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# A COMPREHENSIVE ASSESSMENT OF MULTILAYERED SAFETY IN FLOOD RISK MANAGEMENT – THE DORDRECHT CASE STUDY

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**ABSTRACT:** In the year 2009, the concept of Multilayered Safety (MLS) was introduced in the Netherlands as a possible way to manage the flood risk. MLS consists of three layers: 1. Prevention (dikes, room for the river, etc.), 2. Spatial Solutions (flood-proofing houses, elevating houses, re-locating etc.), 3. Crisis Management (evacuation, warning, etc.). The main characteristic of MLS is the combination of probability- and loss-reducing measures. Combining measures can be technically tricky as it becomes more difficult to oversee the combined effect of those measures. Thus, in the first part of the study a framework has been developed to get insight into the combined effect of flood management measures of different types. MLS only will become reality if it is more cost-efficient than the standard approach. This has been investigated in the second part of the study. The Island of Dordrecht in the Netherlands was used as a case study. This area has ca. 120,000 inhabitants and is threatened by flooding from the North Sea and the river Waal or a combination thereof. The cost-effectiveness of measures has been evaluated by comparing investment costs and reduction in economic risk and risk for the loss of life. As the cost-efficiency is found to be dependent on the initial safety level, it is concluded that in the Netherlands MLS only has the potential to supplement the existing flood protection. In areas with high levels of protection levels like in Dordrecht, MLS is fit to add to rather than to replace the prevailing prevention approach. However, MLS does introduce the option to better customize flood risk management to local circumstances. Additionally, this characteristic makes MLS an alternative where the prevention-approach falls short to provide sufficient safety.

Key Words: Flood risk, flood risk management, multilayered safety, consequence-reducing measures, prevention

## 1. INTRODUCTION

The struggle of the Dutch people to keep their land dry is ever-lasting. After centuries of developing the Dutch flood protection system, the flood-prone parts of the country are now protected by more than 50 dike rings. In response to major floods this system has far advanced. However, the Netherlands still struggles with a number of flood-related problems. Large parts of the country are below sea level. Effects of climate change, such as sea level rise, as well as subsidence of the land continuously increase the difference between sea level and ground level. The conventional approach to answer those developments with upgrading the flood prevention becomes increasingly more complicated and cost-intensive because space is scarce in a small country like the Netherlands. Especially in densely populated areas strengthening the dikes has become a lengthy administrative and technically challenging process. Furthermore, the economic crisis in 2008/09 has given the ubiquitous objective of working as cost-efficient as possible renewed importance. Additionally, flood prevention intensifies the problem: Generally welcomed economic growth leads to a higher flood risk. The dikes have to be reinforced because they protect more value. However, when new economic development occurs the flood defenses need to be reinforced again. This cycle of dike reinforcements is a continuous strain on financial resources and scarce space. Finally, policymakers have urged to apply an integrated risk approach to flood management. The EU flood directive (2007/60/EC) obligates its member states to make flood risk maps for all their water courses and coast lines and draw up flood risk management plans. The Dutch government has taken up this initiative in its National Waterplan published in 2009. Before Dutch flood management concentrated on decreasing the probability of flooding. Turning to an integrated risk approach means extending this approach by taking the consequences of a flood into account as well.

The National Waterplan (Rijksoverheid, 2009) describes the water management measures that have to be taken in 2009-2015 to keep the Netherlands safe and prospering for the generations to come. It thus

had to answer the challenges mentioned above. The proposed strategy is called Multilayered Safety (MLS). It aims at an integrated flood management using three layers: the conventional flood prevention, spatial solutions and crisis management (Nationaal Waterplan, 2009). However, actual guidance for implementation for MLS is not included in that plan. This study will examine the characteristics, potential and cost-efficiency of MLS within the framework of flood risk assessment and management.

MLS intends combining measures of different types. Thus, an approach is needed to assess the effect of those combinations of measures of flood risk and to evaluate optimal combinations of measures. Part A of this study introduces such a framework. In part B it will be investigated if MLS can live up to its numerous expectations. MLS is only going to be serious option to policymakers if it reduces the flood risk and if it does so cost-efficiently. Since the City of Dordrecht struggles with challenges that many other Dutch regions face it will serve as a case study. A representative choice of MLS measures will be modeled in this case study to analyze their cost-efficiency.

## **2. PART A: MULTILAYERED SAFETY CONCEPTS**

Part A is a qualitative research with two objectives: defining and conceptualizing Multilayered Safety (MLS) and studying the effects and interactions of its individual measures to enable an optimal combination of MLS measures.

### **2.1 Multilayered Safety**

Multilayered Safety (MLS) introduces the novelty of integrating different types of measures into Dutch flood management: reducing the probability and the consequences of floods. So far the Netherlands has mainly relied on flood prevention, thus probability-reducing measures. MLS consist of three layers. Prevention is the first layer of MLS. The second and third layers are consequence-reducing measures, namely spatial solutions and crisis management. The first two layers are physical measures, whereas crisis management concentrates on organizational measures.

Prevention (layer 1) is defined as preventing river and sea water from inundating areas that are usually dry (based on the definition of a flood given in the EU flood directive). This is done by building flood defenses or preventing high river discharges. Spatial Solutions (layer 2) mean using spatial planning and adaptation of buildings to decrease the loss if a flood occurs. Crisis Management (layer 3) focuses on the organizational preparation for floods such as disaster plans, risk maps, early-warning systems, evacuation, temporary physical measures (e.g. sand bags) and medical help.

MLS is subject to both expectations and challenges. Firstly, MLS contributes sustainability by slowing down the continuous cycle of dike reinforcements. If the consequences of a flood do not increase as a side-effect of economic growth (e.g. by building flood-proof), stronger flood defenses will be needed less frequently to keep the risk at the same level. But more importantly, MLS increases safety by anticipating the consequences of a flood. Now the Netherlands rely mainly on prevention. Since the consequences of a major flood would be devastating for Dutch society, calls grow louder to enhance safety by preparing for those consequences. It is hoped that MLS will lead to more cost-efficient flood risk management. However, MLS will only become reality if it is more cost-efficient than the conventional focus on prevention. This is studied in the quantitative part of this study (Part B).

### **2.2 Effect and interaction of MLS measures**

Combining measures of different type complicates flood management from a technical and administrative perspective. To make the best choices the effect and interactions of the chosen measures have to be known. This is a complex business that is best done case-to-case when putting together a MLS package for any area. Nonetheless, a framework has been developed as a tool to make a first selection of measures. It gives an overview of all available MLS measures. Furthermore, this framework ranks the

MLS measures by their type of effect and scale of impact. In the following the framework is introduced. Then the effect and interactions of MLS measures are analyzed.

### **2.2.1 Framework**

The framework has been derived from ten strategies introduced by Haddon (Haddon, 1976), see Table 1. Originally meant to be used in a medical context, each of Haddon's strategies corresponds to a stadium that a calamity passes through before it reaches its full consequence. Thus, every additional measure decreases in geographical scale and subsequently addresses another risk parameter. Risk is defined here in terms of loss of life and economical damage. This framework does not say anything about the costs and desirability of any strategy. As an example, moving objects and people out of an endangered area (strategy 5) is an effective way of decreasing the flood risk. But resettling a city to another location is not only extremely costly; it is also undesirable because water is so crucial for human life that many cities have been purposely built along the coast or rivers. However, by categorizing all flood management measures by those strategies it does become possible to see which measures affect which flood risk parameters. Consequently it also unveils which strategies might physically interact. Knowing the effect and the interaction of measures makes it possible to implement MLS efficiently.

Translating Haddon's strategies to flood management shows that all measures fall into one of three categories: those reducing the hazard source (water overload), decreasing the exposure to that hazard (flood) or decreasing the vulnerability. Strategy 1 and 2 are considered to be physically impossible in flood management. Rivers and seas cannot just be removed or made smaller. They can only be regulated as represented by strategies 3 and 4. Strategy 10 falls outside the scope of MLS. Nonetheless, the framework shows that the rehabilitation after a flood is the chance to reduce the flood risk. Re-building destroyed housing offers the opportunity to e.g. choose a location with lower flood risk and to build the houses more flood-resistant. In this way both the exposure as well as the vulnerability to floods can be decrease considerably during rehabilitation.

### **2.2.2 Qualitative analysis MLS**

Based on extensive literature research an overview of possible flood management measures has been created. Those have been sorted by MLS layer and framework strategy. The framework turned out to have the capacity to classify any measure that was encountered during the literature study. The result is summarized in Table 1. Probability-reducing (or prevention) measures mainly reduce the hazard source. The framework is meant as a tool to be used case-to-case to make a first rough selection of MLS measures. However, in the following a few general observations are made.

Spatial solutions and crisis management as consequence-reducing measures concentrate on reducing the exposure to the flood and the vulnerability to it. This implies according to the framework that probability-reducing measures are generally of a larger geographical scale than consequence-reducing measures. MLS measures that are based on the same strategy or fall into the same of the three main groups (reduce hazard, exposure or vulnerability) are more likely to interact. Therefore, caution has to be exercised if they are combined in a MLS package.

Measures decreasing the hazard source change the boundary conditions. They often constitute far-reaching changes to their surroundings. A parameter analysis shows that measures addressing the exposure to floods mainly interact by increasing the inundation depth in an adjunct area. Measures decreasing the vulnerability, such as flood-proofing houses or improving self-reliance, have the smallest scale and consequently show the least interaction with other measures. However, making objects more robust increases their value and thus the maximal possible damage.

If MLS layers are combined they will interact as well. Combining probability-reducing measures with consequence-reducing measures decreases the effect of the consequence-reducing measures and vice versa. After all, prevention makes a flood less likely, so that the consequence-reducing measures will be called upon less often. Vice versa, prevention leads to a larger risk reduction if the consequences are more severe. As a consequence, the cost-efficiency of any additional measures depends on the initial risk

level. Consequence-reducing measures are somewhat more flexible. They are stand-by measures (e.g. sand bags or emergency relief) that adapt to the safety situation. In case of emergency they can be employed where the distress is the largest. However, the organization to keep them on stand-by requires annual spending. If emergencies happen less frequently due to better flood protection, those costs pay off less.

Table 1: Framework to analyze effect of flood management measures and categorization of MLS measures by their effect

Haddon's original strategies	Corresponding strategies in flood management	Flood risk parameter effected	Layer 1: Prevention	Layer 2: Spatial Solutions	Layer 3: Crisis Management
<b>Reduce hazard source (water overload)</b>					
1. Eliminate hazard source	NA	NA			
2. Lower, diminish, reduce hazard source	NA	NA			
3. Prevent release of hazard	Prevent extreme amounts of water in system	Probability of hydraulic load	1-3: Redistributing discharge over river arms; retain run-off		
4. Modify rate of release of hazard source	Relief/alter extreme hydraulic situations	Water level	1-4: Giving waterways more space		
<b>Reduce exposure to hazard (flood)</b>					
5. Separate in space and time hazard source and objects	Prevent that objects/people are in the endangered area	Number of exposed		2-5: Reconsider location of settlements	3-5: Preventive organized evacuation
6. Erect a barrier between the hazard and the objects	Erect a barrier between water masses and objects/people	Probability of exposure/number of exposed	1-6: Large-scale flood defenses	2-6: Compartmentalization	3-6: Temporary flood defenses
7. Modify contact surface of hazard source	Decrease the degree by which objects are affected	Inundation depth	1-7: Flood defenses allowing (controlled) overflow	2-7: Alleviation of buildings (terps etc.)	
<b>Reduce vulnerability</b>					
8. Strengthen objects against hazard	Prevent damage from occurring among exposed	Vulnerability/mortality		2-8: Flood-proofing buildings	3-8: Self-reliance; temporary flood-proofing of buildings
9. Mitigation	Reduce occurring damage among exposed	Vulnerability/mortality			3-9: Emergency relief, rescuing
10. <i>Reparative strategies/stabilization</i>	<i>Re-build what was damaged/rehabilitation</i>	<i>Number of exposed, probability of exposure, inundation depth, vulnerability/mortality</i>			

Taking an array of measures at larger numbers of locations and by a larger number of actors, flood risk management becomes a complicated administrative task. Additionally, it is difficult to oversee what the actual protection level is. After all, not only a larger number of measures has to be maintained and controlled. Implementing more measures will also increase the uncertainty: The interaction between the measures is difficult to foresee and each measure has a chance of failure.

### 3. PART B: COST-EFFICIENCY OF MULTILAYERED SAFETY

Part B is a quantitative research that studies the cost-efficiency of MLS measures to enable an optimal combination of MLS measures. The City of Dordrecht is used as a case study.

#### 3.1 Dordrecht

The City of Dordrecht with its roughly 120,000 inhabitants is located on the Island of Dordrecht, which is protected by dikes that are part of a dike ring (number 22). In the current situation that dike ring has a length of 37km. The dike ring itself is divided by compartmentalization dikes (Figure 1). Those secondary flood defenses are not officially part of the flood defense 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. The island has to withstand high waters from the North Sea, the river Waal or combinations thereof. It is bounded by waterways called the *Beneden Meerwede* and the *Oude Maas* in the north, the *Nieuwe Meerwede* in the south and the *Dordtse Kil* in the west. Most of Dordrecht's urbanized area lies under sea level between NAP -1.0m and 0.0m. The design water level for its current primary flood defenses is roughly NAP 3.0m ± 0.3m, varying per location. The city covers 2,800 ha, while the Island of Dordrecht is 10,000 ha big.

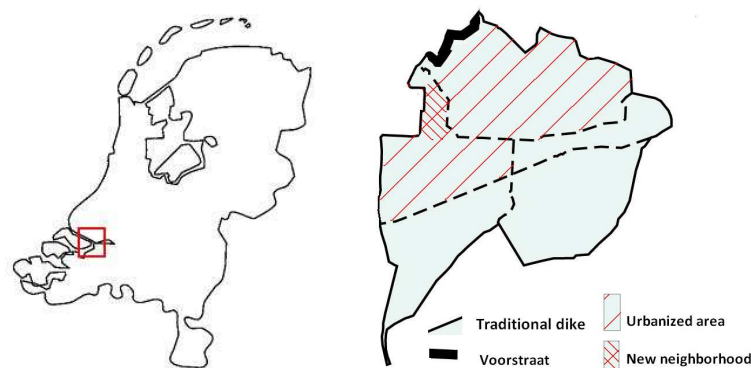


Figure 1: Right side - Location of dike ring 22 in the Netherlands. Left side - Flood defenses of dike ring 22. In the right picture the neighborhood that is to be renovated is indicated.

The flood protection of the Island of Dordrecht mainly consists of its dike ring. Thus, the current focus lies strongly on prevention. By law, the primary dikes along dike ring 22 have to withstand a water level that has a probability of exceedance of  $P=1/2,000$  per year. Part of the historical city center, the *Voorstraat*, is situated on top of the primary dike. As a result, the *Voorstraat* is of insufficient height. But at the same time this dike section has an enormous weight and width, contributing to its strength. Spatial solutions such as adaptation of houses and spatial planning have so far only been used in Dordrecht's areas outside the dike ring. Half of the historical city center is situated outside the primary flood defense. Its buildings have withstood regular floods for centuries. A more recent example is the housing project *Stadswerven* build in 2009. It intends to change the perception of water from a threat to an attraction. This was done by emphasizing the dynamics of ebb and flood and integrating the water into public green space. In terms of crisis management the City of Dordrecht uses sand bags to reinforce the primary flood defenses about every other year. There is no nationally organized evacuation plan in the Netherlands yet. A recent study has shown that during a major flood threat the natural preventive evacuation rate averages 15% of the population for western dike ring areas such as Dordrecht (Maaskant *et al.*, 2009).

In this study particular attention is drawn to the *Wielwijk*. It was build around 1960 and consists of 2155 housing units covering 59ha. Since 2006 this neighborhood is subject to a restructuring process. Such a restructuring process is the chance to implement consequence-reducing measures as e.g. adapting houses and improving crisis management. Therefore, this new neighborhood will be included in the case study to examine if scale matters for the cost-efficiency of MLS.

### 3.2 Cost-effectiveness-analysis

This cost-effectiveness-analysis investigates if MLS's contribution to safety is cost-efficient. Only then MLS becomes a serious option for policymakers.

#### 3.2.1 Method

With the help of the framework different sorts of measures have been identified (Table 1). For almost each sort one measure will be modeled for the case of Dordrecht (Table 2). The risk reduction achieved by each measure was calculated and weighted against the costs. Two types of risk have been looked at. The economical risk expresses the expected annual damage (EAD) for the investigated area. The societal risk indicates the expected annual number of casualties (EANC). The EANC is equal to the surface under the FN-curve (Figure 2). The FN-curve shows the probability of events with consequences of different severity. In this paper, the results regarding the Individual Risk (Figure 2) are only used to illustrate the circumstances in Dordrecht. According to Jongejan, "the individual risk is defined as the probability of death of an average, unprotected person that is constantly present at a certain location" (Jongejan *et al.*, 2009).

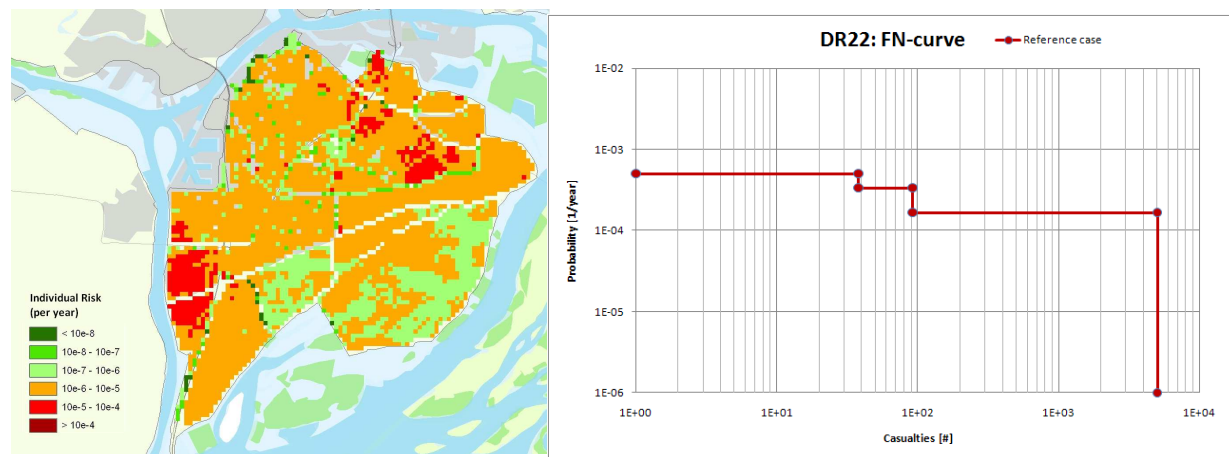


Figure 2: Left side – Individual Risk for dike ring 22. Right side – FN-curve showing the Societal Risk.

Regarding about material damage, a measure is cost-efficient if the net present value (NPV) of the risk reduction exceeds the NPV of the investment. This is the case if the CBA factor is smaller than one (investment/risk reduction<1). In terms of saving lives, the costs for saving and extra statistical life (CSX, [€/((life per year))]) will be calculated. Using the CSX measures can be compared. But the decision which investments to save lives are reasonable remains a political one. The costs are rough estimates. They depend heavily on the chosen case study and the implementation of the measures.

#### 3.2.2 Results

Table 2 shows the results of the cost-effectiveness-analysis. The framework indicates clearly that the three MLS layers feature measures of different geographical scales. To take account of this fact the cost-effectiveness-analysis has been done for the whole dike ring as well as for a neighborhood *Wielwijk* that is going to be restructured and renovated.

All measures, except the sand bags, are not cost-efficient. Strengthening the primary and secondary dikes turns out to be most cost-efficient for the City of Dordrecht. In this case the compartmentalization dike only increases the inundation depth in the individual compartments by a few centimeters. Thus, the physical interaction between measures is minimal. The city is bounded to the Northern half of the dike ring because it was shaped by the compartmentalization dike. This fact makes compartmentalization dikes in this case unexpectedly efficient. Building houses on pillars, a measure applied only in the new neighborhood, is the most cost- inefficient measure if the safety of the whole dike ring is concerned.

However, this measure can compete in terms of cost-efficiency with reinforcing the flood defenses if only the safety of a neighborhood is concerned. This shows that the size of the project area matters significantly for an optimal choice of measures. On both scales, dike ring area and neighborhood, only the sand bags turned out to be cost-efficient. This is due to the fact that, in this case, this is a very cheap measure that can be easily adapted to the circumstances. In Dordrecht the necessary organizational infrastructure is already in place and there is much experience with sand bags. However, the effect of sand bags is limited and depends very much on the condition of the flood defense they reinforce and the quality of their operation in case of emergency. In fact, the effect of crisis management measures relies so much on capable operators that its effect is highly uncertain.

Table 2: Results of cost-effectiveness-analysis for MLS measures. Results for whole dike ring in standard letters, results for new neighborhood in *Italic letters*. NPV: interest rate 4%, unlimited time horizon.

Measure	Effect	NPV of EAD Reduc [million €*]	EANC Reduc. [lives per year*]	NPV of investment [million €]	CBA factor [-]**	CSX [million € /lives per year]**	
1-3: Redistribution of water load over river arms	Decrease probability of water overload to 1/4,000 yr <sup>-1</sup>	44.5 (50%)	0.431 (50%)	200	4.5	500	Dike ring
		<i>1.7 (50%)</i>	<i>0.008 (50%)</i>		<i>118</i>	<i>25,000</i>	<i>Neighbor.</i>
1-6: Strengthen primary dikes	Decrease probability of water overload to 1/20,000 yr <sup>-1</sup>	79.5 (89%)	0.771 (89%)	200	2.5	300	Dike ring
		<i>3.1 (89%)</i>	<i>0.015 (89%)</i>		<i>65</i>	<i>13,300</i>	<i>Neighbor.</i>
2-6: Strengthen compartmentalization dike (Wieldrechtse Zeedijk)	Model compart. dike as unbreachable	72.5 (81%)	0.837 (97%)	100	1.4	100	Dike ring
		<i>3.0 (87%)</i>	<i>0.016 (96%)</i>		<i>33</i>	<i>6,300</i>	<i>Neighbor.</i>
2-7: Build new neighborhood on 1m pillars (alleviation)	Inundation depth decreases by 1m	1.2 (1%)	0.009 (1%)	120	92	13,300	Dike ring
		<i>1.2 (36%)</i>	<i>0.009 (52%)</i>		<i>92</i>	<i>13,300</i>	<i>Neighbor.</i>
3-5a: Evacuate 15% of new neighborhood**	Decrease number of exposed by 15%	0	0.003 (0.3%)	3	NA	1,000	Dike ring
		<i>0</i>	<i>0.003 (15%)</i>			<i>1,000</i>	<i>Neighbor.</i>
3-5b: Evacuate 15% of dike ring**	Decrease number of exposed by 15%	0	0.129 (15%)	25	NA	200	Dike ring
		<i>0</i>	<i>0.003 (15%)</i>			<i>8,300</i>	<i>Neighbor..</i>
3-6: Strengthen primary dike with sand bags	Decrease probability of water overload to 1/2,500 yr <sup>-1</sup>	18.0 (20%)	0.172 (20%)	0.5	0.03	3	Dike ring
		<i>0.7 (20%)</i>	<i>0.003 (20%)</i>		<i>0.7</i>	<i>200</i>	<i>Neighbor.</i>
3-8: Improve warning and preparation	Damage reduces by 10%	8.9 (10%)	0.086 (10%)	12.5	1.4	150	Dike ring
		<i>0.3 (10%)</i>	<i>0.002 (10%)</i>		<i>42</i>	<i>6,300</i>	<i>Neighbor.</i>

\* Percentage of total risk in reference situation; \*\* It was assumed that the percentage of people evacuating is 0 in the reference situation; \*\*\*rounded

### 3.3 Discussion

As opposed to just improving prevention, implementing MLS in Dordrecht means supplementing the existing dike ring with consequence-reducing measures, thus Spatial Solutions and Crisis Management. The cost-benefit-analysis shows that this is rather cost-inefficient due to the high initial prevention level. Consequence-reducing measures are a cost-efficient alternative if only parts of the dike ring area are concerned. This is due to the fact that consequence-reducing measures are generally of a smaller scale than probability-reducing measures and thus can be customized to smaller areas. A number of possibilities to make use of this property of MLS are thinkable. Restructuring processes of neighborhoods like the *Wielwijk* are a good opportunity to implement MLS. During those projects it is desirable to build consequence-neutral to slowing down the continuous cycle of dike reinforcements. Other scenarios are possible. In Dordrecht some neighborhoods have a high flood risk compared to the rest of the dike ring



area (see individual risk map in figure 2). This outcome thus means that it might be cost-efficient to address those neighborhoods with small-scale measures instead of increasing the protection of the entire dike ring area. Another scenario would be if reinforcing the primary dike ring is impossible. This is the case at the *Voorstraat*. There the dike height is insufficient because part of the historical city center covers the dike. If the dike would breach at this location only a small area would flood. In that area MLS has the potential to keep the flood risk in check by increasing the safety with consequence-reducing measures.

When comparing the layers of MLS, prevention stays the most cost-efficient layer for the Island of Dordrecht. This is due to the fact that it has been heavily invested in this strategy for centuries. Spatial solutions have turned out to be more cost-efficient than crisis management in this case. This is due to the fact that keeping crisis management measures on stand-by requires a certain investment in organization structures. Since those costs are made yearly, they add up to considerable amounts. Sand bags are an exception in this case, because they require little organizational infrastructure. Additionally, this infrastructure is already in place in Dordrecht. However, that the effect of crisis management measures is highly uncertain. It depends very much on the way those measures are operated, e.g. the way the evacuation is led in case of emergency. Spatial solutions can only fully be implemented in projects that are to build new. It is very costly or even impossible to apply them to existing neighborhoods.

#### 4. CONCLUSION

This study shows that MLS is not a cost-efficient alternative if already heavy investments in one strategy have been made. This is the case in Dordrecht. Due to the well-developed flood defense system flood defenses stay the most cost-efficient strategy. MLS is thus either an option in an area with a very limited number of flood management measures implemented or MLS can serve as a supplement to the dominant strategy. In the Netherlands MLS could thus be an addition to the prevention-based flood risk management. However, it has to be noted that in most cases each additional measure is less cost-efficient: The smaller the flood risk, the smaller the absolute risk reduction through an additional measure.

As illustrated by the case of Dordrecht, MLS provides the opportunity to tailor flood risk management to the local circumstances. This is due to the fact that consequence-reducing measures are usually of a smaller scale than probability-reducing measures. Thus, those measures are more cost-efficient if only small areas are concerned. Furthermore, the continuous cycle of dike reinforcements can be slowed down by building consequence-neutral. Additionally, consequence-reducing measures can be a cost-efficient remedy for areas with a high flood risk compared to the surrounding dike ring area.

Combining measures significantly increases the technical and administrative complexity of flood protection. In this study a framework has been developed to make a first selection of MLS measures. It categorizes all measures by their effect. In this way the combined effect of the measures chosen can be anticipated. However, a thorough analysis should be done on a case-to-case basis when implementing MLS is intended.

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