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Discussions

Robust, multifunctional flood protection zones in the Dutch Rural Riverine area

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Abstract

This paper reviews the possible functions of robust dikes in the rural riverine areas of the Netherlands. It furthermore reviews and analyses strengths, weaknesses, opportunities, and threats associated with robust, multifunctional flood defense zones in rural riverine zones. The study focused on recent plans and ideas for innovative dike reinforcement at five locations in the Netherlands, supplemented with information obtained in semi-structured interviews with experts and stakeholders. At each of the five locations, suitable robust flood defenses could be identified that would contribute to the envisaged functions and ambitions for the respective areas. Primary strengths of the robust, multifunctional approach were identified as combined uses of limited space, a longer-term focus, and greater safety. The new approach offers opportunities as well, in particular, with regard to tasks, problems, and objectives related to infrastructure, land-use planning, nature and landscape protection, and development. These provide possibilities for co-financing as well.

1 Introduction

1.1 History of flood defenses in the Netherlands

The Netherlands, situated in the delta region of the Rhine, Meuse, Scheldt, and Ems rivers, has a long history of adapting to its deltaic environment. Human settlement began on the natural high grounds, amid coastal dunes, and on natural river levees (Cools, 1948). More than 2000 yr ago the inhabitants of the coastal areas of the Wadden Sea started to create artificial mounds (called *terpen* or *wierden*) to protect themselves against regular flooding by the sea, simultaneously exploiting these fertile zones for agriculture. Starting in the Middle Ages, these mounds were progressively connected by dikes, leading to the formation of dike rings protecting the hinterland. Land reclamation by constructing new sea walls produced a pattern of parallel dikes along

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the Wadden Sea coastal zone. In the Dutch riverine areas, digging of canals and construction of raised areas was also initiated some 2000 yr ago, mainly for transportation purposes along the Rhine River (Cools, 1948). The process of raising riverine dikes started in the Middle Ages. Further exploitation of low-lying riverine areas, and even reclamation of floodplains, led to progressive embankments in the riverine zone. Subsequently, water levels increased in the rivers and the effects of floods became more severe (Technische Adviescommissie voor de Waterkeringen, 1998).

1.2 Flood protection system

Initially, everyone protected their own lands. But in the late Middle Ages a collective system began to emerge of agreements on the building and management of dikes. Nevertheless, flooding disasters still occurred on a regular basis due to deferred maintenance or because the dikes were not designed for extreme discharges. After a flood, the dikes were usually restored using locally available materials (clay, sand, or even weeds) and typically raised to withstand the most recent high-water level.

Today, the Dutch have a well-developed flood protection system formed by dunes, dikes, coastal structures, and areas raised well above sea level. These jointly make up the so-called primary flood defense system of dike rings. By law, these dike rings should protect the encircled hinterland against river floods and storm surges of a severity that could be statistically expected with a frequency of once in 1250 yr up to once in 10 000 yr, depending on the region and the related values at risk. Design requirements are exactly defined in legislation, and regular assessment and management are prescribed. The Netherlands, furthermore, conducts ongoing research aimed at increasing understanding of possible failure mechanisms of flood defenses and to gain insight into developments in physical and hydrodynamic boundary conditions, while also monitoring demographic trends and economic values in the hinterland.

To account for changes in conditions and in the protected values, current Dutch flood protection policy mandates robust design of dike reinforcements (Rijkswaterstaat, 2007). Thus, flood defenses are dimensioned to account for expected changes

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in boundary conditions over an agreed timeframe and are slightly over-dimensioned. Moreover, a spatial zone is reserved for future adaptations.

1.3 New challenges

There is currently widespread interest in the development of new dike reinforcement technologies and new dike designs. This is due to the increase in both economic values and in the number of people at risk in low-lying areas, as well as to new insights on failure mechanisms, the effects of soil subsidence, and projected impacts of climate change on seawater levels and frequency of extreme river discharges and storm surges (see, e.g., Vellinga et al., 2009). Climate change implies increased uncertainty regarding the statistical properties of extreme weather events. Significant reinforcement of protection works has therefore been deemed necessary to maintain safety levels. In the 1990s, the Dutch Ministry of Transport, Public Works and Water Management (currently called the Ministry of Infrastructure and Environment) initiated a program on future flood safety (*Waterveiligheid 21e Eeuw*). Its aim was to thoroughly reconsider Dutch flood protection policy. A comprehensive set of flood protection studies and projects was conducted within the framework of this program. In 2008, the Second Delta Committee advised the Dutch cabinet on an overall strategy for spatial planning and flood safety taking climate change into consideration (Deltacommissie, 2008). In view of the growing economic assets and numbers of people at risk, the Delta Committee recommended reducing the existing annual probability of flooding by a factor of 10.

1.4 Robust, multifunctional flood defenses

The Second Delta Committee also recommended considering the development of "delta dikes", which are virtually unbreachable due to their width, height, or inner construction. The Committee pointed out that the precise implementation of a delta dike requires location-specific designs, which usually take the shape of a very high or broad

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dike or a dike that is considerably strengthened on the landward side (e.g., via retaining walls) (Deltacommissie, 2008). A similar call for unbreachable dikes was made earlier in the Netherlands, after the flood disaster in 1953. A broad, over-dimensioned dike design makes the structure more resistant to erosion. It is thus more likely to retain its protective integrity even if, at extremely high water levels, significant amounts of water flow over the top of the structure (Vellinga, 2008). As indicated in Fig. 1, the dose–response relationship is far less abrupt for a robust, broad dike compared to narrow dikes. Robust, broad dikes do not collapse during a short period of exposure to a surge. Hence, they could significantly improve the robustness of the flood protection system over a wide range of possible futures and uncertainties, and are feasible as an climate adaptation strategy (Vellinga, 2008; Klijn et al., 2012). Silva and Van Velzen (2008) defined "unbreachable" as a 100 times smaller probability of failure due to erosion by overflowing, piping, or macro-instability on the landward side than dikes built to the current standards.

Of course, such a broad, robust dike would require more material and space; but it would offer new opportunities for using the space as well (Vellinga 2008; Hartog et al., 2009). It could be designed as a multifunctional area, combining urban development, transport infrastructure, recreation, agricultural use, and nature conservation, thus contributing to the quality of the characteristic Dutch riverine landscape. A robust flood defense could furthermore be incorporated into the recently adopted three-pronged flood protection policy of the Netherlands. That policy requires that in addition to (1) protection against flooding, attention must be paid to (2) flood-proof spatial planning and (3) strategies for early warning and evacuation (Ministerie van Verkeer en Waterstaat 2009). A robust, unbreachable dike can function as a place of safe refuge during a flooding emergency (Pols, 2007), comparable to the historical mounds, and they could provide part of an evacuation route.

Following the advice of the Second Delta Committee and the National Water Plan (Ministerie van Verkeer en Waterstaat, 2009), several studies were carried out exploring the concept of delta dikes (Knoeff and Ellen, 2011; Klijn and Bos, 2010). Moreover,

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the notion of robust, multifunctional flood defenses has been further explored (see, e.g., Hartog et al., 2009; De Moel et al., 2010; Urbanisten et al., 2010; Ellen et al., 2011). In 2011, the Multifunctional Flood Defense Program was funded by the Dutch Technology Foundation STW. Stalenberg (2010) developed an adaptable multifunctional flood defense design for urban areas.

Figure 2 presents a schematic impression of a traditional dike reinforcement compared to a delta dike and a robust multifunctional dike.

Regional water boards and provincial administrators have expressed interest in robust, multifunctional approaches to flood defenses (e.g., De Moel, 2010). One of the reasons is the long-term character of such an approach. Currently regular reinforcements are needed to maintain the dikes, involving heightening and strengthening of the layer or enlargement of the inner berm every 10 to 20 yr. This could be avoided with the use of an over-dimensioned dike design.

A number of municipalities and private companies have also expressed interest in the approach, because of the opportunities it presents in terms of added values and combining goals and plans. The Municipality of Rotterdam, for example, has initiated explorative studies, and projects to identify opportunities for introducing robust, multifunctional dikes are under way as part of various research programs, including Knowledge for Climate, STW-NWO Perspectief, and the Delta Program.

1.5 Aim

This paper reviews possible functions of robust dikes in the rural riverine areas of the Netherlands. It moreover provides an overview and analysis of strengths, weaknesses, opportunities, and threats associated with robust, multifunctional flood defense zones in rural riverine areas. It is based on recent plans and ideas for innovative dike reinforcement at five riverine locations in the Netherlands and information obtained in semi-structured interviews with experts and stakeholders. The overview and analyses have two aims: to expand insights on opportunities for implementing robust,

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multifunctional flood defense zones and to formulate recommendations concerning strategies for adapting to the effects of climate change in the Dutch riverine area.

2 Exploring the opportunities: an inclusive approach

2.1 Study locations

This study focuses on five locations in the Dutch riverine area where new approaches to dike reinforcement are being explored: Streefkerk, Marsdijk, Arnhem, Grebbedijk, and Munnikenland (Fig. 3). These locations are part of the Dutch program of dike reinforcement that is currently under implementation (the High-Water Protection Program) or are implicated in the current policy to provide more space for the forecast increased river discharges (the "Room for the River" initiative).

The locations at Streefkerk, Marsdijk, and Arnhem were selected based on their challenging boundary conditions. These locations were also the subject of an earlier explorative study on the practical aspects of building a climate-change-proof dike in the riverine region (De Moel et al., 2010). The present study takes a more in-depth look at technical and societal feasibility issues at these locations. The other two locations provide interesting illustrations of current ideas and initiatives exploring robust, multifunctional approaches to flood protection in a rural riverine context.

2.2 Profiles of robust, multifunctional flood defenses for the five locations

For the five locations, this study determined the flood protection task to be accomplished, characteristics of the area, boundary conditions, current functions and values, and plans and ambitions. Based on this information, suitable robust, multifunctional approaches were identified for each location. Table 1 presents an overview of robust, multifunctional approaches, alongside their possible functions and values and the flood-protection strategy utilized (based, e.g., on Hartog et al., 2009; Klijn and Bos, 2010; Van der Zwan and Tromp, 2010).

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2.3 Interviews about chances and constraints

Thirty-three stakeholders were interviewed to gain insight into the main opportunities and constraints for robust, multifunctional flood defenses in the rural riverine area (Table 2). Due to the novelty of the approaches being explored, an open, semi-structured interview method was employed. Stakeholders were asked about their roles, interests, and activities concerning dike reinforcement projects, along with background information. Their views were also solicited concerning adaptations to the effects of climate change, functions of flood defenses, and opportunities and constraints for robust, multifunctional flood defenses. In addition, the interviewees were asked to sketch a picture of the range of interests and stakeholders involved and of pathways to realizing synergy.

3 Results

3.1 Analysis of the five locations and the robust multifunctional approaches identified

For each of the five locations, the flood-protection task to be accomplished, characteristics of the area, boundary conditions, plans and ambitions for the location, envisaged functions, and suitable robust multifunctional approaches were identified.

3.1.1 Streefkerk

Streefkerk is a small town located east of the city of Rotterdam on the south bank of Lek River. The flood-protection task to be accomplished there, according to the latest assessment, is reinforcement of the river dike to prevent shear stress of the inner berm. A common solution in such a situation would be to raise and enlarge a stretch of the inner berm.

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Housing in and near the village of Streefkerk is built in an elongated pattern along the roads (*lintbouwing* in Dutch) on top of the dike. Beyond the dike, part of the floodplains is a nature conservation area. The population of Streefkerk is aging, and village shops, businesses, and local activities are slowly disappearing. Streefkerk has a shortage of housing for young people.

The weak underground, consisting of layers of clay and peat on top of a Holocene sand layer, is an impediment to certain infrastructure and has caused macro-stability problems of the dike. As a result of past dike reinforcements, many historic and characteristic homes are now situated right up against or partly on and in the current dike. Without removal of a substantial number of houses, no further reinforcement is possible.

The recreation harbor of Streefkerk would like to expand, and the municipal government has identified a number of objectives for improving the social facilities of the village and enhancing landscape quality as well. It has therefore initiated a process to develop an integrated, long-term planning vision that connects these objectives with plans for dike reinforcement and third-party plans.

Table 3 lists envisaged functions for the Streefkerk location.

3.1.2 Marsdijk

Marsdijk is located along the south bank of the Rhine River in the central part of the Netherlands between the cities of Utrecht and Arnhem. Most of the dike does comply with current safety standards. Small sections, however, need to be heightened and strengthened, due to problems of macro-stability and piping.

The landscape around the dike shows many remnants of former riverbeds, historic dikes, dike breakthroughs, and polders. The building of the dike in the 19th century transformed the riverine area between the historic "*bandijk*" and the newer Marsdijk into the Mars Polder. The Mars Polder is used for agricultural purposes (fruit and dairy farming), and a few farms and houses are located there. As a result of sand mining, nature has developed during the past 15 yr around extraction pits on the Mars Polder.

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In 2005, the idea was launched to use the Mars Polder to give the Rhine River more space. The suggestion met with staunch resistance from both inhabitants and the municipal government. Ultimately, it was rejected by the ministry.

Table 4 presents envisaged functions for the Marsdijk location.

3.1.3 Arnhem, south of the Rhine River

Along the south bank of the Rhine River, the city of Arnhem has steadily expanded since the 1940s onto the extensive floodplains which carry the marks of former riverbeds. Some sections of the dike here do not comply with the prescribed norms and must be adapted. The location is close to the bifurcation of the Rhine and IJssel rivers, and measures are being implemented here to give the river enough additional space to realize a 7 cm reduction in its water level. For this reason, the dike in the Bakenhof district was relocated in 2000 to broaden the floodplains. Parts of the area east of the urban zone are used for agricultural purposes, with riverine wetlands having developed elsewhere.

On the floodplains south of the river, the groundwater situation is very complicated, as sandy layers in the subsoil connect low-lying areas here to both the "Veluwe Massief" north of the river and to Rhine River itself. The connection with the river results in desiccation during periods of low river levels in summer and to excess water in the housing areas during high water levels in winter.

There are plans to rebuild some areas of the suburbs. Furthermore, after long deliberation, the municipality recently decided to allow limited building in the eastern rural area and to develop a "green river". This latter implies that the area could be used as an extended riverbed during periods of high discharge.

Table 5 lists envisaged functions for the Arnhem location.

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3.1.4 Grebbedijk

Grebbedijk is located along the north bank of the Rhine River west of the city of Wageningen. The dike here protects an extensive, low-lying, densely populated area between two natural heights. Extraction of clay from local floodplains to reinforce the dike has produced new riverine nature and wetlands, which are now key nature conservation areas in the Netherlands. Former brick factories located here have been granted cultural heritage status. Grebbedijk meets current safety standards. However, the provincial government and local water board are exploring opportunities to make the dike more robust.

A 2004 modeling study underscored the strategic importance of the dike. If it were breached a huge area would be affected, with water levels reaching up to 3 m in Veenendaal and damage of more than 10 billion euros (Wouter, 2004). The city of Wageningen has expressed interest in adapting the dike here, to take advantage of opportunities to relocate the unattractive industrial harbor and run-down industrial area away from the city.

Table 6 lists envisaged functions for Grebbedijk.

3.1.5 Munnikenland

Munnikenland is a rural region in the center of the Netherlands along the south bank of the Waal River. The government's "Room for the River" Program mandates that measures be undertaken here to reduce the river level and relocate and improve the dike. The location has a long history of land reclamation, and many remnants of historic dikes can be traced in the landscape. Near Loevenstein Castle is a nature conservation area, while dairy farming is still prominent in other parts of Munnikenland.

The local water board initiated a process to develop a comprehensive planning vision for Munnikenland, including flood defenses. A range of local stakeholders, experts, and artists contributed to an integrated vision for improving flood safety while strengthening the area's cultural, historical, natural, and recreational value. The plan envisages the

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use of the excavated material from the floodplains to over-dimension a newly relocated dike. The planned over-dimensioning will create a dike suited for use for recreational purposes and also provide a place for cattle to take refuge during high-water events.

Table 7 lists the envisaged functions for the Munnikenland location.

3.1.6 Suitable robust, multifunctional flood defenses

Based on the envisaged functions, local boundary conditions, and the plans and ambitions expressed for the five locations, Table 8 lists the most appropriate approaches identified (see Table 1 for a description of these approaches).

3.2 Opinions about robust, multifunctional flood defenses

Current flood safety policy in the Netherlands prescribes robust design of dike reinforcements, anticipating future changes in demographics and society, land uses, and physical conditions, as well as considering uncertainties in these respects. This implies the need to slightly over-dimension dikes with regard to their maximum hydraulic loads and to reserve a spatial zone to allow for dike reinforcements in the future. Interviewers asked stakeholders their views about suitable timeframes for dike reinforcement and on how the effects of climate change and uncertainties about future conditions could best be taken into account. The opinions voiced can be generally categorized into three groups. The first group of stakeholders considered current flood safety policy to be appropriately based on scientific insights about the effects of climate change and recent engineering know-how. The second group of stakeholders considered it wise to make flood defenses more robust than current knowledge suggests, to avoid the need for new adjustments in the short term. A third group of stakeholders called for an intensified search for other solutions, arguing against making the dikes more robust before better insight was available into the effects of climate change (Table 9).

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3.3 Opportunities and constraints of robust, multifunctional approaches to flood defense

Stakeholders' opinions about opportunities, constraints, points of concern, and recommendations for achieving synergy are reported in detail in Van Loon-Steensma (2011). Figure 4 summarizes these in a Strengths, Weaknesses, Opportunities, and Threats (SWOT) framework.

3.4 Initiator and driving forces in the process

Stakeholders share the view that an enthusiastic and strong initiator is needed in any process as complex and often lengthy as the realization of a multifunctional flood defense. Those interviewed suggested that parties wanting to achieve certain objectives would be best suited to act as the initiator and driving force. Another party could possibly take over the lead at a later stage. In the Netherlands, water boards are responsible for maintaining flood defenses and meeting lawful flood safety standards. When dike reinforcements are called for, the local water boards start by collecting information about hydraulic and physical boundary conditions, planning tasks, and noting constraints, while involving stakeholders in the process. Water boards must also take landscape, nature, and cultural values into consideration. Some stakeholders emphasized that the water boards have no mandate or financial resources to realize goals other than flood safety, and the legislative framework within which they work is based on evolving safety standards.

Therefore, over-dimensioned multifunctional flood defenses can be implemented only if all parties voluntarily participate. Expropriation of rights and property is not feasible on behalf of such an innovative approach to flood safety. If other parties propose initiatives to combine functions in a flood defense zone, it is the water board's responsibility to set the preconditions based on the Water Act.

Stakeholders furthermore suggested that the initiator of such a complex and innovative approach would need to facilitate exploration of pathways beyond the usual policy.

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But they also noted that water boards and municipal governments are generally obliged to follow national policy lines; they are thus poorly positioned to play this role.

4 Discussion

Analysis of the five locations revealed that for each several suitable robust flood defenses could be identified that would contribute to the envisaged functions and ambitions for the area. To achieve a robust, multifunctional approach, however, a thorough analysis is needed of all opportunities and constraints, alongside a cost-benefit analysis that also considers long-term trade-offs on a broad range of aspects. Analysis of the stakeholders' responses provides an indication of the full range of considerations at play, as well as insights into the pros and cons of "unbreachable" or robust, multifunctional flood safety zones in riverine areas.

The Netherlands is a densely populated country, so multifunctional use of limited space was identified as an important strength. Space, however, forms a severe constraint as well. According to Silva and Van Velzen (2008) an unbreachable dike based on current norms requires at least a 1 : 3 inner-berm slope. Most existing sea defenses meet this requirement already. Klijn and Bos (2010) estimate based on the assumptions of Silva and Van Velzen (2008) that only some 140 ha is needed to make the 1000 km of Dutch sea defenses unbreachable "delta dikes". However, some 3000 ha would be needed to transform the country's 1400 km of river dikes into unbreachable delta dikes. An unbreachable, multifunctional flood defense zone requires even more space, to avoid the need for further adjustments in the coming 50 to 100 yr, because of climate change or increased value of assets protected by the flood defense system.

In the Netherlands, all space is legally designated and utilized for specific functions, which forms another constraint. Broadening the flood defense zone in favor of flood safety would in all cases compromise other functions and values. In the rural area, many floodplains are used for agricultural purposes or are valued for their nature and landscape qualities. Yet these functions do not automatically conflict with robust,

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multifunctional flood defense zones. Therefore, it is important to explore the conditions under which nature and agricultural land can be made part of flood defense zones. In historic towns and cities, residential areas are now often situated right up against or partly on and in the current dike. Broadening the inner berm there would require destruction or removal of houses, which is technically difficult as well as legally complicated and expensive. Where the hinterland is used for agriculture, expansion outside the protective zone is possible if landowners are willing to voluntary sell their property.

Another constraint is the Dutch legislative framework, which is based on current safety standards and provides no rules concerning over-dimensioning of flood defenses. Broadening the inner berm is prohibited in most riverine locations because of the obligation to maintain the riverbed's discharge capacity. The "Room for the River" Program even aims at widening the riverbeds (Ministerie van Verkeer en Waterstaat 2006, 2007). Moreover, extensive tracts of river floodplains are part of the Netherlands' Ecological Network and the EU Natura 2000 network. They are thus protected by both national and international legislation (Ministerie van Economische Zaken, Landbouw and Innovatie 2011). A number of Dutch riverine areas have been granted National Heritage Landscape status in recognition of their natural, cultural, or historic value (one example is the Nieuwe Hollandse Waterlinie water-based defense system) (Feddes and Companie Rotterdamsche Communicatie, 1999). Up to now, there has been little exploration of how and under what conditions an "unbreachable", multifunctional approach to flood defense fits within the legal framework for nature and landscape conservation, or may even strengthen natural, landscape, and cultural values. Realization of a robust, multifunctional flood defense is therefore a complex process, requiring an initiator and manager capable of galvanizing and persuading involved parties and, if necessary, influencing existing plans and planning processes.

Availability of sufficient financial resources is another prerequisite. Knoeff and Ellen (2011) estimate that transformation of all flood defenses in the Netherlands would cost 20 billion euros. Costs would depend on the water system and physical boundary conditions. To transform dikes along the rivers into "delta dikes", space would be needed

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to enlarge the inner berms, whereas the transformation of coastal dikes would mainly require replacement of the outer layer. Combining the building of delta dikes with regular dike reinforcements could save costs (Knoeff and Ellen, 2011). Such an approach would imply incremental adaptation to the effects of climate change and the uncertainties surrounding them (Vellinga et al., 2009).

"Unbreachable" flood defenses, or "delta dikes", have been recommended by the Netherlands Environmental Assessment Agency as an appropriate measure to reduce future risks of flooding (Ligtvoet and Van Gerwen, 2011). Klijn et al. (2012) found that such "unbreachable" flood defences can effectively reduce the fatality risk at even lower net societal costs than continuation of the present policy.

The building of delta dikes could substantially reduce flooding risks, preventing extensive fatalities and economic damages particularly where densely inhabited areas are located adjacent to flood defenses with a relatively short warning time of potential breaches and evacuation difficulties (De Bruijn and Klijn, 2009). Moreover, overdimensioning flood defenses to provide time to prepare and evacuate is consistent with the third prong of the new flood protection policy.

Although no design standards, assessment framework, or management standards are available as yet, Knoeff and Ellen (2011) note that the current legal framework does not hinder implementation of delta dikes. This is reflected in the current status of the five locations. In Streefkerk, municipal authorities had initiated a planning process to develop an integral vision for the future. Terra Incognita (2010) submitted designs for a robust, multifunctional flood defense incorporating a square and building adjacent to the waterfront. Following on these initiatives, the local water board also developed a design for a robust, multifunctional flood defense, though less comprehensive than that of Terra Incognita, and intends to implement the plan. At the Marsdijk location, the water board has opted for traditional reinforcement. In Bakenhof in Arnhem, houses were built on top of and up against a newly relocated dike. The robust dike forms an integral part of the landscape and connects the neighborhood with the adjacent floodplains and river. The Delta Program has indicated its intention to choose Grebbedijk

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as a pilot location for a delta dike. At the Munnikenland location, an over-dimensioned dike is currently being built.

5 Conclusions

We analyzed the pros and cons of "unbreachable" or robust, multifunctional flood safety zones in riverine areas of the Netherlands, looking at both technical criteria and opinions expressed by stakeholders. The results were presented in the form of a SWOT analysis, indicating strengths, weaknesses, opportunities, and threats of unbreachable or robust, multifunctional flood defenses in rural riverine areas of the Netherlands. We found a number of opportunities for unbreachable, multifunctional flood defenses embedded within challenges identified in the five study locations. Most of these opportunities are associated with tasks, problems, and ambitions in relation to infrastructure, land-use planning, nature and landscape protection, and development. These offer the possibility of co-financing as well.

Our findings suggest several recommendations. First, three pilot locations should be designated by the Delta commissioner to actually implement an unbreachable, multifunctional flood defense and support provided to the process financially as well as administratively and legally. Close monitoring of the process, from initial idea through to implementation, should yield valuable practical lessons. The pilot locations should be chosen to include complex boundary conditions and a wide range of ambitions and stakeholders, and preferably be in three distinct areas: a riverine location, a location in the Southwest Netherlands Delta, and a Wadden Sea location.

Second, further research should be initiated to explore the financial side of the unbreachable, multifunctional approach to flood defense. Can unbreachable, multifunctional flood defenses offer greater security per euro invested than traditional flood-defense systems?

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Third, in order to facilitate the implementation of robust flood defenses which reduce a flood disaster to a shallow flooding, attention should be paid to the development of appropriate design standards, assessment frameworks, and management standards.

Finally, research should explore under what conditions unbreachable multifunctional flood defenses can contribute to nature and landscape values and fit into Natura 2000 aims and legislation.

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Table 1. Overview of robust multifunctional approaches based on Klijn and Bos (2010) and the possible functions and values and water safety strategy associated with each.

Robust Multifunctional Concept	Profile	Possible Functions and Values	Flood Safety Strategy
A. Over-dimensioned inner berm		Flood safety Housing Transport Recreation Energy Nature Landscape	Unbreachable Erosion resistant Refuge area Evacuation route
B. Over-dimensioned outer berm		Flood safety Transport Recreation Energy Nature Landscape	Wave attenuation
C. Over-dimensioned inner and outer berm		Flood safety Housing Transport Recreation Energy Nature Landscape	Unbreachable Erosion resistant Refuge area Evacuation route Wave attenuation
D. Parallel dikes		Flood safety Recreation Energy Nature Landscape Agriculture	Controlled overflow
E. Camouflaged dike		Flood safety Housing Transport Recreation (Urban) landscape	
F. Technical construction		Flood safety Housing Transport Energy Urban landscape	

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Table 2. Overview of the interviewed stakeholders.

Stakeholder	Streefkerk	Marsdijk	Arnhem	Grebbedijk	Munnikenland	Not location-specific	Total
Central government (Ministry of I&E)						2	2
Rijkswaterstaat						3	3
Province	1			2		2	5
Water board	1	1	2		1	2	7
Municipality	1		1				2
Inhabitants or home-owners	4	2	1				7
Entrepreneurs	2	2					4
Nature conservation and Environmental protection organizations						1	1
Experts (knowledge institutes)						2	2
Total	9	5	4	2	1	12	33

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Table 3. Envisaged functions for Streefkerk location.

Functions	Ambitions for Streefkerk
Flood safety	Robust, in order to avoid the need for future adjustments
Housing	Affordable housing for young people; preferably oriented towards the river; accommodations for the elderly
Transport	Local road to connect villages; entrance to houses along the dike; accessibility of local businesses
Economy	Expansion of the recreational harbor
Recreation	Bicycle path; walking path; boating (entrance to marina); touring
Nature	Riverine nature (floodplains)
Landscape	Conservation and strengthening of the typical Dutch riverine landscape
Urban quality	Improved urban quality; space provided for facilities; strengthened connection between the village and the river and adjacent floodplains
Cultural heritage	Conservation and strengthening of the typical Dutch riverine landscape, the traditional housing pattern, and houses
Energy	–

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Table 4. Envisaged functions for Marsdijk location.

Functions	Ambitions for Marsdijk
Flood safety	Comply with current standards; avoiding nuisance
Housing	Maintain current housing
Transport	Local road for use by residents and local businesses
Economy	–
Recreation	Bicycling and touring
Nature	Strengthening nature development near sand extraction pits
Landscape	Conservation of the typical Dutch riverine landscape
Urban quality	–
Cultural heritage	Conservation of the typical Dutch riverine landscape, the traditional housing pattern, and houses
Energy	–

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Table 5. Envisaged functions for Arnhem location.

Functions	Ambitions for Arnhem
Flood safety	Comply with current standards; preferably robust to avoid the need for further adjustments in the short term
Housing	Providing up-to-date housing in the suburbs; limiting building in natural part
Transport	Local transport to suburbs
Economy	–
Recreation	Bicycle path; walking paths in the floodplain area
Nature	Riverine nature (floodplains)
Landscape	Strengthening the typical Dutch riverine landscape
Urban quality	Provision of high-quality residential areas; connection with river and adjacent floodplains
Cultural heritage	–
Energy	–

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Table 6. Envisaged functions for Grebbedijk location.

Functions	Ambitions for Grebbedijk
Flood safety	Protection of the extensive hinterland with a robust flood defense
Housing	Maintain current housing
Transport	Local road for accessibility of local business
Economy	Creating housing facilities for knowledge companies (spin offs of Wageningen UR); relocation of industrial harbor and industrial area
Recreation	Bicycle path; walking paths on floodplains; touring; recreation along riverside
Nature	Strengthen riverine nature (floodplains)
Landscape	Conservation and strengthening of the typical Dutch riverine landscape
Urban quality	Relocation of industrial harbor and outdated industrial area; strengthening the connection between the town, the river, and the adjacent floodplains
Cultural heritage	Conservation and strengthening of riverine landscape; conservation of industrial heritage in the form of the remnants of brick factories
Energy	–

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Table 7. Envisaged functions for Munnikenland location.

Functions	Ambitions for Munnikenland
Flood safety	Robust, as part of an integrated plan for the area, including floodplain excavation to supply material for robust reinforcement
Housing	–
Transport	Local road (mainly for recreation)
Economy	–
Recreation	Enjoying the riverine nature and the historic area; walking; cycling; touring;
Nature	Riverine nature (floodplains)
Landscape	Conservation and strengthening of the historic riverine landscape
Urban quality	–
Cultural heritage	Conservation and strengthening of the cultural heritage, including Loevestein Castle as well as the landscape
Energy	–

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Table 8. The most appropriate approaches for the five locations. Refer back to Table 1 for an overview of the different approaches.

Robust Multifunctional Approach	Streefkerk	Marsdijk	Arnhem	Grebbedijk	Munnikenland
A. Over-dimensioned inner berm		±	+	±	+
B. Over-dimensioned outer berm	+	+	+	+	+
C. Over-dimensioned inner and outer berm	±	+	+	+	+
D. Parallel dikes		+		+	±
E. Camouflaged dike	+		+		
F. Technical construction	+	±			

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Table 9. Opinions of interviewed stakeholders on how to deal with climate change concerning dike reinforcement (+ = share this view, 0 = share this view more or less).

Opinion	Central govern-ment	Rijkwaterstaat	Province	Water board	Municipality	Inhabitants	Entrepreneurs	Nature conservation and environmental protection	Cultural heritage
A	+	+	+	+	0			0	
B			+	+		+	+	0	
C						+	+		+

A: Recent insights concerning the effects of climate change are already integrated in the current water safety policy.
B: It would be wise to anticipate more than is currently done on the effects of climate change and other changes.
C: More robust flood defenses are not desirable.

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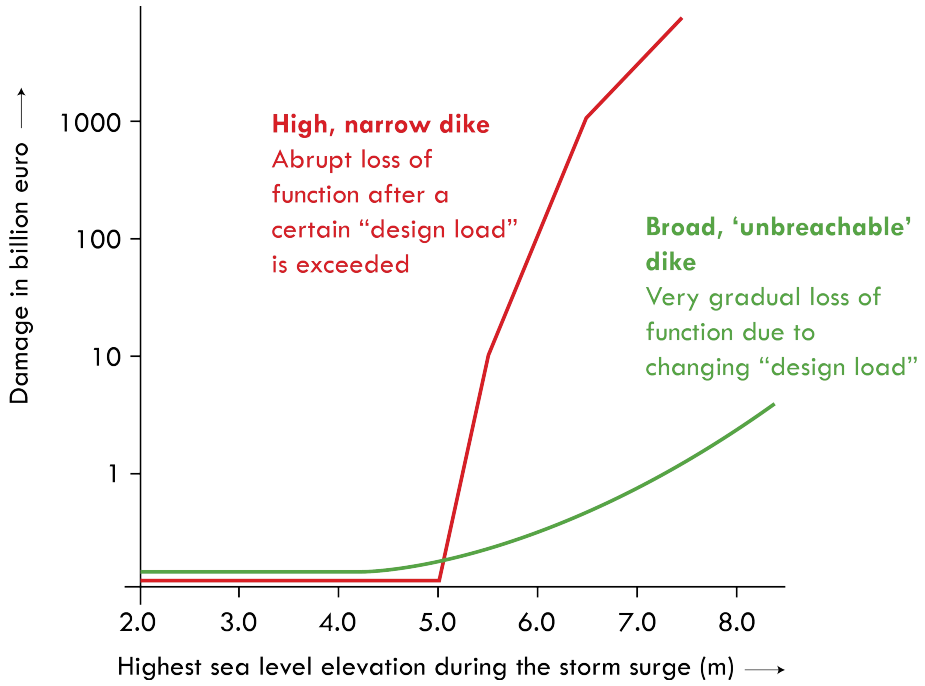

Fig. 1. Damage functions of narrow and broad dike (Vellinga, 2008).

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Robust, multifunctional flood protection zones

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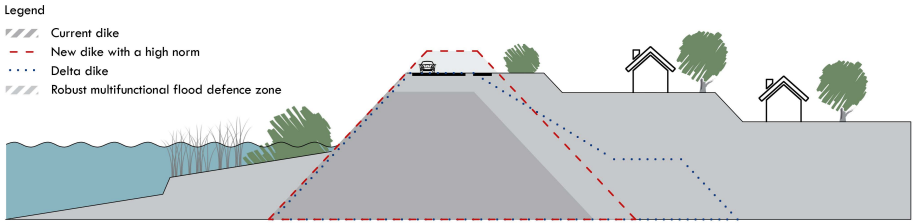

Fig. 2. Diagram of a current dike, a traditional reinforcement, a Delta dike and an unbreachable multifunctional flood defense (adapted from Silva and Van Velzen, 2008 and Stowa, 2011).

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Robust, multifunctional flood protection zones

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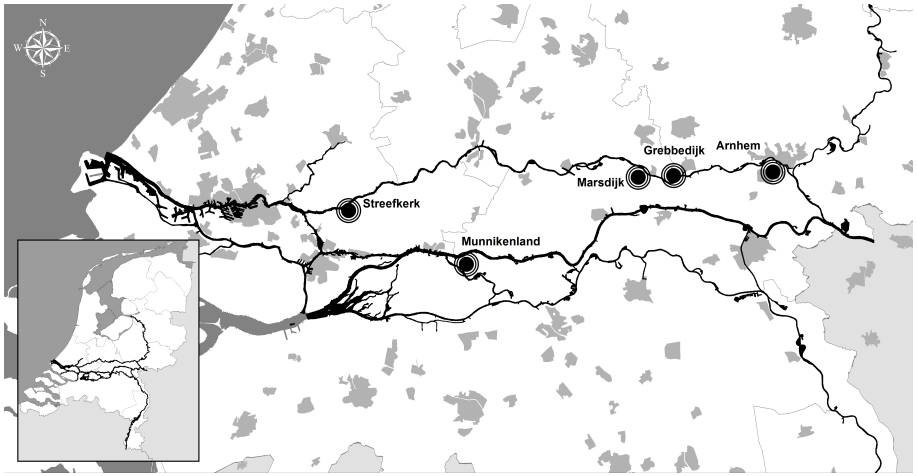

Fig. 3. Locations (a) Streefkerk, (b) Marsdijk, (c) Arnhem, (d) Grebbedijk, and (e) Munnikenland.

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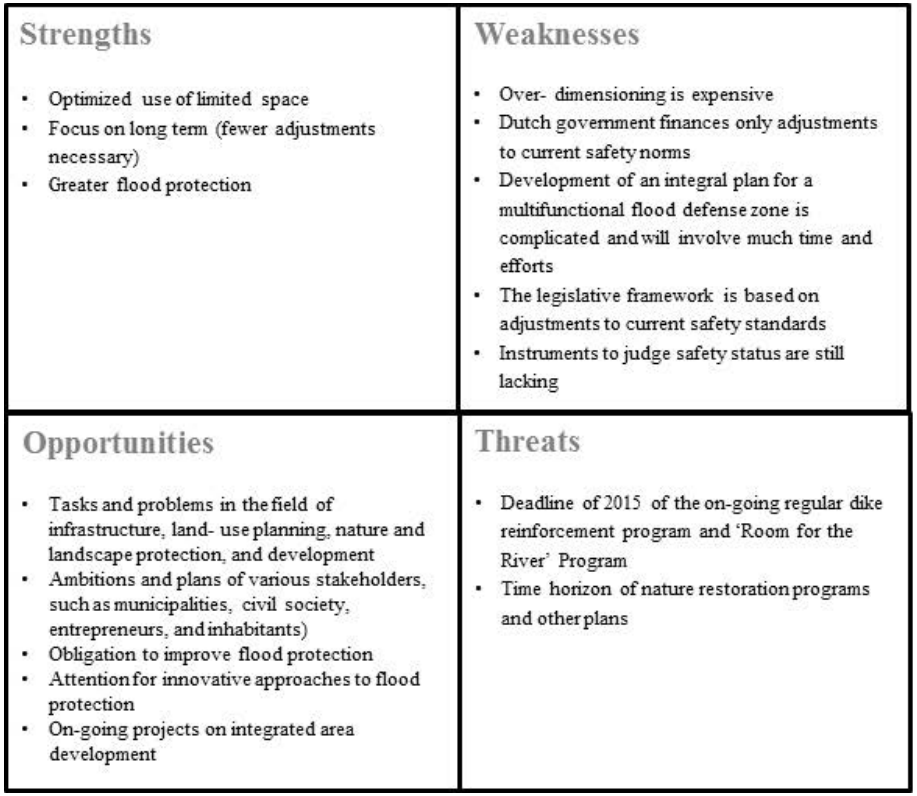

Fig. 4. SWOT analysis based on the interviews.

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