Design concepts of multifunctional flood defence structures

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1. Introduction multifunctional flood defences

Multifunctional Flood Defences (MFD) is a newly developed concept to optimize allocation of urban space rather than constructing stand-alone dikes. Multifunctional Flood Defences are flood defences that combine the function of flood protection with other functions. In addition to flood protection, multi-functional flood protection fulfils functions like housing, recreation and leisure, commercial buildings, ecology, mobility and transport, underground infrastructure and is a functional part of the urban or rural environment. There are various forms of multifunctionality included in the body of a dike or around it, to optimize allocation of space (Hemling and Pérez-Soba, 2011).

The difference between traditional flood defences and a MFD is that instead of modifying the surrounding area for a traditional flood defence, the MFD is modified for the surrounding area. Functions in the surrounding area do not disappear, but they remain or are enhanced. Because of this substantial difference, a MFD can be a spatial solution that allows many functions to be combined using the same area of land as a traditional flood defence, but without jeopardizing the strength of the MFD and the safety of the hinterland. In fact, in some situations functions are a crucial part of the MFD for those functions may serve as a flood defence.

Since a MFD allows more additional functions, more financial benefits can be generated. A MFD can be a expensive solution and therefore not an attractive solution to invest in. But the financial benefits can alter this fear of investment.

Some MFD are over dimensioned allowing not only more additional functions, but can be seen as a delta dike which are thought to be unbreakable and are not designed for 50 years, but for a 100 years. Both themes are going to be investigated in this report.

1.1 Context: need for multifunctional flood defences

Melting mountain glaciers and ice sheets as a result of global warming could raise sea level about one meter in the next century and several meters in the next few hundred years, which will significantly increase the risk of coastal flooding. Extreme river discharges and rainfall are amongst the other factors potentially magnifying pluvial and fluvial flood risk worldwide. In other respects, living in flood prone areas close to the sea shore and river banks has always been dangerous, but usually an attractive option from a socio-economic perspective. The dramatic and ongoing urbanization process together with intensively developed urban infrastructure and population is leading to a significant increase of the flood consequences on the residents and the urban assets. These challenges call for the better integration of urban development and flood management strategies for deltaic cities and lowland areas around the world.

Various methods for flood control have been practiced since ancient times. For example, retaining extra water by planting vegetation, terracing hillsides for slowing flood flow, and making man-made waterways for diverting flood water. More recently, flood-retaining structures, including levees, dikes, dams, reservoirs (retention ponds) were built to hold extra water during times of flooding. Originally, techniques such as constructing dikes and dams or even diverting river water have provided better flood protection to growing cities, but gradually, these have created a new challenge. Where cities are growing along river banks and seas shores, less space becomes available to protect the growing population. Clearly, traditional flood protection and urbanisation seem to have conflicting objectives. Expanding flood retaining structures need space to protect newly developed urban structures. But urban structures that have to be developed along riverfronts need space as well. This current ‘landscape competition’ often makes it impossible to adjust the traditional dikes and alternative solutions are needed.

Comparing the current demand with the available (urban) space, it is likely that new flood mitigation strategies have to be used that are capable of managing not only the sea level rise and increase of the river discharge issues, but also the vulnerability of human settlements in flood prone areas. Recently, there has been a lot of attention given to the concept of multifunctional flood defences as a means to combine a water retaining function with other safety concerns. MFD use scarce space in an effective way. Therefore, flood defence systems should no longer be considered to be mono-functional, providing only flood protection, but can be integrated into everyday life as a sustainable solution. The multifunctional flood defence concept aims to use the (limited) space that is still available along the popular waterfront by integrating several functions into one multifunctional structure. The extra functions added can be designed to be of service for various urban functions such as opportunities for housing, recreation, ecology, transport, etc. In this way multifunctional flood defences can help to reduce the conflicts between urban development requirements and flood alleviation strategies.

The spatial and temporal windows of opportunity provided by multifunctional flood defences have not fully been exploited yet. Innovative concepts and approaches are needed to be developed for integrating functions with extra benefits while reducing the costs of implementation. The concepts must be able to combine a broad range of functions (safety, nature, agriculture, reservoir, transport, recreation, etc) into/ around the dike body along with significantly strengthening the dike structure against flooding.

For this to be effective, the main challenge would be in introducing practical and cost-effective potential alternatives for constructing multi functional flood defences (MFD). By adding extra functions the expectation is it has additional value (benefits) for the whole dike system. Additional functions can contribute in a benefited way to appreciation for the flood defence. For instance accessibility by road, recreation along the water, robustness by overdimensioning for adding real estate (value).It usually requires more investments as well. However, this is potentially shared by many stakeholders. Cost recovery may be possible by adding economic functions. With respect to this position, this design guide discusses further potential for developing MFD alternatives with respect to cost efficiency, and cost effectiveness by providing means of designing alternatives and assessing the associated costs and benefits. It provides a framework for the design and maintenance of multifunctional flood defences that links the state of the art in literature with on the ground (re)development projects.

1.2 Relationship to FloodProbe objectives

FloodProBE is a European research project with the objective of providing cost-effective solutions for flood risk reduction in urban areas. FloodProBE aims to develop technologies, methods and tools for flood risk assessment and for the practical adaptation of new and existing buildings, infrastructure and flood defences leading to a better understanding of vulnerability, flood resilience and defence performance. This research supports implementation of the Floods Directive through the development of more effective flood risk management strategies.

This guidance, entitled ‘Design concepts of multifunctional flood defence structures’, is one of the deliverables for Work Package 4 “Construction technologies and concepts for flood defences and damage mitigation”. It has been produced by Dura Vermeer.

The Floodprobe study MFD focuses on promising design concepts of MFD, integration possibilities of functions and new business models for MFD. This report is a continuation of the State Of The Art (SOTA) which is aimed at gaining a deeper understanding of multifunctional flood defence (MDF)s.

1.3 Objectives of the guidance

The focus of this report is to provide a step-by-step guidance for the identification of promising design concepts for multifunctional flood defences (MFD) and to apply this guidance to the pilot case 'Kop van 't Land' area in Dordrecht, the Netherlands. A costs and benefits assessment method for multifunctional defences is investigated with the ambition to increase safety over current defence designs and/or to provide additional benefits beyond safety. The outcome will be used as a guide for computing the costs and benefits for further studies in the future.

Firstly, several MFD concepts will be introduced and the functions of multifunctional defences will be investigated for several concepts. Secondly, the requirements for design are set out. In chapter 3 a methodology is introduced for feasibility and cost benefit analysis of the alternative interventions to serve as multifunctional flood defences.

In this regard, a MFD structure is proposed for the case study area in 'Kop van 't Land' area of Dordrecht. The associated costs and benefits are investigated in an integrated way to address the practical need for safe and multi-functional solutions and facilitate the integration of trans disciplinary knowledge.

The preliminary analysis of the two alternatives shows that a large amount of data are needed to conduct in depth cost benefit analysis for each case, whilst there are many questions to be asked as regard to the cost benefit process. In case of a MFD this is one of the f relay on. even this is interesting since there is not further founded documents on this subject to relay on.

1.4 Structure of the guidance

This report provides an initial process for the cost benefit analysis (CBA) of a multifunctional flood defence. This has been developed by examining two proposed alternatives for the pilot location ‘Kop van ‘t Land’.

Before the CBA can be explained:

- Chapter 2 will first start with guidance on how to choose and develop a design for a multifunctional defence at a waterfront location Sections 2.2 and 2.3 present the concepts that can be applied to design a defence and the additional functions which can be added to these concepts. Section 2.4 deals with the requirements to be satisfied in order to choose the best concepts for a MFD at ‘Kop van ‘t land’ In Section 2.5 a catalogue of concepts and functions is presented which helps in the case of choosing an alternative. Furthermore the preferred alternatives of ‘Kop van ‘t Land’ are explained.

- Chapter 3 discusses the establishment of a cost-benefit analysis for a multifunctional defence.
- Chapter 4 illustrates how the guidance should be applied in practice. It is important to note here that the results of the cost and benefit analysis of the two alternatives of the Case Study c.q. the ‘concrete structure’ and the ‘soil bank’ are indicative and based on rough estimates and assumptions.
- The report ends with conclusions about the cost-benefit analysis of multifunctional defences in general. It elaborates the applicability of the guidance in general and lessons learned from the pilot case ‘Kop van ‘t Land’ area in Dordrecht, the Netherlands.

2. Guidance for design

2.1 Flow Chart MFD

This report starts with guidance on how to choose and develop a design for a multifunctional defence at any location. There are a number of steps to be followed in order to achieve a preferred alternative (best alternative). These steps assist in the process of achieving a design for a multifunctional defence. Each step is briefly explained below. The elements included in this guidance are shown as chapter numbers between the brackets in figure 2.1.

Step 1 is to establish the demand or need for a MFD which is formed by the existing dike and its environment, the future visions for the dike area and the stakeholders involved. If the dike is in need of improvement, there is an urgency to look at the future profile of the dike. By examining the conditions of the local environment, the (spatial) plans for the area and the interests of the stakeholders present in the area, a first, rough design (charette) showing the features of the MFD can be created. The information in step 1 contributes to the overview of the demand for a MFD and what the opportunities might comprise.

Step 2 is about what to do to devise a number of alternatives for a MFD design. Two elements play a major part. First is the variety of criteria the dike has to meet, such as safety criteria. These will have an impact on the viable MFD options. Not all possible design options are likely to be feasible at every location from a technical social or economical point of view. In section 2.2 options for MFD designs are presented. The second consideration is the possible functions at a specific location. The demand for a future function of a MFD also affects the feasibility of the MFD.
The selection of a design affects the possible functions. Section 2.3 focuses on functions. Elements of criteria and functions interact when determining viable decisions. Which means that decisions related to cooperation, regulation and land development (real estate) have primary consequences for the criteria and functions of a MFD. The output from step 2 leads to definition of alternatives.

Step 3 focuses attention on making a CBA for the alternatives to provide information for selecting the preferred alternative. An attractive design does not necessarily mean that the alternative it presents is financially conceivable. A MFD must be a better solution than the alternative of traditional dike reinforcement otherwise it is not worthy of consideration. Therefore, added value in financial terms is also required. It is also crucial to have a strong discourse around the particular alternative with the stakeholders involved. For a MFD to be viable stakeholder support is needed. Open communication about the pros and cons must be used to jointly make the right decision with all the stakeholders involved.

In Step 4 the results are accessible and advice as regards options is provided. It is important to present the results in such a way that an evaluator or participant is able to judge what is certain, what is a guess and which information is unknown. This advice will be public.

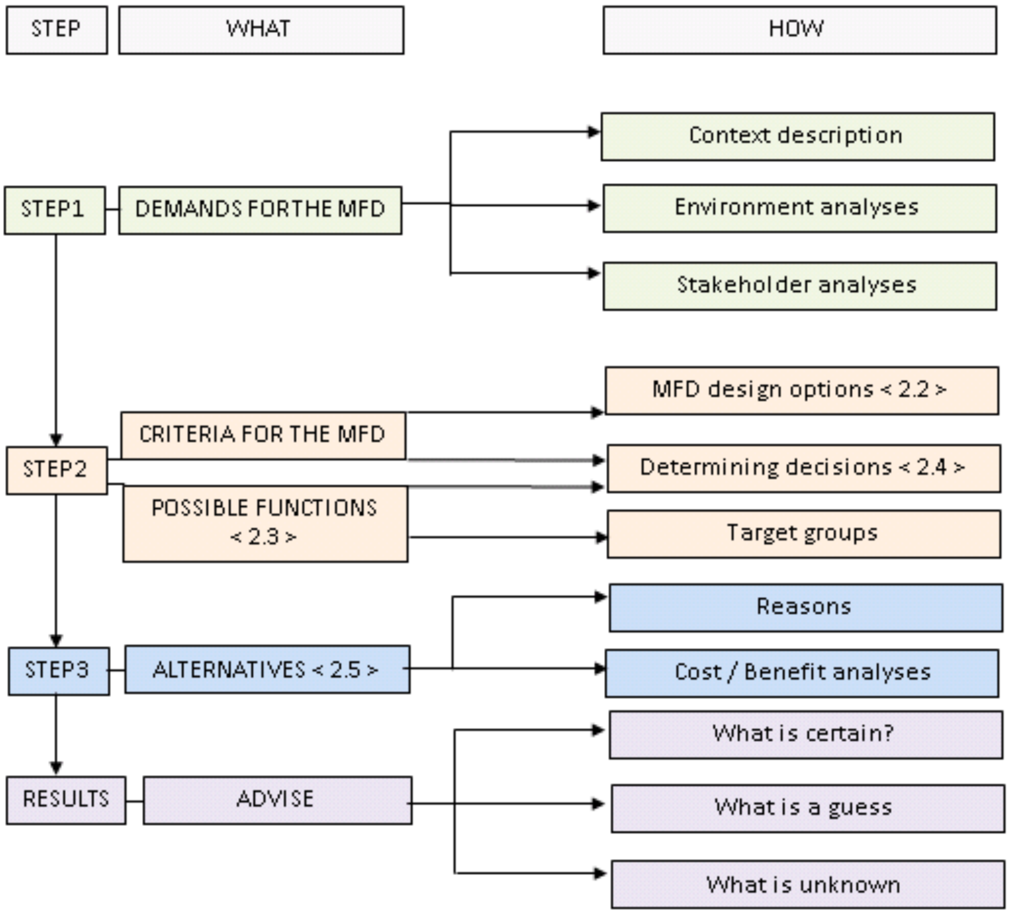


Figure 2.1: guidance for choosing and developing a design for a multifunctional defence

2.2 Concepts

Currently six concepts of multifunctional defences are identified in the FloodProbe State Of The Art (SOTA) report and these will be adapted for use in the study area 'Kop van 't Land' (refer to Chapter 4). This section describes the features and concepts of MFD and the potential functions that could be added to the defence (2.3).

First an overview is given in figure 2.2 of the six concepts and how the concepts relate to one another. The concepts have different affects on usage space. For instance the concepts Step Dike and the Oversized innerslope are capable of providing added functions across the defence (top, in, front, behind). Also the designs of the MFD constrains diverse material use. This means that the concepts has different outcomes in composed of soft (soil), hard (concrete) of hard/soft materials.

It is important to note here that MFD structures usually require (extra) foundations and overall height depending of the properties of the MFD structures such as weight and the properties of the existing defenses. The latter need careful investigation if they are to be used for MFD or refurbished to provide multifunctional use. The type, condition and stability of any existing foundations including the underlying soil properties are the main factors to be considered.

The outline of the designs are first introduced.

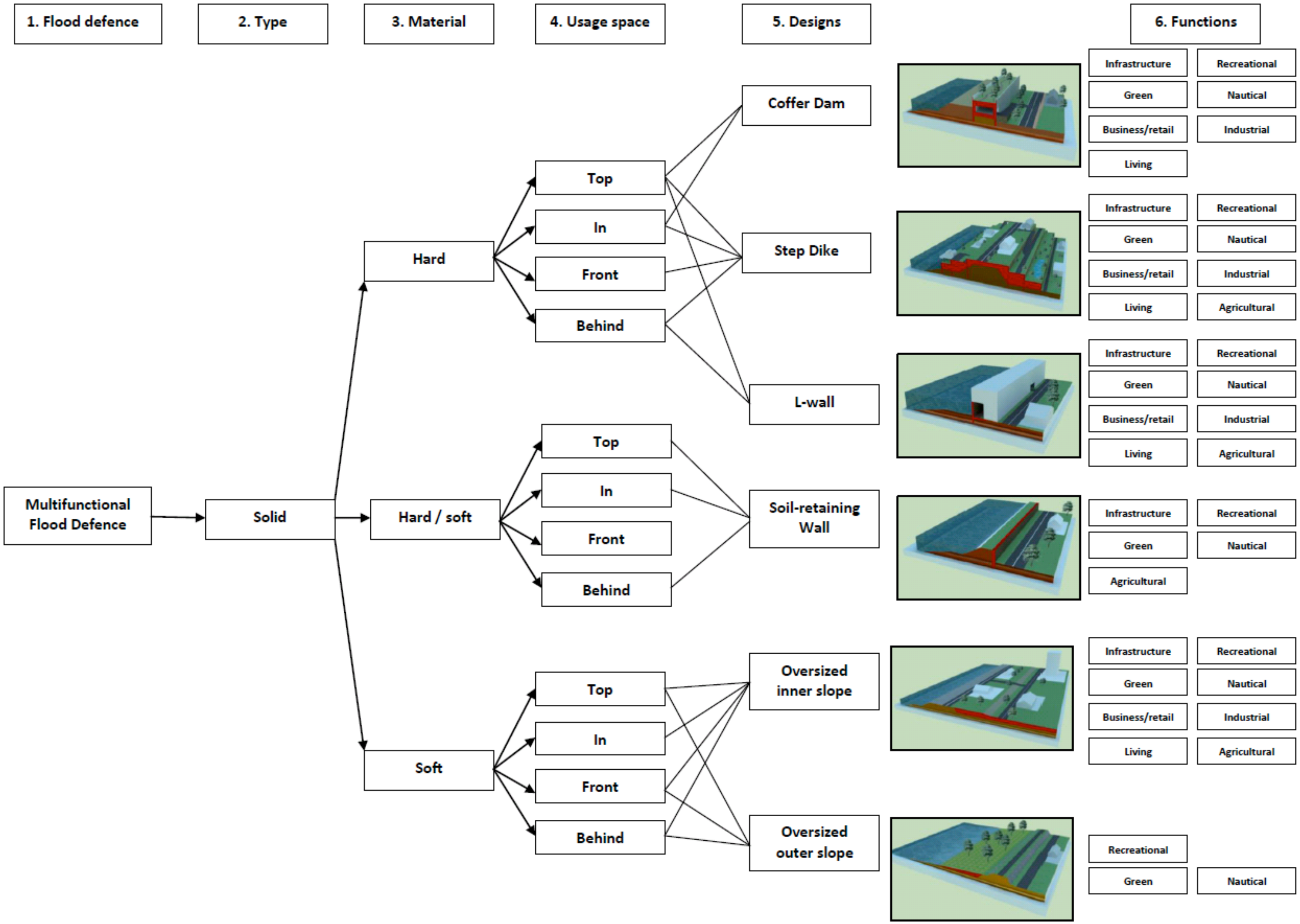


Figure 2.2: features of the six concepts of multifunctional defences

2.2.1 The Coffer Dam

The coffer dam is a concept that can either be a freestanding construction or combined with a traditional dike body. It is a compact spatial solution. The space between the defence walls can be easily filled with soil. Above ground level there are other possibilities . Or functions can be as well situated in the defence for instance infrastructure. See figure 2.3.

When realizing this construction, 2 deep steel walls are placed at least 7 meters apart from each other. The space between these deep walls can either be filled with soil, or used as a tunnel, parking garage etc. The top of the coffer dam can be used for several functions such as a boulevard or park. This construction will, however, need a lot of ramps and stairs.

1. The ratio of the walls above and below ground is 1:2.
2. The height of this concept is determined by several factors. It has to be at least as high as the Maximum High Water level (MHW). Above this an additional 1.0m has to be applied to compensate wave height, another 0.5m to compensate ground subsidence and another 0.5m for additional safety. The additional wave height is needed because waves are stopped abruptly at the wall face and run-up higher than the wave height. A piping screen is needed for this construction and can be realized by making the deep steel walls longer. The anchor points that hold the walls together, need to be above the Maximum High Water level.
3. It is a compact solution. The construction is only hard material and abruptly in the environment, making it a significant border.
4. The construction is not flexible and the functions must be determined in advance. Functions, however, are hard to adjust, especially when a tunnel or boulevard is part of the construction. These functions need to be prepared for future changes.
5. The construction is adaptable to possible climate change. The coffer dam can be adjusted to future changes by preparing the walls with added strength and thickness. When necessary, the walls can be made higher.

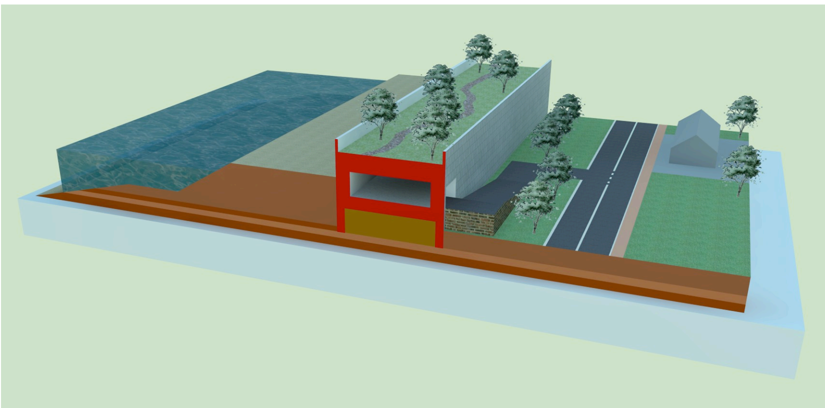


Figure 2.3: Coffer Dam (indicated in red) with promenade and parking garage.

2.2.2 Step Dike

The Step Dike is a concept that can be combined with a traditional dike body, and the traditional dike body serves as the base for the step dike. This concept can use space efficiently as there are a number of horizontal flat surfaces that can be used for several functions. See figure 2.4.

This concept is constructed as follows. Alongside a traditional dike body deep walls are placed. Each deep wall goes equally deep into the ground, but differs in length above ground. If necessary, the step dike can be constructed much wider and higher than required, making it safer. The spaces between the deep walls are filled with soil, creating the characteristic steps.

1 The ratio of the walls above and below ground is 1:1.
2 The height of the step dike is determined by at least the Maximum High Water level (MHW) and the height is adaptable.
3 The construction is very space efficient.
4 The construction is flexible. When the step dike has been constructed, functions can still be added or adjusted later.
5 The construction is adaptable to possible climate change. By extending the deep walls, the construction can be adapted to higher water levels.

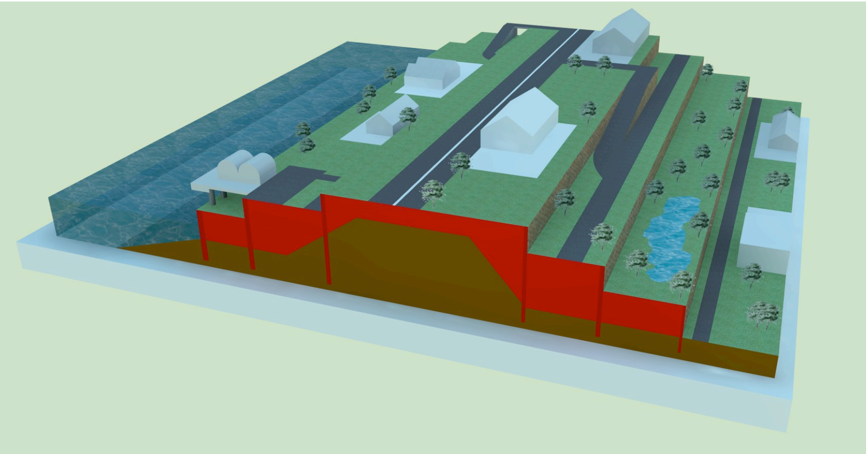


Figure 2.4: Step Dike (indicated in red)with various functions on each step.

2.2.3 L-wall

The L-wall is a structure that could replace a traditional dike body in urban areas. The L-wall is a freestanding concept that does not need a traditional dike body. The building serves as a flood defence and the building needs to be waterproof, flood (stream) resistance and robust built. This concept is a solution in urban centers where lack of space is a big issue. It is a concrete construction of which the horizontal and vertical parts are equal in length, giving it the characteristic L shape. Behind this wall, additional functions can be placed. See figure 2.5. An important consideration for functions in combination with the L-wall is that the walls must always be kept accessible for inspections. The L-wall can also be constructed in such a way that a tunnel can be built below ground. Functions can also be realized on top of the tunnel.

When the horizontal part is constructed deep enough into the ground, it can also withstand piping and thus reduces the chance of the construction failing. The vertical part, however, can also withstand piping.
Because it is a hard construction that directly stands in contact with the water, waves react more intensively to the wall. This is in contrast with traditional dike bodies which have slopes that attenuate the energy of the water and also the waves.

1 Ratio of the wall heights above and below ground depend on wave height and soil structure.

2 The height is determined on the basis of the: dike table height (the minimum required height of the defence). This construction needs to be designed for the following requirements. It has to be at least as high as the Dike Table Height (DTH). Additional height to withstand waves and ground subsidence is also needed. Standard factors are not given for these because it is a customized construction.
3 The construction is very space efficient.
4 The construction is not flexible and the functions must be determined in advance. It is hard to adjust functions, so they have also to be prepared for the future. One very important consideration for functions in combination with the L-wall is that the walls must always be kept accessible for inspections. Placing a house against the L-wall means that the ground floor should remain open. This can be done by using the ground floor as a garage.
5 The construction is adaptable to possible climate change. The L-wall can be adjusted to future changes. The walls have to be strong enough, and because the ratio horizontal/vertical wall has to be the maintained, space must be kept available on land to adjust the base of the L shape if the upright section is altered.

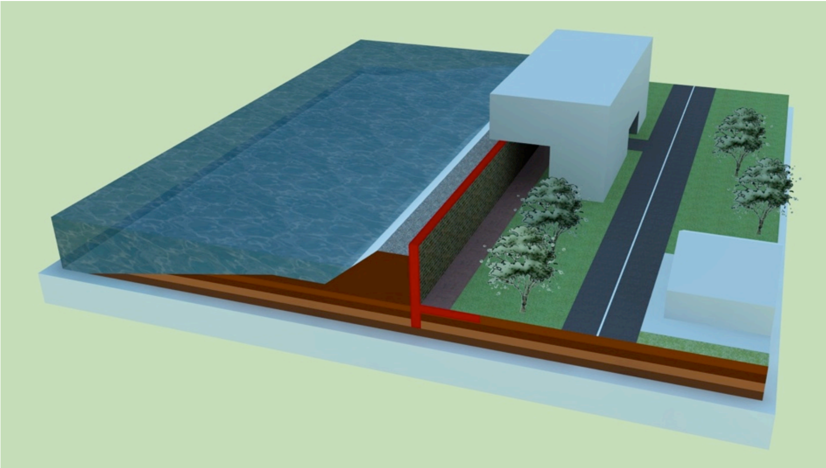


Figure 2.5: L-Wall (indicated in red) with a building against it. This does not show the tunnel variant.

2.2.4 Soil Retaining Wall

This is a concept that can be combined with a traditional dike body. The construction can be applied either behind the dike or in front of the dike. When placed behind the dike, it becomes a very spatial solution creating space for functions. Directly behind the dike the land can be released to private developments, which makes it possible to integrate the defence in the buildings. See figure 2.6.

To realize this construction the traditional dike body has to be excavated until only a half (in plan) remains. The remaining part of the dike body is kept in place by a steel or concrete wall, allowing tome and space to create a soil retaining wall.

This construction does not only demand certain height requirements, but the excavated dike body has to be at least 3 meters wide at the top.

1 The ratio of the walls above and below ground is 1:2.
2 The height requirements are as follows. Minimum height is determined by the Maximum High Water level (MHW). An additional 0.5m for safety and another 0.5m to compensate

any ground subsidence. When the wall is placed on a layer of sand, compensating ground subsidence does not have to be applied. Furthermore, this wall could also function as a piping screen.

3 The construction is medium space efficient.

4 The construction is not flexible and the functions must be determined in advance. Functions can also be combined with this construction, but the walls have to be kept accessible for inspections, the same as for the L-wall above.

5 The construction is adaptable to possible climate change. The soil retaining wall can be adjusted to future changes, as can the dike body.

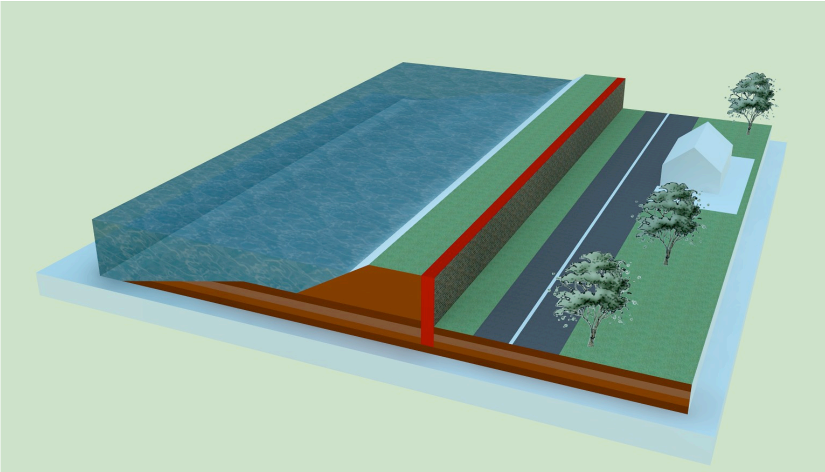


Figure2.6: Soil Retaining Wall (indicated in red).

2.2.5 Oversized inner slope

Over sizing the inner or outer slope of a levee are concepts that have to be combined with a traditional dike body. When realizing, both concepts need a lot of space but when realized they create a lot of space and are believed to be unbreakable. When the inner side of the slope is over dimensioned, all potential functions can be applied. Land is simply raised. The greatest limitation of over dimensioning the inner slope is that all existing functions have to be removed. This is a major undertaking and will also incur enormous financial cost.

The inner or outer slope of an existing dike body is extended by adding soil to the slope, giving the slope a very shallow angle. Because of the shallow angle, waves have less influence on the dike body and the height can be decreased which is positive for the visual aspect of the surrounding area. There are no special demands for these concepts. The only consideration that has a direct influence on the functions is the angle of the slope. An angle of 1:6 is only suitable for green functions or infrastructure. When the angle is >1:9 buildings can be constructed on the slopes.

1 The height is determined by the existing dike body and by the Maximum High Water level (MHW).

2 The construction is very space efficient

3 The construction is flexible.

4 The construction is flexible. When the Oversized outer slope has been made in place, functions can still be added or adjusted later.

5 The construction is adaptable to possible climate change (only on places where functions are added a strategy is needed).

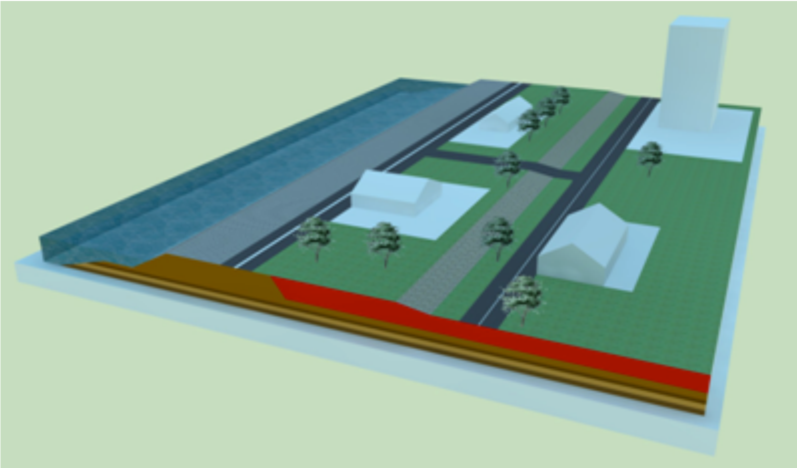


Figure 2.7: Oversized inner slope (indicated in red) with functions along the slope.

2.2.6 Oversized outer slope

Oversizing the outer slope of the existing dike makes the front of the dike higher and longer, and practically unbreakable. For example trees can be planted resulting in a 'park dike'. See figure 2.8. Vegetation or other functions on the outer slope of the dike will have a wave-breaking effect.
A disadvantage is that this concept has a negative influence on the width of the coastal.

Over sizing the front slope does not allow many functions, as tides and currents affect this. Only recreational and green functions can be applied, such as parks and aquatic nature. It is possible that, if applied correctly, these functions can stop or slow down the height and speed of waves making it possible to lower the crest of the dike body. Buildings can be constructed on the front of the dike although these have to be floating.

1. The height is determined by the existing dike body and by the Maximum High Water level (MHW).
2. The construction is of medium space efficiency
3. The construction is flexible.
4. The construction is flexible. When the Oversized outer slope has been made in place, functions can still be added or adjusted later.
5. The construction is adaptable to possible climate change (only on places where functions are added a strategy is needed).

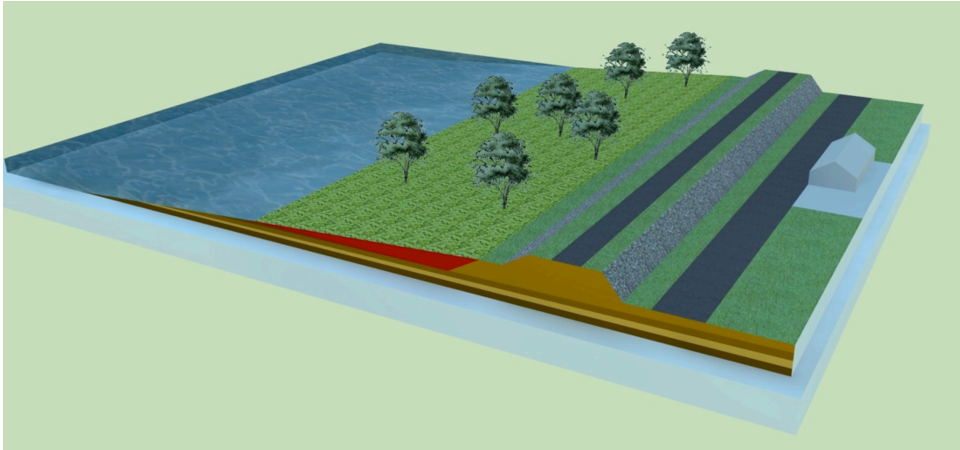


Figure 2.8: Oversized outer slope (indicated in red) with

2.3 Functions for potential integration

The location of a MFD partially determines which functions can be combined with the MFD. This is influenced by several factors at the location. Factors include spatial plans, wishes and demands of local inhabitants and stakeholders. Also any future expectations based on climate change creating rising water levels as well as the amount of space that is available for the MFD.

It is advisable to do research for conducting projects in the nearby area. Connecting with these projects by making the functions related with them, results in a MFD which has additional functions that fit with the needs of the area and is most likely to be more attractive to exploit. This approach makes it also possible that the MFD fits with the vision of stakeholders and city councils, and thus chances are the MFD and the integrated functions are accepted more readily. When looking at a larger area it might become clear which functions are attractive for day tourism people holidays for a couple of days or people who are prepared for driving to the functions. It is not desirable to integrate functions that can already be found in the surrounding area. Making the functions interesting and attractive or aimed at a particular group will make more people visit the MFD and generate more benefits.

The surrounding area and stakeholders determine which functions are best to be integrated with a MFD. Type of MFD determines which functions can be integrated. Each MFD is best suited for specific functions. This means that some functions cannot be integrated with a given MFD, but can be integrated with an alternative MFD. It is not possible to determine in advance which functions are best for which MFD. This depends on too many factors, such as stakeholders or spatial plans. It is, however, possible to give a general idea of the groups of functions that can be integrated with a MFD. Looking at these groups, they can be divided as follows:

- Green functions
- Infrastructural functions (for transport and energy)
- Nautical functions
- Recreational functions
- Business functions
- Industrial functions
- Water retention

- Agricultural functions
- Residential functions
- Energy

These groups can be divided in sub-groups. For infrastructural functions this could mean roads, tunnels, parking spaces etc. Both the L-wall and step dike can be combined with infrastructural functions. However, the L-wall does not allow a tunnel whereas the step dike does. The way the MFD is constructed also determines which functions can and cannot be integrated. For the soil retaining wall, this can either be constructed with the wall facing towards land or towards the water. When the wall is facing towards land, substantially more functions can be integrated than when the wall is facing towards the water. This is due to the respective amounts of space that become available.

For the MFD mentioned in State Of The Art (SOTA) it is possible to give a general idea of the groups of functions that can be integrated with each MFD below.

Coffer dam

Combined with traditional dike body

- Infrastructural functions (tunnels, public transport, parking garages, footpaths)
- Recreational functions (parks, boulevards, gardens, small shopping buildings)
- Green functions (parks, gardens)

As a freestanding construction

- Infrastructural functions (tunnels, public transport, parking garages, footpaths)
- Recreational functions (parks, boulevards, gardens, small shopping buildings)
- Green functions (parks, gardens)
- Nautical functions (harbours, piers)

L-wall

- Infrastructural functions (mainly above ground such as roads, parking spaces)
- Living functions (when attached to the wall, the wall must be accessible for inspections. This can be done by for instance making garages under the houses, see Figure z)
- Industrial functions (same standards as for the living functions above)
- Business functions (same standards as for the living functions)

Soil retaining wall

Land side construction (wall facing towards land)

- Infrastructural functions (roads, parking spaces, public transport)
- Living functions (houses)
- Industrial functions (factories, warehouses)
- Business functions (Offices)
- Recreational functions (parks, boulevards, gardens, shopping malls)
- Green functions (parks, water retention)
- Agricultural functions (livestock, horticulture)

Water side construction (wall facing towards water)

- Recreational functions (parks, gardens, water sports)
- Nautical functions (piers)
- Green functions (water retention)
- Agricultural functions (livestock)

Over sizing inner and outer slope
Inner side (land side)
- Functions are depending on the overdimentioning of the defence. If the land is heighten enough it is similar as land inwards. All functions are possible.

Front side (water side)
- Recreational functions (parks, water sports)
- Green functions (water retention areas, wet nature)
- Nautical functions (floating buildings, (floating) breakwaters)

Step dike
Combined with traditional dike body
- Infrastructural functions (tunnels, public transport, parking garages, footpaths)
- Recreational functions (parks, boulevards, gardens, small shopping buildings)
- Green functions (parks, gardens)

As a freestanding construction
- Infrastructural functions (tunnels, public transport, parking garages, footpaths)
- Recreational functions (parks, boulevards, gardens, small shopping buildings)
- Green functions (parks, gardens)
- Nautical functions (harbours, piers, breakwaters)

2.4 Requirements

This Section deals with which requirements have to be taken into account for bringing a multifunctional flood defence into practice. Such as the governance arrangements between the actors which needs to be effective, as well as having knowledge about real estate. Decisions in the area of governance (cooperation), organisation of regulation and land development (real estate) have primary consequences as to whether or not a MFD is possible and which of the various alternatives may be feasible.

2.4.1 Governance

Governance of multifunctional flood defences needs to be set in the context of an atmosphere of multiple users, multiple sets of administrative rules and multiple legal frameworks. In some cases the government (federal government, municipality or water board) is leading in other private companies are the instigators.

In order to create an adaptation cycle, a cycle in which synergy develops, the adaptation process and the development of knowledge for adaptation must be organized in such a way that scientists, policymakers and others are involved in creating synergy between often unrelated and divergent subjects and goals which results in understanding, balancing, implementing and evaluation the MFD project. Involving local stakeholders is an important contribution to this.
The effects of climate change are dependent on the local conditions, and the local stakeholders are an important source of knowledge and can provide information about local conditions, challenges and wishes. Also, involving local stakeholders will create more acceptance when measures have to be made. The costs for adaptation will differ per location because the measures are dependent on the local, physical circumstances, the expected effects and also the socio-economic circumstances and challenges per location (van Loon – Steensma, 2011).

Therefore in the design process the needs and requirements of current and future stakeholders, such as the municipality and the water board or other parties in the water sector are essential. A

soundly constructed CBA requires good communication and open books. It is important that all information exchange takes place transparently. There is a lot of information input of the (chosen) MFD design needed to estimate the costs and benefits items of the MFD adequately.
In addition, the result for the MFD design is an interaction of integral ownership of the different functions on subject like lifespans, financial responsibility, risks and liabilities, distribution of costs and benefits. Because of the life cycle responsibility it could be necessary to have a form of organization that is takes care of management and maintenance, sharing risks and benefits over time.

In the pilot case in Dordrecht several parties are involved in a dike strengthening project. These parties are "Rijkswaterstaat", the "Delta program", the "Waterboard Hollandse Delta", the municipality of the city of Dordrecht and several other stakeholders in the area such as land- and hotel owners. Moreover, any alternative developed should be able to satisfy the requirements of these parties or at least to not reduce the economic benefits from their main activities. For example, the spatial plan, written by the municipality of Dordrecht, indicates that agricultural and green functions can be expanded in the area. The Structuurvisie Dordrecht 2020 (Structural Vision Dordrecht 2020) and the Strategisch Groenproject (Strategic Green Project) give indications of recreational possibilities for the ‘Kop van ‘t Land’. These plans influence the types of functions that can be combined in the dike.

2.4.2 Regulation

Protection standards for dike ring areas in the Netherlands have been established by national law as the average exceedance frequency of the design water level that the flood defences must withstand. This requirement constraints the minimum height of any dike to be determined partially based on the maximum high water level, subsidence of the subsoil, wind wave attack height, and additional robustness surcharge. The legal protection standard for Limburg river Maas is 1:250, for large rivers 1:1250, the coastal and lakes 1:4000 and the Randstad region 1:10,000 (rijkswaterstaat.nl). Every 5 years a test is performed by the Water Board, the principal owner of the dikes in the Netherlands, to inspect the performance of dikes and whether they meet their designed conditions.

In France the municipality is responsible for the overall safety, although the duty to ensure the safety of individual dikes is that of the owner of the land or the dike. The owners typically pass their responsibility on to managers, because individuals’ do not usually have the capacity or competence to ensure safety. Then the "control service" an assessment organization, determines if the regulations are being complied. In this cases as well as in the Netherlands on different places in France the regulation varies.

2.4.3 Real Estate

With the introduction of additional functions in the flood defence, construction of real estate becomes an option. Real estate wants to ensures that additional benefits can be realized. Commercial functions often earn money, so that real estate is interesting to evaluate in a business case of the development. The rule remains: the extra cost for the realization of the real estate should be lower than the benefits, only then is there a sound business case.

The realization of real estate in combination with a flood defence requires considerations as below.

1. Attention should be directed to the flexibility of the function. Changes in water management, such as climate, should be compensated by the real estate. Adaptability must remain possible to adequately cope with dynamics and uncertainty in the long term.

2. Robustness of the defences is required. In the field of water safety the function must perform well at all times. The security should be guaranteed; this requires an integrated approach to engineering in water management with real estate perspectives.
3. Construction or utilisation of real estate will lead to changes in the design of the defence. The traditional operation and control of the levee invariably needs to be modified resulting in an integrated design. A building in the dike body or on top or around the dike influences the whole system.
4. Before real estate is used, a cost-benefit analysis is required. In a rural location real estate will be less cost effective. For real estate, it is important to examine whether at local scale real estate functions are needed in the long term. In an urban situation it is usually more obvious that there is a need for real estate.
5. Land value of the defence rises. The water board can receive money for the land they rent. This is a direct benefit for the water board or for the owner of the MFD. The cost of renting land will vary depending on who owns the land and what the value is. Also not all land is owned by the water board.

Guidance for cost benefit analysis

2.5 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). However, it is necessary to be prudent in not underestimating the costs due to lack of investigation of specific aspects of the project. 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). Belli (1998) emphasizes that sunk costs should be avoided in any cost benefit analysis because they have already been incurred and are irrevocable. For example, if the aim of the project is to strengthen a dike system by heightening or widening the dike body, the cost of construction of the whole dike system is a sunk cost which is not part of the cost estimation. 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 recommended 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 or occur throughout the life time of the project (termed “recurrent costs” or “lifetime costs”, respectively). Table 3.1 indicates some of the cost items which are likely to be incurred in dike strengthening.

Table 3.1 Costs typically incurred in dike strengthening

Investment costs	Recurrent costs	Lifetime costs
Project planning and preparation	Repair (e.g. slope damage repair)	Monitoring (e.g. period inspection)
Preliminary investigations (e.g. site survey)	Interest repayment	Maintenance (e.g. revetment maintenance)
Project design		Regulation
Supervision or management		
Land acquisition		
Construction		
Landscaping		

Many countries at risk of flooding have provided unit costs which can be used directly to estimate the costs of the dike strengthening. A study conducted by Hillen et al. (2010) compared the costs of adaptation to the effects of climate change for dike improvements in New Orleans, the Netherlands, Vietnam, and Cape Town, all of which are located in low-lying deltaic coastal areas. The unit costs were defined based on a wide range of soft/hard engineering measures, including dike/levee construction, beach nourishment and sea walls.

In addition to the cost of dike improvement, a similar procedure needs to be followed to determine the costs of any extra functions added to a dike system. Except for alternatives integrating secondary functions into the dike body, the cost evaluation process should be carried out separately for the dike and the secondary functions. This provides two general benefits: firstly, it makes it easier to use any available unit costs for dike improvements. As there is no unit cost that can be applied to the combined system of dike and extra functions these have to be dealt with separately. Secondly, in using a spreadsheet for the calculation of lifetime costs, it is simpler to compute these separately as they may have different expected lifetimes.

2.6 Identifying and evaluating benefits

Benefit evaluation aims to consider if the benefits of implementing an alternative option are worth its costs. Principally, assessing the benefits of a flood risk mitigation measure involving various features such as prevented economic losses, injuries and casualties, psychological trauma, etc., and influencing people of different groups is more complicated and surrounded by uncertainty than the costs of implementation of the measure. Moreover in contrast to the costs, the benefits are likely lying far into the future (Hallegatte, 2006).

Benefit items are identified based on the output values (impacts) generated by interventions. Respectively, reduction in flood risk due to implementing the expenditure is taken as the major benefit of flood defence improvement. The benefits of any scheme include flood damages prevented due to either reducing flood frequency or decreasing flood impacts (Penning-Rowsell et al., 2010). The risk based approach of this guidance focuses on cost saving by decreasing the consequences of flooding resulting from a reduction in the probability of flooding.

In addition to the benefits of flood mitigation, this guidance deals with the benefit assessment of adding secondary functions into flood defences. Two perspectives are considered for evaluation of the extra functions' benefits: t*he economic evaluation of ecosystem services*, and *market price valuation*. The purpose of ecosystem valuation methods is to estimate the economic value of changing the baseline environment currently in the area or to assess the amenity and recreational value of extra functions, if any. In addition, market price evaluation methods target the services provided by the real estate assets installed on/around the dike or integrated into the dike body.

As the benefits of each intervention will be compared with the "do nothing" case, the first step to assess the benefits is to determine the "do nothing" situation. This includes evaluation of the current risk level if nothing is done in addition to the changes in risk over time (for example, due to climate change) (DEFRA, 2010). Moreover, the deterioration and failure of structures (e.g. defences) as well as any change in frequency of events and their impacts should also be evaluated. For the evaluation of ecosystem services, this includes a careful analysis and survey of the present environmental and natural situation for further analysis of the impacts of extra functions on these services. It is not necessary to conduct a do nothing analysis for the real estate assets if these have not yet been installed.

2.6.1 Benefits of flood risk reduction

Risk is defined here as a multiplication of consequences and probability of flooding, where the level of the consequences is also dependent on the probability. Whereas the probability of flooding depends on the probability of failure of individual dike sections, and the relationship between these, and knowing that implementing any change to the dike structure directly changes its probability of failure and overall flood probability (MIN VENW, 2005, Stijnen et al., 2008, DEFRA, 2007, Pos et al., 2000). The cost saved due to reduction of flood risk as a result of decreasing the probability of failure is counted as a benefit indicator in this guidance.

The first step in the assessment of flood risk reduction benefits is to estimate the dike failure probability. The essence of the method to assess the probability is that various 'failure mechanisms' are investigated due to either extremely high water levels, or instability in a dike structure (e.g., Den Hengst, 2012). Then, the probability of all failure mechanisms occurring together is estimated to determine the overall probability of flooding in a dike ring. Of special relevance here with regard to MFD are failure mechanisms such as under-flow of floodwater and uplift pressures that may cause leakage. These failures are dependent on the type, condition and stability of existing foundations and soil properties on the one hand and the features such as weight, size of the MFD structure. At present date there is very limited information available regarding the relative importance of these failure mechanisms compared to those associated with traditional flood defense systems. In the cost benefit analyses described in the next chapter these failure mechanisms have not been taken into account in a quantitative sense.

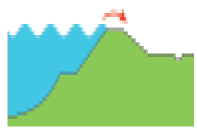
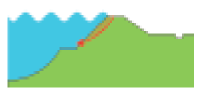
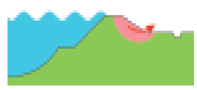
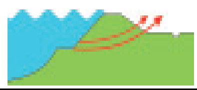
Thereafter, two dominant consequences of flooding, namely flood damages and loss of life (economic value of victims), are estimated for each flooding scenario based on flood and breach modelling results. Eventually, the risk of flooding is expressed as the sum of the damage costs and economic value of victims per year (MIN VENW, 2005). The resultant monetary values are taken as the benefit of flood risk reduction. Such a flood risk assessment comprises of five stages as shown in Figure 3.1.

Figure 3.1 Steps in flood risk assessment (Stijnen et al., 2008)

1. Investigation of the failure mechanisms

Any kind of dike failure significantly influences the impacts of flooding and makes failure a very important factor to be determined. Analysis of the performance of the various types of dikes shows certain failures are more likely to occur under hydraulic loadings and geotechnical (strength) of the dikes. Among these, four mechanisms have a higher probability of occurrence: overtopping; piping; sliding; and damage to revetment (MIN VENW, 2005). Table 3.2 illustrates the four main failure mechanisms by visual schematization of each.

Table 3.2 Main types of failure mechanisms (MIN VENW, 2005)

Failure mechanism	**Description**	**Schematization**
Overflow and overtopping	The water level or the waves are higher than the crest of the dike, the water flows over the dike causing erosion of the landward slope	
Damage to revetment	The dike facing (or revetment) becomes damaged by the waves, following which part of the dike is washed away	
Sliding of inner slope	The landward side of the dike becomes unstable and subsides	
Piping	Water seeps under the dike creating channels which undermine the stability	

The most common approach for mathematical representation of failure modes, as discussed in literature, is the determination of a limit state function for each failure mode, either deterministically

or probabilistically. The final outcome of both probabilistic and deterministic methods can be used to identify the dominant failure mechanisms at certain locations. The general idea is that a dike ring is interpreted as a chain of flood defence sections with equal strength and loading parameters. In order to describe the failure mechanisms, as discussed by Naulin et al. (2010), a combination of the strength of the flood defence (R) and hydraulic loading (S) results in a limit state function, namely Z(R,S).The strength of the flood defence structure (R) depends on geometric and geotechnical characteristics of the structure (e.g. cohesion of the soil, crest level, revetment thickness). Whilst (S) expresses the loading dependent on hydraulic loading, wave action, water level and so on. The structure is safe if strength (S) exceeds (R), otherwise it fails if (S)>(R).
The principal data needed for the process are geometric data (slope, orientation, fetch, etc.), material properties (weight, sliding strength, etc.) and hydraulic boundary conditions (waves, water level, duration, etc.). For a deterministic approach a single value is used, whilst for a probabilistic approach additional data needs to be included. This includes the variation around the average (mean value and standard deviation), and spatial and temporal correlations within a dike section and between sections (Riedstra, 2004).

PC-Ring (Dutch software) and ProDeich (German software) are examples of a number of software packages which take spatial correlations into account for determining the limit state function of dike sections (Boer, 2007). The procedure applied in both of these models necessitates site visits to prepare a defence map, relief lines and geometric data. Knowledge of past events to determine the most probable failure mode and to divide the ring into dike sections is based on related failure modes. Bruijs (2003) explains the steps required for PC-Ring in detail whilst Boer (2007) compares the input data, methods and outcome of PC-Ring and ProDeich.

2. Estimating failure probabilities

The overall idea of the assessment methods for calculating the failure probability is that after dividing a dike ring into sections with similar characteristics and loading, limit state functions can be developed to describe the strength and loading for each failure mechanism as explained above. Finally the failure probabilities are calculated using deterministic or probabilistic methods.

Deterministic methods are the traditional way for assessment of failure probability, where the input parameters are assumed constant in time. The outputs of such methods can be presented as fragility curves in which deterministic loading characteristics are plotted against the failure probabilities. Furthermore, probabilities are interpreted in absolute terms conditioned over the full range of loads to which a system may be exposed. The four basic approaches to develop deterministic fragility curves are: judgemental (based on expert opinion); empirical (observation based); analytical (model based); and hybrid (combination of other approaches). The analytical approach is most commonly used which applies a limit state function, or the numerical methods to obtain the probability of failure (Schultz et al., 2010).

Probabilistic approaches use the limit state functions and the probability density functions of the variables as the base for determination of the failure probabilities. In simplified approaches, the overall probability is the summation of the probabilities of all the failure modes assessed. It is assumed that dike section and failure modes are completely independent (Vrolijk, 2002). In fact, the failure modes of various dike sections are not mutually exclusive, and therefore the failure probabilities are not simply additive (Hill et al., 2003). Hence, by implementing a fault tree analysis for the failure probability of the dike sections and of the whole dike system, the failure probability of every failure mode can be reallocated. The contribution of failure modes to the combined system failure probability can be determined by fault tree analysis (Mai et al., 2007).

Various calculation methods are available to compute the probability of failure for any failure mode. The main methods applied in the literature are: FORM (First Order Reliability Method); SORM (Second Order Reliability Method); MC (Crude Monte Carlo); DS (Directional Sampling); and combinations of the these. The Dutch developed PC-Ring software applies the FORM method to compute the annual probability of flood defence system failure for a number of different failure modes. PC-Ring takes into account the statistical distribution functions and correlation in time and space. PC-Ring works with dike sections which are the most representative of the system's probability of failure, which significantly reduces the amount of data required for the analysis.

3. Modelling breaching and flooding

In addition to failure probabilities, the consequences of flooding need to be determined in order to compute the flood risk. Respectively, simulations of the breach growth and flood maps are required to characterize flood extent, depths, and duration over the flooded areas. Messner et al (2007) has described the potential use of each flood characteristic for the risk assessment as presented in Table 3.3.

Table 3.3 Load characteristics relevant to flood risk assessment (Leenders et al., 2008)

Flood characteristic	Relevance
Area	Determines which elements at risk will be affected
Depth	Has perhaps the strongest influence on the amount of damage
Duration	Special influence on damage to building fabric
Velocity	Only high velocities will lead to increased damage: therefore mainly relevant in flash flood areas or areas near dike breaches
Rise rate	Influence on damage - reducing effects of warnings and evacuation
Time of occurrence	Especially important for agricultural products
Contamination	Contaminants and loads may increase damage significantly
Salt/-freshwater	Saltwater may increase damage; relevant in coastal areas

Floods resulting from the failure of a flood defence can be studied by a combination of 1D and 2D modelling to generate flood risk maps. Respectively, 1D hydraulic models are used to describe breach growth and breach flow, where a coupled 2D model is used to predict flood propagation in the inundated areas. Breaches are modelled by means of time series for breach width, crest level and side slope. Number and location of the breach(es), time of breaching, and hydraulic load outside the breach (i.e. height and duration of the high water level) are among the data needed for breach growth modelling (Vanderkimpen et al., 2009). In addition, a digital Terrain Map (DTM) of the study area generated by GIS (including land elevation, land use, location of water courses and flood defences, etc.), relevant meteorological, hydrological, hydraulic, and geotechnical data are needed as inputs for flood modelling (Jonkman et al., 2008). Various models have been developed aiming for 1D/2D modelling of inundation and breaching, such as MIKE FLOOD and SOBEK 1D2D, that all solve the Saint-Venant equations by means of a finite difference scheme.

4. Computing economic losses and loss of life

Economic losses may occur as direct or indirect flood damage. Direct flood damage results from the actions of floodwaters, inundation and flow on property and structures. Indirect damage arises from the disruptions to physical and economic activities caused by flooding.

The central idea in current flood loss estimation is the concept of loss functions, in which the direct monetary loss is related to the type or use of the affected properties and the inundation depth at each property. Loss functions can provide the absolute loss in monetary values or the loss ratio (i.e. the percentage of the asset value damaged) for the asset values of the exposed elements (Thieken et al., 2008).

The first step to prepare loss functions is to classify various forms of land use, such as valuable objects inside the dike ring, e.g. different types of residential buildings (small houses, apartment buildings, etc.), public buildings (schools, stadia, municipal buildings, churches, etc.), factories and industrial buildings, cars, agricultural equipment, crops and live stock, and so on (Manen and Brinkhuis, 2005). Damage functions are then determined based on the relationship between flood characteristics (mainly depth of flood water), and the amount of economic damage to each specific land use type. In this regard, the extant literature on existing flood-damage functions can be considered in order to determine a volume-water damage function that can be used for flood damage assessment. Also, it is possible to derive the damage functions based on expert estimation for either standardised property types or for the specific properties located in the study area based on data from previous flood events (Messner et al., 2007). Results can be plotted as graphs of flood damage against exceedance probability (the reciprocal of the return period in years) so, the annual average flood damage is the area under each graph for each asset type.

The Dutch approach followed by the Ministry of Transport, Public Works and Water management, documents the probability and impacts of flooding, as well as risk of flooding of dike rings in The Netherlands. The effects of floods on the economy are expressed in monetary terms through the HIS-SSM tool. Three types of damage are included: Direct damage within the flooded area by physical damage to buildings, inventories, terrain and infrastructure; Direct damage within the flooded area as caused by business interruption and economic damage by production loss; indirect economic damages outside the flooded area due to loss of production (Leenders et al., 2008).

Apart from economic losses, floods may cause severe loss of life and injuries. So, loss of life should be monetized and included in the financial balance of cost-benefit studies. Generally, the loss of life is estimated by loss functions relating flood characteristics to the number of victims (Jongejan et al., 2010).

In addition to the spatial and temporal distribution of flood characteristics (obtained from flood simulations described above), the population densities of regions affected and evacuation possibilities (the exposed population equals the number of inhabitants of the flooded area minus the number of evacuated people), and the probabilities of death of the affected individuals (mortality rates) are the main factors determining the number of fatalities for a particular flood scenario (Jonkman et al., 2008). This approach ignores the difference between the vulnerabilities of different individuals to flooding (Jonkman, 2007).

The visual schematization of the fatalities is represented by an FN-curve that shows the exceedance probabilities of the potential numbers of fatalities on a double log scale (Jonkman et al., 2011). The area below the FN curve gives the annual estimation of fatalities for a flood scenario. However, these values should be transferred to the annual economic loss of life in terms of monetary loss to be taken for risk assessment.

Taking the economic value of human life into account is controversial as it is often considered unethical to put a price on human life. However, this prevents the underestimation of economic damage resulting in a lower safety level of the system considered. 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 (life is valued in proportion to a person’s potential economic production); comparative approach (relates the value of human life to the investment made and to the number of prevented fatalities) utility based approach; and contingent valuation.

5. Estimating the combined risk

This guidance considers two main aspects of risk: economic losses (direct and indirect) and loss of life. The risk sum for different consequences is expressed in monetary terms. However, flood risk is referred to as the overall probability of occurrence (considering failure mechanisms) of an unfavourable event multiplied by the consequences. The following equations express the mathematical formulae that can be applied for the risk assessment process explained above.

Annual damage = probability of exceedance x number of the assets x associated damage function

Annual economic representation of loss of life = probability of exceedance x number of fatalities x economic value of human life

Total risk = annual damage (in monetary terms) + annual economic representation of loss of life (in monetary terms)

Knowing the damage-probability curves and FN curves for each flood scenario as a result of implementing each alternative, gives the opportunity to estimate the benefits of risk reduction strategies. For each one of the FN and damage-probability graphs, the area between the two curves of "do nothing" and "implementing an alternative" is equal to the benefit of that measure. However, for the FN-curve, the value obtained should be multiplied by the economic value per loss of one life.

2.6.2 Ecosystem valuation (recreational gains and losses)

Broadly speaking, the benefits of ecosystem services provided/destroyed by a defence system arise from either recreation and amenity benefits of extra (green)functions added (Penning-Rowsell et al., 2010) or as a result of any change (positive or negative) brought about by the implementation of an alternative in comparison with the baseline conditions (DEFRA, 2010).

Correspondingly, this guidance follows the approach of "Economics for the Environment Consultancy" as described by Brouwer et al. (2010) for assessing the potential (positive or negative) benefits. However, it may not be necessary to go through all of the steps in each appraisal.

1. Provide a qualitative and quantitative assessment of the effects (e.g. amount and area affected)

This step includes determination of any added or provided environmental service resulting from the ‘Do nothing’ and the ‘Do something’ options. This concerns qualitative assessment (e.g. significance and magnitude of the effect), and quantitative assessment (e.g. the area of habitat created).

2. Identify the population affected (e.g. number of beneficiaries and non-users who concern)

The population who are the beneficiaries or losers should be determined appropriately for each environmental service provided. Indeed, when it is not possible to assign monetary value to environmental effects, consideration of the population affected (e.g. number of households or visitors) can be valuable for providing an indication of the significance of gains and losses in welfare. Two principal population groups that can be distinguished as described in (Brouwer et al.,

2010) are *Users*, including those who make a direct or indirect use of that environment (even if not quantified), and *Non-users* who do not make direct or indirect use of that facility, but are affected by changes in an environmental resource.

3. Selecting relevant valuation criteria to transfer the vales into monetary terms

The appropriate method should be selected based on the environmental services provided. Alternative methods for economic evaluation of the natural environment have been extensively discussed in (EFTEC, 2006; EFTEC, 2010) where the procedure to be implemented as well as the data needs and other concerns are explained in detail. Examples of these methods are: Market Prices, Replacement Cost, Net Factor Income, Hedonic Pricing, Travel Costs, and Willingness to Pay.

4. Estimate the annual environmental benefits (e.g. €/yr x impact/yr)

The estimation of monetary values of ecosystems services can be carried out using two basic approaches: *unit value estimate*; and *valuation functions* as described in (Brouwer et al., 2010). Once the benefit estimates per year are determined, the annual estimates may be computed using:

Annual ecosystem services benefits = unit benefit estimates x number of affected population

Or

Annual ecosystem services benefits = unit benefit estimates x impact unit

It should be noted that the negative benefits (or costs) of implementing an intervention on a natural ecosystem is also computed and taken into account as a cost.

2.6.3 Real estate appraisal

The term 'real estate' is applied here to identify the real property, or immovable property installed or constructed at the top of a dike, side sections or inside the dike body. This includes any buildings, machinery, roads, and other urban assets which can be added to a dike system to provide more benefits due to the addition of extra functions in addition to protecting habitats.

For the case of multifunctional flood defences, the real estate appraisal methods aim to determine the realization of MFD in addition to evaluate the benefits of secondary functions. Evaluation of exploitation of the extra functions depends on the type of function, as this can be public or private. In any case the owner of the dike (which is the Water Board in the Netherlands) would be the owner of the additional assets as well. Hence, private functions derive from the building which can be rented to individuals to sell or produce marketable goods, whilst public functions are the assets in possession of the dike owner which are used for public use such as libraries and schools. Both private and public assets lay inside the real estate properties and can be evaluated by various methods available for the real estate appraisal. The main methods to value the real estate properties as defined by Wildforster (2011) are: *The Market Value or market prices; Investment Value; Value-in-use; Liquidation Value;* and *Insurable value*. However, the most common method is the market valuation method, comprising of three components to determine the market value: the sales comparison; the cost approach; and the income approach.

1. The sales comparison approach

The sales comparison approach (market data approach) is a sophisticated competitive market analysis, and is the main method for determining the value of single-family homes. The subject property is compared with recently sold comparable properties. This method can be applied for example, where houses are built at the top of the dike, like the super levees in Japan.

2. The cost approach

Generally, the cost approach considers what the land, free from any structure, would cost, then the cost of actually building the structures is added, and depreciation is subtracted. The cost approach is most often used for public buildings, such as schools and churches that don't earn income.

3. The income approach

The income approach values a property by the amount of income that it can potentially generate. Hence, this method is used for apartments, office buildings, malls, warehouses, shopping centres, and other properties that generate a regular income. For private or public properties installed on/around the dike or integrated in the dike structure the dike owner potentially benefits from renting the assets. In view of this, it is this approach that is considered most applicable in this guidance. However, the private parties who rent the assets will have benefit of direct income. Only the benefits to the dike owner are considered here. The appraiser calculates the income (= rent) according to the following steps:

a. Estimate the potential **annual gross income (rent)** by doing market studies to determine what the property could earn.

b. The **effective gross income (rent)** is calculated by subtracting the vacancy rate and rent loss as estimated by the appraiser using market studies.

   Effective Gross Income (Rent) = Gross Income (Rent) - Vacancy Rate - Rent Loss

c. The **net operating income** (NOI) is then calculated by subtracting the annual operating expenses from the effective gross income. Annual operating expenses include real estate taxes, insurance, utilities, maintenance, repairs, advertising and management expenses.

   Net Operating Income (Rent) = Effective Gross Income (Rent) - Operating Expenses

d. Estimate the **capitalization rate**, which is the rate of return, or yield, that other investors of property are getting in the local market. A market cap rate is determined by evaluating the financial data of similar properties which have recently sold in a specific market.

   Capitalization Rate = Net Operating Income (Rent) / Sales Price or Property Value

   Therefore:

   Property Value = Net Operating Income (Rent) / Capitalization Rate

   An alternative way to apply the income approach is by the application of the Gross Rent. The GRM calculation only considers a property's gross rents, whilst the Cap Rate calculation incorporates a property's selling price, gross rents, non-rental income, vacancy amount and operating expenses. The gross rent multiplier (GRM) is used to value residential properties comprising 1 to 4 units and is equal to the sales price divided by the monthly rent:

   GRM = Sales Price / Monthly Rent

   The appraiser does not, however, use the current rent being charged, instead recent rental information from at least 4 comparable properties is used to arrive at a more accurate appraisal. Once the multiplier is found, then the value of the property can be estimated by multiplying the GRM by the monthly income.

   Market Value = GRM x Monthly Rent

The final outcome of evaluating market value of the property gives a monetary term as a direct benefit of any extra function installed in the body of a dike. The total benefit would be sum of the market values for each one of the assets constructed, in addition to the dike, for a purpose other than dike improvement. However, any such building might also contribute to the provision of a higher level of safety overall.

2.7 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, Br 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).

3. Results Pilot study and Lessons Learned

3.1 Multifunctional Defence ‘Kop van ‘t Land’

Dordrecht is one of the oldest historical cities of the Netherlands and is surrounded by several rivers. The pilot case study in Dordrecht is located in an area on the east-side of Dordrecht which is called the ‘Kop van ‘t Land’. It is a remote rural area approximately 7 kilometres from the city centre.

Dordrecht and the surrounding areas have experienced several devastating floods in the past, however, these are traditionally protected by dikes. Currently, Dordrecht is protected by 37 km of primary dike, named as dike ring number 22. The latest geometric and geotechnical studies have shown that the part of this primary dike located in ‘Kop van ‘t Land’ does not meet the minimum safety standards. Figure 4.1 shows from the sky is literally ‘Kop van ‘t Land’ the dike, the harbor, the ferry and a few houses. If ‘Kop van ‘t Land’ will fail severe flooding damages can occur in the hinterland of Dordrecht, see Figure 4.2.

Figure 4.1: situation of ‘Kop van ‘t Land’.

Figure 4.2: (part of) the hinterland of op van ‘t Land

Currently, the Water Board of Dordrecht is working on plans to strengthen the dike before 2017. These plans are connected with the subsidy framework of the "Hoogwaterbeschermings" program (high water protection program). At the same time the municipality of Dordrecht is looking for spatial solutions that fit into the current water safety vision of the city. Also, the Dutch government is looking for national showcases for adaptive delta management and the appliance of innovative delta technologies.

The challenge in ‘Kop van ‘t Land’ is to find flexible solutions that meet the safety demands for flood protection which are more robust and durable in the longer term. Sections 2.2 – 2.4 assist in making decisions regarding a MFD. This section describes the alternatives chosen for the pilot study area. The catalogue supported the decision making process in selecting two appropriate designs. The many other designs in the catalogue are not included in the further analysis of a MFD at ‘Kop van ‘t Land’. Subsequently, the developed CBA is partially applied to realize the feasibility of these alternatives in comparison with the traditional dike strengthening. However, the major difficulty in this process is to determine the appropriate alternatives able to provide the balance between the demands of a water defence and demands of the functions to be combined in order to create a safe and financially attractive design.

3.2 Catalogue: combination of concepts and additional functions

A matrix (FloodProbe, State of the Art Report, 2012) has been used to bring the various types of concepts and possible functions together, helping simplify the selection process between the different concepts (Figure 4.3). The catalogue provides an overview of where the function at the dike (top, front, behind, in) per design is feasible. In parallel each design determines which functions on or around the dike may be an option.
To select the two alternatives the matrix was used to find matches with the information that was already available. For selection of the alternatives that fit, it is important to carefully examine the location in context.

Because the location ‘Kop van ‘t Land’ is a rural location not every functions fits into the MFD like for a urban location. For this MFD if the focus is on functions like green and recreation (see below) the MFD is better connected with the environment. The ‘Oversized innerslope’ appears the most obvious choice for adding green functions. The ‘Cofferdam’ or the ‘Step dike’ are unable to easily add any recreational functions at the defence. Since the situation of ‘Kop van ‘t Land’ had previously looked for the construction for a recreation center in the dike, this study continues this idea by selecting the concept ‘Cofferdam’ (Section 2.1.1).

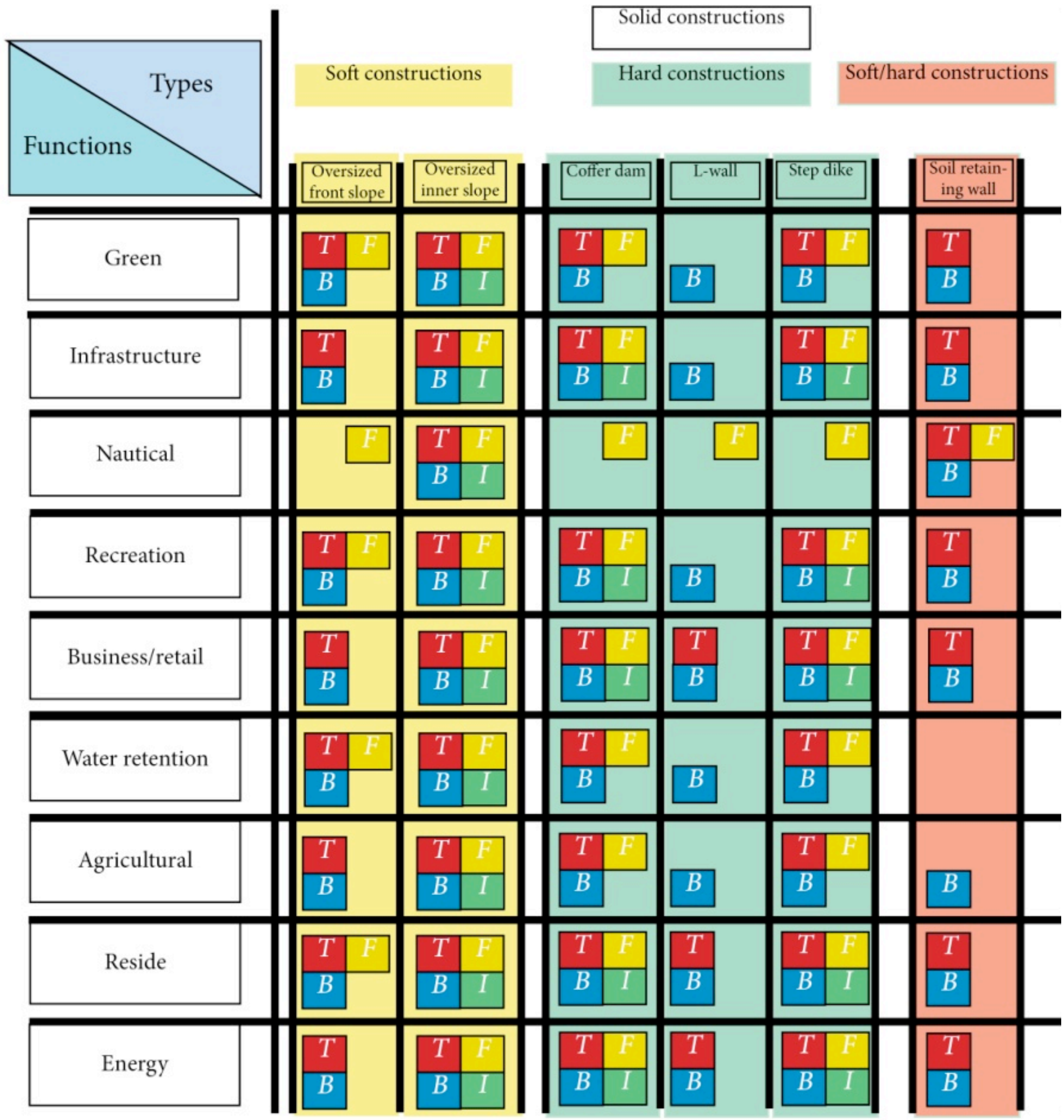


Figure 4.3: the catalog of MFD's guides for choosing the suitable MFD (SoTA, FloodProbe report xx).

3.2.1 Alternative 1 'Concrete structure'

The first alternative selected was a hollow concrete construction placed in the current dike on the water-side. It does not replace the current dike totally; it will become a part of the current dike to function as a water defence as well as providing recreational facilities. This alternative builds on an existing design and fits well in the vision of the 'Strategisch Groenproject' (Strategic Green Project) of the municipality of Dordrecht and the Province of South Holland.

A part of the current defence must be excavated in order to apply this alternative. The concrete construction is placed to replace the excavated soil. A large window is built into the construction on the seaward side, providing a unique view over the water. This construction will have the same height as the current dike and therefore will not be obstructing the sight lines of the area.

Additionally, the hollow structure can be used to install a variety of other services such as a meeting place for visitors to the 'Kop van 't Land', restaurants, and shops, etc.

The selected option is an alternative that requires further research in order to make it sufficiently safe and financially attractive, due to the influence the innovative construction has on the traditional design. In the figure below the construction inside with visitors is presented also is shown how the dike profile will look like including the construction in figure 4.4.

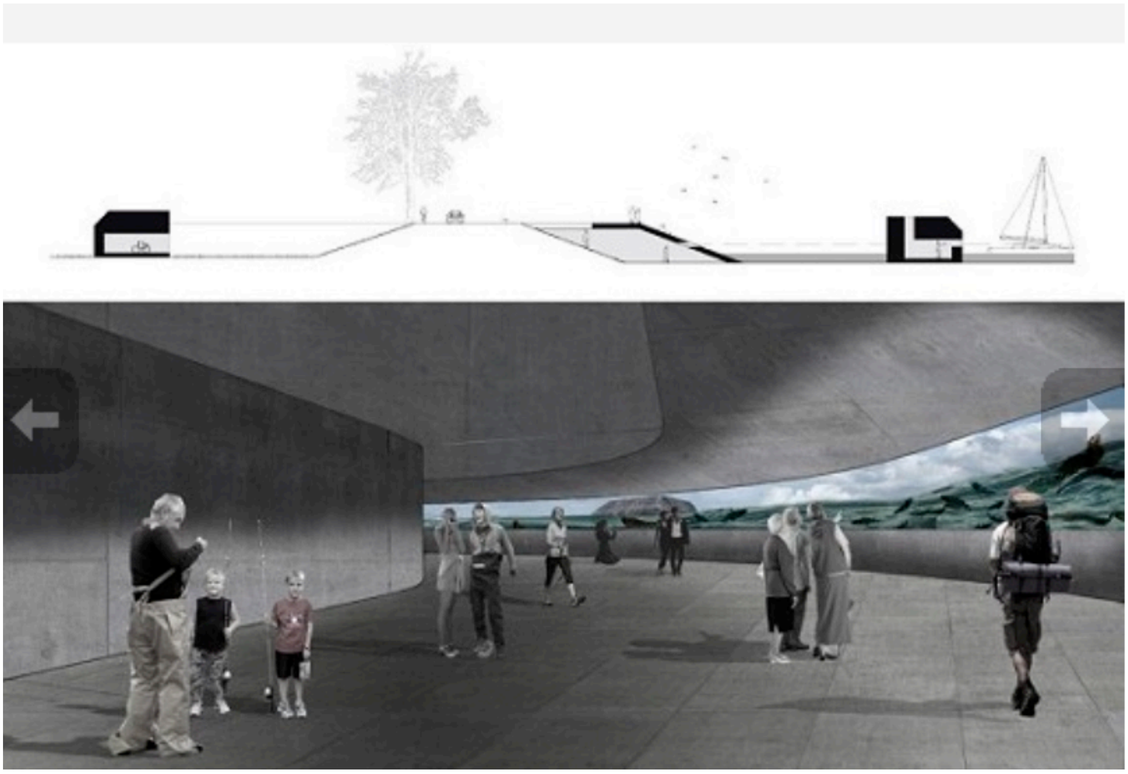


Figure 4.4: the profile and inner design of the concrete structure

3.2.2 Alternative 2 'Soil bank'

The second alternative is based on a growing dike facilitated by soil. Over a period of, say some 10 years, soil is applied behind and against the original dike to make the dike grow into a stronger dike and becoming unbreachable. The development process for this alternative is comparable with a soil bank. A soil bank is a physical place where mixtures of types of soil and silt are accepted, stored and ensures that it can be reused. Contaminated soil or silt which has originated from projects in the area will be handled in the soil bank so that it becomes purified. This purified soil or silt can either be utilised and submitted at the defence for strengthening the dike or sold to others.

The idea of a soil bank offers several opportunities making it an attractive option to be implemented nearby the defence. Firstly, the soil bank can be profitable by itself as the dike strengthening can also generate financial benefits instead of only financial costs. Secondly the purified soil applied at the location ‘Kop van ‘t Land’. Therefore the additional area provided by the soil bank can be used as a recreational area at any time, which adds value to the flood defence system. Functions such as a Spa, Leisure centre, Park with (sport) attractions, Terraces or Vineyards can be imagined. Thirdly, this alternative is very flexible, and can be adjusted based on the requirements of the Water Board for dike strengthening. Nonetheless, it contributes to forming an extra strong dike which is soft (no transitions from hard to soft) and adaptive whilst it is strong enough to prevent failures such as piping. In the figures below the soil bank in operation with compartment in types of soil and silt is shown in figure 4.5. And also the landscape is presented how the dike profile will look like if the soil bank is integrated with the present defence in figure 4.6.

Figure 4.5: compartments of the soil bank

Figure 4.6: a sloping landscape can appear with soil bank

3.3 Identifying costs and benefits

This section identifies the cost and benefits to be considered when evaluating the alternatives. It indicates some of the direct cost and benefits items that are likely to be incurred in the next stages of investment and life cycle for the alternatives. This cost benefit analysis should, therefore, be regarded as **indicative and an inter-comparison** of the costs and benefits of the two alternatives rather than an analysis generating absolute estimates. In Section 4.4, the evaluation of costs and benefits is presented, including the intangible and ecosystem costs and benefits. Only the direct tangible costs and benefits are considered, so as to make a quick scan.

3.3.1 Identifying costs

Generally, the construction, maintenance and operational costs are the cost items that are taken into account for the traditional dike strengthening method as well as the MFD alternatives. However, implementing and determining the items that make up the costs and benefits must be approached differently depending on the specification characteristics of each alternative.

It is more straightforward to estimate the costs for traditional dike types, since there are already unit costs prepared for various strengthening methods such as widening, heightening or a combination of these.

Determining the itemised costs for alternative 1 (Section 4.2.1) depends on many factors such as size of the construction, duration of realizing the construction, materials used, excavating the dike body, placing deep walls to keep the water out of the construction site, technical and other installations, and so on. An uncertain factor here is the duration of realizing the construction. The soil materials used to heightening and strengthening the existing dike have to consolidate to form a stable and compact structure. This consolidation process takes time and impacts the delivery time of the completed MFD considerably. These costs are not taken into account in this analysis. Another challenging task is to determine the operation and maintenance costs, since the influence on connecting (and reacting) of the concrete structure in the dike body is still unknown at this point. There are also technical stability consideration about the effects of the forces from the water and dike body on the construction, which directly influence the maintenance costs.

In contrast to the complexity in determining the costs of alternative 1, determining the cost items is much more straightforward for alternative 2 (Section 4.2.2). In addition to the costs of strengthening the present dike, the costs of essential hardware (e.g equipment, machinery, and installations), and the environmental administration costs (e.g. permits, registration, transport, and quality tests) are the major cost items to be considered.

The general costs of engineering a MFD are determined. Some more specific and unsure cost for a MFD are not mentioned. Depending on the environment of the planned location of the MFD, direct costs are imaginable if there is any contaminant releases during the project or if there are functions in the way on the current defence or if the land for placing the MFD is not only owned by the water board. Additional costs are soil remediation, demolish and moving functions and renting land.

The framework including the cost items in general is presented in Table 4.1.

Table 4.1, the direct costs items in general

Measure to be taken	Cost items
Traditional dike strengthening	Construction, operation, and maintenance for improving primary dike
Multifunctional flood defences	Construction, maintenance, and operation for both improving the primary dike and adding secondary functions. Optional: extra costs for shared use, multiple monitoring and added safety requirements (for avoiding failing of the MFD)

These costs are direct costs and do not take indirect costs into account such as environmental impacts, disruption to transport systems, noise and air pollution costs, and the social costs including providing information and explanations for stakeholders and local residents and assistance and education for engineering and usage of a MFD.

Broadly speaking, determining the cost items requires a detailed design of the structure, the regulations of the location and stakeholders and its additional functions to be used for a more precise cost identification and estimation.

3.3.2 Identifying benefits

Regardless of the type of flood defence, the primary goal is to save peoples' lives and properties. Respectively, the major benefit of each alternative should be contributing to reducing the risk of flooding. This is the most essential benefit that is designed to be achieved by delivering a traditional dike. Although traditional dikes provide roadways, wetlands and space for new ecosystems the focus of the traditional dike is for the major part on a mono-functional design. In a MFD profile the focus is precisely on the secondary effects. The concept of multifunctional flood defences sets out specifically to provide additional benefits in addition to flood risk reduction.

Benefits of alternative 1 are created by exploiting the built hollow concrete structure and associated installed functions (such as shops, restaurant, leisure activities) either by renting or selling the property to investors. In such a case, the Water Board can rent the structure to a private investor which is beneficial for both the Water Board and the investor. The function would then be rented by a tenant who runs the function. This will generate benefits for the investor in rent. The tenant will generate benefits from the function created by for instance visitors to the construction. It is also possible for the Water Board to sell the asset to a private owner, but the owner has to support the periodical inspection required for safety assessment of the dike. Overall, the construction with additional functions can be seen as real estate including more water safety standards. The main issue is determining the profits and cost-savings for the commercial functions. Therefore it is necessary to calculate the additional costs and benefits and connecting them with the business case in order to make the business case correct.

Implementing alternative 2 has a significant advantage in reducing the risk of flooding since using the supplied ground of the soil bank it makes the primary dike 99% unbreachable. Furthermore, additional financial benefits result from using soil and silt transferred from other construction sites to the dike location. In addition, the heightened area created by the purified soil can be modified in future to provide additional functions such as a recreational area that generates extra financial benefit. The income by the trade in mixtures of types of soil and silt makes the soil bank a commercial function.

The general benefits of adding commercial functions to a MFD are determined. Some more detailed or unsure benefits of the shared use of a MFD are not mentioned. Depending on the integrated intelligent design costs for engineering, operation and maintenance of the life cycle can be split up between the several involved stakeholders. Also by gathering the expertise already in the design and planning phase extra water safety can be obtained and construction costs for the dike reinforcement can be paid back. A robust design may in construction be more expensive than a traditional defence but on the long term by fewer adjustments and a lower demand management it could be cheaper. Also customize the design with local available materials could result in cost savings because over-dimensioned makes soil material of lesser quality usable (van Loon – Steensma, 2011).

Table 4.2 lists the general benefit associated with the two alternatives.

Table 4.1, the direct benefit items in general

Measure to be taken	Benefit items
Traditional dike strengthening	Flood risk reduction
Multifunctional flood defences	Flood risk reduction Financial benefit of additional services provided

Indirect benefits of a MFD are for example a smaller footprint (less use of materials), the icon function of the environment (attractive magnet for costumers) and an improved spatial quality of the landscape.

Social benefits may be the green park area (ecosystem services), social acceptance for the MFD, accessibility of the area whilst the traffic route could also serve as evacuation route in case of a emergency which has positive effects on the level of safety. Furthermore provides the additional functions more employment.

Positive synergy occurs when the balance of costs and benefits are more favorable in an integral development than the sum of costs and benefits at a separate implementation of the subprojects. Positive synergies could arise because the strategy 'making work with work', avoiding afterwards valuable mitigation or a higher spatial quality (and ditto benefits) can be realized (Briene and Wien Hoven, 2012).

When both costs and benefits are clear, the next step is to determine who is will take the costs and the benefits. This could either be the water board, operator or tenant. Unfortunately it is not so easy since there is no proper set of instruments to balance the benefits of shared use properly with (if any) additional costs. Is also unclear how the costs and benefits of the different (private) stakeholders should be divided (Ellen ea., 2011).

3.4 Cost benefits analysis Alternative 1 (concrete structure)

This chapter considers the (social) costs and benefits for alternative 1. Alternative 1 is a concrete construction, designed by the architect bureau Dingeman Deijs and Delva Landscape Architects (hereafter Dingeman Deijs) in Amsterdam, the Netherlands. This construction is called 'Dijk van een Kop' (Defence of a Head). This option is a result of a design competition held in 2011 named

Drechtstad 2050 and is an initiative of *Stichting de Stad en Bureau Drechtsteden*. The idea behind the competition was to choose potential designs that could be used to develop recreational hubs in the Drechsteden. The current recreational hubs are locations where large recreational traffic flows meet, but have little facilities and are barely used. With this competition, a vision can be created that shows how these hubs will look in the future.

Dingeman Deijs combined their design with the dike strengthening project required at the 'Kop van 't Land'. The design is a concrete construction which is partially constructed in the outside part of a dike body. This part of the dike body will be excavated and the concrete construction will be placed in this excavated space. The concrete construction is hollow and will be divided in two parts; a front and back part.

The front part of the construction is meant for visitors to meet who, for instance, are paying a visit to the nearby Biesbosch. A window is also installed in this front part, allowing visitors to look at the natural scenery and ecosystems without disturbing them, this is illustrated in figure 4.7. With the tide, the construction will be flooded a couple of hours a day. When flooded, people can have a view of the aquatic life, figure 4.8 gives a view of the construction with high tides. Currently there is no tide in this area, but the Haringvliet locks will be slowly opened again in 2015 bringing back the tide. Rijkswaterstaat will monitor the effects of this tide for 5 years. When and if the effects are positive, the locks will be opened completely. Dingeman Deijs took this possibility into account in their design.

The back part is, according to Dingeman Deijs, meant for functions. This space could be used for the local residents when they have to move due to the dike strengthening plans. This will offer them an option to move their homes or businesses into the construction. This construction will have the following dimensions: 100m long, 15m width and 4m high. The angle of the construction will be 1:3. Impressions of this construction can be found below.

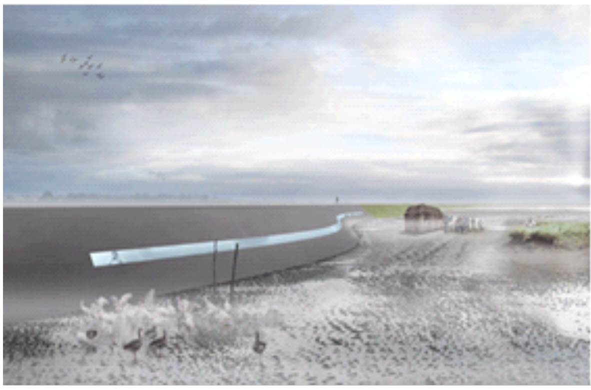


Figure 4.7: impression of the defence during low tide.

Figure 4.8: during high tide

3.4.1 Effect types

To determine the (social) costs and benefits of alternative 1, first the effect types must be identified. Projects can have an influence on all sorts of aspects such as stakeholders, the surrounding area et cetera. These effects can be divided in four groups which are explained below. Based on these effects, the (social) costs and benefits can be analyzed.

Direct effects are the costs for the investment in the project and the benefits from it. Examples of these are:

- Costs: investment costs and exploitation costs. The investment costs are the costs necessary to realize the project. The exploitation costs are the costs needed to either sell or rent the project.
- Benefits: these are advantages for the users of the project. These benefits are the revenues caused by the renting or selling of the project.

Indirect effects are effects which are not directly noticed, but have impacts on the economy and which are a result of the direct effects. Examples of these are:

- Indirect effect: a project creates employment in the surrounding area.

External effects are effects that have no market value, examples are:

- External effect: influence on the environment, influence on nature, (social) safety.

Distributional effects represent the redistribution of welfare, income or employment. This happens particularly with competitive projects, examples of these effects are:

- Distributional effects: jobs go from one place to another.

The effects outlined above identified for alternative 1 below. The results of these effects are dependent on the type of function that is to be combined with alternative 1. The results of are given below.

Direct effects alternative 1

The costs which are part of the direct effects, are:

- Investment costs
    - Investment costs: The investments costs of alternative 1 are relatively high. This is due to the concrete construction that has to be implemented in the dike body. These costs are calculated at €2.8 million. It should be noted here that this estimate may be an underestimation of the real investment costs because there may be additional costs for the installation of pile sheets and water retention screens needed to stabilize and fix the concrete structure (depending on the stability of the soil).
- Exploitation costs
    - Small maintenance: every year the construction and the functions must undergo maintenance. This is called small maintenance and the costs for this are €40.00 /m^2 of the construction surface. The total surface is 1500m^2. Each year the maintenance costs will rise due to inflation.
    - Large maintenance: when large maintenance is applied, the construction will be renovated intensively, e.g. considering replacing or restoring concrete. It is not yet clear when large maintenance will be conducted and how much this will cost. Assuming the construction will last 50 years, it could be assumed that every 12.5 years, large maintenance is conducted. These costs could be up to 75% of the investment costs.

- The benefits of the direct effects are:
  - Rental
    - The function that is to be combined with alternative 1 will be a public function which will be exploited by the municipality of Dordrecht. A total rental price of €14.55 / m^2 will be paid. The total rentable surface is 1320m^2. Each year the rent will rise due to inflation.
  - Parking
    - Parking space is available for the functions. What still has to be investigated is if users of the parking space have to pay for parking.

Indirect effects alternative 1

Some of the indirect effects are:

- Recreational hub
  - Drechtsteden has set up a vision called *Strategic Green Project* in which the needs for several recreational hubs is stated. These recreational hubs will allow visitors to meet and organize activities. Alternative 1 can form a recreational hub.
- Biesbosch
  - The nearby Biesbosch could have more visitors when alternative 1 forms a recreational hub.
- Rise of land value
  - The area is not intended to be used for agricultural or natural purposes. There are some houses in the surrounding area. When alternative 1 is realized, the value of land could rise. This could be positive for the current functions, but could also cause disadvantages for nature projects in the surrounding area. It is possible that the land for such projects becomes more expensive or less attractive to implement these projects.

External effects alternative 1

Some of the external effects include:

- Safety
  - Alternative 1 will also function as a water defence. This function will protect the hinterland from flooding. At this moment, it is not clear how safe or much safer this alternative is and what kind of influence it has on the safety.

3.4.2 Realization costs

The realization costs are part of the direct costs and result from the realization of the construction. A specification of the building costs is given below. An overview of these costs is shown in figure 5.6 where an estimation of the various cost of a MFD construction build into a defence.

Land price

The land price is based on the average land price in the year 2010 for land the South of Holland near the big cities. At that time an average of €60.000,-- was paid per acre resulting in a total price of €6.00 per m^2. For the building cost, a land price of €6.00 per /m^2 is applied.

Surfaces

The total surface of the construction is 100m * 15m = 1500m^2. This is known as the Gross Floor Surface. According to Dura Vermeer, 88% can be used which comes to a total of 1320m^2 Usable Floor Surface.

Parking

According to Neufert (2002), a parking space uses up to 26.5m^2 for 2 vehicles. It is not yet clear how many vehicles can park near the construction, and therefore in this calculation a total of 20 parking spaces is maintained, resulting in a total parking surface of 265m^2.

Kengetallen Kompas (www.kengetallenkompas.nl) states that the building costs for a parking space, including gate barrier and other facilities, are up to €61.50 / m^2 resulting in a total of €16.297.00 for a parking area for 20 vehicles.

Building costs

The building costs can be divided into a function cost (recreational function) and the concrete construction. These costs are as follows.

The recreation centre has a Usable Floor Surface of 1320m^2 costing €150,00/m^2. This includes only the engineering and technical installations. These costs are based on similar projects done by Dura Vermeer and Advin (Dura Vermeer, 2012)).

As for the concrete construction, this construction has a Gross Floor Surface of 1500m^2 costing €1000,00/m^2. This includes only the amount of concrete needed in m^3, windows and finishing of the floor. These costs are based on projects done by Dura Vermeer and Advin (Dura Vermeer, 2012)).

Civil technical costs

The preparation costs include preparing the building site. These are caused by, for instance, deep steel sheets keeping the water from entering the building site, excavation costs etc. The total costs are estimated at €290.000,00 and are based on projects done by Dura Vermeer and Advin (Dura Vermeer, 2012).

Regarding the costs for the parking space, see the section above.

Infrastructural costs are costs done by removing and applying asphalt and the transition between the road and the concrete construction which is partly found on top of the concrete construction and dike. The total costs are estimated at €20.400,00 and are based on projects done by Dura Vermeer and Advin (Dura Vermeer, 2012)

Result

The result of the realization costs are estimated at a total of €2.8 million. These costs include the costs for building the construction and the function, all mentioned below in figure 4.9.

Projectomschrijving	**:**	**Stichtingskosten recreatiecentrum Kop van 't Land**	
Datum	**:**		**Wijzigingsdatum:**

Uitgangspunten			**Tijdsduur**			**Planning**	
*	Prijspeil	Oplevering	*	Ontwerptraject	0 maanden	* Start O	0 januari 1900
*	Grondprijs	€ 6	*	Bouwperiode	0 maanden	* Start B	0 januari 1900
*	Indexering	0%	*			* Opleve	0 januari 1900

oppervlakten										
*	Kavelgrootte (totale terrein)		1.500	m^2						
-	Recreatiecentrum		1.500	m^2	BVO		88%	1.320	m^2	VVO
-	Parkeerplaatsen		265	m^2	BVO		0%	0	m^2	VVO
-	…………		0	m^2	BVO		0%	0	m^2	VVO
		Totaal	**1.765**	**m^2**	**BVO**		0%	**1.320**	**m^2**	**VVO**
*	Parkeren	**norm 1: 88**					m2			
-	Gebouwd parkeren		20	st.		a	61,50	1.230	m^2	BVO
-	…………		0	st.		a	0,00	0	m^2	BVO
		Totaal	**20**	**st.**				**1.230**	**m^2**	**BVO**
*	Terrein		1.500							
-				m^2						
-				m^2						
		Totaal	**0**	**m^2**						

exclusief

* inrichting / kantoormeubilair / losse inventaris / vloerbedekking

* data

financieringsgegevens			
renteperiode grond	0	maanden	
renteperiode bouw	0	maanden	
renteperiode bijkomend	0	maanden	
rentepercentage grond	5,00%	looptijd grond	1,00
rentepercentage bouwkosten	5,00%	looptijd bouwkosten	0,50
rentepercentage bijkomende kosten	5,00%	looptijd bijkomende kosten	0,85
afsluitprovisie	0,00%		

SPECIFICATIE INVESTERINGSKOSTEN

01	**Grondkosten**								
	Grondkosten	1.500	m^2			€	6,00	€	9.000,00
								€	**9.000,00**
02	**Bouwkosten**								
	Recreatiecentrum	1.320	m^2	VVO		€	150,00	€	198.000,00
	Betonnen constructie	1.500	m^2	BVO		€	1.000,00	€	1.500.000,00
			m^2			€	-	€	-
			m^2			€	-	€	-
						€	-	€	-
								€	**1.698.000,00**
03	**Civiel technische kosten**								
	Voorwerk	-				-		€	290.000,00
	Parkeren terrein	265	m^2			€	61,50	€	16.297,50
	Infrastructureel	-				-		€	20.400,00
								€	**326.697,50**
04	**Onvoorzien / planuitwerking**	0,00%	van bouwsom 02 + 03					**€**	**-**
05	**Adviseurs / directievoering**								
	Architect				3,5% van bouwsom 02 + 03	€	70.864,41		
	Constructeur				1,25% van bouwsom 02 + 03	€	25.308,72		
	Adviseur installaties				1,30% van bouwsom 02 + 03	€	26.321,07		
	Overige adviseurs				0,50% van bouwsom 02 + 03	€	10.123,49		
	Directievoering (per maand)			€ 6.000	0,00% van bouwsom 02 + 03	€	-		
	Toezicht (per maand)			€ 6.500	0,00% van bouwsom 02 + 03	€	-		
					6,6%			**€**	**132.617,69**
06	**Grondmechanisch- en milieutechnisch onderzoek**						1 post	**€**	**50.000,00**
07	**Legeskosten**								
	omgevingsvergunning	2,58%	van bouwsom 02 + 03			€	52.237,20		
								€	**52.237,20**
08	**Nutsaansluitingen**	0,00%	van bouwsom 02 + 03			€	200.000,00	**€**	**200.000,00**
09	**Loon- en prijsstijgingen / Afkoop**								
	Indexering tot (start bouw)	0,00%				€	-		
	Afkoop gedurende realisatie	1,00%				€	-		
								€	**-**
10	**Financieringskosten**								
	Rente grondkosten	0	maanden van 01 + 11			€	-		
	Rente bouwkosten	0	maanden van 02 + 03 + 04 + 08 + 09			€	-		
	Rente bijkomende kosten	0	maanden 05+ 06 + 07 + 11 + 12			€	-		
								€	**-**
11	**Bijkomende kosten**								
	Notaris akte koop grond	0,75%	van 01			€	67,50		
	Notaris akte verkoop	0,40%	van stich kst		€ 2.947.692,31	€	11.790,77		
	Makelaarscourtage verhuur	15,00%	van jaarhuur		€ 287.400,00	€	43.110,00		
	Makelaarscourtage verkoop	0,50%	van stich kst		€ 2.947.692,31	€	14.738,46		
	Maquettes/artis impresion	post				€	-		
	Commerciele reserve	0,00%	van 02			€	-		
								€	**69.706,73**
12	**Promotiekosten**					€	-	**€**	**-**
13	**Garantiekosten**	0,25%	van stich kst			€	6.662,93		
	PI verzekering	0,0826%	van stich kst minus bouwkosten			€	445,43		
	AVB verzekering	0,0302%	van stich kst			€	804,02		
								€	**7.912,38**
14	**Ontwikkelingskosten / management**	5,00%						€	127.308,57
						subtotaal		**€**	**2.673.480,07**
15	**Leegstandsrisico / incentives**		maanden			€	-	**€**	**-**
	Resultaat	5,00%						€	133.674,00
						totaal, excl. BTW		**€**	**2.807.154,07**

Figure 4.9: realization costs for the recreation center at ‘Kop van ‘t Land’.

3.4.3 Exploitation costs and benefits

The exploitation costs are also a direct effect resulting from adoption of alternative 1. There are two types of benefits regarding the exploitation costs: rent and usage of the parking spaces.

Rent

The Gross Floor Surface is 1500m^2. The Usable Floor Surface is 1320m^2. When renting or selling the function, the Usable Floor Surface is maintained.

Public or commercial

The function that is to be combined with this alternative will be a recreational centre. This is a public function and thus must be rented.

Comparing renting value method

When using the comparing renting value method, an object is compared with a similar object. Differences in location etc can have a positive or negative impact on the comparison.

For this project, the rental value is compared by using www.fundainbusiness.nl as a source for similar objects. In this case buildings are compared that could be used multifunctionally and as a recreational centre.

Determining the rental price

Knowing that the 'Kop van 't Land' could become a recreational hub if alternative 1 is realized, this could attract many visitors. But this area is also located far from the city of Dordrecht and the function, a recreational centre, might only be usable for a few of the public. It is therefore difficult to determine the rental price. The comparing rental value method shows several potential rental prices. For this situation, a rental price of €14.55 /m2/month is applied for the function.

The total rental price is:

€14.55 * 1320m^2 = €19.206,00 per month.

Per year the rental price shall be:

€19.206,00 * 12 months = €230.472,00

Parking

Constructing the parking facilities will cost €16.297,50.

The parking fee is based on the parking fees in the city of Dordrecht which are €2,50 per parking space per hour. A total of 20 vehicles can park, resulting in a total benefit of €50.00 per vehicle per hour.

The costs for maintaining the parking facility are based on the exploitation calculation of the parking garage Veluwehal. These maintenance costs will rise by 2.5% each year and are needed to maintain the parking facility. This percentage is also maintained in the exploitation calculation of the parking facility in alternative 1. These maintenance costs are €407.44 in year 0. In year 50, the total maintenance costs are calculated at €41.119,19,

The total costs for the parking facility (realization and maintenance) are €57.416,69.

3.4.4 Costs and benefits analysis

A costs and benefits analysis shows if a project is financial affordable or not. With this CBA the costs and benefits are compared and by using the net present value, it can be determined how many financial assets are needed at the start of the project (year 0). When the net present value is positive, the project is financially affordable. These aspects are all mentioned in figure 4.10.

Foundation costs

The foundation costs are costs that occur once and are needed to realize the concrete construction. These costs are specified in Section 4.3.1 and are estimated at a total value of €2.8 million and are applied once in year 0.

Small maintenance costs

Maintenance is needed every year to keep this alternative safe and in use. Components of maintenance are:

- Cleaning costs
- Replacing lights, pipes et cetera.
- Reparation
- Et cetera.

These costs are mainly for small works and the costs are estimated at €4000/m^2/year. The total surface of the construction is subject to small maintenance, an area of 1500m^2. This results in a total of €60.000,00 starting from year 1. After 50 years, the total costs for maintenance are calculated at €6.3 million.

Large maintenance costs

Every 12.5 years, large maintenance will be required. Components of large maintenance are:

- Replacing concrete
- Replacing window
- Replacing sewer, electricity- and water pipelines
- Replacing floor
- Et cetera

Comparative projects show that large maintenance costs are mostly based on 10% to 20% of the total foundation costs. Because alternative 1 is realized in a dike body, these costs will most likely be higher than the realization costs for 'normal' projects. For instance, when the window has to be replaced, deep steel sheets need to be applied again in order to keep the water out of the construction. Therefore the large maintenance costs are for this project 25% of the foundation costs.

The inflation costs of building materials have been around 5% over the last few years. This inflation factor will also be used for the large maintenance costs.

After 12 years the first large maintenance is required. In this year, the total large maintenance costs will be around €538.756,90. After 50 years and 4 large maintenance activities, the total costs for large maintenance are calculated at €8.5 million.

Benefits rent

Assuming the function will last for 50 years and will be occupied for 50 years, the total rental benefits will be as follows. The rent is estimated at €14.55 /m^2 which will be a total of €230.472,00 in year 0.

The inflation for rent is 2.8%. This percentage is based on an annual increase of the rent of 1.5% and the inflation correction of 1.3%.

This means that the total benefits deriving from the rent in year 50 will be €25.428.459,95.

Benefits parking

The parking facility needs maintenance every year and to calculate these costs over 50 years an inflation correction for maintenance of 2.5% is applied. This inflation is taken into the yearly increase of the parking fee. The maintenance costs for the parking facility are calculated at €54.119,19 in year 50. Including the realization costs, this will result in a total of €57.419,69. When the parking facility is used, at least 600 hours of parking is needed to earn these costs back. All the extra parking hours can be seen as benefits for this function.

Balance and net present value

KOSTEN OP T50		BATEN OP T50		VERSCHIL	
Stichtingskosten		Huur		Op T0	-€ 2.568.520,56
Eenmalig met een BVO van		*€14,55 /m2/maand met een*		Op T12	-€ 756.655,79
1500m2		*VVO van 1320m2*		Op T14	-€ 256.342,64
		Inflatie is 2,8%		Op T15	4367,64
				Op T25	€ 1.778.717,53
Totaal	**€ 2.800.000,00**	**Totaal**	**€ 25.428.459,95**	Op T37	€ 4.454.689,39
				Op T50	€ 7.743.325,74
Beheer en onderhoud		Parkeerterrein		**Totaal**	**€ 148.795.733,52**
Jaarlijks met een opp. van		*Tarief €2,50 per uur per vak.*			
1500m2 en €40,00/m2		*Inflatie van 2,5%*			
Inflatiecorrectie van 2,8%					
Totaal	**€ 6.381.251,02**	**Totaal**	**€ 60.552,87**	**NETTO CONTANTE WAARDE**	
Groot onderhoud				Op T0	-€ 2.568.520,56
25% van totaal stichtings-				Op T12	-€ 562.615,87
kosten.				Op T14	-€ 181.420,66
5% inflatie bouwmaterialen				Op T15	€ 3.015,71
per jaar.				Op T25	€ 959.423,50
				Op T37	€ 1.786.629,12
Totaal	**€ 8.524.131,75**			Op T50	€ 2.252.860,29
Parkeerterrein onderhoud				**Totaal**	**€ 48.014.497,52**
265m2 a €61,50/m2					
Beheerskosten van 2,5%					
realisatiekosten.					
Totaal	**€ 41.119,19**				
Totaal lasten:	**€ 17.746.501,96**	**Totaal baten:**	**€ 25.489.012,82**		

Figure 4.10: overview of the estimation of the various cost and benefits over time

The balance sheet above shows a positive outcome when the function is exploited for 50 years. The return on investment break-even point occurs between years 14 and 15. After year 15, the return remains positive. As the function is to be exploited by the municipality of Dordrecht, the function is public and therefore the discount rate for which the net present value is calculated is 2,5%.

3.5 Cost benefits analysis Alternative 2 (soil bank)

A soil bank is a physical location where stakeholders can deliver, store and buy soil and silt of different qualities and types. The soil and silt of the soil bank can be used in a project and/or sold to (external) parties. The owner of the soil bank aims to manage the incoming soil and silt and accommodate the compartments of soil and silt for purification as it builds up on the location.

In this alternative, the soil bank has the function to provide additional soil for the dike reinforcement. The soil bank is situated where the dike needs reinforcement or close by. It is part of the dike itself because purified soil and silt will be applied. The gradual supply of soil to the soil bank ultimately leads to the required dike reinforcement. Figure 4.11 is demonstrating the stadia of the this process and how the soil bank contributes in the dike reinforcement. In the end a

The soil bank is formed in an organic way. It is adaptive, since it can be adapted to the wishes of the water board and/or the end users during the project. The reinforced dike (delta dike) can, in the end, be used for alternative purposes. The soil bank can be interesting from a financial viewpoint. The revenues from a profitable soil bank can be divided amongst the parties involved, in this case, the water board and the owner of the soil bank.

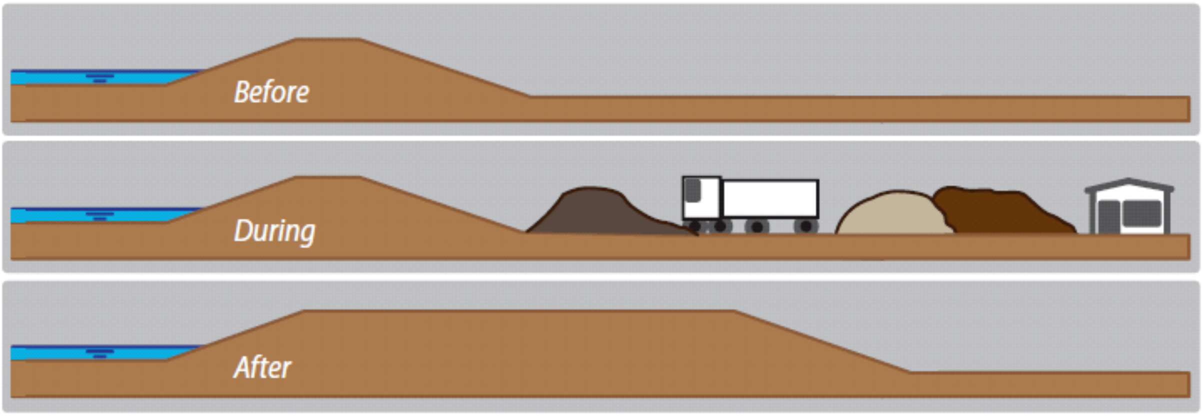


Figure 4.11. Visualisation of the process of the dike reinforcement with the use of a soil bank

3.5.1 Exploitation costs and benefits

The soil bank will be used for the currently required dike reinforcement and the extra reinforcement that is required to create the delta dike. The soil and silt that is delivered will remains on this location and meaned directly for the dike reinforcement dike. In this case none of the purified soil from the soil bank will be applied in another project.. In this cost benefit analysis the revenue generated are only the result of the supplied soil. The soil bank does not require much space since all activities take place along the dike, which is illustrated in figure 4.11. The soil bank can be situated in the area between the dike and its ditch, which is owned by the water board. This option is the cheapest with regard to the design of the location and the rent costs to third parties.

The standard revenue model roughly looks as follows:

- Costs: €2.75 per ton
  Including: personnel, materials, environmental administration (e.g. permits), ground processing and amortisation
- Revenues: €3.75 per ton (max €4.25)
  This only includes the acceptance of soil and the processing of the soil at the location of the dike. The sale of types of soil silt is not included: this would be more difficult to organise, but it could be beneficial.

This revenue model shows average figures. The revenues differ per type of soil. In addition, it takes longer before the total revenues exceed the total costs when the initial costs are high. This depends on whether the soil bank receives usable, clean soil of the type appropriate for constructing dikes (erosion class 1 clay is the needed type of soil for dike reinforcement). This affects the revenues to a great extent and requires further research.

An important parameter for a successful soil bank is the size of the location.
In order to place the soil bank within the project area, the size of the area needs to be made visible. Further it is required to invent at which side of the defence is enough space for the soil bank. There are sides where buildings interfere. Figure 4.12 gives an indication of sides where

buildings that makes the arrival of a soil bank and therefore also the development of a delta dike difficult. The development is even more expensive cause of demolishing these buildings.

A soil bank does not necessarily cover the entire length of a dike (in case of ‘Kop van ‘t Land’ 3,4 km). It is better to place the organisation of a soil bank at a central location with a lot of available space. From there, the purified soil can be further distributed along the dike.

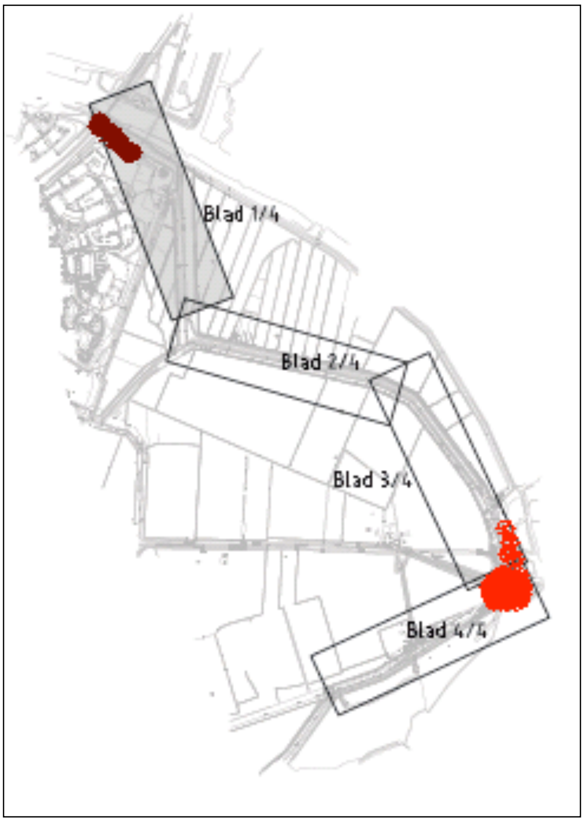


Figure 4.12: shows locations along the Kop van’t Land where situating a soil bank or development of a delta dike will be complicated (red colour means highly probable complication, bordeaux colour means possible complication).

For this cost benefit analysis is important to know the required volume of earthwork for constructing a delta dike in order to estimate its financial feasibility. Figure 4.13 shows the required volume of earthwork. Based on the delta dike, it is estimated that 100*3,400m = 340,000 m^3 is required (ca. 340,000*1.8= 612,000 ton on average),

The eventually produced dike reinforcement by the soil bank depends on the earthworks at the side of the defence. Earthworks of a delta dike design or an even more robust dike is much higher than for the planned dike reinforcement. The for the cost benefits does it mean the more earthworks the more revenue.

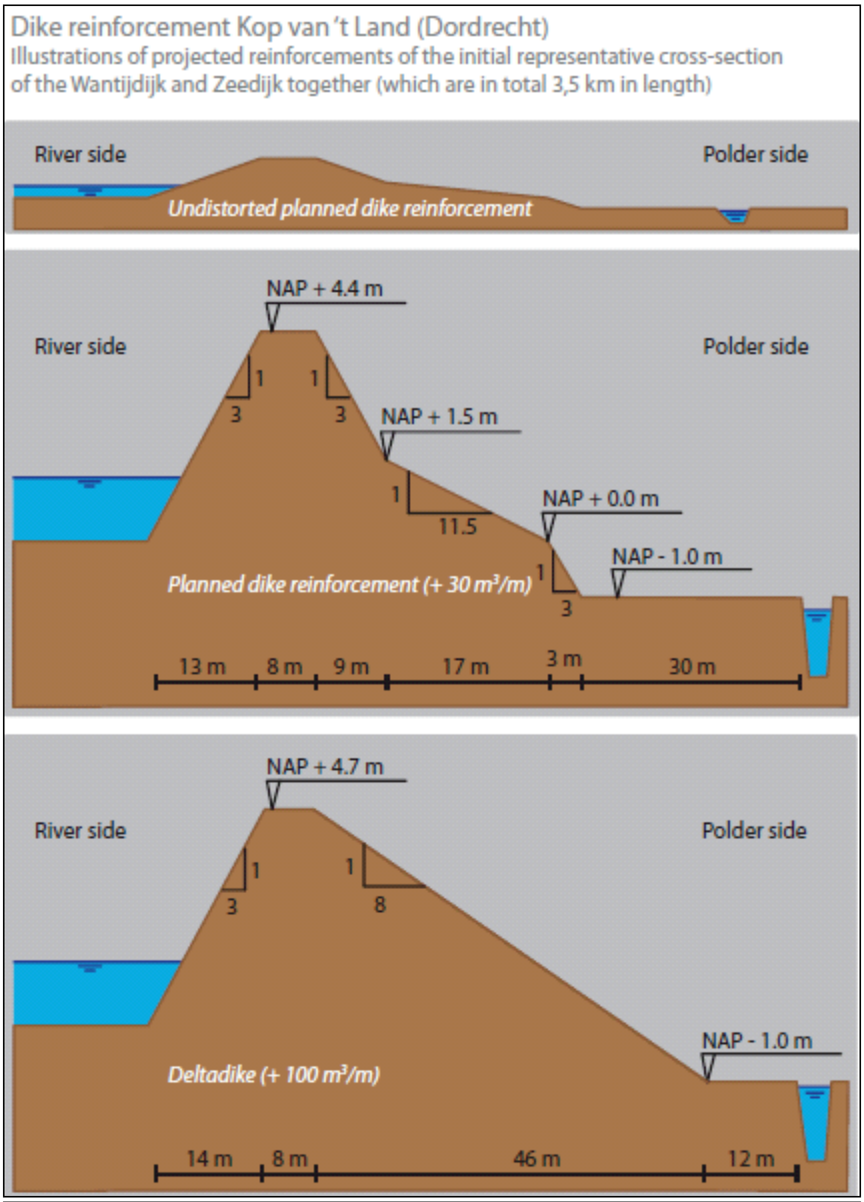


Figure 4.13: the earthworks at the side of the defence in case of plannend dike and delta dike.

3.5.2 Cost-benefit analysis

The estimation of the current dike reinforcement, which is executed by the water board 'Kop van 't Land', is €19.3 million for 4.3 km. It is estimated that the extra costs for a delta dike, which is 10 times safer, are €2 million. These costs will be lower with the use of the soil bank. A soil bank receives financial compensation for the supplied and purified of soil. A profitable soil bank received more financial compensation than it spent on the exploitation of the soil bank. Therefore the water board receives 'free' dike reinforcement.

Tabel 4.3: estimated costs and benefits for a soil bank

Fictive					
	Costs		Benefits		Who
Reinforcement delta dike	Construction of soil bank (purchase of land)	n/a	Reduced costs for dike reinforcements because of lower ground costs	PM	Soil bank is not situated on the area owned by the water board.
Reinforcement delta dike	Establishment of soil bank	€1.7 million	Processing of ground	€2.3 million	Win-Win formula of water board and Dura Vermeer
Reinforcement delta dike	Parts of construction which are not executed by the soil bank	PM	Increase of safety level	€1.6 million	Water Board has investment budget of the state, which can be used for the construction (such as Erosion Class 1 Clay).
Reinforcement delta dike	Nuisance due to works	PM	Future value of area	PM	

The delta dike has a yield of roughly €0.5 million. The analysis of the costs for the design (including the costs for starting-up) have been kept simple. The required amount of soil is not large, so the break even point needs to be reached in a short period of time.

Since the construction of the soil bank is on an area owned by the water board, no costs are involved for the purchase of the location, i.e. the water board ultimately has free soil. However, the water board needs to pay for the extra construction activities that the soil bank cannot provide. The costs incurred by the water board during the dike reinforcement project:

- Precise execution of the soil bank with 'soil dike clay' on the dike.
- Execution of measures regarding improvement of the dike
- Supervision regarding the water safety

The water board can use funds from the investment budget of the national government. Suppose that the required amount of soil consists of soil which is used for dike reinforcement and can be acquired by means of a soil bank. Then the budget for the construction is 30% of €19.3 million. In addition, there is a discount on the soil, because the soil bank can anticipate on the search and storage of this 'erosion class 1 clay (is the needed type of soil for dike reinforcement). The price can be some 10% lower. Another benefit is that the soil bank can test the quality of the soil, which is often not done by external parties. Soil is often cleaner than initially assumed, which makes it cheaper.

3.5.3 Benefits for the water board

The water board is the principal organisation dealing with the plan and execution of the dike reinforcement and needs to be convinced of the advantages. Here are a number of advantages:

- Addressing current soil pollution: the soil bank can clean soil
- The soil bank can partially finance the dike reinforcement
- With the use of the soil bank, safe dikes can be created, which results in *inter alia*, reduction of flood risk, economic damage and casualties.
- The stored spoil in the soil bank is an valuable source for dike reinforcement projects if the required volume of earthwork has to be financed by the water board.
- There are opportunities for a business model for multifunctional dike use between the water board, Dura Vermeer and third parties. For instance, the owner of a golf course could pay rent.

3.5.4 Conclusions

A soil bank can contribute in constructive and financial ways to dike reinforcement projects. Soil has a market for which demand and supply vary over time. The soil bank enables storage of soil, which reduces the dependency on current price levels. It is possible to buy soil when its price is low and use it when the prices are high. The price of the soil for dike reinforcement projects (e.g. erosion class 1 clay) is relatively stable.

In addition, testing of the soil quality is often not done by external parties, because of constraints on time and financial resources. The organisation of the soil bank can test batches of soil to determine their suitability and directly take in soil from these projects.
If during a dike reinforcement project 70% of the required soil is “regular“ soil, the water board gets 70% of the soil “for free”, if it makes use of a soil bank.

Many parameters and factors affect the organisation of a soil bank. In general, it is important to further specify a number of things:

- What is the features of the soil bank? Processing of types of soil or/and silt or dredging? dredging costs more money and uses more space, due to the need for drying.
- Who is the competent authority? Water board or municipality? This affects the applicable regulations.
- What restrictions do the applicable regulations pose on the soil bank? A dike reinforcement requires soil processing on a large scale. Favorable conditions of the environmental license is crucial. Public support is crucial.
- What is the influence of the public parties on a commercial organisation, such as a soil bank?
- How do you organise the partnership and the finances of the soil bank
- Regarding the quality of the soil in the dike, what quality can be produced by the soil bank? The type of materials in the soil bank are usually low-grade. The rest of the types of soil are high-grade. These types of materials need to be searched for, acquired and stored.
- Accurate calculation of the required volume of earthwork and the lifetime of the soil bank.
- How large is the exact size of the soil bank? Who are the owners of the land?

3.6 Conclusions Pilot study

Figure 4.14.a presents a traditional way of dike strengthening; including both heightening and widening measures. Whilst Figure 4.14.b illustrates alternative 1 in which a concrete structure is

integrated into the dike body. Figure 4.14.c represents alternative 2, where a soil bank is positioned on top and around the dike system. It should be noted that alternative 1 will have more influence on the whole dike system than alternative 2.

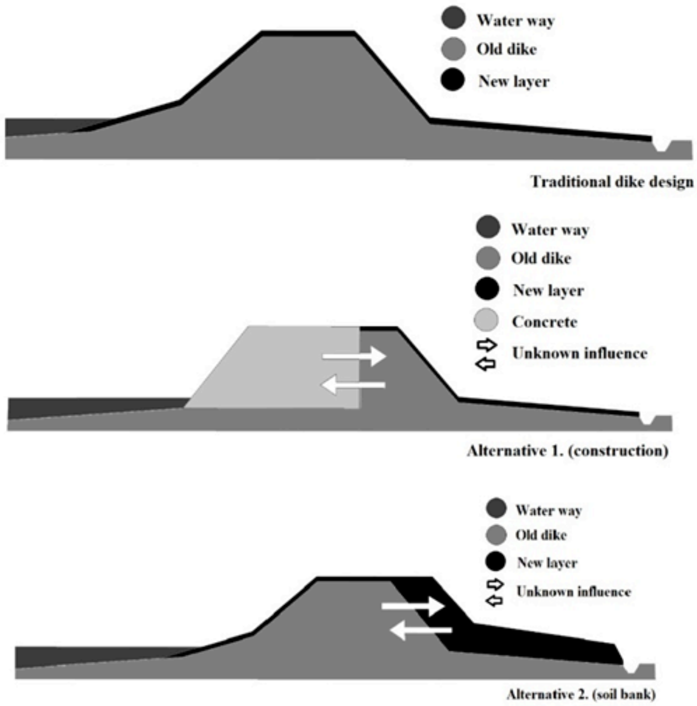


Figure 4.14: the schematization of the traditional way of dike strengthening and the two alternatives proposed.

In the first place, for the two alternatives there has been thought about the possible costs and benefits of each alternative. Subsequently, further research has been conducted on the identified costs and benefits of each alternative.

Both alternatives are mainly reviewed from the perspective spatial planning (implications of the building of the defence and its functions). The flood risk in both CBAs deserves more attention. It is a recommendation to perform a CBA in a team of specialists where also people from the district water participate.

The two alternatives are quite different from each other. In the investment at the beginning, the payback period, the developing process of the defence and the external characteristics of the defence. A comparison reveals the following:

Concrete structure

- ✓ High investment and maintenance costs are needed
- ✓ Return investment point lays between year 14 and 15 out of 50 years life-cycle
- ✓ The concrete structure needs the budget of the water board for starting (over the years returns can be divided)
- ✓ It is not known how this structure will influence the risk of flooding

- ✓ The concrete structure is because of the multifunctionality added value for its environment. The design might be a good example for implementation at several waterfront locations in the Netherlands
- ✓ This options is based on a rigid design and it is not sure if the design can deal with any type of uncertainty (needs more investigation)

Soil bank

- ✓ Low investment and maintenance costs are needed
- ✓ The breakeven point reaches less than 10 years
- ✓ The soil bank can finance the dike reinforcement partially
- ✓ The soil bank can resolve the ground pollution problem. It is the expectation that the soil bank does not influence the risk of flooding much since the dike reinforcement is similar
- ✓ The stored ground in the soil bank can be used for other dike reinforcement projects in the Netherlands
- ✓ The soil bank is a flexible and adaptive option capable of dealing with uncertainties

The results of the CBA of both the "concrete structure" as the "soil bank" are from a financial perspective positive. The "concrete structure" is over time more profitable because of the rental income of the added features. An operation of 50 years covered quite a return. In this cause we are assuming a healthy market, good visitor numbers and stable rental income. The "soil bank" has revenues as a result of adopting types of soil. The company "soil bank" earns a large part of the dike reinforcement back if the company “soil bank” operates for further decades to come. Then we are assuming the market pays for capturing types of soil and a location which is an advantageous location to accommodate this types of soil.

In short, the CBA shows beneficial results in both alternatives. Both design concepts offer potential for an MFD on the pilot site 'Kop van 't Land'. Both promising concepts are also a suitable answer on other locations. Of course, further research recommended.

4. Summary and conclusions

The search for multi-functionality in flood defences has been increased by the long-term trends of urbanisation and climate change. These two factors will have a large influence on (urban) flood defences as well as on the spatial quality of cities and landscapes, to be adjusted in the next decades. Influences on the urban area, such as rising sea levels, soil subsidence, increasing river flows and rainfall intensities, form a threat to urban areas. Aggravating this problem, invested capital (mainly) in the urban area has strongly increased and populations have grown. Additionally, due to this urbanisation, the request for high-quality water fronts is increasing and of a larger necessity. As a consequence, simple adaptations to increased risks from flooding, such as the broadening and heightening of flood defences, are in many situations difficult, because of a more intensive form of land use. Meaning that flood defences are literally and figuratively close to the population (Dijk and Van der Ziel, 2010).

The combination of previously mentioned factors is reason for adjusting the safety norms. Serious adaptations of flood defences are necessary to guarantee safety and attractiveness of cities in the future. This growing complexity requires investments of other organisations (both public and private), financial and organisational innovations, as well as process-oriented, spatial, and technical solutions (Van Veelen et al., 2010). The vision of multi-functionality strives for the best possible response to this growing complexity in the design and adaptation of flood defences. In the Netherlands, this vision has been described by the second Delta Commission. But also in other countries in Europe and beyond, MFD is a subject of interest for policy makers. In this new vision, flood defences must not only meet up to their primary function of safety, but also have to be incorporated in their environment. Therefore, being able to fulfil several functions for society and/or ecology. Stated differently, the flood defence must be able to provide multiple benefits and achieve synergies.

This design guidance has provided the means (concepts; functions for potential integration; requirements) for developing MFD alternatives and assessing the associated costs and benefits. This has been achieved by linking the current state-of-the-art in literature with the knowledge and experiences from actual (re)development projects. Six design concepts for multi-functionality have been identified from the review of the state-of-the-art, and these can be summarised as follows:

1. The **coffer dam** is a concept that can either be a freestanding construction or combined with a traditional dike body. It is not a very spacious solution; however, the top of the coffer dam can be used for several functions, like a boulevard or park.
2. The **step dike** is a concept that can be combined with a traditional dike body, and the traditional dike body serves as the base for the step dike. This concept can use space efficiently as there are a number of horizontal flat surfaces that can be used for several functions.
3. The **L-wall** is a freestanding concept that does not need a traditional dike body. It is a concrete construction of which the horizontal and vertical parts are equal in length, giving it the characteristic L shape. Behind this wall, additional functions can be placed. The L-wall can also be constructed in such a way that a tunnel can be built below ground.
4. The **soil retaining wall** is a concept that can be combined with a traditional dike body. The construction can be applied either behind the dike or in front of the dike. When placed behind the dike, it becomes a spacious solution, creating space for functions.
5. **Oversizing the inner slope** of a dike body is realised by adding soil to the inner slope, giving the slope a very shallow angle. This concept can create a large amount of space, and many potential functions can be applied.

6. **Oversizing the outer slope** of a dike body makes the front of the dike higher and longer. This concept does not allow many functions, as tides and currents affect the functions on the outer slope. Only recreational and green functions can be applied, such as parks and aquatic nature. If applied correctly, these functions can reduce the height and speed of waves.

The design concepts determine which functions can be integrated into the MFD. Each design concept is suitable for a specific set of functions. It is, however, not possible to determine in advance which functions are best suited for which MFD. This depends on a broad range of factors, such as stakeholder interests, spatial plans, etc. Yet, this design guidance has provided novel insight into the sets of functions that can be integrated into each type of MFD (refer to §2.3).

The additional functions have an impact on engineering, economics, society and the environment. The potential integration of a specific function affects the design of the flood defence. For example, a green function, such as a park, will result in a different dike profile than the integration of parking garages. Choosing a particular function has impacts in terms of economics. This has to do with the distinction between public and private functions. Certain functions, like infrastructure, can potentially be funded from public funds, whereas other functions, like businesses, can be financially more interesting from a commercial perspective. The available financial resources from the public and private domains are often limited and decisions must be taken to use these in the best way. It is, therefore, important that all costs and benefits of the interventions for water safety and other functions are included in an integrated assessment.

This design guidance has introduced a CBA method that can be used for the analysis of the possible alternatives for MFDs. The CBA method is a dynamic process in which it might often be needed to return to previous steps during the design process, so the sequences of the steps are not to necessarily linear. Furthermore, a CBA is able to provide both a quantitative and qualitative comparison of the possible alternatives.

The developed CBA methodology has been (partly) applied to the strengthening of a dike section near 'Kop van 't Land', Dordrecht (the Netherlands). For this case study, two possible alternatives for a MFD have been proposed, namely (1) a hollow concrete structure and (2) a soil bank. Application of the CBA to analyse the feasibility of the two alternatives showed that there are certain benefits in application of each alternative. The benefits of alternative 1 are realised by exploiting the hollow concrete structure and the installed functions (such as shops, a restaurant, leisure activities) by renting the properties. The benefits of alternative 2 arise from accepting, storing, and reusing soil and silt from projects in the area. However, each alternative generates additional costs for the construction and maintenance for the extra functions added. Given the many uncertainties and assumptions the CBA is used here to **compare** the costs and benefits of the two alternatives rather than providing absolute estimates. Uncertain factors comprise amongst others the consolidation time of the soil materials used to heightening and strengthening the defence structure, the need for additional foundations and interventions to curtail seapage.

In conclusion, the most significant advantage of multi-functionality is that it can generate financial, social and environmental benefits. In contrast with MFDs, traditional dike strengthening only generates financial costs with non-monetary benefits (i.e., increased flood safety / reduced flood risk). By designing MFDs, the costs for dike strengthening can in some cases be partially funded with the revenues from the secondary functions. It is important to note here that further detailed research is needed into the structural and hydraulic engineering aspects in order to provide more reliable estimates of the costs and benefits of MFDs,

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