Towards a sustainable peat meadow.

Cost-benefit scenarios of soil subsidence in the jurisdiction of water board de Stichtse Rijnlanden.

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Preface

After about eight months, I hereby present the final report of my MSc. graduation research. When I started exploring the possibilities in thesis subjects and possible ways to carry out this final product of my master's program Sustainable Development, the first decision was to look for a place where I could not only get my final mark of years of studying, but where I could also get acquainted with the world where sustainable development is put in practice. Therefore, I am very grateful to Hoogheemraadschap de Stichtse Rijnlanden that I got the chance to gain the useful experiences of an internship there.

My primary acknowledgements are for Henk van Hardeveld from HDSR, Paul Schot and my second reader, Jerry van Dijk, from the Utrecht University, who assisted me in this most intensive project of my career as a student and who supplied me with their helpful and refreshing insights and critique. Furthermore, I would like to thank my colleagues at HDSR for the support and information they gave me on this versatile subject. I am particularly grateful to Harm de Jong, Astrid de Boer, Maaike Klomp and Epke van der Werf, who were always willing to interrupt their work to provide me with data and useful thoughts. Even though it is, hopefully, the capstone of my study, I have learned a lot, including the lesson that there is still so much to learn. After all, I can look back on an exciting and valuable experience and I hope I can look forward to a career in which this progress will continue.

Daan Henkens
Utrecht, 24-06-2013

Front page image: Hiske Wegman Architecten

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Summary

Large parts of the west of the Netherlands consist of peat meadows. In these areas, soil subsidence occurs, mainly as a result of the oxidation of the peat layer above the groundwater level. This subsidence is causing sagging of houses and infrastructure, greenhouse gas emissions and eutrophication of the surface water. Therefore, governments are currently looking for a sustainable approach to combat soil subsidence in the peat meadows. Water board De Stichtse Rijnlanden (HDSR) is responsible for setting the water levels in about 25.000 hectares of peat meadows. Since the soil subsidence rate is depending on the groundwater levels, the water board is facing the choice whether to lower the water levels, following the soil subsidence, in order to maintain a freeboard that is suitable for agriculture (current practice) or stop this lowering of the water levels in order to slow down the subsidence of the soil.

The first part of study aims at filling some of the knowledge gaps that are currently still obstructing an inclusive assessment of the different management options available. These are the lack of a comprehensive overview of the outcomes of previous studies on this subject and the lack of knowledge concerning the relationship between soil subsidence and the costs for road and sewer management. The second part of the study aims at indicating what scenarios for future management may contribute to a sustainable development of the peat meadows.

For the first part, a literature study and interviews with municipal road and sewer managers were carried out. For the second part, four scenarios were compared, of which two assumed a continuation of the lowering of the water levels, and in the other two, water level lowering is ceased. Of both scenario sets, the first assumed no additional measures to mitigate the negative consequences of the scenario, and the second did include such measures.

It turned out that, when contemplating soil subsidence and measures to mitigate soil subsidence, the following costs and benefits are relevant to take into account: pumping costs, initial investment costs, agricultural yield, foundation damage, damage to roads, sewers, pipelines and cables, high water level facilities, sagging of dikes, inundation damage, water quality, property prices, recreational benefits, greenhouse gas emissions, landscape and cultural heritage, biodiversity/non-use value of nature and further emotional aspects.

Furthermore, it became clear that municipal road and sewer managers indeed need to take additional measures as a result of soil subsidence. The costs per m^2 for road management in peat meadow areas are about 25% to 35% higher than in areas without soil subsidence. Concerning sewers, the major difference was that the depreciation periods of sewers in peat meadow areas were much shorter (40 years instead of 60 years for gravity drained sewers) and that there are additional costs for cleaning the sewers.

The scenario study indicated that it is not possible to maintain the current use of peat meadows in a way that is physically sustainable. Agricultural use of the peat meadows will always entail some soil subsidence. Although the scenario study showed that the total costs of soil subsidence will likely be the lowest in scenarios where the lowering of the water levels is ceased and additional measures are taken to mitigate loss of agricultural yield, this will still have a negative impact on the agricultural yield. Therefore, the choice whether to put a strategy like this in practice will be mainly a political one.

1. Introduction

1.1 Background

1.1.1 *Peat meadows*

The peat meadows are a typical element of the landscape in the western part of the Netherlands. The dairy farms with their open grasslands with grazing cows and the many ditches are famous all over the world. Until today, grasslands for dairy farming are prevailing in the area. In these peat meadows, irreversible soil subsidence occurs. The largest contributor to soil subsidence in these areas is oxidation of the peat in the soil. Oxidation occurs in the aerobic soil layer above the ground water level. If the groundwater level is lowered, which is required to maintain a suitable freeboard, i.e. the distance between surface water level and ground level, for agriculture, more peat becomes subject to oxidation and soil subsidence is accelerated (Querner et al., 2012; Vreman et al., 2012). Continuing to lower the water levels, following the subsiding surface level, would mean that the peat layer will eventually disappear completely.

The consequences of this process are numerous: roads, pipelines, cables, houses, dikes and other water structures become seriously damaged by the (unequal) sagging of the subsoil (Van Hardeveld et al., 2011), mineralization of peat causes eutrophication of surface water (Hellmann & Vermaat, 2012), changes may occur in the typical peat meadow landscape, for example if land use shifts in response to wetter circumstances are implemented, and the water board faces increased costs of drainage pumping as a result of the enlarged elevation difference between peat polders and their surroundings (Van Hardeveld et al., 2011). Furthermore, peat oxidation causes substantial greenhouse gas emissions, mainly CO_2, responsible for about 2,5% of the total anthropogenic CO_2 emissions of the Netherlands (Van den Akker et al., 2008).

In order to cope with these problems, different strategies may be practiced. Safeguarding the agricultural functions of the peat meadows by continuing the current policy, i.e. adjusting the water levels to the soil subsidence, is an option for future management. However, this entails high costs for house owners, whose house becomes damaged, local governments, which are responsible for infrastructure maintenance and the water board, which is facing increasing water management costs (Van Hardeveld et al., 2011). In order to stop soil subsidence, the only way is to reduce the freeboard, which will slow down the oxidation of peat, but the consequence is less favorable circumstances for agriculture (Querner et al., 2012; Van Hardeveld et al., 2011; De Vos et al., 2010). Therefore, adaptations in land use and/or water management should be considered. This could imply adaptations in the current land use and water management so it is better able to cope with higher groundwater levels. Examples are the construction of underwater drains to stabilize the groundwater level (Querner et al., 2012; Van den Akker et al., 2010; Hoving et al., 2008) or using cattle breeds and grass species that are more productive under wet circumstances (Koornneef, 2012; Koole & Verburg, 2012). Otherwise, the land use may completely change, abandoning the traditional dairy farming, for example by shifting to reed farming (Korevaar, 2011) or by converting agricultural land into nature (Verhoeven et al., 2010).

Figure 1.1. Aerial view of a typical peat meadow landscape near Zegveld (Het Utrechts archief, 1988).

1.1.2 *Cost-benefit analyses*

In order to aggregate and weigh the costs and benefits of different management alternatives, a cost benefit analysis (CBA) can be conducted in which the costs and benefits per scenario are quantified and assessed. In this study, the term cost-benefit analysis will refer to the socio-economic cost-benefit analysis which, as opposed to merely economic cost-benefit analyses, takes not only the direct financial costs and benefits into account, but also the indirect and non-market costs and benefits.

Determining relevant costs and benefits in order to support decisions concerning the approach to soil subsidence inherently means that one has to assign values to each effect of the management choices on the goods and services provided by the peat meadow ecosystem. These values are divided into direct use values, indirect use values and non-use values. Direct use values refer to goods provided by the peat meadow ecosystem that can be directly used, such as agricultural products and recreation. Indirect values are services that indirectly add to social welfare, such as water retention or the provision of clean air. Non-use values are values that do not relate to the use of the ecosystem, such as value assigned to the conservation of the system for future generations or the mere knowledge that the system exists. Also, the possibility to make use of the goods and services provided by an ecosystem in the future (option value) is an example of a non-use value. Together, these values comprise the total economic value (TEV) of an ecosystem (Robbins & Daniels, 2012; Turner et al., 2000). Note that the TEV is not equal to the total value of an ecosystem. TEV only includes values that are linked to human interests. The 'intrinsic value', which is the value an ecosystem has in itself, thus without any reference to human interest, is not included in the TEV (Turner et al., 2000; Costanza, 2006).

Although linked to human interests, not all elements of the TEV can directly be expressed in monetary terms. In particular, indirect use values and non-use values like biodiversity or water retention are hard to monetize since they do not have direct market prices and it is often not possible to identify one single actor that is accountable for the cost or benefit at hand. Moreover, there may not even be an actual flow of money involved, while the effect unambiguously affects the TEV of the peat meadow system. For these factors, methods have been developed to express them in monetary terms. One may assign a hypothetical price to the value by asking stakeholders for their willingness to pay to maintain the value (contingent valuation), or one can link the value to other values that do have a market price. For example, one can determine the effect of the value under study on the price of market goods, such as houses (hedonic pricing), or one can state that the amount of money people spend to visit an area is a reflection of their valuation of, for example, the quality of the nature in the area (the travel cost method) (Robbins & Daniels, 2012; Lebret et al., 2005; Nunes & Van den Bergh, 2001).

The use of cost-benefit analyses in the context of sustainability is not undisputed. Costanza (2006) argues that, when thinking in terms of costs and benefits and willingness to pay, one puts values in the context of current individual preferences and utility maximization as goals, while sustainability does often imply different goals than these. In accordance with Costanza (2006), Turner (2007) warns that thinking only from a cost-benefit point of view may be misleading to policy makers, since the scope of CBA is often limited to instrumental values, while the value of ecosystems is often more than just the goods and services it provides, or the sum of its parts. After all, thresholds and complex feedback mechanisms may lead to unforeseen impacts. The author states that, in a time where ethical and scientific arguments are often not enough to be decisive, CBA has started to play an increasingly important role as a tool to identify the most profitable management strategy. He argues that, in this role, it is unlikely that CBA will gain relevance in the future. Both Costanza (2006) and Turner (2007) stress that CBA can only contribute to a sustainable way of policy making if the scope of CBA is broader than just the financial aspects, and if it is embedded in a wider spectrum of other forms of analysis that can cover the effects that are not included in a CBA.

1.1.3 *Problem description*

The current approach of continuing to lower the water levels in order to maintain the freeboard will not be able to mitigate the negative consequences of the ongoing soil subsidence described above. Moreover, the consequences of soil subsidence are even expected to become aggravated in the future when keeping the current approach and the costs and benefits of the current approach likely become increasingly unequally distributed over the stakeholders, since the costs of soil subsidence are mainly for house owners and governments, while farmers benefit from the lowering of the water levels (e.g. Querner et al., 2012; Van Hardeveld et al., 2011). This development is in several aspects conflicting with the common definition of sustainable development (WCED, 1987), as future generations will face increasing costs as a result of the current policy since houses and infrastructure will become damaged and the irreversibility of soil subsidence implies that potential changes in land use as a consequence of soil subsidence are definite. The current development arguably even fails meeting the needs of the current generation, since damage to houses and infrastructure is already causing unusually high costs for the inhabitants and governments of the peat meadows. Therefore, this approach is currently being considered unsustainable (Querner et al., 2012) and governments throughout the Netherlands are searching for a sustainable way to cope with the problem of soil subsidence (Waarheen met het Veen, 2008).

One of the governments in the Netherlands coping with soil subsidence in their jurisdiction is the water board of the Stichtse Rijnlanden (HDSR). HDSR covers about 82.000 ha, mostly in the province of Utrecht and for a minor part in the province of Zuid-Holland and has 283.000 inhabitants.
The eastern part of the water board is largely located on the sandy hill ridge of the 'Utrechtse Heuvelrug'. In the middle of the area, the towns of Maarssen, Utrecht and Nieuwegein form an urban corridor between the higher, eastern part of the water board and the lower lying western part. The western part of the jurisdiction of HDSR predominantly consists of peat meadows and is part of the 'green heart' of Holland. Since this is the area that is facing major soil subsidence through peat oxidation, this is the area of interest for the present study.

Because the consequences of soil subsidence will become worse if the current water level management is maintained, and the associated costs for the water board and other stakeholders will become higher, several management options to cope with the various consequences of soil subsidence are currently contemplated by HDSR. All of these strategies aim at reducing the total costs for society, or reduce the costs for one of the actors, but it is not yet possible to fully assess the desirability of these management strategies in the context of sustainable development.

Several cost-benefit analyses have been done by HDSR to get insight in these costs and benefits in the future (Van Hardeveld et al., 2011; Van Hardeveld et al., 2013) but still, a number of unresolved gaps in knowledge remain. First, the different types of costs and benefits, especially those that are not directly

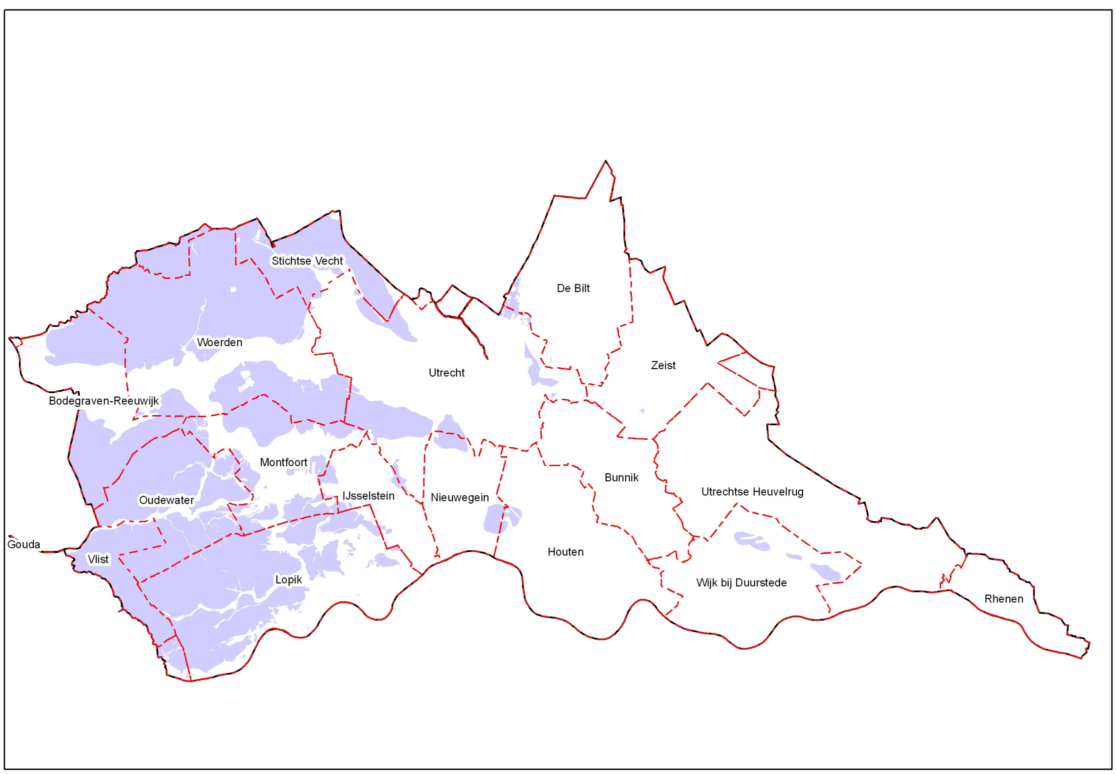

Figure 1.2. Map of the jurisdiction of HDSR with municipality borders. Purple shaded areas indicate the location of peat meadows.

expressible in market values, are not completely included in the previous research done by HDSR. A comprehensive analysis of the available literature is needed to provide a full overview of what types of cost and benefit factors are relevant and how these factors can be assessed. Furthermore, there is a lack of knowledge concerning potential damage to roads and sewers as a consequence of soil subsidence.

If these knowledge gaps are resolved, the sustainability of several future management scenarios can be explored. In order to be considered sustainable in the present research, a few criteria are defined that serve as a touchstone for sustainability of the strategy under study. First, the approach should not result in aggravation of the current problems in the future, second, should not create new, already foreseeable problems and, third, should have a wide support among the stakeholders. Concerning this latter point, it is important that the costs are limited as much as possible and, moreover, are being fairly distributed over the stakeholders in the future to maintain the support of the stakeholders.

1.2 Research aim and research questions

1.2.1 *Research aim*

The aim of this study is to fill in the knowledge gaps described above and, with this knowledge completed, provide a more adequate analysis of the sustainability of future management scenarios. Thereby, this study facilitates the assessment of management strategies for their sustainability and the realization of sustainable approach to the issue of soil subsidence in peat meadow areas.

1.2.2 *Research question and hypothesis*

The guiding research question in this study is:
What are the costs and benefits of soil subsidence in the HDSR peat meadow area, and what management strategies may contribute to a sustainable development of these costs and benefits?

The hypothesis is as follows:
Continuing to adjust the water levels to soil subsidence will lead to increased and unequally distributed costs and is therefore unsustainable; reconsidering the choices in policy and management of soil subsidence will lead to a more sustainable approach.

1.2.3 *Sub-questions*

The research question consists of two parts: the first aims at revealing what costs and benefits are relevant. Answering the following sub-question will result in an inclusive overview of the relevant costs and benefits and methods that are used to value and quantify them:

1. *Which costs and benefits are deemed relevant in the current literature, and how are they valued and assessed?*

As stated in section 1.1.3, the costs of road and sewer maintenance remain an important gap in knowledge. Answering sub-question 2 will resolve this knowledge gap.

2. *What are the costs for maintenance and renovation of roads and sewers as a consequence of soil subsidence?*

The second part of the research question is aimed at indicating what strategies contribute to a sustainable approach to soil subsidence in the peat meadows. The following sub-question aims at providing insight in the development of costs and benefits in different future scenarios and its implication for sustainability.

3. *What is the development of costs and benefits associated with soil subsidence under different management scenarios, and to what extent is this development sustainable?*

2. Methodology

2.1 General Approach

The research is set up in two main phases, which are schematically explained in figure 1. The first phase focuses on framing the current knowledge on costs and benefits of soil subsidence, obtained from literature (1). Next to the literature study, stakeholder interviews result in a reduction of the current range of uncertainty on road and sewer maintenance costs (2). This results in an overview of the knowledge that is available, including data on roads and sewer management costs which were formerly undisclosed (3). The second phase is aimed at studying the impact of a number of future scenarios, which represent different approaches of coping with soil subsidence, on the relevant costs and benefits. This will result in an overview of the costs and benefits per actor in each scenario (4), which will be used to compare the scenarios and assess their sustainability (5).

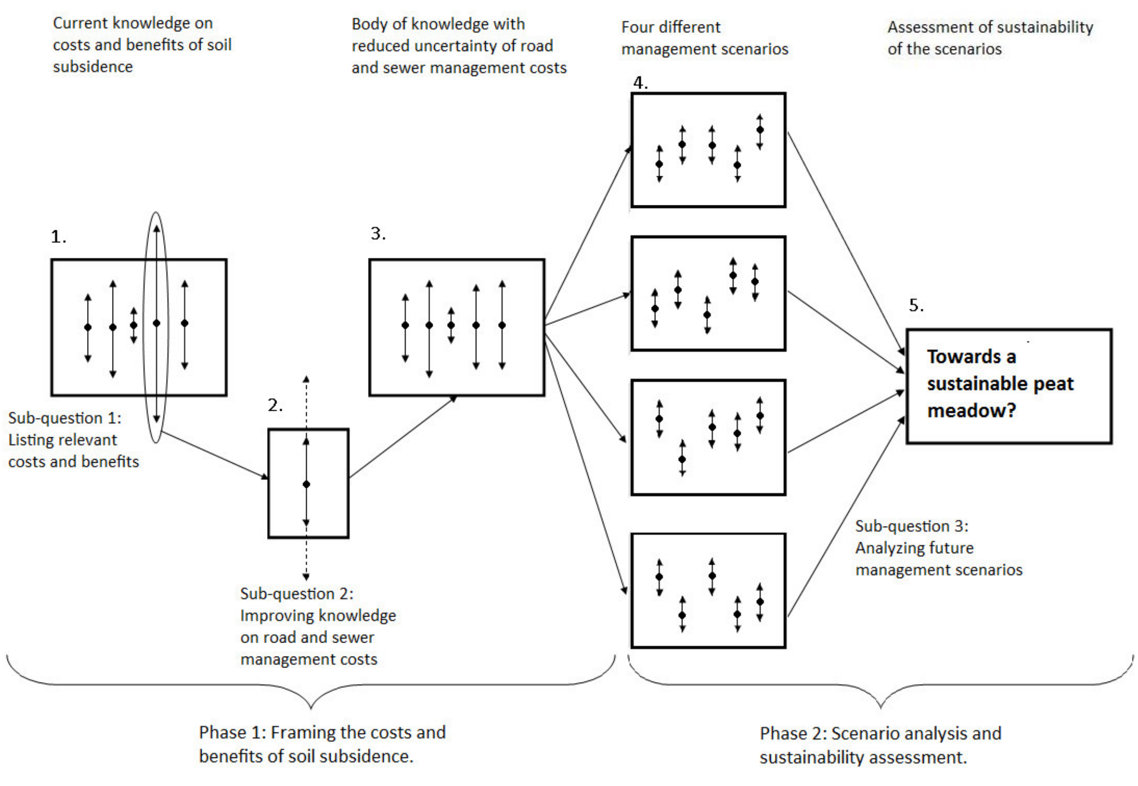

Figure 2.1. Schematic overview of the research phases. Double vertical arrows represent different cost or benefit factors and their uncertainty range.

2.2 Phase one: Inventory and assessment of relevant costs and benefits

2.2.1 *Literature study on the costs and benefits of relevance*

Previous cost-benefit analyses, related to the issue of soil subsidence, offer insight in the currently available knowledge on the costs and benefits that are deemed relevant for soil subsidence and potential strategies to combat (the adverse effects of) soil subsidence. For this research, eight cost benefit analyses from the last decade were reviewed, namely Graaff et al. (2003), Uran et al. (2006), Witteveen + Bos (2006), Witteveen + Bos (2007), Bos & Vogelzang (2008), Van Hardeveld et al. (2011), Van der Kooij et al. (2012) and Van Hardeveld et al. (2013). These studies are, in the first place, analyses of possible adaptations in land and water management within peat meadow areas in the study area, or in comparable peat meadow areas outside the study area. Furthermore, in several cases, measures have been studied in order to solve problems that are not caused by soil subsidence, but require a similar solution. These studies can provide valuable information about the effects of such measures. Examples of problems for which water level increase is a proposed solution are the prevention of excessive seepage in polders, causing desiccation of the surroundings (Graaff et al., 2003), high pumping costs and water quality decrease (Uran et al., 2006). This 'grey literature' is acquired from the archives of HDSR and from the websites of the involved organizations, such as the peat meadow innovation center (VIC) and the foundation for applied water management research (STOWA).

An overview was made of the effects that were taken into account in each of these studies and the context of each effect within the issue of soil subsidence was sketched. Also, the available methods for quantification and monetizing of the effects were addressed and evaluated. Additional literature from peer-reviewed journals and research institutes was gathered to provide a comprehensive description of the available valuation methods where needed. In this way, a complete overview of the effects and valuation methods that are relevant when contemplating scenarios for the future of peat meadow areas is obtained, which serves as the basis for the scenario analysis in the next section.

2.2.2 *Complementing the knowledge on road and sewer management costs*

In order to gather data about the influence of soil subsidence on the maintenance and restoration costs for roads and sewers to answer the second sub-question, four municipalities were consulted which are located on peaty soils within or near the HDSR peat meadow area. As a consequence of their peaty underground, these municipalities were expected to face problems caused by soil subsidence within their jurisdiction. In addition, two municipalities within the HDSR jurisdiction were selected which are located on stable sand or clay soils and where, therefore, no problems related to soil subsidence were foreseen. These municipalities served as a control group, displaying the costs and benefits of road and sewer management in the absence of soil subsidence. The four selected municipalities where soil subsidence likely occurs are Bodegraven-Reeuwijk, Gouda, Stichtse Vecht and Woerden, while De Bilt and Wijk bij Duurstede were selected as control municipalities. These municipalities, except for Gouda, were selected because they are all rather average sized and all include both rural and urban areas, making them representative of the HDSR peat meadow area. In addition, Gouda was selected because it is a relatively urban municipality which is nationally known for its subsidence-prone soil. This municipality was expected to offer a magnified representation of the soil subsidence issue which can be used to pinpoint points of concern.

This part of the research consisted of two steps. First, road and sewer managers of the selected municipalities were interviewed in a series of semi-structured interviews. The goal of these interviews was twofold. First, the interviews were used to identify the problem of soil subsidence in the context of road and sewer management. Second, the actual costs this problem entails for municipal road and sewer management were identified. The following questions were used to gather the required information:

Identification of the problem:

- Does the municipality face soil subsidence in its jurisdiction, and is this considered a problem?
- How is soil subsidence manifested in the municipality?
- Are there specific measures applied to control the consequences of soil subsidence?
- What is the municipality's vision on the future development of soil subsidence management in the municipality?

- What are the basic assumptions underpinning this vision? (E.g. are changes in water management or technological progressions anticipated?)
- What depreciation periods are used for roads and sewers?

Identification of costs for road and sewer management:

- What are the budgets for maintenance and replacement of roads and sewers?
- Are there notable external factors, such as overdue maintenance, influencing these budgets?

In order to support the data gathered from the interviews, the management plans for public space (Integraal Beheersplan Openbare Ruimte, IBOR) and sewers ((verbreed) Gemeentelijk Rioleringsplan, vGRP) and the municipal budgets were studied for each of the interviewed municipalities. This second step of the research provided municipality-specific data on the features and the budgets reserved for management of the roads and sewers. The benchmark sewage management, a 2010 survey among all Dutch municipalities conducted by the overarching organization for the sewage sector, was used to support the comparison of characteristics of the sewage system per municipality (RIONED, 2010).

2.3 Phase two: Scenario analysis

2.3.1 *Outline of the scenario analysis*

In the second research phase, four scenarios are defined, based on the available literature and judgment of experts from HDSR. These scenarios represent substantially different potential directions for future development. Roughly, only 2 scenarios for future water level management in the peat meadow area exist: continue lowering the water levels to keep the land suitable for current agricultural use, or cease the lowering of water levels to slow down soil subsidence. Within these two possibilities, numerous alternative strategies are possible. In this section, four alternatives for future management of land and water in the HDSR peat meadow area are defined, of which two start from a continuation of adjusting the water levels to soil subsidence, and two assume that the lowering of the water levels is ceased. In both cases, the first scenario presents a conservative approach, i.e. no additional measures are taken to abate any negative consequences of the approach, and the second scenario does include measures to mitigate the negative effects of the approach that is taken. The use of scenarios provides insight in the influence of future choices regarding strategies and the deployment of measures on the development of cost and benefits of soil subsidence.

The methods and the data available for this study do not allow a high level of detail in the outcome of the scenario study, since the consequences of soil subsidence vary within jurisdictional borders, while the data are often only available per municipality or for the entire HDSR jurisdiction. Hence, making a distinction between, for example, the parts of a municipality which are vulnerable for soil subsidence and the parts that are located on stable ridges is not possible within the setup of this research. Therefore, it cannot readily be determined which part of the municipal infrastructure is suffering damage from soil subsidence at what costs. If such a level of detail is to be obtained, this would imply a very time and labor-intensive research, including GIS-work for which the time and resources available for this study were insufficient. Therefore, a simplified, fictional peat meadow area is defined which is based on the features of the peat meadow area of HDSR, but which lacks spatial detail. A detailed description of this fictional study area is given in paragraph 2.3.2.

As a benefit of the simplification of the study area, we get a higher degree of freedom to experiment with future scenarios. Exploring more extreme scenarios, i.e. scenarios that strongly deviate from the current situation would otherwise be impossible since the input information concerning such more extreme scenarios is typically accompanied by a high range of uncertainty. This makes it impossible to fit this information within the detailed features of the actual HDSR peat meadow area while maintaining a high level of detail in the outcome of the study. In other words, we may have sacrificed a part of the spatial detail level, but this allows us to explore more extreme scenarios which would otherwise not have been easily made. These scenarios may reveal useful insights for the formulation of a strategy towards a sustainable approach to soil subsidence.

The study area is modeled to be representative for the peat meadow area within the HDSR jurisdiction. It has a similar surface area, similar land use and a similar division of soil subsidence rates over the surface area. For example, the information about paved area (roads) and length of the sewage system, available per municipality, is converted into a rounded number per hectare and aggregated for fictional study area. In this way, a study area is created which is representative for the characteristics of the peat meadow area of HDSR. For this fictional study area, the effects on costs and benefits of the five scenarios are calculated. First, the physical effects of each scenario are determined and quantified, based on the list of effects collected from previous studies and presented in the first phase of the research. The following costs and benefits are included in the scenario study: pumping costs, initial investment costs (in this case only the costs for underwater drains), agricultural yield loss, sagging of houses, sagging of roads, sagging of sewers, pipelines and cables, high water level facilities, dikes, inundation damage, water quality, recreation, greenhouse gas emission, landscape and cultural heritage and biodiversity/non-use value of nature. Private property prices are not taken into account since the available information is considered unusable, as explained in section 3.1.4.

The physical effects are estimated by determining the soil subsidence in the study area, based on maps and GIS-data available at HDSR and, subsequently, calculating the effects associated with these soil subsidence rates, following the methods that are found in literature and that were listed in the first phase of the research. The surface area per soil subsidence class and the other input variables (i.e. input values that were not derived from the amount of soil subsidence) are shown in table 1). Based on the physical effects, the costs and/or benefits associated with each effect are calculated. This is, where possible, done using methods and standard cost factors that have been put forward in previous cost-benefit analyses and are explained in paragraph 3.1.4. For the costs of roads and sewers, the additional data gathered in the previous phase of this research are used. Where relevant, the unit prices used in the cost calculations are given in table 2. Subsequently, the costs and benefits are allocated to and aggregated for four actors or actor groups: the water board, farmers, house owners and society, including municipalities, utility companies, the recreation sector and other citizens who, directly or indirectly, make use of the peat meadow area.

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Soil subsidence (cm in 2100)				
0-25	6.000 ha	5.000 ha	10.500 ha	11.000 ha
25-50	11.000 ha	9.000 ha	8.500 ha	5.000 ha
50-75	5.000 ha	4.000 ha	2.500 ha	2.500 ha
75-100	2.500 ha	2.000 ha	500 ha	1.000 ha
>100	500 ha	500 ha	-	-
Pumping				
- Flushing	2.500 mm	2.500 mm	750 mm	500 mm
- Regular pumping	*	*	*	*
Agricultural yield				
- Mean high water level	20 cm-surf.	20 cm-surf.	5-10 cm-surf.	30 cm-surf.
- Mean low water level	80 cm-surf.	80 cm-surf.	50-60 cm-surf.	60 cm-surf.
Pipelines and cables	*	*	*	*
Inundation damage	*	*	*	*
Recreation	950.000 visits	950.000 visits	1.200.000 visits	1.200.000 visits
Biodiversity/non-use value of nature	0	0	5,-/person/year	11,-/person/year

*Table 2.1. Input variables per scenario. * indicates that no variables are used but that, instead, the costs are taken over from literature.*

Parameter	Unit price (€)	
Pumping costs		0,01/m^3
Initial investment costs: drain construction		1.666,-/ha
Agricultural yield		825,-/ha
Sagging of houses	Lower limit	Upper limit
- Cracks	4.000,-	10.000,-
- Foundation restoration	65.000,-	100.000,-
Road maintenance costs	Lower limit	Upper limit
- Pavers	3,20/m^2/yr.	4,36/m^2/yr.
- Asphalt	2,85/m^2/yr.	4,54/m^2/yr.
Sewer replacement costs		
- Gravity (300mm)		370,-/m
- Pressure (90mm)		45,90/m
Levering pipelines and cables		1.250,-/km
Dikes		
- Soil		15,-/m^3
- Land		70,-/m^2
- Sheet piling		1.500,-/m
Inundation damage	Grass	Built-up area
	727,-/ha	6.000.000/ha
Recreation		1,-/visit
Greenhouse gas emission		7,-/ton CO_2

Table 2.2. Unit prices for scenario cost calculations.

2.3.2 *Definition of the study area*

The study area for the scenario analysis is a fictional peat meadow area based on the peat meadows of HDSR. Where municipal data are used, data are used from the municipalities that together cover the majority of the HDSR peat meadows, i.e. Stichtse Vecht, Woerden, Bodegraven-Reeuwijk, Oudewater, Vlist and Lopik, hereafter called the peat meadow municipalities. The study area has a total surface area of 25.000 hectare, which is approximately the surface of the area within HDSR where soil subsidence occurs. The occurring soil types in the study area are peat meadow soils (70%) and clay on peat (30%). The percentages are estimated based on the soil map of HDSR. In the study area, 860 dairy farms are present, covering 24.000 hectare of grassland. The current surface water levels in the peat meadows are about 50 centimeter below surface level (HDSR, 2011), and for the study area, a mean high groundwater level is set of 20 centimeters below surface, and a mean low groundwater level of 80 centimeters below surface. This range is based on the water level data available within HDSR. The amount of CO_2 emitted as a consequence of the oxidation of peat is depending on the soil composition. For the study area, the soil composition is set according to the Zegveld polder. For this polder, Van den Akker et al. (2008) determined a CO_2 emission per millimeter of soil subsidence of 2.259 kg/ha. This amount is assumed for the entire study area.

In the area, 8.500 houses are built, with an age distribution as shown in table 2.3. The assumption is that the houses are equally distributed over the study area. The lifespan of houses in the HDSR peat meadows is unknown. As a lower limit, a life span of 100 years is assumed, and 200 years is assumed as upper limit (Van Hardeveld et al., 2013). Because the study area is mainly rural, the average road surface per hectare of Oudewater, the most rural municipality in the HDSR peat meadow area, is assumed, which is 130 m^2 per hectare (CBS, 2013). Municipal pavement data reveal a division of approximately 45% of the pavement consisting of asphalt and 55% of pavers. A total sewer length of 750 kilometers is assumed, of which 400 kilometers is gravity drained sewer with a tube diameter of 300 mm, and 350 kilometers is pressure drained sewer with a tube diameter of 90 mm. This is calculated by multiplying the average sewer length per hectare of the peat meadow municipalities, taken from the municipal sewage management plans, by the total surface of the study area. The length of the dikes in the study area is 120 kilometers, which are mostly regional dikes. The dikes are 10 meters wide at the basis and are on average 2 meters high. The dikes have a slope of 1:4. These numbers are based on an inventory of dikes in the HDSR peat meadow area and on elevation maps.

Feature	Unit	Quantity	Source
Area	ha	25.000	Approx. HDSR peat meadow area
Road surface - Pavers - Asphalt	ha % %	325 55 45	CBS (2013) Municipality information
Agricultural grassland	ha	24.000	Estimate based on land use maps.
Houses < 1919 1920-1959 1960-1974 1975-1989 > 1990	-	8.500 750 850 1.700 2.800 2.400	Van Hardeveld et al. (2013)
High water level facilities - current - extended	ha	 0 4.500	 Van Hardeveld et al. (2013)
Sewers - Gravity drained - Pressure drained	Km	750 400 350	Municipality information
Dikes	Km	120	HDSR
CO_2 emission	Kg/ha/mm subsidence	2.259	Van den Akker et al. (2008)
Agricultural yield in optimal conditions	€/ha	825	Brouwer & Huinink (2002); STOWA (2012)
Pumping flow rate	mm	3.000-5.500	HDSR discharge data

Table 2.3. Features of the study area.

2.3.3 *Scenario description*

Scenario 1: Maintaining the freeboard
The water board continues adjusting the water levels to maintain a freeboard that keeps the land suitable for current agricultural use. As a consequence, there will be no water logging, but soil subsidence will continue. As a consequence, the emission of CO_2 from peat oxidation and deterioration of water quality by eutrophication will continue. Furthermore, sagging of houses and infrastructure will occur.

Scenario 2: Protecting houses
The water board continues adjusting the water levels to maintain a drainage that keeps the land suitable for current agricultural use and water logging is avoided. The second scenario is equal to the first scenario, apart from that high water level facilities are constructed and maintained to keep the water levels high around houses. This will slow down or prevent rotting of the foundation poles, so houses will no longer suffer from sagging. The total area of high water level facilities is about 4.500 ha.

Scenario 3: Limiting soil subsidence
The water board ceases further lowering of the water levels. Soil subsidence slows down and damage through sagging is reduced. On the other hand, water logging and crop damage will increase over time as the freeboard is gradually reduced. Current (dairy) farming remains in place, but agricultural yield will gradually diminish as the water levels, relative to the surface level, rise. CO_2 and nutrient emissions from peat oxidation will decline, and the room for nature will gradually increase where agriculture becomes more extensive.

Scenario 4: Mitigating losses
The water board ceases further lowering of the water levels. Underwater drainage systems are constructed in the grasslands, limiting the fluctuations of the groundwater level. Hereby, on the one hand, the soil subsidence rates are reduced, and on the other hand, groundwater level peaks causing crop damage are reduced. Although yield loss still occurs, farmers compensate it by broadening their activities, creating chances for nature development and recreation. Where possible, traditional dairy farming is maintained but, overall, the focus of agricultural activity becomes much broader. Emissions of greenhouse gases and nutrients will be still occur, albeit at a lower rate, and will slowly decrease over time as peat oxidation declines. Extensification of

agriculture and nature preservation by farmers stimulate the development of nature and growth of biodiversity.

2.3.4 *Assessing the sustainability of the scenarios*

In order to answer the central research question, the sustainability of each scenario will be evaluated. Since this study focuses on costs and benefits, which inherently means human interests, the assessment is based on the definition of sustainability of the WCED (1987) which reads that a development is sustainable when it "*meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987, p.15). Hence, the emphasis of the evaluation is on the human interests, both of the current and of the future generations. The assessment is based on 3 aspects, namely (1) the total costs associated with soil subsidence in the scenario, (2) the distribution of the costs over the stakeholders and (3) whether the approach advocated in the scenarios is oriented at abating the cost factor in the future and safeguarding long-term benefits (source oriented) or at limiting and postponing the costs and conserving the current benefits as long as possible (effect oriented).

When assuming that costs reflect negative impacts on the environment and human activities, this implies that lower total costs of a scenario likely represent lower negative impacts on the environment and human activities. Therefore, it is assumed that less costly scenarios are more likely to be sustainable from a cost-benefit perspective than the more costly ones. The second aspect assumes that a scenario needs wide support from the stakeholders in order to be considered sustainable. A disproportional distribution of costs and benefits in a certain scenario is expected to put this wide support at risk, which implies that the sustainability of the scenario becomes questionable. Regarding the third aspect, a source oriented approach is considered to contribute more to a sustainable development of the peat meadows than an effect oriented approach, since the latter does not actually solve the problem, but leaves solving the problem to future generations.

3. Results

3.1 Relevant costs and benefits of soil subsidence

3.1.1 *Introduction*

In the past decade, several cost-benefit analyses have been conducted which are related to the issue of soil subsidence. These studies provide useful insight in the foreseen effects of management strategies in peat meadow areas, the methods to calculate these effects and the costs and benefits that are relevant. Also, the assessment of the economic feasibility of different strategies in previous studies can serve as useful input for the discussion on the sustainability of strategies. In this section, first the most relevant cost-benefit studies that have been conducted in the past decade will be reviewed (see appendix A for more detailed descriptions) and, subsequently, the relevant costs and benefits that emerge from this review, and the ways available to value and assess them, are listed and explained.

3.1.2 *Review of the most relevant existing cost-benefit analyses*

Horstermeer, 2003
In 2003, Graaff et al. analyzed the costs and benefits of seven different options for redevelopment of the Horstermeer polder. Although soil subsidence is not considered a problem in this area, the problems that are addressed in the Horstermeer require solutions similar to the measures considered in subsiding peat polders. Graaff et al. (2003) conclude that, in monetary terms, none of the alternatives is considered feasible and that, in this case, the alternatives were not sufficiently different to make a good distinction between the outcomes of the analysis.

Water level increase Polder de Noordplas (2006)
The water board Rijnland conducted a cost-benefit analysis of raising the water levels in Polder the Noordplas in order to reduce this brackish seepage flux. Although Polder de Noordplas predominantly has a clay soil and soil subsidence is not a relevant problem here, the measure of raising water levels is also applicable to restrain soil subsidence. Uran et al. (2006) conclude that, of the two alternatives considered, none is clearly profitable. The balance of the one alternative of raising water levels is slightly positive; the other has a clearly negative balance.

Water level determines land use (2006)
Land use as defining factor for water level management causes low water levels and, thus, soil subsidence. Therefore a shift towards a mindset in which water levels determine the function of the land came under the attention. Witteveen + Bos (2006) analyzed two scenarios of water level increase in the west of the Netherlands and extrapolated the results of this analysis to the entire western peat meadow area.

The conclusion was that in almost all cases, water level increase was profitable, where the more radical scenario, also entailing the highest costs, eventually resulted in the highest net benefits. However, the study generated a vigorous discussion, resulting in a second opinion set up by the CPB (2006). This second opinion stated that, in the original report, the environmental benefits/saved environmental costs are overestimated. Furthermore, the estimated investment cost savings that are achieved when increasing the water levels in the one of the study areas are overrated according to the second opinion. On the other hand, Witteveen + Bos (2006) omitted the ‘soft’ benefits, such as the intrinsic value of nature in the study areas, the present cultural heritage and the experience of the landscape by the public. Because of on the one hand the overestimation of monetary benefits and on the other hand the omission of ‘soft’ values, the conclusions of Witteveen + Bos (2006) become questionable. The second opinion does, therefore, not provide any alternative conclusions.

Collective high water level facilities (2007)
Witteveen + Bos (2007) has conducted a study to the costs and benefits of collective high water level facilities, which are constructed to maintain a higher water level around houses in order to protect the foundations and locally limit the soil subsidence. The study concludes that the collective high water level facilities in the study area can be considered a socially responsible investment. However, this conclusion became debated as the assumptions concerning the base case became subject to discussion. The assumption was that high water level facilities around houses would result in a relative increase of agricultural yield, since water levels no longer have to be kept high to prevent foundation damage. However, instead, continue lowering the water levels and allow damage to foundations is currently considered a more plausible base case. Therefore, further study is done to the profitability of high water level facilities, given this alternative base case (Van Hardeveld et al., 2013).

Water level change Zegveld (2008)
Bos & Vogelzang (2008) aim at identifying the costs and benefits of water level change in the Zegveld area. Changing the water level in this area may be necessary to combat soil subsidence through peat oxidation. Overall, Bos & Vogelzang (2008) conclude that most actors will benefit from the scenario of increased water levels. If both monetary and non-monetary costs and benefits are included, the conclusion is that the project scenario is certainly beneficial compared to the autonomous development. When only looking at actual money flows, the uncertainty range includes both positive and negative balances.

Continuation of desired ground and surface water regime (2011)
In this report, Van Hardeveld et al. (2011) present a cost-benefit analysis of several alternatives for future water level management in the HDSR area. Worth mentioning is that their study does not draw explicit conclusions on whether a strategy yields a positive cost-benefit balance. Instead, Van Hardeveld et al. (2011) present the costs and benefits per scenario per actor, taking into account the water board, farmers and society (including house owners and municipalities). From these results, Van Hardeveld et al. (2011) conclude that there is no alternative that undisputedly leads to the most beneficial strategy, but that the choice for a strategy is merely a matter of political considerations. Therefore, the authors call for a more explicit inventory of the foreseen costs and benefits and preparation of the debate on the vision on the management of the peat meadow landscape on the future. Here, Van Hardeveld et al. (2011) provide a starting point for further research, which will be partly done in the present study.

Future scenarios Laag Holland (2012)
Van der Kooij et al. (2012) aim at defining a strategy to cope with the increasing costs of maintaining the so-called ‘core qualities’ of the area, i.e. landscape elements that are deemed typical for the area and worth preserving. Van der Kooij et al. (2012) conducted a cost-benefit analysis of these scenarios, incorporating the amenity value assigned by citizens, which makes this study of particular interest. The scenarios with the least interference of the government are considered the least costly for society, while the amenity value assigned by citizens is the highest in the scenarios where the landscape changes the least.

High water level facilities (2013)
At HDSR, concerns arose concerning the sustainability of the current high water level facility policy. Therefore, Van Hardeveld et al. (2013) conducted a study to the necessity and avail of these facilities. The most important finding of this study is that the costs for foundation damage are temporal. On the other hand, the costs to maintain the high water level facilities will increase in the future because of the increasing elevation differences and continuing maintenance costs of the high water level facility. As a consequence, the division of costs and benefits of high water level facilities will become increasingly in favor of house owners in the future. Therefore, Van Hardeveld et al. (2013) advise to consider alternative ways to mitigate the problem of foundation damage, such as settlement of damage or temporal high water level facilities.

3.1.3 *Concluding remarks on the previous cost-benefit studies*

From the studies addressed above, it becomes clear that, in the first place, identifying the costs and benefits of strategies to cope with problems that occur when managing the peat meadows is exceptionally complex. This complexity starts when determining the scope of the analyses; what costs and benefits are relevant in the context of the question under study is subject to debate (cf. Bos & Vogelzang, 2008; CPB, 2006; Witteveen +

Bos, 2006). Although the study areas of the analyses are often clearly delineated (e.g. the jurisdiction of HDSR, the polders of Zegveld, Horstermeer or Noordplas) the costs and benefits often transcend these borders. The abovementioned studies had different approaches to the incorporation of such boundary crossing costs and benefits. Furthermore, each study area has its own site-specific features. This makes comparing the different studies, or transferring the values found in one peat meadow area to another rather cumbersome (Brouwer & Spaninks, 1999).

So, it is impossible to simply take over the conclusions of previous cost benefit analyses when contemplating future scenarios for the peat meadow management. In the first place because previous research do not reveal clear uniformity in the conclusions; Witteveen + Bos (2006) conclude that implementing higher water levels in peat meadow areas is almost always profitable, while, for example, Graaff et al. (2003) conclude exactly the opposite. In the second place, each study incorporates different costs and benefits, in order to serve various goals. Moreover, the choices and assumptions that are made quite often evoke fierce debates which do not necessarily end up in a widely supported outcome. An example is the study by Witteveen + Bos (2007) on collective high water level facilities, which concludes that investing in more collective high water level facilities is profitable, while their assumption of autonomous development is contested. When assuming a different base case, the conclusion would have been the opposite (Van Hardeveld, 2013; Witteveen + Bos, 2007).

Concerning the outcomes of the studies, the studies discussed here vary too much for unequivocal conclusions to be drawn. However, the literature does provide a rather complete overview of relevant aspects to be incorporated when studying management alternatives to cope with soil subsidence in peat meadow areas and indicates where points for discussion remain. Thus, a thorough study of the existing literature at least prevents that major costs or benefits are omitted and that note is taken of previous discussions, so unnecessary repetition of debates is prevented. The table below shows the effects that were found in literature, and to what extent they were taken into account in the reviewed cost-benefit analyses.

	Pumping costs	Initial investment costs	Dike maintenance	Water quality	Foundation damage	Road and sewer mgt.	Pipelines and cables	CO_2 emission	Agricultural yield	Inundation damage	Property prices	Recreation	Landscape	Biodiversity/non-use
Graaff et al.(2003)	X	X							X		X	X	PM	X
Uran et al. (2006)	X	X		X[1]				X	X	X				
Witteveen + Bos (2006)/ CPB (2006) (*)	X	X	X	X		X[1]		X	X		X[2]	X	X*	X*
Witteveen + Bos (2007)	X	X	X[3]	X[1]				X	X	X				X
Bos & Vogelzang (2008)	X	X			X	X[1]		X	X		X	X		X
Van Hardeveld et al. (2011)	X	X[4]	X[3]		X	X	X	X	X	X				
Van der Kooij et al. (2012)	X[5]	X[6]						X	X		X	X	X	X
Van Hardeveld et al. (2013)	X	X	X	X[7]	X	X	X	X					X[7]	

[1] Taken into account but considered insignificant, [2] Only agricultural land, [3] Including high water level facilities, [4] Only civil structures, [5] Included in 'water management', [6] 'Structural improvement of agriculture', [7] Not quantified but scored with + and -

Table 3.1. Incorporation of cost and benefit factors in the addressed cost-benefit studies. X indicates that the effect is taken into account in the study; the shaded cells indicate which effects were considered of most influence on the balance between costs and benefits.

3.1.4 *Costs and benefits of relevance*

Following, the relevant costs and benefits, as extracted from the previous cost-benefit analyses which are reviewed above, are presented. As discussed in section 3.1, some costs and benefits are rather easy to quantify and monetize as they are represented by a concrete flow of money between actors. For other cost factors, an extra transformation step is needed to express them in amounts of money. Finally, some costs and benefits are not at all reflected by any money flow, for example since no stakeholder can be identified as accountable actor. The overview below starts with the direct costs or benefits, and subsequently the more intangible costs are described. Figure 3.1 gives a simple, schematic overview of the mentioned effects, with the numbers in the figure corresponding with the numbers in the description below.

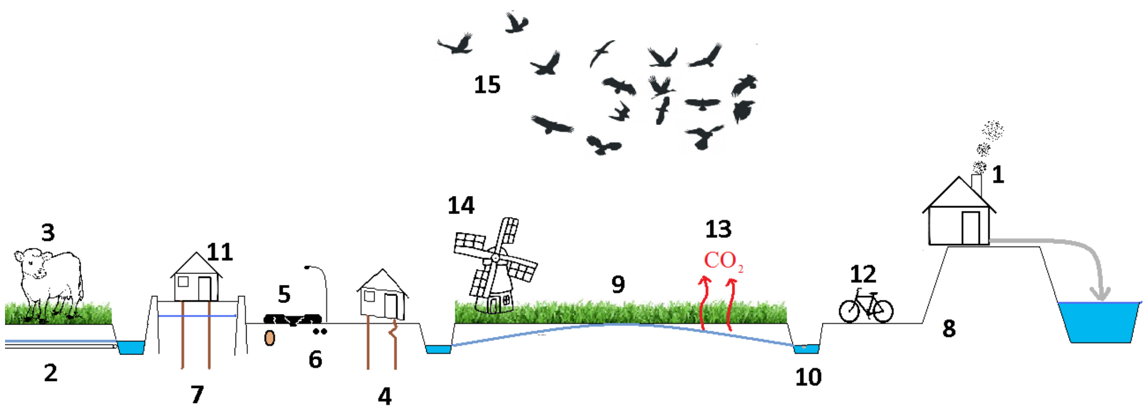

Figure 3.1. Schematic overview of the costs and benefits as discussed below.

Direct costs and benefits:

1. **Pumping costs**. Maintaining the water levels in peat meadow polders requires pumping of water out of the polders, which is a cost factor for the water board which operates the pumping stations. As a consequence of shifts in water management or climate change, the amounts of water that have to be discharged from the polders may change, resulting in a change in required pumping capacity. The required pumping capacity differs strongly per polder, depending on the amount of seepage and the amount of flushing required to maintain the water quality. For this study, the average required pumping capacity is assumed to be between 3.500 millimeters and 5.500 millimeters, depending on the amount of flushing required. The pumping costs are set at €0,01 per m^3 (Van Hardeveld et al., 2011). Additionally, there are costs for the emission of greenhouse gases as a consequence of the energy use of the pumping stations. The emissions of greenhouse gases will be addressed later in this overview.
2. **Initial investment costs.** In order to realize a certain management alternative, often modifications in the physical environment have to take place, entailing costs for the responsible authorities. Examples are rearrangement of spatial planning, construction or removal of weirs, installation of underwater drains, modification of waterways or realization of new nature areas (Witteveen + Bos, 2006). In this study, only the costs for the construction of underwater drains are taken into account.
3. **Agricultural yield.** The benefits of agriculture are related to the ground water level. Within the peat meadows of HDSR, a freeboard of about 50 cm below surface, 45 cm in summer and 55 cm in winter, is pursued. In exceptional cases, winter levels can drop to 60 cm below surface level. These levels are compromises between on the one hand limiting soil subsidence and on the other hand creating good farming circumstances (HDSR, 2011). Hence, the optimal freeboard for agriculture is larger than the current freeboard. Reduced freeboards will therefore lead to reduced agricultural yield because the soil is too wet for optimal crop growth (De Vos et al., 2010). Furthermore, agricultural activities become obstructed if heavy machinery and cattle sink into the soggy soil as a consequence of elevated water levels. In optimal conditions, the yield of agricultural grassland is set at €825, - per hectare per year, with 2010 price levels (Brouwer & Huinink, 2002; STOWA, 2012). The yield loss, relative to the optimal yield, is calculated using the HELP tables and accompanying application (Van Bakel et al., 2005; Brouwer & Huinink, 2002).

4. **Foundation damage.** Many (older) houses are founded on wooden poles, sometimes with concrete extenders on top of them, or on a shallow foundation without poles. These houses may suffer from sagging if the water level is lowered. Rotting occurs when the groundwater level drops below the top of wooden foundation poles, causing houses to sag. This is a cost factor for the owner of the house. When this process starts occurring depends on the amount of soil subsidence (which is the cause of water level lowering) and the type of foundation. As shown in table 3.2, wooden poles are used until about 1990, but the major damage is expected for houses older than 1970 as, in this period, no or shorter concrete extenders are used (Van Hardeveld, 2011). The costs of foundation restoration, as estimated by Van Hardeveld et al. (2013) range from €65.000, - per house to €100.000, - per house. If a house is only shallowly founded (houses built before 1920), cracks may occur as a consequence of unequal subsidence of the soil, which will result in repair costs varying from €4.000, - to €10.000,-. The investment of restoring houses is depreciated in 40 years. Since the number of houses per age category is known, it can be calculated what the costs of sagging of houses are by multiplying the number of houses that are potentially subject to sagging by the upper and lower limits of restoration costs. An important factor of uncertainty, however, is the life span of houses. If houses are demolished because of their age, before the damage occurs, there are no costs for foundation restoration. For cost calculations, the upper limit is a maximum life span of 200 years is taken, and the lower limit assumes a life span of 100 years. The range of uncertainty is therefore limited by on the one hand the total costs if the restoration costs are at the lower limit, and the life span of houses is 100 years, and on the other hand the costs if the restoration costs are at the upper level, and houses last 200 years.

Age class	Foundation type	Groundwater lowering (cm) to cause damage
< 1919	Shallow (no poles)	50 (cracks)
1920-1959	Wood	20 (foundation)
1960-1974	Wood + 1m concrete	100 (foundation)
1975-1989	Wood + 1,5m concrete	150 (foundation)
> 1990	Concrete	No damage

Table 3.2. Foundation type of houses per age class (Van Hardeveld, 2013).

5. **Roads and sewers.** Roads and sewers are closely related, as sewers are mainly constructed underneath the road. This means that if the sewers are replaced, the road surface needs to be replaced as well, and that it may be profitable that, if pavements are renewed, the sewers are also renovated. In this way, no good pavements need to be broken up in order to replace the sewers. As the rate of soil subsidence will locally differ, sagging occurs, causing serious damage to pavements and sewers. Road surfaces will become lower, causing problems when connecting to founded structures such as bridges, and potential more water nuisance. The standard costs factors set in literature are considered not suitable for this research. Section 3.3 will address these costs in further detail.

   Sewers are subdivided in roughly two types, gravity drained sewers and pressure drained sewers. In the first category, the sewers are constructed slightly angled, so the waste water is drained by gravity. Pumping stations are incidentally used to transport the waste water to a higher level where necessary. Tube diameters vary from 250 to 1.500 mm and tubes are mostly made of concrete (RIONED, 2007). For this study, 300 millimeters, which is one of the most commonly used sizes (N. Schoenmaker and H. van der Laan, 2013 pers. comm. May 13 & 24), is taken as starting point for cost calculations. Replacing this type of sewer costs €370,- per meter (RIONED, 2007). Pressurized sewers transport the waste water through pressure or vacuum. This system mostly consists of narrower plastic tubes with diameters ranging from 63 to 315 mm (RIONED, 2007) and is mainly used in rural areas. For this type of sewer, an average diameter of 90 mm is assumed (Bunt & Van Leussen, 2011), which costs €45,90 per meter to replace (RIONED, 2007). Especially gravity drained sewers suffer from soil subsidence. If the construction angle is changed by sagging, drainage of the sewage system is disrupted, even though the tubes themselves may remain undamaged. This results in increased cleaning costs and eventually to dysfunctioning and, therefore, replacement. Cleaning costs for gravity drained sewers are €2,04 per meter (RIONED, 2007). The calculation of the influence of soil subsidence on sewer management costs is addressed in detail in section 3.3.
6. **Pipelines and cables.** Apart from sewers, also pipelines for gas and water and cables for, for example, electricity and data may suffer from unequal sagging of the soil. The costs of the damage caused to these pipelines and cables are difficult to verify, as there are different parties responsible for these facilities. Also, the actual damage that can be caused by soil subsidence will likely be different for each

pipeline or cable. It has been assumed in past calculations that cables and pipelines need to be levered each 20 cm of soil subsidence, and that five types of cables and pipelines are present below the major roads (water, gas, electricity, data and one other cable). Levering costs of cables and pipelines have been assumed €1.250, - per km per 20 cm of soil subsidence. The calculated costs do not include costs of material renewal (Van Hardeveld et al., 2011).

7. **High water level facilities (HWLF).** To protect houses from foundation damage, facilities are sometimes constructed to locally maintain a higher water level than in the surrounding polders. These facilities consist of inlets (or inlet pumps) and weirs to regulate the water level within the high water level facility. If the elevation difference becomes larger, a water retaining structure, which could be a soil body or a sheet pile wall, may become necessary. In most cases, the water board is responsible for the construction and maintenance of these structures. Van Hardeveld et al. (2013) calculated the costs for construction and maintenance of these structures. This study takes over the outcomes of their calculations.
8. **Dikes.** As a consequence of soil subsidence, dikes will sag and additional raising of the dikes will be required. How much raising is required depends on the amount of soil subsidence. If the water retaining height of a dike increases by more than 60 cm as a consequence of the subsiding hinterland, also widening of the dike is required (Van Hardeveld et al., 2011). The costs of these measures are mainly determined by the chosen method of dike construction. Soil bodies are relatively low in cost, but in some cases, especially when space is limited, sheet piling needs to be used, which is much more expensive. The cost of raising a dike is €15,- per m^3 of soil, and, in case widening is required, €70,- per square meter of extra land at the base of the dike. Depreciation periods are 10 years for soil and 25 years for land, and the maintenance is estimated 4% of the soil costs. For sheet piling, €1.500,- per meter with depreciation period of 75 years and 1% maintenance costs is assumed. Because it is not known where sheet piling is required, the lower limit is set at 10% of the raising is done by sheet piling, and the upper limit at 25% (Van Hardeveld et al., 2013).
9. **Inundation damage.** If the water board ceases further lowering of the water levels, the freeboard is gradually reduced. The result is a decrease in water storage capacity of the water system. This will increase the probability of inundation in case of heavy rainfall, and, thus, cause damage to crops and buildings. This damage has to be compensated by the water board, since it is one of the water board's core tasks to prevent inundation, and allowing inundation would mean that the water board fails to fulfill this core task (Van Hardeveld et al., 2011). Note that only the inundation damage as a result of the water level management is taken into account. For this study, the following costs have been assumed per inundation incident (norms vary from once in 10 years for grassland to once in 100 years for built-up areas (Unie van Waterschappen, 2010)): grass: €727,- per ha and €6.000.000,- per ha for built environment (Van Hardeveld et al., 2011).

Indirect costs and benefits:

10. **Water quality.** Mineralization of peat causes release of nutrients from the soil, resulting in eutrophication of the surface water (Hellmann & Vermaat, 2012; Witteveen + Bos, 2006). Thus, reduction of the soil subsidence rate will result in a reduction of nutrient emissions, while ongoing soil subsidence will cause higher costs to mitigate the occurring eutrophication. One way to do this is flushing the polder with cleaner river water. In this way, the nutrients are diluted and discharged from the polders. Little is known about the severity and costs of reduced water quality. Therefore, in this study, the extra pumping costs, associated with the additional flushing that is required if the water quality declines are used to monetize the costs of water quality decline. The flushing will likely vary between 500 millimeters per year in a rather clean polder, and 2.500 millimeters per year if the water quality of the polder is bad. These rates have been estimated using discharge data from the HDSR peat meadow polders.
11. **Property prices.** Changes in the landscape may induce shifts in the prices of property in the study area. This results in costs (in case of devaluation of property) or benefits (in case of increasing prices) for property owners on the one hand, and the state government on the other hand, as the latter receives more property transfer tax when selling prices increase. However, the benefits for the national government will become less as a result of the increasing mortgage interest relief (Bos & Vogelzang, 2008). As a result of recent shifts in the property market as a result of the current financial crisis, the available information on this aspect is deemed not applicable any more to the current situation.
12. **Recreation.** If measures result in increased nature quality or improved scenery in the peat meadow landscape, more recreants will visit the area, which means more profit for the recreational sector.

However, the change in recreational benefits is very hard to quantify, especially when working with hypothetical scenarios. The method suggested by Ruijgrok et al. (2006) is based on determining the 'recreation deficit' of an area and calculates the recreation benefits by assessing how the proposed scenario will influence the recreation deficit. However, this calculation requires area-specific data which is currently not available. Past research has therefore estimated the increase of recreational visitors, although these estimates vary with about a factor ten, while the scenarios are comparable (cf. Bos & Vogelzang, 2008 and Witteveen + Bos, 2006). The estimate of Bos & Vogelzang (2008) is considered the most transparent and realistic one of the studies that were considered. They indicate that, currently, about 153.000 recreants visit the Zegveld polder, which is about 4.000 hectare, each year. Assuming that this area is representative for the entire HDSR peat meadow area, this means that the yearly number of recreants is approximately 38 per hectare. A daily expense of €11,73 per recreant is assumed (Bos & Vogelzang, 2008; Witteveen + Bos, 2006), but the source of this number remains unclear. Although not specified for peat meadow areas, the CBS indicates a daily average expenditure per recreant of €10,25, including only activities that are deemed relevant for the study area (sunbathing, picnicking, swimming, sporty recreation including hiking, cycling, jogging and touring) (CBS, 2012, p. 132). In this study, a daily expense of €10, - is assumed for the study area, based on the CBS number and rounded down to create a safety margin (the expense for 'touring' was remarkably high compared to the other activities, while it is not clear how relevant it is for the peat meadow area).

Non-monetary costs and benefits:

13. **Greenhouse gas emission.** Decomposition of peat is associated with emission of greenhouse gases, mainly CO_2. About 2,5% of the Dutch anthropogenic CO_2 emission is caused by oxidation of peat in the western peat meadow region (Van den Akker et al., 2010). For the Zegveld polder, a peat meadow polder within HDSR, a yearly CO_2 emission of 2.259 kg/ha/mm of soil subsidence has been calculated (Van den Akker et al., 2008). This number is considered representative for all HDSR peat meadows. These emissions are currently only a societal burden, since the reduction of greenhouse gases is a challenge to the entire society and CO_2 emissions are not yet monetized in practice. However, a trade market for CO_2 emission already exists, and a discussion is emerging on ways to assign accountability to the emissions of CO_2 from peat oxidation (e.g.: Jannink et al., 2012). The price of CO_2 emission is currently about €7,- per ton (Cozijnsen, 2013). To monetize the cost of greenhouse gas emissions for society, the current price of CO_2 emission per ton is used, although one should bear in mind that this price is only theoretical as long as there is no trading system for CO_2 emitted from peat oxidation and pumping stations and there is thus no actual financial flow.
14. **Landscape and cultural heritage.** The peat meadows are iconic for the Dutch landscape, and are well known all over the world. Therefore, the peat meadow landscape is highly valued as cultural heritage by many, and should be considered as a valuable asset worth protecting. Moreover, preservation of typical peat meadow elements will safeguard the continued existence of the peat meadows as tourist attraction and recreation area (Stroeken & Dijkman, 2010; Van Brouwershaven & Lokker, 2010; Stroeken et al., 2009). However, there is no consensus on what is exactly meant by 'preservation of typical elements'. Quantifying and monetizing this value is rarely done because of methodological difficulties and the value is rather characterized as 'important' but 'intangible', 'subjective' and 'hard to quantify' (Plieninger et al., 2013; Daniel et al., 2012). Indeed, it is hard to make a sound valuation of landscape changes. Bos & Vogelzang (2008) state that the landscape quality will likely benefit from wetter circumstances because it would create chances for nature, but a large scale shift towards wet nature would mean that the traditional dairy farming would disappear. Hence, Van der Kooij et al. (2012) find that such a shift is valued negative by citizens. Furthermore, it is not certain whether current landscape preferences are representative for the preferences of future generations. Because of the lack of a widely supported method to value landscape and cultural heritage and the well-argued reluctance of scholars to quantify this value, the effects on landscape and cultural heritage will be assessed qualitatively in this study. This assessment is based on preservation of the seven core qualities of the peat meadow landscape, as formulated by Stroeken et al. (2009). These core qualities are, summarized: (1) the cultural history of the landscape and the landscape elements, (2) the openness of the peat meadow landscape, (3) small-scale diversity and many slightly crooked lines, (4) typical (agricultural) peat meadow nature, (5) marshy wetland nature displaying the cultivation history, (6) prominent visibility of water and (7) typical wetland infrastructure.

15. **Biodiversity and non-use value of nature.** Alternative management of peat meadows may result in a change in biodiversity. This is valued by inhabitants and visitors of the area, as well as by people who do not make use of the peat meadows but simply value the knowledge that an ecosystem is there. The latter case is referred to as non-use value (e.g. Ruijgrok et al., 2006). Although biodiversity and the value of nature are highly debated benefits for which reliable quantification is problematic (e.g. Brouwer & Spaninks, 1999), there have been attempts to quantify the non-use value and the value of biodiversity of peat meadow landscapes by contingent valuation. Ruijgrok et al. (2006) presented a synthesis of several relevant studies for different types of ecosystems, but the amount of money attributed to the (non-use) value of nature and/or biodiversity strongly varies according to the methods and assumptions used. Values vary between €5, - per household for biodiversity preservation per year (Witteveen + Bos, 2006) to €49, - per year for nature conservation in peat meadow areas (Ruijgrok et al., 2006). For this study, the value used by Bos & Vogelzang (2008) of €11,- per person per year is taken over as the benefit of improving the circumstances so biodiversity can be maintained, since it is the lowest value with a methodically sound basis. A low amount is taken because this benefit is no actual financial flow and overestimation would possibly lead to a distorted comparison of scenarios. To calculate the total benefit, the amount per person is multiplied by the number of inhabitants of the HDSR peat meadow municipalities (172.000).
16. **Emotional aspects.** Although impossible to quantify, emotional arguments play a large role in the debate on alternative future strategies. Farmers will likely suffer emotional damage as a result of being forced to give up their agricultural activities as a consequence of new management strategies; the presence of open water in the vicinity of houses may induce a feeling of unsafety and anxiety for insects for the inhabitants (Graaff et al., 2003). Furthermore, any landscape change could evoke resistance, based on all kinds of sentimental arguments rather than on rational reasoning. These sentiments influence the public support for future management strategies, but can hardly be predicted and have yet not been quantified. These aspects can therefore not be taken into account here, but they could probably influence the debate in a later stage of the decision making process.

Note that, as explained in section 1.1.2, the intrinsic value of nature cannot be included as a cost factor, since it does not relate to human interests.

3.2 Complementing the knowledge of road and sewer maintenance costs

3.2.1 *Introduction*

As a consequence of soil subsidence, roads and sewers constructed on peaty soils are more vulnerable to damage through sagging than roads and sewers constructed on stable sand or clay soils. In peaty areas, municipalities, responsible for the maintenance of most roads and sewers, may therefore face higher costs for maintenance and replacement of pavements and sewage tubes. However, most of the previous studies to the costs and benefits of soil subsidence did not take this aspect into account (e.g. Van der Kooij et al., 2011; Bos & Vogelzang, 2008; Witteveen + Bos, 2006). In contrast, Van Hardeveld et al. (2011) imply that when investigating the costs and benefits of soil subsidence, the effect of soil type on the required budgets for maintenance and reconstruction of roads and sewers is an important factor to take into account, since higher costs for road and sewer management in peat meadow areas, compared to the rest of the Netherlands, could be an argument for adapting the strategy to cope with soil subsidence.

The second sub-question aims at reducing the uncertainty on the effects of soil subsidence on the maintenance costs of roads and sewers. Municipalities were interviewed to gain information on what costs they are actually facing as a consequence of soil subsidence, since these current soil subsidence costs are considered a gap in the present knowledge (Van Hardeveld, 2011). With the results of the municipality interviews, the existing assumptions regarding road and sewer maintenance costs and the effects of soil subsidence can be evaluated. Where necessary, the assumptions can be adjusted to the outcomes of the interviews. Also, the interviews contributed to a broader insight in the context of the expenses for roads and sewers, such as the vision of the responsible managers to developments of water management and technologies in the future and ways municipalities attempt to control the consequences of soil subsidence in their jurisdiction. In this section, present knowledge and used assumptions are compared to the information provided by the municipality interviews. The findings from the interviews and the supporting study of the municipal management plans are discussed, according to the two sub-goals of the interviews explained in paragraph 2.2.2. First, this is done for roads, and, second, for sewers. This is followed by the outcomes concerning sewer replacement and management.

3.2.2 *Road maintenance on peat soils*

The interviewed municipal road managers stated that the higher costs for road management on peat soils comes to expression on the one hand by the need for more advanced and more expensive foundation techniques to prevent damage through sagging (preventive), and on the other hand by shorter depreciation periods and higher yearly costs for repair of damage through sagging and maintenance of roads (reactive). In the first place, since the road surface will gradually subside if they are constructed on peat soils, problems will occur at connections to piled structures, such as bridges. Also, the lower surface level can increase water nuisance, resulting in the need to raise the road surface. Furthermore, unequal subsidence will cause damage to the pavement, for example cracks and pits, resulting in extra costs for the municipality to repair the damage. The other way municipalities may face extra costs for road management in peat areas is the need for advanced and more expensive foundation techniques to prevent sagging of the roads. Mostly, this implies the use of light materials for the foundation of the road, such as EPS or pumice, to reduce the pressure on the weak subsoil.

The choice between either of the approaches depends on the severity of the extra damage through sagging. This implies that the choice between either accepting more maintenance and repair costs or applying advanced foundation techniques is a pragmatic one. The road managers of Bodegraven-Reeuwijk and Stichtse Vecht stated that they based the choice on a comparison between the required investment to make a new road more 'subsidence proof' and the foreseen extra costs for maintenance and depreciation if a conventional approach would be taken. The maintenance costs that would be saved if more advanced foundation techniques to make a road less prone to subsidence would be applied indicate the room for investment to improve the road design. If the maintenance and depreciation costs that can be saved when applying a lighter road design exceed the extra investment cost required to realize the construction improvement, it is profitable to make the additional investment. If the sagging is not severe enough to result in extra maintenance costs that exceed the costs to prevent the extra maintenance, a conventional road is constructed and some additional costs for maintenance and a shorter life span are accepted.

Concerning the budgets for maintenance of roads, it is important to notice that soil subsidence may have an influence, but is certainly not the only factor that may result in a difference between municipal budgets for road maintenance. In fact, all municipalities stated that the requirements set to the visual quality of the public space largely determine the budgets for daily maintenance. These standards for visual quality are considered such an important determinant for the setting of maintenance budgets that other influences are surpassed. Furthermore, budgets for road maintenance and reconstruction are often covered in management plans for the public space as a whole. The setup of these management plans differs strongly per municipality and often only provides information for short periods and yearly budgets for major maintenance works and renovations show strong variations as a consequence of overdue maintenance from the past. Hence, just comparing the municipal road management plans and budgets does not reveal reliable information on the influence of soil subsidence on maintenance costs.

3.2.3 *Determining the costs of soil subsidence for road management*

Especially municipalities that cover both peat meadow areas and sandy/clayey areas offer valuable information for determining the influence of soil subsidence on road management. In these municipalities, there is a potential difference in costs for maintaining a road in the peat meadow area and the costs for a road on stable soil. This difference within municipalities gives a reliable indication of the influence of soil subsidence on required budgets for road renovation, since the other influencing factors can be assumed constant.

Although the interviews have resulted in improved insight in the way in which municipalities face increased costs for road management in peat meadow areas, not all municipalities were able to provide reliable data concerning the costs per square meter of pavement they face. In Woerden and Stichtse Vecht, municipalities are currently working to improve their insight in the costs of road maintenance. The municipality of Woerden indicated that the construction of a road in the peat meadow area is approximately three to five times more expensive than the construction of roads on stable soil, but reliable data on the actual costs were not available yet at the time of writing. Within the project of 'Kockengen Waterproof', the municipality is currently working on a comparing calculation of the costs of road management in the eastern part of the municipality and in the western, peaty part of the municipality around the village of Kockengen. For this part, which has a peat soil, a few different approaches were taken into account, including continuing the conventional approach, applying techniques to make the roads more adaptive to soil subsidence and trying to limit soil subsidence as much as possible. Unfortunately, the outcomes of these calculations were not yet available at the time of writing. However, Gouda, Woerden and Bodegraven-Reeuwijk did provide a specification of the costs for maintenance and depreciation per square meter of each road type. Moreover, Bodegraven-Reeuwijk specified these numbers for three classes of vulnerability to soil subsidence. The costs per square meter of road surface per municipality are shown in table 3.3. From this table, especially from the data provided by Woerden and Bodegraven-Reeuwijk, it becomes clear that the costs for maintenance and replacement of roads are indeed higher on subsidence-sensitive soils than on stable soils. Furthermore, the exploitation costs (management costs without investment costs) are notably higher in Woerden and Bodegraven-Reeuwijk than in De Bilt and Wijk bij Duurstede. However, concerning the latter remark, it should be noticed that the visual quality will likely influence the amounts as well. The remarkably low amounts provided by the municipality of Gouda are explained by the financial problems of the municipality, resulting in drastic cuts on the road maintenance budgets (R. Swets, 2013 pers. comm. February, 19).

Municipality	Average expense per m^2 of pavers (€)	Average expense per m^2 of asphalt (€)	Source
De Bilt	*0,95*	*0,95*	Verbal notification M. Seyman
Bodegraven-Reeuwijk	*1,58 - 1,88* 3,20 - 4,36 [1]	*1,40 - 1,63* 2,85 - 4,54 [1]	Cost calculation spreadsheet municipality
Gouda	*0,05* [2] 1,67	*0,84* [2] 2,81	Unit prices document municipality
Stichtse Vecht	Not available	Not available	
Woerden	*1,48* 3,05 - 4,08 [1]	*1,37* 3,39 - 5,20 [1, 3]	Cost calculation spreadsheet municipality
Wijk bij Duurstede	*0,63*	*0,63*	IBOR

[1] Stable soil – subsidence-sensitive soil. [2] Only major maintenance included. [3] Municipality questions the reliability of this number.

Table 3.3. Costs per square meter of road surface per municipality. Numbers in italics are exploitation costs, excluding the costs for replacement at the end of the life span.

3.2.4 *Maintenance and replacement of sewers*

Concerning sewers, a notable result from the municipality interviews is the differences in life span of sewers between municipalities with a stable (matured clay or sand) soil and municipalities with a peaty soil. In the control municipalities, the responsible managers stated that the life span can be over 60 years, provided that the quality of the used material is sufficient. Concerning reasons to reconstruct sewers, insufficient concrete quality and external (aboveground) restructuring were mentioned in the control municipalities.

In contrast, the municipalities with large areas of peaty underground mentioned damage as a consequence of soil instability as the major reason to renovate the sewers. Gouda and Woerden use a depreciation period of 40 years for their sewers, whereas Bodegraven-Reeuwijk and Stichtse Vecht also use a depreciation period of about 40 years, but only for the areas with peaty soils. The representatives of Woerden and Stichtse Vecht explicitly stated that the depreciation period was reduced only recently from 60 till 40 years because it became clear that a lifespan of 60 years in the peat meadow areas was unrealistic. As a consequence, the depreciation period was shortened for the entire municipality in Woerden, and for the village of Kockengen, which is located in the peat meadow area, in Stichtse Vecht. In Bodegraven-Reeuwijk, depreciation periods are set based on soil stability, so a differentiation is made between areas with peaty soils and areas with more stable soils.

In general, it can be concluded that the expected lifespan of sewers in areas with a stable soil is about 60 years, and 40 years in areas with weaker, peaty soils. Deviations that were found are explained by differences in the depreciation approach. For the weakest soils, Bodegraven-Reeuwijk depreciates their sewers in 35 years, but this municipality is the only one in the study area where the approach is differentiated to soil stability. Woerden stated that where the life span defers from the 40 years that were set, these outliers will likely compensate for each other. In De Bilt, the slightly shorter depreciation period was explained by a safety margin that was set to cope with the variation in concrete quality. Concerning Wijk bij Duurstede, the difference in depreciation periods and expected actual lifespan is currently being abolished in order to synchronize the budgets with the actual costs, and thereby reduce the yearly expenses of depreciation. Thus, although the depreciation periods still differ from the technical life span in the municipal sewage management plan, the municipality confirms that the expected life span of sewers of 60 years.

The above goes for gravity drained sewers. However, sewage managers Woerden, Stichtse Vecht and Bodegraven-Reeuwijk mentioned that pressure drained sewers are less prone to sagging than gravity drained sewers, since pressurized sewers are (1) constructed of lighter tubes, (2) do not depend on the angle of the slope in which they are constructed and (3) are often constructed next to roads instead of underneath the pavement, which means they are not influenced by the pressure of passing traffic. However, the experience with this kind of sewers is insufficient to provide a reliable basis for life span assumptions, since most pressurized sewers are only 30 years in place. Most municipalities depreciate the pressurized sewers in 40 years, but it was claimed that the technical life span of the pressurized sewers may be even 60 years, regardless of the soil type (W. van Bodegraven, 2013, pers. comm. April 25). In this study, a life span of 40 years for pressurized sewers in peat soils is assumed, and 45 years for sand and clay soils. These life spans are based on sewage management plans of the studied municipalities and, indeed, reflect a much lower vulnerability to sagging.

3.2.5 *Determining the costs of sewage management*

Ruijgrok et al. (2006) stated that the construction of sewers in peat meadow areas requires a larger investment than in stable soils, since the sewers need an extended foundation, using poles. The interviews with the peat meadow municipalities do not confirm this statement, since founding sewers on poles is currently not considered a proper solution for sagging. Sewage managers stated that sewers that are rigidly constructed on poles could still suffer from cracks between the poles and furthermore, cause ridges in the road pavement since the road continues subsiding. Nevertheless, techniques to reduce the pressure of sewage tubes on the weak peaty soil, such as using lighter materials and applying tubes with air cells or wings to increase the surface area, are currently contemplated (N. Schoenmaker, 2013 pers. comm. April 19). These techniques are, however, currently in such an early phase of development that there is yet no reliable information available on the costs and effects of application. Construction costs are therefore assumed independent of the soil type, whereas the depreciation period does differ, resulting in higher yearly costs. The replacement costs per meter of gravity drained sewage tube, assuming a common tube diameter of 300 millimeters, are €370.– per meter (RIONED, 2007). In case of a depreciation period of 40 years and 4% interest, this yields a yearly cost of €17,97 per meter, while, with a depreciation period of 60 years, the costs are €15,73 (see table 3.4).

Assuming an average diameter of 90 millimeters for pressurized sewers (Bunt & Van Leussen, 2011), replacement costs per meter are €45,90 (RIONED, 2007). With an interest rate of 4%, this results in €2,23 per year for peat soils and €2,13 per year for stable soils. Note that these prices are excluding the pumping units necessary for pressurized sewers, since the functioning of pumping units is assumed independent of soil subsidence. Actual construction prices for the entire system are, therefore, higher.

Apart from the costs resulting from the shortened lifespan, soil subsidence has consequences for the cleaning costs of gravity drained sewers. Because of the (unequal) subsidence of the soil, the slope of sewers which is necessary to discharge the waste water becomes distorted, resulting in suboptimal drainage of the sewage system. This causes accumulation of dirt in the lower parts of the sewage systems and, thus, extra cleaning is required to keep the sewers functioning. The municipal sewage management plan of Stichtse Vecht states that the sewers in the peat meadow area need to be cleaned once a year, and sometimes even twice a year, in contrast to once every ten years in the rest of the municipality. However, this only applies to sewers that have already suffered damage from soil subsidence. The municipality assumes that the cleaning frequency progressively increases over the life span of the sewers, starting with once every five years in the first decade of the life time, once every two years in the second decade and once a year during the final two decades before the sewers are replaced. Thus, during the entire life span of gravity drained sewers in the peat meadow area, the sewers are cleaned 27 times, while in the same period of 40 years, four times would be normal in areas with stable subsoil (N. Schoenmaker, 2013 pers. comm. April 19). Using the standard cost factors for cleaning provided by RIONED (2007) and assuming an average tube diameter of 300 mm, the average yearly costs for cleaning in peat meadow areas are calculated by multiplying the standard cost factor per meter sewer plus the dumping costs of the sewage sludge (€1,52 + €0,52) by the number of cleanings required during a sewer (27), divided by the life span of the sewers (40 years). This results in a yearly cleaning expense of €1,38 per meter. For comparison, the yearly costs for cleaning the same sewer in a non-peat meadow area would be €0,20 per meter. No additional cleaning costs are assumed for pressurized sewers in peat meadow areas, since regular cleaning of such sewers is not usual (RIONED, 2007).

	Replacement costs GDS* (€/yr./m)	Average cleaning costs GDS* (€/yr./m)	Total maintenance and replacement costs GDS* (€/yr./m)	Replacement costs PDS* (€/yr./m)	Average cleaning costs PDS (€/yr./m)
Peat soils	17,97	1,38	19,35	2,23	-
Stable soils	15,73	0,20	15,93	2,13	-
Difference	2,43	1,18	3,42	0,10	-

*GDS=gravity drained sewers, PDS=pressure drained sewers

Table 3.4. Overview of the replacement and cleaning costs per meter sewage tube. The bottom row shows the difference between the costs in peat meadow areas and areas with stable soil.

3.3 Scenario analysis

3.3.1 *Introduction*

In this section, a comparison of the development of costs and benefits in four possible future scenarios is presented. The aim of this comparison is to explore which strategies of management may contribute to a sustainable development of the peat meadow area, and which will likely lead to an amplification of the problems caused by soil subsidence. Whether the scenarios may contribute to a sustainable peat meadow area will be discussed at the end of the chapter.

3.3.2 *Scenario 1. Maintaining the freeboard*

Pumping costs
Van Hardeveld et al. (2011) calculated the extra pumping costs as a result of climate change and changing elevation differences for a similar scenario, which are between approximately €1,2 million and €1,5 million per year. Since this also includes pumping costs outside the peat meadows, the lower limit is used for this calculation.
Additionally, the relatively high rate of soil subsidence will cause eutrophication, which results in relatively high flushing costs. Assuming 2.500 mm of flushing for the entire area, the costs of flushing are yearly €6,25 million. The total yearly pumping costs for the study area are €7,45 million.

Initial investment costs.
No investment costs are required to realize this scenario.

Agriculture
In the first scenario, the surface water levels relative to the ground level are kept at approximately 50 cm below ground level, which causes the groundwater level to fluctuate between an upper limit of 20 cm below ground level and a lower limit of 80 cm below ground level. Added up for the entire study area, the yield loss per year in the first scenario approximately €3,00 million compared to the situation in optimal conditions.

Sagging of houses
To calculate the number of foundation restorations required, the number of houses per square kilometer is multiplied by the area where the soil subsidence will be higher than the damage threshold. The rounded results are displayed in table 3.5. Where the number of required restorations is less than ten, the damage is considered negligible.

In the case of the lower limit, the total costs for damage to houses until 2100 are €8.125.000,-. The total costs for repairing cracks and foundation restoration until 2100 in the case of the upper limit are €73,2 million. Considering these amounts investments with a depreciation period of 40 years (Van Hardeveld et al., 2013), the yearly costs are between €0,40 million and €3,56 million. However, note that these costs are expected to decline during the coming century, since more and more houses which are vulnerable to sagging will be either demolished or restored, after which no damage will occur any more.

Age class	Number of foundation restorations if life span = 100 y	Number of foundation restorations if life span = 200 y
< 1919	<10	120*
1920-1959	125	735
1960-1974	<10	35
1975-1989	<10	<10

*It is assumed that only half of the houses in this age class which suffer damage are restored, the other half is demolished because of its age.

Table 3.5. Number of foundation restorations required per age class in scenario 1.

Sagging of roads
The costs of road maintenance in the study area are calculated using the costs per square meter found in the previous chapter. The yearly maintenance costs for roads in the study area with pavers are €7,8 million and for roads paved with asphalt €6,6 million. The total management costs of roads for the study area are €14,4 million per year. So, until 2100, municipalities will spend €1.256 million to road management.

Sagging of sewers
For sewers, the depreciation periods will remain 40 years in this scenario. The total yearly management costs for gravity drained sewers are approximately €7,74 million, of which about €0,55 million for cleaning, and for pressurized sewers €0,78 million. So, total yearly sewage management costs for the study area are approximately €8,52 million. Until 2100, this results in an expense for municipalities of €766,8 million for sewer management.

Pipelines and cables
For the impact of soil subsidence on pipelines and cables, the calculations of Van Hardeveld et al. (2011) are deemed useful. Using the findings of Van Hardeveld et al. (2011), the total costs for re-aligning the cables and pipelines are yearly €1,6 million. Added up until 2100, this results in a cost for the joint utility companies of about €145 million.

High water level facilities
In the first scenario, no high water level facilities are present to protect the houses. Unlike in the actual situation in the HDSR peat meadow area, it is assumed that there are also no existing high water level facilities. Therefore, the costs of maintaining and constructing such facilities is assumed zero, which also implies there are no costs of abolishing any high water facilities, such as a temporally increased soil subsidence rate or removal of water management structures.

Dikes
Raising dikes by 90% soil and 10% sheet piling (the lower cost scenario) will cost €6,7 million of soil and about €0,9 million of land which is required for the widening of the dikes. The 12.000 m of sheet piling will cost about €18,0 million. The total investment for the water board for dike maintenance in this lower limit scenario until 2100 is €25,6 million. Including depreciation and interest costs and maintenance, this means €2,51 million per year. In the higher cost scenario with 25% sheet piling, the soil costs are €5,6 million, the land costs for widening are €0,7 million and the sheet piling costs are €45 million, so, in total until 2100, €51,3 million. The yearly costs for the water board are, in this case €4,15 million per year, including interest and maintenance.

Inundation damage
Inundation damage is considered zero in this scenario, since the water board only adjusts the water levels to the occurred soil subsidence, and therefore, is not responsible for inundation damage.

Water quality
As stated in section 3.1.4, the costs for water quality maintenance are included in the pumping costs.

Recreation
The number of recreants is assumed to remain constant in this scenario, i.e. 38 per year per hectare (Bos & Vogelzang, 2008). For the entire study area, this implies 950.000 visits per year. Assuming that each recreant spends €10, - per visit, and the profit margin of the recreational sector is 10% (Witteveen + Bos, 2006), this yields a yearly benefit of €950.000, - from recreation. Until 2100, recreation in the study area will yield €85,5 million.

Greenhouse gas emission
The CO_2 emission resulting from this soil subsidence in the first scenario is calculated by multiplying the area per soil subsidence class by the median of the soil subsidence class, by the emission per mm soil subsidence per ha. For lack of a median, a value of 112,5 cm is taken for the last class. For this scenario, this results in a total CO_2 emission of 24,3 million ton until 2100, including the emission of the pumping stations. With the current price levels (€7, - per ton (Cozijnsen, 2013)), this will cost society about €170,1 million, i.e. about €1,9 million per year.

Landscape and cultural heritage
The ongoing soil subsidence will cause differences between the subsiding peat meadows and surrounding areas on stable soils and water ways in which the water level is kept constant. The water retaining height of dikes should therefore increase, which requires dike enforcements. Within the polders, the landscape is assumed to remain the same. The increasing elevation differences are expected to have minor effects on the openness of the landscape, since the view will be increasingly confined by dikes. Therefore, it is likely that the quality of landscape will have decreased slightly in 2100.

Biodiversity/non-use value of nature
In this scenario, the quality of nature will likely not improve. If the way nature is managed in the peat meadows remains the same, it is even more likely that biodiversity will decline in the future (Brouwer & Slangen, 1999). Therefore, there will be no benefit of biodiversity improvement and improved non-use value of nature. It is assumed that biodiversity will not decline significantly as a consequence of soil subsidence. The total value for this effect is therefore set at €0,-.

3.3.3 *Scenario 2: Protecting houses*

Since the second scenario is on many aspects equal to the first scenario, only the aspects on which this scenario differs from the first one are addressed.

Sagging of houses
Because scenario two assumes that the high water level facilities are extended in order to protect all houses against sagging, foundation damage is limited in this scenario. Soil subsidence cannot be avoided completely, but how much soil subsidence will occur within high water level facilities is unknown. Therefore, foundation damage costs are assumed to be 10% of the costs in absence of high water level facilities, i.e. between €0,81 million and €7,32 million until 2100 and, yearly, between €0,04 million and €0,36 million.

Sagging of roads, sewers, pipelines and cables
It is yet unknown how the costs for road and sewer management of this scenario relate to the costs of a scenario without soil subsidence. Sagging of roads and sewers will still occur outside the high water level facilities, but will be less within the high water level facilities. On the other hand, the increasing elevation difference between high water level facilities and the surrounding polders will likely cause increased damage at the edges of high water level facilities. Since the total surface of subsiding roads and the length of sagging sewers are smaller than in scenario 1, it is likely that the costs will be lower than in that scenario. Because of the increased damage at the edges of the high water level facilities, the costs for road and sewer management are expected to be higher than the aggregate road and sewer management costs for the subsiding and not subsiding areas. The total amount per year is therefore estimated at about €14 million of road management costs, and about €8 million of sewer management costs for the entire study area. For pipelines and cables,

High water level facilities
The costs of maintaining high water level facilities have been calculated by Van Hardeveld et al. (2013). In the scenario where high water level facilities are extended to protect all houses which are prone to sagging from foundation damage, the costs until 2100 are given in table 3.6.

Actor	Cost factors	Amount until 2100 (€ x 10^6)	Amount per year (€ x 10^6)
Water board	Weirs, fish migration, pumping	175,28	1,95
House owners	Individual high water level facilities	56,67	0,63
Farmers	Water logging near HWLF	42,76	0,48
Society	CO_2 emission from pumping	0,90	0,01
Total		275,61	3,06

Table 3.6. Costs for maintenance of high water level facilities per actor. (Due to rounding, the total of the last column differs from the sum of the above numbers.)

Greenhouse gas emission
In the second scenario, soil subsidence will be limited in the 4.250 hectare of the high water level facilities. Assuming an average soil subsidence until 2100 of 42,5 cm (scenario 1) and no oxidation of peat within the high

water level facilities, this will result in a reduction of CO_2 emission of about 4,1 million ton until 2100. Thus, the total emission in this scenario is 20,1 ton until 2100, which costs €140,1 million, i.e. €1,56 million per year.

Landscape and cultural heritage
The landscape is expected to remain similar to the landscape of scenario 1. There is one major difference, namely that additional elevation differences will occur around built up areas. The high water level facilities will become higher, relative to the hinterland. If this elevation difference becomes larger, dikes or sheet piling walls may be needed to retain the high water level around the houses. This will enlarge the contrast between built up areas and the rest of the polders. The proportion between the typical landscape elements could become distorted, which makes the landscape quality somewhat worse than in the first scenario.

Biodiversity/non-use value of nature
The natural quality will develop similar to the first scenario. However, the increased elevation differences are hindering fish migration. In order to maintain the possibility for fish to migrate through the study area, additional fish ladders are required. The costs for constructing these fish ladders are already included in the costs for management of high water level facilities (see table 3.7), so also in this scenario, the costs for biodiversity are set at zero.

3.3.4 *Scenario 3: Limiting soil subsidence*

Pumping costs
Van Hardeveld et al. (2011) calculated the pumping costs as a consequence of climate change and changing elevation differences for a similar scenario. They find a yearly cost for the water board of €0,88 million. Additionally, flushing is required to maintain the water quality. However, since soil subsidence is slowed down, this is less than in the first scenario. Based on the flushing data of several peat meadow polders within HDSR, it is assumed that 750 mm of flushing is required in this scenario. This entails a yearly cost for the water board of €1,88 million. Thus, the total yearly costs for pumping for the water board are €2,76 million.

Agricultural yield
The groundwater levels will gradually go up in the third scenario. In 2100, the mean high groundwater level will be between 5 and 10 cm below surface level, and the mean low groundwater level between 50 and 60 centimeters below surface level, causing crop damages of over 50%. The total agricultural yield loss per year in 2100 for the entire study area is between €7,1 million and €10,6 million, relative to the optimal situation. The range of uncertainty is a consequence of the abolition of the target water level, allowing more spatial variety in groundwater levels. In the period until 2100, the agricultural damage will increase from a relative damage of about €3,0 million per year (current situation) to between €7,1 million and €10,6 million. Assuming a linear increase of the crop damage, the total damage until 2100 will be between €454,5 million and €612,0 million.

Sagging of houses
The number of foundation restorations required in scenario 3 is displayed in table 3.7. The total costs in this scenario for foundation restorations are between €2,28 million and €41,45 million. Yearly costs will then be between €0,11 million and €2,01 million.

Age class	Number of foundation restorations if life span = 100 y	Number of foundation restorations if life span = 200 y
< 1919	<10	45*
1920-1959	35	410
1960-1974	<10	<10
1975-1989	<10	<10

*It is assumed that only half of the houses in this age class which suffer damage are restored, the other half is demolished because of its age.

Table 3.7. Number of foundation restorations required per age class in scenario 3.

Sagging of roads
The costs for road maintenance will likely decline during the period until 2100, since the soil subsidence will be less. The area that will still subside in this scenario will cost €12,7 million per year, of which €6,86 million for pavers and €5,84 million for asphalt, and the area that does not subside any more will cost €1,19 million. Thus, the total yearly management costs for roads in the study area are €13,89 million.

Sagging of sewers
For this scenario, it is assumed that, given the gradual decline of the soil subsidence rate, sewers will initially have a life span of 40 years, but the life span will gradually increase to 60 years and 45 years, respectively for gravity drained sewers and pressurized sewers. The assumption is that the first half of the 21^{st} century, the yearly costs will be equal to the upper row of table 3.7. For the final half of the 21^{st} century, the sewers behave like sewers in stable soils, as represented by the second row of table 3.7. The yearly costs for the first half of the century are €8,25 million. For the second half of the century, the yearly costs are €6,37 million for gravity drained sewers and €0,75 million for pressurized sewers, so in total €7,12 million. The total costs for sewer management until 2100 are €640,80 million

Pipelines and cables
Because of the lower rate of soil subsidence, there will be less sagging of pipelines and cables. The yearly costs for levering pipelines and cables in this scenario are €1,21 million and, added up until 2100, the costs are €10912 million (Van Hardeveld et al., 2011).

High water level facilities
In this scenario, no high water level facilities are present. The costs are therefore set to zero.

Dikes
Carrying out the required dike raisings by 90% of soil and 10% of sheet piling, the lower cost scenario, will cost the water board about €3,95 million for the soil, €0,30 million for the land required for widening of the dikes and €15,84 million for sheet piling. This implies a yearly cost for the water board of €1,78 million, including depreciation and maintenance. In the higher cost scenario, assuming that 25% of the dike reinforcements are done by sheet piling, the costs are €3,29 million for soil, €0,25 million for land and €39,60 million for sheet piling. The yearly costs for the water board would then be €3,37 million.

Inundation damage
Because the water board waives the target of maintaining the freeboard, more inundation damage will occur. This damage is to be compensated by the water board. Van Hardeveld et al. (2011) estimated the inundation damage in a similar scenario between €2,1 million and €4,2 million.

Water quality
Costs for water quality maintenance are included in the pumping costs.

Recreation
If the wetter circumstances that emerge in this scenario are accompanied by increased nature quality, Bos & Vogelzang (2008) and Witteveen + Bos (2006) state that the area will become more attractive for recreation. Bos & Vogelzang (2008) estimate that this will result in about 10 extra visits yearly per hectare. For the study area, this would imply 250.000 extra visits, which will yield €0,25 million from recreational expenses, in addition to the €0,95 million of the first scenario. Thus, the total yearly benefit from recreation in this scenario is €1,2 million, which means €108 million until 2100. Note that the actual benefit may be somewhat lower, since the nature quality will likely gradually increase, so the number of recreants will probably not start growing immediately.

Greenhouse gas emissions
The emission of CO_2 is lower than in the first two scenarios since less peat is oxidized in this scenario. The CO_2 emission is calculated by multiplying the area per soil subsidence class (table 2.1) by the median of the soil subsidence class by the emission per mm soil subsidence per ha. For lack of a median, a value of 87,5 cm is taken for the last class. Added up until 2100 for the entire study area, the CO_2 emission from peat oxidation is 14,69 million tons, including the emissions from pumping stations. This will cost society €102,8 million until 2100, so €1,14 million per year.

Landscape and cultural heritage
The landscape will gradually change in this scenario. The conditions will become wetter as a result of the decreasing freeboard, and as a result, agriculture is forced to become more extensive. On the lower lying plots, the agricultural function of the grassland will be abandoned, and the land will become marshier. Thereby, more room for nature will emerge and the landscape will become more diverse. This can either be interpreted positive, arguing that a more varied and natural landscape is more attractive for recreation, or negative, when one interprets the shift in landscape as a decay of the typical Dutch agricultural landscape. Given the relative fast change that is expected in this scenario, and the likely elimination of many farms, it is expected that the landscape shifts in this scenario will encounter substantial resistance in society.

Biodiversity/non-use value of nature
The third scenario will provide possibilities for nature development since the distortion of the ecosystem through agricultural activities will decline. Although no active measures are carried out to enhance the biodiversity in the area, the value of nature will likely increase. Since it is not known how much this value will increase, the lowest value for the willingness to pay for nature conservation in peat meadows, €5,- per person per year (Witteveen + Bos, 2006) is taken. This number represents the lower limit of the nature quality improvement benefits of Bos & Vogelzang (2008). Thus, the total benefit of nature quality improvement in this scenario is €0,86 million per year.

3.3.5 *Scenario 4: Mitigating losses.*

Pumping costs
The pumping costs in this scenario will likely be lower than in the first scenario, since the elevation differences do not increase that much. Because mean high groundwater level is lowered as a result of the underwater drainage, less water is stored in the ground. This results in slightly increased pumping to discharge the water that has otherwise been stored in the soil. The additional inlet required to keep the drains functioning in summer is not influencing the pumping costs since inlet water can flow in freely. Because no calculations on this scenario have yet been made, it is assumed that the pumping costs will be about €1 million per year, between the costs in scenario 1 and scenario 4. Since soil subsidence is slowed down even more than in scenario 3, less flushing is required. Assuming 500 mm flushing, the total pumping costs are €2,25 million per year and €202,5 million added up until 2100.

Initial investment costs.
In order to realize this scenario, underwater drains are constructed in the grasslands in the study area. Construction of these drains costs €1.666,- per hectare (Hoving et al., 2008), thus, for the entire study area, the required investment is about €40 million. According to Hoving et al. (2008) the total yearly costs are €165,- per hectare, including depreciation and maintenance, so €3,96 million per year for the entire study area. It is assumed that these costs are subsidized by the water board.

Agriculture
The underwater drainage system limits the fluctuation of the groundwater level to a mean high water level of 30 cm below surface and a mean low water level of 60 cm below surface, assuming that the drainage system is constructed 45 cm below surface level. The yield loss for the entire study area in this scenario is about €3,9 million per year, compared to the situation in optimal conditions. However, farmers will start broadening their activities to recreation and nature conservation in order to compensate the diminishing agricultural yield as much as possible. Bos & Vogelzang (2008) estimated that the development of nature could offer opportunities for broadening of agricultural activities for 13% of the farmers, that broadening could lead to €5.540,- extra income per farmer per year and that the profit margin is 10%. For the study area, this would lead to a yearly benefit of €0,62 million.

Sagging of houses
To calculate the number of foundation restorations required, the number of houses per square kilometer is multiplied by the area where the soil subsidence will be higher than the damage threshold. The rounded results are displayed in table 3.8. Where the number of required restorations is less than ten, the damage is considered negligible.

In the case of the lower limit, the total costs for damage to houses until 2100 are €2,93 million. The total costs for repairing cracks and foundation restoration until 2100 in the case of the upper limit are €37,05 million. The yearly costs are, on average, between €0,14 million and €1,80 million. However, note that these costs are expected to decline during the coming century, since more and more houses which are vulnerable to sagging will be either demolished or restored, after which no damage will occur any more.

Age class	Number of foundation restorations if life span = 100 y	Number of foundation restorations if life span = 200 y
< 1919	<10	55*
1920-1959	45	365
1960-1974	<10	<10
1975-1989	<10	<10

*It is assumed that only half of the houses in this age class which suffer damage are restored, the other half is demolished because of its age.

Table 3.8. Number of foundation restorations required per age class in scenario 4.

Sagging of roads

The costs of road maintenance in the study area are calculated using the costs per square meter found in the previous chapter. The costs for the subsiding area are yearly €6,08 million for roads with pavers and €5,18 million for roads paved with asphalt. For the area that does not subside any more in this scenario, the costs are €1,26 million and €0,92 million for pavers and asphalt respectively. In total, the yearly costs for the entire study area for road management are €13,44 million. Until 2100, municipalities will spend €1.209,6 million to road management.

Sagging of sewers

In scenario 4, soil subsidence is limited. Therefore, the expected damage to sewers is lower and the management costs for sewers will be lower than in the first scenario. The data gathered in this study does, however, not show how much lower the damage would be, since the available data only distinguishes between two types of soil. Anyway, the costs will be not as low as the management costs for sewers in stable soils, since soil subsidence still occurs in this scenario. The yearly management costs in scenario 4 are expected to be similar to the costs in the third scenario, with as a major difference that in scenario 3, the yearly costs will clearly decrease since the soil subsidence rate will decrease, and in scenario 4, the yearly costs will decline much slower until 2100.

Pipelines and cables

Since this scenario was not included by Van Hardeveld et al. (2011), so the costs for levering of cables and pipelines are estimated by dividing the approximately 500 km of cables and pipelines over the soil subsidence classes. When multiplying the length of the cables and pipelines per subsidence class by the cost per kilometer for levering of the cables and pipelines, a total yearly cost for the utility companies is found of €0,88 million.

High water level facilities

In this scenario, no high water level facilities are present to protect the houses. Therefore, the costs of maintaining and constructing such facilities is assumed zero.

Dikes

Raising dikes by 90% soil and 10% sheet piling (the lower cost scenario) will cost €3,52 million of soil and about €0,37 million of land which is required for the widening of the dikes. The 9.360 m of sheet piling will cost about €14,04 million. The total costs for the water board for dike maintenance in this lower limit scenario until 2100 are €17,93 million, so about €1,59 million per year, including maintenance and depreciation costs. In the higher cost scenario with 25% sheet piling, the soil costs are €2,93 million, the land costs for widening are €0,23 million and the sheet piling costs are €35,10 million, so, in total until 2100, €38,62 million. The yearly costs for the water board are, in this case €2,99 million per year.

Inundation damage

Inundation damage will likely be lower than in the third scenario, since the underwater drainage system allows results in lower mean high water levels and, therefore, more storage capacity of the soil. On the other hand, it will likely be larger than in the first scenario, since the groundwater levels are generally higher, so there is less storage capacity in the soil. Because no similar scenario has been included by Van Hardeveld et al. (2011), it is assumed here that the inundation damage in this scenario will be about half of the damage that would occur in scenario 3, i.e. between €1,0 million and €2,1 million.

Water quality
As stated in section 3.1.4, the costs for water quality maintenance are included in the pumping costs.

Recreation
The number of recreants is assumed to increase in this scenario, since the increased nature quality that is expected will likely make the area more attractive for visitors. Bos & Vogelzang (2008) have estimated that a similar scenario would yield about 10 visits per year per hectare in addition to the current number of visitors. Therefore, total number of visits per year for the entire study area in this scenario is 1.200.000. Assuming an expense €10, - per visit, and a profit margin of 10% (Witteveen + Bos, 2006), this yields a yearly benefit of €1,20 million from recreation. Until 2100, recreation in the study area will yield €108 million.

Greenhouse gas emission
The CO_2 emission resulting from this soil subsidence in this scenario is calculated by multiplying the area per soil subsidence class by the median of the soil subsidence class, by the emission per mm soil subsidence per ha. For lack of a median, a value of 87,5 cm is taken for the last class. The total CO_2 emission in this scenario until 2100 is about 12,9 million tons, including the emission from pumping stations. This will cost society €90,3 million until 2100, so about €1,0 million per year.

Landscape and cultural heritage
Likewise the third scenario, landscape shifts will occur in this scenario. However, changes will occur slower and later than in the previous scenario, since the underwater drainage system will maintain agriculturally favorable conditions longer than in the scenario without underwater drainage. In addition, farmers will broaden their activities to nature preservation and recreation, which means they actively enhance the landscape diversity and the conditions for wildlife, which will be have a positive effect on the landscape quality. Because the conditions for agriculture will decline much slower than in the previous scenario, phasing out of intensive agriculture will happen more gradually, which likely results in less acute landscape changes and, thereby, less resistance from society. However, one should bear in mind that, with the larger landscape changes postponed, the uncertainty on the appreciation of these shifts becomes larger since it is not known what the opinion of future generations will be on these shifts.

Biodiversity/non-use value of nature
With the farmers expanding their activities to nature development and conservation, the quality of nature and biodiversity is actively enhanced. Because the intensive dairy farming will become less common as a result of the soils slowly becoming wetter, the conditions for birdlife and rare plant species will likely become better. Therefore, it is assumed that, in this scenario, the benefits of biodiversity and the non-use value of nature will be equal to the full willingness to pay for nature conservation that is found for the peat meadow landscape of €11,- per person. For the entire study area, this results in a benefit of €1,89 million per year.

3.3.6 *Scenario comparison*

In this paragraph, the outcomes of the scenario analysis are compared by presenting some of the most relevant graphs and tables. The following tables summarize the costs and benefits per scenario. The first two tables represent the total costs per effect of each scenario, with the first table showing the costs assuming the lower limits for the shaded effects, and the second table showing the upper limits of the shaded costs. Red amounts represent costs, green amounts represent benefits.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Pumping costs	7.450.000	7.450.000	2.760.000	2.250.000
Initial investment costs	-	-		440.000
Agricultural yield loss	3.000.000	3.000.000	5.050.000	3.840.000
Foundation damage	400.000	40.000	110.000	142.000
Roads	14.400.000	14.000.000	13.890.000	13.440.000
Sewers	8.520.000	8.000.000	7.120.000	7.120.000
Pipelines/cables	1.600.000	1.400.000	1.212.500	880.000
High water level facilities	-	3.040.000	-	-
Dikes	2.510.000	2.510.000	1.780.000	1.590.000
Inundation damage	-	-	2.100.000	1.000.000
Recreation	950.000	950.000	1.200.000	1.200.000
CO_2 emission	1.900.000	1.560.000	1.140.000	1.000.000
Biodiversity/non-use value of nature	-	-	860.000	1.890.000
Total costs per year	38.830.000	40.050.000	33.102.500	28.612.000

Table 3.9. Total costs/benefits per year, assuming lower costs limits. Shaded cells indicate that the amounts differ with table 3.10.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Pumping costs	7.450.000	7.450.000	2.760.000	2.250.000
Initial investment costs	-	-		440.000
Agricultural yield loss	3.000.000	3.000.000	6.800.000	3.840.000
Foundation damage	3.560.000	360.000	2.010.000	1.800.000
Roads	14.400.000	14.000.000	13.890.000	13.440.000
Sewers	8.520.000	8.000.000	7.120.000	7.120.000
Pipelines/cables	1.600.000	1.400.000	1.210.000	880.000
High water level facilities	-	3.040.000	-	-
Dikes	4.150.000	4.150.000	3.370.000	2.990.000
Inundation damage	-	-	4.200.000	2.100.000
Recreation	950.000	950.000	1.200.000	1.200.000
CO_2 emission	1.900.000	1.560.000	1.140.000	1.000.000
Biodiversity/non-use value of nature	-	-	860.000	1.890.000
Total costs per year	43.630.000	42.010.000	40.440.000	32.770.000

Table 3.10. Total costs/benefits per year, assuming upper costs limits. Shaded cells indicate that the amounts differ with table 3.9.

The following tables compare the scenarios 2, 3 and 4 to the first scenario. For the study area of this research, scenario 1 can be considered the most conservative one; hence, it can be seen as a base case. The comparison in the following two tables shows the costs of the three other scenarios relative to this base case. Note that the first scenario differs from the actual base case in the real HDSR peat meadows, since this scenario assumes no high water level facilities are present, while in reality, high water level facilities have already been constructed. Again, the upper table shows the outcomes when assuming the lower cost limits, and the lower table shows the outcomes with the upper cost limits assumed.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Pumping costs	-	-	4.690.000	5.200.000
Initial investment costs	-	-	-	440.000
Agricultural yield loss	-	-	2.050.000	840.000
Foundation damage	-	360.000	290.000	258.000
Roads	-	400.000	510.000	960.000
Sewers	-	520.000	1.400.000	1.400.000
Pipelines/cables	-	200.000	387.500	720.000
High water level facilities	-	3.040.000	-	-
Dikes	-	-	730.000	920.000
Inundation damage	-	-	2.100.000	1.000.000
Recreation	-	-	250.000	250.000
CO_2 emission	-	340.000	760.000	900.000
Biodiversity/non-use value of nature	-	-	860.000	1.890.000
Difference with scenario 1	-	1.220.000	5.727.500	10.218.000

Table 3.11. Costs and benefits relative to scenario 1, using lower costs limits. Red amounts indicate that costs are higher, green amounts indicate that costs are lower than in the first scenario. The red cell indicates the major difference between scenario 1 and the actual autonomous development. Shaded cells imply a difference to table 3.12.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Pumping costs	-	-	4.690.000	5.200.000
Initial investment costs	-	-	-	440.000
Agricultural yield loss	-	-	3.800.000	840.000
Foundation damage	-	3.200.000	1.550.000	1.760.000
Roads	-	400.000	510.000	960.000
Sewers	-	520.000	1.400.000	1.400.000
Pipelines/cables	-	200.000	387.500	720.000
High water level facilities	-	3.040.000	-	-
Dikes	-	-	780.000	1.160.000
Inundation damage	-	-	4.200.000	2.100.000
Recreation	-	-	250.000	250.000
CO_2 emission	-	340.000	760.000	900.000
Biodiversity/non-use value of nature	-	-	860.000	1.890.000
Difference with scenario 1	-	1.620.000	3.187.500	10.860.000

Table 3.12. Costs and benefits relative to scenario 1, using lower costs limits. Red amounts indicate that costs are higher, green amounts indicate that costs are lower than in the first scenario. The red cell indicates the major difference between scenario 1 and the actual autonomous development. Shaded cells imply a difference to table 3.11.

The outcomes of the above tables are graphically displayed in the figures 3.2 and 3.3. Note that in the upper graph, the total costs are represented as positive values, while in the lower graph, lower costs are represented as positive values and higher costs than in the first scenario are shown as negative values. This was done to improve the readability of the graphs.

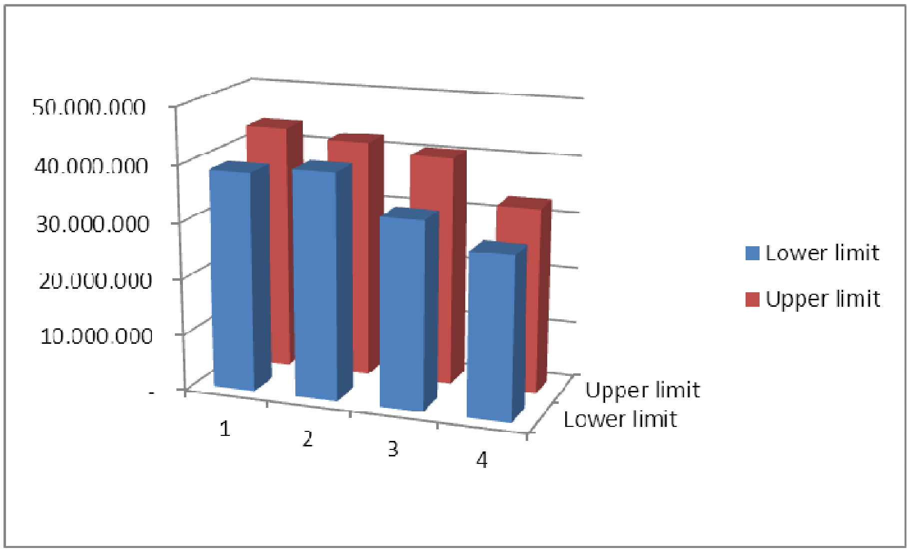

Figure 3.2. Aggregate costs per scenario using lower cost limits (blue) and upper cost limits (red).

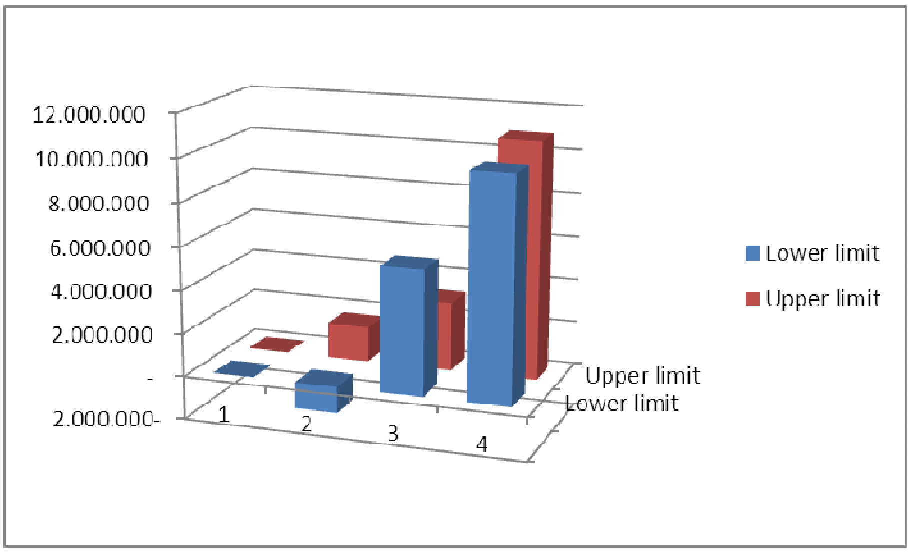

Figure 3.3. Costs relative to scenario 1. Positive values indicate lower costs than in scenario 1, negative values indicate that costs are higher than in scenario 1.

The distribution of the costs over the actors is shown in figures 3.4 and 3.5. In these graphs, the costs and benefits are aggregated for four actor groups, and displayed for the lower costs level (figure 3.4) and the upper costs level (figure 3.5). Note that these graphs clearly show for what the influence of the uncertainty range is for each actor. Especially for house owners, the conclusion that can be drawn from the cost distribution is heavily depending on the assumptions done concerning foundation damage. In appendix B, graphs which display the costs in the four scenarios for each separate effect are shown.

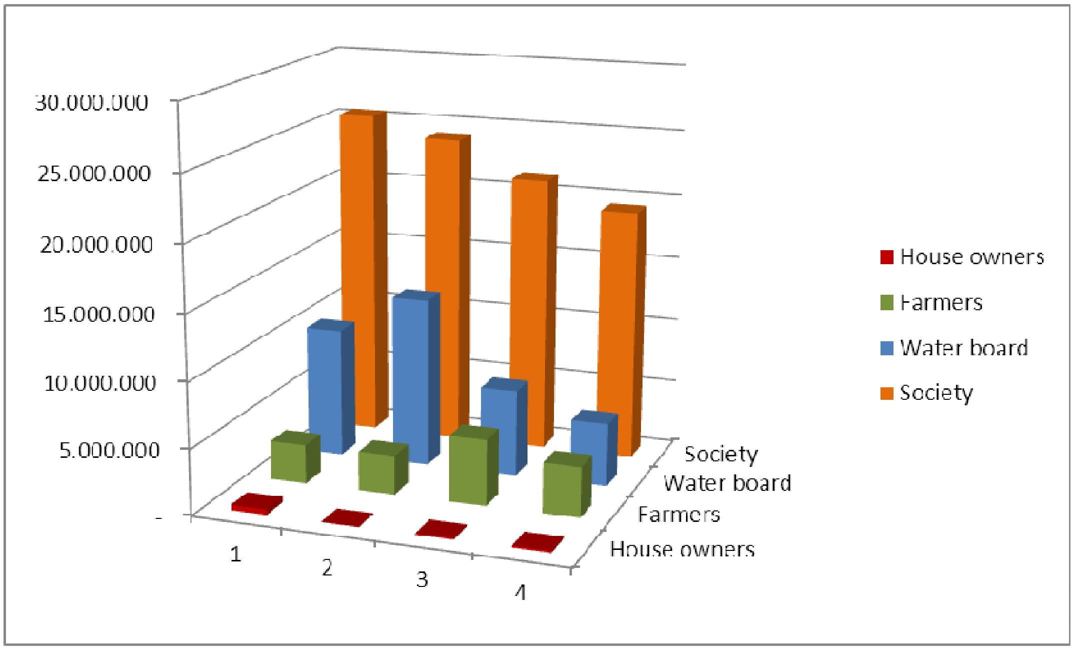

Figure 3.4. Costs and benefits aggregated per actor group, assuming all costs are according to the lower limit scenario.

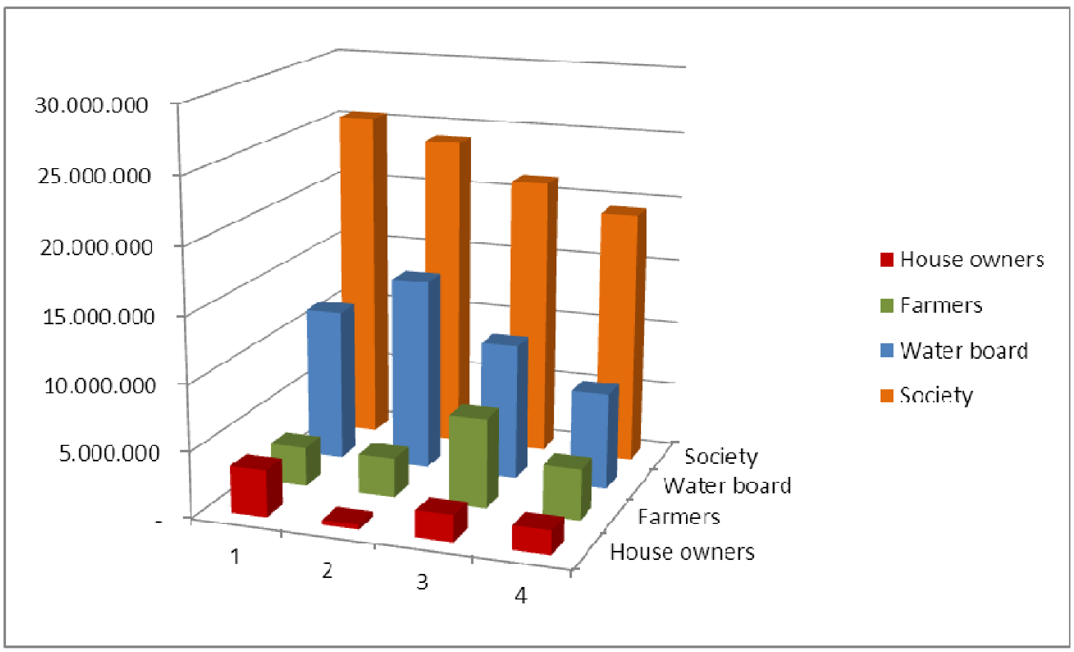

Figure 3.5. Costs and benefits aggregated per actor group, assuming all costs are according to the upper limit scenario.

3.3.7 *Sustainability assessment*

Scenario 1. Maintaining the freeboard

The first scenario does not solve the problem of soil subsidence but rather, it is accepted that the peat meadows are prone to soil subsidence. Hence, the first scenario does not offer a solution for the damage caused by sagging of houses, dikes and infrastructure and neither does it for the ongoing emission of CO_2 and the decreasing water quality resulting from peat oxidation. In return, the loss of agricultural yield is kept relatively low. In total, the costs of soil subsidence are likely the highest in this scenario. However, for the farmers, this scenario is the least costly. Moreover, the strategy to maintain the current freeboard is actually only profitable for farmers, although it should be noted that, still, the freeboard that is maintained in this scenario is a compromise between limiting soil subsidence and agriculture. In this scenario, it is expected that most costs will remain more or less on a constant but high level in the future. Pumping costs will increase as a consequence of the increasing elevation differences. On the other hand, costs for foundation restoration will diminish, since the number of houses that will suffer from foundation damage is limited and will decrease since new houses do not suffer from damage any more. Concerning the non-monetary costs and benefits, the scenario results in the highest emission of CO_2. The landscape, the cultural heritage and biodiversity will likely not benefit from this scenario.

Given the remarks above, this scenario will likely not lead to a sustainable development of the peat meadow area, in terms of costs and benefits. The costs in this scenario remain high, and no long-term solution is pointed out. Only from a farmer's point of view, the first scenario is attractive. One could argue that maintaining the agricultural production is essential for sustainable development since food production depends on agriculture. However, if one would choose to pursue this scenario, it should be noted that this is only feasible if the other stakeholders are willing to bear the costs of maintaining favorable conditions for agriculture.

Scenario 2. Protecting houses

In the second scenario, the problem of soil subsidence itself is not solved. CO_2 emissions will be somewhat lower than in scenario 1, but will remain relatively high compared to the other two scenarios. Roads, sewers, dikes, pipelines and cables outside and on the edges of high water level facilities will still suffer from sagging. However, the sagging of houses is substantially limited, resulting in lower foundation damage costs for the house owners and a large decrease of the uncertainty range of the total costs. House owners do face additional costs because the water board is not responsible for construction and maintenance of individual high water level facilities but, overall, the costs for house owners will likely be lower. In return, farmers face somewhat declining yields as a consequence of the water logging in the vicinity of the high water level facilities.

Furthermore, the water board faces much higher costs than in the first scenario, since they are responsible for the high water level facilities from which the house owners benefit. An important remark on this aspect is pointed out by Van Hardeveld et al. (2013), namely that the high water level facilities are actually a permanent solution for a temporal problem. After all, the foundation damage is expected to diminish over time since the houses with wooden foundation poles are either being demolished or get their foundations restored, which makes them subsidence-proof. On the other hand, the high water level facilities are most likely permanent; abating them in the future will cause a sudden drop in groundwater level which causes rapid soil subsidence which still results in foundation damage and sagging of roads, sewers and parcels. For houses founded on concrete, subsidence of parcels will result in houses being 'elevated' above ground level. Moreover, the costs of maintaining the high water level facilities will increase in the future, since the elevation differences with the surroundings will become larger. This will cause increasing pumping costs, additional weirs and fish passages. If the elevation difference is increasing by more than 60 cm, even water retaining structures need to be constructed for which investment costs are potentially very high (Van Hardeveld et al., 2013). Therefore, this scenario can only be profitable if the high water facilities are eventually being abolished. In such a scenario, the facility is maintained until all sagging-prone houses are demolished. A precondition is then, that newly built houses are resistant to soil subsidence. However, it is most likely that expanding high water level facilities is, on a short term, attractive for house owners but, on the long term, results in an unsustainable situation.

Scenario 3. Limiting soil subsidence

The third scenario does provide a perspective to an end of soil subsidence. On a short term, there may not be large differences in soil subsidence rate, but as the aerobic peat layer above the ground water level becomes thinner, the soil subsidence rate will gradually decrease. This will result in a slowdown of sagging of roads, sewers, pipelines and cables, dikes and houses and a decrease in CO_2 and nutrient emissions, but to increasing yield losses in agriculture. Concerning the costs, almost all stakeholders stand to gain from this scenario, compared to the first two scenarios. Only farmers will suffer from increasing crop damage, resulting in substantially higher costs than in the first two scenarios. Since no high water level facilities are present in the third scenario, the uncertainty on foundation damage costs is again high, but the costs are obviously lower than in the first scenario. For the water board, the cumulative costs are somewhat lower than in the first scenario and much lower than in the second. This is mainly due to the sharp decrease of pumping costs, for a large deal caused by less flushing. However, inundation damage will occur in this scenario, which is a cost on the account of the water board. Still, the benefits of extensifying the water management in the peat meadows outweigh the costs for compensating inundation damage, when comparing the scenario to the previous two.

Since the agriculture in the area is forced to become more extensive until 2100 as a result of the less favorable circumstances for dairy farming, it is expected that chances are created for nature development in the area. Whether this also contributes to an increase in landscape quality is disputable. On the one hand, one may argue that the increase of natural quality will result in a more varied landscape and more possibilities for recreation but, on the other hand, the wetter circumstances and extensification of agriculture may be interpreted as a sign of decay of the traditional peat meadow landscape with its dairy farms. Because the costs for almost all actors are lower than in the two scenarios where the water board continues to lower the water levels, one may conclude that, from a cost-benefit point of view, this scenario may fit in a sustainable development of the peat meadows. However, one should notice that the costs for farmers are increasing disproportionally to the benefits other actors gain from this scenario. As a result, traditional dairy farming may eventually disappear completely if the water levels remain unchanged, since farmers may lose up to 40% of their current income from dairy farming.

Scenario 4. Mitigating losses

The fourth scenario is seeking for a compromise between on the one hand limiting the soil subsidence as much as possible but, on the other hand, keeping the circumstances for agriculture favorable. This means that strictly solving the problem of soil subsidence is not the primary goal in this scenario, but, as concluded when comparing the amount of soil subsidence in table 2.1, the effect of the strategy chosen in this scenario on the limitation of soil subsidence is greater than of the scenario in which no underwater drainage is constructed. After all, over the period until 2100, the fourth scenario contributes most of all scenarios to the mitigation of soil subsidence. The total costs are substantially lower than in the other three scenarios. However, farmers will still lose more income as a result of wet soils than in the scenarios where the water levels are being lowered. The expected extra incomes from the broadening of the activities are by far not sufficient to compensate for the yield losses that result from water logging. The water board is facing costs for compensation of inundation damage and the construction of underwater drainage, but still, the costs are lower than in the other scenarios since the pumping costs are much lower. Furthermore, the costs of foundation damage are still potentially high, although the range of uncertainty on this aspect remains large.

A remarkable aspect of this scenario is that this scenario scores rather positive on the non-monetary costs and benefits. In reality, these costs and benefits will not come to expression in actual money flows, but for an assessment of the sustainability, they are particularly interesting since they concern long-term effects for which no one is directly accountable, but which have a potentially large influence on the environment of the future. However, even if these non-monetary effects are not incorporated in the calculation of the total costs of the scenario, scenario four is still substantially less costly.

In conclusion, the fourth scenario will likely best fit in a sustainable development of the peat meadows. Although the scenario is not favorable for farmers, the construction of underwater drainage systems substantially restrict the loss of agricultural yield, and all other actors will face lower costs than in the other three scenarios. Because of the relatively low greenhouse gas emissions and the positive effect on the biodiversity of the peat meadows, the general society will even face a net benefit from the fourth scenario. It should be noted that this relative positive assessment of the scenario does not mean that the scenario is directly sustainable from a cost-benefit point of view. Resistance to a scenario like this one could still be expected, especially from house owners, whose costs for foundation restoration are still potentially much higher than in the second scenario, and farmers, who still face much larger income losses than when the water board would continue adjusting the water levels to soil subsidence.

4. Discussion

4.1 Research phase one

4.1.1 *Literature study*

One of the most striking uncertainties of this research is the potential costs for foundation damage. The uncertainty is mainly caused because the life span of the houses in the study area is unknown. Although the costs are potentially very high, it is unlikely that the costs will actually become so high in reality. In order to make the differences between the scenarios as clear as possible, this study did not include any pragmatic approaches to foundation restorations, but rather focused on the extremes. The upper limit of the costs for foundation damage is therefore extremely unlikely. The lower limit can be considered more plausible, although one should keep in mind that, in this calculation, it is assumed that no such thing as monumental value exists. Thus, when contemplating the costs for foundation restorations, one should particularly be cautious not to overestimate the costs.

For the effects on recreation and biodiversity/non-use value of nature, the numbers presented are encompassed by uncertainty. Especially for the non-monetary costs and benefits, such as biodiversity/non-use value of nature and landscape and cultural heritage (greenhouse gas emission is an exception since CO_2 equivalents are being traded elsewhere), it proved to be hard to find a reliable way to quantify these effects. Hence, if any quantitative values were found in literature, there was no consensus. For biodiversity, the values found almost vary with a factor 10. Furthermore, recreational benefits remain highly uncertain because it is difficult to make a sound estimation of the change in number of recreants as a result of changes in landscape and nature. Although this means that the reliability of these numbers is low, and one should be very cautious when basing a decision upon them, the uncertainty is considered inherent to this type of effects. It is unlikely that these data can be improved substantially, without conducting thorough additional research in the study area. Therefore, this research gave indicative numbers for these aspects, which will likely give a useful indication of the costs or benefits, but which should be used with care. Only concerning landscape and cultural heritage, the uncertainty was even such, that quantification of this aspect was waived.

The information presented in chapter 3.1 can contribute to making future cost-benefit analysis more inclusive than the previous studies. Especially for the indirect and non-monetary costs, this review provides insight in the available methods to quantify them and, in cases where these methods are not available or insufficient, the knowledge gaps are identified.

4.1.2 *Municipality interviews*

Despite of the small number of municipalities that were able to produce reliable and comparable data concerning road and sewer management costs, the interviews have yielded data on the costs of road and sewer maintenance that are suitable for further use. The approach was, opposite to the approach taken in previous research, focused at revealing the actual costs, and was aimed to verify whether there is indeed a difference in management costs between roads and sewers in peaty areas and in areas with other soil types. Previous research calculated the theoretical costs, based on the predicted soil subsidence, the amount of affected roads and sewers and standard cost factors. The outcomes show that the costs are indeed not only theoretically higher in peat meadows, but that these higher costs are also visible in practice.

For the costs of road management, the interviews showed that municipalities often have a rather practical approach to road maintenance. Except for Bodegraven-Reeuwijk, the interviewed municipalities did not systematically include the impact of soil subsidence in the assignment of budgets for road maintenance. Hence, the numbers produced by the municipality of Woerden were claimed to be uncertain. However, the numbers that were found do not show strikingly large variations, and, especially for the data provided by Bodegraven-Reeuwijk, no reason was found to judge these numbers as unreliable. Thus, the data provided by this study, in particular the data from Bodegraven-Reeuwijk, are considered fit to be used by the water board to verify the current assumptions concerning road and sewer management costs. It should be noted, though, that the municipalities of Stichtse Vecht and Woerden both announced that they will soon publish improved data on this subject. Incorporating these studies when evaluating the current assumptions used in cost calculations is recommended.

Concerning sewers, the findings of the municipality interviews correspond with the assumptions of previous studies concerning the replacement of sewers. Ruijgrok et al. (2006) also stated a lifespan of 60 years in a stable soil and 40 years in weaker soils. Furthermore, in the study by Van Hardeveld (2011), it was assumed that sewers need to be reconstructed after each 20 centimeters of soil subsidence. The life span that is implied by this assumption is about 42 years. This fits quite well with the depreciation period of 40 years which is commonly used by the peat meadow municipalities that were interviewed and thus, the assumptions are confirmed by the research done in this study. However, it should be noted that previously, no distinction was made between gravity drained sewers and pressure drained sewers, while this study shows that the extra costs of soil subsidence for the management of pressurized sewers is remarkably lower than for gravity drained sewers, assuming that pumping units do not suffer from sagging (see table 3.4). Inclusion of this distinction in potential future study will likely help to make the cost calculations more adequate.

4.2 Research phase two

The scenario analysis was aimed to compare different future management alternatives with each other. In order to avoid the analysis to become very complex and time consuming, the input data for the analysis were simplified, and in many cases, assumptions were used to be able to value and quantify effects without extensive empirical research. Furthermore, for road maintenance costs, capital costs were omitted from the calculations, since the capitalization method strongly differs per municipality, while for the other costs, capital costs were taken into account as much as possible. The result is that the absolute amounts that are presented in this study will likely defer from the amounts in reality. However, the conditions per effect were kept constant over the scenarios so, as a basis for comparison of the scenarios, the results are useful. Thus, one should avoid using the absolute costs calculated for the four scenarios as concrete predictions of the actual costs but rather use them as an indicator for the order of magnitude of these costs and, more important, to assess the different effects relative to other effects.

The scenario study was set up in a way that would create room for analyzing the impact of more extreme scenarios on the cost-benefit balances. However, too little quantitative data turned out to be available to actually explore more extreme scenarios than in previous studies. The advantage of choosing a fictional study area instead of analyzing the real peat meadows of HDSR could therefore not be utilized maximally. As a result, the level of detail and the reliability of the outcomes of the scenario analysis will likely be lower than if the scenario analysis was done using more specific data and more detailed ways of calculation, such as analyses with GIS. But still, it is not expected that the overall conclusion of the scenario analysis will be substantially overturned by any more detailed calculations. Moreover, although the studies discussed in section 3.1.2 do not have a clearly shared conclusion, the outcomes of the present study do not clearly conflict with the outcomes of these studies when one takes the critique that followed the publication of these studies into account. Hence, the present study is believed to be suitable to offer input for the debate on future strategies for peat meadow management. Moreover, because no way is found for the peat meadows to be unequivocally sustainable, it is likely that the decision will be merely a political one.

5. Conclusion

This research aimed at providing insight in the costs and benefits that are relevant for soil subsidence, including the costs for sagging of roads and sewers. Furthermore, the aim was to identify which management scenarios would possibly contribute to a sustainable development of the peat meadows. It was found that the most important costs when comparing different scenarios are the pumping costs, the loss of agricultural yield, the costs for sewer management and the costs for inundation damage. Also, although the range of uncertainty remains high, the costs for foundation damage or measures to prevent foundation damage are potentially of great importance to assess the profitability of different scenarios. It can be concluded that the only way the peat meadows can be physically sustainable is when the groundwater levels are increased to surface level. In all other cases, soil subsidence will continue. However, such a scenario is not sustainable from a cost-benefit point of view. Without one solution clearly standing out as being sustainable, the decision of choosing an approach to combat soil subsidence will be primarily a political one. However, a compromise between limiting soil subsidence and maintaining conditions suitable for agriculture as long as possible, in this study represented by scenario 4, seems to be the most promising option for developing a sustainable approach to soil subsidence. In this way, soil subsidence is slowed down, while the gradual shift towards wetter circumstances gives stakeholders the time to search for appropriate solutions to cope with the higher water levels.

6. Recommendations

Regarding the costs for road management and, to a lesser extent, for sewage management, some interesting new results are expected to be presented by the municipalities of Stichtse Vecht and Woerden. In particular the project of ‘Kockengen Waterproof’, which is currently being carried out in Stichtse Vecht, will likely offer useful data to complement the data presented in this study in the nearby future. It is therefore recommended to keep in contact with these municipalities, so, when available, their data can contribute to the establishment of improved calculation methods for the costs for road and sewer management as a result of soil subsidence. The amounts that were found for road maintenance costs could, when combined with the soil subsidence data of the associated municipality, be used to verify the currently used costs factors for sagging of roads. Furthermore, the detailed information system that is being used by the municipality of Bodegraven-Reeuwijk can probably offer useful insights when calculating road and sewer management costs on a more detailed spatial scale.

Having stated the above remark, it is recommended to recognize that the further process of developing a strategy to cope with soil subsidence will probably be dominated by political arguments. It appears that the most crucial knowledge to indicate substantial differences in future scenarios is present and that, where not, it is unlikely that this knowledge could be substantially improved without intensive additional research. Nevertheless, if one would choose to do extra research to explore more extreme scenarios, it is recommended to consider different, probably more qualitative methods to explore potentially interesting scenarios that further deviate from the current situation. Since it proved to be hard to find suitable input data for a cost-benefit study of more extreme scenarios, it is expected that conducting a reliable cost-benefit analysis on such scenarios will be hardly possible.

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Appendices

Appendix A. Extended descriptions of cost-benefit analyses included in the literature review.

Horstermeer (2003)

In 2003, Graaff et al. analyzed the costs and benefits of seven different options for redevelopment of the Horstermeer polder, located about 15 kilometers north of Utrecht. Apart from a clay/sand area in the west of the polder, the soil largely consists of peat (Alterra, 2013). Although soil subsidence is not considered a problem in this area, the problems that are addressed in the Horstermeer require solutions similar to the measures considered in subsiding peat polders. In the Horstermeer polder, the relative low ground level compared to the surrounding lakes and wetlands cause a substantial groundwater flow from the surroundings to the polder, which means that intensive pumping is required to maintain a groundwater level suitable for agriculture in the polder. Furthermore, the surrounding nature area becomes desiccated as a result of the deep Horstermeer polder attracting water from the surroundings. This effect is mitigated by letting in extraneous water into the nature areas, which causes eutrophication as a result of the higher concentration of nutrients in the inlet water. The measures that are proposed to solve this problem mainly imply implementing higher water levels in (parts of) the polder in order to reduce the difference in hydraulic head between the polder and its surroundings. Since this generates similar discussions on land use shifts and potential costs and benefits as elevating the water levels in order to combat soil subsidence, the study by Graaff et al. (2003) contains interesting input for the present research.

Graaff et al. (2003) compare five alternatives for turning parts of the polder into lakes or wetlands to the alternative of continuing the current policy. Investment costs to realize the proposed alternatives are the most distinguishing costs when comparing the alternatives. In general, the proposed strategies imply a displacement of dairy farms out of the polder and replacement by wetland nature or lakes. The alternatives vary in location and extent of the water level increase.

Also, the alternative of blocking the groundwater flow is considered, but as this alternative is less relevant in the context of this study, it will be disregarded in this review. Graaff et al. (2003) conclude that, in monetary terms, none of the alternatives is considered feasible. Balances are between € 4,4 million and € 21,2 million negative, compared to the autonomous development scenario. However, several immaterial effects such as the reduction of damage to the surrounding nature caused by desiccation or the change in experiential value of the landscape are not monetized.

They also conclude that, in this case, the alternatives were not sufficiently different to make a good distinction between the outcomes of the analysis. Overall, one may say that increasing the groundwater level is, in monetary terms, is scarcely feasible. Probable different conclusions depend on the value accounted to the aspects that have not been quantified.

Collective high water level facilities (2007)

Witteveen + Bos (2007) has conducted a study to the costs and benefits of collective high water level facilities, which are constructed to maintain a higher water level around houses in order to protect the foundations and locally limit the soil subsidence. Based on the case of the Zegveld polder, which is often used as an exemplary peat meadow area, Witteveen + Bos (2007) listed the relevant costs and benefits of the collective high water level facilities and determined whether these facilities are a socially responsible investment. Mainly because the water levels in the polders can be lowered further in the presence of high water level facilities and, therefore, the agricultural benefits increase substantially, the study concludes that the collective high water level facilities in the study area can be considered a socially responsible investment. However, this conclusion became debated as the assumptions concerning the base case became subject to discussion.

The 2007 study assumed that in the base case, water levels would no longer be lowered to keep up with the subsiding ground level. This implies high costs as a result of agricultural yield loss caused by water logging. The assumption was that high water level facilities around houses would again enable lowering of water levels in the farmland, and thus result in a relative increase of agricultural yield. However, later insights pointed out that this base case could not be assumed as a given fact. Instead, continue lowering the water levels and, instead of causing agricultural damage, allow damage to foundations could also be a possible base case. Since in Witteveen + Bos (2007), the relative gain of agricultural yield was the major benefit of the collective high water level facilities, the outcome would significantly be affected by changing the base case. The permanent loss of agricultural yield in the original base case would then become an incidental investment of restoring damage to foundation which is caused by the lower groundwater levels. Therefore, further study is being done to the profitability of high water level facilities, given this alternative base case (Van Hardeveld et al., 2013).

Water level change Zegveld (2008)

The study by Bos & Vogelzang (2008) aims at identifying the costs and benefits of water level change in the Zegveld area. Changing the water level in this area may be necessary to combat soil subsidence through peat oxidation. As Zegveld is an important part of the peat meadow area under the responsibility of HDSR and the study explicitly focuses on soil subsidence, Bos & Vogelzang (2008) offers valuable information on the costs and benefits of soil subsidence in the HDSR area.

Bos & Vogelzang (2008) compare the autonomous development to a project scenario in which the amount of water level areas is reduced and, thus, water levels change. The consequence of the project scenario is that in some parts of the study area, the water levels will become lower and in other parts of the study area they will become higher. In general, a larger area will face water level increase than water level decrease. This also results in a decrease in soil subsidence.

Overall, Bos & Vogelzang (2008) conclude that most actors will benefit from the project scenario. Only farmers will suffer from a loss of income because more land will have increased water levels, so agricultural yield will face a net decrease. The profitability of the project scenario is assessed in two ways, one incorporating the non-monetary costs and benefits and one only looking at actual money flows. In the first case, it is concluded that the project scenario is certainly beneficial compared to the autonomous development. When only looking at actual money flows, the uncertainty range includes both positive and negative balances.

Continuation of desired ground and surface water regime (2011)

In this report, Van Hardeveld et al. (2011) present a cost-benefit analysis of three alternatives for future water level management in the HDSR area. One is assuming further adaptation of the water level to the subsiding surface level, in order to maintain a constant drainage, the second assuming no further lowering of the water level and a third scenario in which the water level areas are enlarged, water levels are increased and periodically adjusted to the subsiding ground level. Being focused on revealing relevant costs and benefits of future water management scenarios in the peat meadow area of HDSR, Van Hardeveld et al. (2011) can be considered a direct predecessor of the present study. Worth mentioning is that their study does not draw explicit conclusions on whether a strategy yields a positive cost-benefit balance. Instead, Van Hardeveld et al. (2011) present the costs and benefits per scenario per actor, taking into account the water board, farmers and society (including house owners and municipalities).

The conclusion is that the costs of soil subsidence are considerably high in all scenarios, but that each scenario yields a different division of the costs among the actors. The first scenario is mostly beneficial for farmers, as the circumstances for agricultural activities remain the same. However, the costs for the water board increase as a result of increased pumping and sagging of the present high water level facilities. Furthermore, sagging of houses and extra emission of CO_2 result in increasing costs for society. In the second scenario, the restriction of soil subsidence save society over 10 million Euros per year compared to the current situation as a result of less sagging of houses and infrastructure and less CO_2 emissions. On the other hand, the water board runs into high costs, mainly because water boards are obliged to compensate for water logging. Furthermore, farmers suffer from substantial yield loss as a result of the rising water levels. The third scenario takes an intermediate position. Water board and society benefit from this scenario, the first mainly because of a reduction in water management costs, the latter because of avoided costs of sagging. Farmers face a loss of crop yield as a result of water logging.

From these results, Van Hardeveld et al. (2011) conclude that there is no alternative that undisputedly leads to the most beneficial strategy, but that the choice for a strategy is merely a matter of political considerations. Therefore, the authors call for a more explicit inventory of the foreseen costs and benefits and preparation of the debate on the vision on the management of the peat meadow landscape on the future. Here, Van Hardeveld et al. (2011) provide a starting point for further research, which will be partly done in the present study. Later, a full overview of the identified costs and benefits from Van Hardeveld et al. (2011) and the most significant knowledge gaps will be presented.

Future scenarios Laag Holland (2012)
Commissioned by the province of Noord-Holland, the study by Van der Kooij et al. (2012) of future scenarios for the national landscape of Laag Holland aims at defining a strategy to cope with the increasing costs of maintaining the so-called 'core qualities' of the area, i.e. landscape elements that are deemed typical for the area and worth preserving. The authors state that fundamental choices about the desired development of the area and the action that is required to steer the development in this direction have not been made and that, therefore, a discussion on these choices should be generated.

Four scenarios have been proposed in order to direct this discussion: scenario 1 is the autonomous development which will probably take place if no strategy change is executed. This scenario is characterized by commitment to the current core qualities of the area and continuing of the current land use but, on the other hand, increasing financial deficit, which puts the achievement of the goals at risk. Scenario 2 assumes that the maintenance of the current land use and the safeguarding of the core qualities of the area get increased financial support from the EU Common Agricultural Policy. This offers room for maintaining continuity in the current land use and policy, so landscape changes only occur if the (thinner) peat layers are exhausted. The third scenario proposes a withdrawal of the government from the management of the peat meadows. Land use is determined by competing market parties without government interference. This means agriculture is forced to broaden activities or to scale up, and other market sectors, such as tourism, are given freedom to expand their activities. The responsibility for the core qualities is left to the market, which will probably result in abandonment of non-profitable targets. Soil subsidence rates will increase as a result of optimized agricultural circumstances. Scenario 4 focuses on the achievement on long-term targets such as soil subsidence control and climate-robustness. This implies the abandonment of the preservation of current landscape elements and a transition towards a robust marshy wetland system. A distinction is made between a passive and an active scenario, where in the first, lowering of the water levels following the soil subsidence is ceased, resulting in a gradual reduction of drainage and in the second, water levels are actively raised to 10 cm below surface level in 2025.

Van der Kooij et al. (2012) conducted a cost-benefit analysis of these scenarios, incorporating the amenity value assigned by citizens, which makes this study of particular interest. The authors conclude that scenarios in which the core qualities are preserved generally lead to a more negative cost-benefit balance than scenarios where these core qualities are not safeguarded. The first and third scenarios are, therefore, the least costly alternatives for society. Furthermore, the authors state that the amenity value assigned by citizens to the third and fourth alternatives is remarkably lower than to the autonomous scenario and scenario 2. This is a substantial disadvantage of the third and fourth scenario, which is even considered the major cause of the strong negative balance of these scenarios.

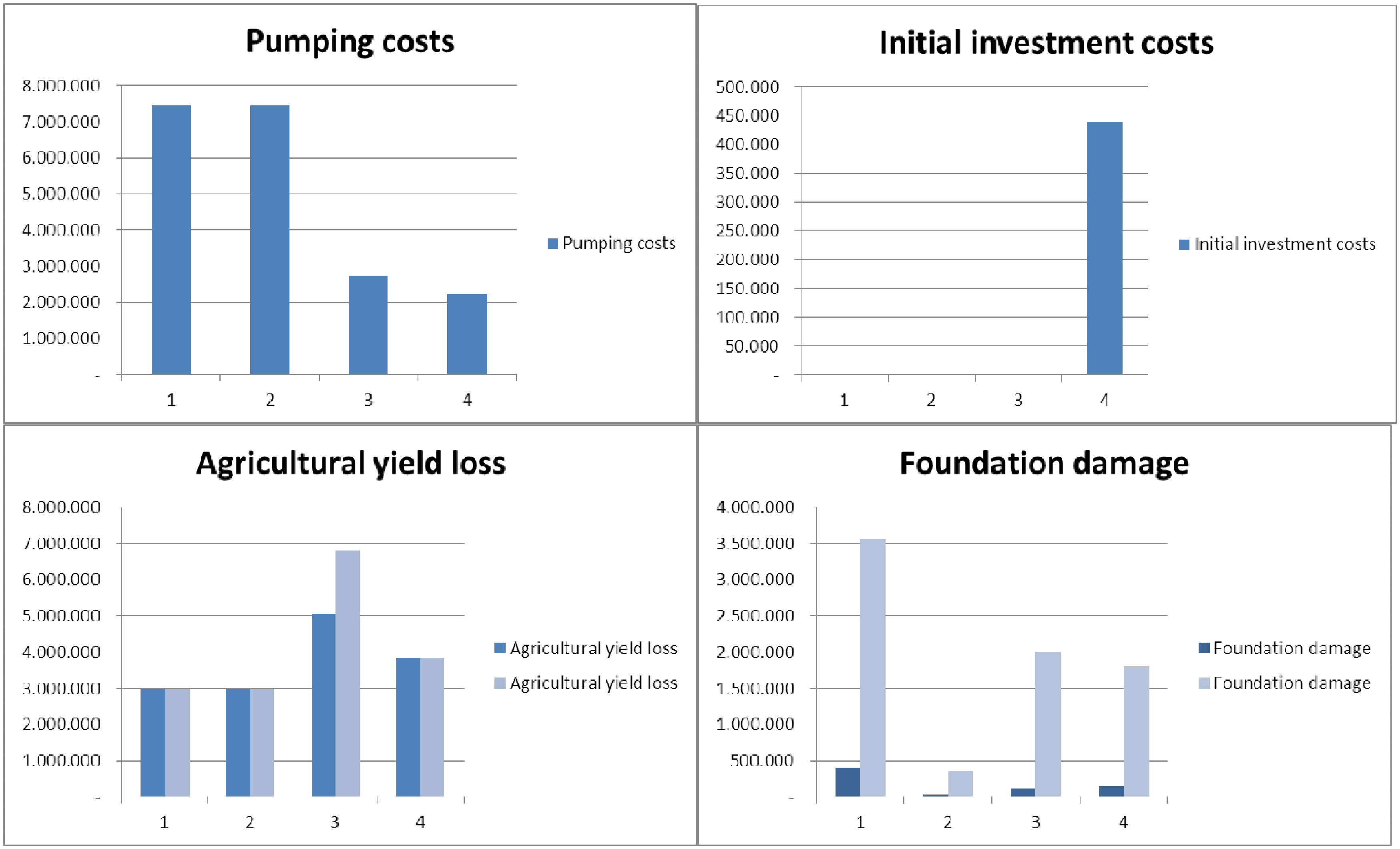
High water level facilities (2013)
Because of concerns of the water board that constructing high water level facilities is in conflict with sustainability and other goals of the water board, a study to the necessity and profitability of such facilities was commissioned. The concerns on sustainability are both financially, because the costs of high water level facilities will increase, and physically, since the elevation differences continue increasing, resulting in more complex water management and obstruction of fish migration (Van Hardeveld et al., 2013). Since the high water level facilities are constructed to protect the foundation of houses against sagging, the study focuses merely on foundation damage. Two scenarios are taken into consideration; one assuming that the high water level facilities are maintained the way they are, but no new facilities are constructed and the other assuming an extension of the high water level facilities where necessary to protect houses against sagging.

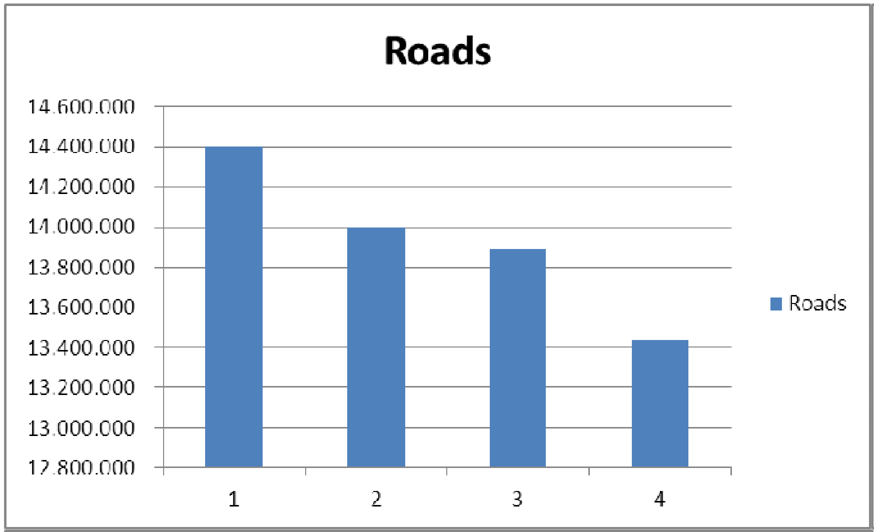
For these two scenarios, it is investigated what the costs are for foundation damage, additional water management structures that are required, pumping costs, sagging of roads, sewers and pipelines, dike maintenance and the emission of CO_2. Furthermore, the effects on the water quality, landscape and environment, reputation of the water board and the management context are taken into account, although these effects are not quantified but scored with + and -.

The most important finding of this study is that the costs for foundation damage are temporal since only houses older than 1990 are prone to damage and these houses will likely either be renovated in the future, making them resistant to sagging, or reach the end of their life span and will, therefore, be demolished. On the other hand, the costs to maintain the high water level facilities will increase in the future because of the increasing elevation differences and continuing maintenance costs of the civil structures necessary for the high water level facility. As a consequence, the division of costs and benefits of high water level facilities will become increasingly in favor of house owners in the future, given that their houses are protected from sagging, while the water board will have to bear the increasing costs of maintaining the facilities. Therefore, also provided that there is no juridical obligation for the water board to construct the high water level facilities, Van Hardeveld et al. (2013) advise to consider alternative ways to mitigate the problem of foundation damage, such as settlement of damage or temporal high water level facilities.

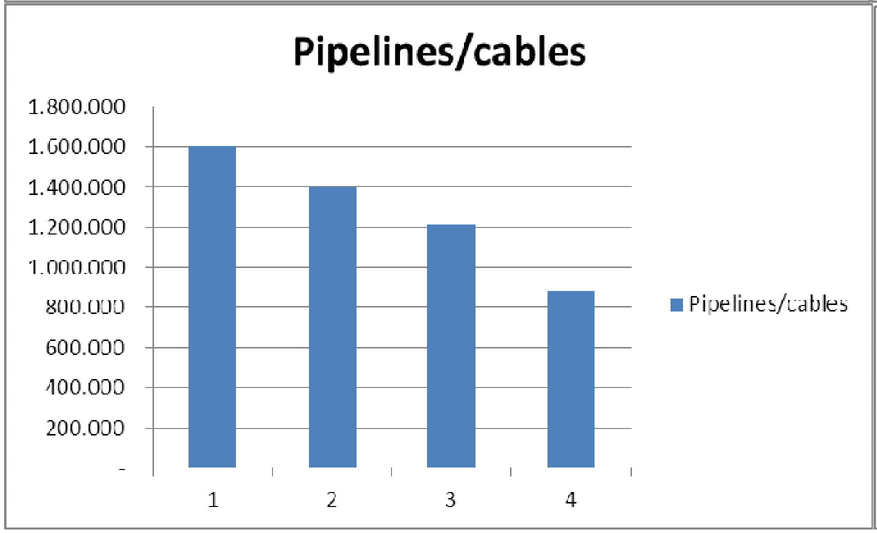
Appendix B. Graphs per effect.

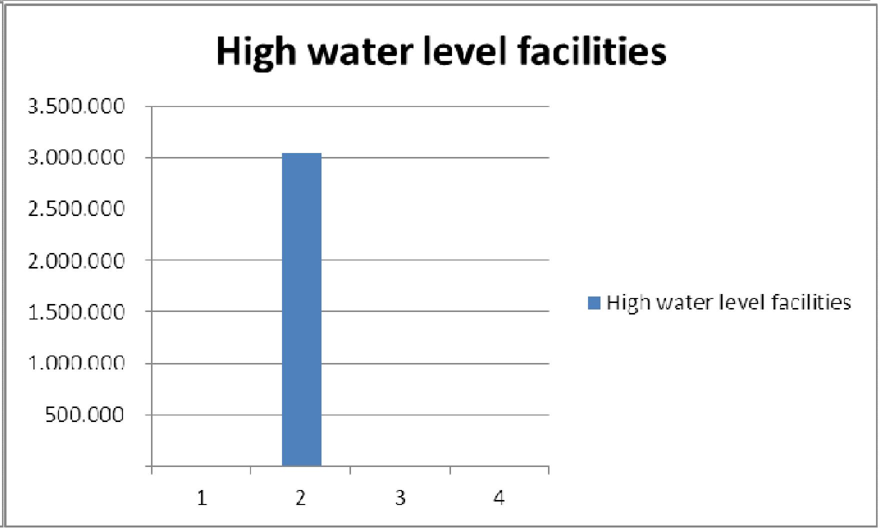
In case of double columns: left column represents lower cost limit, right column represents upper cost limit. Positive values represent net costs, negative values are net benefits.

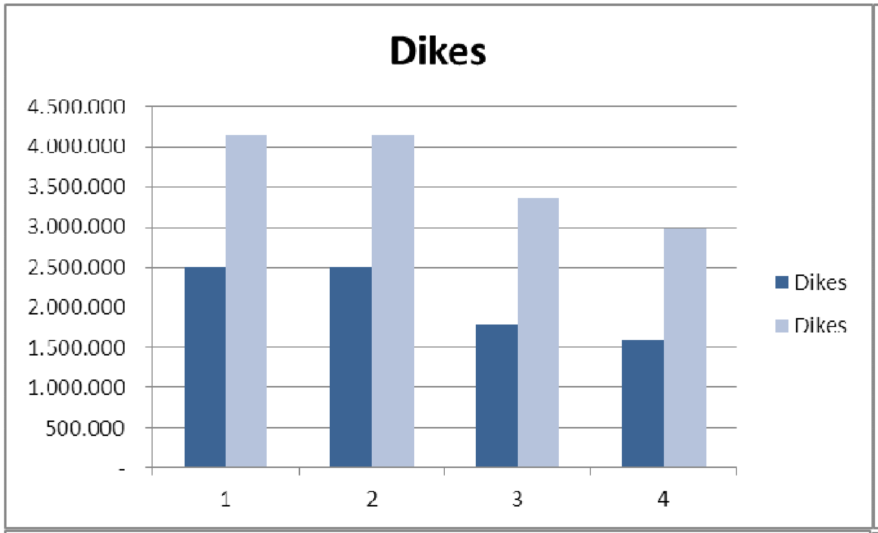

Pumping costs
8.000.000
7.000.000
6.000.000
5.000.000
4.000.000
3.000.000
2.000.000
1.000.000
-
1
2
3
4
Pumping costs
Initial investment costs
500.000
450.000
400.000
350.000
300.000
250.000
200.000
150.000
100.000
50.000
-
1
2
3
4
Initial investment costs
Agricultural yield loss
8.000.000
7.000.000
6.000.000
5.000.000
4.000.000
3.000.000
2.000.000
1.000.000
-
1
2
3
4
Agricultural yield loss
Agricultural yield loss
Foundation damage
4.000.000
3.500.000
3.000.000
2.500.000
2.000.000
1.500.000
1.000.000
500.000
-
1
2
3
4
Foundation damage
Foundation damage

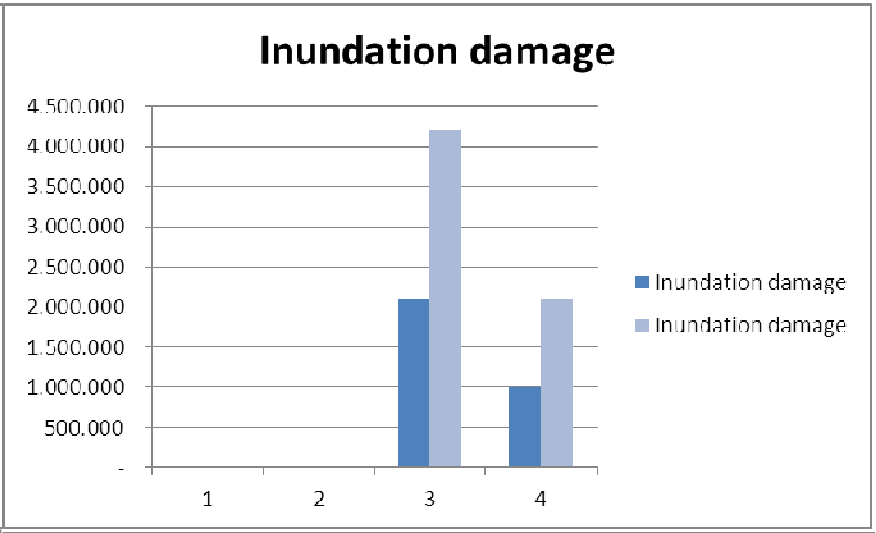

Roads
14.600.000
14.400.000
14.200.000
14.000.000
13.800.000
13.600.000
13.400.000
13.200.000
13.000.000
12.800.000
1
2
3
4
Roads

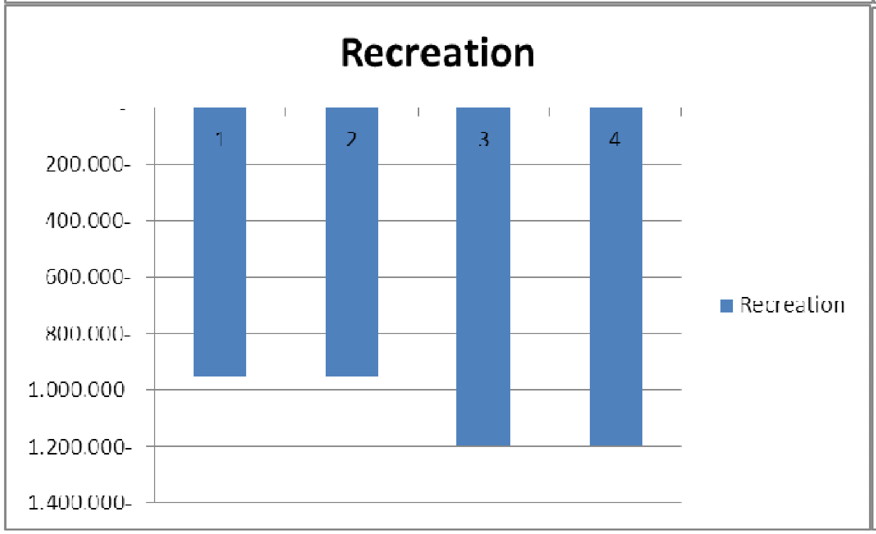

Sewers
9.000.000
8.500.000
8.000.000
7.500.000
7.000.000
6.500.000
6.000.000
1
2
3
4
Sewers

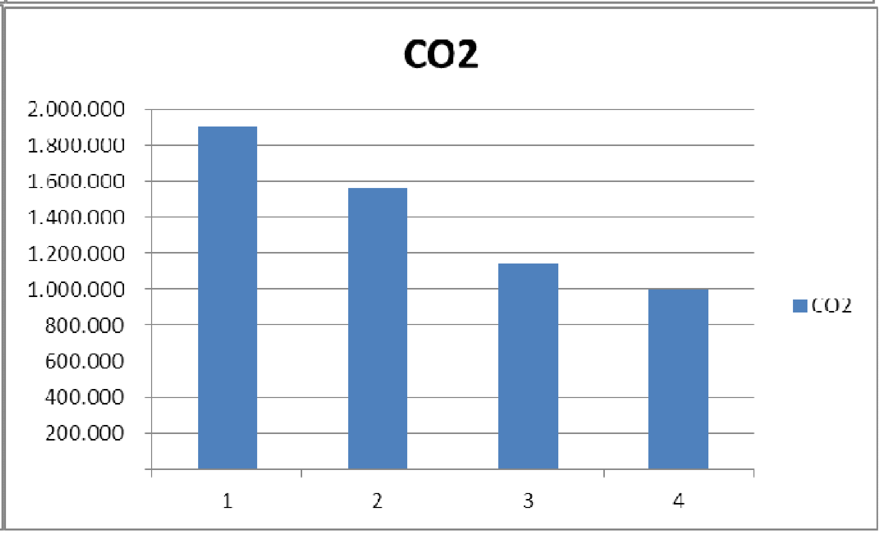

Pipelines/cables
1.800.000
1.600.000
1.400.000
1.200.000
1.000.000
800.000
600.000
400.000
200.000
-
1
2
3
4
Pipelines/cables

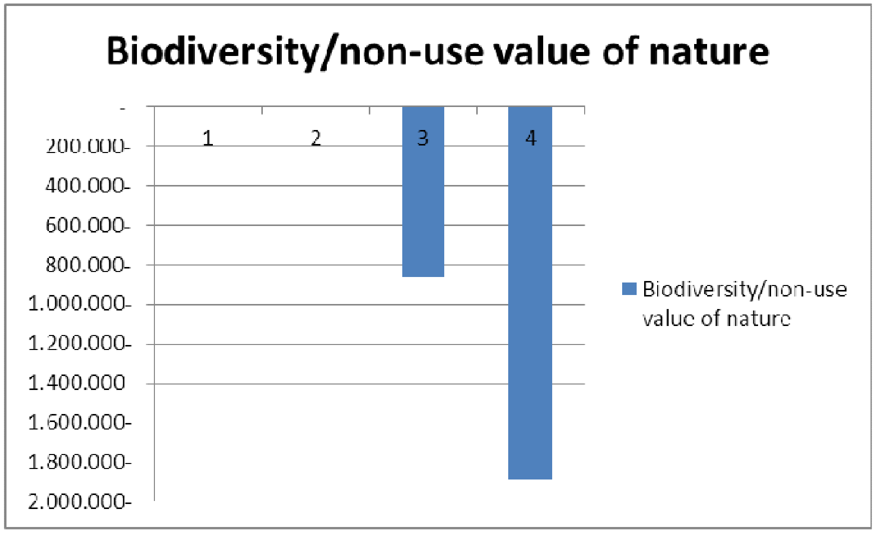

High water level facilities
3.500.000
3.000.000
2.500.000
2.000.000
1.500.000
1.000.000
500.000
1
2
3
4
High water level facilities


Dikes
4.500.000
4.000.000
3.500.000
3.000.000
2.500.000
2.000.000
1.500.000
1.000.000
500.000
-
1
2
3
4
Dikes
Dikes


Inundation damage
4.500.000
4.000.000
3.500.000
3.000.000
2.500.000
2.000.000
1.500.000
1.000.000
500.000
-
1
2
3
4
Inundation damage
Inundation damage


Recreation
-
200.000-
400.000-
600.000-
800.000-
1.000.000
1.200.000-
1.400.000-
1
2
3
4
Recreation


CO2
2.000.000
1.800.000
1.600.000
1.400.000
1.200.000
1.000.000
800.000
600.000
400.000
200.000
1
2
3
4
CO2



Biodiversity/non-use value of nature
-
200.000-
400.000-
600.000-
800.000-
1.000.000-
1.200.000-
1.400.000
1.600.000-
1.800.000-
2.000.000-
1
2
3
4
Biodiversity/non-use value of nature