Water nuisance in Greenport Boskoop:

Searching for a cost-efficient strategy to reduce water nuisance from interacting water level areas in the Gouwepolder

A thesis presented to Utrecht University in compliance with the thesis requirement for the degree of Master of Water Science and Management

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Utrecht, The Netherlands, July 2017

Summary

During extreme rainfall conditions, the Greenport Boskoop is highly vulnerable to water nuisance. Water nuisance was observed previously inside water level areas in the Gouwepolder, situated in the east of Greenport Boskoop. This thesis specifically focuses on water nuisance that is caused by interacting water level areas in the Gouwepolder. In the past, several parcels located inside lower water level areas in the Gouwepolder experienced water nuisance orginating from the surface water system in the higher compartiment. Damage to horticultural production was limited due to the removal of floodwater within 48 hours. Future climate change is expected to increase the occurrence of extreme rainfall conditions and the probability of water nuisance, while horticultural production may irreversibly be damaged when the soil is fully saturated for more than two days.

According to a former study by the Rijnland Water Board, which is responsible for the management of surface water and other local water structures in the Greenport, the average protection height of parcels that separate water levels areas should be increased in order to reduce or prevent this flooding phenomenon. There are still a number of questions: (1) whether the water level border should be upgraded entirely, (2) what is the optimal height of the new construction and (3) what construction types and materials can be used. These questions are relevant to determine the cost-efficiency of a structural measure for the water level areas in the Gouwepolder.

The resilience of local surface water systems to water nuisance is assessed on the basis of national protection standards included in the National Administrative Agreement on water (Nationaal Bestuursakkoord Water, henceforth: NBW). The NBW assessment for the Gouwepolder has identified many potential flooding locations at water level borders, which at present fail to meet the protection standard for horticulture. Due to the establishment of NBW standards nationally, it may be questionable whether these standards also provide the optimal protection level locally. In current dike improvement projects along large Dutch rivers, a more risk-oriented approach is currently used by Water Boards. This is based on cost estimates of flood damage and investment in protection, to determine the most cost-efficient protection level. This concept has been centralized in this thesis, to determine on the one hand whether it may improve protection levels and on the other hand whether the Gouwepolder and the Rijnland Water Board can benefit in economic terms from this approach.

Inundation damage caused by surface water or groundwater within water level areas of the Gouwepolder was studied before by Huizinga and Groot (2012). In this thesis, inundation damage was estimated for the water level area of Koetsveld, which specifically originates from a different surface water system (Gouwepolder). Firstly, potential water nuisance was determined by simulating inundation maps for several return periods in relation to the pertinent protection level. Secondly, a spatial model was developed which calculated inundation damage for four dominant land-use classes (open field cultivation, pot-and container cultivation, meadow and greenhouse), by converting inundation depth to damage with characteristic depth-damage functions. Furthermore, the protection level was manually changed to determine how flood damage estimates change in relation to higher protection. Additionally, the full protection approach and critical protection approach were formulated in the model to identify the effect of different protection strategies on estimated flood damage. Furthermore, a second spatial model was developed to collect information about the current protection level and what is required to increase the water level border protection. The calculation results for flood damage and protection have been culminated into a single Excel file, that calculates curves for both the flood damage costs and protection costs for a defined project period.

According to the results, the optimal protection level for the *full protection approach*, whereby the entire water level border is upgraded, closely matches the actual protection standard for horticulture. Different results were obtained for *the critical approach*, whereby only selected critical locations are upgraded. Firstly, the optimal protection level, in case of a low unit price, couldn't be extracted from the protection levels, as considered in the analyses. In contrast, an optimum was found close to -1,88 m NAP for a high unit price, which is higher than the actual protection standard for horticulture. This protection level results in an annual flood risk reduction from 35.000 EUR up to 10.000 EUR. Obviously, the total investment cost for flood protection in this strategy is lower due to the smaller construction size. The higher protection level was probably found due to lower investment cost for the critical protection strategy.

Furthermore, it was found that the cost-efficiency of measures is generally lower for the full protection approach than for the critical protection approach. The cost and benefit ratio for a 30-year project period is negative for almost all protection levels for the full protection approach, while the critical protection strategy shows a positive ratio. It is however important to note that these conclusions for the protection strategies have been drawn from just one composition of construction materials, which was primarily the composition with the highest cost-efficiency. This combination is mainly based on the following construction materials: clayish peat (open field cultivation and others), EPS or foam concrete (pot-and container cultivation) and bamboo (greenhouses).

Acknowledgment

This Master thesis is the final product of six years of studying, which I started with a Bachelor Earth and Economics at the Vrije Universiteit Amsterdam and which I continued with a Master Water Science and Management at Utrecht University. This research was facilitated by Water Board Rijnland (in Dutch: Hoogheemraadschap van Rijnland) in Leiden, which manages the regional and local water systems in the area between IJmuiden and Gouda.

I would like to express my gratitude towards the people without whom this thesis would not have been possible. First of all, I would like to thank, Niels Minnen, my main supervisor at Rijnland for his guidance and feedback. Furthermore, my gratitude comments on Eva Eigenhuijsen and Jacob Wijbenga from Rijnland Water Board which gave me this internship opportunity and supported me throughout my stay at Rijnland. Secondly, I would like to thank Marc Bierkens, my university supervisor, for his willingness to supervise this thesis and his valuable comments on the final product. Finally, I would express my thanks and appreciation to all other people which I have not mentioned yet. Many employees from Water Board Rijnland who reserved time in their schedule to answer all my questions. Gerard Jansen from Vlotterkering B.V. and Martin Egas from Dura Vermeer who reserved time to answer my questions about a new temporary flood barrier concept, the Vlotterkering. Koen Staalen and Piet Harlaar from Geonius, who guided me with troubleshooting in the Modelbuilder of ArcGis.

Finally, I would thank my parents, sisters, girlfriend and close relatives and friends for their moral support which helped me finally finish this thesis after the physical and mental struggles I had. Thank you all for your endless patience!

Martijn van Huizen

Haarlem, June 2017

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Used terms

This section provides a short overview of definitions that are used frequently in this thesis.

Actual water level (in Dutch: actueel peil): surface water level that is actually measured and differs from the target water level formalized in the Water Level Decision.

Arboriculture: term that is used for the cultivation of ornamental trees directly into the local peat soil outside or inside greenhouses. This is the traditionally cultivation type in the Greenport Boskoop.

Discharge: only refers to the movement of water in ditches and channels in a water level area

Drainage: refers to the artificially installed drainage systems to dewater optimally at parcel level and improve the movement of groundwater to the surface water. The type of drainage differs per business operation. The drainage system for the *arboriculture* is installed below the target surface water level, whereas for the *floriculture* this can be both below and above. Therefore, based on the drainage used the floriculture distinguishes generally two types: *open cultivation* and *closed cultivation* (figure a). The same drainage system is used for the open cultivation and arboriculture, but a different type for the closed cultivation. This drainage system is particularly used by a business that is permitted by law to recirculate the drainage water in a recirculation basin (figure b). This depends on the type of plant and the nutrient quantities used in the production process.

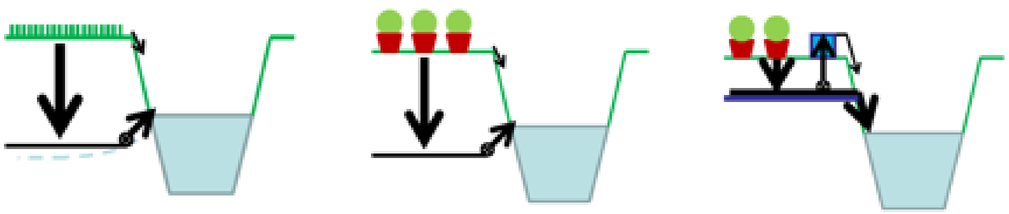


figure a - (Left) open field cultivation with pumped drainage; (middle) open pot- and container cultivation; (right) closed pot- and container cultivation (with recirculation basin) (source: Vemden-Versprille, 2013)

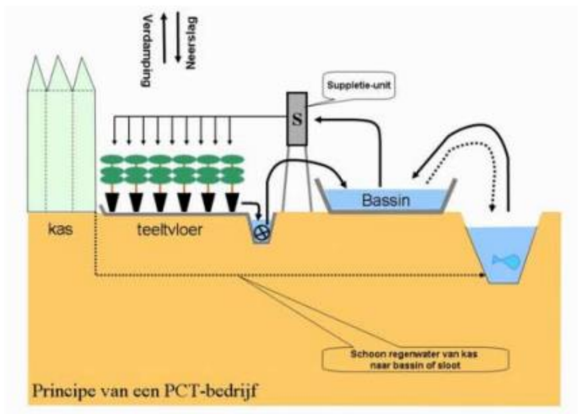


Figure b – Layout of a parcel for Pot-or container cultivation with a recirculation basin (source: Aendekerk, Wit and Lint, 2005)

Floriculture: term that is used for the cultivation of small plants and shrubs. Previously, these plants were also produced in the local soil. Currently, for optimization purposes the production is done in plastic containers in combination with artificially cultivation floors outside and inside greenhouses. This is called *'pot or container cultivation'*. Because of a higher production efficiency, the share of this cultivation type has increased significantly in the Greenport.

Greenport: short notation for Greenport Boskoop. This implies the water management areas 'Gouwepolder', 'Laag Boskoop' and a part of 'het Zaanse Rietveld'.

Horticulture: collection term that includes the production of ornamental trees (*arboriculture*) and plants (*floriculture*) in the Greenport Boskoop. This is done directly into the local soil and small plastic containers.

Pumping: refers to displacement of water between two different water level areas with a pumping unit.

Target water level (in Dutch: peilbesluitpeil): surface water level in a polder established by the Water Board and captured in the Water Level Decision (in Dutch: Peilbesluit). The Waterboard should pursuit this water level.

Water level area: refers to a hydrological unit in a polder system with its own self-contained surface water level

Water nuisance: refers explicitly to inundation caused by excess precipitation. In this thesis, water nuisance specifically refers to the flooding in lower water level areas due to a rising surface water level in the neighbouring higher water level area.

Chapter 1 – introduction

1.1 Background

Behind the primary flood defences of the west coast of the Netherlands, a large urban zone hosts a large share of the Dutch population in cities like Amsterdam, Rotterdam and The Hague. But it also accommodates residential areas and different economic sectors accounting for a large share of GDP. Increasing development of housing, infrastructure, industry and agriculture have increased the human pressure on this fragile delta system (Schuetze and Chelleri, 2011), but also the flooding risk as the financial and human consequences may be larger with a higher density of financial assets and population.

Peat soils prevail in large parts of the western coastal region of the Netherlands. A large part of these soils is drained and used for agriculture purposes (Hoogland et al., 2011). This resulted in decomposition and compaction of organic matter and consequently the initiation of land subsidence. The many man-made lakes in the western coastal region were drained and reclaimed. These reclaimed areas are called 'polders' in Dutch terminology. Generally, water in a polder system is drained by ditches and channels and discharged out of the area by pumping stations (Andel, Lobbrecht and Price, 2008). Without this system, it will be impossible to maintain water levels below the present surface level and facilitate land-use functions.

Water Boards are responsible for the regulation of the surface water levels in polders. A polder water system operates as it should be when it complies with the protection standards and the inundation damage caused by high surface water levels remains within the acceptable range (Hoes, 2007). This applies for the surface water system inside the compartment, but also for surface water systems nearby that may cause inundation. The system fails if inundation damage is caused, which must be prevented according to the protection standards.

Inundation damage in rural areas is mainly caused by heavy precipitation. According to the KNMI, the Dutch National Meteorological institute, an rainfall event is denoted as 'extreme' if more than 50 millimetres of rainfall is recorded within 24 hours. These events cause an increase of the surface water level and exceedance of the current limits of the water system (Hoes, 2006).

The frequency of inundation as well as the inundation damage, is expected to increase due to the effects of climate change. Especially, the intensity of extreme rainfall events is expected to increase in the Netherlands, while the frequency of rainfall events will decrease (KNMI, 2015). Accordingly, a polder water system should process additional water in a reduced time span to comply with protection standards and prevent unacceptable inundation damage.

The exposure to inundation and the height of inundation damage has increased due to expansion of agricultural activities in polders. Inundation may have large financial consequences for the agricultural sector, especially when a crop is irreversibly damaged or business operations are paused due to unfavourable soil conditions for production, such as oversaturation. The Water Board should implement measures if (part of) the inundation damage is not acceptable.

Basically, implementation of measures against inundation are based on the concept of weighing costs and benefits. However, the way of doing this has been changed over the years (Hoes and Schuurmans, 2006). Currently, the Water Board may assess a polder water system at three different levels:

1. The first level concerns the assessment of different elements in a polder water system. For example, pumping stations for polder areas were designed at 10 m^3/min per 100 ha according to the Dutch guideline (Hoes & Schuurmans, 2006).

2. A second level of assessment concerns the acceptability of the water level increase, caused by the combined functioning of elements in a polder water system. Several protection standards for a number of land-use classes are captured in the National Administrative Agreement on Water to assess the acceptability of the water level increase (Nationaal Bestuursakkoord Water, henceforth: NBW). The standards are based on the probability distribution function (PDF) of simulated water levels for the polder area in question. The application of the NBW assessment is further explained in Annex 1.

3. The third level of assessment concerns the cost-benefit assessment, whereby the effect of measures on the reduction of inundation damage is analyzed. Investment cost in protection can be optimized by analyzing different protection levels.

Polders are actively monitored by Water Boards to gain more knowledge about the water system behaviour and determine effective measures to optimize the water system (HHR, n.d (a)). These measures are necessary to comply with the NBW protection standards on the one hand. On the other hand, to prevent large and valid inundation damage claims in the future.

One of the Dutch Water Boards that deals with the effects of extreme precipitation in peat polders is the Rijnland Water Board (in Dutch: Hoogheemraadschap van Rijnland). This Water Board is managing more than 200 polders along the west coast of the Netherlands with a total area of 1070 km^2 (figure 1.1) (HHR, n.d.(b)). Currently, the area accommodates a population of 1.3 million people and three large hotspots for agricultural production, known as the Greenports (Holland Rijnland, n.d). In the southwest region of Rijnland a large floricultural and arboriculture sector, known as the Greenport Boskoop, has developed due to excellent growing conditions on peat for trees and shrubs (figure 1.2). Rijnland contains a high concentration of peat soils, which are subject to the highest subsidence rate in the Netherlands.

The Greenport Boskoop is one of the six Greenports in the Netherlands and worldwide known for its valuable arboricultural and floricultural productions. This region represents a € 455 milion export value per year, which is nearly 30% of the total national revenue in the arboricultural sector (ISV Boskoop, 2011). Currently, the Greenport accommodates a total area of 1200 hectares with a high density of business operations. As a result, the water balance has changed in the Greenport due to additional drainage and reduction of the infiltration capacity in the soil. Furthermore, there is lack of space to upgrade current water courses or implement new water retention areas.

Polders of the Greenport are not that climate proof as they were expected to be according to rainfall events in the past. This concern is shared by the floricultural and arboricultural sector in the Greenport. They experienced large inundations due to extreme rainfall in the summer of 2010, 2011 and 2014 (Van Vemden-Versprille, 2013). Furthermore, during this research inundations nearly occurred in the Greenport after a few days of intense rainfall in June 2016. Therefore, measures are imperative to prevent future flood damage.

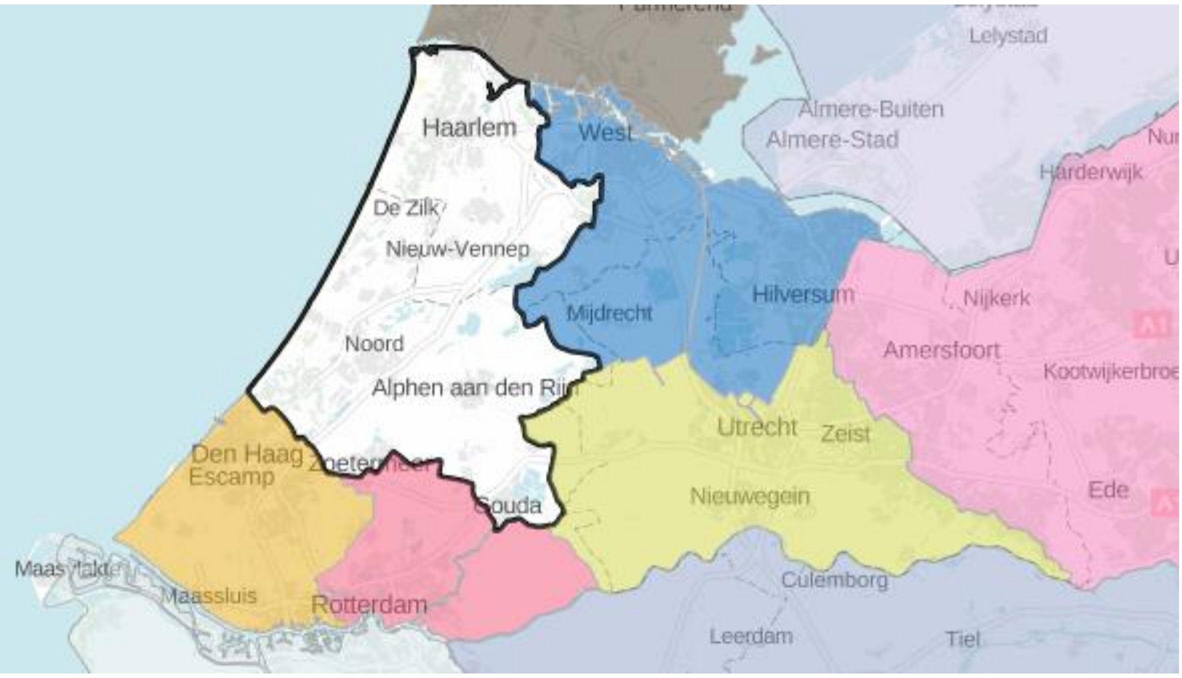


Figure 1.1 - management area Rijnland Water Board (HHR, n.d. (c))

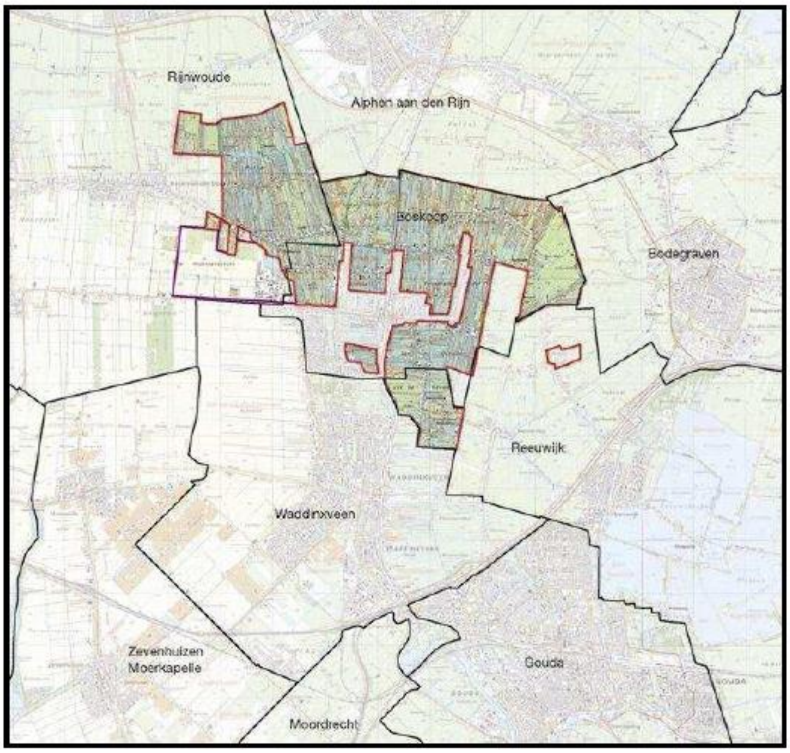


Figure 1.2 - Arboriculture concentration contour Greenport Boskoop (ISV Boskoop, 2011)

1.2 Problem description

Rainfall events in the past caused inundation in lower water level compartments in the Gouwepolder, which are the coloured areas in figure 1.3. This inundation was specificially caused by surface water from the higher water level compartment. Extreme precipitation forces the surface water in the higher compartment to a level, which causes inundation in the lower water level compartments. These water level areas have been initiated to facilitate arboriculture and horticulture in areas with an average lower surface level than the Gouwepolder (table 1.1). Rijnland Waterboard controls the water level in these lower compartments by pumped drainage. In management terms, the division between water level compartments in the Gouwepolder is denoted as 'water level borders' (in Dutch: peilvakscheidingen). Water level borders divide different water level compartments. Due to the small differences in surface height and water levels, these borders are difficult to observe. Currently, the protection height of these borders is insufficient to withstand the water level increase up to a certain level in the higher water level compartment. Consequently, inundation may prevail in the lower water level compartments.

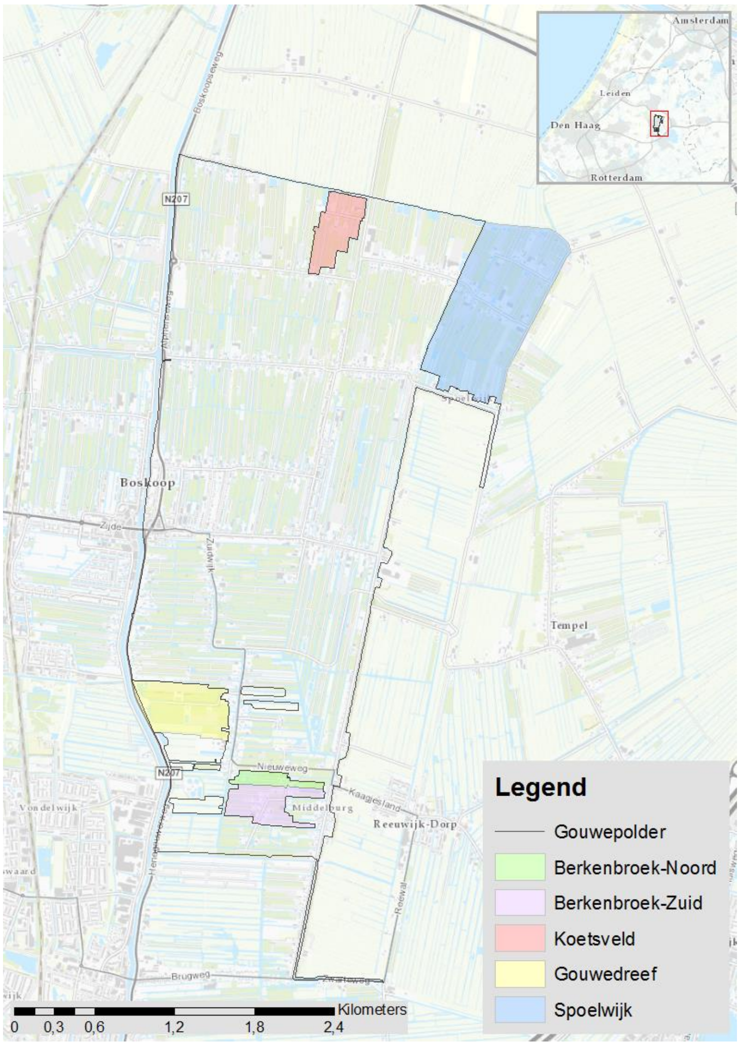


Figure 1.3 – Arrangement of the Gouwepolder. The lower water level areas are coloured

Small inundation depths may already cause serious issues for the present horticultural. Besides the interruption of business activities, horticulture is highly sensitive to saturated conditions which may damage productions irreversibly. These losses of productions may cause high financial damage. In the past, inundation events in the Greenport fortunately caused minimal financial damage for the horticulture in the lower water level compartments. The frequency of summer rainfall events is expected to decrease in light of climate change, while the intensity of extreme rainfall decreases. Accordingly, the occurrence of high water levels is likely to increase.

Table 1.1 - surface level measurements for the Greenport Boskoop (modified from Van Vemden-Versprille, 2014). **) no measurements

Unit	Code	Average surface level height (m NAP)	Maximum height (m NAP)	Minimum height (m NAP)	Standard deviation (m)
Gouwepolder	WW-28a	-1,90	2,03	-3,16	0,21
Spoelwijk	WW-28b	-2,15	0,13	-3,23	0,19
Berkenbroek-Noord	WW-28c	-2,27	-1,85	-2,58	0,12
Berkenbroek-Zuid	WW-28d	-2,02	-1,53	-2,86	0,11
Koetsveld	WW-28e	-1,95	-1,25	-2,33	0,11
Gouwedreef	WW-28f	**	**	**	**

As previously mentioned, the degree of protection of water systems in polder is assessed with the NBW protection standards. Protection levels in NBW assessments are based on coarse cost-benefit analyses. The main advantage is that a protection level can be determined relatively easy. Hoes & Schuurmans (2006) have proven that a more detailed *cost-benefit analysis* of measures, whereby the reduction of inundation damage is balanced against the investment cost, results in more efficient protection levels than currently prescribed by the NBW protection standards.

1.3 Previous research on the problem

NBW-assessment of the Gouwepolder

A NBW assessment was conducted for all water level compartments in the Gouwepolder, to identify the areas that do not comply with the protection standards. This assessment assumed that the areas only inundate from the surface water system inside the water level compartment. Inundation in lower water level compartments that originates from the surface water system in the higher compartment was excluded from the analysis. Table 1.2 shows the results of the NBW assessment of the different water level compartments in the Gouwepolder (Van Vemden-Versprille, 2014). Furthermore, an inundation map was constructed which shows the areas that are likely to inundate when a water level increase with a return period of 1:50 appears in the Gouwepolder (Annex 2).

The NBW protection standard for horticulture (corresponding to a water level increase with a return period of 1:50) was used to assess the current protection height of the water level borders (Van Vemden-Versprille, 2014). This assessment gives a first rough indication of the areas that can potentially be flooded in the lower compartments. All water level borders contain areas that are below the protection standard, as illustrated in figure 1.4. These results did not precisely indicate the extent of inundation in these critical zones.

Table 1.2 – results of the NBW assessment of the Gouwepolder (based on Van Vemden-Versprille, 2014).

Water level compartment	**Area (in hectares) below applicable protection standard (percentage in brackets)**			
	Horticulture	*Meadow*	*Main roads*	*Total area (ha)*
Gouwepolder (28a)	23 (6%)	21 (32%)	0,79 (5%)	844
Spoelwijk (28b)	8 (23%)	0	0,04 (4%)	86
Berkenbroek-Noord (28c)	0	0	0	5
Berkenbroek-Zuid (28d)	0	0	0	15
Koetsveld (28e)	0,42 (4%)	0	0	16
Gouwedreef-Randenburg (28f)	0	1,53 (17%)	0	31

Figure 1.4 - locations in blue that may be involved in pluvial flooding for a T50 event in the fixed water level areas: Koetsveld (top left, note: left border has been adapted), Spoelwijk (top right), Berkenbroek-Noord & Berkenbroek-Zuid (bottem left) and Gouwedreef-Randenburg (bottom right)

Expected inundation damage

The expected inundation damage was estimated for the areas in the Gouwepolder that do not comply with the protection standards (Huizinga and Groot, 2012). Again, this only includes damage that is caused by the water system located inside the water level compartment. First of all, the inundation depth was calculated for the selected areas in the NBW assessment. This was done for water levels that correspond to a 1:10 and 1:50 return period. Then, the inundation depth was converted to inundation damage by depth-damage functions representing the following land-use types: meadow, greenhouse farming and horticulture. Three different alternative damage calculations have been performed to vary the impact of high groundwater levels on the final damage estimate. Table 1.3 includes the results of these calculations in relation to a water level return period interval of 1:10 - 1:50. Huizinga and Groot (2012) concluded that the inundation damage is highly overestimated when the groundwater damage is included in the damage calculations of alternatives B and C. The presence of drainage systems in the Greenport significantly reduces the negative impacts of an increasing groundwater table. Furthermore, the expected annual inundation damage or risk was calculated for the return period interval 1:10 - 1:50 (table 1.4). The expected annual inundation damage increases with 7% up to 32% when the return period interval 1:5 – 1:10 is included in the calculation. Therefore, the lower damage limit should be defined with caution, since low return periods are more decisive than high return periods in the final damage estimate. Despite that the inundation damage caused by the interaction between the higher surface water system and the lower compartments was not determined, the results give an indication of the bandwith of inundation damage, in particularly for the lower water level compartments. The expectation is this inundation damage caused by the higher compartment will be higher than the annual expected damage for variant A in table 1.4.

Table 1.3 – total economic damage after inundation for the water level compartments in the Gouwepolder. Extracted and modified from Huizinga and Groot (2012). ***Note: Berkenbroek-Noord and Berkenbroek-Zuid comply with the protection standards and are not included in the damage calculation.***

Polder compartment	**Total damage [x 1000 €]**					
	T = 10 year			**T=50 year**		
	Alternative A	*Alternative B*	*Alternative C*	*Alternative A*	*Alternative B*	*Alternative C*
Gouwepolder (28a)	1591	3150	6397	2785	3948	9697
Spoelwijk (28b)	219	676	727	1093	1565	1928
Koetsveld (28e)	3	40	90	20	44	172
Gouwedreef (28f)	0,1	2	4	1	3	14

Alternative A: inundation damage is only caused by surface water
Alternative B: open field cultivation less sensitive to high groundwater table
Alternative C: open field cultivation highly sensitive to high groundwater table

Table 1.4 – expected annual inundation damage for the return period interval 1:10 – 1:50 in the water level compartments of the Gouwepolder. Extracted and modified from Huizinga and Groot (2012).

	Annual expected damage (x1000 Euro)		
Polder (code)	*Alternative A*	*Alternative B*	*Alternative C*
Gouwepolder (28a	231	363	838
Spoelwijk (28b)	74	121	145
Koetsveld (28e)	1	4	14
Gouwedreef (28f)	0	0	1

Flood measure costs

One way of reducing the effects of a water level increase in the higher compartment is to reduce the water level increase by improving the current water system. Rijnland Waterboard examined several options that might improve the water system and reduce the water level increase in the higher compartment during extreme precipitation:

-The construction of new culverts to connect watercourses and improve discharge towards the pumping station;
-The improvement of current culverts by increasing the discharge capacity
-The implementation of additional surface water;
-A permanent lower water level under normal conditions.

Especially, the last option causes a lot of resistance from the area as it further stimulates the process of subsidence. Therefore, this option is not preferred by the landowners and the Water Board. The other options have received more support, but are less effective when a significant reduction of the water level increase is required locally. Due to the large size of the surface water system in the high compartment, the overall water level reduction in the system will be limited to only a few centimeters. This will be insufficient to prevent inundation in lower water level areas. Therefore, the second way to reduce the effects of a water level increase is the creation of additional protection height, by increasing the current surface level. A surface level increase in the Gouwepolder will minimally cost € 5000 per hectare according to a first estimate (Van Vemden-Versprille, 2014). This number may fluctuate depending on the surface level height locally and the size of the measure.

1.4 Objectives

Given that the cost-efficiency of structural flood measures following NBW standards might be suboptimal, the main objective of this thesis is: *to devise a framework for finding a cost-efficient strategy to reduce water nuisance in lower water level areas in the Gouwepolder*. To determine a cost-efficient strategy, the following sub-objectives has been formulated:

1) to gain insight about how water nuisance evolves along water level borders during peak rainfall events;

2) formulate flood protection strategies which includes measures to reduce the inundation risk along the water level border;

3) quantify the inundation risk for a water level area for the current situation and how this changes in relation to a higher protection height;

4) determine what is required in terms of flood protection to reduce the inundation risk along the water level border;

5) determine the cost-efficiency of measures for different protection levels for a specified project period;

6) determine the total cost curve to identify the optimal protection level for a specified project period.

1.5 Outline

This thesis contains six chapters, excluding the bibliography and appendices after the final chapter. Chapter 2 explains the relevant theories, from which concepts have been extracted and used in the next chapters. Chapter 3 describes more specifically how the research has been conducted to answer the relevant research questions. The relevant results are described in chapter 4. These results are placed in perspective by reflecting on the results in relation to the relevant literature (chapter 5 discussion). Finally, a recapitulation of the results is given in chapter 6.

Chapter 2 – Theory

Firstly, in section 2.1 a description is given of how water levels are currently managed in the Gouwepolder. Section 2.2 describes how this water system reacts to precipitation and what may cause water nuisance specifically. After that in section 2.3, a description is given of the risk framework, that has been developed to monetarize the effects of water nuisance. In sections 2.4 and 2.5 the theoretic concepts behind this framework are described for three different elements: hazard, exposure and damage. Section 2.6 describes what measures can be taken to reduce the risk of water nuisance. Finally, section 2.7 considers the cost-benefit concept more in detail, to balance the costs for implementation of measures and the benefits expressed in terms of the risk reduction of water nuisance.

2.1 The polder water system: water levels in the Gouwepolder

Figure 2.1 provides an overview of the active hydrological processes in a traditional polder area without artificial drainage. Naturally, precipitation in the summer (1) infiltrates into the soil, (2) percolates to lower groundwater systems and (3) drains to surface water if the groundwater table is higher than the surface water level. Due to the lower evaporation rates in the winter, the groundwater table is generally higher than the surface water level.

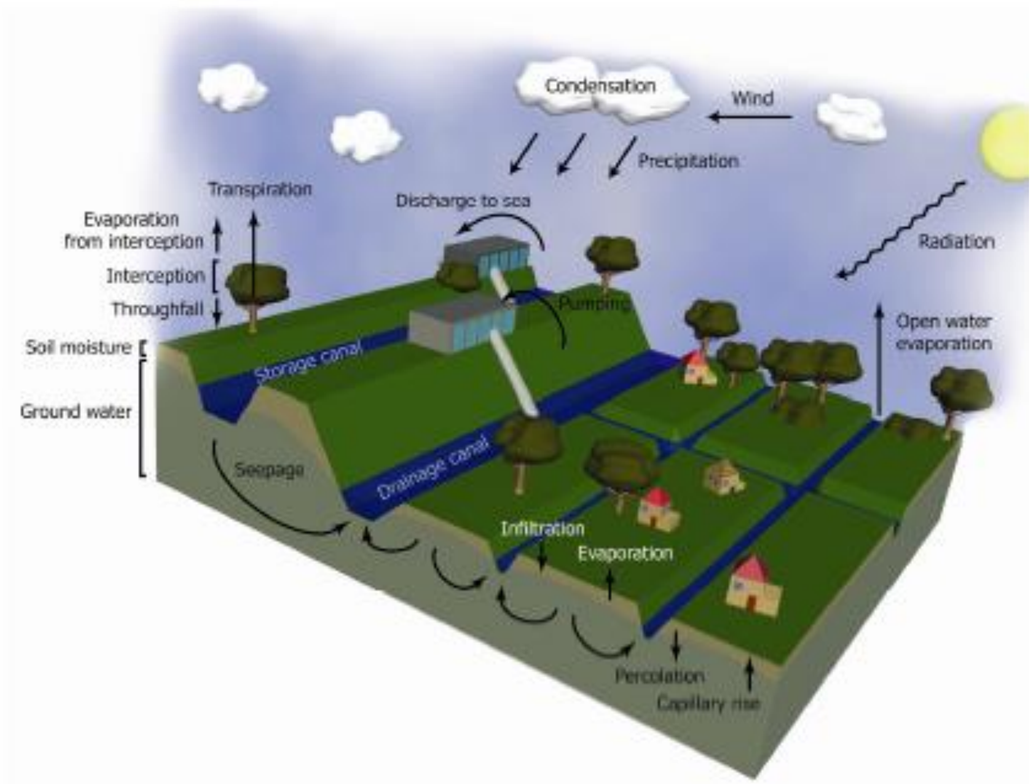


Figure 2.1 - active hydrological processes in a polder area (Hoes, 2006)

In the Greenport, these natural processes have been affected by the installation of drainage systems. Consequently, water that infiltrates into the soil is almost directly drained towards the surface water system. Therefore, the duration of water retention is relatively short and the water storage capacity of the soil may not be used effectively.

During winter the precipitation rate is higher than the evaporation. This causes a higher groundwater table and increasing drainage to the surface water. Consequently, pumping is necessary to maintain the target water level and to lower the groundwater table (Schuetze and Chelleri, 2011). During the summer, a reverse pattern is observed, which led to lower surface water and groundwater levels.

Water is also occasionally let into the polder, for instance during days of frost when plants and trees must be sprinkled to protect them against frost damage (Van Vemden-Versprille, 2013). Despite the higher water availability, water nuisance is less common during winter in the Greenport. One the one hand, because precipitation is more distributed and less intense in the winterseason compare to the summerseason. On the other hand, artificial drainage prevents oversaturation of parcels.

In the summer, more water evaporates than precipitates and therefore water is let into the polder to maintain the water quantity and quality in the polder (Schuetze and Chelleri, 2011). Despite the lower water availability, the occurrence of water nuisance is more likely in the summer. This is mainly because of the high-intensity of rainfall events, which means additional water must be processed by the water system in a shorter amount of time.

The polder water system is designed to collect excess rainfall, whereby water is stored temporarily in the surface water system before it is eventually discharged out from the polder by pumping units or discharge sluices (Wandee, 2005). The surface water system serves as a hydraulic conveyance to the structures and pumps, and at the same time as storage reservoir for precipitation (Wandee, 2005).

Due to the spatial differences in surface height, the polder water system in the Gouwepolder has different water level areas to regulate the surface water. Figure 2.2 provides a schematization of the surface water level system of the Gouwepolder. The Gouwepolder is denoted as the main drainage area and includes five smaller areas with a lower surface water level. The surface water level in these areas is maintained by pumping towards the main drainage area, except for the area Berkenbroek-Zuid (28d) that uses a weir to discharge towards Berkenbroek-Noord (28d). Eventually, the main drainage area discharges by pumping to the Gouwe storage basin (in Dutch: Gouwe boezem), which flows west of the Gouwepolder.

Rijnland Water Board should maintain several polder water levels in the Gouwepolder as established in the *Water Level Decision* (in Dutch: Peilbesluit) (HHR, 2015a). These water levels apply under normal conditions and within a reasonable bandwidth. The groundwater table is generally maintained by (pumped) drainage. This is done primarily to create an optimally moisture balance at parcels with horticultural production. Consequently, the influence of a higher surface water level on the groundwater table is limited (HHR, 2015a).

Despite the fact, the Water Board pursuits to maintain the polder water level close to target water level, spatial variation in polder water level occurs in the Gouwepolder. Especially, the polder water level in the north is at least fifteen centimetres higher than the target water level (-2,25 m NAP) (figure 2.3). The average increase of the polder water level is close to 6 cm/km, exceeding the hydraulic gradient norm for peat polders (1 cm/km) (Van Vemden-Versprille, 2013). A higher polder water level diminishes the freeboard, reducing the storage capacity in the surface water system locally.

Figure 2.2 - schematization of the Gouwepolder surface water level system: Gouwepolder (28A), Spoelwijk (28B), Berkenbroek-Noord (28C), Berkenbroek-Zuid (28D), Koetsveld (28E) and Gouwedreef-Randenburg (28F) (HHR, 2017)

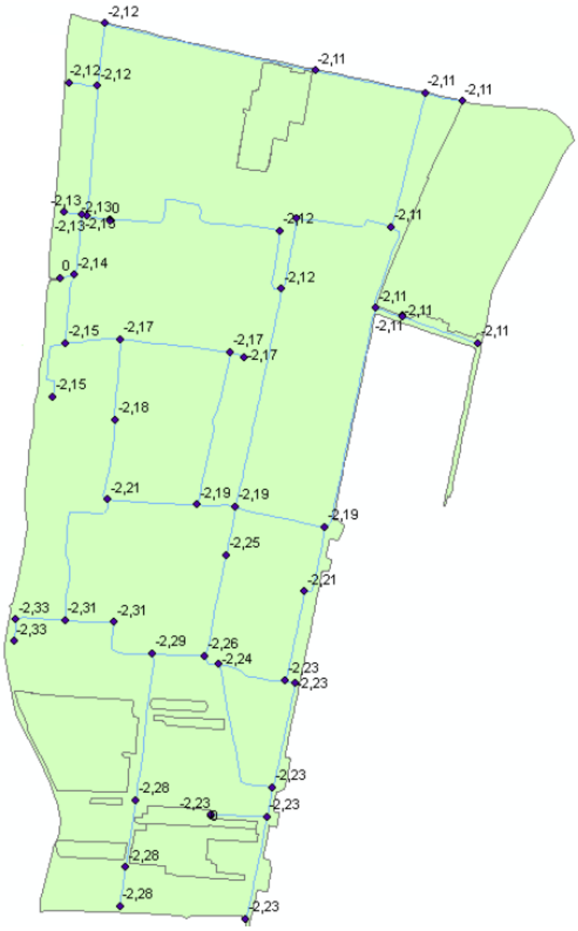


Figure 2.3 – spatial variation in polder water level in the Gouwepolder (Van Vemden-Versprille, 2013, p.42)

A SOBEK rainfall-runoff model was used to determine the effect of historic rainfall data on the water level increase in the higher surface water compartment (van Vemden-Versprille, 2013). The water level in the surface system of the higher compartment may increase up to 22 centimeters on average for a 1:100 return period (figure 2.4).

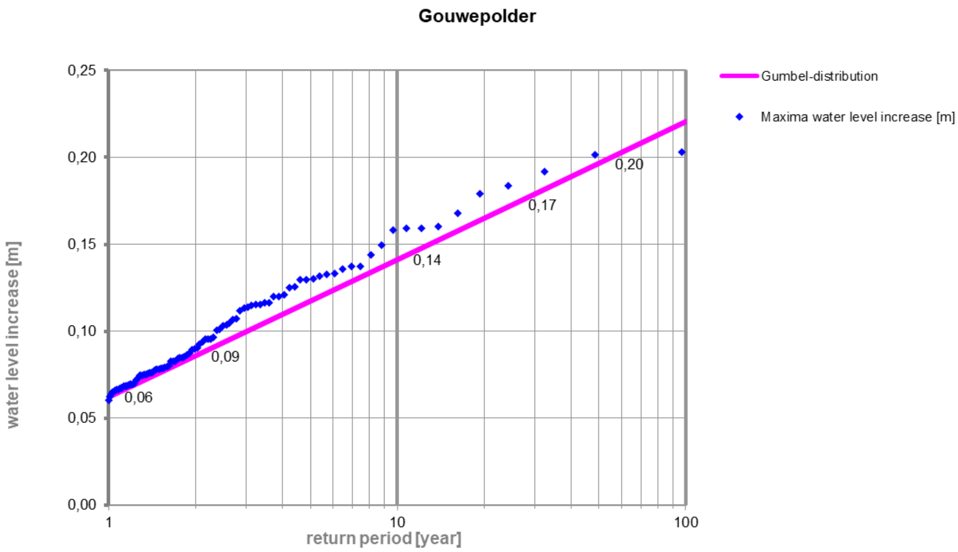


Figure 2.4 – Gumbel distribution for the Gouwepolder drainage network (Van Vemden-Versprille, 2013, p.137)

2.2 Water nuisance in polders

There are different types of flooding that may appear in a polder; therefore, a definition should be given first for the term *water nuisance*. The term water nuisance is usually adopted to describe the combined flooding in urban areas during heavy precipitation (Falconer et al., 2009). This includes: (1) pluvial flooding, (2) sewer flooding, (3) overland flows from groundwater springs and (4) flooding from small open-channel and culverted urban watercourses.

Pluvial flooding specifically refers to flooding that results from rainfall-generated overland flow and ponding *before* the runoff enters any watercourse, drainage system or sewer (Falconer et al., 2009). Sewer flooding results from heavy rainfall that cannot enter the sewage system due to exceedance of the sewer capacity. Overland flow from groundwater in a rural area may be caused by (1) drainage obstruction or (2) a limited soil drainage capacity (Verhoeven, 2006). A rising surface water level may block natural drainage of groundwater to the surface water system which results in a higher groundwater table (figure 2.5, top). The issue of limited drainage appears mainly in soils with a low hydraulic conductivity, particularly clay or peat soils. This may result eventually in water ponding when the soil becomes oversaturated during heavy precipitation (figure 2.5, middle). Most of the parcels in the Greenport have been equipped with a drainage system that also drains water when the surface water level is higher than the target level (Van Vemden-Versprille, 2013). These systems prevent on the one hand overland flow, but on the other hand they stimulate surface water level increase during heavy precipitation. This may eventually result in flooding from open channels. Mainly, due to the limitations in the discharge capacity the surface water level is forced to move upwards when excess precipitation is stored (figure 2.5, bottom).

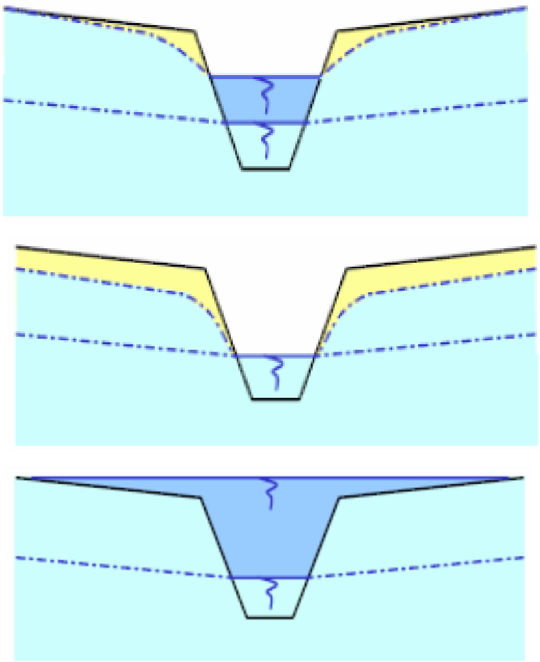


Figure 2.5 - (top) water nuisance due to a rising groundwater table caused by discharge limitations in the surface water system; (middle) water nuisance caused by a failing groundwater drainage system; (bottom) water nuisance caused by a rising surface water level due to discharge limitations in the surface water system (Verhoeven, 2006)

Figure 2.6 – part of the Gouwepolder surface water system around water level area Koetsveld. During peak rainfall events water from this surface water system may flow into this area.

In the remaining of this thesis, the term water nuisance is specifically attributed to flooding that originates from the local surface water system. During peak rainfall events the water storage capacity may be exceeded quicker, which forces surface water to enter parcels close to the watercourses (Figure 2.5 bottom and Figure 2.6) (Klopstra and Kok, 2009). Other types of flooding may be relevant as well, but are not within the scope of this thesis.

2.3 The risk framework: hazard x exposure x susceptibility = risk

Traditionally, flood management has concentrated on flood protection by means of technical measures aimed at reducing flood hazard, i.e. the probability of a flood occurring (Ward, De Moel and Aerts, 2011; Merz et al., 2010). This concept has increasingly been questioned in recent years leading to a shift towards a new concept, usually referred to as "flood risk management" (FRM). The traditional flood policies mainly focused on the control or reduction of flood hazard while the emphasis in FRM is more concentrated on flood risk than flood damage. Risk may be defined as the probability of flooding multiplied by the potential consequences (Ward et al., 2011). The main advantage of risk analyses is that decision makers are able to evaluate the cost-effectiveness of mitigation measures and optimize investments (Apel et al., 2009).

The concept of expected annual damage (EAD) is used to express flood risk in economic terms (Ward et al., 2011). To calculate the expected annual damage for a specific flood event, combination of four different information components is required: (1) the flood hazard, (2) the exposure to the flooding event, (3) the value of the elements at risk and (4) the susceptibility of these elements to hydrologic conditions (De Moel and Aerts, 2011) (figure 2.7). The following sections will describe how these elements can be specified. To estimate EAD for a given protection level, the exceedance probability-loss curve (or risk curve) is constructed and the area below the curve is calculated (Meyer et al., 2009). To illustrate this, the yellow area in figure 2.8 reflects the EAD for a T200 protection period. Important to mention, is that the number of return periods to construct the risk curve may considerably affect the estimated risk. According to the study of Ward et al., 2011, overestimation of annual risk for a section of the Meuse river ranges from 33% up to 100% by using only three return periods.

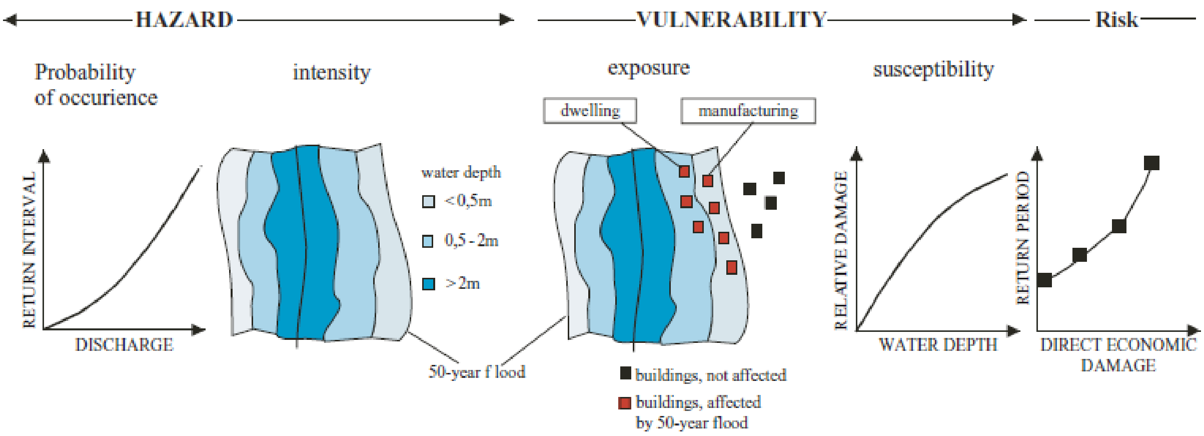


Figure 2.7 – flood risk as the product of hazard (exceedance probability and intensity) and vulnerability (Merz, Thieken and Gocht, 2007, p.232)

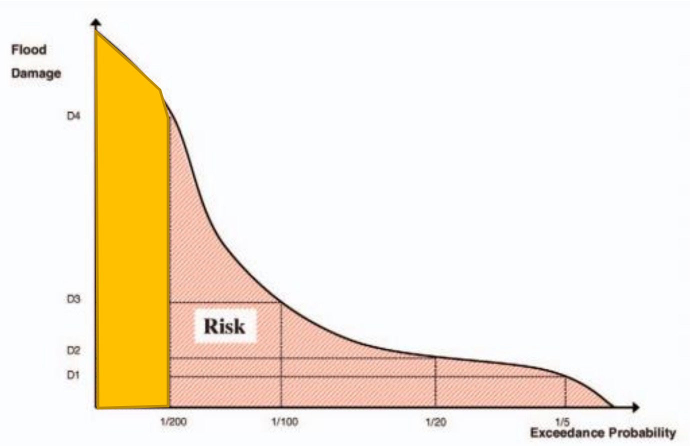


Figure 2.8 – Damage – probability curve (modified from Meyer et al., 2009, p.18)

2.4 Inundation modelling: analysis of water nuisance

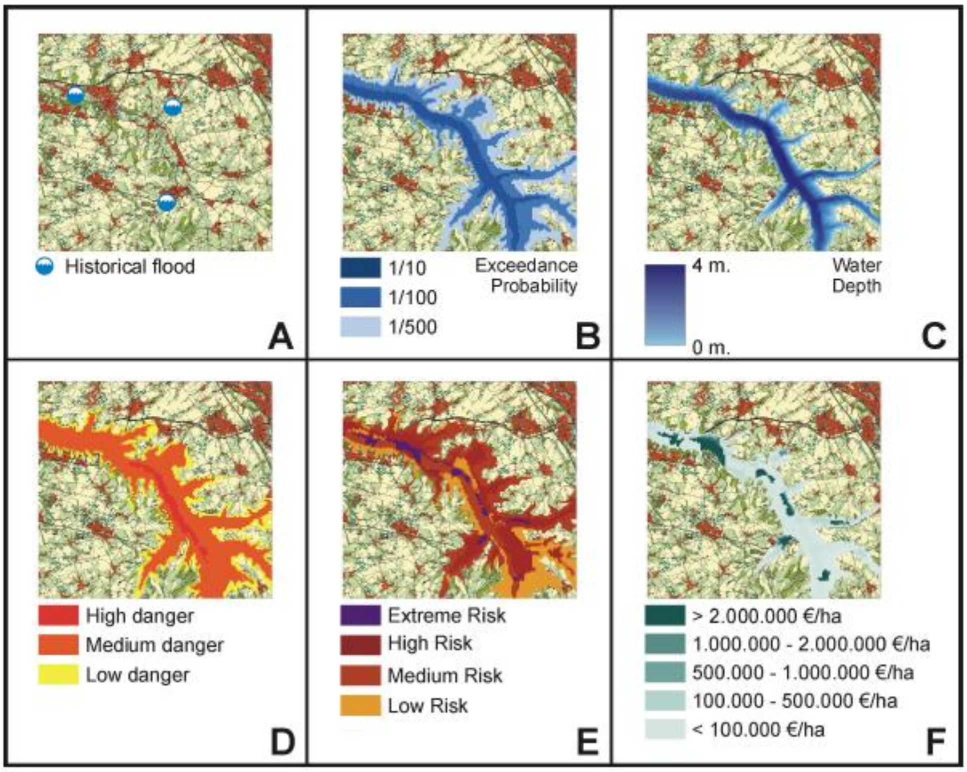


Figure 2.9 - different flood map types. (A) historical flood map; (B) flood extent map; (C) flood depth map; (D) flood danger map; (E) qualitative risk map; (F) quantitative risk (damage) map (De Moel et al., 2009, p.293)

Statistical and modelling tools are mainly applied to calculate the hazard of hypothetical flooding events. Several flood hazard parameters are available to express the flood hazard, among others flood extent, inundation depth, flow velocity, duration of the event, water front propagation, and the magnitude of water level flucuation (De Moel, Alphen and Aerts, 2009). One of the factors that is frequently used to estimate flood damage, is the inundation depth. Methods of varying complexity are used to calculate flood hazard of rivers and develop various types of flood maps (figure 2.9). The conceptual framework behind the calculation of flood hazards roughly consists broadly of three steps (figure 2.10):

1. First of all, river discharges are estimated for specific return periods. This is mostly done by using frequency analysis on discharge records and fitting extreme value distributions (Te Linde et al., 2008). Furthermore, hydrological models are applied to solve the water balance for each geographical unit and time step (De Moel et al., 2009). These models vary in complexity, but spatial input is required for all with respect to

meteorological conditions (temperature, precipitation etc.), soil conditions and land cover data.

2. The next step concerns the translation of river discharges into water levels with rating curves or 1-D or 2-D hydrodynamic models.

3. The final step is to create a inundation map by combination of the water levels and the digital elevation model (DEM) to determine the inundation extent and depth.

While the concept of conversion from river discharge into water levels may be relatively easy, this step may be more difficult for polder water systems. The flooding hazard in a polder ranges from high groundwater levels locally to large inundation from surface water. In generally, the relation between precipitation and water level development is not unique, which means a single water level probability distribution may not be representative for each geographical unit (or pixel cell). In a polder, the water level development is determined by the impact of different components in the water system, such as the discharge capacity of watercourses or runoff from parcels. Multiple water level probability distributions will be necessary to improve the the reliability of inundation depth modelling.

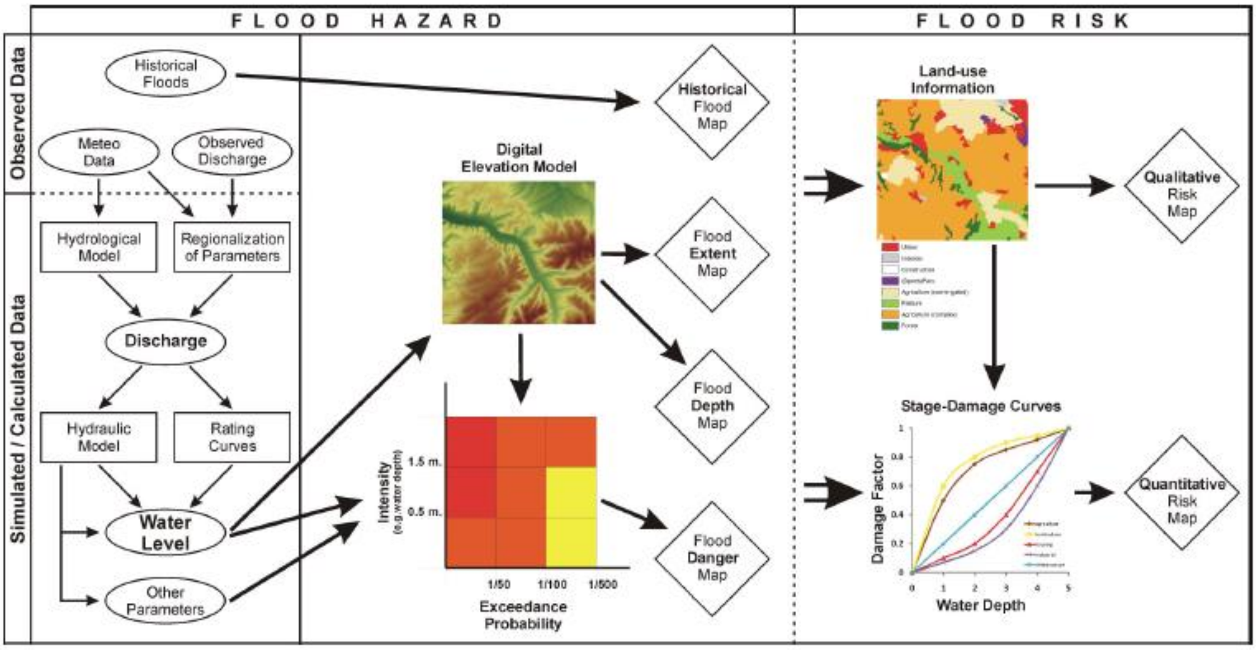


Figure 2.10 – conceptual framework for flood hazard and risk calculations (De Moel et al., 2009, p. 291)

2.5 Damage modelling: exposure and susceptibility

Another aspect of flood risk modelling is the flood damage assessment (Merz et al., 2010). Flood damage estimates in the Netherlands are used for different purposes, for instance to determine economic optimal protection standards for flood defences (van der Most, Tanczos, Bruijn and Wagenaar, 2014), to prioritize investments (Jongejan and Maaskant, 2013) or to compare the impact of different flood risk management strategies (Kind et al., 2014)

Types of flood damage

Generally, flood damage in flood damage assessments is classified into direct and indirect damages. According to Merz et al. (2010): "direct damages are those which occur due to physical contact of flood water with humans, property or any other objects", while "indirect damages are induced by the direct impacts and occur – in space or time – outside the flood event. Another distinction is made between tangibles damages that can be priced, and intangible damages for which no market prices exist. These types may be further classified into tangible damages that can be specified in monetary values, while intangible damage cannot or hardly be transferred into monetary values (Merz et al., 2010). A comprehensive flood risk assessment should comprise all damage dimensions, but damage modelling is frequently limited to direct monetary damage (Jonkman et al., 2008). The other types of damage are often neglected, because the methods to obtain estimates are less reliable (Merz et al., 2010). Furthermore, indirect flood damage may have impact on time scales of months and years, which increases the complexity of damage modelling and the degree of uncertainty (Merz et al., 2010).

Flood damage assessment: the unit-loss method

In the field of flood damage assessment, the unit loss method is the most commonly applied method to estimate direct monetary flood damage (de Bruijn, 2005). This method assesses the damage for each unit separately, which consist of four different elements: (1) a maximum damage price (s_i) for each category, (2) the flood characteristics (for instance water depth *d*) at all locations *j*, (3) the damage functions (*f(d))* for all categories which determine the damage fraction and the number of objects *n* affected (Wagenaar, de Bruijn, Bouwer, and de Moel, 2016). Ultimately, the sum of all damage categories *I* for all grid cells *n* determines the damage in the study area of interest. Figure 2.11 shows graphically how damage can be estimated from these elements. In formula form this may be expressed as (Egorova et al., 2008):

$$\text{Damage} = \sum_{i=1}^{m} s_i \sum_{j=1}^{n} f_{ij}\left(d_j\right) n_{ij}$$

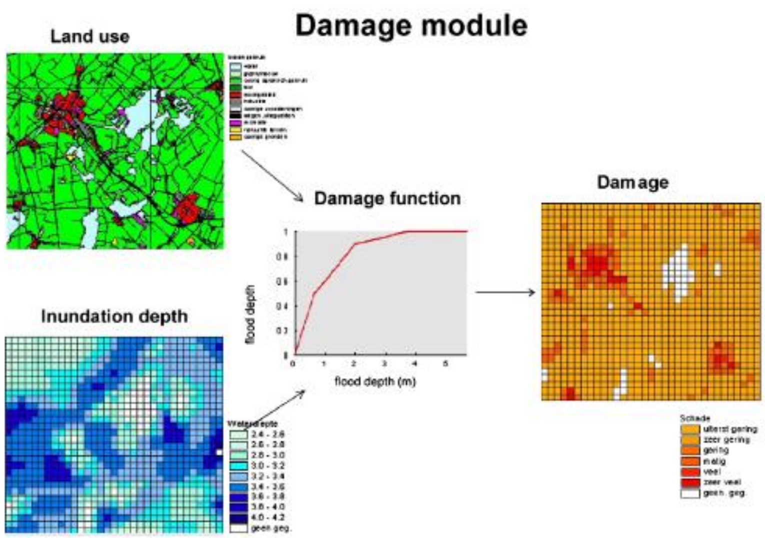


Figure 2.11 – schematization of the assessment of direct monetary damage due to flooding (Egorova et al., 2008, p. 140)

Flood characteristics

Potential flood characteristics in damage modelling are the maximum flood depth, flood velocity, duration of inundation, sediment concentration, contamination by flood water, information content of flood warning, and the quality of external response in a flood situation (Wagenaar et al., 2016; Merz et al., 2010). Commonly, the water depth is only used in the assessment (Merz et al., 2010). Although a few studies attempt to quantify the influence of the other factors (Kreibrich et al., 2009; Thieken et al., 2005; Wind et al., 1999), a trustworthy and comprehensive approach to include them is not available yet. Furthermore, these factors are highly heterogeneous in space and time, complex to predict, and knowledge about the quantitative effects is scarce (Merz et al., 2010).

Classification of objects

In general, a damage assessement for all affected objects is not realistic, as the damage behavior of each object differs and a huge effort is necessary to conduct such a analysis in detail (Merz et al., 2010). In order to reduce the complexity of the damage calculation, different object categories are usually used, such as houses, industries, commercial companies, roads and agriculture (Wagenaar et al., 2016). According to Merz et al. (2010) this categorization has been based on the principle that "different economic sectors show different characteristics concerning assets and susceptibility". For instance, buildings are the main elements at risk for the residential sectors, while they contribute less in other sectors like the commercial, agriculture or public (Merz et al., 2010). Another reason is that the impact varies between sectors. For example, the time of flooding and flood duration are decisive factors for the magnitude of flood damage to agricultural crops, while inundation depth is more relevant for flood damage to buildings (Förster et al., 2008). Furthermore, data to estimate the monetary value of objects at risk are usually compiled according to principle of economic sectors (Merz et al., 2010).

Damage functions

The damage assessment is performed with a classification of economic sectors, while differences in damage patterns are not taken into account for elements at risk within a single category (Merz et al., 2010). To relate objects and flood characteristics, in particularly inundation depth, damage functions are used to express the fraction of the maximum damage as a function of flood intensity. These functions represent the susceptibility of the objects at risk (Merz et al., 2010), as graphically shown in figure 2.11. Eventually, the inundation damage is calculated by multiplying the damage fraction with the maximum damage.

In particularly, flood damage in the agricultural sector concerns the losses of agricultural products, buildings and farm infrastructure (Dutta et al., 2003). The majority of inundation damage models in the agricultural sector only made a distinction between the classes *crops* and *meadow* (Hoes and Schuurmans, 2006), while a limited number also distinguishes different crop types (Dutta et al., 2003; Förster et al., 2008). Furthermore, timing of inundation in inundation damage modelling may be more relevant for the agricultural sector. Crops are highly vulnerable to flood damage during the growing season, in particularly the initial growing stage (Penning-Rowsell et al., 2003).

In the literature depth-damage functions are available for meadows, horticulture and greenhouses. These functions have been developed by Nelen & Schuurmans (2005) and used by the Waterplanner, which is a tool to perform the NBW assessment of regional water systems.

Estimation of asset values

Different approaches exist to define the maximum monetary damage for objects that have been identified by exposure analysis and are affected by a flood event. Wagenaar et al. (2016) defines the maximum damage as "the expected damage corresponding with an extreme water depth". This means that (1) the damage function will reach one (or 100 percent damage) for extreme water depths and (2) the maximum damage defined already contains information about what part of the object is susceptible to flood damage (Wagenaar et al., 2016). Furthermore, the maximum damage only covers that value of an object that is likely to be susceptible to floods. Other definitions include more elements for the valuation of the maximum damage and apply damage functions which never approach the value of one (Wagenaar et al., 2016). This is mainly because part of the value included in the maximum damage is on average not susceptible to flooding.

2.6 Possible measures to combat water nuisance

Different adaptation strategies are available to reduce current and future flood damage and risk. These strategies mainly concerns the application of technical measures to reduce the probability of flooding (Vis et al., 2003; Merz et al., 2010); implementation of insurance to compensate for flood damage (Kunreuther, 2006; Paudel et al., 2012); the application of spatial zoning policies to control land-use changes and development in urban areas (Burby et al., 2000); and the use of mitigation or flood-proofing measures (Kreibrich et al., 2005; Kreibich et al., 2009). Implementation of flood-proofing measures can significantly reduce the costs of floods (Poussin et al., 2012).

To select measures against inundation, Dutch Water Boards decide according to the principle of 'retention > infiltration > discharge (in Dutch: 'vasthouden > bergen > afvoeren') (van Vemden-Versprille, 2014). First of all, it is assessed whether the polder area contains the minimum amount of surface water. At least 5,2% of the total area in a peat polder should be covered with surface water (van Vemden-Versprille, 2013). Additional surface water is often necessary in horticultural areas to compensate for the high drainage pressure on surface water. The current amount of surface water in the higher water level compartment (Gouwepolder) is below the standard for a peat polder (van Vemden-Versprille, 2013).

To achieve a water level reduction of 10 centimeters for a T=50 rainfall event in the Gouwepolder, 17% of the current surface area of the Gouwepolder should be converted into surface water (van Vemden-Versprille, 2014). This implies that the effectiveness of additional surface water decreases with an increasing polder surface. Currently, 30 hectares of horticulture is not sufficiently protected for a T=50 rainfall event. At least 55 hectares of surface water should additionally be created, to improve only 10 hectares of unprotected horticulture. This option requires a 10-million-euro investment at least, which is relatively a high investment for a small water level reduction locally.

The cost-effectiveness of other measures have also been assessed by the Water Board (van Vemden-Versprille, 2014):

- The current pump capacity in the Gouwepolder should be increased by a factor 5 to achieve a 10-centimeter surface water level reduction. This requires an investment of hundreds of thousands euro to improve a single hectare, while less than 20 percent of the horticultural areas with a critical status will effectively be improved.

- By lowering the surface water level with at least 20 centimeters, all critical horticultural areas in the Gouwepolder will be sufficiently protected during a T=50 rainfall event. However, a permanent surface water level decrease is not considered as sustainable given the fact that the oxidation process in peatlands is further stimulated by lowering of the water level. Furthermore, costs will be incurred to adjust watercourses and water engineering structures, such as weirs. To prevent those costs and the negative impact of oxidation, a permanent water level decrease of only 5 centimeters might be more realistic, which improves protection against inundation of nearly 50% of the vulnerable horticultural areas. Other measures will be required to improve remaining critical areas.

- Another option of assessment is to increase the current surface level of areas below the protection standard, especially the ones with a horticultural function. It was estimated that an investment of approximately 700.000 euro is required to protect 24 hectares of highly vulnerable horticulture in the Gouwepolder.

  Besides adaptations in the water system, the Waterboard also considers the issue of inundation at the source. Spatial planning can be used as a measure to restrict further development of horticultural spaces. Furthermore, new horticulture developments should comply to strict regulations. The Water Board also participates actively in restructuring of the area in order to to improve the functioning of the water system, such as the implementation of water retention areas. These opportunities are very limited, primarily because the horticulture has rapidly developed in the last decade. However, a new transition phase wherein the horticultural industry leaves the Greenport and the issue of inundation will be solved by itself is not expected in the near future (ISV Boskoop, 2011).

- The final option basically focuses on the compensation of inundation damage up to a certain level. This primarily concerns the areas where the investment cost outweigh against the benefits of inundation reduction. The expectation is that most of the claims by landowners will be unfounded as they do not comply with the mandatory protection height for parcels in the Greenport. Furthermore, a compensation strategy has little legal foundation in areas like the Greenport. Therefore, the Water Board deploys this strategy not on a large scale.

A high investment is generally necessary to reduce the water level increase locally. Therefore, the Water Board considers a structural measure as the best way to reduce the impact of a water level increase. This mean specificially for the water level borders that the current protection height should be increased.

2.7 Economic optimisation and cost benefit analysis in theory

To minimize costs associated with floods the optimization principle can be applied in a cost-benefit analysis. This method was originally applied by Van Danzig (1956) to determine the optimal level of flood protection for Central Holland. This typical analysis sums the costs of flood protection (C_{tot}) and the costs of expected flood damage (E(D)) to find the point of minimum costs (figure 2.12). Finally, the optimal protection situation can be found at the point where the total costs are minimised (Jonkman et al., 2004):

$$\min(C_{tot}) = \min(I + E\,(D))$$

Investments in flood protection basically continues until the cost of the last investment outweighs the next decrease of expected flood damage (Kind, 2014). The protection height is economically optimal in economic terms when marginal costs equal marginal benefits (Kind, 2014). The protection level will be suboptimal beyond this point, whereby the investment costs in protection will be higher than the actual flood risk reduction.

The total investments in flood protection (I_{tot}) are determined by the initial costs (I_{h0}) and the variable costs (I_h). *X* represents the surface level increase, which is the difference between the new flood protection level *(h)* and the current flood protection (*h_0*) (Jonkman et al., 2004):

$I_{tot} = I_{ho} + I_h * X$ and $X = h - h_0$

To express a more general formulation between investments and the flood protection level (denoted by flooding probability), the investment function is reformulated as (Jonkman et al., 2004):

$$I_{tot} = I_0 + I'(-\ln(P_f))$$

Where:
I_0 = constant (as: $I_0 = I_{h0} + I_h(A - h_0)$)
I' = steepness (as: $I' = I_h * B$)
P_f = exponentially distributed flooding probability (as: $P_f = e^{\frac{h-A}{B}}$)

The expected value of the economic flood damage can be estimated from the probability of flooding *(P_f)* times the damage caused by the flood *(D)* (Jonkman et al, 2004). This concerns the discounting of the expected value with the reduced interest rate *(r')*, which take into account the interest rate (*r)* and the economic growth rate (g) for a defined project period. This can be expressed as (Jonkman et al., 2004):

$E(D) = P_f \times \frac{D}{r'}$ $r' = r - g$

The economically optimally flooding probability *($P_{f,opt}$)* may be calculated by taking the derivative of the total costs and the flooding probability. From this result the optimal flood protection height can be derived (Jonkman et al., 2004):

$$C_{tot} = I_0 + I' \times (-\ln(P_f)) + P_f * D/r'$$

$$\frac{dC_{tot}}{dP_f} = 0 \rightarrow P_{f,opt} = I' \times \frac{r'}{D}$$

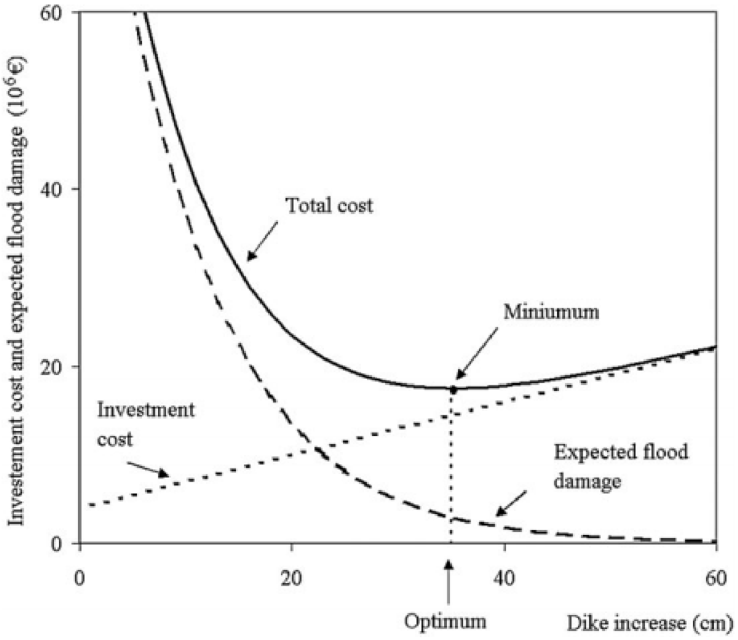


Figure 2.12 – General principle of a cost-benefit analysis (Kind, 2014, p. 106)

Cost-benefit analysis

The economic optimization only considers the costs of flood protection, while a cost benefit analysis can be executed to assess the profitability of a project. Firstly, it should be checked that the costs in the initial situation should exceed the total costs after the project has been completed (Jonkman et al., 2004). This cost benefit criterion should be applied after finding the economic optimum of the project. This can be written as:

$$I_0 + I' \left(-\left(\ln\left(P_f\right)\right) \right. < (P_{f,0} - P_f) \times \frac{D}{r'}$$

Where:
$P_{f,0}$ – flooding probability in the initial situation

The cost effectiveness of a flood protection measures will eventually depend on the ratio between investments and the reduction of risk. Finally, the most cost effective measure is the measure for which the highest protection level is found at lowest costs (Jonkman et al., 2004). However, if other non-economic considerations are taken into account, it may end up in a less-favourable option.

Chapter 3 methods and materials

Four different analyses steps have been performed in this study:

1. The current state analysis
2. The inundation risk analysis
3. The inundation protection analysis
4. The cost-benefit analysis

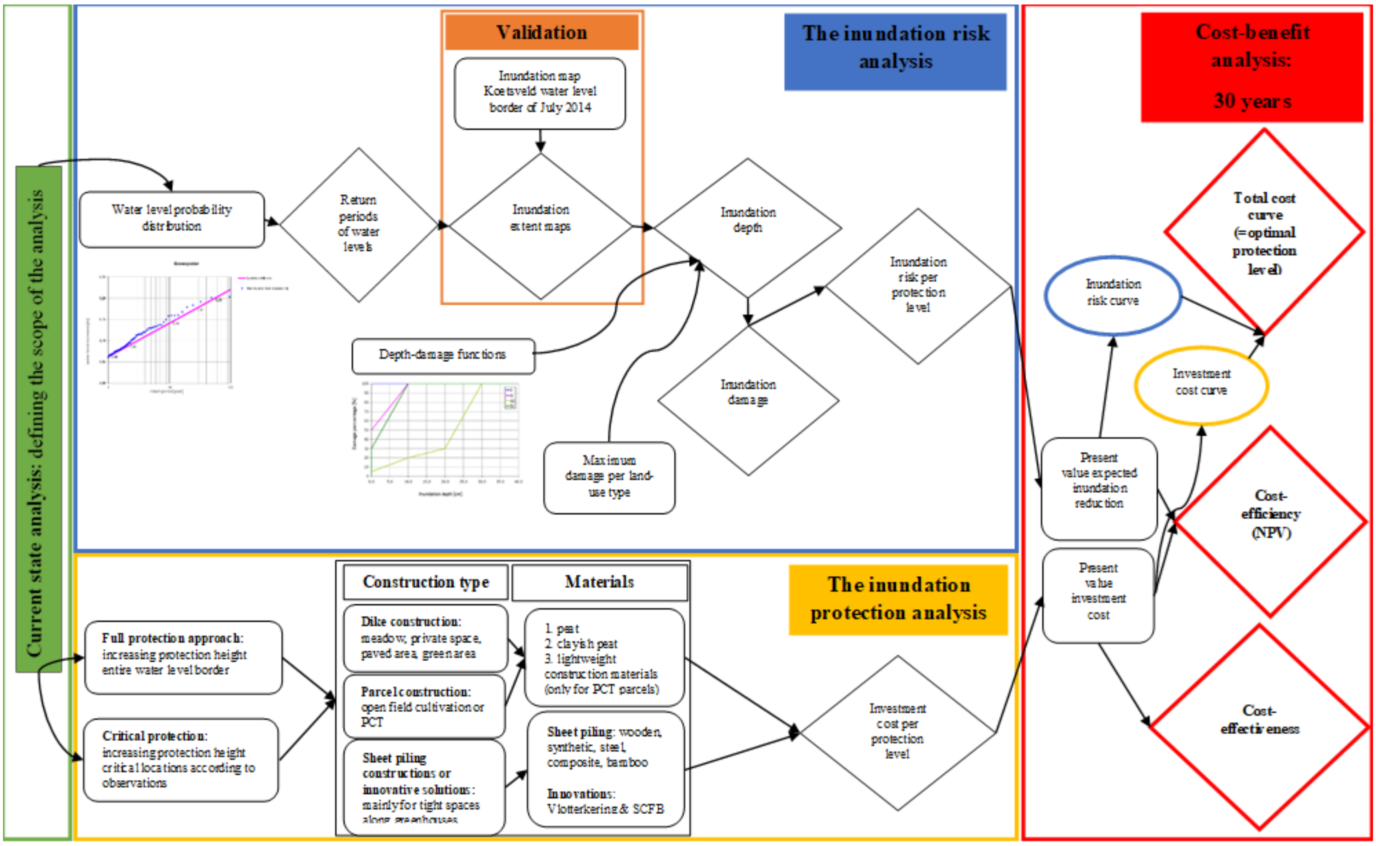


Figure 3.1 – flowchart of analysis steps: (1) current state analysis (green); (2) the inundation risk analysis (blue); (3) the inundation protection analysis (yellow); (4) the cost-benefit analysis

These analyses have closely interacted with each other, as the result of each step is necessary to perform the cost-benefit analysis (figure 3.1). The first analysis was performed to make an inventory of the input for the inundation risk analysis. The second analysis was aimed at estimating the total expected damage costs for a number of land-use classes. The third analysis has focused on the flood protection. In this step it was analysed what volume must be added to the water level border in accordance with the protection level and protection strategy (par 4.1.2). Finally, the results of the inundation risk and flood protection were used as input for the cost-benefit analysis.

3.1 The current state analysis

In order to reduce the number of analyses for this study area, a scope for the remaining analyses has been defined first. The main goal of this analysis is to identify the status of the water level border and what is important to consider in the following analyses, for example the current positioning of the water level border and the land-use functions on top of the border. Furthermore, two strategies have been formulated in order to improve the protection level of the water level border.

3.2 The inundation risk analysis

The inundation risk (or the expected flood damage) was examined in relation to different protection heights for the water level border, corresponding to different water level return periods in the higher surface water compartment. In this way, the reduction of inundation risk can be examined in relation to a higher protection level. To estimate the inundation risk for a specified protection height, three different elements were examined. Firstly, inundation maps were simulated to determine the inundation extent in relation to different protection heights. Secondly, the inundation damage was calculated for the inundated area. Finally, the inundation risk was calculated by summing all inundation damage intervals above the return period of the protection level. A more detailed description of these elements is given below.

Simulation of inundation maps

A python script developed by Huber (2013) was used to simulate inundation maps for different return periods in ArcMap (Annex 3). This script determines the inundation extent based on the water level height and the DEM. The effect of increased protection upon the inundation extent was simulated by changing the DEM file. To simulate this DEM map, a script was developed in the ModelBuilder (Annex 4). A grid cell map produces 0's and 1's, indicating respectively unaffected and affected areas. This map is used as an overlay to determine the inundation damage in the next step. A potential problem with this approach is that no flood maintains a constant elevation. When the water flows into the water level area, the elevation descends as the surface water level descends. The flood extent can be limited by the "nExtent" expression in the script. Several test simulations have been performed to define this value. Eventually, it has been decided to define nExtent at 10.

Estimation of inundation damage costs

The damage costs for the water level area have been estimated with a spatial model developed in the Modelbuilder of ArcMap (Annex 5). The Modelbuilder automatically calculates the total damage for preselected land-use classes (open field cultivation, meadow, pot-and container cultivation and greenhouse) by application of different tools in the ArcToolbox. The Gumbel distribution obtained from van Vemden-Versprille (2013) was used to define the protection levels. A step by step description have been included in Annex 6, which explains how to calculate inundation damage per protection level. Different data layers and parameters were applied in the inundation damage simulation This generally includes the following elements:

-A *LGN4 vector dataset* obtained from Water Board Rijnland, which contains vector layers for a specified number of land-use classes. This dataset has been modified and improved manually in the *Editor* environment with satellite images and field observations.

-A *AHN3 raster dataset* obtained from Water Board Rijnland, which contains laser altimetry ground level measurements for the Gouwepolder with a grid cell resolution of 0,5x0,5m. Because the dataset did not contain representative raster values for greenhouses, the average height along the edges was calculated. This average value per greenhouse was calculated and assumed as a representative value for the height. The other cells with a NoData value have been filled up with the DEM update (Annex 4)

- A *polyline feature* that contains the current position of the water level border of Koetsveld. An alternative polyline feature has been constructed based on this information, which is close to the nearest watercourse in the higher water level area. This has been done, because the first signs of water nuisance from the higher water level may theoretically be observed along this line.

- *Depth-damage* functions in *Wordpad* to convert the inundation depth per cell to a damage factor per cell (figure 3.2). These damage functions have been used in a previous flood damage study for the Greenport Boskoop conducted by Huizinga and Groot (2012).

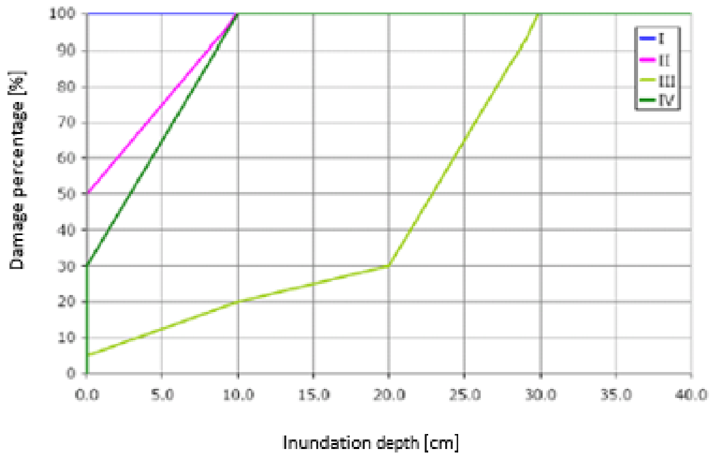


Figure 3.2 – Depth-damage functions which converts the inundation depth (x-as) to a fraction of the maximum damage unit price. Groundwater damage is excluded from these functions. The functions apply to the following land-use class: I) open cultivation; II) pot-and container cultivation; III) Greenhouses; IV) Pot-and container cultivation (modified from Huizinga and Groot, 2012)

- The available damage functions have been designed for a limited number of land-use types (open field cultivation, pot-and container cultivation, meadow and greenhouse). Groundwater damage was excluded in these functions, because drainage systems may prevent a large part of this damage. The open field cultivation has the highest sensitivity for surface water inundation with maximum damage at all surface water levels.

- The maximum damage cost per land-use class were determined by and extracted from STOWA (2013) (table 3.1). The cost factors were required to convert a damage factor to a damage cost per cell per land-use type. Because the damage functions were developed specifically for the land-use types in table 3.1, the damage costs have not been considered and calculated for other land use functions in Koetsveld. In particularly, individual houses, private gardens, green zones, paved areas, small green areas and local roads.

Table 3.1 – Damage functions, applicability and maximum damage cost

Type of damage function (Huizinga and Groot, 2012)	***Applicable for land-use type***	***Maximum damage cost (euro/ha) (STOWA, 2013)***
II	Meadow	1108
III	Greenhouse	818.833
I	Open ground cultivation	59.855
IV	Pot- and container cultivation	59.855

-The depth-damage functions used by Huizinga and Groot (2012) have been improved by including a damage factor per centimetre instead of a damage factor per five centimetres (figure 3.3). This has been done particularly to prevent overestimation of the damage costs in relation to damage functions II, III and IV.

```
Schadefunctiell - Kladblok
Bestand   Bewerken   Opmaak   Beeld   Help

from     to       output
-10000.0          -0.9     0
-0.1     0.1      500
0.9      1.1      505
1.9      2.1      510
2.9      3.1      515
3.9      4.1      520
4.9      5.1      525
5.9      6.1      530
6.9      7.1      535
7.9      8.1      540
8.9      9.1      545
9.9      10.1     550
10.9     11.1     555
11.9     12.1     560
```

Figure 3.3 – Example of conversion table depth-damage function II. The 'from' and 'to' above the columns reflect the inundation depth. The 'output' above column contains the associated damage factor

Annual flood damage per land-use class

The annual inundation risk per land-use class was calculated by summing the outcomes of different return period intervals. The number of return intervals that are summed depend on the pertinent protection level. In this thesis protection levels mainly coincide with the protection standards used in the NBW assessment (table 3.2). The highest possible water level increase was defined at 30 centimeters (T500). The formula from Huizinga and Groot (2012) has been used to calculate the inundation risk per interval:

$$JVW = \frac{1}{OF1} * S1 + \left(\frac{1}{OF2} - \frac{1}{OF1}\right) * \frac{S1 + S2}{2}$$

Where:
OF1 = the exceedance frequency of the largest recurrence interval
OF2 = the exceedance frequency of the second largest recurrence interval
S1 = damage caused by exceedance frequency 1
S2 = damage caused by exceedance frequency 2

The annual expected damage for a given protection level is calculated by summing the damage of all intervals for return periods above the return period of the protection level. The intervals that are summed for each protection levels are included in table 3.2.

Table 3.2 – defined protection height in combination with the pertinent inundation damage intervals per protection level

Minimum protection height (m NAP)	Intervals to calculate inundation damage
-2,03 (T1,5)	T2-T10, T10-50, T50-T100, T100-T500
-1,99 (T5)	T6-T10, T10-T50, T50-T100, T100-T500
-1,97 (T10 NBW standard)	T11-T50, T50-T100, T100-T500
-1,91 (T50 NBW standard)	T51-T100, T100-T500
-1,88 (T100 NBW standard)	T101-T500
-1,82 (T500)	T501

3.3 the inundation protection analysis

3.3.1 constructions types including materials

Several construction types have been examined to increase the protection height of the water level border. In this thesis the following construction types were considered: (1) the dike construction; (2) lifting of a parcel; (3) sheet piling constructions; and (4) innovative flood barriers.

The dike construction is known as a measure against inundation with generally a high cost-efficiency and is therefore frequently applied in the Dutch water engineering sector. The cost-efficiency decreases however if land for construction must be purchased, primarily because a shared function is not feasible. This particularly applies for parcels with horticultural productions, that can only produce on flat surfaces. To prevent the purchase of land and maintain the production function, the surface height of the production parcel could entirely be raised to the same level. Another option is the implementation of sheet piling constructions. These constructions are known for their high initial investment cost, but can be more cost-efficient when the implementation of a dike construction is too costly, especially when the initial removal costs for objects are relatively high. For example, removal or displacement of greenhouse complexes constructed on the water level border is highly expensive. Innovative flood barriers may be useful if there are serious objections against a permanent higher surface height. These constructions appear only temporarily in case of high water levels. Parcels owners involved in the water level border have primarily objections against a higher water level border as the depth between surface level and drainage system increases. A quick comparison of the initial investments cost shows that the innovative flood barrier can definitely not compete against earthen structures. Therefore, the costs of innovative flood barriers has only been weighted against the costs of the sheet piling constructions.

Different construction materials type can be used to implement the construction types considered in this thesis. A more extensive description of these materials is given below:

1. Dike construction

The dike construction might have similar design dimensions like the one previously constructed in the Geerpolder (figure 3.4). The Gouwepolder experiences high settlement rates, up to 1 cm per year (van Vemden-Versprille, 2013). Therefore, the construction materials for water engineering constructions in peat polders should be coordinated to the local soil conditions. The main aim is to increase the durability of the construction and decrease the construction costs.

Peat or clayish peat is primarily used for dikes on a subsurface of peat. These construction materials should have similar density characteristics as the peat in the subsurface to stabilize or reduce the settlement rate after the construction. Any collapsing mechanisms will be less relevant for the dike construction, primarily because of the small water level differences in the polder and the limited height of the construction.

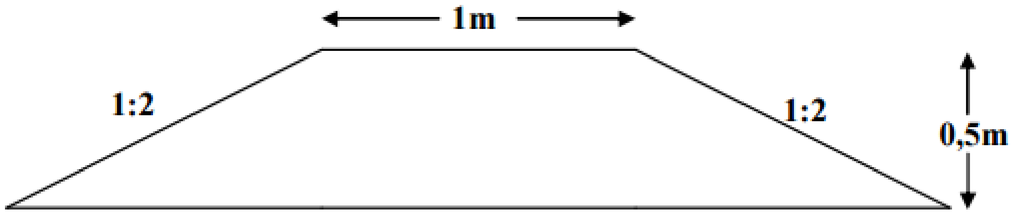


Figure 3.4 – schematic view of the water level border Geerpolder (HHR, 2012, p.13)

2. Increasing protection height of entire parcel

The land-use type mainly determines what materials can be applied for upgrading of the protection height. For example, open field cultivation requires a high soil quality at the top, while pot-and container parcels demand for a high water permeability below the cultivation floor. Therefore, these floors are primarily provided with a lava stone layer on top of the drainage system. Lava stone has excellent drainage properties and reduces soil subsidence. When the protection height increases, cultivation floors must be re-installed to maintain the optimal drainage properties. This gives the possibility to implement also other lightweight materials in order to increase the protection height and minimize subsidence of the construction. In this thesis the following other lightweight materials were examined for parcels with pot-and container cultivation: expanded polystyrene (EPS), foam concrete and flugsand (Annex 8). These materials are frequently applied in road or water engineering constructions in areas subjected to high subsidence rates. These materials have been selected based on the volume-weight and potential for applicability in the current situation.

3. Sheet piling constructions

For land-use functions that cannot easily be removed from the water level border, in particularly greenhouses or other buildings, a traditional sheet piling construction is more suitable as measure (Annex 9). In the water engineering sector, a distinction is made between light piling walls and heavy sheet piling walls. Light sheet piling walls are used and applicable for embankment protection not higher than 0,8 meter, whereas heavy sheet piling is necessary to retain embankments higher than 0,8 meter (HHR, 2015b). Light sheet piling walls are mainly constructed with wooden piles and boards, which have a shorter lifespan (< 20 years) but are less expensive. Construction materials with a longer durability (20 ≥ and ≤ 50 years, such as plastic or composite, are more expensive. A durability up to 100 years is obtained with a heavy sheet piling wall manufactured from steel, which can be stabilized on deeper sand layers. The investment cost per m^2 are however much higher than a light sheet piling construction.

4. Innovative flood barriers

The cost-effectiveness of two innovative solutions, the Vlotterkering and Self Closing Flood Barrier (figure 3.5 & 3.6), have been examined as alternatives for sheet piling walls. The functionality of these solutions has been explained in more detail in Annex 10. These constructions have been used for assessment to compare the current costs of innovative solutions with traditional sheet piling wall constructions. Besides that, the innovations might be appropriate for locations with a lack of space, especially for greenhouses close to surface water, and to retain the current image of the area.

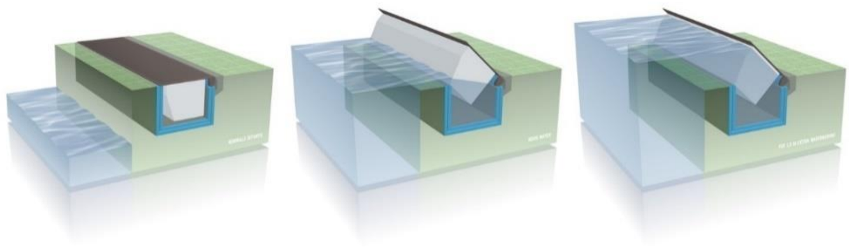


Figure 3.5 – Vlotterkering (Dura Vermeer, 2016)

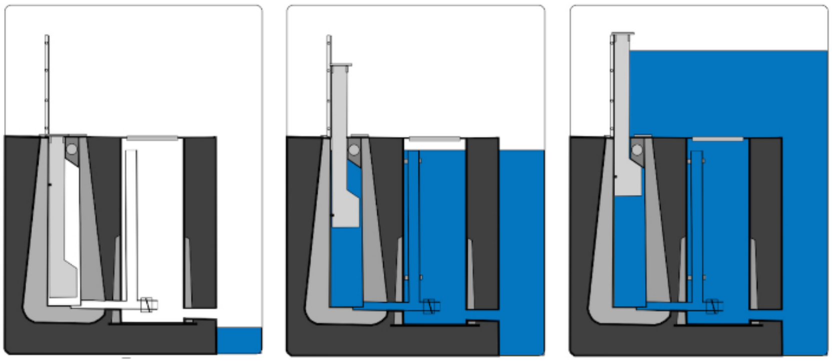


Figure 3.6 – Self Closing Flood barrier (Hyflo, n.d.)

3.3.2 Approaches for reconstruction of a water level border

The Water Board has not formulated any protection approaches yet to modify a water level border, specificially in an area with a high pressure on space. Therefore, two potential strategies have been developed, in which the area characteristics were considered. First, *the full protection approach* will be explained followed by *the critical protection approach*. The main difference between these approaches is that the latter only increases the protection height of parts in the water level border that were selected as critical based on inundation observations previously. The former approach does not consider these observations and focuses on an increase of the protection height along the entire length of the water level border.

The full protection approach

The most straightforward way to increase the protection level, is to upgrade the water level border along the entire length. In this way the water level border will uniformly be protected. To increase the protection height and technically implement this approach , parcels having a cultivation function should entirely be raised to preserve the land-use function that coincide with the water level border. This is especially relevant for the parcels with horticultural production, which cannot effectively produce in combination with large surface level variations. The construction requirements are less strict for meadows or paved areas. For these land-use types, a small dike construction will be more appropriate. For buildings that have already been founded close to surface water, such as greenhouses or residential buildings, this construction will be less appropriate. A sheet piling construction is more feasible at these locations. This prior knowledge was used to produce a map in ArcMap that roughly shows which parcels should be raised in the full protection approach (figure 3.7, left).

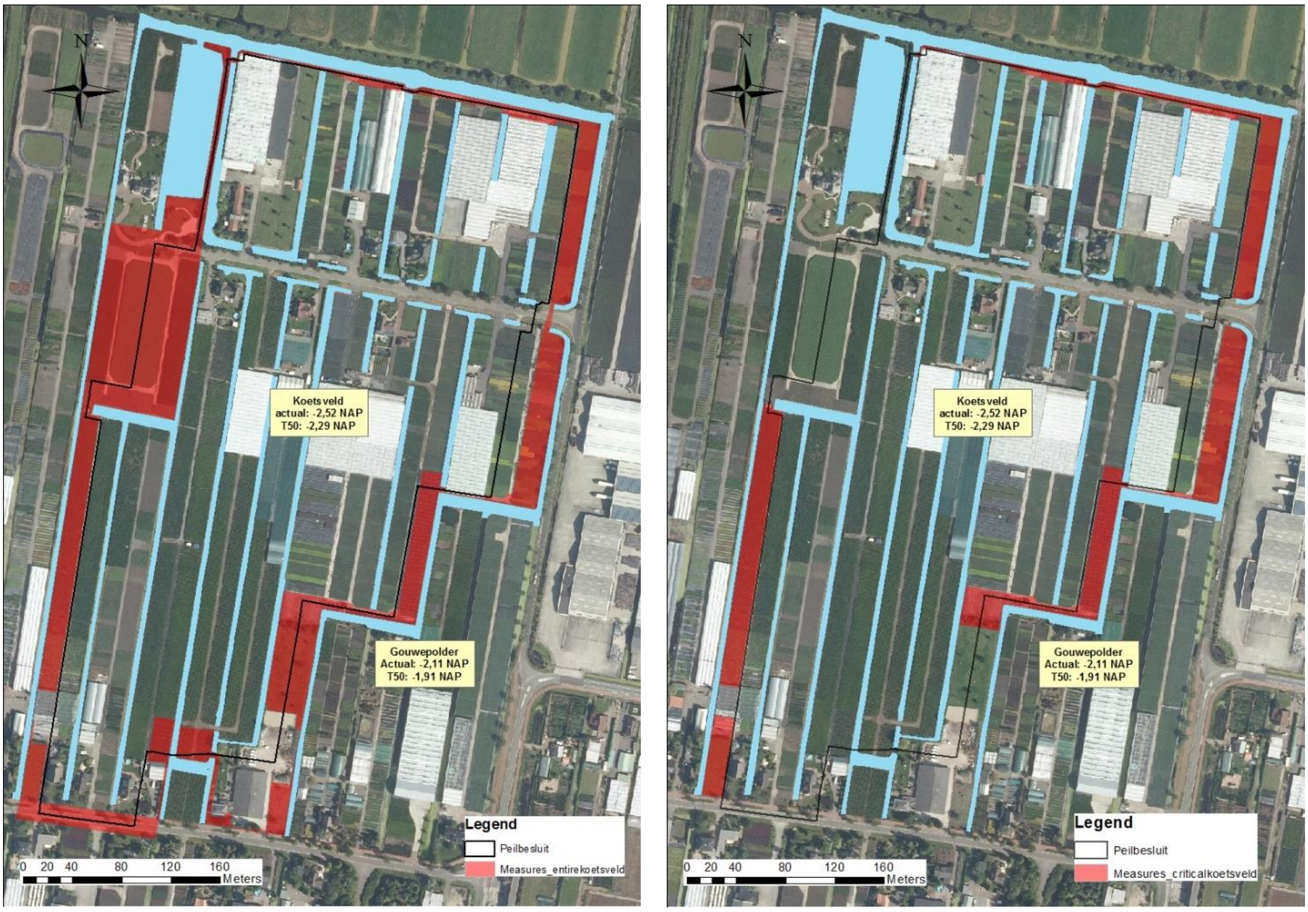


Figure 3.7 – positioning upgrade water level for entire flood protection approach (left) and critical flood protection approach (right)

The application of these construction types was chosen on the basis of the presence of land-use functions and the possibility to implement a specific solution. Therefore, the national land-use map (GBKN) and the aerial pictures of the Gouwepolder were consulted first to identify the land-use functions. Subsequently, the construction type was chosen according to the land-use map. To allocate sheet piling constructions or innovative flood barriers, greenhouse complexes were identified that coincide with the water level border and are within a distance of 3 metres to the watercourse of the higher compartment.

Figure 3.8 shows the positioning of the different construction types in case of the *full protection approach*. The same figure applies for the critical protection approach, but than for the indicated areas in figure 4.3. The dike construction was only applied for the following land-use types: meadow, private areas, paved paths and green areas. For the open field cultivation and pot-and container cultivation, the parcels will completely be raised to prevent land purchase and maintain the current function. Finally, a sheet piling construction or innovative flood barrier is specificially applied to greenhouses within a distance of 3 metres to the watercourse of the higher compartment.

Figure 3.8 - positioning of dike construction, parcel construction and sheet piling constructions or innovations in the water level border of Koetsveld

The critical protection approach

In order to prevent unnecessary investments in protection, the critical parts of the water level border should only be identified and upgraded. This is however more challenging, primarily because the critical locations should be determined first with modelling or observations from the field. The main advantage of this approach is that the investment cost will be reduced when a limited number of locations is upgraded. However, locations that have now been identified as uncritical, may still turn into critical in the future due to effect of subsidence. To implement this in the current available space, the same principles for construction will be used as previously mentioned. Based on the flood hazard analysis in par 4.3, a map was composed that shows the extent of the critical locations that should be raised (figure 3.7, right).

The flood protection analysis was performed for the two protection approaches in relation to different construction types, construction materials and protection levels. ArcMap was to identify and extract different numbers from the DEM and land-use map.

3.4 The cost-benefit analysis

Efficiency is measured by means of a cost-benefit analysis with the net present value (NPV) as the major output criterion (Meyer, Priest and Kuhlicke, 2012). This was determined for two protection strategies by subtracting the total discounted cost from the total discounted benefits for a 30-year analysis period. The NPV is calculated by the following formula (Meyer et al., 2012):

$$NPV = \sum_{t=0}^{n} B_t \, (1+i)^{-t} - \sum_{t=0}^{n} C_t \, (1+i)^{-t}$$

where B = project benefits
C = project costs
t = the year in which the benefits and costs occur
i = discount rate

With this formula future expenses and benefits are converted into a present value. For water engineering projects an annual discount rate of 3% is commonly applied. The input for the benefits and costs is provided by the inundation risk analysis and the flood protection analysis. The optimal protection level is determined graphically, by finding the minimum of the total cost curve. This curve has been plotted by summing the risk curve and investment curve for different protection levels.

The development of benefits and costs for water engineering constructions in time is highly affected by the subsidence process. This process has considerably impact upon the durability of water engineering constructions in the Greenport. A specific lifetime can be guaranteed by adding an additional height to the construction in order to compensate for large initial settlements and small secondary settlements afterwards. In this way, the durability of a construction and the time of maintenance can be extended. The effect of subsidence is included in the cost-benefit analysis by updating the construction height for each year in relation to the subsidence rate. The expected inundation damage per year is based on the updated construction height as well. This thesis assumes a subsidence rate of 10 mm per year for a peat construction with the lowest protection height (-1,99 m NAP). This rate increases with 1 mm/year in combination with a higher protection level. Subsidence rate for clayish peat is assumed to be a factor 0,23 higher than peat, after comparison of the density. Furthermore, subsidence is neglected for lightweight materials.

In this thesis, the total investment cost for a combination of construction type and material contain four different cost elements: 1) initial investment; 2) running costs per year; 3) maintenance cost per year; 4) emergency pumping costs per year.

For peat and clayish peat, the initial investment cost concerns the material costs to update to a specific protection height and an additional material costs for the surplus height. Surplus heights were assumed based on nearby parcel raising projects (table 3.2). The height of the investment cost for a surplus height is primarily depending on the construction type and the protection approach. By contrast, costs for surplus height were excluded for lightweight materials, sheet piling constructions and innovative flood barriers, mainly because the subsidence effects can be minimized for these constructions. The unit prices for all construction materials have been included in Annex 7. A lower and upper price limit is used in the analysis, because the exact unit price cannot precisely be defined.

Running costs per year implies the cost for small repairs and management of the water level border. Individual unit prices for running costs have not been defined for water level borders yet. Therefore, the running costs were assumed as a fraction of the maintenance costs (table 3.3). This cost was neglected for sheet piling constructions and innovations, since these constructions will be maintenance-free for a longer period.

Table 3.3 – assumptions for surplus height and operation cost per protection level

Protection level (m NAP)	Surplus height (m)	Running costs (as % of total maintenance cost)
-1,99	0,15	5
-1,97	0,17	10
-1,91	0,21	15
-1,88	0,3	20
-1,82	0,35	30

In this thesis, maintenance cost can differently be interpreted. For the traditional construction materials peat and clayish peat, this term refers to the recovery of the construction to its original height. By contrast, sheet piling constructions and innovative flood barriers will entirely be replaced after the lifetime of the construction expires. Therefore, this cost is not taken into account every year. For example, the timing and extent of maintenance for earthen structures mainly depends on the subsidence rate. A lifespan of at least 10 years was assumed for the earthen construction materials (peat and clayish peat). The re-investment for sheet piling constructions and innovative flood barriers mainly depend on the lifetime of the material (table 3.4). Finally, running costs are excluded in years of maintenance for all construction materials.

Table 3.4 – lifetime for the construction materials in question

Construction materials	Life span (years)
Traditional construction materials	
Peat	10
Clayish peat	8
Lightweight materials	
Lava stone	30
Foam concrete	30
Flugsand	30
Sheet piling construction	
Wooden	15
Synthetic	30
Steel	100
Composite	50
Bamboo	15
Innovative construction	
Vlotterkering	50
Self Closing Flood Barrier	50

The last element in the total investment cost is the emergency pumping cost per year. In this thesis, it is assumed that the application of emergency pumping will remain necessary in the future, but the duration of emergency pumping will decrease in relation to a higher protection level (table 3.5). According to the analysis of Baalbergen (2016), the application emergency pumping costs in the Gouwepolder amounts to € 1350 per day. Furthermore, the number of days for application of emergency pumping for a T50 rainfall event corresponds to three days. Subsequently, the number of days for other return periods were estimated. Emergency pumping costs were calculated as “running costs” for the current protection height.

Table 3.5 – The number of days assumed with emergency pumping in relation to the recurrence interval

Return period	Emergency pumping time (days)	Cost (EUR)
T2	0	0
T5	0	0
T6	0	0
T10	0,2	270
T11	0,2	270
T50	3	4050
T51	3	4050
T100	5	6750
T101	5	6750
T500	7	9450
T501	7	9450

Chapter 4 Results

This chapter provides the results obtained from the analyses steps that have been described in the previous chapter. First, the scope of the analysis will further be introduced in section 4.1. Then, in section 4.2 the results of the inundation model validation will be presented. Section 4.3 will present the results of the risk analysis, which identifies how the risk curve develops in relation to increasing protection and how this differs between the approaches for protection. Section 4.4 will focus on the flood measure analysis, that presents what is required per approach to increase the protection level. In section 4.5 the results of section 4.3 and 4.4 will confluence in a cost-benefit analysis, which will select the most cost-effective protection measures and determines the optimal protection level for both approaches.

4.1 Current state analysis

4.1.1 Scope of the analysis

The next analysis steps have been restricted to the water level area Koetsveld which is situated in the north of the Gouwepolder (figure 4.1).

Figure 4.1 – (left) aerial view of Koetsveld, the red line indicates the hydrological water level border and the actual water level border is indicated by the orange line; (right) land-use map of Koetsveld

This has primarily been done, because the Gumbel distribution of water levels, determined for the Gouwepolder surface water system and used in the inundation damage estimation, is less representative for the surface water system in the south. Spatial differences of water nuisance in lower water level areas were recorded after extreme rainfall in July 2014. The water system analysis has revealed a water level increase of twenty centimeters on average in the north of the Gouwepolder surface water system, while an increase of a few centimeters was measured in the south for the same event. Therefore, this analysis revealed that the response of the surface water system to extreme precipitation and the vulnerability for water nuisance differs spatially. When applying this Gumbel distribution in the risk estimation for water level areas in the south, results would probably have been overestimated.

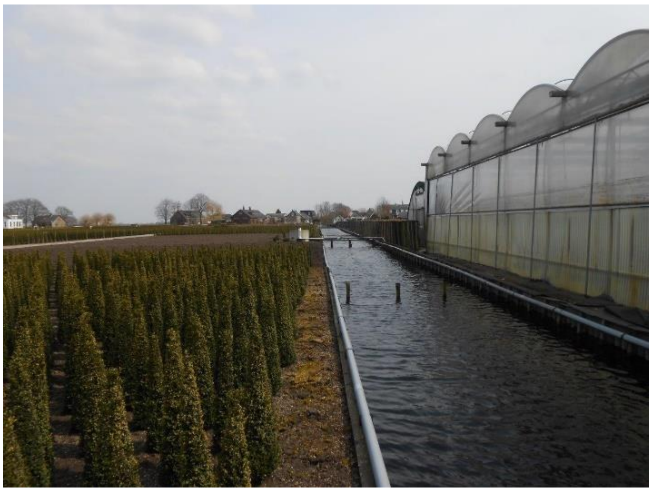


Figure 4.2 – open field cultivation and greenhouses close to surface water

Koetsveld is one of the smallest water level areas in the Gouwepolder, covering up to 16 hectares within the hydrological border and up to 18,5 hectares within the actual water level border. The horticulture and arboriculture are the most prevalent land-use types in Koetsveld, almost covering a similar surface (figure 4.1). Furthermore, the area hosts a few large greenhouse complexes and residential houses, some of them are closely built to the Gouwepolder drainage network. The dashed line in red in figure 4.1 has been established as the 'hydrological' border between the drainage network of the Gouwepolder and Koetsveld. In practice, the reconstruction of the border should be close to the drainage network of the Gouwepolder (figure 4.1, orange line). This position has not been established in Water Board policies officially (HHR, 2010). Therefore, a water level border in the Greenport Boskoop may not be visible as a major water engineering structure. Formerly, these borders provided sufficient protection and the Water Board had no substantiated arguments for strict regulations from a NBW point of view. Furthermore, the impact of inundation has been relatively low, resulting in low inundation damage. Consequently, requirements for construction or maintenance of these structures have not been formulated by the Water Board.

Due to the increased conversion of remaining meadows into horticulture, the water retention has been decreased significantly in the Greenport. Consequently, the runoff towards surface water has increased, while the discharge capacity of the channels of the surface water system remain unchanged. This imbalance has resulted into an increasing rate of water level increase for the entire Greenport area during extreme precipitation. Currently, the condition of the water level border is mainly determined by different land-use types on the water level border. These functions range from production parcels for plants and trees to individual houses and gardens (figure 4.2). Two different approaches have been developed to increase the protection level of a water level border and preserve current land-use functions as well.

4.2 Validation of the inundation extent model

One way to check the performance of the model, is to compare the inundation locations identified previously with the locations obtained by the inundation model. The extreme precipitation event during the summer of 2014 was selected to validate the results. From 27 July 2014 6.00 p.m. to 28 July 2014 6.00 p.m., the Greenport Boskoop experienced extreme rainfall, that resulted in more than 100 mm of rainfall in the Gouwepolder in 24 hours (figure 4.3). According to the KNMI precipitation statistics, this rainfall event was equal to a return period of 1:100 years. Parcel owners at the water level border were asked after the event whether they experienced water nuisance, especially from the higher water level compartiment. Direct recordings of the inundation depth and extent were not collected, but the survey revealed spatial differences in inundation extent.

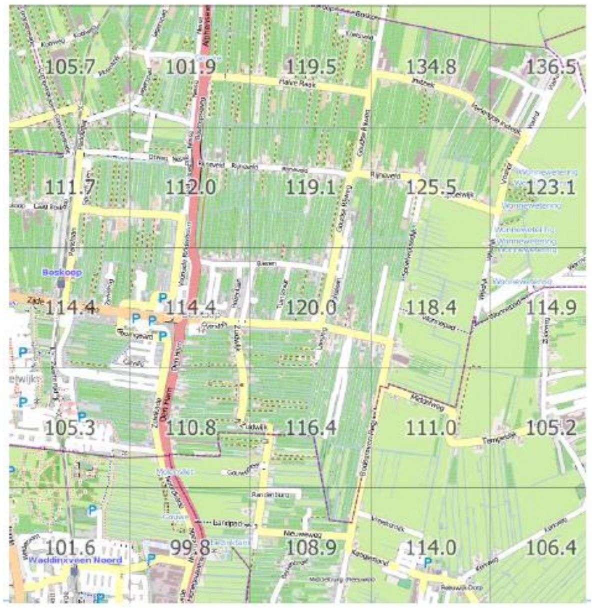


Figure 4.3 - interpolated radar statistics for 27-28 July 2014 for Gouwepolder. The unit is in millimetres (from: HHR, 2014)

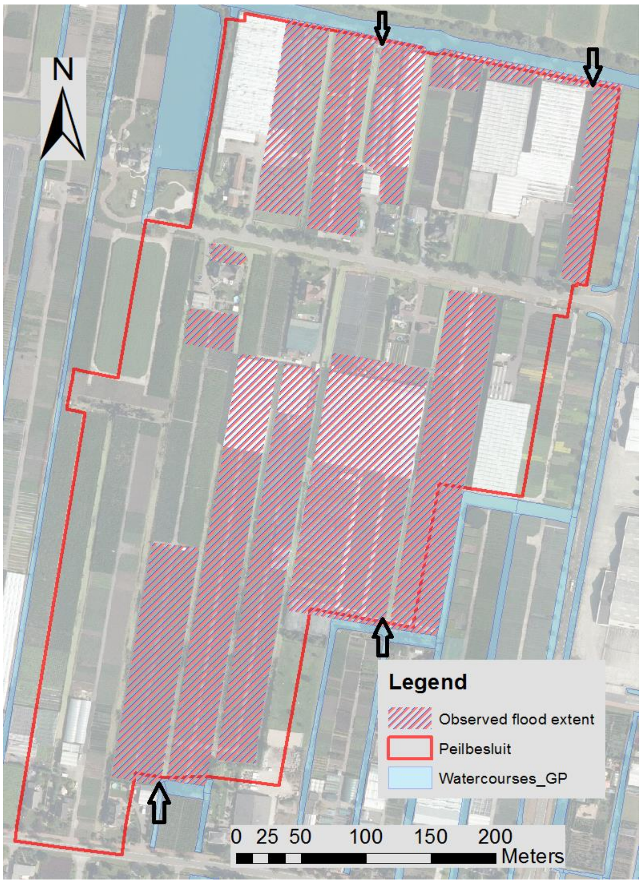


Figure 4.4 – flood extent observed by the parcel owners after the extreme rainfall event in July 2014. The black arrows show the locations where water has flowed into the water level area.

Inundation was simulated for a water level increase in the Gouwepolder surface water system that corresponds to a return period of 1:100 years. This simulation was performed for a T100 water level increase relative to two different normal water levels: (1) the actual water level (-2,11 m NAP) and (2) the target water level (-2,25 m NAP) (for additional explanation see chapter 'used terms') . This was done on the one hand, to simulate realistic inundation maps and on the other hand to provide reasonable estimates of flood damage. The modelled inundation maps were compared with the map compiled with local observations after the rainfall event in July 2014 (figure 4.4).

According to figure 4.5, the inundation extent considerably differs when applying a different reference water level. The inundation extent modelled for a T100 water level of -1,88 m NAP (figure 4.5, left) matches quite well with the observed inundation extent, while the maximum water level recorded during the rainfall event reaches a maximum of -2,02 m NAP. Nevertheless, backwater effects, which further enhance a water level increase, may cause higher water levels in the surface water system that is located at a larger distance from the pumping station. This effect is probably caused by the high pumping pressure from the Koetsveld surface water system towards the Gouwepolder surface water system and water discharge in a single direction only. Furthermore, the model has simulated several flooding locations that matches quite well with the observations. For example, the critical locations in the north and southeast can be identified, while the locations without flooding can be verified with the observations as well (Annex 11). These critical locations have been identified as well by using the target water level as reference, but the flood extent is clearly underestimated. The large inundation in the west could not be verified with observations, but inundation may probably occur relative easy due to the presence of open field cultivation that commonly have low average surface levels. ich commonly reduce the surface level.

Another aspect that could be validated, is the flood damage that is inferred from the inundation depth. Unfortunately, this validation cannot be performed, primarily because inundation damage dataset are not specificially attributed to malfunctioning of the water level border. Therefore, the modelling results from the damage estimations from Huizinga and Groot (2012) were used as a reference instead.

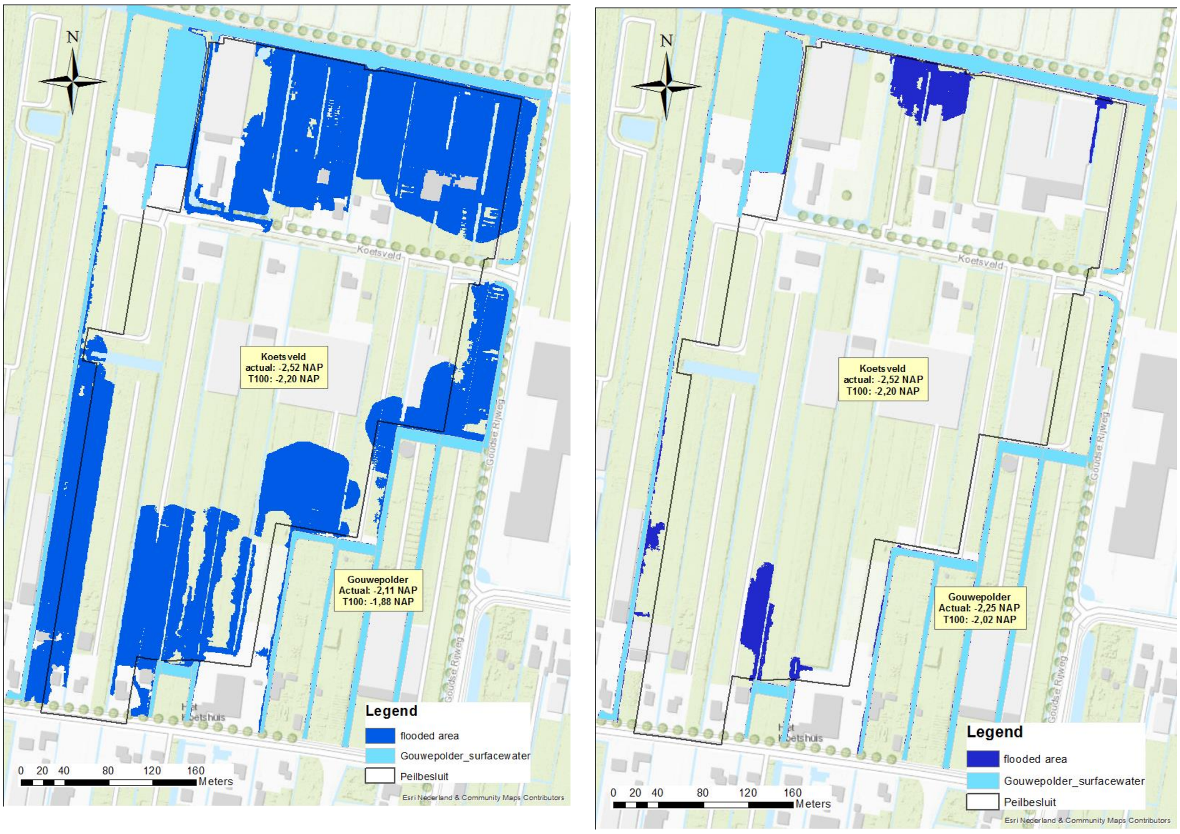


Figure 4.5 – inundation extent in Koetsveld for a T100 water level. (Left) water level of -2,02 NAP, relative to the target water level of -2,25 NAP; (right) water level of -1,88 NAP, relative to the actual water level of -2,11 NAP

4.3 the inundation risk analysis

The inundation risk was calculated for different protection levels by merging three different information elements: hazard, exposure and susceptibility. The effect of a higher protection level on the development of inundation risk was determined by summing the return intervals above return period of the protection level.

Flood hazard: inundation maps

For several protection levels inundation maps have been simulated to obtain flood damages per return period (table 4.1). The NBW protection norms were used as a reference to determine the distribution of protection levels. This procedure was applied to the reconstruction approaches, as discussed in paragraph 3.3.2.

Table 4.1 – simulated inundation maps in relation to the protection level

Minimum protection level (m NAP)	Inundation maps simulated
-2,03 (T1,5)	T2, T5, T10, T50, T100, T500
-1,99 (T5)	T6, T10, T50, T100, T500
-1,97 (T10 NBW standard)	T11, T50, T100, T500
-1,91 (T50 NBW standard)	T51, T100, T500
-1,88 (T100 NBW standard)	T101, T500
-1,82 (T500)	T501

There are several locations in the water level border, particularly in the north and southwest, that may experience inundation according to the simulations. The inundation extent up to return period T10 is minimally, while the inundation extent significantly increases for the T50 return period (figure 4.6). The extent of inundation per return period significantly changes by increasing the protection level of the water level border (figure 4.7). The differences between the protection scenarios are however relatively small.

The intensity of the flood hazard for Koetsveld is expressed by the inundation depth. The area that could be inundated by exceeding of the water level border was determined for several return periods (figure 4.10). Due to the small water level differences and the surface water volume, it would be unrealistic that the entire water level area could be flooded. This could have resulted in a substantial overestimation of the total flooding risk.

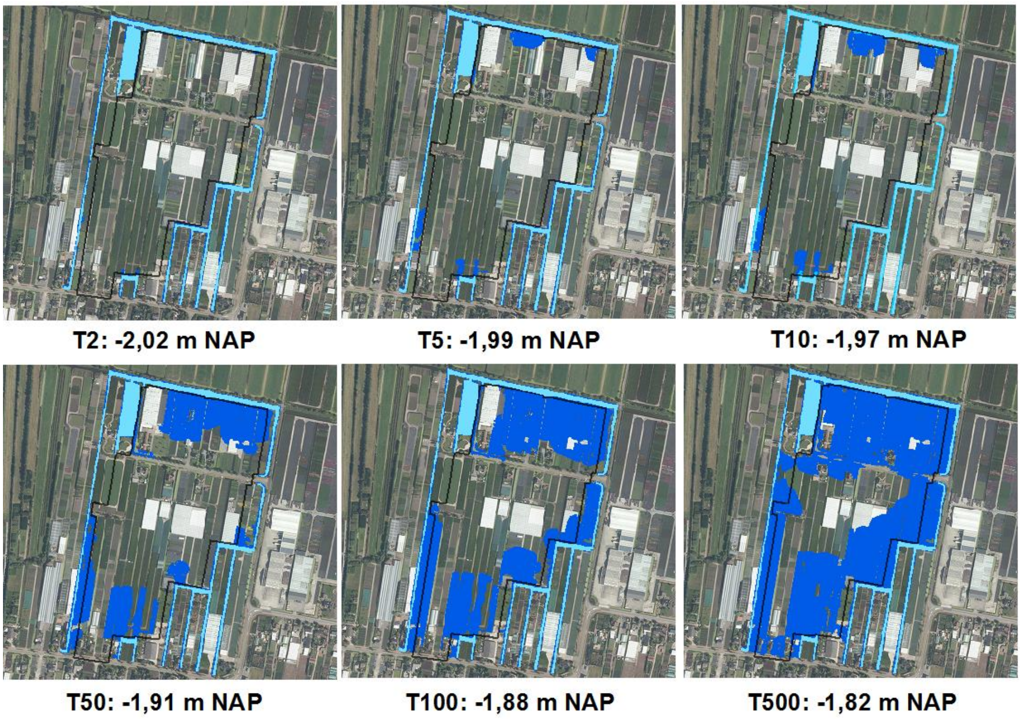


Figure 4.6 – inundation extent according to the model calculations in ArcMAP for different water level return periods in combination with the current DEM. Significant inundation is not expected below a T2 return period (= -2,03 m NAP).

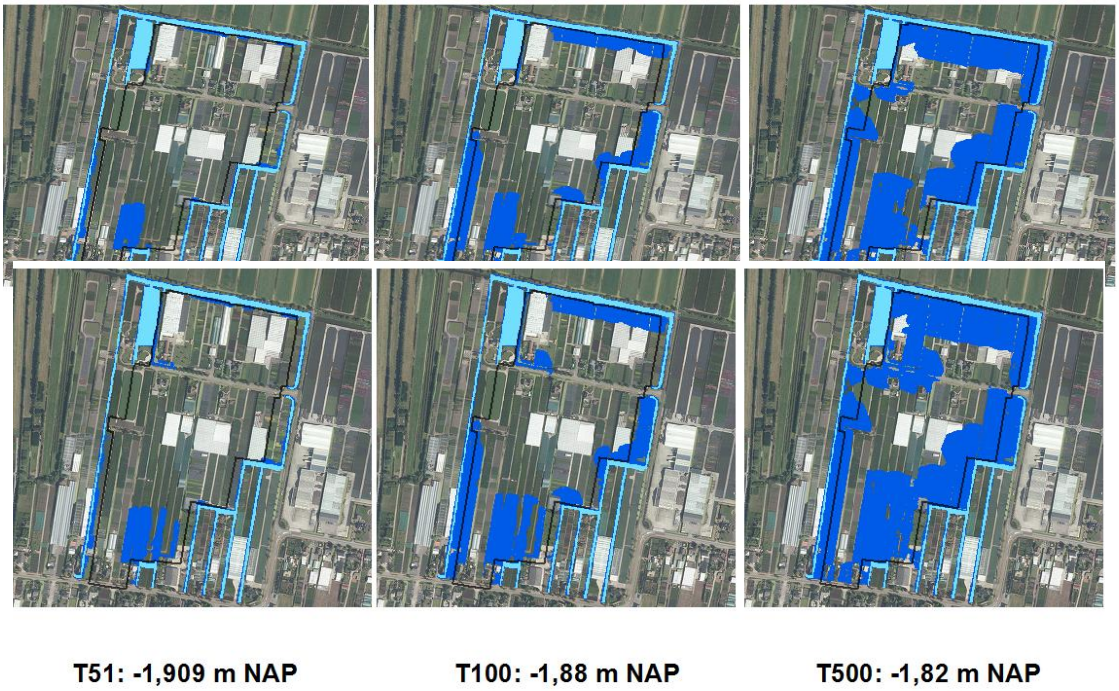


Figure 4.7 – inundation extent according to the model calculations in ArcMap for return periods above a -1,91 m NAP protection level. Results are shown for the full protection approach (top) and critical protection approach (bottom)

Comparison inundation risk curve between protection strategies

Inundation risk per year was calculated in relation to different protection levels to plot the risk curves and compare them between the protection approaches. The model that calculates the risk for the entire water level border has been included in Annex 5. This has been simulated for the current situation and higher protection levels as well. Furthermore, inundation risk was only calculated for the most prominent land-use types in Koetsveld, for which depth-damage functions were developed. This concerns the following land-use types: open field cultivation, pot-and container cultivation, greenhouses and meadows.

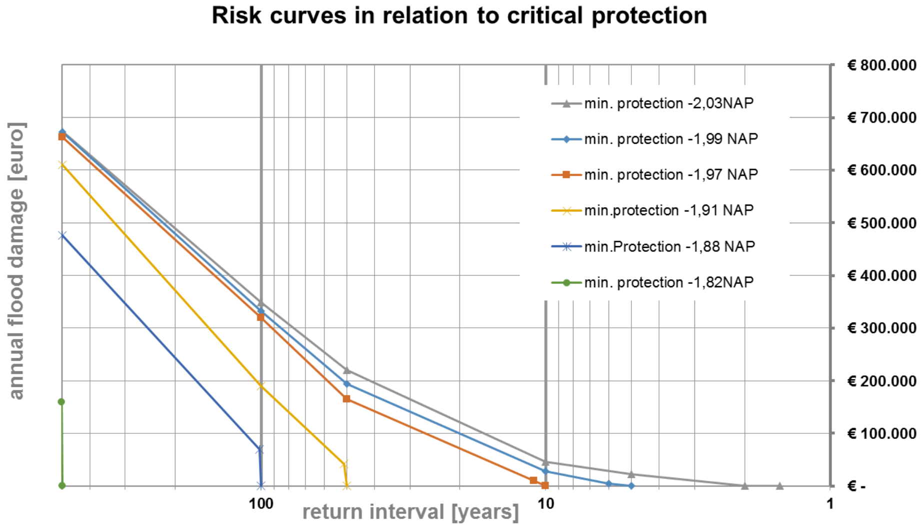
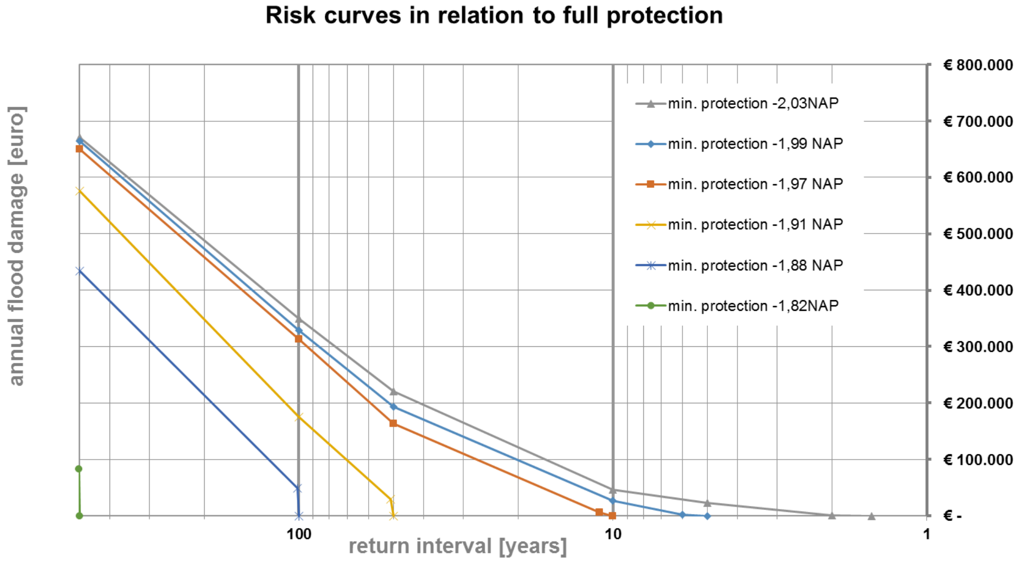


Figure 4.8 – development of risk curves by increasing the protection height for areas in the *critical protection approach*. Note the horizontal axis is logarithmic.



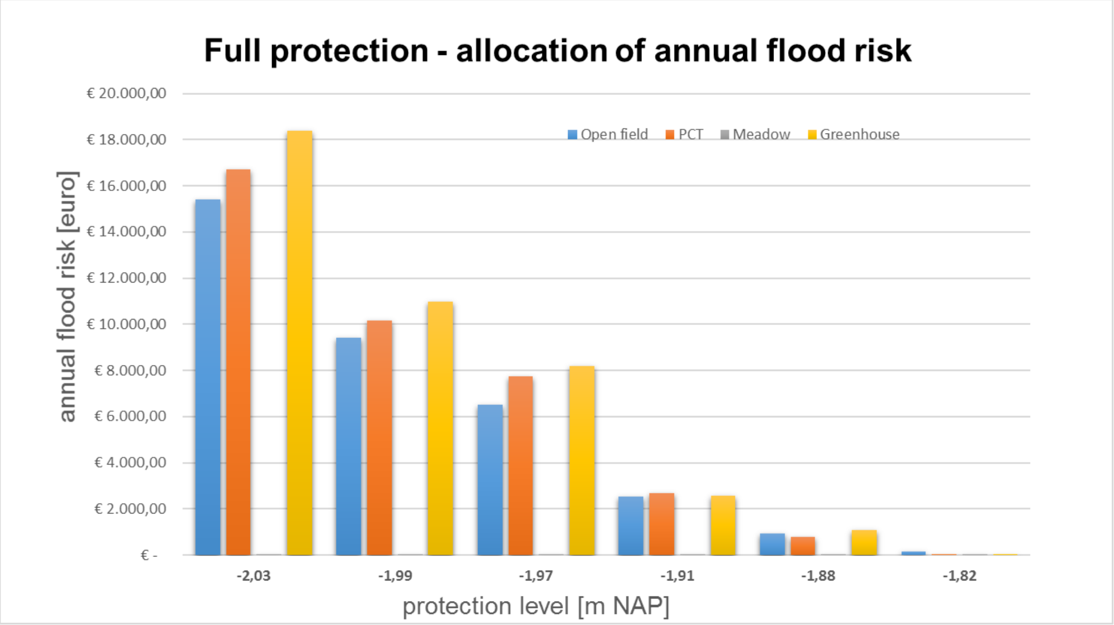
Fgure 4.9 – development of risk curves by increasing protection height for areas in the *full protection approach*. Note the horizontal axis is logarithmic.

Figure 4.8 and figure 4.9 show the development of the risk curve in relation to a higher protection height. The absolute flood damage differences per return period are relatively small between the two protection approaches, therefore the shape of the risk curves are very similar. The risk curves of the critical protection approach are slightly higher than for the full protection approach. The difference in annual flood damage between protection scenarios especially increases for higher return periods, while the differences for lower return periods is almost negligible. Furthermore, the effect of lower protection heights on flood damage reduction of high water level return periods is minimially, especially for the protection levels -1,99 and -1,97 m NAP which have a small decrease in flood damage for the T50-T500 interval.

Allocation of annual inundation risk for various protection levels

To determine the most vulnerable land-use classes to inundation, the total annual flood risk has been allocated into four land-use classes which are prominently present. This was done for both protection approaches (figure 4.10). The following conclusions can be extracted from these figures:

- The total expected annual risk is predominantly determined by open field cultivation, pot-and container cultivation and greenhouses in both protection scenarios. The meadow land-use type contributes minimally to the total inundation risk, because of the small surface in combination with a low damage price (€1108 per ha). The greenhouse land-use type has the highest contribution to the total annual risk for all protection levels, which is mainly attributed to the high damage price (=€ 818833 per ha). Several greenhouse complexes in Koetsveld are situated nearby the surface water system of the higher compartiment, which means they are highly vulnerable to inundation. The damage price for open field and pot-and container cultivation is a factor nine lower (= € 59855 per ha) than for greenhouses, while these types considerably contribute to the total inundation risk, which is almost equivalent to the inundation damage of greenhouses. The analysis have shown that the inundated area for open field cultivation and pot-and container cultivation is considerably higher than the area for greenhouses. Therefore, open field and pot-and container cultivation are highly affectd by inundation.



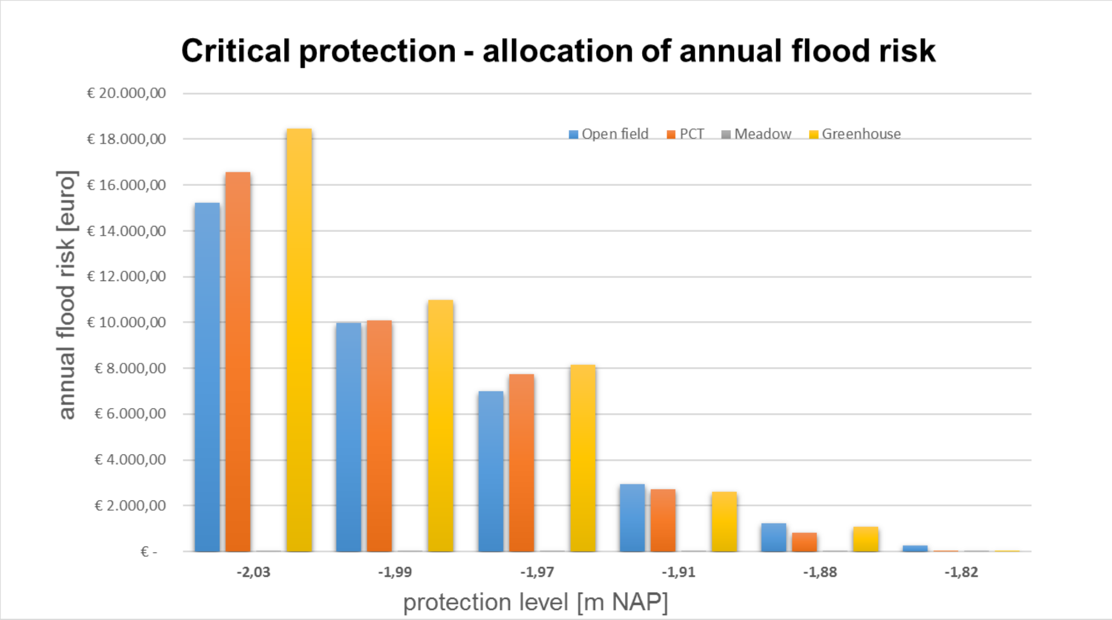


Figure 4.10 – the expected annual flood risk per land-use class in relation to different protection level. Full protection (top) and only protection critical parts (bottom)

- The annual inundation risk may significantly be reduced in both protection scenarios by increasing the protection level towards -1,99 m NAP. This reduction is at least 35% for open field and pot-and container cultivation up to at least 40% for greenhouses. This means the T2-T5 interval has a large contribution to the total annual inundation risk. Furthermore, the annual inundation risk reduction ranges from 80-86 percent if the protection level of -1,91 m NAP is applied, which is the horticulture protection standard for the Gouwepolder. In the entire flood protection scenario almost 100% flood risk reduction may be accomplished in combination with a minimum protection level of -1,82 m NAP.

Table 4.2 – Annual inundation risk reduction relative to the lowest possible damage level (-2,03 m NAP). Full protection scenario (top) and critical protection scenario (bottom)

Min. protection level in m NAP (return period in brackets)	-1,99 (t5)	-1,97 (t10)	-1,91 (t50)	-1,88 (t100)	-1,82 (t500)
Open field	-38,9%	-57,7%	-83,5%	-93,9%	-99,1%
PCT	-39,1%	-53,6%	-84,0%	-95,4%	-100,0%
Greenhouse	-40,2%	-55,5%	-86,1%	-94,2%	-99,9%

Min. protection level in m NAP (return period in brackets)	-1,99 (t5)	-1,97 (t10)	-1,91 (t50)	-1,88 (t100)	-1,82 (t500)
Open field	-34,6%	-54,1%	-80,6%	-92,0%	-98,2%
PCT	-39,0%	-53,3%	-83,5%	-95,1%	-99,9%
Greenhouse	-40,5%	-55,8%	-85,8%	-94,2%	-99,8%

4.4 Inundation protection analysis

Two flood protection scenarios for upgrading of the water level border have been discussed in paragraph 3.3. The inundation protection analysis has focused on two types of protection scenarios to examine how the inundation risk changes in relation to protection heights that are not consistently applied for the entire water level border. The current surface level height of the flood protection area was analysed to obtain (1) the size of the area that is below a specified protection level and (2) to calculate the total volume that should be added to obtain the required protection height. Furthermore, the total length for the implementation of sheet piling constructions and innovative flood barriers alongside greenhouses have been determined.

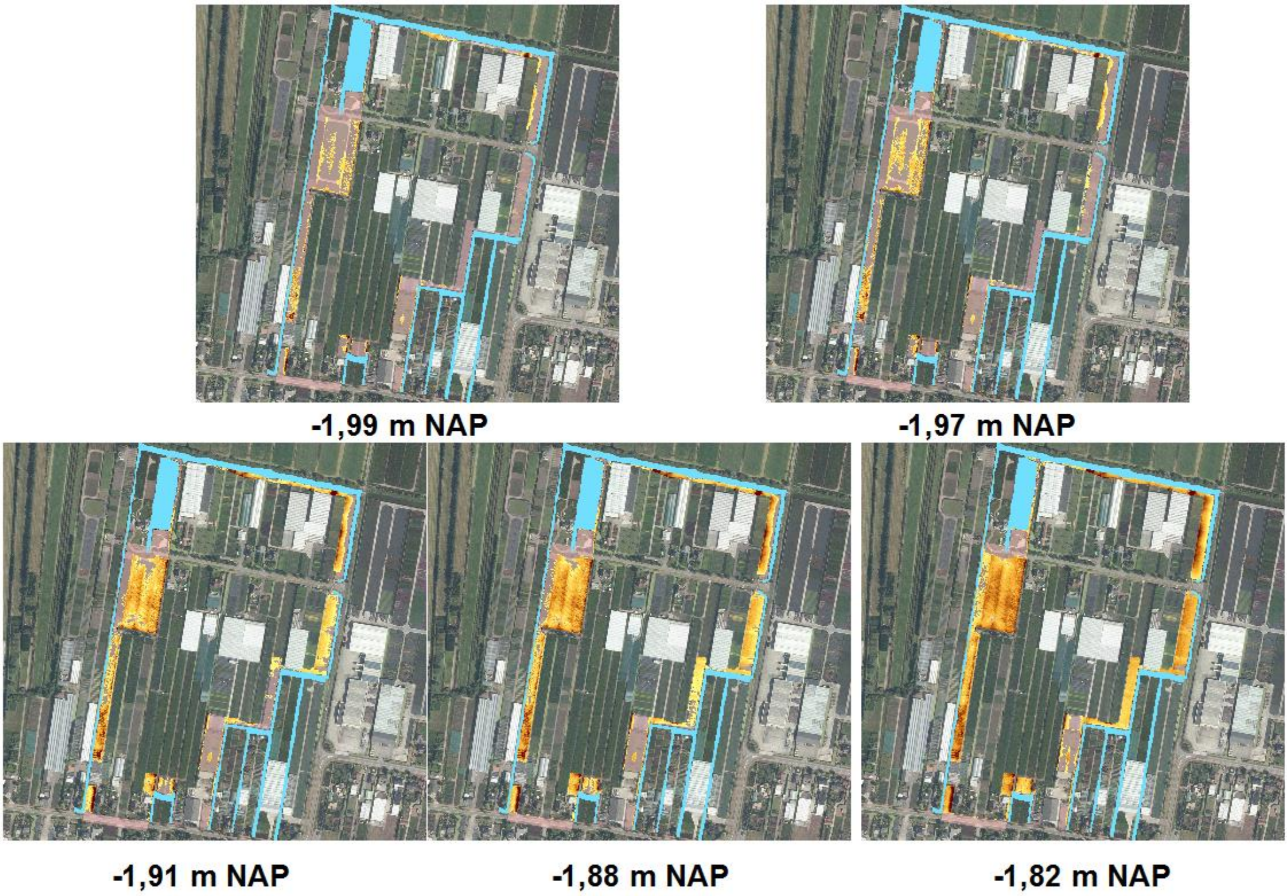
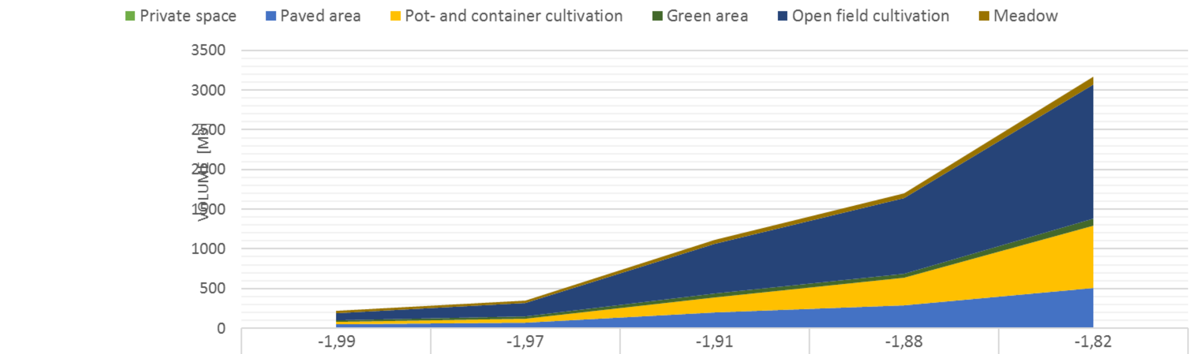


Figure 4.11 - distribution of cells below the protection level, as indicated below each map, that applies to the *full protection approach*

The flood protection area that should be raised, significantly increases for a protection level of -1,91 m NAP and higher, in particularly the cells in the DEM that are present nearby the surface water of the higher compartiment (figure 4.11). The area of selected cells in the full protection approach fluctuates from 0,5 hectares for the lowest protection level up to 2,6 hectares for the highest protection level. The full protection approach corresponds to a total area of 3,55 hectares. The analysis has also identified some highly vulnerable locations that are very likely to inundate in combination with a -1,99 m NAP water level (figure 4.12). Inundation regularly occurs at these locations, primarily because of the high concentration of cells below the protection level which further amplifies the inundation in a larger area.

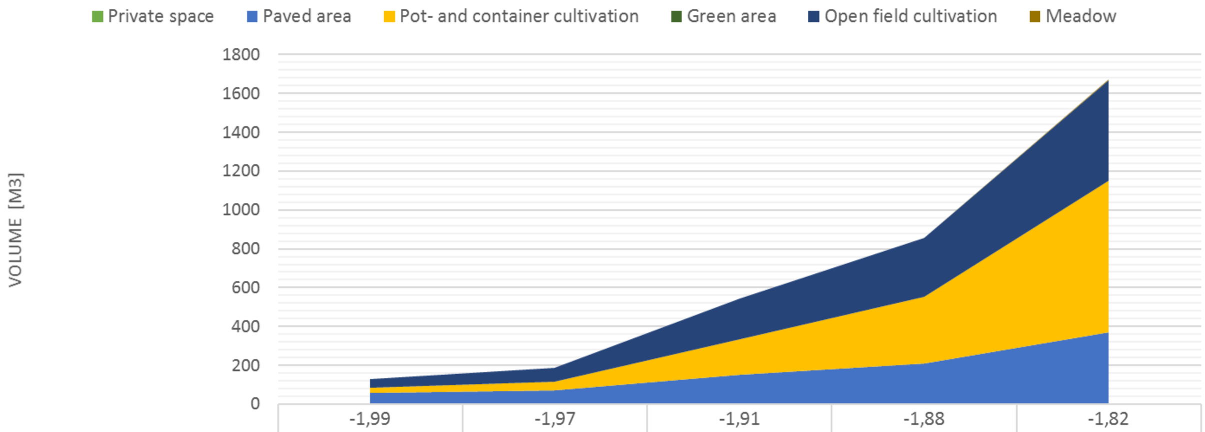
Figure 4.12 – selected areas in the water level border below the protection level of -1,99 m NAP

The total additional volume that is required for each protection level, is presented in figure 4.13. The total volume fluctuates between 200 m^3 and 3200 m^3 in case of the *full protection approach*, while for the *critical protection approach* the total volume fluctuates between 130 m3 up to a maximum of 1700 m3. To express these numbers in monetary terms, the development of the investment costs for peat have been illustrated for both approaches in figure 4.14. Several land-use types contribute to these numbers as can be been seen from figure 4.13 and 4.14. This also includes other land-use types which have not been considered in the inundation risk calculation, but are included as these land-use types are involved in the reconstruction as well. The result for the full protection approach shows that the open field cultivation has the highest contribution for all specified protection levels, followed by the pot- and container cultivation. The open field cultivation removes soil during the production annually, however this "consumption of soil" is generally not properly restored. Consequently, the parcels with open field cultivation regularly have the lowest protection heights in the polder. The total additional volume for the critical protection approach is recuded by half compare to the full protection approach. The main reason is that the total area of open field cultivation involved in the critical approach is one third of the total area included in the full protection approach. The area of pot-and container cultivation has been unchanged.



	-1,99	-1,97	-1,91	-1,88	-1,82
Meadow	23	28	48	62	99
Open field cultivation	94	176	632	950	1689
Green area	22	27	46	59	92
Pot- and container cultivation	29	45	184	339	779
Paved area	48	71	199	286	496
Private space	2	2	5	7	14

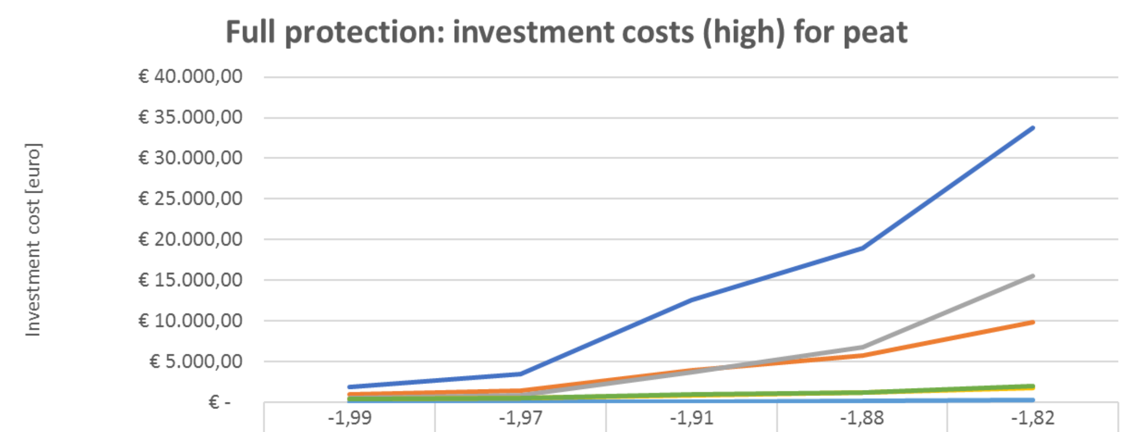
PROTECTION LEVEL [M NAP]



	-1,99	-1,97	-1,91	-1,88	-1,82
Meadow	0,0	0,1	0,3	0,9	2,9
Open field cultivation	42,5	72,0	210,6	305,6	520,4
Green area	0	0	0	0	0
Pot- and container cultivation	29,1	44,7	185,1	340,1	780,5
Paved area	55,5	70,5	149,9	210,9	368,4
Private space	0	0	0	0	0

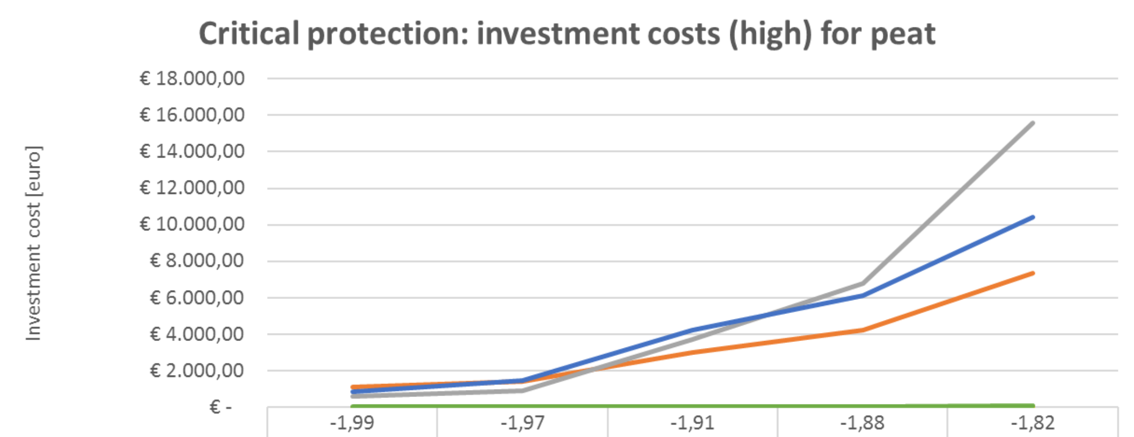
PROTECTION LEVEL [M NAP]

Figure 4.13 – the total additional volume that is necessary to increase the selected cells below a relevant protection level. The contribution of different land-use classes has been shown as well. Full protection approach (top) and critical protection approach (bottom)



	-1,99	-1,97	-1,91	-1,88	-1,82
Private space	€ 31,77	€ 41,99	€ 98,53	€ 143,92	€ 282,95
Paved area	€ 950,39	€ 1.427,86	€ 3.975,51	€ 5.714,76	€ 9.910,83
PCT	€ 585,94	€ 894,87	€ 3.681,48	€ 6.774,90	€ 15.572,00
Green area	€ 434,10	€ 530,96	€ 916,95	€ 1.170,73	€ 1.831,35
Open field cultivation	€ 1.882,36	€ 3.521,73	€ 12.630,33	€ 19.007,98	€ 33.789,97
Meadow	€ 456,55	€ 565,28	€ 969,35	€ 1.232,23	€ 1.977,59

Private space — Paved area — PCT — Green area — Open field cultivation — Meadow



	-1,99	-1,97	-1,91	-1,88	-1,82
Private space	€ -	€ -	€ -	€ -	€ -
Paved area	€ 1.110,60	€ 1.410,91	€ 2.998,99	€ 4.218,86	€ 7.367,70
PCT	€ 581,91	€ 893,12	€ 3.702,17	€ 6.801,94	€ 15.610,99
Green area	€ -	€ -	€ 0,31	€ 0,77	€ 2,57
Open field cultivation	€ 850,90	€ 1.440,79	€ 4.212,39	€ 6.112,47	€ 10.407,95
Meadow	€ 0,91	€ 1,21	€ 5,43	€ 17,58	€ 58,21

Private space — Paved area — PCT — Green area — Open field cultivation — Meadow

Figure 4.14 – development of investment costs in peat for different land-use classes. In this example a high unit price of 20 euro/per m³ for peat was used. Full protection approach (top) and critical protection approach (bottom)

For three specific locations in the water level border, a greenhouse is closely situated alongside the surface water channel (figure 4.15). For these locations, a sheet piling construction or innovative flood barrier should be implemented in order to increase the protection level, which sums up to a total length of 104 metres according to figure 4.19.

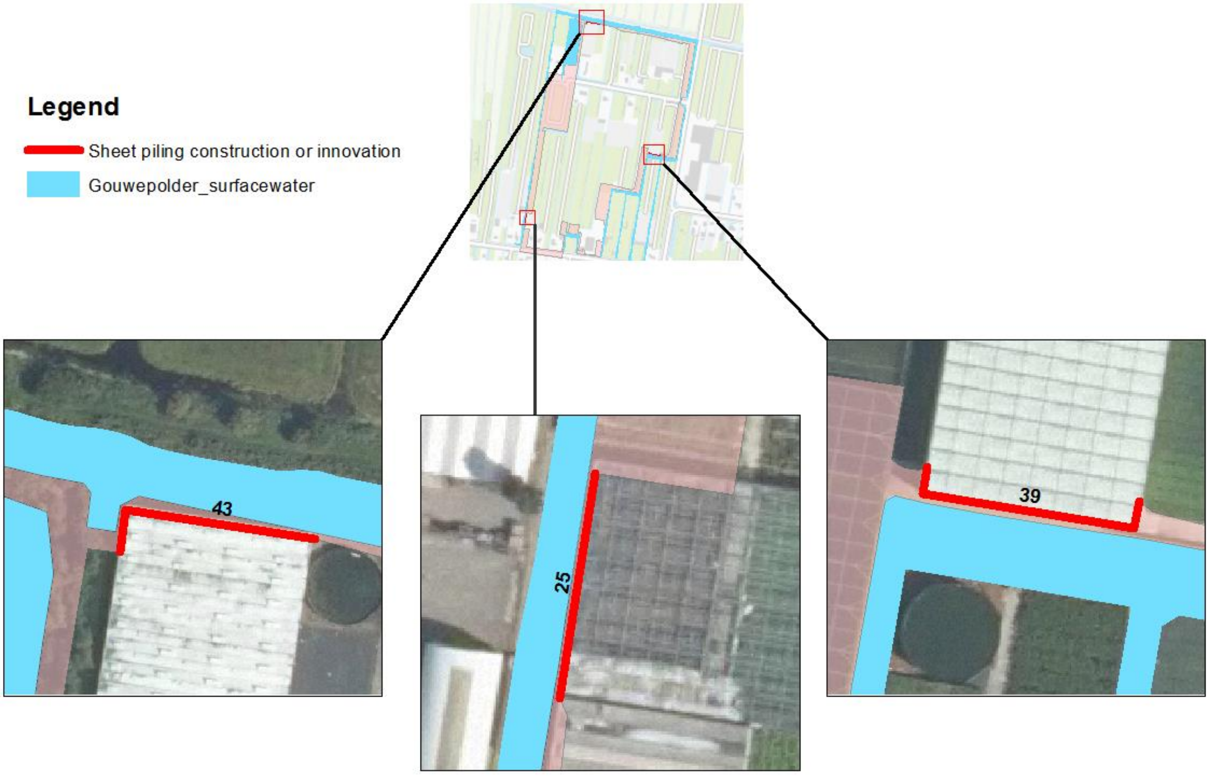


Figure 4.15 – locations including greenhouses in the water level border that should be protected with a sheet piling construction or innovative flood barrier. The numbers indicate the length (in m) of the construction.

4.5 Cost-benefit analysis

The first section of this chapter will present the results related to the cost-effectiveness of construction materials. This was calculated for different protection levels. The second section will focus on the cost-efficiency of construction materials. Having discussed the results for cost-effectiveness and cost-efficiency, the final section will focus on the question what protection level will be optimally for the water level border in relation to the protection approach and how this differs from the current protection standard.

Cost-effectiveness flood protection

Different construction types and materials have been considered for the reconstruction of the water level border of Koetsveld. Each protection approach contains the construction types presented in figure 4.16. It is important to note that the lightweight materials were only examined for the pot-and container cultivation. The investment cost were considered into three different construction groups, to identify for each land-use type the construction material with the highest cost-effectiveness for a 30 year project period.

The following three groups were considered in the analysis:

(1) the first group assigns to the *dike* and *parcels* constructed with *peat* or *clayish peat*. This group concerns the following land-use types: open field cultivation, meadow, private areas, paved paths and green areas;

(2) the second group only assigns to the *parcels* constructed with *peat, clayish peat* or

lightweight construction materials (including *EPS, flugsand and foam concrete)*. This group only concerns the pot-and container cultivation land-use type;

(3) the final group assigns to the *sheet piling constructions (including the following materials: wooden, synthethic, steel, composite and bamboo)* and *the innovative flood barriers* (including the *Self Closing Flood Barrier* and *Vlotterkering*).

To calculate the total cost-effectiveness for a composition of construction materials, one construction material from each group was selected from the available construction materials. Subsequently, the discounted costs for three different construction materials were summed to calculate the total cost-effectiveness. Ultimately, the cost-effectiveness of 82 different compositions of construction materials was calculated. The discounted investment costs for each material only apply to the land-use types as defined for each group. In this thesis, the cost-effectiveness for each material equals to the discounted investment costs for a 30 year analysis period. This is because inundation risk reduction is similar for all construction materials when the protection height increases with one additional centimeter.

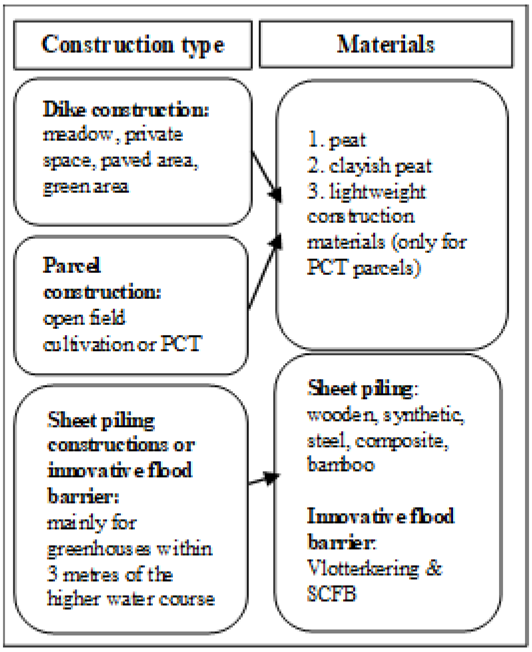


Figure 4.16 - construction types and materials used for upgrading of the protection height of the water level border

Table 4.5 – fractions assumed for operation cost per protection level

protection level (m NAP)	% of maintenance costs
-1,99	5,00%
-1,97	10,00%
-1,91	15,00%
-1,88	20,00%
-1,82	30,00%

Table 4.4 – assumptions for the surplus height per protection level

Protection level (m NAP)	Surplus height (cm)
-1,99	15
-1,97	17
-1,91	21
-1,88	30
-1,82	35

As discussed in chapter 3, the initial investment is generally determined by the material costs to increase the areas below the minimum protection height. In case of traditional construction materials, a surplus height on top of the flood measure construction was included to compensate for the increased subsidence process after the construction. This surplus height was not included for lightweight construction materials which experience hardly any subsidence. The material costs were calculated by multiplying the cost number per material with the required volume. Exact cost numbers could not be defined from the literature; therefore, a price range was defined which includes a lower and upper price limit (paragraph 3.4). The surplus height per protection level was estimated based on information from a former upgrade of the water level border in Spoelwijk (table 4.4). Two different types of running costs were included: (1) the maintenance costs in case the construction is restored to the original height. The timing depends on the annual settlement rate. (2) the operation costs, which has been assumed as a fraction of the maintenance costs. The height of the fraction depends on the protection level of the flood measure (table 4.5). Running cost were only calculated for the traditional and lightweight construction materials. For sheet pilings and innovative flood barriers, the maintenance costs correspond to a re-investment in a new construction. Furthermore, the subsidence rate for the first protection level (-1,99 m NAP) was defined at 10 mm/year, with an increase of one millimetre per year in accordance with a higher protection level.

The cost-effectiveness of 82 different compositions of construction materials was calculated in relation to different protection levels. The compositions with the highest cost-effectiveness for each protection level have been presented in table 4.6 and 4.7, respectively for the *full protection approach* and the *critical protection approach*. The cost-effectiveness of the other compositions of construction materials for the three highest protection heights are included in Annex 12 and 13, respectively for the *full protection approach* and *critical protection approach*. It becomes apparent from the results in the table 4.6, that for the full protection approach the composition of construction materials differs for each protection level. Bamboo sheet pilings have the highest-cost effectiveness in the group of sheet pilings and innovative flood barriers. This type of construction is used for greenhouse complexes within a distance of 3 metres to the nearest watercourse of the higher compartment. The initial investment for a bamboo sheet piling construction is relatively low compare to other types. Furthermore, lightweight construction materials are only cost-effective for low unit pricing. The alternating pattern between lightweight materials and peat or clayish peat may be linked to the assumption for the surplus heights per protection level. The costs for surplus height may cause a higher total investment cost for traditional materials than for lightweight materials. Cost effectiveness decreases for lightweight construction materials due to a larger difference in unit price.

The results of the critical protection approach (table 4.7) and the full protection approach are similarly, in particularly when considering the composition of construction materials for the protection heights. However, the cost-effectiveness is considerably higher for the critical protection approach than for the full protection approach, primarily because of the difference in construction size and the height of the investment costs.

Table 4.6 – composition of construction materials with the highest total cost-effectiveness per year for several protection heights in the *full protection approach*. The results are shown for a low price unit (left) and high price unit (right).

	Cost-effectiveness (low unit price)				Cost-effectiveness (high unit price)			
Protection level (m NAP)	*Composition of construction materials*			Total cost-effectiveness [EUR/year]	*Composition of construction materials*			Total cost-effectiveness [EUR/year]
	Group 1	*Group 2*	*Group 3*		*Group 1*	*Group 2*	*Group 3*	
-1,99	peat	EPS	bamboo	*6.615,49*	peat	peat (pct)	bamboo	*8.999,61*
-1,97	peat	EPS/foam concrete	bamboo	*8.930,21*	clayish peat	clayish peat (pct)	bamboo	*12.004,86*
-1,91	clayish peat	clayish peat (pct)	bamboo	*11.838,70*	clayish peat	clayish peat (pct)	bamboo	*15.838,97*
-1,88	clayish peat	EPS	bamboo	*15.240,80*	clayish peat	clayish peat (pct)	bamboo	*20.935,50*
-1,82	clayish peat	EPS/foam concrete	bamboo	*20.726,83*	clayish peat	clayish peat (pct)	bamboo	*29.239,25*

Table 4.7 - composition of construction materials with the highest total cost-effectiveness per year for several protection heights in the *critical protection approach*. The results are shown for a low price unit (left) and high price unit (right).

	Cost-effectiveness (low unit price)				Cost-effectiveness (high unit price)			
Protection level (m NAP)	*Composition of construction materials*			Total cost-effectiveness [EUR/year]	*Composition of construction materials*			Total cost-effectiveness [EUR/year]
	Group 1	*Group 2*	*Group 3*		*Group 1*	*Group 2*	*Group 3*	
-1,99	peat	peat (pct)	bamboo	*3.386,84*	clayish peat	peat (pct)	bamboo	*4.711,12*
-1,97	clayishpeat	EPS	bamboo	*4.472,72*	clayish peat	clayish peat (pct)	bamboo	*6.090,72*
-1,91	clayish peat	clayish peat (pct)	bamboo	*5.865,77*	clayish peat	clayish peat (pct)	bamboo	*7.906,56*
-1,88	clayish peat	EPS	bamboo	*7.273,02*	clayish peat	clayish peat (pct)	bamboo	*10.346,79*
-1,82	clayish peat	EPS/foam concrete	bamboo	*9.150,19*	clayish peat	clayish peat (pct)	bamboo	*13.279,48*

Cost-efficiency per protection level

The cost-efficiency was determined by means of cost-benefit analysis with the net present value (NPV) as output criterion. Generally, a NPV > 0 indicates that a specific protection option has positive impact on the social welfare, as the benefits outweigh the investments costs.

The cost-efficiency was calculated for the same 82 compositions of construction materials as used for the cost-effectiveness, by substracting the discounted costs from the discounted benefits. The compositions of construction materials with the highest NPV per year applying to several protection heights in the *full protection approach* are presented in table 4.8. The cost-efficiency of the other compositions of construction materials for the three highest protection heights are included in Annex 12 and 13, respectively for the *full protection approach* and *critical protection approach* According to the results, the NPV per year in the *full protection protection* only shows positive numbers for a low unit price. The NPV per year is solely negative for the high unit price. This means the investment costs for a higher protection height outweigh the benefits of inundation reduction. Furthermore, what stands out in the table is that parcel constructions for the pot-and container land-use type (the second group) can be constructed more efficiently with lightweight materials than traditional earthen materials, such as peat or clayish peat. The highest cost-efficiency for these materials is specificially obtained for EPS or foam concrete. Furthermore, the bamboo sheet piling construction has the highest cost-efficiency for all protection heights. The total investment costs for this construction is relatively low compare to other sheet piling constructions, resulting in a highly positive NPV. Clayish peat has the highest cost-efficiency per year for the first group of constructions.

Table 4.9 includes the compositions of construction materials with the highest NPV per year that apply to several protection heights in the *critical protection*. What stands out in the table is that except for the -1,99 m NAP protection level the total cost-efficiency per year is generally positive for all compositions. The NPV for *the critical protection approach* is generally more positive than the *full protection approach*, primarily because of the lower total investment costs.

Table 4.8 – compositions of construction materials in the *full protection approach* with highest cost-efficiency per protection level. Low pricing (left) and high pricing (right)

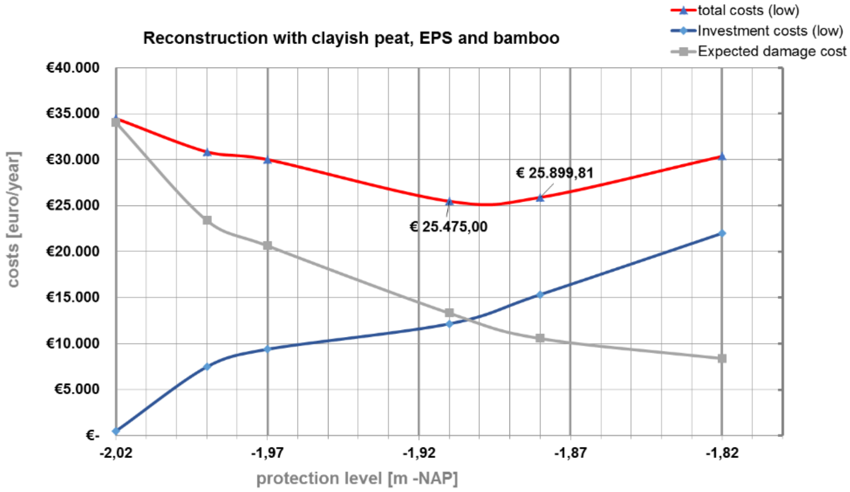
	Cost-efficiency (low unit price)				Cost-efficiency (high unit price)			
Protection level (m NAP)	*Composition of construction materials*			Total NPV [EUR/year]	*Composition of construction materials*			Total NPV [EUR/year]
	Group 1	*Group 2*	*Group 3*		*Group 1*	*Group 2*	*Group 3*	
-1,99	peat	EPS/foam concrete	bamboo	*-1.011,84*	clayish peat	EPS/foam concrete	bamboo	*-4.537,69*
-1,97	clayish peat	EPS/foam concrete	bamboo	*-285,34*	clayish peat	EPS/foam concrete	bamboo	*-4.698,69*
-1,91	clayish peat	EPS/foam concrete	bamboo	*4.010,51*	clayish peat	EPS/foam concrete	bamboo	*-1,947,20*
-1,88	clayish peat	EPS/foam concrete	bamboo	*3.464,20*	clayish peat	EPS/foam concrete	bamboo	*-3.584,20*
-1,82	clayish peat	EPS/foam concrete	bamboo	*154,19*	clayish peat	clayish peat (pct)	bamboo	*-9.365,69*

Table 4.9 – compositions of construction materials in *critical protection approach* with highest cost-efficiency per protection level. Low pricing (left) and high pricing (right)

	Cost-efficiency (low unit price)				Cost-efficiency (high unit price)			
Protection level (m NAP)	*Composition of construction materials*			Total NPV [EUR/year]	*Composition of construction materials*			Total NPV [EUR/year]
	Group 1	*Group 2*	*Group 3*		*Group 1*	*Group 2*	*Group 3*	
-1,99	peat	EPS/foam concrete	bamboo	*2.107,03*	clayish peat	EPS/foam concrete	bamboo	*-290,76*
-1,97	clayish peat	EPS/foam concrete	bamboo	*3.852,92*	clayish peat	EPS/foam concrete	bamboo	*894,78*
-1,91	clayish peat	EPS/foam concrete	bamboo	*9.439,18*	clayish peat	EPS/foam concrete	bamboo	*5.430,12*
-1,88	clayish peat	EPS/foam concrete	bamboo	*10.903,05*	clayish peat	EPS/foam concrete	bamboo	*6.204,63*
-1,82	clayish peat	EPS/foam concrete	bamboo	*11.308,91*	clayish peat	clayish peat (pct)	bamboo	*6.161,50*

Optimal protection level: minimum total costs

The optimal protection level for the new water level border was determined by identifiying the minimum of the total costs among a number of protection levels. The total cost curve was calculated by adding the inundation damage cost and the investment cost in flood protection. Finally, the minimum was determined by plotting the total cost curve.



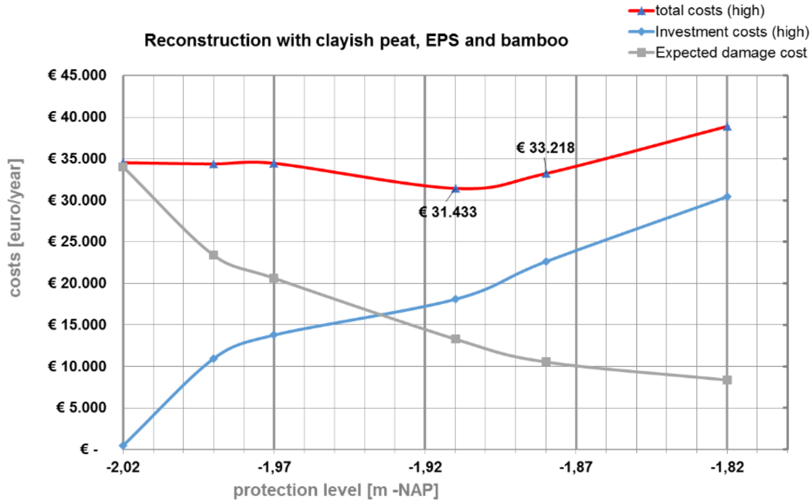
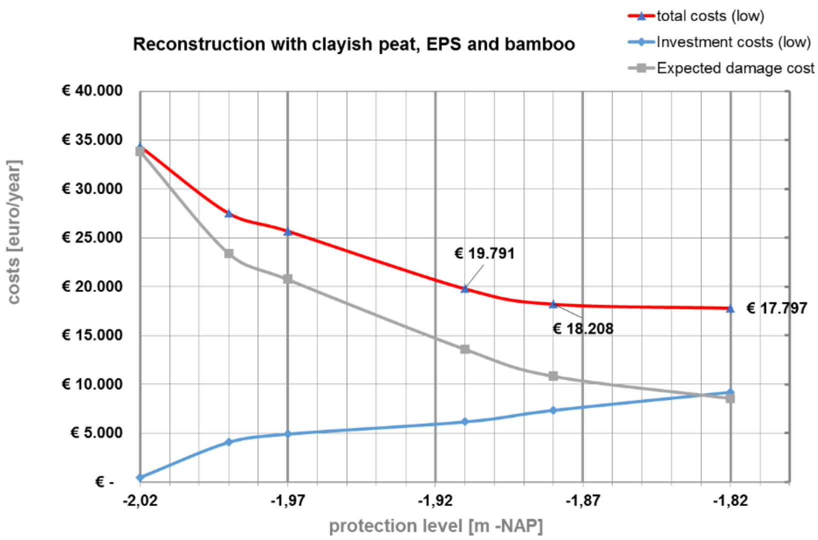


Figure 4.17 - the total annual costs (red) for the full protection approach. The investment cost includes the investment in clayish peat (for open field cultivation, meadow and other small land-use types), EPS (for pot-and container cultivation) and a wooden sheet piling constructions (along greenhouses). This has been simulated for a lower price limit (top) and a higher price limit (bottom)

The optimal protection level was examined for the composition of construction materials with the highest cost-efficiency. This concerns the following materials: (1) clayish peat for dike and parcel constructions in the first group; (2) EPS or foam concrete for parcel constructions in the second group and (3) bamboo sheet pilings for the third group. The investment costs for the construction materials were summed to determine the total investment cost curve. The cost curves in question are graphically presented in figures 4.17 and 4.18, which represent the *full protection* and *critical protection* approach respectively.

The red curves indicate the development of the total cost curve among different protection heights for the water level border. The total cost curve for the low investment scenario of the *full protection* approach reaches a minimum at -1,90 m NAP which is close to the protection standard of horticulture established at -1,91 m NAP. The flood protection will cost on average € 12.000 per year for a 30 year analysis period. Furthermore, the inundation risk per year will be reduced from € 34.000 per year on average to approximately € 13.000 per year on average. The average total cost curve for the high investment scenario shows a flatter development among the protection heights. This is mainly because a single unit price was applied to calculate the investment costs or emergency pumping costs for the current situation or protection height. As a result, the average total costs per year fluctuates minimally. Despite the small fluctuations, the optimal protection height of the high investment scenario is similar to the low investment scenario. This corresponds to an average investment cost of nearly € 18.000, which is approximately less than € 5000 lower than the investment costs for the low investment scenario.

The average total cost curves that apply to the *critical protection* approach develop differently. This is mainly because large reductions of inundation costs are obtained in combination with relatively low average investment costs, especially up to -1,91 m NAP protection level. The reduction in average inundation costs is however smaller above the -1,91 m NAP protection level.



What stands out in the top chart of figure 4.18 that represent the low investment scenario is the lack of a minimum in the average total cost curve. This means the optimal protection height is beyond the -1,82 m NAP protection level, which is higher than the horticultural protection norm and equals to a protection level of -1,91 m NAP. The inundation risk reduces on average from nearly € 35.000 per year to less than € 10.000 per year. An average investment costs of € 9000 per year in flood protection is required to obtain at least the -1,82 m NAP protection level. The high investment scenario, conversely, has an visble optimum protection level of -1,82 m NAP as can be observed in the bottom chart of figure 4.21. This is nearly 10 centimeters higher than the horticultural protection norm. The average investment costs for this higher protection level corresponds to almost € 12.000 per year. This results in average flood risk reduction of € 35.000 per year currently to less than € 11.000 per year.

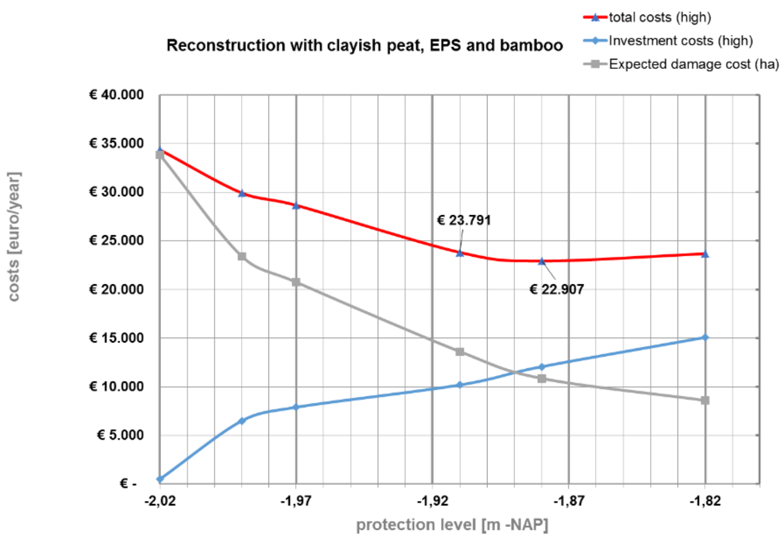


Figure 4.18 - the total annual costs (red) for the critical protection approach. The investment cost includes the investment in clayish peat (for open field cultivation, meadow and other small land-use types), EPS (for pot- and container cultivation) and a wooden sheet piling constructions (along greenhouses). This has been simulated for a lower price limit (top) and a higher price limit (bottom)

Chapter 5 Discussion

The first objective in this study was to gain insight into the development of water nuisance along water level borders due to extreme precipitation. One of the main findings is that water nuisance along water level borders mainly originates from surface water, whereby the surface water level considerably increases during peak rainfall. Damage due to rising groundwater levels is prevented by the extensive installation of drainage systems, while these systems contribute considerably to the surface water level increase. There is however a high degree of uncertainty about the actual amount of drainage, especially because the potential of water storage in recirculation basins for pot- and container productions may vary considerably during the seasons. One of the main reasons is that most of the peak rainfall events develop suddenly, while at the same time storage capacity is reserved for irrigation purposes, especially in the summer. Consequently, there is less storage capacity than potentially available. When the maximum capacity of a storage basin is reached, the runoff from a pot-and container parcel behaves as a paved surface. Water nuisance was prevented after the peak event in July 2016 due to the utilization of storage basins, while in July 2011 there was extensive inundation due to less basin storage. This option is however only effective if all basins empty at least 24 hours before the peak event reaches the Greenport. This is an important precondition to make sure the surface water level increase, that is caused by emptying the basins, is sufficiently reduced. Emptying of recirculation basins negatively affects the water quality, therefore, the Water Board limits the application of this solution.

Another important finding, is that the impact of water nuisance for previous events was more intense for the water level areas in the north (Koetsveld and Spoelwijk) than in the south (Gouwedreef-Randenburg, Berkenbroek-Noord and Berkenbroek-Zuid). A first explanation is that the surface water level of the Gouwepolder is spatially distributed under standard conditions. This results in higher surface water levels for areas that bridges a longer distance to the main pumping station. This is a well-known issue in polder areas with a wide surface water system. A second explanation for the difference in water nuisance, is the presence of under-dimensioned culverts in the main surface water system. This discontinues discharge and further stimulates the water level increase. This generally means that the surface water system in the north, which bridges a longer distance to the main pumping station, experiences a faster surface water level increase than areas closer to the main pumping station.

The third objective in this study was to quantify the current inundation risk and how this changes in relation to additional protection. This analysis has only been performed for the water level area of Koetsveld. The inundation risk of the lower water level areas in the south would be overestimated when apply the water level distribution simulated for the entire Gouwepolder surface water system. This distribution is more representative for the surface water system in the north than in the south.

A simple python script was used to provide estimates of the inundation extent for several return periods. The locations in the north and south of the water level border, where inundation of the water level border was observed previously, have properly been displayed in the inundation maps for low return periods. This result demonstrates the potential of high resolution DEM measurements to identify inundation locations in the water level border locally and eventually provide reliable inundation estimates. A lower resolution may have resulted in different or additional inundation locations, especially when surface level differences are small. Due to the small freeboard levels in the Greenport, the boundary between safe and unsafe locations in the water level border is very close. Despite the high resolution of the DEM measurements, a note of caution is due here for the reliability of inundation locations for open field cultivation. Due to soil removal for tree production annually, the surface level experience large changes which magnifies the number of inundation locations and the probability of inundation. Unfortunately, the reliability for open field cultivation results in this thesis could not be verified properly, mainly because the parcel owner along the border in the west was not interviewed yet. Another source of uncertainty is the method of validation for inundation maps. The inundation extent for the peak event in July 2014 was estimated pragmatically according to the observations of parcel owners. Improvements in modelling of inundation maps would be possible by exact recordings of the inundation extent, for example aerial pictures. The inundation simulations could be improved by applying a hydrodynamic approach. The question is however, whether inclusion of a flow component would considerably affect the inundation extent in an area with small inclination. Furthermore, it is questionable whether a higher effort for hydrodynamic modelling will improve the inundation damage results for Koetsveld considerably.

A depth-damage model was applied in this thesis, to estimate inundation damage of four different land-use types: (1) open field cultivation, (2) pot-and container cultivation, (3) meadow and (4) greenhouses. The inundation damage estimates should however be interpreted with caution, because the results could not be validated. The main reason is that a suitable damage dataset is not available to validate the estimates. The limited availability of (reliable) damage data has extensively been recognized by other studies, as cited by Merz et al. (2010). Merz et al. (2010) proposed several suggestions to perform the validation in other ways, for example uncertainty and sensitivity analysis of important assumptions, model inputs or processes. Prior studies to flood damage estimation (Wagenaar et al., 2016; de Moel and Aerts, 2011; Merz et al., 2010), have also noticed the importance of the assessment of uncertainties in model inputs and assumptions for flood damage estimates. According to Wagenaar et al. (2016) uncertainty is typically large for inundation events with smaller water depths and for smaller inundation events.

There are several issues relating to the damage functions and their application that warrant further research. A number of these issues are discussed here:

- It could be argued that the actual damage pattern, especially for open field cultivation and pot-and container cultivation, is not exactly captured by the damage functions. The inundation damage in this thesis has only been estimated by inundation depth. This may result in overestimation of the inundation damage, especially for open field and pot-and container cultivation. Prior studies argue that the magnitude of damage for trees and plants for these land-use types is also determined by the timing of inundation. The issue of damage overestimation can be illustrated with an example related to the damage function of open field cultivation. In this damage function, the maximum damage unit price is applied for all inundated cells regardless the inundation depth. This was assumed because peat soils generally experience delayed infiltration and saturated soil conditions may last longer, especially for the open field cultivation. Saturation for a long period may cause irreversible damage to plant and trees. It is however difficult to define the minimum inundation depth and the point of 'irreversible damage' at which damage actually appears to trees and plants. A parcel with open field cultivation in Koetsveld has proven to remain free from tree damage after at least 48 hours of inundation in July 2014. This supports the idea that the damage function for open field cultivation is significantly different from the actual damage pattern.

- In this thesis, only two distinctive damage functions were applied for open field cultivation and pot-and container cultivation. Additional damage functions should be applied for these land-use types to perform the damage calculation for different plant and tree species. In the agricultural sector different damage functions have been developed for the most dominant crops, which are differently affected by inundation. This differentiation in water resilience for plants and trees may improve the damage estimate. Further research will be necessary to enlarge the differentiation in damage functions for these cultivation types.

- Another source of uncertainty is captured in the maximum damage price unit, which is necessary for the conversion of inundation depth to damage factor. In this thesis, damage unit prices are applied for a number of land-use classes. In practice, the damage price per plant or tree differs, which affects the total damage estimate. In the current land-use maps, there is no differentiation in pot-and container cultivation and open field cultivation. Therefore, a similar damage unit price was applied for pot-and container cultivation and open field cultivation. The damage price per plant contains however less uncertainty, because a plant will irreversibly be damaged or not. Conversely, the total damage is affected by the number of plants or trees that are acutally lost. In the damage calculation, a damage price was awarded to the inundation of each cell, but in reality the height of the total damage is primarily determined by the plants and trees that are not sold. The question remains whether the damage estimate significantly improves when the analysis is shifted to a local scale, for example only at parcel level.

- The damage calculation in this thesis has not considered fluctuations in monthly risk. Furthermore, it was assumed that the exposure of land-use classes is similar throughout the year. Therefore, the damage associated with a specific return period is representative for the entire year. In reality, the exposure to damage in horticultural areas differs per season, specifically for pot-and container productions. During the spring and summer there is a peak in the production. Pot-and container productions are concentrated on the outdoor fields, while during the winter and fall productions are mainly inside greenhouses. Consequently, the exposure to inundation damage is higher in the summer and fall and therefore a higher inundation damage may be expected. High water levels may occur in the winter and fall as well, but with a lower exposure to inundation damage. These monthly exposure differences should be taken into account for a better estimation of the annual flood damage. This also means the inundation risk per year is only based on the summer.

Chapter 6 Conclusion and recommendations

The present study was designated to determine a cost-efficient framework that aims to reduce water nuisance in lower water level areas in the Gouwepolder. Several objectives were pursued in order to establish this framework.

The first objective was to gain insight in the development of water nuisance along water level borders during peak rainfall events. It became apparent from the water system analysis, that water nuisance along water level borders in the Gouwepolder is mainly orginating from the surface water system in the higher compartiment (Gouwepolder). This surface water system, which is present alongside the parcels of the lower water level areas, experiences rapid surface water level increase due to peak rainfall events. Extensive drainage of parcels is one of the main reasons for the rapid increase of the surface water level during these events. While inundation due to a rising groundwater table is mainly prevented by drainage systems, they considerably contribute to the rapid increase of the surface water level. Furthermore, this study has revealed that the intensity of water nuisance along water level borders differs spatially. In particularly, the water level areas in the North, in particularly Koetsveld and Spoelwijk, experienced more water nuisance than water level areas in the south after previous peak rainfall event. A large discharge distance to the main pumping station in combination with under-dimensioned culverts causes a higher water level (increase) towards the north. This means a single water level probability distribution function is not representative for the entire surface water system of the Gouwepolder.

The second objective in this study was to formulate flood protection strategies including measures to reduce the inundation risk alongside water levels borders. Eventually, this objective has only been implemented for the water level border of Koetsveld. According to the results of the first objective, application of the current available water level PDF of the Gouwepolder for all water level areas would have resulted in unreliable estimates for inundation risk, specifically for the water level areas in the south. Furthermore, structural measures have only been considered. The main reason is that other non-structural measures, such as a permanent water level reduction or an expansion of pumping capacity, are not that cost-effective to reduce water nuisance along water level borders. Ultimately, two protection strategies, (1) full protection and (2) critical protection, were formulated and considered in the subsequent analyses. The former strategy aims to upgrade the water level border entirely, while the latter only considers improvement of critical locations, as identified and selected by the inundation analysis. To preserve the cultivation land-use types, parcels should be raised entirely instead of a dike-shaped construction. Contrarily, the dike construction is more appropriate for the meadow land-use type as the function is not seriously hindered. The protection height for greenhouses within a distance of 3 metres to the watercourses of the higher compartiment should be improved with a sheet piling construction or innovative water protection. In this study the Vlotterkering and Self Closing Flood Barrier were considered as innovative solutions.

The third objective in this study was to quantify the inundation risk for a water level area and how this changes in relation to additional protection. For different return periods, the inundation depth of the potential flooded area was converted into a damage cost using several depth-damage functions. According to these simulations, differences in risk curves between the protection strategies are relatively small, simply because the simulated inundated areas and calculated inundation damages are nearly similar. Furthermore, the annual expected inundation costs were determined for four dominant land-use classes. According to these results, greenhouses are most vulnerable to inundation due to the high unit price, followed by the open field cultivation and pot-and container cultivation. The contribution of meadows to the annual expected damage is marginal, simply because the area and unit price is low compare to the other land-use classes. Furthermore, the largest absolute reduction in annual expected damage is accomplished with a -1,99 m NAP protection level, the lowest protection level considered in this thesis. More than 50% of the annual expected damage can be reduced by application of the second lowest protection level (-1,97 NAP) in both protection strategies. The contribution to the annual expected damage generally decreases for higher return periods. Furthermore, it was found that the annual flood damage can completely be reduced when applying a protection level of -1,88 NAP, the highest protection level considered in this thesis. The results of inundation risk are subject to different sources of uncertainty as pointed out in the discussion. Further research is necessary to determine what elements in the risk calculation should be adjusted to improve the reliability of the results.

The fourth objective of this study was to determine the requirements in terms of flood protection for the protection approaches. According to the results, supplements to the current water level border are relatively limited for peat and clayish peat due to the small differences in protection height. Larger supplements will be required to compensate for primary and secondary settlements. The initial investment cost for lightweight materials, which are only applied below pot-and container fields, are generally higher for lightweight materials than traditional construction materials, specifically peat or clayish peat. The entire area of pot-and container fields should be provided with lightweight materials to prevent variations in surface heights. Consequently, the initial investment for these materials will be higher. Furthermore, the analysis has shown that for a length of at least 100 meters, the water level border of Koetsveld should be raised with a sheet piling construction or innovative protection measure. This concerns three greenhouses, where the space between greenhouse and watercourse is too limited for a dike construction.

The fifth objective in this study was to determine the cost-efficiency of measures for different protection levels in relation to a specified project period. The results suggest that the cost-efficiency of measures is generally lower for the full protection approach than for the critical protection approach. The difference between costs and benefits is generally negative for the protection levels in the full protection approach, while the critical protection strategy is dominated by only positive cost-efficiency. It is however important to note that these conclusions for the protection strategies have been drawn from just one combination of measures, which was primarily the combination with the highest cost-efficiency. This combination includes predominantly the following construction materials: clayish peat (open field cultivation and others), EPS or foam concrete (pot-and container cultivation) and bamboo (greenhouses).

The final objective in this study was to determine the total cost curve to identify the optimal protection level for a specified period. According to the results, the optimal protection level for the full protection approach closely matches with the actual protection standard for horticulture. This protection level results in an annual flood risk reduction from € 34,000 to € 13,000. Different results are obtained for the critical protection approach. Firstly, the optimal protection level, in case of a low unit price, couldn’t be extracted from the protection levels, as considered in the analyses. In contrast, for a high unit price an optimum was found close to -1,88 m NAP, which is higher than the -1,91 m NAP protection standard for horticulture in the Gouwepolder. This protection level results in an annual flood risk reduction from € 35,000 to € 10,000. Obviously, the total investment cost for flood protection in this strategy is lower due to the smaller construction size. Probably, a higher protection level was found due to a lower investment cost for the critical protection strategy.

Recommendations for the Waterboard:

-The bandwidth of the risk analysis results is very large due to the many uncertainities the inundation damage estimation. Therefore, the Waterboard should further examine the actual development of inundation damage for horticultural productions.

-Besides the natural soil subsidence, parcels used as open field cultivation experience additional reduction of the surface height due to removal of substrate. The AHN3 measurements are however a temporary recording in time. This means that the actual surface height of open field cultivation parcels is not precisely recorded in the AHN3 dataset. Consequently, the estimations of inundation depth and inundation extent for open field cultivation should be interpreted with caution. Local surface height measurements will be necessary to check whether these estimates are acceptable.

-This study has only examined the water level border of Koetsveld. The remaining water level borders in the Gouwepolder should be treated in the same way to identify the inundation risk and propose measures to reduce the inundation risk.

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Annexes

Annex 1

Nationaal Bestuursakkoord Water (NBW)

A more advanced assessment method is the ‘Nationaal Bestuursakkoord Water, that provides protection against water nuisance with predefined standards. The water level is assessed according to specific standards, which corresponds with the water level probability distribution. These standards differ per land-use type. The land-use types with a higher financial value are expected to be more vulnerable to higher damage costs than the ones with a lower value (table a). For example, water nuisance for meadows should be prevented for a water level that appears once every 10 year (=T10). Except for the lowest 5% of the meadow area which is permitted to inundate. The assessment of the water system with the national standards is based on the water system behaviour. First of all, the frequency distribution of the surface water levels is determined. A specific land-use type may inundate for a specific return period when the average surface level is below the water level in question (figure a).

Table a – NBW protection standards per land-use type

Tabel 2.2: werknormen regionaal wateroverlast

Normklasse gerelateerd aan grondgebruikstype	Maaiveldhoogtecriterium	Basis criterium [1/jr]
Grasland	5 procent	1/10
Akkerbouw	1 procent	1/25
Hoogwaardige land- en tuinbouw	1 procent	1/50
Glastuinbouw	1 procent	1/50
Bebouwd gebied	0 procent	1/100

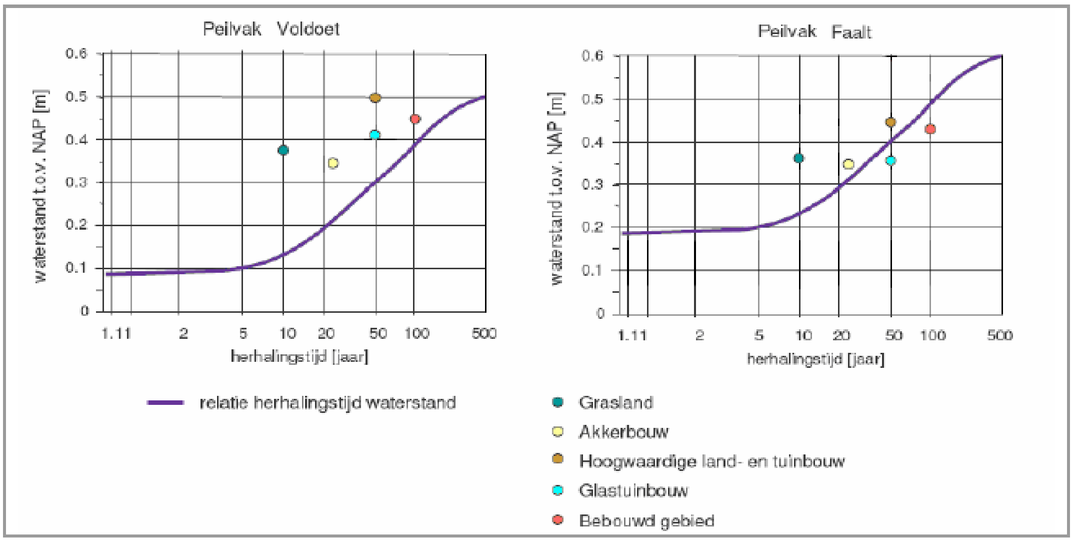


Figure a – assessment of two frequency distributions of water levels for two different water level areas. (left figure) all land-use types are sufficiently protected, (right figure) Greenhouse horticulture and residential area are flooded T50 and T100 water levels (Verhoeven, 2006)

Annex 2

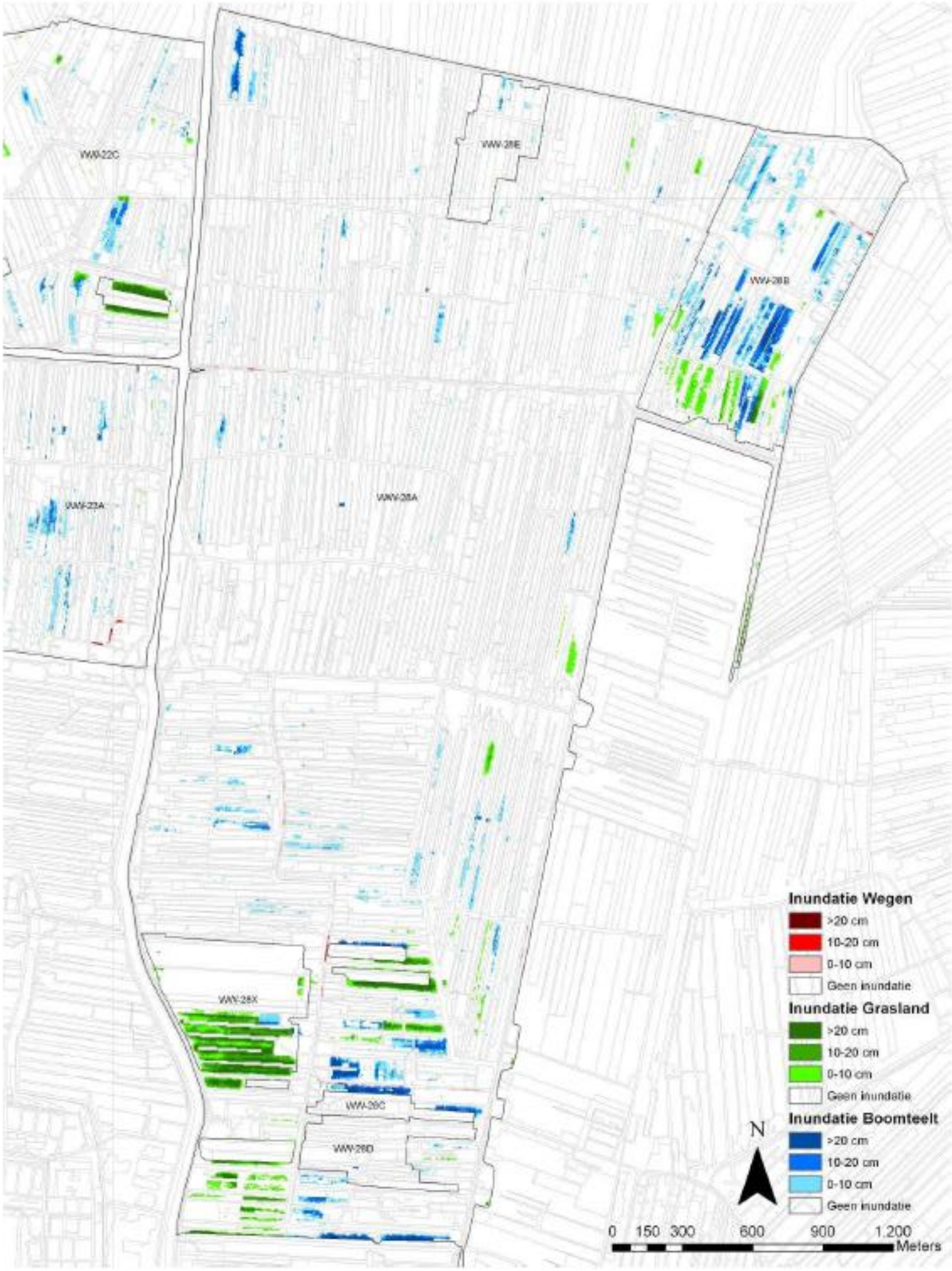


Figure c – Inundated areas according to NBW assessment Gouwepolder (note: buildings and greenhouses not included) (van Vemden-Versprille, 2013)

Annex 3

Python script used in ArcMap to simulate flood inundation maps. The input files are in bold

```
# Name:       SimulateFlood.py
# Purpose:    Simulate a Flood
#
# Source:     William A. Huber (Quantitive Decisions)
#             http://www.quantdec.com/SYSEN597/studies/flood/index.htm
#
# Created:    14-11-2013

def main():
    import arcpy,os
    arcpy.CheckOutExtension("Spatial")
    arcpy.env.workspace = r'G:\Rijnland\ArcGIS\SchadeberekeningKoetsveld\AHN_upd'

    source =
r'G:\Rijnland\ArcGIS\SchadeberekeningKoetsveld\AHN_upd\AHN_upd.gdb\Water_r_2
16'  # The source water body (raster)
    dem =
r'G:\Rijnland\ArcGIS\SchadeberekeningKoetsveld\AHN_upd\AHN_total\Selected\Selec
ted_AHN_float.gdb\AHN3_202' # The elevation DEM (raster)
    floodname = r'G:\Rijnland\ArcGIS\SchadeberekeningKoetsveld\AHN_upd\Flooding.gdb\Flood_'
# outputs

    # settings
    nSourceElevation = -2.16  # The elevation corresponding to the source body
    nFloodMax = -1.96 # The maximum flood elevation; must not be less then nSourceElevation
    nIncrement = 0.01         # The flooding elevation increment
    nExtent = 10          # Do not flood outwards more than this many cells.
    nTiny = 0.5/nExtent    # Used for limiting flood extents

    sourceRas = arcpy.Raster(source)
    demRas = arcpy.Raster(dem)

    steps = int((nFloodMax - nSourceElevation) / nIncrement) + 1
    for i in range(0,steps):
        xElevation = (i * nIncrement) + nSourceElevation
        outname = "{0}{1}".format(floodname,i)
        cost = (demRas > xElevation)+nTiny
        costdist = arcpy.sa.CostDistance(sourceRas, cost, "#", "#")
        flood = costdist <= (nExtent*nTiny)
        if arcpy.Exists(outname):
            arcpy.Delete_management(outname)
        flood.save(outname)
        sourceRas = arcpy.sa.Log10(outname) # Converts 1 to 0, 0 to NoData

    del cost, costdist, flood
    print "ready..."

if __name__ == '__main__':
    main()
```

Annex 4

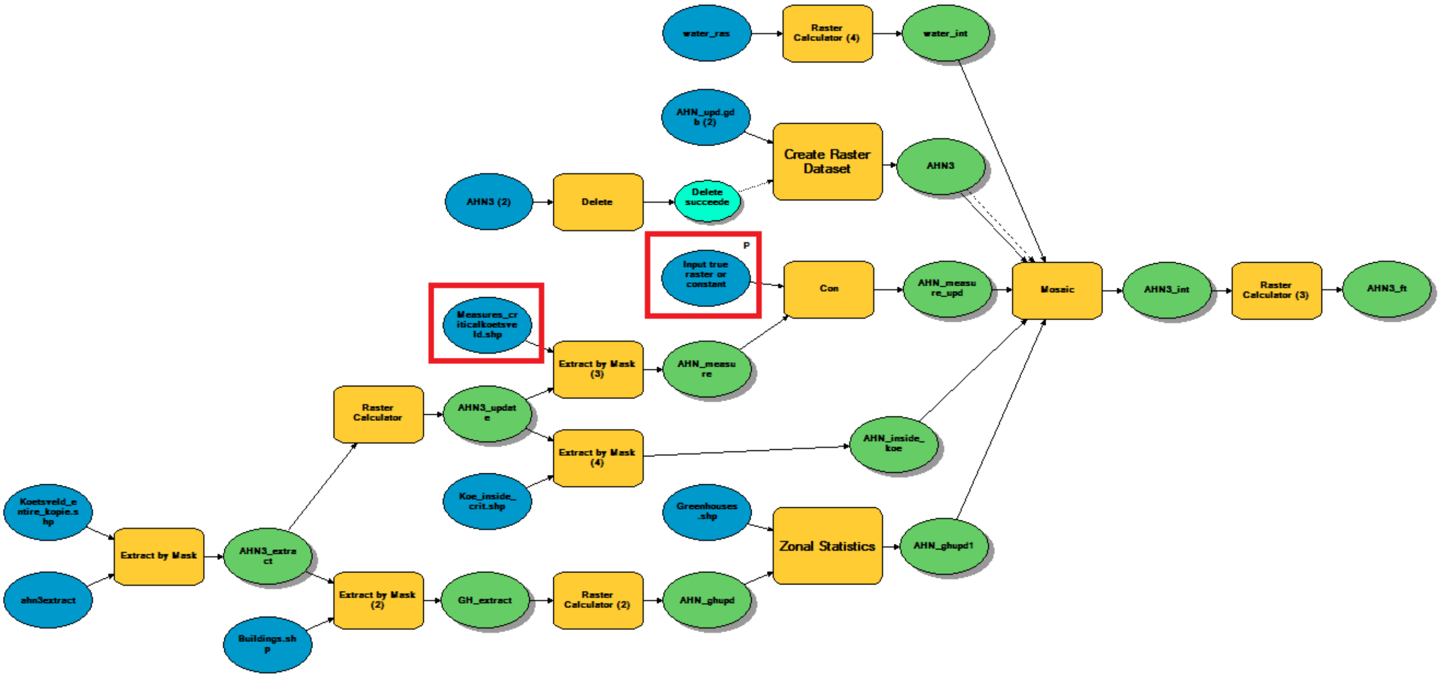
ModelBuilder script to update the water level border in the digital elevation map (DEM) to a higher protection level. The updated DEM is used as input in the Python script to simulate the inundation maps in relation to the pertinent protection level.

Parameters that can be adjusted:

-**Input true raster or constant:** *insert here the protection level of interest*
-**Measures_criticalkoetsveld.shp:** *polygon file which reflects the protection approach*

Output:

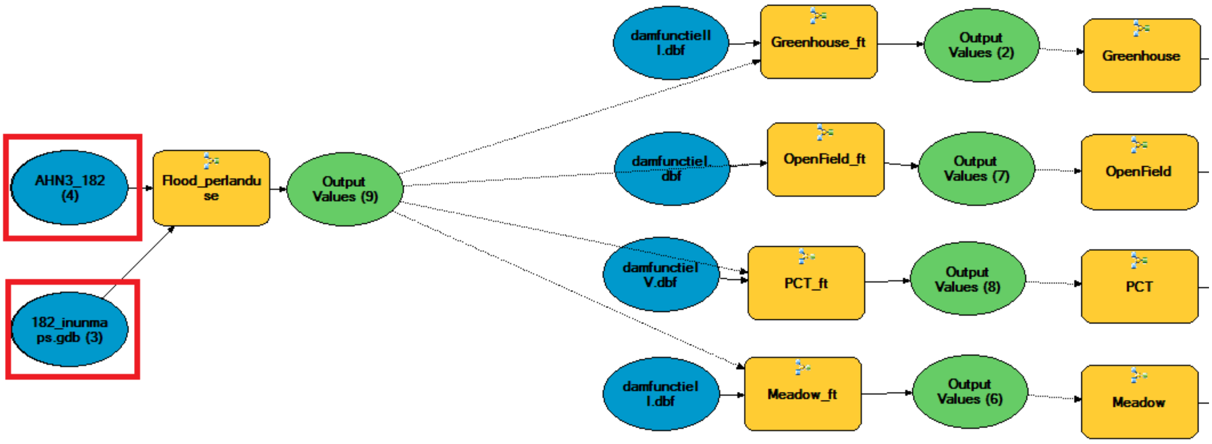
Updated DEM map which contains the new protection height in combination with the protection approach



Annex 5

Overview of the flood damage model which includes four land-use classes. For each land-use class a separate submodel was created. The aim of these sub-models is further discussed in Annex 6. The input of the model (DEM file and database with inundation maps) can be changed in the red circled boxes. The damage

Note: the final data collection steps are not included in this figure.



Annex 6

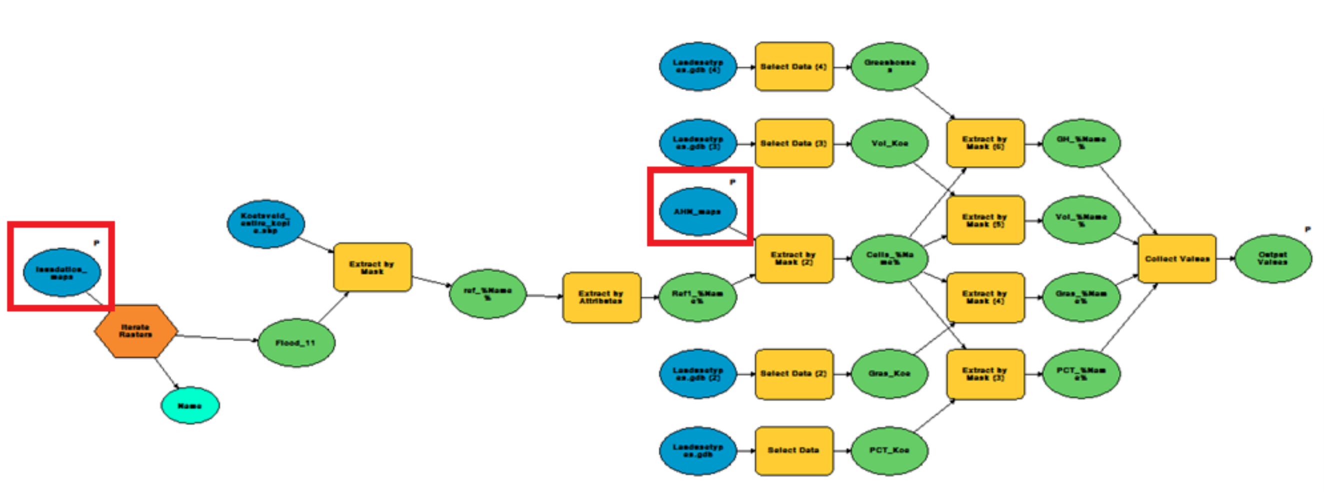
Step by step guide to calculate flood damage cost for four land-use classes (pot-and container cultivation, open field cultivation, meadow and greenhouse)

1. Simulate the DEM map according to the pertinent protection level and protection approach (Annex 4);

2. Simulate the inundation maps by inserting the DEM file from the previous simulation into the python script (Annex 3). Run Python in ArcMap. A database is created with inundation maps for several return periods.

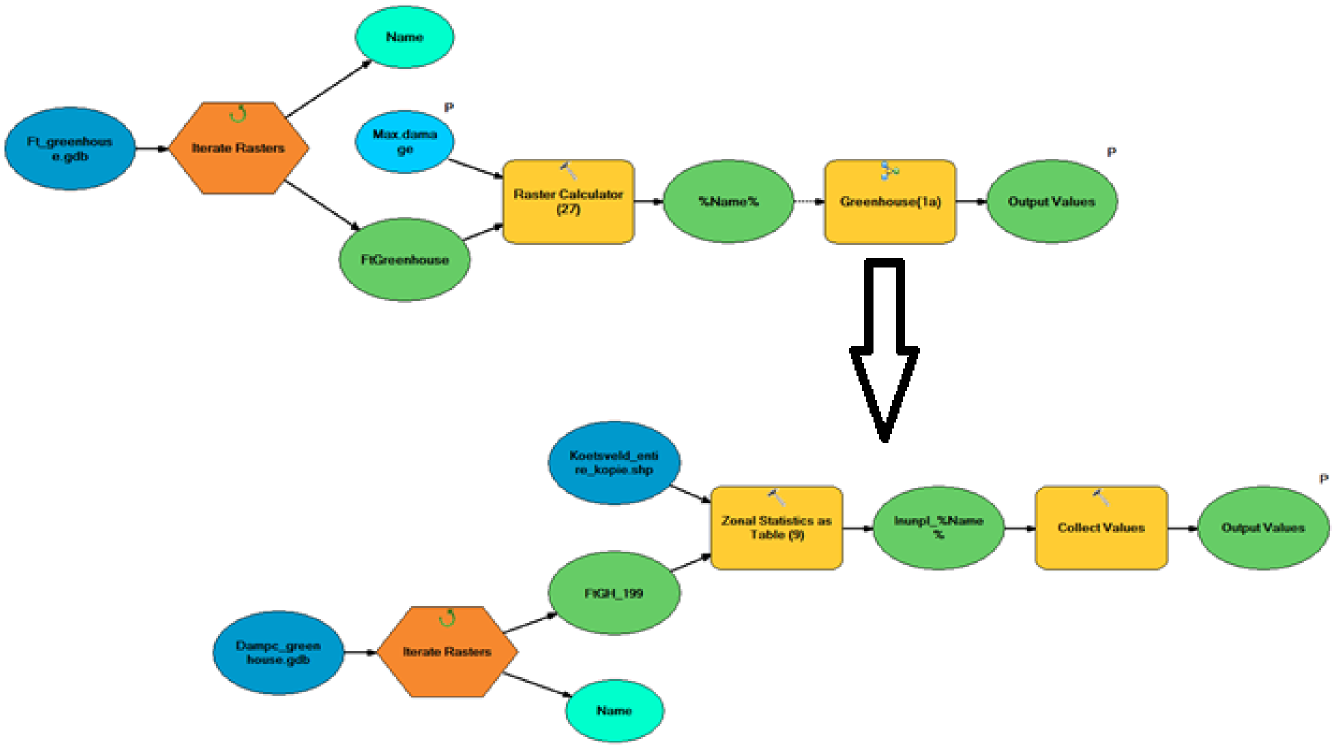
3. Simulate the flood damage per land-use by inserting the inundation maps and the updated DEM into the main damage model (Annex 5). The main model runs the sub-models for the different land-use classes automatically. The following sequence of sub-models is executed for the land-use type greenhouse. The other land-use types operate similarly, but with different parameters.

    1. *Flood_perlanduse: output is inundation depth per cel per land-use. Red boxes indicate parameters: database with inundation maps (Inundation_maps) and DEM file (AHN_maps)*



    2. *Greenhouse_ft:* conversion of inundation depth per cel into damage factor per cel for different water levels. This step has been executed with the depth-damage function for greenhouse (red box)

3. *Greenhouse:* conversion of inundation factor per cel into inundation damage per cel. Another submodel *(Greenhouse 1a*) was implemented in this model to calculate the total inundation damage for the land-use type greenhouse



Annex 7

Soft constructions		
Construction material	**Low price (€/m³)**	**High price (€/m³)**
peat	15	20
clayish peat	15	20
EPS	30	60
flugsand	30	60
lava stone	30	60
foamed concrete	30	60
Hard constructions		
Sheet piling construction	**Low price (€/m²)**	**High price (€/m²)**
wooden	40	50
synthetic	70	100
steel	90	140
composite	75	100
bamboo	25	45
Innovative construction	**Low price (€/m)**	**High price (€/m)**
Vlotterkering	1000	2500
Self Closing Flood Barrier	1000	2500

Annex 8

Lava rock

Currently, the cultivation floor for the pot-and container production is constructed with a small layer of crumbled lava rock. Lava rock is very porous with a high water permeability and therefore applied frequently in this type of cultivation floor. The volume weight of lavastone varies between 10 kN/m3 and 12 kN/m3, which is similar to peat (Deltares, 2009). But the cost price may considerably higher: starting from 40 euro/m3 up 60 euro/m3.

source: http://www.gravelart.be/nl/product/gesteente/lava/lava-816-en-1632

Flugsand

Flugsand has been composed of smaller grains than lava rock and with a lower water permeability. The volume weight of flugsand varies significantly. The Eifellith-Lava 0/40 type may be compared with the volume weight of standardal sand; the volume weight varies between 14 kN/m3 (without water absorption) up to 18,5 kN/m3 (with water absorption). On the contrary, the Porodur lava 16/32 may be compared with peat or clayish peat. The volume weight starts from 10,5 kN/m3 (without water absorption) up to 12,0 kN/m3 (with water absorption) (Deltares, 2009).

source: http://www.derooijzand.nl/producten/flugsand

Expanded Polysterene (EPS)

EPS is a synthetic insulating material that is almost 80 times lighter than sand (0,2 kN/m3 vs 18 kN/m3) and is frequently used for road constructions in areas with high settlement rates (Deltares, 2009). Two types of EPS are distinguished: the EPS 15 and EPS 20 variant with a dry volume weight of 0,15 kN/m3 and 0,2 kN/m3 respectively. The absorption of water by EPS is relatively small for EPS 15 and 20: 3% v/v and 2% v/v respectively (Deltares, 2009). Though the material contains more air than solid material, the cost price for EPS 15 and 20 fluctuates between 40 euro/m3 and 50 euro/m3 respectively. This is more than 2,5 times the average cost price of peat (15 euro/m3).

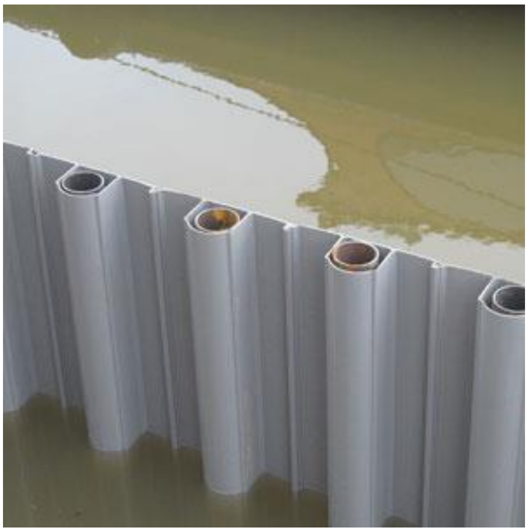
Source: http://www.eps.co.uk/sustainability/sustainability_credentials.html

Foam concrete

Foam concrete is a mixture of cement, a fraction of sand and water with a foaming agent. It has a volumeweight that varies between 4 and 6 kN/m3; heavier than EPS but lighter than for example peat (10,3 kN/m3). Foam concrete has compare to EPS a higher water absorption when it is applied below the ground water level, varying from ca. 10% v/v for 6 kN/m3 up to 15% v/v for 4 kN/m3. When applied above the ground water table this is 10% v/v and 7% v/v respectively. Foam concrete has been previously applied for the reconstruction of the road (N207) along the Gouwe in Boskoop (Innovatievematerialen, 2015).

Source:
http://www.innovatievematerialen.nl/index.php/dijkverbreding_met_ZAP_elementen?id=252

Annex 9

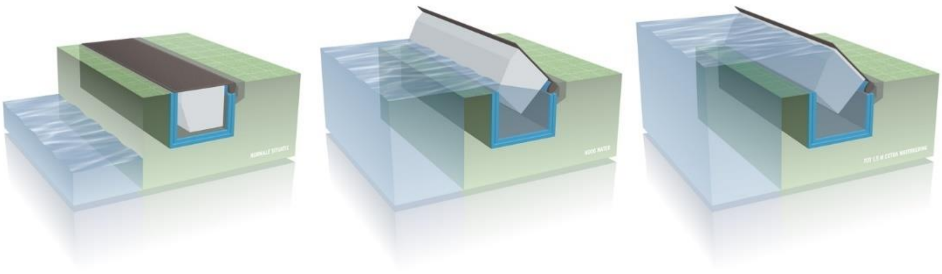


examples of sheet piling walls: (top left) wooden http://glasgroen.nl/waterbouw/) ; (top right) steel (http://www.wijdeven.net/damwanden/) ; (middle left) composite http://www.hisixsur.com/ ; (middle right) bamboo sheet piling (https://www.deckx.nl/project/63/Damwand, Woerden/; (bottom left) synthethic (http://www.prolock.nl/ons_bedrijf/over_prolock/)

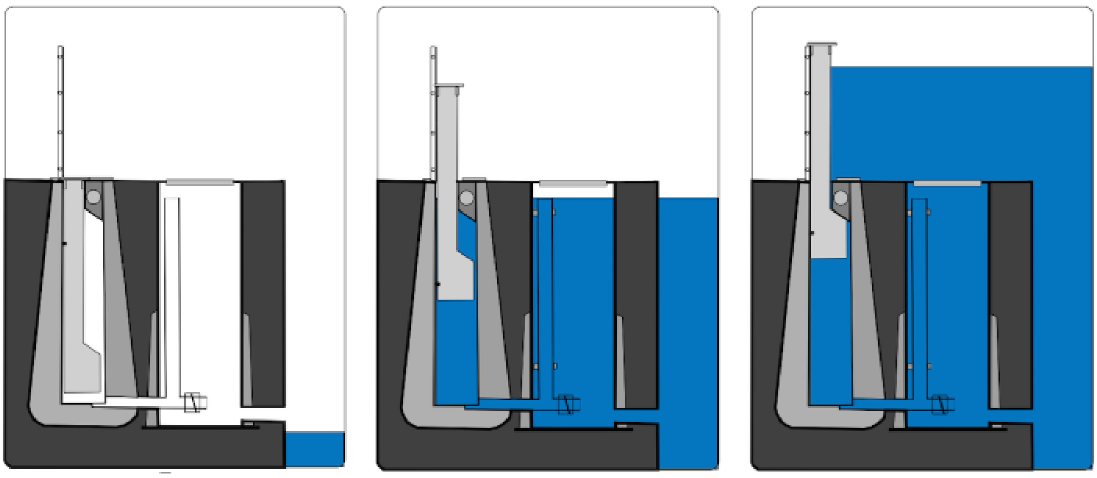
Annex 10

Vlotterkering and Self Closing Flood Barrier (SCFB)

The Vlotterkering is an innovative solution that creates a temporary dike profile along a water course. It only appears when the water level exceeds a critical level. The construction is characterized by a flexible squared element, which floats upwards when the water level increases. The light weight element that is present in the concrete box is forced to move upwards when the water flows into the concrete box. This creates a temporary higher protection height'dike' that is able to protect the lower parcels from a rising water level. The element returns into the box after the water level is restored to a normal level. The Vlotterkering was originally designed for a temporal water retaining project for the Water Board of Delfland, but have not been implemented yet. The functionality and confidentiality has comprehensively been tested with a testing site on a dredging depot in Hoek van Holland (Grontmij, 2014). The exact costs numbers for construction and maintenance cannot not be given precisely, but based on the investment costs of the current test location it may vary from 1000 euro/m up to 4500 euro p/m.



The operation of the SCFB is based on the same principle as the Vlotterkering, but has slightly differences in the design. The construction has a more compact design as the element that flows upward is more flat than the Vlotterkering. A lifespan is guaranteed of minimal 50 years, increasing up to 100 years with regular maintenance (Self Closing Flood Barrier, 2016). This concept has been applied previously in several European countries. Currently, the historical centre of Spakenburg in the Netherlands is protected with the longest flexible protection dam in the world (GWW totaal, 2016). Unfortunately, exact numbers related to the investment lack in the literature, but it is expected that they are more or less equal to the Vlotterkering.



Annex 11

Inundation observations parcel owners Koetsveld after rainfall event June 2014

Parcel owner	Water level border critical according to height measurements?	Experienced water nuisance from Gouwepolder surface water system?	What was inundated and for how long?
A. Blanken	Not critical at the southern border	Yes, but owner doubts about the origin of the flooding.	Entire parcel, including greenhouses, were flooded. After 24 hours the parcels were cleared
A. Looman	Yes, but mainly at the north-east side	Yes, especially from the border in the South	Entire parcel, including greenhouse. Also, inundation from the southern location. Embankment probably subsided due to storage of heavy equipment
B. Blanken	Not part of Koetsveld	No, but flooding is related to the issues in Koetsveld. Looman pumps water towards the Gouwepolder. Culvert is blocked below Halve Raak, therefore water discharge is forced towards the north	Parcel has been inundated, the extent is unknown
B. Rijnbeek	No, the northern and western border are sufficient	Yes, but the owner was not sure whether the flooding originated from the higher surface water system	Almost entire parcel. Troubles with removing the water from the parcels.
J. van Dam	Yes, the border is partly critical	Yes, but the assumption that the southern dam failed is not very likely.	Entire parcel was inundated, but production (ilexen) are water resistance. The parcel was cleared from water after 24-48 hours.
S. van Dam	No	No, but experienced other types of flooding	Part of the nursery and front garden.
T. Verbakel	No	No	No
V. Hooftman	Yes, the northern border	Yes, this was observed by the owner	Parcel was inundated, but the water was quickly removed
W.F. van Waaij	Yes, the northern border	Yes, this was observed by the owner	Parcel was completely inundated. Inundation depth circa 5-10 centimeters. After 24 hours

Annex 12

Full protection approach *-1,91 NAP protection height* - Overview of the average annual total costs & benefits of a 30 year analysis period. Note: NPV = present expected benefits - present costs

Group 1	Group 2	Group 3						
Open field, meadow private, greenzone, paved,	PCT	Greenhouse	Present expected benefits	Present expected damage	Present costs (low)	Present costs (high)	NPV (low)	NPV (high)
clayish peat	EPS	bamboo	€ 15.960,00	€ 13.320,31	€ 11.949,49	€ 17.907,20	€ 4.010,51	€ -1.947,20
clayish peat	foam concrete	bamboo	€ 15.960,00	€ 13.320,31	€ 11.949,49	€ 17.907,20	€ 4.010,51	€ -1.947,20
clayish peat	EPS	wooden	€ 15.960,00	€ 13.320,31	€ 12.213,01	€ 17.995,04	€ 3.747,00	€ -2.035,04
clayish peat	foam concrete	wooden	€ 15.960,00	€ 13.320,31	€ 12.213,01	€ 17.995,04	€ 3.747,00	€ -2.035,04
clayish peat	EPS	synthetic	€ 15.960,00	€ 13.320,31	€ 12.259,29	€ 18.186,65	€ 3.700,71	€ -2.226,64
clayish peat	foam concrete	synthetic	€ 15.960,00	€ 13.320,31	€ 12.259,29	€ 18.186,65	€ 3.700,71	€ -2.226,64
clayish peat	flugsand	bamboo	€ 15.960,00	€ 13.320,31	€ 12.361,03	€ 18.730,28	€ 3.598,98	€ -2.770,28
clayish peat	lava stone	bamboo	€ 15.960,00	€ 13.320,31	€ 12.361,03	€ 18.730,28	€ 3.598,98	€ -2.770,28
clayish peat	EPS	steel	€ 15.960,00	€ 13.320,31	€ 12.473,29	€ 18.614,65	€ 3.486,71	€ -2.654,64
clayish peat	foam concrete	steel	€ 15.960,00	€ 13.320,31	€ 12.473,29	€ 18.614,65	€ 3.486,71	€ -2.654,64
clayish peat	flugsand	wooden	€ 15.960,00	€ 13.320,31	€ 12.624,55	€ 18.818,12	€ 3.335,46	€ -2.858,12
clayish peat	lava stone	wooden	€ 15.960,00	€ 13.320,31	€ 12.624,55	€ 18.818,12	€ 3.335,46	€ -2.858,12
clayish peat	flugsand	synthetic	€ 15.960,00	€ 13.320,31	€ 12.670,83	€ 19.009,72	€ 3.289,17	€ -3.049,72
clayish peat	lava stone	synthetic	€ 15.960,00	€ 13.320,31	€ 12.670,83	€ 19.009,72	€ 3.289,17	€ -3.049,72
clayish peat	flugsand	steel	€ 15.960,00	€ 13.320,31	€ 12.884,83	€ 19.437,72	€ 3.075,17	€ -3.477,72
clayish peat	lava stone	steel	€ 15.960,00	€ 13.320,31	€ 12.884,83	€ 19.437,72	€ 3.075,17	€ -3.477,72
peat	EPS	bamboo	€ 15.292,15	€ 13.988,17	€ 12.345,94	€ 18.488,67	€ 2.946,21	€ -3.196,53
peat	foam concrete	bamboo	€ 15.292,15	€ 13.988,17	€ 12.345,94	€ 18.488,67	€ 2.946,21	€ -3.196,53
clayish peat	EPS	composite	€ 15.960,00	€ 13.320,31	€ 13.115,29	€ 19.256,65	€ 2.844,71	€ -3.296,64
clayish peat	foam concrete	composite	€ 15.960,00	€ 13.320,31	€ 13.115,29	€ 19.256,65	€ 2.844,71	€ -3.296,64
peat	EPS	wooden	€ 15.292,15	€ 13.988,17	€ 12.609,46	€ 18.576,51	€ 2.682,69	€ -3.284,37
peat	foam concrete	wooden	€ 15.292,15	€ 13.988,17	€ 12.609,46	€ 18.576,51	€ 2.682,69	€ -3.284,37
peat	EPS	synthetic	€ 15.292,15	€ 13.988,17	€ 12.655,74	€ 18.768,12	€ 2.636,41	€ -3.475,97
peat	foam concrete	synthetic	€ 15.292,15	€ 13.988,17	€ 12.655,74	€ 18.768,12	€ 2.636,41	€ -3.475,97
peat	flugsand	bamboo	€ 15.292,15	€ 13.988,17	€ 12.757,48	€ 19.311,75	€ 2.534,67	€ -4.019,61
peat	lava stone	bamboo	€ 15.292,15	€ 13.988,17	€ 12.757,48	€ 19.311,75	€ 2.534,67	€ -4.019,61
clayish peat	flugsand	composite	€ 15.960,00	€ 13.320,31	€ 13.526,83	€ 20.079,72	€ 2.433,17	€ -4.119,72
clayish peat	lava stone	composite	€ 15.960,00	€ 13.320,31	€ 13.526,83	€ 20.079,72	€ 2.433,17	€ -4.119,72
peat	EPS	steel	€ 15.292,15	€ 13.988,17	€ 12.869,74	€ 19.196,12	€ 2.422,41	€ -3.903,97
peat	foam concrete	steel	€ 15.292,15	€ 13.988,17	€ 12.869,74	€ 19.196,12	€ 2.422,41	€ -3.903,97
peat	flugsand	wooden	€ 15.292,15	€ 13.988,17	€ 13.020,99	€ 19.399,59	€ 2.271,15	€ -4.107,45
peat	lava stone	wooden	€ 15.292,15	€ 13.988,17	€ 13.020,99	€ 19.399,59	€ 2.271,15	€ -4.107,45
peat	flugsand	synthetic	€ 15.292,15	€ 13.988,17	€ 13.067,28	€ 19.591,19	€ 2.224,87	€ -4.299,05
peat	lava stone	synthetic	€ 15.292,15	€ 13.988,17	€ 13.067,28	€ 19.591,19	€ 2.224,87	€ -4.299,05
peat	flugsand	steel	€ 15.292,15	€ 13.988,17	€ 13.281,28	€ 20.019,19	€ 2.010,87	€ -4.727,05
peat	lava stone	steel	€ 15.292,15	€ 13.988,17	€ 13.281,28	€ 20.019,19	€ 2.010,87	€ -4.727,05
peat	EPS	composite	€ 15.292,15	€ 13.988,17	€ 13.511,74	€ 19.838,12	€ 1.780,41	€ -4.545,97
peat	foam concrete	composite	€ 15.292,15	€ 13.988,17	€ 13.511,74	€ 19.838,12	€ 1.780,41	€ -4.545,97
peat	flugsand	composite	€ 15.292,15	€ 13.988,17	€ 13.923,28	€ 20.661,19	€ 1.368,87	€ -5.369,05
peat	lava stone	composite	€ 15.292,15	€ 13.988,17	€ 13.923,28	€ 20.661,19	€ 1.368,87	€ -5.369,05
clayish peat	clayish peat (pct	bamboo	€ 13.152,57	€ 16.127,74	€ 11.838,70	€ 15.838,97	€ 1.313,87	€ -2.686,40
clayish peat	clayish peat (pct	wooden	€ 13.152,57	€ 16.127,74	€ 12.102,22	€ 15.926,81	€ 1.050,35	€ -2.774,24
clayish peat	clayish peat (pct	synthetic	€ 13.152,57	€ 16.127,74	€ 12.148,50	€ 16.118,42	€ 1.004,07	€ -2.965,85
clayish peat	EPS	SCFB	€ 15.960,00	€ 13.320,31	€ 15.076,96	€ 26.033,31	€ 883,05	€ -10.073,31
clayish peat	foam concrete	SCFB	€ 15.960,00	€ 13.320,31	€ 15.076,96	€ 26.033,31	€ 883,05	€ -10.073,31
clayish peat	EPS	vlotterkering	€ 15.960,00	€ 13.320,31	€ 15.076,96	€ 26.033,31	€ 883,05	€ -10.073,31
clayish peat	foam concrete	vlotterkering	€ 15.960,00	€ 13.320,31	€ 15.076,96	€ 26.033,31	€ 883,05	€ -10.073,31
clayish peat	clayish peat (pct	steel	€ 13.152,57	€ 16.127,74	€ 12.362,50	€ 16.546,42	€ 790,07	€ -3.393,85
clayish peat	peat (pct)	bamboo	€ 12.442,18	€ 16.838,13	€ 11.968,73	€ 16.012,35	€ 473,45	€ -3.570,17
clayish peat	flugsand	SCFB	€ 15.960,00	€ 13.320,31	€ 15.488,50	€ 26.856,39	€ 471,51	€ -10.896,39
clayish peat	lava stone	SCFB	€ 15.960,00	€ 13.320,31	€ 15.488,50	€ 26.856,39	€ 471,51	€ -10.896,39
clayish peat	flugsand	vlotterkering	€ 15.960,00	€ 13.320,31	€ 15.488,50	€ 26.856,39	€ 471,51	€ -10.896,39
clayish peat	lava stone	vlotterkering	€ 15.960,00	€ 13.320,31	€ 15.488,50	€ 26.856,39	€ 471,51	€ -10.896,39
peat	clayish peat (pct	bamboo	€ 12.484,71	€ 16.795,60	€ 12.235,15	€ 16.420,44	€ 249,56	€ -3.935,73
clayish peat	peat (pct)	wooden	€ 12.442,18	€ 16.838,13	€ 12.232,25	€ 16.100,19	€ 209,93	€ -3.658,01
clayish peat	peat (pct)	synthetic	€ 12.442,18	€ 16.838,13	€ 12.278,53	€ 16.291,79	€ 163,65	€ -3.849,61
clayish peat	clayish peat (pct	composite	€ 13.152,57	€ 16.127,74	€ 13.004,50	€ 17.188,42	€ 148,07	€ -4.035,85
peat	clayish peat (pct	wooden	€ 12.484,71	€ 16.795,60	€ 12.498,67	€ 16.508,28	€ -13,96	€ -4.023,57
clayish peat	peat (pct)	steel	€ 12.442,18	€ 16.838,13	€ 12.492,53	€ 16.719,79	€ -50,35	€ -4.277,61
peat	clayish peat (pct	synthetic	€ 12.484,71	€ 16.795,60	€ 12.544,95	€ 16.699,89	€ -60,24	€ -4.215,17
peat	EPS	SCFB	€ 15.292,15	€ 13.988,17	€ 15.473,41	€ 26.614,78	€ -181,26	€ -11.322,64
peat	foam concrete	SCFB	€ 15.292,15	€ 13.988,17	€ 15.473,41	€ 26.614,78	€ -181,26	€ -11.322,64
peat	EPS	vlotterkering	€ 15.292,15	€ 13.988,17	€ 15.473,41	€ 26.614,78	€ -181,26	€ -11.322,64
peat	foam concrete	vlotterkering	€ 15.292,15	€ 13.988,17	€ 15.473,41	€ 26.614,78	€ -181,26	€ -11.322,64
peat	clayish peat (pct	steel	€ 12.484,71	€ 16.795,60	€ 12.758,95	€ 17.127,89	€ -274,24	€ -4.643,17
peat	peat (pct)	bamboo	€ 11.774,32	€ 17.505,99	€ 12.365,18	€ 16.593,82	€ -590,86	€ -4.819,49
peat	flugsand	SCFB	€ 15.292,15	€ 13.988,17	€ 15.884,94	€ 27.437,86	€ -592,80	€ -12.145,72
peat	lava stone	SCFB	€ 15.292,15	€ 13.988,17	€ 15.884,94	€ 27.437,86	€ -592,80	€ -12.145,72
peat	flugsand	vlotterkering	€ 15.292,15	€ 13.988,17	€ 15.884,94	€ 27.437,86	€ -592,80	€ -12.145,72
peat	lava stone	vlotterkering	€ 15.292,15	€ 13.988,17	€ 15.884,94	€ 27.437,86	€ -592,80	€ -12.145,72
clayish peat	peat (pct)	composite	€ 12.442,18	€ 16.838,13	€ 13.134,53	€ 17.361,79	€ -692,35	€ -4.919,61
peat	peat (pct)	wooden	€ 11.774,32	€ 17.505,99	€ 12.628,70	€ 16.681,66	€ -854,38	€ -4.907,33
peat	peat (pct)	synthetic	€ 11.774,32	€ 17.505,99	€ 12.674,98	€ 16.873,26	€ -900,66	€ -5.098,94
peat	clayish peat (pct	composite	€ 12.484,71	€ 16.795,60	€ 13.400,95	€ 17.769,89	€ -916,24	€ -5.285,17
peat	peat (pct)	steel	€ 11.774,32	€ 17.505,99	€ 12.888,98	€ 17.301,26	€ -1.114,66	€ -5.526,94
peat	peat (pct)	composite	€ 11.774,32	€ 17.505,99	€ 13.530,98	€ 17.943,26	€ -1.756,66	€ -6.168,94
clayish peat	clayish peat (pct	SCFB	€ 13.152,57	€ 16.127,74	€ 14.966,17	€ 23.965,08	€ -1.813,60	€ -10.812,51
clayish peat	clayish peat (pct	vlotterkering	€ 13.152,57	€ 16.127,74	€ 14.966,17	€ 23.965,08	€ -1.813,60	€ -10.812,51
clayish peat	peat (pct)	SCFB	€ 12.442,18	€ 16.838,13	€ 15.096,20	€ 24.138,46	€ -2.654,02	€ -11.696,28
clayish peat	peat (pct)	vlotterkering	€ 12.442,18	€ 16.838,13	€ 15.096,20	€ 24.138,46	€ -2.654,02	€ -11.696,28
peat	clayish peat (pct	SCFB	€ 12.484,71	€ 16.795,60	€ 15.362,62	€ 24.546,55	€ -2.877,91	€ -12.061,84
peat	clayish peat (pct	vlotterkering	€ 12.484,71	€ 16.795,60	€ 15.362,62	€ 24.546,55	€ -2.877,91	€ -12.061,84
peat	peat (pct)	SCFB	€ 11.774,32	€ 17.505,99	€ 15.492,65	€ 24.719,93	€ -3.718,33	€ -12.945,60
peat	peat (pct)	vlotterkering	€ 11.774,32	€ 17.505,99	€ 15.492,65	€ 24.719,93	€ -3.718,33	€ -12.945,60

Full protection approach *-1,88 NAP protection height* - Overview of the average annual total costs & benefits of a 30 year analysis period. Note: NPV = present expected benefits - present costs								
Group 1	Group 2	Group 3						
Open field, meadow private,	PCT	Greenhouse	Present expected benefits	Present expected damage	Present costs (low)	Present costs (high)	NPV (low)	NPV (high)
clayish peat	EPS	bamboo	€ 18.705,00	€ 10.575,31	€ 15.240,80	€ 22.559,20	€ 3.464,20	€ -3.854,20
clayish peat	foam concrete	bamboo	€ 18.705,00	€ 10.575,31	€ 15.240,80	€ 22.559,20	€ 3.464,20	€ -3.854,20
clayish peat	EPS	wooden	€ 18.705,00	€ 10.575,31	€ 15.504,32	€ 22.647,04	€ 3.200,68	€ -3.942,04
clayish peat	foam concrete	wooden	€ 18.705,00	€ 10.575,31	€ 15.504,32	€ 22.647,04	€ 3.200,68	€ -3.942,04
clayish peat	EPS	synthetic	€ 18.705,00	€ 10.575,31	€ 15.550,60	€ 22.838,64	€ 3.154,40	€ -4.133,64
clayish peat	foam concrete	synthetic	€ 18.705,00	€ 10.575,31	€ 15.550,60	€ 22.838,64	€ 3.154,40	€ -4.133,64
clayish peat	EPS	steel	€ 18.705,00	€ 10.575,31	€ 15.764,60	€ 23.266,64	€ 2.940,40	€ -4.561,64
clayish peat	foam concrete	steel	€ 18.705,00	€ 10.575,31	€ 15.764,60	€ 23.266,64	€ 2.940,40	€ -4.561,64
clayish peat	flugsand	bamboo	€ 18.705,00	€ 10.575,31	€ 15.652,34	€ 23.382,28	€ 3.052,66	€ -4.677,27
clayish peat	lava stone	bamboo	€ 18.705,00	€ 10.575,31	€ 15.652,34	€ 23.382,28	€ 3.052,66	€ -4.677,27
clayish peat	clayish peat (pct)	bamboo	€ 16.252,34	€ 13.027,97	€ 15.669,18	€ 20.935,50	€ 583,16	€ -4.683,16
clayish peat	flugsand	wooden	€ 18.705,00	€ 10.575,31	€ 15.915,86	€ 23.470,12	€ 2.789,15	€ -4.765,11
clayish peat	lava stone	wooden	€ 18.705,00	€ 10.575,31	€ 15.915,86	€ 23.470,12	€ 2.789,15	€ -4.765,11
clayish peat	clayish peat (pct)	wooden	€ 16.252,34	€ 13.027,97	€ 15.932,70	€ 21.023,34	€ 319,64	€ -4.771,00
clayish peat	flugsand	synthetic	€ 18.705,00	€ 10.575,31	€ 15.962,14	€ 23.661,72	€ 2.742,86	€ -4.956,72
clayish peat	lava stone	synthetic	€ 18.705,00	€ 10.575,31	€ 15.962,14	€ 23.661,72	€ 2.742,86	€ -4.956,72
clayish peat	clayish peat (pct)	synthetic	€ 16.252,34	€ 13.027,97	€ 15.978,98	€ 21.214,94	€ 273,36	€ -4.962,60
clayish peat	EPS	composite	€ 18.705,00	€ 10.575,31	€ 16.406,60	€ 23.908,64	€ 2.298,40	€ -5.203,64
clayish peat	foam concrete	composite	€ 18.705,00	€ 10.575,31	€ 16.406,60	€ 23.908,64	€ 2.298,40	€ -5.203,64
clayish peat	flugsand	steel	€ 18.705,00	€ 10.575,31	€ 16.176,14	€ 24.089,72	€ 2.528,86	€ -5.384,72
clayish peat	lava stone	steel	€ 18.705,00	€ 10.575,31	€ 16.176,14	€ 24.089,72	€ 2.528,86	€ -5.384,72
clayish peat	clayish peat (pct)	steel	€ 16.252,34	€ 13.027,97	€ 16.192,98	€ 21.642,94	€ 59,36	€ -5.390,60
peat	EPS	bamboo	€ 18.072,39	€ 11.207,92	€ 16.061,05	€ 23.670,48	€ 2.011,34	€ -5.598,09
peat	foam concrete	bamboo	€ 18.072,39	€ 11.207,92	€ 16.061,05	€ 23.670,48	€ 2.011,34	€ -5.598,09
peat	EPS	wooden	€ 18.072,39	€ 11.207,92	€ 16.324,57	€ 23.758,32	€ 1.747,82	€ -5.685,93
peat	foam concrete	wooden	€ 18.072,39	€ 11.207,92	€ 16.324,57	€ 23.758,32	€ 1.747,82	€ -5.685,93
clayish peat	peat (pct)	bamboo	€ 15.573,80	€ 13.706,51	€ 15.938,21	€ 21.294,21	€ -364,41	€ -5.720,40
clayish peat	peat (pct)	wooden	€ 15.573,80	€ 13.706,51	€ 16.201,73	€ 21.382,05	€ -627,93	€ -5.808,24
peat	EPS	synthetic	€ 18.072,39	€ 11.207,92	€ 16.370,85	€ 23.949,92	€ 1.701,54	€ -5.877,53
peat	foam concrete	synthetic	€ 18.072,39	€ 11.207,92	€ 16.370,85	€ 23.949,92	€ 1.701,54	€ -5.877,53
clayish peat	peat (pct)	synthetic	€ 15.573,80	€ 13.706,51	€ 16.248,02	€ 21.573,65	€ -674,21	€ -5.999,85
clayish peat	flugsand	composite	€ 18.705,00	€ 10.575,31	€ 16.818,14	€ 24.731,72	€ 1.886,86	€ -6.026,72
clayish peat	lava stone	composite	€ 18.705,00	€ 10.575,31	€ 16.818,14	€ 24.731,72	€ 1.886,86	€ -6.026,72
clayish peat	clayish peat (pct)	composite	€ 16.252,34	€ 13.027,97	€ 16.834,98	€ 22.284,94	€ -582,64	€ -6.032,60
peat	EPS	steel	€ 18.072,39	€ 11.207,92	€ 16.584,85	€ 24.377,92	€ 1.487,54	€ -6.305,53
peat	foam concrete	steel	€ 18.072,39	€ 11.207,92	€ 16.584,85	€ 24.377,92	€ 1.487,54	€ -6.305,53
peat	flugsand	bamboo	€ 18.072,39	€ 11.207,92	€ 16.472,59	€ 24.493,55	€ 1.599,80	€ -6.421,16
peat	lava stone	bamboo	€ 18.072,39	€ 11.207,92	€ 16.472,59	€ 24.493,55	€ 1.599,80	€ -6.421,16
peat	clayish peat (pct)	bamboo	€ 15.619,73	€ 13.660,58	€ 16.489,43	€ 22.046,78	€ -869,70	€ -6.427,05
clayish peat	peat (pct)	steel	€ 15.573,80	€ 13.706,51	€ 16.462,02	€ 22.001,65	€ -888,21	€ -6.427,85
peat	flugsand	wooden	€ 18.072,39	€ 11.207,92	€ 16.736,10	€ 24.581,39	€ 1.336,28	€ -6.509,00
peat	lava stone	wooden	€ 18.072,39	€ 11.207,92	€ 16.736,10	€ 24.581,39	€ 1.336,28	€ -6.509,00
peat	clayish peat (pct)	wooden	€ 15.619,73	€ 13.660,58	€ 16.752,95	€ 22.134,61	€ -1.133,22	€ -6.514,89
peat	flugsand	synthetic	€ 18.072,39	€ 11.207,92	€ 16.782,39	€ 24.773,00	€ 1.290,00	€ -6.700,61
peat	lava stone	synthetic	€ 18.072,39	€ 11.207,92	€ 16.782,39	€ 24.773,00	€ 1.290,00	€ -6.700,61
peat	clayish peat (pct)	synthetic	€ 15.619,73	€ 13.660,58	€ 16.799,23	€ 22.326,22	€ -1.179,50	€ -6.706,49
peat	EPS	composite	€ 18.072,39	€ 11.207,92	€ 17.226,85	€ 25.019,92	€ 845,54	€ -6.947,53
peat	foam concrete	composite	€ 18.072,39	€ 11.207,92	€ 17.226,85	€ 25.019,92	€ 845,54	€ -6.947,53
clayish peat	peat (pct)	composite	€ 15.573,80	€ 13.706,51	€ 17.104,02	€ 22.643,65	€ -1.530,21	€ -7.069,85
peat	flugsand	steel	€ 18.072,39	€ 11.207,92	€ 16.996,39	€ 25.201,00	€ 1.076,00	€ -7.128,61
peat	lava stone	steel	€ 18.072,39	€ 11.207,92	€ 16.996,39	€ 25.201,00	€ 1.076,00	€ -7.128,61
peat	clayish peat (pct)	steel	€ 15.619,73	€ 13.660,58	€ 17.013,23	€ 22.754,22	€ -1.393,50	€ -7.134,49
peat	peat (pct)	bamboo	€ 14.941,19	€ 14.339,12	€ 16.758,46	€ 22.405,48	€ -1.817,27	€ -7.464,30
peat	peat (pct)	wooden	€ 14.941,19	€ 14.339,12	€ 17.021,98	€ 22.493,32	€ -2.080,79	€ -7.552,14
peat	peat (pct)	synthetic	€ 14.941,19	€ 14.339,12	€ 17.068,26	€ 22.684,93	€ -2.127,07	€ -7.743,74
peat	flugsand	composite	€ 18.072,39	€ 11.207,92	€ 17.638,39	€ 25.843,00	€ 434,00	€ -7.770,61
peat	lava stone	composite	€ 18.072,39	€ 11.207,92	€ 17.638,39	€ 25.843,00	€ 434,00	€ -7.770,61
peat	clayish peat (pct)	composite	€ 15.619,73	€ 13.660,58	€ 17.655,23	€ 23.396,22	€ -2.035,50	€ -7.776,49
peat	peat (pct)	steel	€ 14.941,19	€ 14.339,12	€ 17.282,26	€ 23.112,93	€ -2.341,07	€ -8.171,74
peat	peat (pct)	composite	€ 14.941,19	€ 14.339,12	€ 17.924,26	€ 23.754,93	€ -2.983,07	€ -8.813,74
clayish peat	EPS	SCFB	€ 18.705,00	€ 10.575,31	€ 18.368,27	€ 30.685,31	€ 336,73	€ -11.980,31
clayish peat	foam concrete	SCFB	€ 18.705,00	€ 10.575,31	€ 18.368,27	€ 30.685,31	€ 336,73	€ -11.980,31
clayish peat	EPS	vlotterkering	€ 18.705,00	€ 10.575,31	€ 18.368,27	€ 30.685,31	€ 336,73	€ -11.980,31
clayish peat	foam concrete	vlotterkering	€ 18.705,00	€ 10.575,31	€ 18.368,27	€ 30.685,31	€ 336,73	€ -11.980,31
clayish peat	flugsand	SCFB	€ 18.705,00	€ 10.575,31	€ 18.779,81	€ 31.508,39	€ -74,80	€ -12.803,38
clayish peat	lava stone	SCFB	€ 18.705,00	€ 10.575,31	€ 18.779,81	€ 31.508,39	€ -74,80	€ -12.803,38
clayish peat	flugsand	vlotterkering	€ 18.705,00	€ 10.575,31	€ 18.779,81	€ 31.508,39	€ -74,80	€ -12.803,38
clayish peat	lava stone	vlotterkering	€ 18.705,00	€ 10.575,31	€ 18.779,81	€ 31.508,39	€ -74,80	€ -12.803,38
clayish peat	clayish peat (pct)	SCFB	€ 16.252,34	€ 13.027,97	€ 18.796,65	€ 29.061,61	€ -2.544,31	€ -12.809,27
clayish peat	clayish peat (pct)	vlotterkering	€ 16.252,34	€ 13.027,97	€ 18.796,65	€ 29.061,61	€ -2.544,31	€ -12.809,27
peat	EPS	SCFB	€ 18.072,39	€ 11.207,92	€ 19.188,52	€ 31.796,59	€ -1.116,13	€ -13.724,20
peat	foam concrete	SCFB	€ 18.072,39	€ 11.207,92	€ 19.188,52	€ 31.796,59	€ -1.116,13	€ -13.724,20
peat	EPS	vlotterkering	€ 18.072,39	€ 11.207,92	€ 19.188,52	€ 31.796,59	€ -1.116,13	€ -13.724,20
peat	foam concrete	vlotterkering	€ 18.072,39	€ 11.207,92	€ 19.188,52	€ 31.796,59	€ -1.116,13	€ -13.724,20
clayish peat	peat (pct)	SCFB	€ 15.573,80	€ 13.706,51	€ 19.065,68	€ 29.420,32	€ -3.491,88	€ -13.846,52
clayish peat	peat (pct)	vlotterkering	€ 15.573,80	€ 13.706,51	€ 19.065,68	€ 29.420,32	€ -3.491,88	€ -13.846,52
peat	flugsand	SCFB	€ 18.072,39	€ 11.207,92	€ 19.600,05	€ 32.619,66	€ -1.527,67	€ -14.547,27
peat	lava stone	SCFB	€ 18.072,39	€ 11.207,92	€ 19.600,05	€ 32.619,66	€ -1.527,67	€ -14.547,27
peat	flugsand	vlotterkering	€ 18.072,39	€ 11.207,92	€ 19.600,05	€ 32.619,66	€ -1.527,67	€ -14.547,27
peat	lava stone	vlotterkering	€ 18.072,39	€ 11.207,92	€ 19.600,05	€ 32.619,66	€ -1.527,67	€ -14.547,27
peat	clayish peat (pct)	SCFB	€ 15.619,73	€ 13.660,58	€ 19.616,90	€ 30.172,89	€ -3.997,17	€ -14.553,16
peat	clayish peat (pct)	vlotterkering	€ 15.619,73	€ 13.660,58	€ 19.616,90	€ 30.172,89	€ -3.997,17	€ -14.553,16
peat	peat (pct)	SCFB	€ 14.941,19	€ 14.339,12	€ 19.885,93	€ 30.531,59	€ -4.944,74	€ -15.590,41
peat	peat (pct)	vlotterkering	€ 14.941,19	€ 14.339,12	€ 19.885,93	€ 30.531,59	€ -4.944,74	€ -15.590,41

Full protection approach *-1,82 NAP protection height* - Overview of the average annual total costs & benefits of a 30 year analysis period. Note: NPV = present expected benefits - present costs								
Group 1	**Group 2**	**Group 3**						
Open field, meadow private, greenzone, paved,	**PCT**	**Greenhouse**	**Present expected benefits**	**Present expected damage**	**Present costs (low)**	**Present costs (high)**	**NPV (low)**	**NPV (high)**
clayish peat	clayish peat (pct)	bamboo	€ 19.873,56	€ 9.406,75	€ 21.913,17	€ 29.239,25	€ -2.039,61	€ -9.365,69
clayish peat	clayish peat (pct)	wooden	€ 19.873,56	€ 9.406,75	€ 22.176,69	€ 29.327,09	€ -2.303,13	€ -9.453,53
clayish peat	EPS	bamboo	€ 20.881,02	€ 8.399,30	€ 20.726,83	€ 30.401,06	€ 154,19	€ -9.520,04
clayish peat	foam concrete	bamboo	€ 20.881,02	€ 8.399,30	€ 20.726,83	€ 30.401,06	€ 154,19	€ -9.520,04
clayish peat	EPS	wooden	€ 20.881,02	€ 8.399,30	€ 20.990,34	€ 30.488,90	€ -109,33	€ -9.607,88
clayish peat	foam concrete	wooden	€ 20.881,02	€ 8.399,30	€ 20.990,34	€ 30.488,90	€ -109,33	€ -9.607,88
clayish peat	clayish peat (pct)	synthetic	€ 19.873,56	€ 9.406,75	€ 22.222,97	€ 29.518,70	€ -2.349,41	€ -9.645,14
clayish peat	EPS	synthetic	€ 20.881,02	€ 8.399,30	€ 21.036,63	€ 30.680,50	€ -155,61	€ -9.799,48
clayish peat	foam concrete	synthetic	€ 20.881,02	€ 8.399,30	€ 21.036,63	€ 30.680,50	€ -155,61	€ -9.799,48
clayish peat	clayish peat (pct)	steel	€ 19.873,56	€ 9.406,75	€ 22.436,97	€ 29.946,70	€ -2.563,41	€ -10.073,14
clayish peat	peat (pct)	bamboo	€ 19.568,74	€ 9.711,57	€ 22.259,62	€ 29.701,19	€ -2.690,88	€ -10.132,45
clayish peat	peat (pct)	wooden	€ 19.568,74	€ 9.711,57	€ 22.523,14	€ 29.789,03	€ -2.954,40	€ -10.220,29
clayish peat	EPS	steel	€ 20.881,02	€ 8.399,30	€ 21.250,63	€ 31.108,50	€ -369,61	€ -10.227,48
clayish peat	foam concrete	steel	€ 20.881,02	€ 8.399,30	€ 21.250,63	€ 31.108,50	€ -369,61	€ -10.227,48
clayish peat	flugsand	bamboo	€ 20.881,02	€ 8.399,30	€ 21.138,36	€ 31.224,13	€ -257,35	€ -10.343,12
clayish peat	lava stone	bamboo	€ 20.881,02	€ 8.399,30	€ 21.138,36	€ 31.224,13	€ -257,35	€ -10.343,12
clayish peat	peat (pct)	synthetic	€ 19.568,74	€ 9.711,57	€ 22.569,42	€ 29.980,63	€ -3.000,68	€ -10.411,89
clayish peat	flugsand	wooden	€ 20.881,02	€ 8.399,30	€ 21.401,88	€ 31.311,97	€ -520,87	€ -10.430,96
clayish peat	lava stone	wooden	€ 20.881,02	€ 8.399,30	€ 21.401,88	€ 31.311,97	€ -520,87	€ -10.430,96
clayish peat	flugsand	synthetic	€ 20.881,02	€ 8.399,30	€ 21.448,17	€ 31.503,58	€ -567,15	€ -10.622,56
clayish peat	lava stone	synthetic	€ 20.881,02	€ 8.399,30	€ 21.448,17	€ 31.503,58	€ -567,15	€ -10.622,56
clayish peat	clayish peat (pct)	composite	€ 19.873,56	€ 9.406,75	€ 23.078,97	€ 30.588,70	€ -3.205,41	€ -10.715,14
clayish peat	peat (pct)	steel	€ 19.568,74	€ 9.711,57	€ 22.783,42	€ 30.408,63	€ -3.214,68	€ -10.839,89
clayish peat	EPS	composite	€ 20.881,02	€ 8.399,30	€ 21.892,63	€ 31.750,50	€ -1.011,61	€ -10.869,48
clayish peat	foam concrete	composite	€ 20.881,02	€ 8.399,30	€ 21.892,63	€ 31.750,50	€ -1.011,61	€ -10.869,48
peat	clayish peat (pct)	bamboo	€ 19.625,34	€ 9.654,97	€ 22.969,46	€ 30.616,88	€ -3.344,11	€ -10.991,54
clayish peat	flugsand	steel	€ 20.881,02	€ 8.399,30	€ 21.662,17	€ 31.931,58	€ -781,15	€ -11.050,56
clayish peat	lava stone	steel	€ 20.881,02	€ 8.399,30	€ 21.662,17	€ 31.931,58	€ -781,15	€ -11.050,56
peat	clayish peat (pct)	wooden	€ 19.625,34	€ 9.654,97	€ 23.232,98	€ 30.704,72	€ -3.607,63	€ -11.079,38
peat	EPS	bamboo	€ 20.632,80	€ 8.647,51	€ 21.783,11	€ 31.778,68	€ -1.150,31	€ -11.145,88
peat	foam concrete	bamboo	€ 20.632,80	€ 8.647,51	€ 21.783,11	€ 31.778,68	€ -1.150,31	€ -11.145,88
peat	EPS	wooden	€ 20.632,80	€ 8.647,51	€ 22.046,63	€ 31.866,52	€ -1.413,83	€ -11.233,72
peat	foam concrete	wooden	€ 20.632,80	€ 8.647,51	€ 22.046,63	€ 31.866,52	€ -1.413,83	€ -11.233,72
peat	clayish peat (pct)	synthetic	€ 19.625,34	€ 9.654,97	€ 23.279,26	€ 30.896,32	€ -3.653,92	€ -11.270,98
peat	EPS	synthetic	€ 20.632,80	€ 8.647,51	€ 22.092,92	€ 32.058,13	€ -1.460,12	€ -11.425,33
peat	foam concrete	synthetic	€ 20.632,80	€ 8.647,51	€ 22.092,92	€ 32.058,13	€ -1.460,12	€ -11.425,33
clayish peat	peat (pct)	composite	€ 19.568,74	€ 9.711,57	€ 23.425,42	€ 31.050,63	€ -3.856,68	€ -11.481,89
clayish peat	flugsand	composite	€ 20.881,02	€ 8.399,30	€ 22.304,17	€ 32.573,58	€ -1.423,15	€ -11.692,56
clayish peat	lava stone	composite	€ 20.881,02	€ 8.399,30	€ 22.304,17	€ 32.573,58	€ -1.423,15	€ -11.692,56
peat	clayish peat (pct)	steel	€ 19.625,34	€ 9.654,97	€ 23.493,26	€ 31.324,32	€ -3.867,92	€ -11.698,98
peat	peat (pct)	bamboo	€ 19.320,52	€ 9.959,79	€ 23.315,91	€ 31.078,81	€ -3.995,38	€ -11.758,29
peat	peat (pct)	wooden	€ 19.320,52	€ 9.959,79	€ 23.579,43	€ 31.166,65	€ -4.258,90	€ -11.846,13
peat	EPS	steel	€ 20.632,80	€ 8.647,51	€ 22.306,92	€ 32.486,13	€ -1.674,12	€ -11.853,33
peat	foam concrete	steel	€ 20.632,80	€ 8.647,51	€ 22.306,92	€ 32.486,13	€ -1.674,12	€ -11.853,33
peat	flugsand	bamboo	€ 20.632,80	€ 8.647,51	€ 22.194,65	€ 32.601,76	€ -1.561,85	€ -11.968,96
peat	lava stone	bamboo	€ 20.632,80	€ 8.647,51	€ 22.194,65	€ 32.601,76	€ -1.561,85	€ -11.968,96
peat	peat (pct)	synthetic	€ 19.320,52	€ 9.959,79	€ 23.625,71	€ 31.358,26	€ -4.305,18	€ -12.037,73
peat	flugsand	wooden	€ 20.632,80	€ 8.647,51	€ 22.458,17	€ 32.689,60	€ -1.825,37	€ -12.056,80
peat	lava stone	wooden	€ 20.632,80	€ 8.647,51	€ 22.458,17	€ 32.689,60	€ -1.825,37	€ -12.056,80
peat	flugsand	synthetic	€ 20.632,80	€ 8.647,51	€ 22.504,46	€ 32.881,20	€ -1.871,66	€ -12.248,40
peat	lava stone	synthetic	€ 20.632,80	€ 8.647,51	€ 22.504,46	€ 32.881,20	€ -1.871,66	€ -12.248,40
peat	clayish peat (pct)	composite	€ 19.625,34	€ 9.654,97	€ 24.135,26	€ 31.966,32	€ -4.509,92	€ -12.340,98
peat	peat (pct)	steel	€ 19.320,52	€ 9.959,79	€ 23.839,71	€ 31.786,26	€ -4.519,18	€ -12.465,73
peat	EPS	composite	€ 20.632,80	€ 8.647,51	€ 22.948,92	€ 33.128,13	€ -2.316,12	€ -12.495,33
peat	foam concrete	composite	€ 20.632,80	€ 8.647,51	€ 22.948,92	€ 33.128,13	€ -2.316,12	€ -12.495,33
peat	flugsand	steel	€ 20.632,80	€ 8.647,51	€ 22.718,46	€ 33.309,20	€ -2.085,66	€ -12.676,40
peat	lava stone	steel	€ 20.632,80	€ 8.647,51	€ 22.718,46	€ 33.309,20	€ -2.085,66	€ -12.676,40
peat	peat (pct)	composite	€ 19.320,52	€ 9.959,79	€ 24.481,71	€ 32.428,26	€ -5.161,18	€ -13.107,73
peat	flugsand	composite	€ 20.632,80	€ 8.647,51	€ 23.360,46	€ 33.951,20	€ -2.727,66	€ -13.318,40
peat	lava stone	composite	€ 20.632,80	€ 8.647,51	€ 23.360,46	€ 33.951,20	€ -2.727,66	€ -13.318,40
clayish peat	clayish peat (pct)	SCFB	€ 19.873,56	€ 9.406,75	€ 25.040,64	€ 37.365,36	€ -5.167,08	€ -17.491,80
clayish peat	clayish peat (pct)	vlotterkering	€ 19.873,56	€ 9.406,75	€ 25.040,64	€ 37.365,36	€ -5.167,08	€ -17.491,80
clayish peat	EPS	SCFB	€ 20.881,02	€ 8.399,30	€ 23.854,29	€ 38.527,17	€ -2.973,28	€ -17.646,15
clayish peat	foam concrete	SCFB	€ 20.881,02	€ 8.399,30	€ 23.854,29	€ 38.527,17	€ -2.973,28	€ -17.646,15
clayish peat	EPS	vlotterkering	€ 20.881,02	€ 8.399,30	€ 23.854,29	€ 38.527,17	€ -2.973,28	€ -17.646,15
clayish peat	foam concrete	vlotterkering	€ 20.881,02	€ 8.399,30	€ 23.854,29	€ 38.527,17	€ -2.973,28	€ -17.646,15
clayish peat	peat (pct)	SCFB	€ 19.568,74	€ 9.711,57	€ 25.387,09	€ 37.827,30	€ -5.818,35	€ -18.258,56
clayish peat	peat (pct)	vlotterkering	€ 19.568,74	€ 9.711,57	€ 25.387,09	€ 37.827,30	€ -5.818,35	€ -18.258,56
clayish peat	flugsand	SCFB	€ 20.881,02	€ 8.399,30	€ 24.265,83	€ 39.350,25	€ -3.384,82	€ -18.469,23
clayish peat	lava stone	SCFB	€ 20.881,02	€ 8.399,30	€ 24.265,83	€ 39.350,25	€ -3.384,82	€ -18.469,23
clayish peat	flugsand	vlotterkering	€ 20.881,02	€ 8.399,30	€ 24.265,83	€ 39.350,25	€ -3.384,82	€ -18.469,23
clayish peat	lava stone	vlotterkering	€ 20.881,02	€ 8.399,30	€ 24.265,83	€ 39.350,25	€ -3.384,82	€ -18.469,23
peat	clayish peat (pct)	SCFB	€ 19.625,34	€ 9.654,97	€ 26.096,93	€ 38.742,99	€ -6.471,58	€ -19.117,65
peat	clayish peat (pct)	vlotterkering	€ 19.625,34	€ 9.654,97	€ 26.096,93	€ 38.742,99	€ -6.471,58	€ -19.117,65
peat	EPS	SCFB	€ 20.632,80	€ 8.647,51	€ 24.910,58	€ 39.904,79	€ -4.277,78	€ -19.271,99
peat	foam concrete	SCFB	€ 20.632,80	€ 8.647,51	€ 24.910,58	€ 39.904,79	€ -4.277,78	€ -19.271,99
peat	EPS	vlotterkering	€ 20.632,80	€ 8.647,51	€ 24.910,58	€ 39.904,79	€ -4.277,78	€ -19.271,99
peat	foam concrete	vlotterkering	€ 20.632,80	€ 8.647,51	€ 24.910,58	€ 39.904,79	€ -4.277,78	€ -19.271,99
peat	peat (pct)	SCFB	€ 19.320,52	€ 9.959,79	€ 26.443,38	€ 39.204,92	€ -7.122,85	€ -19.884,40
peat	peat (pct)	vlotterkering	€ 19.320,52	€ 9.959,79	€ 26.443,38	€ 39.204,92	€ -7.122,85	€ -19.884,40
peat	flugsand	SCFB	€ 20.632,80	€ 8.647,51	€ 25.322,12	€ 40.727,87	€ -4.689,32	€ -20.095,07
peat	lava stone	SCFB	€ 20.632,80	€ 8.647,51	€ 25.322,12	€ 40.727,87	€ -4.689,32	€ -20.095,07
peat	flugsand	vlotterkering	€ 20.632,80	€ 8.647,51	€ 25.322,12	€ 40.727,87	€ -4.689,32	€ -20.095,07
peat	lava stone	vlotterkering	€ 20.632,80	€ 8.647,51	€ 25.322,12	€ 40.727,87	€ -4.689,32	€ -20.095,07

Annex 13

Critical protection approach *-1,91 NAP protection height* - Overview of the average annual total costs & benefits of a 30 year analysis period. Note: NPV = present expected benefits - present costs								
Group 1	Group 2	Group 3						
Open field, meadow private, greenzone,	PCT	Greenhouse	Present expected benefits	Present expected damage	Present costs (low)	Present costs (high)	NPV (low)	NPV (high)
clayey peat	EPS	bamboo	€ 15.406,42	€ 13.609,29	€ 5.976,24	€ 9.976,30	€ 9.430,18	€ 5.430,12
clayey peat	foam concrete	bamboo	€ 15.406,42	€ 13.609,29	€ 5.976,24	€ 9.976,30	€ 9.430,18	€ 5.430,12
clayey peat	EPS	wooden	€ 15.406,42	€ 13.609,29	€ 6.239,76	€ 10.064,14	€ 9.166,66	€ 5.342,28
clayey peat	foam concrete	wooden	€ 15.406,42	€ 13.609,29	€ 6.239,76	€ 10.064,14	€ 9.166,66	€ 5.342,28
clayey peat	EPS	synthetic	€ 15.406,42	€ 13.609,29	€ 6.286,04	€ 10.255,74	€ 9.120,37	€ 5.150,68
clayey peat	foam concrete	synthetic	€ 15.406,42	€ 13.609,29	€ 6.286,04	€ 10.255,74	€ 9.120,37	€ 5.150,68
clayey peat	clayey peat (pct)	bamboo	€ 12.647,59	€ 16.406,95	€ 5.865,77	€ 7.906,56	€ 6.781,82	€ 4.741,03
clayey peat	EPS	steel	€ 15.406,42	€ 13.609,29	€ 6.500,04	€ 10.683,74	€ 8.906,37	€ 4.722,68
clayey peat	foam concrete	steel	€ 15.406,42	€ 13.609,29	€ 6.500,04	€ 10.683,74	€ 8.906,37	€ 4.722,68
clayey peat	clayey peat (pct)	wooden	€ 12.647,59	€ 16.406,95	€ 6.129,29	€ 7.994,40	€ 6.518,30	€ 4.653,19
clayey peat	flugsand	bamboo	€ 15.406,42	€ 13.609,29	€ 6.388,19	€ 10.800,20	€ 9.018,23	€ 4.606,22
clayey peat	lava stone	bamboo	€ 15.406,42	€ 13.609,29	€ 6.388,19	€ 10.800,20	€ 9.018,23	€ 4.606,22
peat	EPS	bamboo	€ 14.778,79	€ 14.237,18	€ 6.096,32	€ 10.255,69	€ 8.682,47	€ 4.523,11
peat	foam concrete	bamboo	€ 14.778,79	€ 14.237,18	€ 6.096,32	€ 10.255,69	€ 8.682,47	€ 4.523,11
clayey peat	flugsand	wooden	€ 15.406,42	€ 13.609,29	€ 6.651,71	€ 10.888,04	€ 8.754,71	€ 4.518,38
clayey peat	lava stone	wooden	€ 15.406,42	€ 13.609,29	€ 6.651,71	€ 10.888,04	€ 8.754,71	€ 4.518,38
clayey peat	clayey peat (pct)	synthetic	€ 12.647,59	€ 16.406,95	€ 6.175,57	€ 8.186,01	€ 6.472,02	€ 4.461,58
peat	EPS	wooden	€ 14.778,79	€ 14.237,18	€ 6.359,84	€ 10.343,53	€ 8.418,96	€ 4.435,27
peat	foam concrete	wooden	€ 14.778,79	€ 14.237,18	€ 6.359,84	€ 10.343,53	€ 8.418,96	€ 4.435,27
clayey peat	flugsand	synthetic	€ 15.406,42	€ 13.609,29	€ 6.697,99	€ 11.079,64	€ 8.708,42	€ 4.326,77
clayey peat	lava stone	synthetic	€ 15.406,42	€ 13.609,29	€ 6.697,99	€ 11.079,64	€ 8.708,42	€ 4.326,77
peat	EPS	synthetic	€ 14.778,79	€ 14.237,18	€ 6.406,12	€ 10.535,13	€ 8.372,67	€ 4.243,66
peat	foam concrete	synthetic	€ 14.778,79	€ 14.237,18	€ 6.406,12	€ 10.535,13	€ 8.372,67	€ 4.243,66
clayey peat	EPS	composite	€ 15.406,42	€ 13.609,29	€ 7.142,04	€ 11.325,74	€ 8.264,37	€ 4.080,68
clayey peat	foam concrete	composite	€ 15.406,42	€ 13.609,29	€ 7.142,04	€ 11.325,74	€ 8.264,37	€ 4.080,68
clayey peat	clayey peat (pct)	steel	€ 12.647,59	€ 16.406,95	€ 6.389,57	€ 8.614,01	€ 6.258,02	€ 4.033,58
clayey peat	flugsand	steel	€ 15.406,42	€ 13.609,29	€ 6.911,99	€ 11.507,64	€ 8.494,42	€ 3.898,77
clayey peat	lava stone	steel	€ 15.406,42	€ 13.609,29	€ 6.911,99	€ 11.507,64	€ 8.494,42	€ 3.898,77
clayey peat	peat (pct)	bamboo	€ 11.948,07	€ 17.106,47	€ 5.995,93	€ 8.080,11	€ 5.952,14	€ 3.867,96
peat	clayey peat (pct)	bamboo	€ 12.019,96	€ 17.034,84	€ 5.985,85	€ 8.185,95	€ 6.034,12	€ 3.834,01
peat	EPS	steel	€ 14.778,79	€ 14.237,18	€ 6.620,12	€ 10.963,13	€ 8.158,67	€ 3.815,66
peat	foam concrete	steel	€ 14.778,79	€ 14.237,18	€ 6.620,12	€ 10.963,13	€ 8.158,67	€ 3.815,66
clayey peat	peat (pct)	wooden	€ 11.948,07	€ 17.106,47	€ 6.259,45	€ 8.167,95	€ 5.688,62	€ 3.780,12
peat	clayey peat (pct)	wooden	€ 12.019,96	€ 17.034,84	€ 6.249,37	€ 8.273,79	€ 5.770,60	€ 3.746,17
peat	flugsand	bamboo	€ 14.778,79	€ 14.237,18	€ 6.508,27	€ 11.079,59	€ 8.270,52	€ 3.699,20
peat	lava stone	bamboo	€ 14.778,79	€ 14.237,18	€ 6.508,27	€ 11.079,59	€ 8.270,52	€ 3.699,20
peat	flugsand	wooden	€ 14.778,79	€ 14.237,18	€ 6.771,79	€ 11.167,43	€ 8.007,00	€ 3.611,36
peat	lava stone	wooden	€ 14.778,79	€ 14.237,18	€ 6.771,79	€ 11.167,43	€ 8.007,00	€ 3.611,36
clayey peat	peat (pct)	synthetic	€ 11.948,07	€ 17.106,47	€ 6.305,73	€ 8.359,55	€ 5.642,34	€ 3.588,52
peat	clayey peat (pct)	synthetic	€ 12.019,96	€ 17.034,84	€ 6.295,65	€ 8.465,40	€ 5.724,32	€ 3.554,57
peat	flugsand	synthetic	€ 14.778,79	€ 14.237,18	€ 6.818,07	€ 11.359,03	€ 7.960,72	€ 3.419,76
peat	lava stone	synthetic	€ 14.778,79	€ 14.237,18	€ 6.818,07	€ 11.359,03	€ 7.960,72	€ 3.419,76
clayey peat	clayey peat (pct)	composite	€ 12.647,59	€ 16.406,95	€ 7.031,57	€ 9.256,01	€ 5.616,02	€ 3.391,58
clayey peat	flugsand	composite	€ 15.406,42	€ 13.609,29	€ 7.553,99	€ 12.149,64	€ 7.852,42	€ 3.256,77
clayey peat	lava stone	composite	€ 15.406,42	€ 13.609,29	€ 7.553,99	€ 12.149,64	€ 7.852,42	€ 3.256,77
peat	EPS	composite	€ 14.778,79	€ 14.237,18	€ 7.262,12	€ 11.605,13	€ 7.516,67	€ 3.173,66
peat	foam concrete	composite	€ 14.778,79	€ 14.237,18	€ 7.262,12	€ 11.605,13	€ 7.516,67	€ 3.173,66
clayey peat	peat (pct)	steel	€ 11.948,07	€ 17.106,47	€ 6.519,73	€ 8.787,55	€ 5.428,34	€ 3.160,52
peat	clayey peat (pct)	steel	€ 12.019,96	€ 17.034,84	€ 6.509,65	€ 8.893,40	€ 5.510,32	€ 3.126,57
peat	flugsand	steel	€ 14.778,79	€ 14.237,18	€ 7.032,07	€ 11.787,03	€ 7.746,72	€ 2.991,76
peat	lava stone	steel	€ 14.778,79	€ 14.237,18	€ 7.032,07	€ 11.787,03	€ 7.746,72	€ 2.991,76
peat	peat (pct)	bamboo	€ 11.320,45	€ 17.734,35	€ 6.116,01	€ 8.359,50	€ 5.204,44	€ 2.960,95
peat	peat (pct)	wooden	€ 11.320,45	€ 17.734,35	€ 6.379,53	€ 8.447,34	€ 4.940,92	€ 2.873,11
peat	peat (pct)	synthetic	€ 11.320,45	€ 17.734,35	€ 6.425,81	€ 8.638,94	€ 4.894,64	€ 2.681,50
clayey peat	peat (pct)	composite	€ 11.948,07	€ 17.106,47	€ 7.161,73	€ 9.429,55	€ 4.786,34	€ 2.518,52
peat	clayey peat (pct)	composite	€ 12.019,96	€ 17.034,84	€ 7.151,65	€ 9.535,40	€ 4.868,32	€ 2.484,57
peat	flugsand	composite	€ 14.778,79	€ 14.237,18	€ 7.674,07	€ 12.429,03	€ 7.104,72	€ 2.349,76
peat	lava stone	composite	€ 14.778,79	€ 14.237,18	€ 7.674,07	€ 12.429,03	€ 7.104,72	€ 2.349,76
peat	peat (pct)	steel	€ 11.320,45	€ 17.734,35	€ 6.639,81	€ 9.066,94	€ 4.680,64	€ 2.253,50
peat	peat (pct)	composite	€ 11.320,45	€ 17.734,35	€ 7.281,81	€ 9.708,94	€ 4.038,64	€ 1.611,50
clayey peat	EPS	SCFB	€ 15.406,42	€ 13.609,29	€ 9.103,71	€ 18.102,41	€ 6.302,71	€ -2.695,99
clayey peat	foam concrete	SCFB	€ 15.406,42	€ 13.609,29	€ 9.103,71	€ 18.102,41	€ 6.302,71	€ -2.695,99
clayey peat	EPS	vlotterkering	€ 15.406,42	€ 13.609,29	€ 9.103,71	€ 18.102,41	€ 6.302,71	€ -2.695,99
clayey peat	foam concrete	vlotterkering	€ 15.406,42	€ 13.609,29	€ 9.103,71	€ 18.102,41	€ 6.302,71	€ -2.695,99
clayey peat	clayey peat (pct)	SCFB	€ 12.647,59	€ 16.406,95	€ 8.993,24	€ 16.032,67	€ 3.654,35	€ -3.385,08
clayey peat	clayey peat (pct)	vlotterkering	€ 12.647,59	€ 16.406,95	€ 8.993,24	€ 16.032,67	€ 3.654,35	€ -3.385,08
clayey peat	flugsand	SCFB	€ 15.406,42	€ 13.609,29	€ 9.515,66	€ 18.926,31	€ 5.890,76	€ -3.519,89
clayey peat	lava stone	SCFB	€ 15.406,42	€ 13.609,29	€ 9.515,66	€ 18.926,31	€ 5.890,76	€ -3.519,89
clayey peat	flugsand	vlotterkering	€ 15.406,42	€ 13.609,29	€ 9.515,66	€ 18.926,31	€ 5.890,76	€ -3.519,89
clayey peat	lava stone	vlotterkering	€ 15.406,42	€ 13.609,29	€ 9.515,66	€ 18.926,31	€ 5.890,76	€ -3.519,89
peat	EPS	SCFB	€ 14.778,79	€ 14.237,18	€ 9.223,79	€ 18.381,80	€ 5.555,01	€ -3.603,00
peat	foam concrete	SCFB	€ 14.778,79	€ 14.237,18	€ 9.223,79	€ 18.381,80	€ 5.555,01	€ -3.603,00
peat	EPS	vlotterkering	€ 14.778,79	€ 14.237,18	€ 9.223,79	€ 18.381,80	€ 5.555,01	€ -3.603,00
peat	foam concrete	vlotterkering	€ 14.778,79	€ 14.237,18	€ 9.223,79	€ 18.381,80	€ 5.555,01	€ -3.603,00
clayey peat	peat (pct)	SCFB	€ 11.948,07	€ 17.106,47	€ 9.123,40	€ 16.206,22	€ 2.824,67	€ -4.258,15
clayey peat	peat (pct)	vlotterkering	€ 11.948,07	€ 17.106,47	€ 9.123,40	€ 16.206,22	€ 2.824,67	€ -4.258,15
peat	clayey peat (pct)	SCFB	€ 12.019,96	€ 17.034,84	€ 9.113,32	€ 16.312,06	€ 2.906,65	€ -4.292,10
peat	clayey peat (pct)	vlotterkering	€ 12.019,96	€ 17.034,84	€ 9.113,32	€ 16.312,06	€ 2.906,65	€ -4.292,10
peat	flugsand	SCFB	€ 14.778,79	€ 14.237,18	€ 9.635,74	€ 19.205,70	€ 5.143,05	€ -4.426,91
peat	lava stone	SCFB	€ 14.778,79	€ 14.237,18	€ 9.635,74	€ 19.205,70	€ 5.143,05	€ -4.426,91
peat	flugsand	vlotterkering	€ 14.778,79	€ 14.237,18	€ 9.635,74	€ 19.205,70	€ 5.143,05	€ -4.426,91
peat	lava stone	vlotterkering	€ 14.778,79	€ 14.237,18	€ 9.635,74	€ 19.205,70	€ 5.143,05	€ -4.426,91
peat	peat (pct)	SCFB	€ 11.320,45	€ 17.734,35	€ 9.243,48	€ 16.485,61	€ 2.076,97	€ -5.165,16
peat	peat (pct)	vlotterkering	€ 11.320,45	€ 17.734,35	€ 9.243,48	€ 16.485,61	€ 2.076,97	€ -5.165,16

Critical protection approach *-1,88 NAP protection height* - Overview of the average annual total costs & benefits of a 30 year analysis period. Note: NPV = present expected benefits - present costs								
Group 1	Group 2	Group 3						
Open field, meadow private, greenzone, paved,	PCT	Greenhouse	Present expected benefits	Present expected damage	Present costs (low)	Present costs (high)	NPV (low)	NPV (high)
clayey peat	EPS	bamboo	€ 18.176,07	€ 10.851,66	€ 7.273,02	€ 11.971,44	€ 10.903,05	€ 6.204,63
clayey peat	foam concrete	bamboo	€ 18.176,07	€ 10.851,66	€ 7.273,02	€ 11.971,44	€ 10.903,05	€ 6.204,63
clayey peat	EPS	wooden	€ 18.176,07	€ 10.851,66	€ 7.536,54	€ 12.059,28	€ 10.639,53	€ 6.116,79
clayey peat	foam concrete	wooden	€ 18.176,07	€ 10.851,66	€ 7.536,54	€ 12.059,28	€ 10.639,53	€ 6.116,79
clayey peat	EPS	synthetic	€ 18.176,07	€ 10.851,66	€ 7.582,82	€ 12.250,88	€ 10.593,25	€ 5.925,19
clayey peat	foam concrete	synthetic	€ 18.176,07	€ 10.851,66	€ 7.582,82	€ 12.250,88	€ 10.593,25	€ 5.925,19
clayey peat	EPS	steel	€ 18.176,07	€ 10.851,66	€ 7.796,82	€ 12.678,88	€ 10.379,25	€ 5.497,19
clayey peat	foam concrete	steel	€ 18.176,07	€ 10.851,66	€ 7.796,82	€ 12.678,88	€ 10.379,25	€ 5.497,19
clayey peat	clayey peat (pct)	bamboo	€ 15.738,65	€ 13.315,89	€ 7.702,34	€ 10.346,79	€ 8.036,31	€ 5.391,86
clayey peat	flugsand	bamboo	€ 18.176,07	€ 10.851,66	€ 7.684,97	€ 12.795,34	€ 10.491,10	€ 5.380,73
clayey peat	lava stone	bamboo	€ 18.176,07	€ 10.851,66	€ 7.684,97	€ 12.795,34	€ 10.491,10	€ 5.380,73
clayey peat	clayey peat (pct)	wooden	€ 15.738,65	€ 13.315,89	€ 7.965,86	€ 10.434,63	€ 7.772,79	€ 5.304,02
clayey peat	flugsand	wooden	€ 18.176,07	€ 10.851,66	€ 7.948,49	€ 12.883,18	€ 10.227,58	€ 5.292,89
clayey peat	lava stone	wooden	€ 18.176,07	€ 10.851,66	€ 7.948,49	€ 12.883,18	€ 10.227,58	€ 5.292,89
peat	EPS	bamboo	€ 17.555,42	€ 11.472,58	€ 7.521,46	€ 12.430,44	€ 10.033,96	€ 5.124,98
peat	foam concrete	bamboo	€ 17.555,42	€ 11.472,58	€ 7.521,46	€ 12.430,44	€ 10.033,96	€ 5.124,98
clayey peat	clayey peat (pct)	synthetic	€ 15.738,65	€ 13.315,89	€ 8.012,14	€ 10.626,23	€ 7.726,51	€ 5.112,42
clayey peat	flugsand	synthetic	€ 18.176,07	€ 10.851,66	€ 7.994,77	€ 13.074,79	€ 10.181,30	€ 5.101,28
clayey peat	lava stone	synthetic	€ 18.176,07	€ 10.851,66	€ 7.994,77	€ 13.074,79	€ 10.181,30	€ 5.101,28
peat	EPS	wooden	€ 17.555,42	€ 11.472,58	€ 7.784,98	€ 12.518,28	€ 9.770,44	€ 5.037,14
peat	foam concrete	wooden	€ 17.555,42	€ 11.472,58	€ 7.784,98	€ 12.518,28	€ 9.770,44	€ 5.037,14
clayey peat	EPS	composite	€ 18.176,07	€ 10.851,66	€ 8.438,82	€ 13.320,88	€ 9.737,25	€ 4.855,19
clayey peat	foam concrete	composite	€ 18.176,07	€ 10.851,66	€ 8.438,82	€ 13.320,88	€ 9.737,25	€ 4.855,19
peat	EPS	synthetic	€ 17.555,42	€ 11.472,58	€ 7.831,26	€ 12.709,89	€ 9.724,16	€ 4.845,53
peat	foam concrete	synthetic	€ 17.555,42	€ 11.472,58	€ 7.831,26	€ 12.709,89	€ 9.724,16	€ 4.845,53
clayey peat	clayey peat (pct)	steel	€ 15.738,65	€ 13.315,89	€ 8.226,14	€ 11.054,23	€ 7.512,51	€ 4.684,42
clayey peat	flugsand	steel	€ 18.176,07	€ 10.851,66	€ 8.208,77	€ 13.502,79	€ 9.967,30	€ 4.673,28
clayey peat	lava stone	steel	€ 18.176,07	€ 10.851,66	€ 8.208,77	€ 13.502,79	€ 9.967,30	€ 4.673,28
peat	EPS	steel	€ 17.555,42	€ 11.472,58	€ 8.045,26	€ 13.137,89	€ 9.510,16	€ 4.417,53
peat	foam concrete	steel	€ 17.555,42	€ 11.472,58	€ 8.045,26	€ 13.137,89	€ 9.510,16	€ 4.417,53
clayey peat	peat (pct)	bamboo	€ 15.070,94	€ 13.983,60	€ 7.971,64	€ 10.705,86	€ 7.099,30	€ 4.365,08
peat	clayey peat (pct)	bamboo	€ 15.118,00	€ 13.936,80	€ 7.950,77	€ 10.805,79	€ 7.167,22	€ 4.312,21
peat	flugsand	bamboo	€ 17.555,42	€ 11.472,58	€ 7.933,41	€ 13.254,35	€ 9.622,01	€ 4.301,07
peat	lava stone	bamboo	€ 17.555,42	€ 11.472,58	€ 7.933,41	€ 13.254,35	€ 9.622,01	€ 4.301,07
clayey peat	peat (pct)	wooden	€ 15.070,94	€ 13.983,60	€ 8.235,16	€ 10.793,70	€ 6.835,78	€ 4.277,24
peat	clayey peat (pct)	wooden	€ 15.118,00	€ 13.936,80	€ 8.214,29	€ 10.893,63	€ 6.903,71	€ 4.224,37
peat	flugsand	wooden	€ 17.555,42	€ 11.472,58	€ 8.196,93	€ 13.342,19	€ 9.358,49	€ 4.213,23
peat	lava stone	wooden	€ 17.555,42	€ 11.472,58	€ 8.196,93	€ 13.342,19	€ 9.358,49	€ 4.213,23
clayey peat	peat (pct)	synthetic	€ 15.070,94	€ 13.983,60	€ 8.281,44	€ 10.985,30	€ 6.789,50	€ 4.085,64
clayey peat	clayey peat (pct)	composite	€ 15.738,65	€ 13.315,89	€ 8.868,14	€ 11.696,23	€ 6.870,51	€ 4.042,42
peat	clayey peat (pct)	synthetic	€ 15.118,00	€ 13.936,80	€ 8.260,58	€ 11.085,24	€ 6.857,42	€ 4.032,76
clayey peat	flugsand	composite	€ 18.176,07	€ 10.851,66	€ 8.850,77	€ 14.144,79	€ 9.325,30	€ 4.031,28
clayey peat	lava stone	composite	€ 18.176,07	€ 10.851,66	€ 8.850,77	€ 14.144,79	€ 9.325,30	€ 4.031,28
peat	flugsand	synthetic	€ 17.555,42	€ 11.472,58	€ 8.243,21	€ 13.533,79	€ 9.312,21	€ 4.021,63
peat	lava stone	synthetic	€ 17.555,42	€ 11.472,58	€ 8.243,21	€ 13.533,79	€ 9.312,21	€ 4.021,63
peat	EPS	composite	€ 17.555,42	€ 11.472,58	€ 8.687,26	€ 13.779,89	€ 8.868,16	€ 3.775,53
peat	foam concrete	composite	€ 17.555,42	€ 11.472,58	€ 8.687,26	€ 13.779,89	€ 8.868,16	€ 3.775,53
clayey peat	peat (pct)	steel	€ 15.070,94	€ 13.983,60	€ 8.495,44	€ 11.413,30	€ 6.575,50	€ 3.657,64
peat	clayey peat (pct)	steel	€ 15.118,00	€ 13.936,80	€ 8.474,58	€ 11.513,24	€ 6.643,42	€ 3.604,76
peat	flugsand	steel	€ 17.555,42	€ 11.472,58	€ 8.457,21	€ 13.961,79	€ 9.098,21	€ 3.593,63
peat	lava stone	steel	€ 17.555,42	€ 11.472,58	€ 8.457,21	€ 13.961,79	€ 9.098,21	€ 3.593,63
peat	peat (pct)	bamboo	€ 14.450,29	€ 14.604,51	€ 8.220,08	€ 11.164,86	€ 6.230,22	€ 3.285,43
peat	peat (pct)	wooden	€ 14.450,29	€ 14.604,51	€ 8.483,59	€ 11.252,70	€ 5.966,70	€ 3.197,59
clayey peat	peat (pct)	composite	€ 15.070,94	€ 13.983,60	€ 9.137,44	€ 12.055,30	€ 5.933,50	€ 3.015,64
peat	peat (pct)	synthetic	€ 14.450,29	€ 14.604,51	€ 8.529,88	€ 11.444,30	€ 5.920,41	€ 3.005,99
peat	clayey peat (pct)	composite	€ 15.118,00	€ 13.936,80	€ 9.116,58	€ 12.155,24	€ 6.001,42	€ 2.962,76
peat	flugsand	composite	€ 17.555,42	€ 11.472,58	€ 9.099,21	€ 14.603,79	€ 8.456,21	€ 2.951,63
peat	lava stone	composite	€ 17.555,42	€ 11.472,58	€ 9.099,21	€ 14.603,79	€ 8.456,21	€ 2.951,63
peat	peat (pct)	steel	€ 14.450,29	€ 14.604,51	€ 8.743,88	€ 11.872,30	€ 5.706,41	€ 2.577,99
peat	peat (pct)	composite	€ 14.450,29	€ 14.604,51	€ 9.385,88	€ 12.514,30	€ 5.064,41	€ 1.935,99
clayey peat	EPS	SCFB	€ 18.176,07	€ 10.851,66	€ 10.400,49	€ 20.097,55	€ 7.775,58	€ -1.921,48
clayey peat	foam concrete	SCFB	€ 18.176,07	€ 10.851,66	€ 10.400,49	€ 20.097,55	€ 7.775,58	€ -1.921,48
clayey peat	EPS	vlotterkering	€ 18.176,07	€ 10.851,66	€ 10.400,49	€ 20.097,55	€ 7.775,58	€ -1.921,48
clayey peat	foam concrete	vlotterkering	€ 18.176,07	€ 10.851,66	€ 10.400,49	€ 20.097,55	€ 7.775,58	€ -1.921,48
clayey peat	clayey peat (pct)	SCFB	€ 15.738,65	€ 13.315,89	€ 10.829,81	€ 18.472,90	€ 4.908,84	€ -2.734,25
clayey peat	clayey peat (pct)	vlotterkering	€ 15.738,65	€ 13.315,89	€ 10.829,81	€ 18.472,90	€ 4.908,84	€ -2.734,25
clayey peat	flugsand	SCFB	€ 18.176,07	€ 10.851,66	€ 10.812,44	€ 20.921,45	€ 7.363,63	€ -2.745,38
clayey peat	lava stone	SCFB	€ 18.176,07	€ 10.851,66	€ 10.812,44	€ 20.921,45	€ 7.363,63	€ -2.745,38
clayey peat	flugsand	vlotterkering	€ 18.176,07	€ 10.851,66	€ 10.812,44	€ 20.921,45	€ 7.363,63	€ -2.745,38
clayey peat	lava stone	vlotterkering	€ 18.176,07	€ 10.851,66	€ 10.812,44	€ 20.921,45	€ 7.363,63	€ -2.745,38
peat	EPS	SCFB	€ 17.555,42	€ 11.472,58	€ 10.648,93	€ 20.556,55	€ 6.906,49	€ -3.001,13
peat	foam concrete	SCFB	€ 17.555,42	€ 11.472,58	€ 10.648,93	€ 20.556,55	€ 6.906,49	€ -3.001,13
peat	EPS	vlotterkering	€ 17.555,42	€ 11.472,58	€ 10.648,93	€ 20.556,55	€ 6.906,49	€ -3.001,13
peat	foam concrete	vlotterkering	€ 17.555,42	€ 11.472,58	€ 10.648,93	€ 20.556,55	€ 6.906,49	€ -3.001,13
clayey peat	peat (pct)	SCFB	€ 15.070,94	€ 13.983,60	€ 11.099,11	€ 18.831,97	€ 3.971,83	€ -3.761,03
clayey peat	peat (pct)	vlotterkering	€ 15.070,94	€ 13.983,60	€ 11.099,11	€ 18.831,97	€ 3.971,83	€ -3.761,03
peat	clayey peat (pct)	SCFB	€ 15.118,00	€ 13.936,80	€ 11.078,24	€ 18.931,90	€ 4.039,76	€ -3.813,90
peat	clayey peat (pct)	vlotterkering	€ 15.118,00	€ 13.936,80	€ 11.078,24	€ 18.931,90	€ 4.039,76	€ -3.813,90
peat	flugsand	SCFB	€ 17.555,42	€ 11.472,58	€ 11.060,88	€ 21.380,46	€ 6.494,54	€ -3.825,04
peat	lava stone	SCFB	€ 17.555,42	€ 11.472,58	€ 11.060,88	€ 21.380,46	€ 6.494,54	€ -3.825,04
peat	flugsand	vlotterkering	€ 17.555,42	€ 11.472,58	€ 11.060,88	€ 21.380,46	€ 6.494,54	€ -3.825,04
peat	lava stone	vlotterkering	€ 17.555,42	€ 11.472,58	€ 11.060,88	€ 21.380,46	€ 6.494,54	€ -3.825,04
peat	peat (pct)	SCFB	€ 14.450,29	€ 14.604,51	€ 11.347,54	€ 19.290,97	€ 3.102,75	€ -4.840,68
peat	peat (pct)	vlotterkering	€ 14.450,29	€ 14.604,51	€ 11.347,54	€ 19.290,97	€ 3.102,75	€ -4.840,68

Critical protection approach *-1,82 NAP protection height* - Overview of the average annual total costs & benefits of a 30 year analysis period. Note: NPV = present expected benefits - present costs								
Group 1	Group 2	Group 3						
Open field, meadow private, greenzone, paved,	PCT	Greenhouse	Present expected benefits	Present expected damage	Present costs (low)	Present costs (high)	NPV (low)	NPV (high)
clayey peat	clayey peat (pct)	bamboo	€ 19.440,98	€ 9.613,56	€ 9.914,65	€ 13.279,48	€ 9.526,33	€ 6.161,50
clayey peat	clayey peat (pct)	wooden	€ 19.440,98	€ 9.613,56	€ 10.178,17	€ 13.367,32	€ 9.262,81	€ 6.073,66
clayey peat	clayey peat (pct)	synthetic	€ 19.440,98	€ 9.613,56	€ 10.224,45	€ 13.558,93	€ 9.216,53	€ 5.882,06
clayey peat	peat (pct)	bamboo	€ 19.138,39	€ 9.916,15	€ 10.167,65	€ 13.616,82	€ 8.970,74	€ 5.521,57
clayey peat	clayey peat (pct)	steel	€ 19.440,98	€ 9.613,56	€ 10.438,45	€ 13.986,93	€ 9.002,53	€ 5.454,06
clayey peat	EPS	bamboo	€ 20.459,10	€ 8.583,97	€ 9.150,19	€ 15.006,54	€ 11.308,91	€ 5.452,56
clayey peat	foam concrete	bamboo	€ 20.459,10	€ 8.583,97	€ 9.150,19	€ 15.006,54	€ 11.308,91	€ 5.452,56
peat	clayey peat (pct)	bamboo	€ 19.182,79	€ 9.872,02	€ 10.148,05	€ 13.735,45	€ 9.034,73	€ 5.447,34
clayey peat	peat (pct)	wooden	€ 19.138,39	€ 9.916,15	€ 10.431,17	€ 13.704,65	€ 8.707,22	€ 5.433,73
clayey peat	EPS	wooden	€ 20.459,10	€ 8.583,97	€ 9.413,70	€ 15.094,38	€ 11.045,39	€ 5.364,72
clayey peat	foam concrete	wooden	€ 20.459,10	€ 8.583,97	€ 9.413,70	€ 15.094,38	€ 11.045,39	€ 5.364,72
peat	clayey peat (pct)	wooden	€ 19.182,79	€ 9.872,02	€ 10.411,57	€ 13.823,29	€ 8.771,21	€ 5.359,50
clayey peat	peat (pct)	synthetic	€ 19.138,39	€ 9.916,15	€ 10.477,45	€ 13.896,26	€ 8.660,93	€ 5.242,13
clayey peat	EPS	synthetic	€ 20.459,10	€ 8.583,97	€ 9.459,99	€ 15.285,98	€ 10.999,11	€ 5.173,12
clayey peat	foam concrete	synthetic	€ 20.459,10	€ 8.583,97	€ 9.459,99	€ 15.285,98	€ 10.999,11	€ 5.173,12
peat	clayey peat (pct)	synthetic	€ 19.182,79	€ 9.872,02	€ 10.457,85	€ 14.014,89	€ 8.724,93	€ 5.167,89
clayey peat	peat (pct)	steel	€ 19.138,39	€ 9.916,15	€ 10.691,45	€ 14.324,26	€ 8.446,93	€ 4.814,13
clayey peat	clayey peat (pct)	composite	€ 19.440,98	€ 9.613,56	€ 11.080,45	€ 14.628,93	€ 8.360,53	€ 4.812,06
peat	peat (pct)	bamboo	€ 18.880,19	€ 10.174,61	€ 10.401,05	€ 14.072,78	€ 8.479,14	€ 4.807,41
clayey peat	EPS	steel	€ 20.459,10	€ 8.583,97	€ 9.673,99	€ 15.713,98	€ 10.785,11	€ 4.745,12
clayey peat	foam concrete	steel	€ 20.459,10	€ 8.583,97	€ 9.673,99	€ 15.713,98	€ 10.785,11	€ 4.745,12
peat	clayey peat (pct)	steel	€ 19.182,79	€ 9.872,02	€ 10.671,85	€ 14.442,89	€ 8.510,93	€ 4.739,89
peat	EPS	bamboo	€ 20.200,90	€ 8.842,43	€ 9.383,58	€ 15.462,50	€ 10.817,32	€ 4.738,40
peat	foam concrete	bamboo	€ 20.200,90	€ 8.842,43	€ 9.383,58	€ 15.462,50	€ 10.817,32	€ 4.738,40
peat	peat (pct)	wooden	€ 18.880,19	€ 10.174,61	€ 10.664,57	€ 14.160,62	€ 8.215,62	€ 4.719,57
peat	EPS	wooden	€ 20.200,90	€ 8.842,43	€ 9.647,10	€ 15.550,34	€ 10.553,80	€ 4.650,56
peat	foam concrete	wooden	€ 20.200,90	€ 8.842,43	€ 9.647,10	€ 15.550,34	€ 10.553,80	€ 4.650,56
clayey peat	flugsand	bamboo	€ 20.459,10	€ 8.583,97	€ 9.562,14	€ 15.830,44	€ 10.896,96	€ 4.628,66
clayey peat	lava stone	bamboo	€ 20.459,10	€ 8.583,97	€ 9.562,14	€ 15.830,44	€ 10.896,96	€ 4.628,66
clayey peat	flugsand	wooden	€ 20.459,10	€ 8.583,97	€ 9.825,66	€ 15.918,28	€ 10.633,44	€ 4.540,82
clayey peat	lava stone	wooden	€ 20.459,10	€ 8.583,97	€ 9.825,66	€ 15.918,28	€ 10.633,44	€ 4.540,82
peat	peat (pct)	synthetic	€ 18.880,19	€ 10.174,61	€ 10.710,85	€ 14.352,22	€ 8.169,34	€ 4.527,97
peat	EPS	synthetic	€ 20.200,90	€ 8.842,43	€ 9.693,39	€ 15.741,94	€ 10.507,51	€ 4.458,96
peat	foam concrete	synthetic	€ 20.200,90	€ 8.842,43	€ 9.693,39	€ 15.741,94	€ 10.507,51	€ 4.458,96
clayey peat	flugsand	synthetic	€ 20.459,10	€ 8.583,97	€ 9.871,94	€ 16.109,88	€ 10.587,16	€ 4.349,22
clayey peat	lava stone	synthetic	€ 20.459,10	€ 8.583,97	€ 9.871,94	€ 16.109,88	€ 10.587,16	€ 4.349,22
clayey peat	peat (pct)	composite	€ 19.138,39	€ 9.916,15	€ 11.333,45	€ 14.966,26	€ 7.804,93	€ 4.172,13
clayey peat	EPS	composite	€ 20.459,10	€ 8.583,97	€ 10.315,99	€ 16.355,98	€ 10.143,11	€ 4.103,12
clayey peat	foam concrete	composite	€ 20.459,10	€ 8.583,97	€ 10.315,99	€ 16.355,98	€ 10.143,11	€ 4.103,12
peat	peat (pct)	steel	€ 18.880,19	€ 10.174,61	€ 10.924,85	€ 14.780,22	€ 7.955,34	€ 4.099,97
peat	clayey peat (pct)	composite	€ 19.182,79	€ 9.872,02	€ 11.313,85	€ 15.084,89	€ 7.868,93	€ 4.097,89
peat	EPS	steel	€ 20.200,90	€ 8.842,43	€ 9.907,39	€ 16.169,94	€ 10.293,51	€ 4.030,96
peat	foam concrete	steel	€ 20.200,90	€ 8.842,43	€ 9.907,39	€ 16.169,94	€ 10.293,51	€ 4.030,96
clayey peat	flugsand	steel	€ 20.459,10	€ 8.583,97	€ 10.085,94	€ 16.537,88	€ 10.373,16	€ 3.921,22
clayey peat	lava stone	steel	€ 20.459,10	€ 8.583,97	€ 10.085,94	€ 16.537,88	€ 10.373,16	€ 3.921,22
peat	flugsand	bamboo	€ 20.200,90	€ 8.842,43	€ 9.795,54	€ 16.286,40	€ 10.405,37	€ 3.914,50
peat	lava stone	bamboo	€ 20.200,90	€ 8.842,43	€ 9.795,54	€ 16.286,40	€ 10.405,37	€ 3.914,50
peat	flugsand	wooden	€ 20.200,90	€ 8.842,43	€ 10.059,05	€ 16.374,24	€ 10.141,85	€ 3.826,66
peat	lava stone	wooden	€ 20.200,90	€ 8.842,43	€ 10.059,05	€ 16.374,24	€ 10.141,85	€ 3.826,66
peat	flugsand	synthetic	€ 20.200,90	€ 8.842,43	€ 10.105,34	€ 16.565,85	€ 10.095,56	€ 3.635,06
peat	lava stone	synthetic	€ 20.200,90	€ 8.842,43	€ 10.105,34	€ 16.565,85	€ 10.095,56	€ 3.635,06
peat	peat (pct)	composite	€ 18.880,19	€ 10.174,61	€ 11.566,85	€ 15.422,22	€ 7.313,34	€ 3.457,97
peat	EPS	composite	€ 20.200,90	€ 8.842,43	€ 10.549,39	€ 16.811,94	€ 9.651,51	€ 3.388,96
peat	foam concrete	composite	€ 20.200,90	€ 8.842,43	€ 10.549,39	€ 16.811,94	€ 9.651,51	€ 3.388,96
clayey peat	flugsand	composite	€ 20.459,10	€ 8.583,97	€ 10.727,94	€ 17.179,88	€ 9.731,16	€ 3.279,22
clayey peat	lava stone	composite	€ 20.459,10	€ 8.583,97	€ 10.727,94	€ 17.179,88	€ 9.731,16	€ 3.279,22
peat	flugsand	steel	€ 20.200,90	€ 8.842,43	€ 10.319,34	€ 16.993,85	€ 9.881,56	€ 3.207,06
peat	lava stone	steel	€ 20.200,90	€ 8.842,43	€ 10.319,34	€ 16.993,85	€ 9.881,56	€ 3.207,06
peat	flugsand	composite	€ 20.200,90	€ 8.842,43	€ 10.961,34	€ 17.635,85	€ 9.239,56	€ 2.565,06
peat	lava stone	composite	€ 20.200,90	€ 8.842,43	€ 10.961,34	€ 17.635,85	€ 9.239,56	€ 2.565,06
clayey peat	clayey peat (pct)	SCFB	€ 19.440,98	€ 9.613,56	€ 13.042,12	€ 21.405,59	€ 6.398,86	€ -1.964,61
clayey peat	clayey peat (pct)	vlotterkering	€ 19.440,98	€ 9.613,56	€ 13.042,12	€ 21.405,59	€ 6.398,86	€ -1.964,61
clayey peat	peat (pct)	SCFB	€ 19.138,39	€ 9.916,15	€ 13.295,12	€ 21.742,93	€ 5.843,27	€ -2.604,54
clayey peat	peat (pct)	vlotterkering	€ 19.138,39	€ 9.916,15	€ 13.295,12	€ 21.742,93	€ 5.843,27	€ -2.604,54
clayey peat	EPS	SCFB	€ 20.459,10	€ 8.583,97	€ 12.277,65	€ 23.132,65	€ 8.181,44	€ -2.673,55
clayey peat	foam concrete	SCFB	€ 20.459,10	€ 8.583,97	€ 12.277,65	€ 23.132,65	€ 8.181,44	€ -2.673,55
clayey peat	EPS	vlotterkering	€ 20.459,10	€ 8.583,97	€ 12.277,65	€ 23.132,65	€ 8.181,44	€ -2.673,55
clayey peat	foam concrete	vlotterkering	€ 20.459,10	€ 8.583,97	€ 12.277,65	€ 23.132,65	€ 8.181,44	€ -2.673,55
peat	clayey peat (pct)	SCFB	€ 19.182,79	€ 9.872,02	€ 13.275,52	€ 21.861,56	€ 5.907,27	€ -2.678,77
peat	clayey peat (pct)	vlotterkering	€ 19.182,79	€ 9.872,02	€ 13.275,52	€ 21.861,56	€ 5.907,27	€ -2.678,77
peat	peat (pct)	SCFB	€ 18.880,19	€ 10.174,61	€ 13.528,52	€ 22.198,89	€ 5.351,67	€ -3.318,70
peat	peat (pct)	vlotterkering	€ 18.880,19	€ 10.174,61	€ 13.528,52	€ 22.198,89	€ 5.351,67	€ -3.318,70
peat	EPS	SCFB	€ 20.200,90	€ 8.842,43	€ 12.511,05	€ 23.588,61	€ 7.689,85	€ -3.387,71
peat	foam concrete	SCFB	€ 20.200,90	€ 8.842,43	€ 12.511,05	€ 23.588,61	€ 7.689,85	€ -3.387,71
peat	EPS	vlotterkering	€ 20.200,90	€ 8.842,43	€ 12.511,05	€ 23.588,61	€ 7.689,85	€ -3.387,71
peat	foam concrete	vlotterkering	€ 20.200,90	€ 8.842,43	€ 12.511,05	€ 23.588,61	€ 7.689,85	€ -3.387,71
clayey peat	flugsand	SCFB	€ 20.459,10	€ 8.583,97	€ 12.689,61	€ 23.956,55	€ 7.769,49	€ -3.497,45
clayey peat	lava stone	SCFB	€ 20.459,10	€ 8.583,97	€ 12.689,61	€ 23.956,55	€ 7.769,49	€ -3.497,45
clayey peat	flugsand	vlotterkering	€ 20.459,10	€ 8.583,97	€ 12.689,61	€ 23.956,55	€ 7.769,49	€ -3.497,45
clayey peat	lava stone	vlotterkering	€ 20.459,10	€ 8.583,97	€ 12.689,61	€ 23.956,55	€ 7.769,49	€ -3.497,45
peat	flugsand	SCFB	€ 20.200,90	€ 8.842,43	€ 12.923,00	€ 24.412,51	€ 7.277,90	€ -4.211,61
peat	lava stone	SCFB	€ 20.200,90	€ 8.842,43	€ 12.923,00	€ 24.412,51	€ 7.277,90	€ -4.211,61
peat	flugsand	vlotterkering	€ 20.200,90	€ 8.842,43	€ 12.923,00	€ 24.412,51	€ 7.277,90	€ -4.211,61
peat	lava stone	vlotterkering	€ 20.200,90	€ 8.842,43	€ 12.923,00	€ 24.412,51	€ 7.277,90	€ -4.211,61