = **Classified with the mention of the classification level restricted "Restraint UE"**

CL confidential = **Classified with the mention of the classification level confidential "Confidential UE"**

CL secret = **Classified with the mention of the classification level secret "Secret UE"**

Table of Contents

1. Introduction

1.1 Context

Floods are one of the most destructive natural hazards and the cause of most natural disasters affecting society. During recent decades, the intensity and occurrence of catastrophic flooding has increased and is predicted to occur even more often in the future. Flooding not only affects people and livestock's health, but also causes enormous damage to the economy. Every year, many people lose everything when disaster strikes often with no warning in advance of the event.

Various and diverse mitigation plans have been implemented across the world to reduce the consequences of flooding. Examples include the building of embankments, constructing detention and retention areas, and other structural measures to protect people and properties especially in urban areas. However, the current records of flood damages indicate that these measures are so far not adequate to cope with flooding. Therefore, in addition to structural measures, other emergency measures such as flood shelters are also needed immediately and urgently when disaster strikes.

It is necessary to evacuate people when the benefits of leaving significantly outweigh the costs of 'sheltering-in-place'. A well-progressed emergency plan for the period of inundation comprises of mass evacuation during the warning period before flood water reaches a critical level, during flooding for the people exposed and after flooding in the recovery phase. In this regard, evacuation means instructing people how to leave and where to go to leave their current dangerous or potentially dangerous location. Sheltering is one of the essential parts of the evacuation plan in addition to the other essential functions like transportation. The primary target is to evacuate the entire population at risk into areas outside the inundated region. However, always, there are groups of people (elderly, sick people, disabled etc.) who have mobility issues. These should be accommodated as near to their homes as possible to increase the efficiency of the evacuation during the warning time.

Primarily, sheltering plans focus on providing a survival place for the victims during a flood and when a process of rehabilitation is underway immediately afterwards. However, shelters will often be used only for a short period of time during a flood. In order to realise economic benefits and be sustainable, shelter structures need to be used synergistically for multiple purposes for the periods when there is no flood risk or inundation, which are likely to be lengthy compared with their usage during periods of flooding. In this way, the investment in constructing new flood shelters can be offset against a variety of normal use functions that will ensure the structures are continually maintained. These multi-purpose flood shelters can then be used to manage hazard relief and rehabilitation activities as needed in a pre-planned way.

Practically, multi-use shelter structures can be effective through two options. Firstly, a shelter can be constructed aimed solely at flood relief with other functions added later. Secondly, any suitable existing public buildings such as schools, hospitals, and so on can be modified over time to act as shelters. This is the core idea of this guidance, i.e. to introduce '**smart shelters'** that are not only a means of mitigation but also a means of development. Smart shelters can provide facilities for a wide variety of sustainable uses such as education and health care and promote local development if they are built appropriately. Alternatively, the modification of existing buildings is a smart idea to reduce the need for a huge amount of investment that may be needed for construction and maintenance of new smart shelters.

The guidance deals with the socio-economic aspects of smart shelters that have to be considered to design and implement shelters that are as cost-effective as possible.

1.2 Relationship to FloodProbe objectives

The principal aim of FloodProBE is to provide cost-effective means for flood risk reduction in urban areas. For this purpose WP4 has been set up to develop new concepts and building technologies to reduce the vulnerability of urban areas to flooding. In this work package new concepts and technologies for essential flood management systems are developed. The systems that are addressed in this work package are flood defence networks, flood damage mitigation of critical vulnerable buildings, shelters and lifeline infrastructure.

WP4 contributes to the following general objectives of FloodProbe: To develop and test construction technologies and concepts to improve the performance of existing and new flood defences and for flood-proofing of the urban environment (general objective #3).

In order to realize this objective WP4 utilizes results that follow from the activities that address the following project objectives: vulnerability assessment (objective #1) and understanding and assessment of flood defence performance (objective #2).

WP4 aimed to provide a number of cost effective technologies and concepts to reduce the flood vulnerability of urban areas. These results have also been applied in work packages that address the following overall project objectives: knowledge integration for holistic flood management strategies (objective #4) and development of guidelines (objective #5).

1.3 Objectives of the guidance

Events such as flooding by hurricane Katrina have demonstrated that "shelter in place" strategies have benefits over large horizontal evacuation. The aim is to develop technologies that integrate a shelter function in various building types in urban areas, such as high-rise or (semi-)public buildings such as sport stadiums. Foreseen technologies are aimed at both, new buildings as well as retrofitting. The benefits include effectiveness by function integration, and reduction of loss of life by offering a safe alternative for evacuation. The following issues have also been considered: how to finance shelters and what incentives can be given; how to take care of large numbers of people in shelters; how to stock them (smaller but frequent shelters may be better; how to ensure sanitation is provided to a satisfactory level.

The overall objective of this guidance is to provide information, together with concepts for the design of cost-effective shelters (both retrofit and new build) for flood preparedness as well as the response and recovery phases. Here the major task addressed is in developing a planning tool for implementation of shelter strategies for people affected by flood.

The focus of this guidance is for adapted existing buildings or new buildings to be used as shelters during flooding, whilst maintaining their usual functionality during periods where there is not a crisis. Herein, the buildings that can potentially become shelters should be determined by investigating the location, size and structural needs of each specific building type. There is also a requirement for demographic information about the numbers of people who may need shelter, and distribution and type of people (e.g. weak, sick, and elderly) should also be determined. This information can then be used to develop alternative scenarios for evacuation. Finally, the costs for each alternative needs to be assessed and compared with the economic value of the lives saved (benefits) for determining the best alternative in a cost-benefit assessment.

1.4 Structure of the guidance

This guideline comprises of three main parts:

Chapter 2 gives a broad review of the issues related to the design of smart shelters. This includes a state of the art review dealing with shelters including the comparison of different smart shelter concepts, functional and spatial requirements as well as technical information as reference for the implementation of the shelters.

Chapter 3 is a guidance for a cost-benefit analysis recommended to compare different alternatives for sheltering. It identifies and evaluates both the costs and benefits in order to calculate net present values.

Chapter 4 offers information of the case study area in Dordrecht. The Island of Dordrecht lies in the transition zone between a tidal reach and a river regime reach, where the extreme water stages are influenced by both the river discharge and the sea level. The objective for the municipality is to find practical measures on the city level that make the Island of Dordrecht safer and improve self-reliance by implementing a smart shelter strategy. An important starting point in this respect is connecting flood safety with spatial developments and water awareness.

2. Guidance for planning and design

2.1 Concepts

The type of smart shelter will define the required functions. For example, various shelter types and corresponding functions were assigned to certain buildings during Hurricane Katrina [Nigg et al. 2006]. The Superdome was assigned as a shelter of last resort, or emergency shelter, during the flooding event where the main function was to protect the population within from the hazards for the duration of the event. The Superdome actually became an unplanned temporary shelter which also had altered functional requirements; the population housed required basic necessities such as food, water, sanitation, and comfort. However, the use of the Superdome for these purposes was not foreseen before the event and not all of these functions were effectively met. In addition, hotels were used first as emergency shelters during the storm and then became short-term temporary housing. Even cruise ships were utilised to provide temporary housing. Quarantelli (1982) outlines two major categories of shelter and two categories of housing that are used to house the general population in times of a hazard: in emergency shelters, temporary shelters, temporary housing, and permanent housing. Since this report focuses on a new typology of shelters, we will redefine the emergency shelters and temporary shelters as short-term and long-term smart shelters, respectively.

Like the Superdome, the main function of a short-term shelter is to provide a safe haven within the hazard area for people who are unable or unwilling to evacuate the flooded area in time. The duration that short-term shelters are occupied is equal to the duration of the event, plus the time between the evacuees entering the shelter and the start of the event. For short-term shelters this period may be no longer than e.g. one week.

The functioning of a long-term shelter is broadly equivalent to that of a short-term shelter, other than for the duration of the occupancy, which would typically be longer. In addition to the evacuation time and the duration of the flood, long-term shelters will function as a safe haven during the recovery phase in the aftermath of a disaster. This is therefore expected to be in the order of days to weeks, with the functional and spatial requirements for the long-term shelter potentially differing from those for the short-term shelter. For instance; additional space is needed per evacuee to provide comfort and privacy; additional storage is needed for supplies such as food and medicines and critical infrastructure within the building, such as electricity, water and wastewater all of which will need to be functional.

2.2 Typology based on shelter size

2.2.1 Existing buildings vs. new construction

It is usually more cost effective to utilize existing facilities for shelters that can structurally withstand the hazard event [Kar and Hodgson 2008]. However, a perfect existing location that meets all the outlined functions chosen for a shelter is rare, and a smart shelter location may require retrofitting or future renovation to meet all the desired functions. Therefore, a wide range of potential locations should be considered for an evaluation of functions provided by each location. The relationship between smart shelter function and location is synergistic. The location is dependent on the function, but the function is also dependent on the location. An iterative approach may be necessary to choose the optimal shelter functions and existing location that provide the greatest benefits at the lowest costs. The best financial strategy is to incorporate a smart shelter during the design of a new building when the functional requirements can be integrated into the final structural design. Creation of new policy addressing the construction of smart shelters within new buildings (government, public, private, etc.) could streamline the process for future endeavors and further minimize smart shelter construction costs. However, the scale, scope, location and design of new projects in an urban environment may be limited in opportunity to utilize as shelters and not in ideal locations to be used as smart shelters, at least not in the short-term. Therefore, new construction of smart shelters may need to be investigated, but will in any case require a long-term plan.

2.2.2 Single VS Multiple

In order to come up with the most effective and efficient smart shelter strategy, stakeholders will have to decide on building and maintaining one larger shelter or multiple smaller shelters spread out across, or in the vicinity of, the hazard area. The spatial distribution of the land use, flood risk maps, evacuation plans and demographic data will determine the need for shelters, site selection and the number and capacity of the shelters needed. Having to build and maintain one or multiple shelters has both pros and cons, but the main need will be for shelters to be accessible/reachable within the warning time available. This includes considerations of the possibility that fast transportation systems may not function as expected prior to and during a flood.

Having several smart shelters throughout the city will usually increase the extent of the population that are able to reach the shelter in time during a hazard. This is preferable in large urban areas with high populations, or widespread urban areas with less dense populations. Refugees will need to reach the shelter in time, which depends on the warning times, as well as on the available means of transportation and infrastructure. Building a smart shelter next to flood proof infrastructure is recommended.

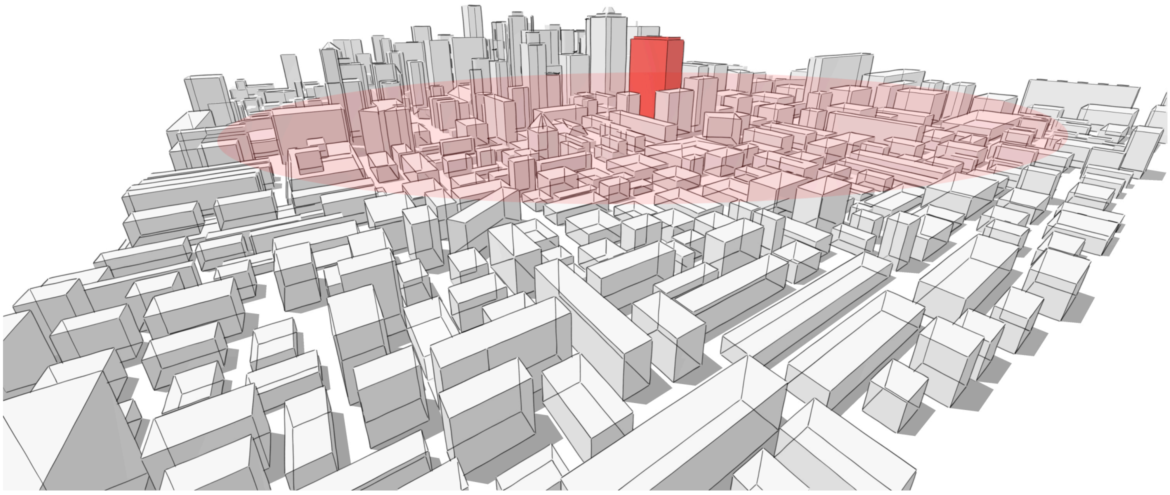

Fig. 2.1 One large smart shelter covering a large area

Having fewer or just a single smart shelter (as shown in figure 2.1) will reduce both initial building and maintenance costs compared to having several smaller smart shelters throughout the city (as shown in figure 2.2). All shelters need to comply with the building requirements described as above. Modifying one building into a flood proof smart shelter will almost definitely be cheaper than flood proofing multiple buildings, even if they are smaller in size. Keeping both fresh food and medicine in one centralized storage space is both easier and cheaper to distribute. There is also a social advantage to centralizing shelter capacity. In flood management and communications it will be clearer to the general public where to go in times of a flooding event; which increases the effectiveness of the shelter strategy.

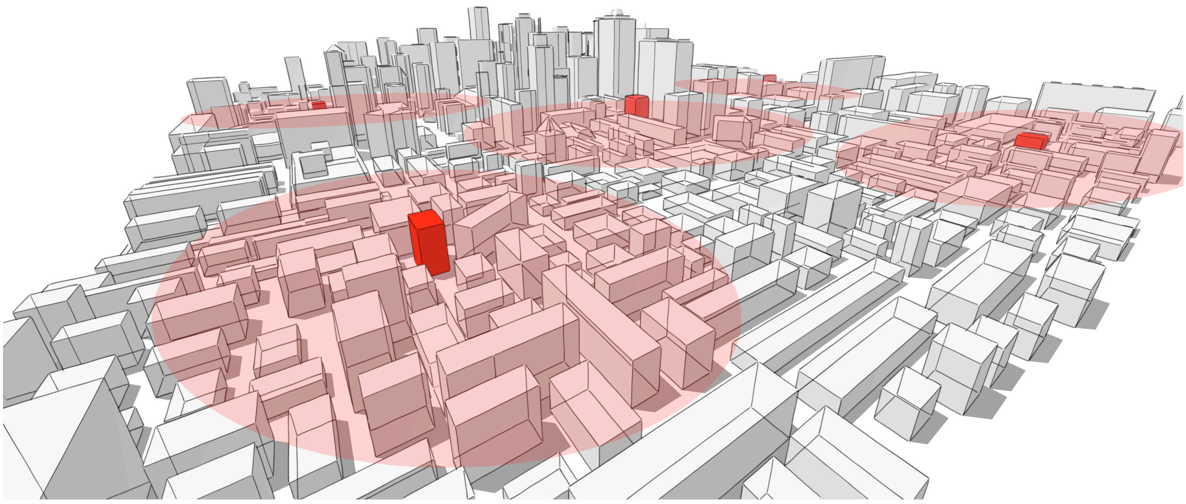

Fig. 2.2 Multiple smaller smart shelters covering several smaller areas

2.3 Requirements

2.3.1 Clarifying constraints

For the case of shelters, a main consideration prior to the development of the alternatives is to investigate if there are (inter)national standards. The constraints should include those elements that are likely to be influencing (prohibiting) factors for the number and location of shelters and the services provided. These comprise e.g. the names of the organisations who might be involved in an evacuation plan (emergency services), their specific requirements and capacities. Additionally, the condition of the roads for providing safe access to the shelter, the time available for evacuation, and the safety level of people settled in the shelter during flooding [Corsellis and Vitale, 2005] are inter alia, factors that should be taken into account.

2.3.2 Design modifications

In order for an existing or new building to function as a smart shelter some design modifications are usually necessary for coping with the hazard. These modifications are mainly structural and made on the exterior of the building and the bearing structure. The design of a building needs to be modified in such a way that all forces of flooding can be withstood. In order to plan and design a smart shelter the facility should be completely functional and operational during a flood event. That means avoidance of the flood is the most effective way to minimize the life-safety risk to the community that relies on the shelter, as well as to minimize the potential damage to the building. A well-planned, designed, constructed and maintained smart shelter needs to be able to withstand damage and remain functional during a flood event. Other possibilities of flood proofing a building are wetproof, dryproof or even floating options which can be achieved by adding a factor of safety (i.e. freeboard, levees, or elevation). Performance evaluation of a facility affected by flooding needs to include consideration of the building response to the following load conditions:

- Lateral hydrostatics forces
- Vertical (buoyant) hydrostatic forces
- Hydrodynamic forces
- Surge forces
- Impact forces of flood-borne debris
- Breaking wave forces
- Localized scour

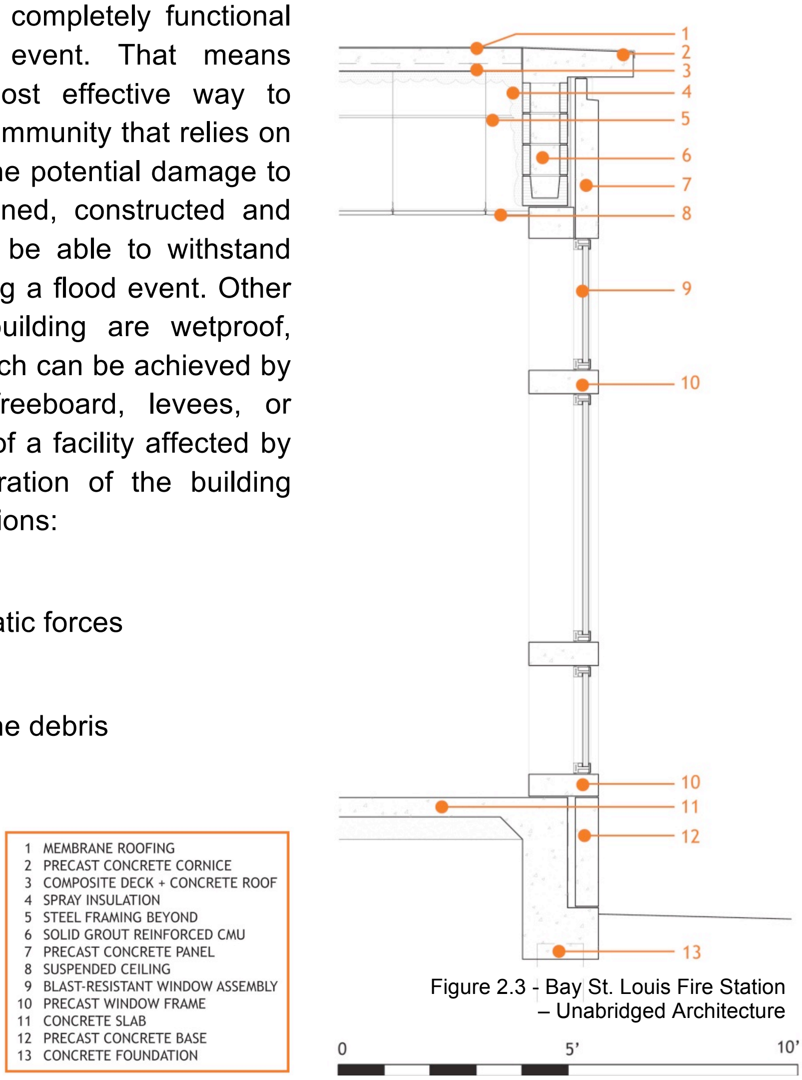

Figure 2.3 - Bay St. Louis Fire Station – Unabridged Architecture

The parts of the building that are vulnerable to these forces will need extra protection. They may include the use of strengthened glass, water and blast proof windows, temporary flood barriers and the use of water resistant materials. Figure 2.3 shows a FEMA approved cross section of a smart shelter wall of the Bay St. Louis Fire Station. It shows the use of precast concrete, water resistant insulation and blast-resistant windows.

2.3.3 Functional requirements

Buildings will need several additional requirements to normal buildings to be able to function as a smart shelter. During normal circumstances multi-use smart shelters will provide their primary function. But in times of emergency smart shelters change their function. The smart shelter requirements can be categorized into: spatial requirements (floor area for refugees and storage for food, medicine and water) and infrastructural requirements (sanitation, drinking water, sewage, power supply, ventilation and communication) in order to be self-sufficient during floods.

It is necessary to define the spatial requirement per refugee in order to determine the capacity of shelters. These requirements may differ in each country. The American Red Cross [2002] recommends the following minimum floor spaces. These criteria are based on the use of the shelter both as a refuge area during the event and as a recovery centre after the event:

- 20 square feet / 1.86 m^2 per person for a short-term stay (i.e., a few days)
- 40 square feet / 3.72 m^2 per person for a long-term stay (i.e., days to weeks)

. The Dutch Red Cross recommends slightly larger floor areas:

- 2.5 m^2 per person for a short-term stay (day time)
- 2 – 4 m^2 per person for a long-term stay (day and night)
    - 4 m^2 = 1 bed + chair
    - 3 m^2 = 1 stretcher + chair
    - 2 m^2 = 1 stretcher

Notice that the terms short-term and long-term may be different in different countries and that spatial requirements should be according to local law and regulation.

Additional floor space is needed for the storage of supplies in order to change the function of the building into the shelter function, i.e. beds, food and water and for additional installations that are needed to guarantee electricity, water, ventilation and sanitation. This additional space depends highly on the primary function and the spatial floor plan of the building. For instance: hotels may offer ideal floor plans to host evacuees and most likely have large parts of the food supplies reserved for guests. The additional space for this is estimated at 10% of the gross floor area of the shelter. The ICC-500 (2008 Standard for the Design and Construction of Storm Shelters) states that depending on the arrangement of the floor area of the primary function of the shelter, there are three possible calculations to define the usable floor space (Table 2.1):

- Useable floor area is 50% of the gross floor area in case of high density and fixed furnishings
- Useable floor area is 65% of the gross floor area in case of low density and unfixed furnishings
- Useable floor area is 85% of the gross floor area in case of open floor spaces with unfixed furnishings

Table 2.1 Usable floor space (in m$^{2)}$ for shelters

Smart Shelter Capacity									
Smart Shelter building type			Cinema		School		Conference Hall	
Gross Floor Area			5000	m^2	5000	m^2	5000	m^2
Spatial Requirements + 10%			500	m^2	500	m^2	500	m^2
Total Gross Floor Area			5500	m^2	5500	m^2	5500	m^2
Useable net. Area (50% / 65% / 80%)			2750	m^2	3575	m^2	4400	m^2
Capacity short-term	1,86	m^2/pers.	1478	pers.	1922	pers.	2365	pers.
Capacity long-term	3,72	m^2/pers.	739	pers.	961	pers.	1182	pers.

Of the infrastructural requirements, water and sanitation are the most discussed needs in reports on shelters and temporary housing. The ability to maintain proper operation of water and sanitation systems in the aftermath of a disaster is fundamental to the protection and recovery of health of the affected population. Maintenance of sanitation infrastructure is often even more critical in urban areas. Reconstruction projects therefore need to identify the failures in the damaged systems and design around those failures to reduce vulnerability

Emergency lighting and power, as well as a backup power source, need to be included in the design of shelters. FEMA [2007, 2008] as well as the Dutch Red Cross advises that route marking and way finding should also be included in the shelter design. A backup power source for lighting is essential during a disaster because the main power source is often disrupted. Shelters will have different emergency (backup) power needs based upon the duration of the hazard and the use of the shelters. For short-term shelters a battery-powered system is recommended as the backup source, because it can be located, and fully protected, within the shelter. Long-term shelters may need renewable energy generators, like solar and wind power to recharge batteries if power sources continue to be disrupted during an event. Failing to provide proper illumination in a shelter may make it difficult for shelter owners/operators to minimize the agitation and stress of the shelter occupants during the event. In addition to the essential requirements that must be provided in the design of the shelter, comfort and convenience should be addressed. For smart shelters, the most critical use of emergency power is for lighting. Emergency power may also be required in order to meet the ventilation requirements, heating and to establish lines of communication.

2.4 Planning

2.4.1 Planning smart shelter strategies

The planning of a smart shelter strategy starts by determining the need for smart shelters. It is recommended that within the warning time of a flood event the majority of people will evacuate the area preventively and find shelter on safer grounds. However, a certain percentage of the population will stay behind, unable to leave by own means or unwilling to leave their property. Using demographic data and software tools such as the 'evacuation calculator' [software 'de evacuatie calculator') of the urban area, we can estimate the number of help-needed to determine the capacity need of the shelters in that area.

In case of a flooding event the help-needed will have to reach the shelter in time. That means that the shelter has to be reachable at all times and is located close enough to the victims. Planners and stakeholders will have to take into account the maximum distance to a shelter. The maximum distance (D_{max}) to a shelter can be calculated by multiplying the minimum warning time (T_{min}) by the travel speed (a). The travel speed of evacuees is estimated at 4 km/h (source: evacuatie calculator).

$$D_{max} = a \times T_{min}$$

To have complete smart shelter coverage within an area, all potential refugees will need to have access to a shelter within the maximum distance. Otherwise multiple shelters are needed.

2.4.2 Locating smart shelters in flood risk areas

The location of a smart shelter is dependent on multiple criteria. The risk assessment performed as part of the shelter needs determination defines the at-risk areas and associated at-risk populations, but the predicted behavior of the population will partially dictate proper smart shelter locations [Dawson et al, 2012]. Therefore, it is important to first evaluate the potential movement or evacuation types available. Next, knowledge about the demographics of the area should be determined in order to evaluate the population groups that can or will evacuate and those that are unable or must stay within a certain area. Finally, potential smart shelter sites can be identified based on a regional vulnerability assessment, as well as on the suitability as described by the physical and social criteria [Kar and Hodgson 2008; ARC 2002].

3. Guidance for cost-benefit analysis

3.1 Identifying and evaluating costs

Various literature sources classify cost items in alternative ways. The method suggested by APFM (2007) is to proceed step-by-step from the beginning to the end of the project. This helps to identify the cost elements at each step and to represent them in a flowchart. It is also possible to make a comprehensive list of the costs based on available literature such as (ADB, 2005). A common approach in economic literature (Canada, 1998, HM-Treasury, 2011) is to classify the costs into the fixed costs (e.g. rents, rates, insurances), variable costs (e.g. material and labour costs), semi-fixed costs (e.g. energy costs dependent on demand), and semi-variable costs (e.g. maintenance and transportation costs). The negative costs (e.g. savings on energy costs) should be counted as benefits or deducted from the total cost of the project (DEFRA, 2010).

A potential starting point to identify the cost items is to distinguish between those costs incurred only at the start of the intervention, and whose benefit lasts for more than one year (termed "investment" costs), and the costs that recur over the life time of the project (termed "recurrent" costs). With respect to smart shelters, costs can be classified as the costs incurred in the preparation phase, the response phase and/or the recovery phase. Table 3.1 indicates some of the cost items which are likely to be incurred in each phase.

Table 3.1 Costs typically incurred in each phase

Cost items		
Investment costs in preparation phase	Recurrent costs in preparation phase	Recurrent costs in response and recover phases
Data collection costs (e.g. gathering information of structures to be modified to act as shelter)	Risk communication between different emergency services involved in evacuation programs and to the public	Re-construction costs for cleaning and repairing smart shelters
Planning cost to determine the type, number, and size of the needed shelters	Maintenance costs to keep the structure ready for response to flooding at any occurrence time	Costs of displacement of people into shelter
Modification of existing buildings to be a smart shelter / Construction of new buildings to be smart shelter	Education and training of the emergency services staffs	Cost of providing immediate and urgent needs such as food, health care, etc.
Environmental costs (e.g. contaminant releases during construction)	Storage costs to keep the shelter ready for response to flooding at any occurrence time	
	Monitoring and regulation	

3.2 Identifying and evaluating benefits

Benefit items are identified based on the output values (impacts) generated by the possible interventions. Evaluating benefits is typically more difficult than costs, as the impacts typically cover various aspects (economic losses, injuries and casualties, psychological trauma, etc) and are lying in the future (Hallegatte, 2006).

Since any type of shelter (either a newly constructed shelter or a retrofitted building to act as shelter) aims to prevent fatalities and injuries, the cost saved per fatality/injury avoided is taken as the benefit of the sheltering alternative (Merrell et al., 2002). The success of any sheltering alternative is dependent on determining the best location for the shelter(s), evacuation routes and number of shelters and this can be derived from evacuation models (see Box 4.1). By applying evacuation models, the scale of loss of life and injuries saved can be estimated for each sheltering alternative option accompanied by an evacuation scenario. The computed values for loss of life prevented in each alternative can be monetized and included in the financial balance of cost-benefit studies. However, taking the economic value of human life into account is controversial as it may be considered unethical to put a price on human life. However, the value can prevent the underestimation of the economic damage, resulting in a lower safety level for the considered system.

Among the different methods of valuation of human life discussed in literature on risk management and safety, the main approaches distinguished in Jonkman et al. (2003) are macroeconomic valuation, comparative approach, utility based approach and contingent valuation. The macro-economic valuation approach uses the net national product per capita as a basis for the valuation of human life, so, life is valued in proportion to a person's potential economic production. In the comparative approach the value of human life is estimated by evaluating the incremental investment needed to prevent an extra loss of life or injury; therefore, this approach relates the value of human life to the investment made and to the number of fatalities prevented. Moreover, the utility based approach focuses on evaluating safety investments leading to an increasing life expectancy. Herein, the utility function is the life quality index, and the final outcome of the approach is a monetary utility curve representing the relation between utility, risk aversion and a monetary valuation. The final potential approach is contingent valuation which is applied to value the benefits of prevented fatalities by estimating the people's willingness to pay for the safety investment based on purposely carried out survey results.

Box 4.1 Evacuation modelling

Modelling of evacuation generates information on potential bottlenecks in the system that may pose problems for safe and efficient displacement of people to shelters and other safe locations. These kinds of models investigate e.g. the impact of road closures due to flooding, the impact of phased evacuation on traffic loadings (Lumbroso et al., 2009) and some other probable impacts of evacuation [e.g. Dawson et al, 2012]. In order to simulate evacuation scenarios, results of 2D hydraulic models are needed to provide accurate estimation of floodwater velocity and depth. Additionally, spatially-referenced population data and transport links are needed to be linked to the 2D hydraulic model outcome resulting modelling of mass evacuation (Lumbroso et al., 2010). The main three evacuation models developed are: Traffic simulation models; Evacuation behaviour models; Time-line/critical path management diagrams.

Traffic simulation models simulate the time evolving traffic flow in a road network from the 'origin' to the 'destinations'. For the purpose of evacuation modelling, the residential areas or the locations of individuals are the usual originsand the 'exits' of the threatened area (shelters in this case) are the destinations (Lumbroso et al., 2010).

Evacuation behaviour models consider the trade-off between people's decisions and the level of traffic information (Pel et al., 2011). Multiple aspects of human behaviour contributing to the evacuation time, such as age, awareness of the hazard, knowledge of the area at risk, and so on are taken into account. Lumbroso et al. (2010) mention that these model types make it possible to assess the effects of improvements in the dissemination of flood warnings or changes in the location and/or number of shelters.

A time-line diagram/critical path tool is the simplest form showing the critical path of emergency response for flood evacuation. As mentioned in FLOODsite (Lumbroso et al., 2009), "this method has the advantage of showing how critical the relationship is between flood prediction, evacuation decisions, emergency service response and community actions and the passage of time in a flood. The resulting time-line can then be used to show participants in a flood planning or response activity what has to be done, when it has to be started, and approximately how long it might take during the flood scenario analysed."

With respect to the level of modelling detail and scale, the evacuation models may be classified into three groups: macroscopic, microscopic and mesoscopic models. Lumbroso et al (2009) explain the characteristics of each scale as follows:

Micro – This corresponds to a scale where each individual receptor at risk (e.g. person, vehicle or property) is modelled and there is a detailed representation of the evacuation routes. A complex modelling system (e.g. an agent-based model, Dawson et al, 2012) is often used to estimate the evacuation times for each individual receptor;

Meso – This corresponds to a scale that is between a micro and macro-scale. In meso models the receptors are lumped together. The evacuation time is estimated by assessing the demand for and the capacity of the evacuation routes, which are evaluated geographically;

Macro – In a macro model the receptors are also lumped together. The estimates of the evacuation times are based purely on the distance to the exit of the at-risk area, the capacity of the route and the average evacuation speed. A macro scale model is often used to provide an initial estimate of the evacuation time for a large area (e.g. at a regional scale).

The evacuation model type fitting a particular flood risk area is determined based on the level of risk and the information that is expected to result from the model. For example, a micro model could be the best choice for an emergency plan for a relatively small, densely populated at-risk area. This is because a detailed simulation model is needed for modelling flood hazard and traffic in a truly dynamic way for large groups of evacuated people. Figure 3.1 shows the appropriate level of evacuation analysis considering the scale of analysis versus the level of detail, as suggested by Lumbroso (2010).

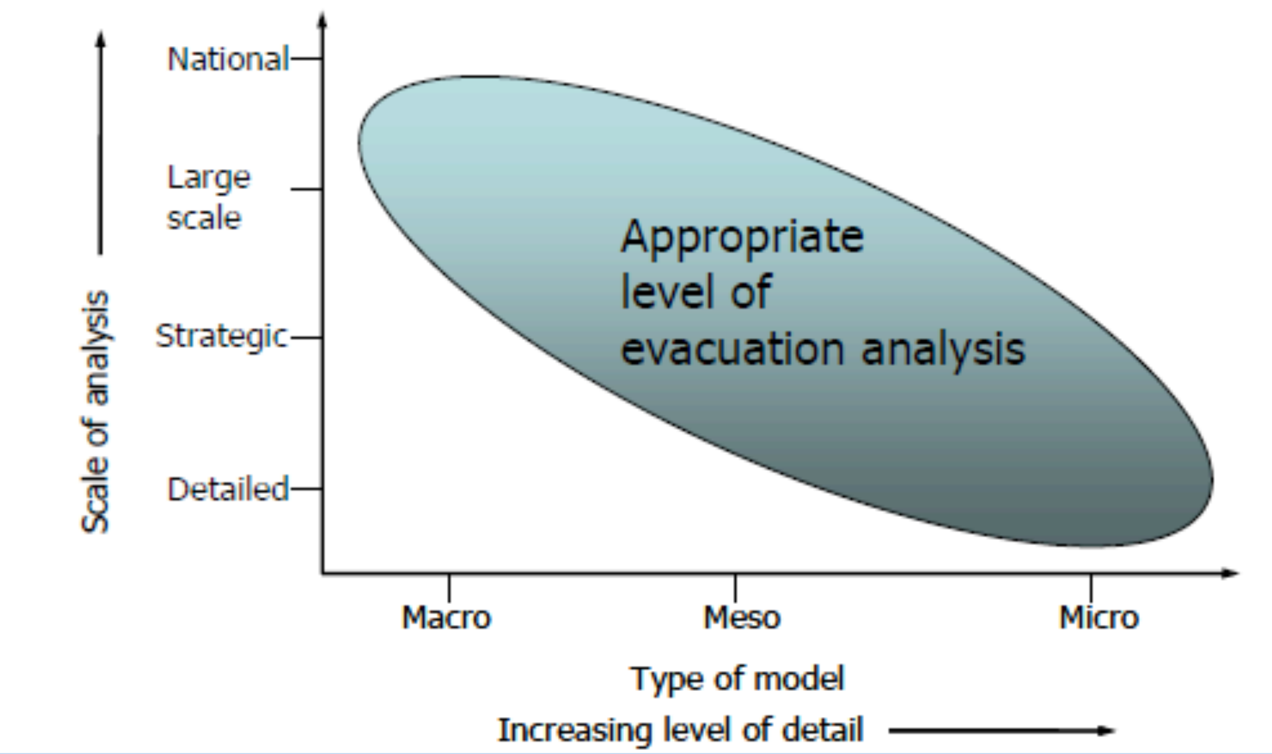

Figure 3.1 Appropriate level of evacuation analysis (source: Lumbroso et al., 2010)

Three types of mass evacuation models have been implemented in the UK, the Netherlands and North America in order to assess mass evacuation times for floods, and these are: Life Safety Model (LSM); INtegrated DYnamic traffic assignment model (INDY); and The Evacuation Calculator. Table 3.1 summarises the characteristics of each model type.

Table 3.1 Main available evacuation models

Evacuation models			
Model Name	Scale	Model input	Model Output
Life Safety Model (LSM)	Micro scale	Iinitial state of the world (which describes modelling receptors such as people, buildings, cars, roads) Flood wave characteristics	Estimates the potential loss of life Estimates evacuation times Estimates potential number of buildings that will collapse Produces a spectrum of virtual representations of how a flood emergency could evolve
The INtegrated DYnamic traffic assignment model (INDY)	Meso scale	Details of the road network of the area	Estimates mass evacuation times for floods Predicts traffic conditions over time Identifies the locations where

			congestion is expected Estimates the corresponding delays
The Evacuation Calculator (ESCAPE)	Macro scale	Average number of people per vehicle Average travel velocities Outflow at the exits	Estimates required time for evacuation Determines the effect of traffic management on required evacuation time
Spreadsheet based approach for evacuation time estimation	Macro scale	Number of vehicles Distance of the vehicles from the exits	Quick overall estimate of the maximum time it could take to evacuate an area

3.3 Calculating net present values

The standard approach to valuing costs and benefits that occur at different times is based on the fact that a Euro now is worth more than a Euro next year. Discounting is a technique used to convert all costs and benefits that occur in different time periods to 'present values,' so that they can be compared. The discount rate is normally equivalent to the average return one might expect if the same amount of money was invested in an alternative project. The present value of the stream of benefits is the sum of all annual benefits, with each annual benefit discounted by the appropriate discount rate (r) to convert it into present value terms. A fixed discount rate is used to represent the opportunity costs of using the public funds for the given project. In the following formula, B_r denotes the annual net financial cost or benefit.

Present value of benefits = $\sum_{r=0}^{T} \frac{B_r}{(1+r)^t}$

The net present value rule should be a key basis for recommendation and decision-making in every project evaluation, among other evaluation criteria (e.g., social, environmental). The total costs of the project over its lifetime, per each year, are subtracted from the total benefits in that year to yield the net benefits in each year. The NPV takes the net benefit (benefit minus cost) each year and discounts these to their present day value. If the result is greater than zero, this indicates that the benefits outweigh the costs. The higher the value, the greater the financial argument for initiating the project (Chadburn et al., 2010).

4. Pilot study: addition of shelter-function to schools in Dordrecht

4.1 Case study description

The city of Dordrecht (the Netherlands) forms the southern gateway to the urban agglomeration of Amsterdam, Utrecht, Rotterdam and The Hague and is situated in one of the lowest parts of the Netherlands (from -1 m to +3 m above sea level). It counts approximately 120.000 inhabitants and lies next to the bifurcation of the Beneden Merwede, the Oude Maas and the Noord. The city is effectively located on an island, being surrounded by the Beneden Merwerde and the Oude Maas in the north, the Dordtsche Kil in the west and the Nieuwe Merwede and Hollandsch Diep in the south (figure 4.1).

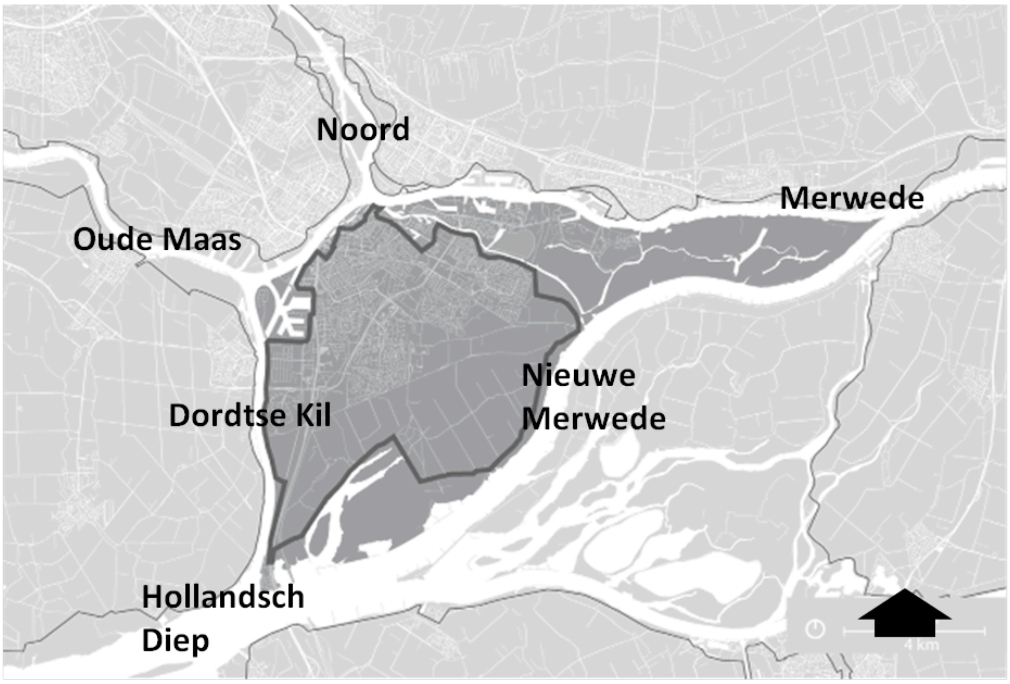

Fig. 4.1 Rivers and canals surrounding the Island of Dordrecht

The Island of Dordrecht lies in the transition zone between a tidal reach and a river regime reach, where the extreme water stages are influenced by both the river discharge and the sea level. The flow direction depends on the discharge of the Rhine and (to a lesser extent) the Meuse. During low tides, water flows toward the sea through the Maeslant barrier in the Nieuwe Waterweg, the Hartel barrier in the Hartelkanaal and the locks in the Haringvliet. The Nieuwe Waterweg and the Hartelkanaal are open outlets, which can be closed off. The discharge at the Haringvliet locks depends on the Rhine discharge at Lobith. The locks are shut when the river discharge is low (<1,200 m3/s), and fully open at a river discharge of 10,000 m^3/s. The flow direction changes when the Rhine discharge at Lobith is larger than 4,000 m^3/s. From this point onwards the river discharge starts to dominate the incoming tide flow.

The Island of Dordrecht is encompassed by a 37.1 km long dike ring, which protects an area of about 70 km^2. The dike ring comprises the system of primary flood defences. Protection standards for dike ring areas in the Netherlands have been established by national law (VenW, 2010) as the average exceedance frequency of the design water level that the flood defences must withstand. The legal protection standard for the Island of Dordrecht has been set at 1/2,000 per year. This refers to the average exceedance frequency of the design water level that the every dike section must withstand. The dike ring area is, furthermore, divided by a number of compartmentalization dikes. These secondary flood defences are not part of the flood risk management strategy. Nevertheless, they are kept in their original state as much as possible. The (Wieldrechtse) Zeedijk is the most important compartmentalization dike. It runs from west to east and divides the island into halves.

Figure 4.2 shows the three main land use categories of the Island of Dordrecht. These categories are residential and transport, industry and commerce and agriculture and recreation. These categories are based on the damage categories used in the standard method to calculate damages and casualties due to floods (Kok et al, 2005). The figure shows that most agriculture and recreational areas lie south of the (Wieldrechtse) Zeedijk and east of the city, while the residential, industrial and commercial areas lie in the north west of the Island. Most industrial areas lie next to the rivers, outside the primary defence system.

The island is connected to the main land by only a few bridges and tunnels. The four main important connections are: the Drecht tunnel and (train and vehicles) bridge in the north east, the Merwede and Baanhoek bridges (train and vehicles) in the north, the Kil tunnel (vehicles) in the east and the Moerdijk bridge (train and vehicles) in the south west (ANWB and TD, 2004).

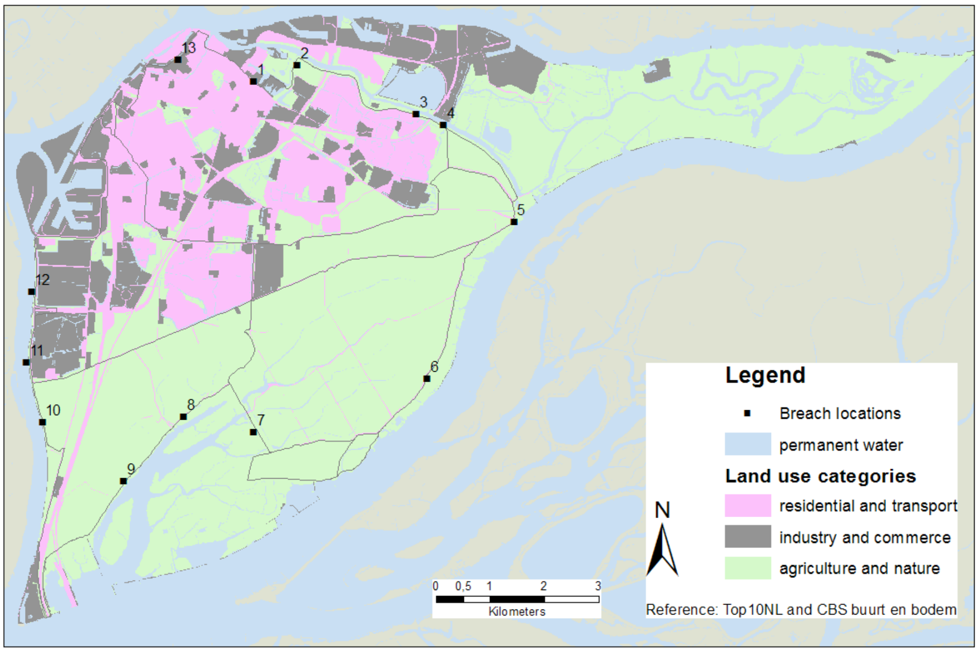

Fig. 4.2 Main land use on the Island of Dordrecht (source: Lips, 2012)

4.2 System Analysis

The primary flood parameters for the Island of Dordrecht have been analysed within the context of the European project MARE, and the results of this project are summarised here after Hoss et al. (2011). These parameters are: flood probability: flood probability, flood pattern, preventive evacuation and casualties.

4.2.1 Flood probability

This parameter describes the probability that a breach occurs in the dike ring, and it is build up from the probability of failure of the dike ring sections and several failure mechanisms. The dike ring of the Island of Dordrecht has a legal protection standard of 1/2,000 per year. The factor between the failure probability of a dike section and the failure probability of the dike ring is taken by Hoss et al. (2011) as approximately 4 for the mechanism Overtopping/Overflow. Furthermore, they assumed that the mechanism Overtopping/Overflow and the mechanisms Piping and Instability have an equal contribution to the failure probability. Taking into account the protection standard, the length effect and the distribution of the failure probability over the failure mechanisms, they have estimated the failure probability of the dike ring at 1/250 per year.

4.2.2 Flood pattern

The flood pattern describes how floodwater enters and propagates through a dike ring area. For each of the dike sections several flood scenarios have been derived in the project Water Safety 21st century and flood characteristics have been determined. Because it is not known in advance at which water level a dike will breach, the Water Safety 21st century project considered two situations: a situation where a breach occurs at a water level equal to the design water level (1/2,000 per year) and a situation that has a factor 100 lower probability (1/200,000 per year). The maximum water depth and maximum water velocities through the different breaches used in the Water Safety 21st century project are shown in figures 4.3 and 4.4 for the situation with a Design Water Level. These figures show that for the area north of the (Wieldrechtse) Zeedijk the maximum water depth (from different breaches) lies in between 2 and 5 meters. The maximum water depths south of the (Wieldrechtse) Zeedijk are much lower and lie in between 0.2 and 2 meters. Furthermore, these studies showed that a breach near breach location 5, Kop van het land, is the most destructive and inundates the largest area with the highest water depths compared to the other breaches. Figure 4.4 shows that the highest velocities are reached near the breach locations and small areas in between higher areas (embankments) that lie within the dike ring. The velocities can be faster than 0.5 m/s near the breaches and in between higher areas, but are less than 0.2 m/s in most areas of the island.

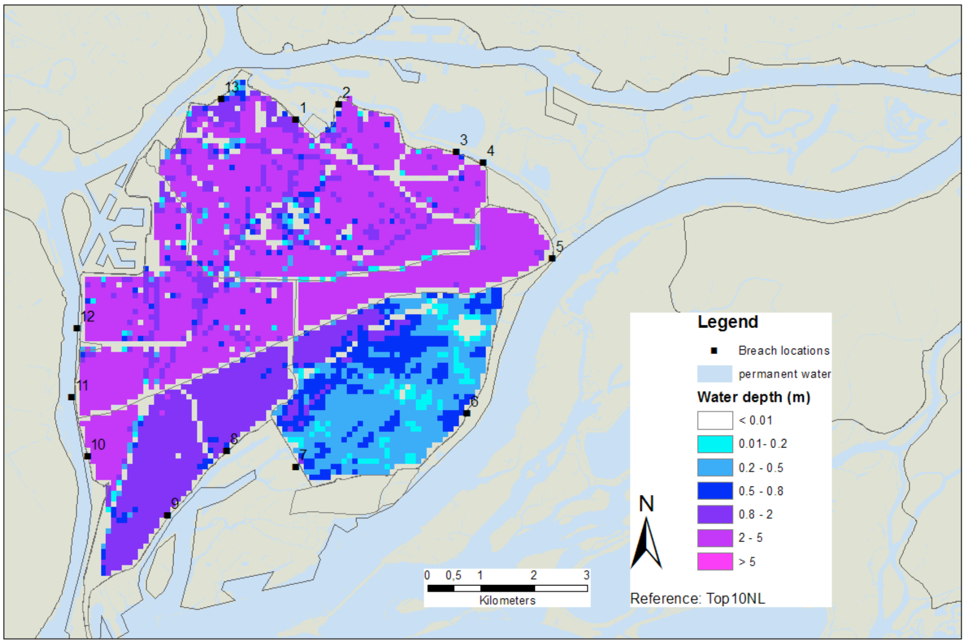

Fig. 4.3 Maximum water depths for all breaches (source: Lips, 2012)

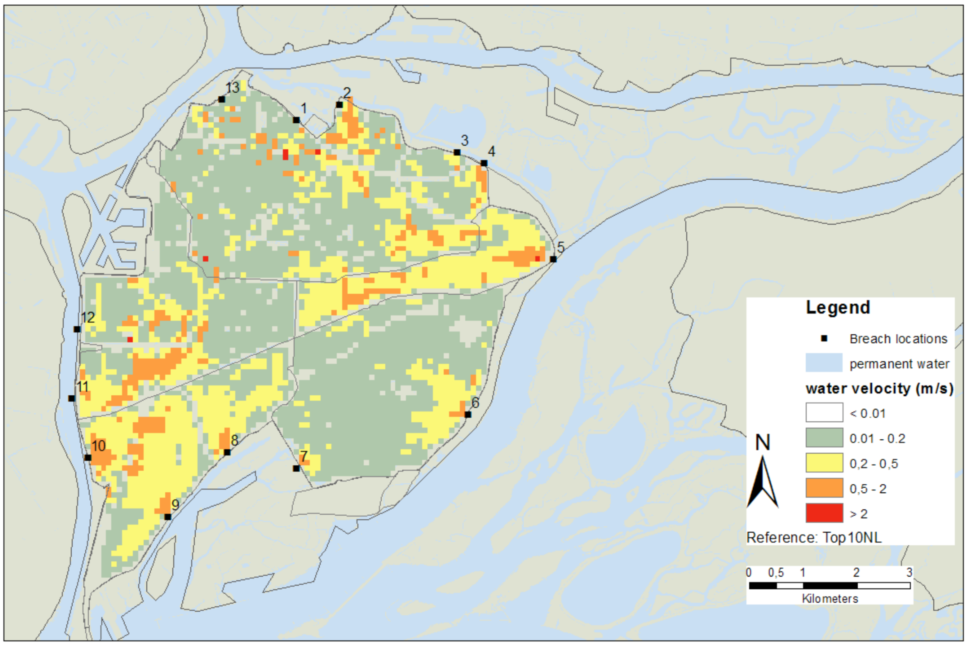

Fig. 4.4 Maximum water velocities for all breaches (source: Lips, 2012)

4.2.3 Preventive evacuation

The preventive evacuation is the percentage of inhabitants of the dike ring area that can be evacuated before a breach occurs. In the Water Safety 21st century project, preventive evacuation has been schematized with four evacuation scenarios: 1) unexpected, no evacuation; 2) unexpected, unorganized; 3) expected, unorganized; and, 4) expected, organized. A conditional probability (which is the probability that a given evacuation scenario occurs) and an evacuation percentage have been assigned to each evacuation scenario (Table 4.1). By combining the conditional probabilities and the evacuation percentages an average evacuation percentage of 15% of the inhabitants is found for the Island of Dordrecht (Maaskant et al. 2009).

Table 4.1 Conditional probability and evacuation percentage per evacuation scenario (source: Hoss et al. 2011)

Preventive evacuation strategy					
Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Average
Conditional probability	0.40	0.44	0.12	0.04	
Evacuation percentage	0.00	0.03	0.59	0.76	0.15

4.2.4 Number of casualties

The number of causalities gives the human lives lost as a direct consequence of a flood. This can be determined using the mortality rate (the probability that a person dies as a result of the flood characteristics occurring at a particular location) and the ability to evacuate before a breach occurs. The Flood Information System Damage and Casualty Module (HIS-SSM) contains mortality functions that calculate the probability of death at a particular location based on the flood characteristics occurring, such as the water depth, water velocity and rise rate. The number of casualties for the Island of Dordrecht is analysed with HIS-SSM for two situations. A first set of calculations has been made for the situation with a Design Water Level (1/2,000 per year) and a further set of calculations has been made for a situation with a factor 100 lower probability (1/200,000 per year). Table 4.2 shows the number of casualties as calculated by Hoss et al (2011). This table shows that the number of casualties is high in areas with many residential areas (e.g. dike section 5), while it is lower in areas with an industrial function (e.g. dike section 12). Furthermore, damage and casualties are higher in areas that suffer a bigger water depth. In general the areas that suffer the biggest flood impact lay at the northern side of the island, while at the southern side flood impact is less.

Table 4.2 Number of casualties per dike section (source: Hoss et al. 2011)

Number of casualties													
Dike section	1	2	3	4	5	6	7	8	9	10	11	12	13
Casualties with a 1/2,000 per yr water level	25 - 100	40 - 165	40 - 160	40 - 160	170 - 710	0	0	0	0	2 - 7	20 - 85	10 - 40	0
Casualties with a 1/200,000 per yr water level	55 - 230	90 - 370	140 - 600	115 - 480	285 - 1,200	0	0	0	1 - 4	5 - 20	40 - 170	25 - 105	15 - 75

The expected value of the numbers of casualties was calculated by the summation of all possible breach scenarios. Here, all breach scenarios have a contribution depending on the probability that it occurs and the number of casualties associated with it. This expected value gives the total flood risk of a dike ring with regard to casualties, expressed in expected annual number of casualties (EANC). For the Island of Dordrecht, the expected value of the numbers of casualties has been estimated by Hoss et al. (2011) at 0.42 casualties per year.

The visualization of the Local Individual Risk (LIR) - including evacuation - is given in figure 4.5. The Individual Risk expresses the flood risk at every location in the dike ring area. It is equal to the probability of dying as a result of the flood characteristics (water depth, water velocity and rise rate) for a certain location. The IR is larger in the urbanised parts of Island of Dordrecht than in the rural parts. The industry park Dordtse Kil in the west of the island is by far the largest area with an increased LIR (Hoss, 2010).

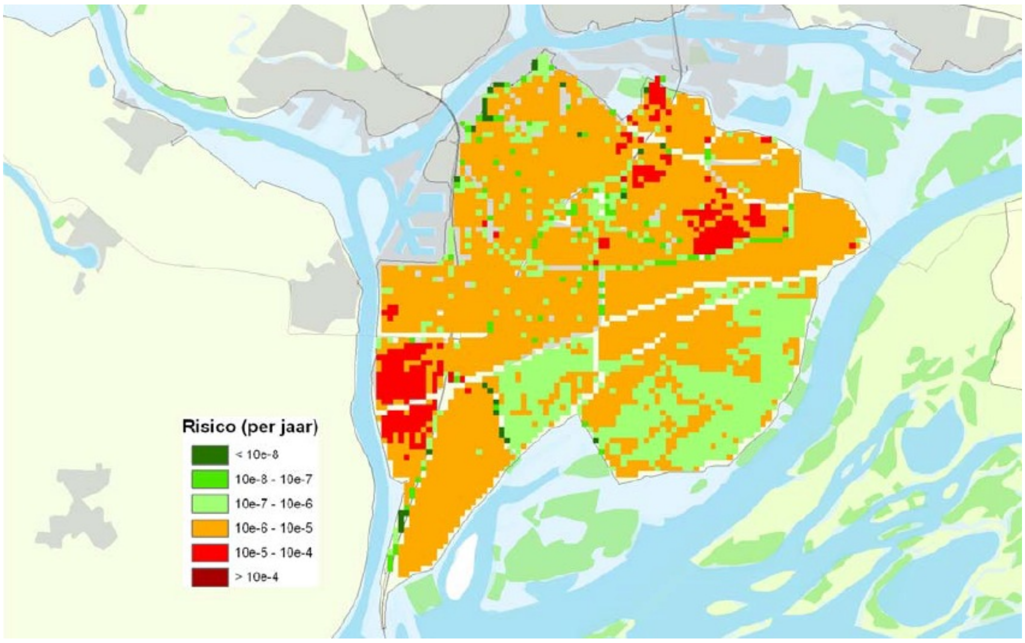

Fig. 4.5 Local Individual Risk (including evacuation) for the Island of Dordrecht (source: Hoss et al. 2011)

4.3 Setting objectives

The objective set by the municipality, in close cooperation with the other stakeholders involved in flood risk management for the Island of Dordrecht, is to find practical measures on the city level that make the Island of Dordrecht safer and more attractive. An important starting point in this respect is connecting flood safety with spatial developments and water awareness.

The city of Dordrecht aims to identify synergistic opportunities where measures in one level of flood safety, such as protection, are synergetic to the effectiveness of other levels of flood safety, such as prevention or preparedness. Another important connection is that between flood safety and spatial development. Successfully connecting policy development ambitions in different sectors can speed up the implementation process for flood safety. Furthermore, new sources of funding can be addressed and/or costs can be reduced.

The area specific evacuation strategy is mainly directed toward measures in the third safety level (preparedness) and is supported by measures from the first safety level (protection) and second safety level (prevention). This strategy strives to reduce the flood risk with regard to casualties below certain target values. Target values can be predefined by the stakeholders or can be imposed by law. Different target values can be established for the different risk measures, such as the LIR and EANC. These target values can be used to assess whether a given intervention reaches the desired flood safety. One of the objectives of the Second Delta Committee is to make the Netherlands ten times safer. In this respect, the potential interventions can be ranked according to the degree by which they reduce the EANC. The actual target value for flood risk corresponding with a ten times saver situation can be calculated by dividing the EANC for the reference situation by ten. The target value for the LIR, as proposed by the Delta Programme Rhine Estuary-Drechtsteden, should be below 10^{-5} per year.

4.4 Potential Interventions

Complete preventive evacuation for the Island of Dordrecht is not seen as feasible for the following reasons: 1) there are few main escaping routes (main high ways) off the Island; 2) the amount of time for the evacuation is short (24 hours before the highest water levels it is not possible to evacuate anymore due to the fact that a heavy storm is blowing over the area); 3) the number of people that need to be evacuated is large (densely populated area); 4) neighbouring dike ring areas will be experiencing the same problem, so that there is no place to evacuate to. Therefore, an area specific evacuation strategy is envisioned. The proposed interventions for this strategy are to designate buildings on high places as smart shelters, to improve the self-reliance of the people, and to improve warning and crisis communication.

4.4.1 Smart shelters

Buildings on naturally existing high places on the island are to be designated as smart shelters for the non self reliant people. For this purpose, several schools have been selected to serve as shelters to receive evacuees. This is because these buildings already have a function in accommodating large amounts of people. Their canteens will be constructed on higher floor levels once these schools are renovated or newly build.

4.4.2 Improving self reliance

Through communication about potential disasters and training the self reliance of the people will be increased. This is aimed at encouraging self-reliant people to stay in their houses or to seek shelter in high buildings in the area.

4.4.3 Improving warning and crisis communication

By an improved warning system the likelihood of an expected and organized evacuation increases. The improvement of the communication to the people during a disaster will increase the effectiveness of disaster management. This intervention will need to be implemented on several levels: local, regional and national.

4.5 Setting functional requirements

As part of the area specific evacuation strategy, about 20% of the people that remain on the island after preventive evacuation will still be evacuated to the smart shelters. The required sheltering capacity has been calculated using these factors (see chapter 4.6), and it amounts to about 8.000 to 14.000 shelter places. The shelters should be self-sufficient, either permanently or temporarily (i.e. using emergency responses), in terms of sanitation, drinking water, sewage, power supply, ventilation and communication.

4.6 Cost-effectiveness analysis

4.6.1 Effectiveness of area specific evacuation strategy

The effect of the area specific evacuation strategy on the flood risk with regard to casualties has been assessed by Hoss et al. (2011). The improved warning system will alter the conditional probabilities per evacuation scenario in favor of the scenarios with higher evacuation factors, whereas improved preparation will increase the evacuation factors for these scenarios (Table 4.3). This results in a higher average evacuation percentage, raising from 15 to 28%. Furthermore, the construction of smart shelters will lead to a reduction of the mortality by 50%. This means that the number of casualties is halved.

Table 4.3 Conditional probability and evacuation percentage per evacuation scenario (source: Hoss et al. 2011)

Area specific evacuation strategy					
Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Average
Conditional probability	0.28	0.38	0.18	0.16	
Evacuation percentage	0.00	0.07	0.71	0.79	0.28

With the area specific evacuation strategy the EANC reduces to 0.145 expected casualties per year, which amounts to 0.28 less expected casualties per year. This comes down to a reduction of the risk of 66%. Though this is a significant reduction, these interventions alone are not sufficient to make the Island of Dordrecht ten times safer in terms of casualties compared to the reference situation.

Figure 4.6 shows the LIR map for the area specific evacuation strategy. Comparing this figure with figure 4.5, it can be seen that the LIR changes considerably. The critical spots with a LIR greater than 10^{-5} per year, like the Dordtse Kil, become much smaller. This suggests that the proposed interventions are largely effective in reducing the LIR to the target value (10^{-5} per year). Furthermore, there is little "unnecessary" risk reduction in areas that already meet the target value in the reference situation.

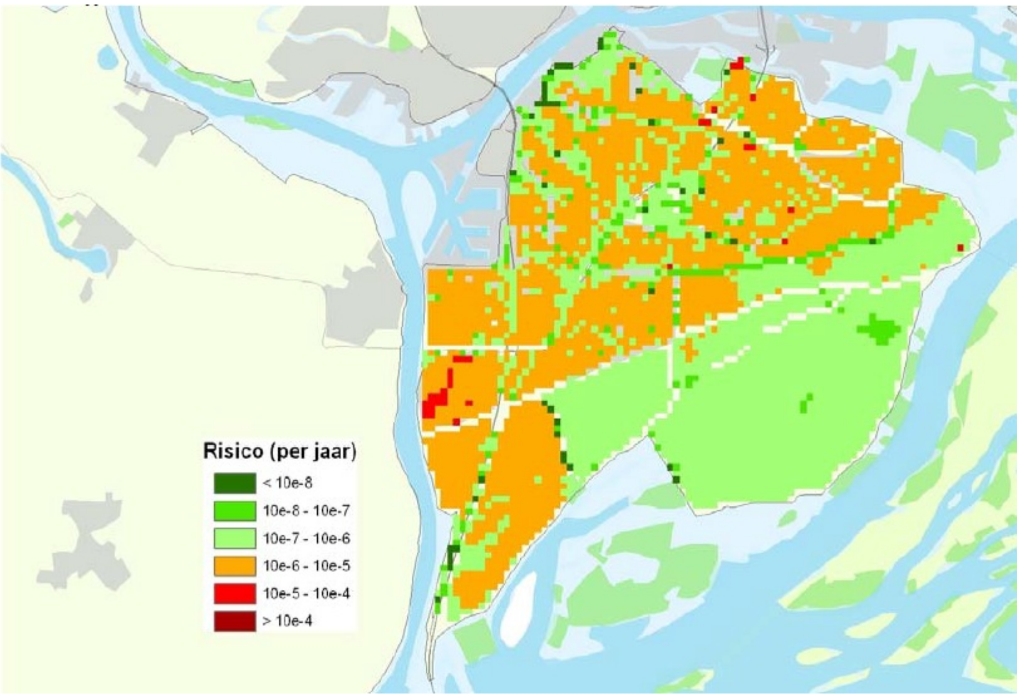

Fig. 4.5 Local Individual Risk (including evacuation) for the Island of Dordrecht (source: Hoss et al. 2011)

4.6.2 Costs

Table 4.4 gives an overview of the cost items and cost estimates for the area specific evacuation strategy. The cost items have been classified as investment cost in the preparation phase, recurrent cost in the preparation phase, and recurrent cost in the response and recovery phase. The cost estimates give the order of magnitude of estimated cost for the cost items. These are shown as a range (minimum - maximum) for some cost items.

Table 4.4 Overview cost items and cost (adapted from: Stone et al. 2011)

Area specific evacuation strategy		
Investment cost in the preparation phase	Cost estimate	
Planning cost to determine the type, number, and size of the needed shelters	0.1	MEuro
Implementation of modification measures to improve present buildings to be a shelter	9.8 - 17.2	MEuro
Recurrent costs in the preparation phase		
Risk communication between different emergency services involved in evacuation programs and to the public	-	MEuro
Education and training of the emergency services staffs	2.5	MEuro
Recurrent cost in the response and recovery phase		
Costs of displacement of people into shelter	0.2 - 0.4	MEuro
Cost of providing immediate and urgent needs such as food, health care, etc.	10 - 35	MEuro

The modification and extension of the existing crisis management plan is required, because the area specific evacuation strategy requires different responses and capacities than the current strategy. For example, the type, number, and size of the shelters should be investigated as part of the planning process. The planning cost has been estimated from the cost incurred for the development of the Regional Basic Plan Floods. This amounted to approximately 0.1 MEuro.

The cost for adding the shelter-function to schools is estimated at 20% of the investment cost of building new schools. The average construction cost for an educational building in Dordrecht amount to 1,000 Euro per square meter of gross floor area. The costs for the addition of shelter locations are therefore equal to 200 Euro per square meter of gross floor area. Assuming a ratio of usable flood area versus gross floor area of 0.65, this amounts to € 308 Euro per square meter. The required usable floor area for sheltering one person (for the period of 1-2 weeks) is approximately 4 square meters (based on the American RedCross recommendations - see Section 2.3.3). The cost for the addition of a shelter-function to schools is therefore € 1232 per shelter place. Assuming 8000-14000 shelter places, the total investment cost amount to 9.8 to 17.2 MEuro.

Risk communication between different emergency services involved in evacuation programs and to the public is an essential part of the area specific evacuation strategy. For example, people should be made aware that it is safer to find shelter on the island than to evacuate and risk getting stuck in traffic. Also, for the non self reliant people it should be clear that they can get health care, etc. in designated shelter locations in the neighborhoods. The cost for risk communication are not known.

The emergency services staff should be trained and the new strategy should be practiced. These costs were estimated at 2.5 MEuro per year.

It is estimated that about 100 policemen are required for the displacement of 5000 non self reliant people into shelters. Given the short early warning period, it is assumed that the displacement into shelters has to take place within one day. The cost of a policeman per 24 hours is 1500 Euro. Assuming that 8000 to 14,000 persons have to be displaced, the total cost is estimated at 0.2 to 0.4 MEuro.

The cost of providing health care has been estimated using the average care cost per day in a nursing home. This amounts to 185 Euro per person per day. These costs do not include medical supervision. Assuming 8000-14000 shelter places for 1-2 weeks, the total cost is about 10 to 35 MEuro (minimum: 1 week shelter for 8,000 people; and maximum: two weeks shelter for 14,000 people).

4.7 Cost-benefit analysis

The benefits of the area specific evacuation strategy can be calculated by expressing the casualties in terms of economic damages. In the Water Safety 21st century project a monetary value of 6.7 MEuro is assumed per casualty. The reduction in casualties with the area specific evacuation strategy has been estimated at 0.28 less expected casualties per year. This implies that the economic damage is reduced by 1.9 MEuro per year. These annual benefits should be discounted into present values terms, taking into account a discount rate of 4%. In case of an infinite time horizon, the present value of benefits comes down to 48.8 MEuro.

The costs of the area specific evacuation strategy consists of investment cost in the preparation phase, recurrent cost in the preparation phase, and recurrent cost in the response and recovery phase. The present value of costs has been calculated at 75.0 to 82.8 MEuro, by adding the discounted costs together over the time horizon.

Subtracting the benefits from the costs gives a negative NPV of 26.3 to 34.0 MEuro. This implies that the investment in smart shelters cannot be justified economically. It is of note, however, that this is mainly due to the relatively high cost of education and training of the emergency services staffs.

5. Conclusions

Floods are one of the most destructive natural hazards and the cause of most natural disasters affecting society. During recent decades, the intensity and occurrence of catastrophic flooding has increased and is predicted to occur even more often in the future. Flooding impacts cause enormous damage to the economy. Various and diverse mitigation plans including embankments, constructing detention and retention areas, and other structural measures have been implemented across the world to reduce the consequences of flooding and to protect people and properties especially in urban areas. However, the current records of flood damages indicate that these measures are so far not adequate to cope with flooding. Therefore, in addition to structural measures, other emergency measures such as flood shelters are also needed immediately and urgently when disaster strikes.

An emergency plan for the period of inundation comprises of mass evacuation during the warning period before flood water reaches a critical level, during flooding for the people exposed and after flooding in the recovery phase. The primary target is to evacuate the entire population at risk into areas outside the inundated region. However, there are groups of people (elderly, sick people, disabled etc.) who cannot evacuate on their own. These should be accommodated in shelters as near to their homes as possible to increase the efficiency of the evacuation during the warning time. However, traditionally, shelters will often be used only for a short period of time during a flood. In order to realise economic benefits and be sustainable, shelter structures need to be used synergistically for multiple purposes for the periods when there is no flood risk. These multi-purpose flood shelters can then be used to manage hazard relief and rehabilitation activities as needed in a pre-planned way. Smart shelters are not only a means of mitigation but also a means of development. Smart shelters can provide facilities for a wide variety of sustainable uses such as education and health care and promote local development if they are built appropriately. Alternatively, the modification of existing buildings is a smart idea to reduce the need for a huge amount of investment that may be needed for construction and maintenance of new smart shelters.

This guide describes two typologies of smart shelters: short-term and long-term, depending on the duration of the occupancy. In addition to the functions offered by a short-term shelter (during the evacuation time and the duration of the flood), long-term shelters will function as a safe haven during the recovery phase in the aftermath of a disaster. This is therefore expected to be in the order of days to weeks. Functional and spatial requirements for short-term and long-term shelters may therefore potentially be different.

To determine the most efficient smart shelter strategy, decision makers have to decide how many shelters to build and where to build them, to be able to cover the designated area and to give shelter to all non self reliant refugees. The spatial distribution of the land use, flood risk maps, evacuation plans and demographic data will determine the need for shelters, site selection and the number and capacity of the shelters needed. Careful planning of shelters can be cost-efficient since fewer shelters are most certainly less expensive and planning smart shelters on natural higher ground could severely reduce the costs of a shelter. Having to build and maintain one or multiple shelters has both pros and cons, but the main need will be for shelters to be accessible/reachable within the warning time available. Both existing buildings and new construction can be used to plan the smart shelter strategy.

In order for an existing or new building to function as a smart shelter design modifications are usually necessary for coping with the hazard. The design of a building needs to be modified in such a way that all forces of flooding can be withstood. In order to plan and design a smart shelter the facility should be completely functional and operational during a flood event. Buildings will need several additional requirements to normal buildings to be able to function as a smart shelter. The smart shelter requirements can be categorized into: spatial requirements (floor area for refugees and storage for food, medicine, water, and access) and infrastructural requirements (sanitation, drinking water, sewage, power supply, ventilation and communication) in order to be self-sufficient during floods. All requirements will have to comply with international and national codes.

One of the objectives of the second Delta Committee is to make the Netherlands ten times safer. The example of the city of Dordrecht has been used to illustrate the costing of smart shelters to be provided. Complete preventive evacuation for the Island of Dordrecht is not seen as feasible. Therefore, an area specific evacuation strategy is envisioned. The proposed interventions for this strategy are to designate buildings on high places as smart shelters, to improve the self-reliance of the people, and to improve warning and crisis communication. Several schools on naturally existing high places on the island have been selected to serve as shelters to receive evacuees. Assuming 8000-14000 shelter places for 1-2 weeks, the present value of total costs for the area specific evacuation strategy has been calculated at 75.0 to 82.8 MEuro. The present value of benefits from the reduction in casualties amounted to about 48.8 MEuro. Because the costs exceeded the benefits, the investment in smart shelters was not economically worthwhile in the case study.

6. References

American Red Cross (ARC) (2002) *Standards for Hurricane Evacuation Shelter Selection*. Publication No. 4496.

ANWB and Topografische Dienst Kadaster (TD) 2004. *ANWB Topografische Atlas Zuid-Holland 1:25.000*. ANWB Media en Bart Bennis. Papendrecht 101 p.

Asian Development Bank (ADB) 2005. *Financial Management and Analysis of Projects*.

Associated Programme on Flood Management (APFM) 2007. *Economic Aspects of Integrated Flood Management*. WMO-No.1010.

Canada 1998. *A Benefit-Cost Analysis Guide*. Ottawa, Canada: Treasury Board of Canada Secretariat.

Chadburn, O., Ocharan, J., Kenst, K. & Venton, C. C. 2010. Cost Benefit Analysis for Community Based Climate and Disaster Risk Management: Synthesis Report.

Corsellis, T. & Vitale, A. 2005. transitional settlement, displaced populations. *University of Cambridge shelterproject.* Oxfam GB in association with University of Cambridge

Dawson, R., Wang, M. & Buhler, J. Year. Flood incident management for water sensitive urban design. *In:* WSUD 2012: Water sensitve urban design; Building the water sensitve community; 7th international conference on water sensitive urban design, 21-23 February 2012, Melbourne Cricket Ground, 2012. Engineers Australia, 483.

Defra 2010. Flood and Coastal Erosion Risk Management appraisal guidance. UK: Environmental Agency.

FEMA 2004. *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings*.

FEMA 2008. P646 *Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*.

Hallegatte, S. 2006. *A Cost-Benefit Analysis of the New Orleans Flood Protection System*.

Hm-Treasury 2011. *The Green Book: Appraisal and Evaluation in Central Government*.

Hoss, F., Ter Horst, W., Jonkman, B. & Maaskant, B. 2011. Multilayered Safety Strategies in Dordrecht. Analysis of risk to life. TU Delft, Faculty of civil engineering and geosciences. 65p.

International Code Consortium (ICC-500) 2008. *Standard for the Design and Construction of Storm Shelters*.

Jonkman, S. N., Gelder, P. H. A. J. M. V. & Vrijling, J. K. 2003. An overview of quantitative risk measures for loss of life and economic damage. *Journal of Hazardous Materials,* 99**,** 1-30.

Kar, B. & Hodgson, M. E. 2008. A GIS-Based Model to Determine Site Suitability of Emergency Evacuation Shelters. *Transactions in GIS,* 12**,** 227-248.

Kok, M., Huizinga, H.J., Vrouwenvelder A.C.W.M. & Van den Braak, W.E.W. 2005. *Standaardmehtode 2005 Schade en Slachtoffers als gevolg van overstromingen*. HKV Lijn in water en TNO Bouw in opdracht van Rijkswaterstaat DWW. PR999.10. 33p.

Lips, N. 2012. *Application of storylines for strategy development in flood risk management (FRM): A case study on the flooding of the island of Dordrecht (the Netherlands)*. MSc Thesis, Utrecht University.

Lumbroso, D., Gaume, E., Logtmeijer, C., Mens, M. & Vat, M. V. D. 2009. Evacuation and traffic management: Executive Summary *In:* Floodsite (ed.).

Lumbroso, D. M., Johnstone, W., Bruijn, K. D., Mauro, M. D., Lence, B. & Tagg, A. 2010. Modelling mass evacuations to improve the emergency planning for floods in the UK, the Netherlands and North America. *the International Conference on Emergency Preparedness (InterCEPt), the Challenges of Mass Evacuation.* University of Birmingham, UK

Maaskant, B., Kolen, B., Jongejan, R., Jonkman, B. & Kok, M. 2009. *Evacuatieschattingen Nederland*. Projectnummer: PR1718.10, HKVlijninwater.

Merrell, D., Simmons, K. & Sutter, D. 2002. Taking Shelter: Estimating the Safety Benefits of Tornado Safe Rooms. *ican Meteorological Society*.
Nigg, J. M., Barnshaw, J. & Torres, M. R. 2006. Hurricane Katrina and the flooding of New Orleans: Emergent issues in sheltering and temporary housing. *The Annals of the American Academy of Political and Social Science,* 604**,** 113-128.
Pel, A., Bliemer, M. & Hoogendoorn, S. 2011. Modelling Traveller Behaviour under Emergency Evacuation Conditions. *EJTIR,* 2**,** 166-193.
Quarantelli, E. L. 1982. General and particular observations on sheltering and housing in American disasters. *Disasters,* 6**,** 277-281.
VenW 2010. *Water Act*. Available at: http://www.rijksoverheid.nl/documentenen-publicaties/rapporten/2010/02/01/water-act.html