EMBANKMENTS 2.0 AS PART OF THE TRANSITION TO A ROBUST WATER SYSTEM

PERSPECTIVE FOR THE FRISIAN PEAT AREA

MASTER THESIS LANDSCAPE ARCHITECTURE
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COLOFON

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PREFACE

Deze masterthesis is begonnen vanuit een facinatie voor polderdijken, regionale keringen, in het Friese veenweidegebied. Na mijn stage bij Waterschap Friesland, leerde ik over de problemen in het Friese veenweidegebied omtrent het waterbeheer in combinatie met het huidige agrarische landgebruik. Ik zag potentie om polderdijken op andere manieren te benutten om zo bij te dragen aan oplossingen voor huidige en toekomstige problemen in het veenweidegebied. Beginnend bij het analyseren van zulke keringen op kleine schaal liep ik al snel tegen moeilijkheden aan: Hoe zat het watersysteem nu precies in elkaar? Waarom zijn ze eigenlijk aangelegd? En waarom onderhouden we ze nu nog steeds?

Met zulke belangrijke vragen moest het roer om. In plaats van werken op gedetailleerd niveau stapte ik over naar de regionale schaal met belangrijke conclusies als gevolg. Een veel groter probleem bleek aan de orde met hier het eindrapport als antwoord. 5 jaar Wageningen komt hiermee ten einde, 5 jaar waarin ik mezelf heb kunnen ontwikkelen als landschapsarchitect.

Ik wil Waterschap Friesland als opdrachtgever bedanken voor de kennis en ervaring. In het bijzonder Bieuwe Couperus voor de goede begeleiding gedurende de periode waarin ik aan mijn scriptie heb gewerkt. Daarnaast wil ik Bureau Noordpeil bedanken voor het zoeken en vinden van structuur in mijn verhaal en voor het faciliteren van een werkplek om mijn rapport af te kunnen ronden. Tot slot wil ik Ingrid Duchhart bedanken voor het geven van feedback gedurende het hele proces.

GUIDE TO THE READER

CHAPTER 1 INTRODUCTION

The first chapter introduces the subject; problems at the Frisian peat area as a result of the current type of agricultural land use. The aim of this thesis, to find out what measures lead to regional embankments as part of a robust water system, is explained. Also the main research and design questions are given. A design process is introduced which is a method to generate an answer to the main research question and the design question. This design process will be elaborated at chapter 4.

CHAPTER 2 PROBLEM ANALYSIS

Chapter 2 inlcudes a comprehensive problem analysis to find out what causes lead to the current and future problems at the Frisian peat area. This in order to understand what measures could be helpfull to design a robust water system.

CHAPTER 3 ANALYSIS ON THE CURRENT WATER SYSTEM

The current water system is the basis for new developments according to the water system. If it is not understood how the current water system functions, it is much harder to design measures that can improve the current system and problems related to this current water system. Therefore an analysis is given which elaborates the functioning of the current water system.

CHAPTER 4 DESIGNING A ROBUST WATER SYSTEM

Within this chapter different scale levels are analysed. These analyses form the basis for measures that lead to a robust water system for the Frisian peat area that include regional embankments as part of such a system. Also measures at local scale are illustrated which show the transition of the current landscape to a Frisian peat area where a robust water system is present. Some pages are framed by a yellow rectangle. This means that this page includes analyses results, extra information to understand further findings. However, this information could be skipped.

CHAPTER 5 GENERIC GUIDELINES

Now local measures to develop a robust water system are extrapolated to the whole Frisian peat area. These local measures result in generic guidelines or measures that illustrate what measures are necessary to create a robust water system at the Frisian peat area and how regional embankments can become part of this system.

CHAPTER 6 DISCUSSION

Within the discussion some important points are discussed. Like the design strategy or the possible impacts of the development of a robust water system on farmers or the water management organisation; Wetterskip Fryslân.

CHAPTER 7 CONCLUSION

At the last chapter the main research question is being answered. Conclusions are being made about the measures to develop a robust water system and their consequences for different stakeholders.

Appendice A represents a glossary. This glossary may be helpfull to understand unknown terms.

CONTENT

SAMENVATTING

Deze thesis geeft een toekomstmodel voor een robuust watersysteem voor het Friese veenweidegebied gericht op een adaptiever landgebruik en de toepassing van regionale keringen. Deze thesis geeft een antwoord op de vraag welke maatregelen moeten worden getroffen om regionale keringen een rol te laten spelen in een robuust watersysteem.

Het huidige landgebruik van het veenweidegebied is gericht op de melkveehouderij en wordt ontwatert voor optimale grasproductie. De ontwatering leidt tot veenoxidatie met een bodemdaling van minimaal 1 cm per jaar als gevolg (Provincie Fryslân 2015) (Hendriks 2013; Beuving en Akker, van den 1996). Naast de bodemdaling wordt verwacht dat de toename van extreme neerslagperiodes (Hurk, van den et al. 2007; Bresser et al. 2005) en de stijging van de hoeveelheid neerslag per jaar (Bresser et al. 2005) als gevolg van klimaatverandering vaker tot wateroverlast en hogere (grond)waterstanden gedurende extreme neerslagperioden zal leiden.

De bodemdaling in combinatie met de extreme neerslagperioden bemoeilijkt de veehouders om het land te kunnen gebruiken, om gras te kunnen oogsten en dus om de koeien te kunnen voeren zonder forse investeringen te hoeven doen. Dit zal niet alleen leiden tot investeringen gerelateerd aan het waterbeheer om Friesland veilig en functioneel te houden, dit proces moet worden gestopt, gezien het ook leidt tot een CO2 emissie van plusminus 30 ton per hectare per jaar. Dit betekent een emissie van 2.550.000 ton CO2 per jaar voor het hele Friese veenweidegebied! (Kwakernaat et al. 2010).

In het huidige Friese watersysteem spelen waterkerende dijken een uiterst belangrijke rol. Ze beschermen Friesland tegen water vanuit de Waddenzee en het IJsselmeer. Naast deze primaire keringen bevat Friesland 3200 kilometer aan kleinere niet minder belangrijke regionale keringen waarvan 1000 kilometer in het veenweidegebied ligt. Deze kleinere keringen beschermen onder andere landbouwgebieden tegen overstromingen, gezien ze de Friese boezem, een intern water opslag systeem in Friesland, scheiden van de lagere polders.

Wetterskip Fryslân is verantwoordelijk is voor het waterbeheer en de waterveiligheid van Friesland en een deel van Groningen. In het Water Beheer Plan 2016-2021 neemt Wetterskip Fryslân verantwoordelijkheid voor een robuust en duurzaam watersysteem op de lange termijn (Wetterskip Fryslân 2015b). Dit document licht toe welke kant Wetterskip Fryslân op wil gaan de komende 5 jaar wat betreft het beleid. Contrasterend hieraan is dat de maatregelen voorgesteld en uitgevoerd door Wetterskip Fryslân laten zien dat het huidige type landgebruik in het veenweidegebied functioneel moet blijven. Dit terwijl de grasproductie met intensieve ontwatering juist de hoofdoorzaak is van het huidige niet-duurzame watersysteem waarbij een toegenomen veiligheidsrisico wordt gehanteerd.

Niet alleen dalen de landbouwgebieden en ervaren deze nu en in de toekomst problemen van intensieve neerslagperioden, ook de regionale keringen staan hierdoor onder druk. Momenteel worden enorme investeringen gedaan om de hoge veiligheidsnorm van de keringen te behouden. Met het dalende veengebied en meer water in het Friese watersysteem als gevolg van extreme neerslag, staat wel vast dat deze investeringen niet eenmalig zijn. Daarom is het belangrijk na te denken of en hoe deze regionale keringen een deel zullen zijn van een robuust watersysteem en hierdoor bij kunnen dragen aan oplossingen voor de problemen die momenteel spelen in het Friese veenweidegebied omtrent het waterbeheer.

Om in de toekomst een robuust watersysteem te ontwikkelen is op verschillende schaalniveaus gekeken naar de condities voor een dergelijk robuust systeem. Dat betekent voor de regionale schaal dat is geanalyseerd waar bodemdaling als gevolg van veenoxidatie zich zal voortzetten. Dit heeft ertoe geleid dat de focus is gelegd op een regio die in de toekomst nog enkele meters zal dalen bij ongewijzigd land- en waterbeheer waarbij de waarschijnlijkheid van grote problemen ten gevolg van bodemdaling en intensieve neerslag groot zal zijn. Daarom is geanalyseerd welk type landgebruik in deze regio's in combinatie met toekomstige klimaatomstandigheden functioneel zou kunnen zijn zonder dat het leidt tot verdere problemen. Paludicultuur bied hier een gunstig perspectief.

Lokaal is een gebied uitgewerkt waarbij is gekeken welke maatregelen moeten worden genomen om de transitie naar zo'n gepast type landgebruik, paludicultuur, in te zetten. Hierbij is gekeken naar de functie van regionale keringen en welke rol deze kunnen spelen in een robuust watersysteem met een adaptiever landgebruik.

Het toekomstperspectief voor de ontwikkeling van een robuust watersysteem voor het Friese veenweidegebied bestaat uit maatregelen die de transitie naar een ander type landgebruik vormen waarbij de paludicultuur centraal staat. Principes voor een veiliger en functioneel watersysteem zijn geïntegreerd, zoals het creëren van extra ruimte voor waterberging en het ontwikkelen van extra keringen. Hierbij bieden de hellingen en oevers van bestaande en/of extra keringen mogelijkheden om bij te dragen aan een verbeterde waterkwaliteit, extra veiligheid, recreatie en ecologische structuren. Al met al leiden maatregelen tot een systeem waarbij niet alleen de regionale kering, maar het gehele gebied waarin een transitie naar een ander type agrarisch landgebruik plaatsvindt tot een verhoogde waterveiligheid en een systeem dat bijdraagt aan oplossingen voor huidige en toekomstige problemen in het Friese veenweidegebied om zo het tij van problemen te keren naar een duurzame vorm van agrarisch waterbeheer.

SUMMARY

This thesis gives a perspective for a robust water system for the Frisian peat area. The focus is on a more adaptive type of agricultural land use and the role of regional embankments in this. This thesis gives an anwer to the question what measures must be taken to let regional embankments be part of a robust water system.

As a result of the climate change it is predicted that there will be more extreme precipitation events (Klein Tank et al. 2014; Bresser et al. 2005) and that the precipitation level per year will rise (Bresser et al. 2005). This will cause more flooding problems, a higher water level during extreme precipitation events and higher ground water levels which are likely to have all negative effects on the agricultural terrains in the Frisian peat area.

These areas are used for dairy farming. Here the agricultural fields are drained to produce grass. This intensive draining leads to a soil subsidence up to 1 cm per year (Provincie Fryslân 2015) as a result of peat oxidation (Hendriks et al. 1993; Beuving and Akker, van den 1996). This soil subsidence together with the occurence of more extreme precipitation events will impede farmers to work the land, to harvest grass and thus feed the cows without making investments. This soil subsidence does not only leads to investments according to the water management to keep Friesland safe and the land functional, this process needs to be slowed down, since it also leads to a CO_2 emission of about 30 tons per acre per year (Kwakernaak et al. 2010). Which means an emission of 2.550.000 tons CO_2 per year for the whole Frisian peat area!

The Dutch government is well aware of these problems and commissioned the Second Delta Committee to think about these problems in relation to water safety in The Netherlands. Wetterskip Fryslân, the governmental organisation responsible for the water management in Friesland and a part of the province Groningen, translated such abstract visions commissioned by higher policy levels into direct measures to secure the water safety and to keep current functions possible within the province, including dairy farming with a type of land use that is becoming increasingly difficult to implement and therefore will ask for investments.

'In the Water Management Plan 2016-2021 Wetterskip Fryslân takes responsibility for a robust and sustainable water system at a long term'(WBP 2016-2021). This document explaines the policy Wetterskip Fryslân handles the coming 5 years. However, the measures proposed and executed by Wetterskip Fryslân, show that the current type of land use at the Frisian peat area should remain functional. While this type of land use is the main cause of the current unsustainable water system where an increased safety risk is present.

In the current Frisian water system, embankments play an important role. They protect Friesland against water from the Waddensea or the Lake IJssel. Next to these large primary embankments, Friesland contains 3200 km of smaller regional embankments of which 1000 km is in the Frisian peat area. These smaller embankments prevent agricultural terrains from flooding, since they separate an interior water storage system from the lower peat areas. Not only the agricultural areas, polders, decrease and experience problems, also the regional embankments are hereby under pressure. Currently huge investments are being made to secure their high level of protection. With the decreasing landscape and higher water levels as a result of more (extreme) precipitation events, it is almost determined that these investments are not disposable. Therefore it is important to think what measures are necessary to let these objects be part of a robust water system in Friesland and if and how these embankments can play a role in solutions for current problems occuring at the Frisian peat area. This thesis tries to give an answer to this question about what role regional embankments play in such a robust water system.

The main point of discussion central in this thesis is about the continuation of the current type of land use or a more adaptive type of land use to the changing climate conditions in relation to the physical landscape. This thesis gives a possible development of a robust water system that incorporates another type of agricultural land use at the Frisian peat area. Different scale levels are analysed to find out the conditions for a development of a robust water system. At the local scale several measures have been established, based on the different analyses, that illustrate a transition to another type of agricultural land use at the Frisian peat area. Paludiculture plays a central role in this. Principles for a safe and functional water system based on analyses have been integrated. Embankments within this robust water system offer possibilities to contribute to an improved water quality, extra safety, recreation and ecological structures.

In short, measures lead to a perspective for the development of a robust water system at the Frisian peat area. They exist of the transition to another type of agricultural land use in which paludiculture plays a central role. As a result not only regional embankments play a key role in this robust water system to maintain the water safety, but the whole area in which the type of agricultural land use has been changed to a form of paludiculture helps to improve the water safety and other problems at the Frisian peat area. Thus a new form of agricultural water management has been developed with changing roles for different stakeholders at the Frisian peat area.

1. INTRODUCTION

1. INTRODUCTION

1.1 OCCASION FOR RESEARCH

I grew up at a farm in the middle of the Frisian peat area. Here my great-grandfather already cultivated grass in order to feed his cows to produce milk for the dairy industry. Back in those days no large tractors tillaged the rural areas and no stables for 120 cows were visible in the landscape. Just 40 cows and a couple of acres was normal then. What has not changed is the aim of this lifestyle; making a living, taking care of the land and the well-being of the animals.

During my internship at Wetterskip Fryslân I learned about the struggles at the Frisian peat area. Especially problems occuring there as a result of the soil subsidence which started long before my grandfathers time. Soil subisidence occurs as a consequence of drainage of the peat which is a condition for the functioning of the agricultural type of land use. Next to this problems like tillage difficulties at such drained peat areas together with the occurence of more intense periods of rain which are likely to occur more often in the future (KNMI 2014). However, Wetterskip Fryslân has the aim to serve this type of agricultural land use at the Frisian peat area which comprises a large part (62%) of the Frisian peat area (85.000 ha) (Provincie Fryslân 2015).

Together these problems lead to an increase of 30% of the costs for the water management at the Frisian peat area compared to 2010 (Hartman et al. 2012). It leads to an increase of circa €150.000 per 1000 ha per year, which means about €1,3 million per year for the whole Frisian peat area! This community money is necessary since regional embankments must be enforced and extra water regulation constructions must be installed (Hartman et al. 2012). Regional embankments separate the Frisian system of reservoirs for superfluous polder-water, an intern water storage system, from the lower (agricultural) peat areas. They protect these areas from flooding and thus they secure the current type of land use at such drained peat areas. Next to this more water level regulating constructions must be installed to secure the water safety and to eliminate redundant water to keep agricultural areas functional.

The CO2 problem is not even mentioned yet. The peat demolition as a result of the agricultural type of land use leads to an estimated CO2 emission of 30 ton CO2 per ha every year (Kwakernaak et al. 2010). At Friesland this level of CO2 emmission is higher than at the western peat area of the Netherlands, where water levels are higher. In total 4.7 million tons greenhouse gases derived from peat areas in the Netherlands are being released into the atmosphere every year (Kwakernaak et al. 2010). This is 2-3% of the total CO2 emission of the Netherlands, coherent to the CO2 emission of 2 million cars per year!

These problems occuring at the Frisian peat area are likely to become more worse in the (near) future. With increasing costs for the water management, tillage problems experienced by farmers and large numbers of CO2 emission every year, the type of agricultural land use is not sustainable. This agricultural type of land use at Frisian peat area leads to problems like decreasing regional embankments and as a consequence such regional embankments must be enforced and water pumping installations must be installed with community money to keep the agricultural type of land use at the Frisian peat area functional. So actually a negative vicious circle is being maintained. Therefore some measures according to the water management must be taken. Measures to develop a robust water system, a sustainable system that does not lead to increased problems.

The aim of this thesis is to find generic guidelines that can be implemented to develop a robust water system. Which means what measures should be taken to start a transition to a sustainable type of agricultural land use. Thus how such a system could lead to a decrease of problems like soil subsidence, a decreased water safety and huge investments to maintain the agricultural type of land use. It is important to find out what measures can be taken to let regional embankments be part of a robust water system, because of their important role related to the water safety. This in order to reduce the costs for enforcing regional embankments.

1.2 KNOWLEDGE GAP

Currently Wetterskip Fryslân and the Province of Friesland are working on measures to deal with problems like the soils subsidence. They developed the ‘Peat area vision’ in which several strategies of how to deal with problems at the Frisian peat area area mentioned. A sustainable type of agricultural land use is mentioned in this document, however, no information exists of how this could be achieved and what the advantages of such a type of land use would be.

Also several studies have been developed about measures to reduce the negative effects of soil subsidence while maintaining the current type of agricultural land use at the peat areas. An example of this study is the study ‘Peat areas and Climate: Possibilities for mitigation and adaptation’ (Kwakernaak et al. 2010). In this study measures like under water drainage and higher water levels are mentioned as contributions to solutions for current problems related to the soil subsidence at peat areas. However, these measures still maintain the current type of agricultural land use which is the main cause of problems related to the water management. Also no information is given about how an area should look if such measures would be incorporated and what the effects would be at the long term.

The study ‘Waarheen met het veen - Kennis over keuzes in het Westelijke veenweidegebied’ (Woestenburg 2009) does highlight several options like nature management at peat areas which have become unusable for agricultural use. Although no sustainable transformations of peat areas are mentioned in this study. However, sometimes paludiculture is mentioned as a sustainable type of land use at agricultural peat areas, like in the Peat Area Vision, or the study 'Natte teelten' (STOWA -). In this last study the (economical) possibilities of paludiculture are explored. However, no information is given about how such a system with paludiculture as the type of land use at peat areas could be realised.

In short: Studies have been developed about the conditions of peat areas; studies have been developed about measures to reduce the effects of soil subsidence while maintaining the current type of agricultural land use at peat areas, studies have been developed about possibitilies to harvest other crops at peat areas that do not need a high drainage level that leads to soil subsidence and no studies have been developed about possibilities of a system in which other, more suitable, crops that do not need a high drainage level, are implemented at the Frisian peat area to contribute to solutions for problems occuring there. Thus a chance would be to find out how such a robust water system coul be developed and what measures must be taken to let regional embankments be part of such a system.

If would be researched on a landscape architectural way how a robust water could be designed at the Frisian peat area, and what the effects would be at the long term, this perhaps could lead to new answers of how to deal with problems at peat areas at Friesland and in general. Therefore a research design is developed.

1.3 RESEARCH DESIGN

1.3.1 PROBLEM DEFINITION

The agricultural type of land use at the Frisian peat area is not sustainable. It leads to problems like soil subsidence, tillage problems and huge investments to secure the water safety and the functioning of the current type of agricultural land use at the Frisian peat area. Regional embankments are important objects that prevent low lying peat area from flooding. As a consequence of the soil subsidence caused by the current type of agricultural land use at the Frisian peat area, the regional embankments must be enforced to secure the functioning of such agricultural areas and to secure the water safety.

1.3.2 PURPOSE STATEMENT

The aim of this thesis is to find generic guidelines that can be implemented to develop a robust water system. Which means what measures should be taken to start a transition to a sustainable type of agricultural land use. Thus how such a system could lead to a decrease of problems like soil subsidence, a decreased water safety and huge investments to maintain the agricultural type of land use. It is important to find out what measures can be taken to let regional embankments be part of a robust water system, because of their important role related to the water safety. This in order to reduce the costs for enforcing regional embankments.

1.3.3 RESEARCH QUESTIONS

After investigating the problem context, the knowledge gap and writing the purpose statement a research and a design question were formulated:

Main research question:
What measures could be taken to let regional embankments be part of a robust water system at the Frisian peat area?

This main research question cannot be answered without formulating search questions.

SQ 1: How did the current problems in the Frisian peat area occur?
By investigating this question it will be possible to find out which elements caused the current problems. Everything is a consequence of a former happening. If it is known which happenings caused the problems it could be easier to find useful solutions to the problems. That can be incorporated in the development of a robust water system.

This search question will take a central place in chapter 2.

SQ2: How does the current water system in Friesland function?
It is important to understand the origin of the Frisian water system and past happenings. This information helps to generate usefull information for the development of measures that result in the development of a robust water system at the Frisian peat area.

This search question wil take a central place in chapter 3

SQ 3: What is already done to tackle current and future problems at the Frisian peat area?
You must understand what measures are already taken to find out new measures which can contribute to the water management and its related problems in the Frisian peat area.

This search question will take a central place in chapter 3

Desgn question: How to design a robust water system?
Designing a robust water system will illustrate how regional embankments can become a part of a robust water system, what measures must be taken for this and what the advantages of this will be.

This search question wil take a central place in chapter 4

1.3.4 RESEARCH AND DESIGN STRATEGY

The aim of this thesis is to design generic guidelines for the Frisian peat area. Guidelines which lead to a robust water system of which regional embankments are part of. Before it can be clear what measures can be taken to let regional embankments be part of a robust water system, the functioning of a robust water system must become clear. Therefore a design process has been established, a design process to design a robust water system for the Frisian peat area. Scheme 1 at page 14 illustrates this design process.

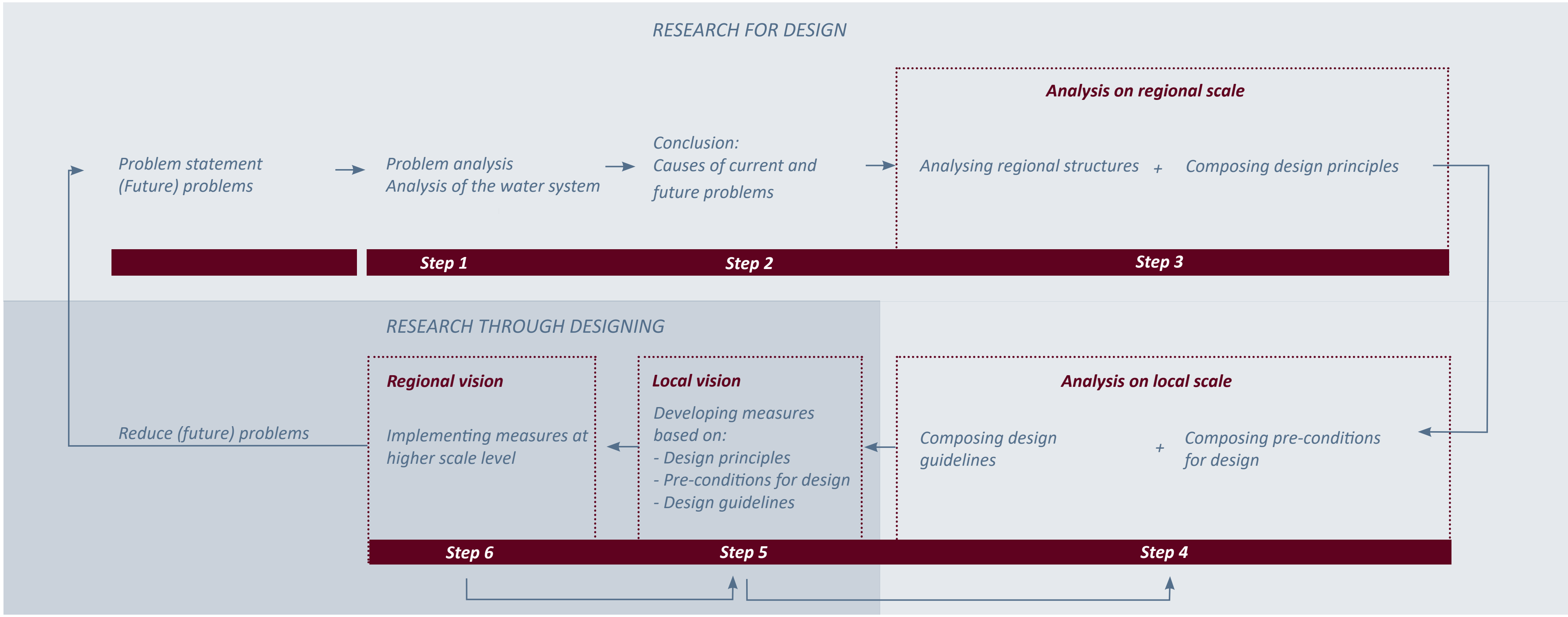
First a wider problem analysis together with an analysis of the current water system will be done to find out what the exact causes of current problems are and how the water system works. These answers to the search questions are the starting point of the design process. The methodological framework at page 15 illustrates what measures must be taken to generate the answers to the search questions.

After this, on different scale levels analysis will be done to compose conditions for the development of a robust water system. At the local scale a case study will be used to investigate local conditions for the functioning of a robust water system. Also design principles and guidelines for this system will be composed based on the problem analysis and the functioning of the current water system. Hereby quantitave data will be gathered by studying computer data of the cases and qualitative data will be gathered by literature review, observation studies and site visits. These steps can be explained as research for design (Lensholzer et al. 2013).

After the research for design, we will continue with research through designing (Lensholzer et al. 2013). This means generating measures based on the analysis on different scale levels and the composed design guidelines and principles. During the local vision it will become clear what measures must be taken to develop a robust water system and thus what measures lead to regional embankments as part of a robust water system. When upscaling these local measures, generic guidelines for a robust water system at the Frisian peat area will become clear. These are actually the main findings and thus the answer to the main research question. While the whole design process of designing a robust water system forms an answer to the design question.

The pragmatic worldview lies on de basis of this thesis. It means that with the collection of diverse types of data there will be a more complete understanding of the research problem (Creswell 2014). It largely follows a design process that solves a problem, but still has to comply with research. This design process is an evidence based design.

DESIGN PROCES



Scheme 1 *Flowchart of the design process to design a robust water system*

METHODOLOGICAL FRAMEWORK

SEARCH QUESTIONS	METHODS AND TECHNIQUES *(Martin and Hannington 2012; Creshwell 2009; Demming and Swaffield 2011; Lenzholzer et al 2013)*	DATA BASE	EXPECTED RESULTS	ASSUMPTIONS
SQ 1: How did the current problems in the Frisian peat area occur?	*Literature review* *Expert interview*	*Scientific articles* *Books* *Governmental documents* *Results interviews*	*Understand the current problems and how they started*	*I assume documents are developed with information about how the problems occured and why*
SQ 2: How does the current water system in Friesland function?	*Literature review* *Expert interview* *Case study*	*Scientific articles* *Results of the interviews* *Observations at the cases*	*The main functioning of the water system in Friesland and especially at the Frisian peat area. What contructions are necessary and and explanation why the water system functions as the way it functions.*	*I assume measures are already taken to tackle the problems of soil subsidence, climate change and KRW implementa-tion at regional embankments* *I assume multifunctional (regional) embankments already exist*
SQ 3: What is already done to tackle current and future problems at the Frisian peat area?	*Literature review* *Conversations*	*Scientific articles* *Books* *Results of conversations*	*Find out which measures are already taken to tackle the current problems and find out if they work(ed).* *An overview of which applications are already present at (regional) embankments.*	*I assume there is a difference between theoratical integration and integration of applications in real situations*

Scheme 2 *Methodological framework with information about how to answer the search questions. Search questions that are important to answer the main research question*

1.4 THE PERSPECTIVE OF THE RESEARCHER

A theoretical lens is the overall orientation of the world which a researcher has (Creswell 2009). This lens becomes an advocacy perspective that shapes the types of questions asked, informs how data is collected and analyzed and provides a call for action or change (Creshwell 2009).

The Frisian water system and especially its fuctioning at the Frisian peat area are studied through the lens of a landscape architect. A landscape architect deals with the 'unique, situational and complex interactions with humans and their environment' (Lenzholzer et al. 2013). It is a multidisciplinary discipline which takes many aspects of the landscape into account when designing or doing research. I can totaly find myself in the words of Bruce Ferguson in the article 'Innovative stormwater design: the role of a landscape architect'. Here he sees landscape architecture as 'integration, bringing different elements together' (Ferguson 1991) Especially for this study it is a good explanation of the role of the landscape architect. Much information is there about technical interventions, embankment systems and technical water aspects; the engeneering part. Next to this information can be gathered about for example the relation of the phenomenon with its environment, understanding human needs and functions and desired functions gathered by interviews or questionnaires. The landscape architect is the one who brings these data together. This can be shown in designs.

Also the description of a landscape architect stated by the ASLA (American Society of Landscape Architects) fits good to how I see landscape architecture; ''landscape architects use a comprehensive working knowledge of architecture, civil engineering, and urban planning to "design aesthetic and practical relationships with the land." (Tunney 2001). Especially the term 'practical' is important. If a design is not practical, the feasibility declines. As a landscape architect I have the function to integrate the technical, social, envrionmental and aesthetic aspects with each other. I see the functioning of nature as the basis of this.

1.4.1 THE FUNCTIONING OF NATURE AS THE BASIS FOR DESIGN

Ian Mcharg was one of the first people who explicitly wrote about ecological processes which form the basis for design. In 1969 he published the book: Design with nature. This book lead to fundamental changes in landscape architecture teaching and practicing. 'McHarg advocated the suystematic application of a set of 'rules' derived from ecological science and demonstrated the value of his approach in professional projects' (Johnson & Hill, 2001). He defines the study of ecology 'as the study of physical and biological processes, as dynamic and interacting, responsive to laws, having limiting factors and exhibiting certain opportunities and constraints, employed in planning and design for human use' (McHarg 1967). He sees ecology not only 'as an explanation, but also as a command' (McHarg 1997)

Mcharg states that a place can only be understood by knowing its historical geology. 'The place, any place, can only be understood through its physical evolution' (McHarg 1969) Mcharg explaines, that if you know the historical geology, the climate and the physiography, than you will also understand the water regiment, its patterns, its flooding areas and their physical properties. The next phase is to understand plant communities. 'As plants are highly selective to environmental factors, by identifying physiographic, climatic zones and soils we can perceive order and predictability in the distribution of constituent plant communities' (Mcharg 1969). Animals are related to the plant communitites, so as a result of earlier analyses, it is possible to identify the types of animals occurring in a specific type of landscape. The data acquired is an ecological inventory which contains all the information needed for further research. Now it is important how this data is interpreted to analyse the current and future land use management.

This information can reveal the suitability of sites for any kind of land use activity, like recreation, urbanization, industry etc. However it is important to describe 'all coexistent, compatible uses which may occupy each area' (Mcharg 1969). In the end a matrix with all possible land use activities possible on each area where the activities are examined on compatibility or incompatibility against each other is the result. This method forms the basis for design and planning in specific areas as McHarg states. This method allows people to understand places. 'It permits us to interpret natural processes as resources, to prescribe and even to predict for prospective land uses, not singly, but in compatible communities' (Mcharg 1969). We manage to form a plan bases upon natural process.

As a continuation on what McHarg started in 1969, Marsh introduced the system approach (Marsh 2010). This approach is not meant as a methodology, but more to provide a concept, a way of thinking. This approach has many similarities to McHargs method of using ecology as the starting point for design. It is about using the system to understand as a starting point for landscape planning or designing. Again this approach starts with defining the system, its physiographic character and understanding its functioning. Thereafter it is important to understand where you are in the system. Marsh states that 'all landscape systems function as open systems, meaning they receive inputs of matter and/or energy and release outputs of matter and/or energy. Within the system, work may be performed, and energy and matter may be stored' (Marsh 2010). Marsh describes this on the basis of a watershed. He mentions that there is 'a) a zone that gives up (or contributes) water and sediment, (b) a zone that collects water and sediment and/or conveys it downslope or stores it, and (c) a zone that releases water and sediment at the output end of the system' (Marsh 2010) 'To maintain the system's long-term performance, that is, to achieve sustainability in the watershed system, a land use plan should be designed to mimic the natural performance of the site' (Marsh 2010) Understanding the broader system can also help to make decisions in an early stage about landscape planning and design.

Those approaches above more or less cover the same message. In this thesis the main goal will be the development of a robust water system at the Frisian peat area. I try to find out how such a system can be sustainable by using natural processes. And thus to find out what type of land use will be suitable for the site.

1.5 RELEVANCE

Friesland contains 85.000 ha of peat. However, not only Friesland contains peat. Within the Netherlands and beyond large areas exist of peat where the same or matching problems occur like in Friesland. Here soil subsidence leads to problems with infrastructure, water management decreasing houses and CO2 emission. This gives extreme high expenses for municipalities, provinces and water management organisations. In the Netherlands it is calculated that the soil subsidence costs €250 per inhabitant per year! (Deltares 2015).

However, it seems that the larger public, including people living and working at the Frisian peat area, does not notice the problem, since the speed of the soil subsidence and thus the increase of problems is slow. In combination with the changing climate, it is important to see how big the problems already are. Not only in Friesland but beyond Friesland too (figure 1).

Especially now a lot of changes are present when it comes to dairy farming. Changes at the phosphate regulation and the allowed amount of cows. These measures are likely to impede farmers when it comes to the financial management of their company. Together with the problems like soil subsidence and more intense periods of rain, it could be that farmers consider maintaining another type of land use, more suitable for the Frisian peat area. This to generate more income from their land. It is thus usefull to think about other possibilities for the Frisian peat area that generate income and reduce the problems which lead to huge investments.

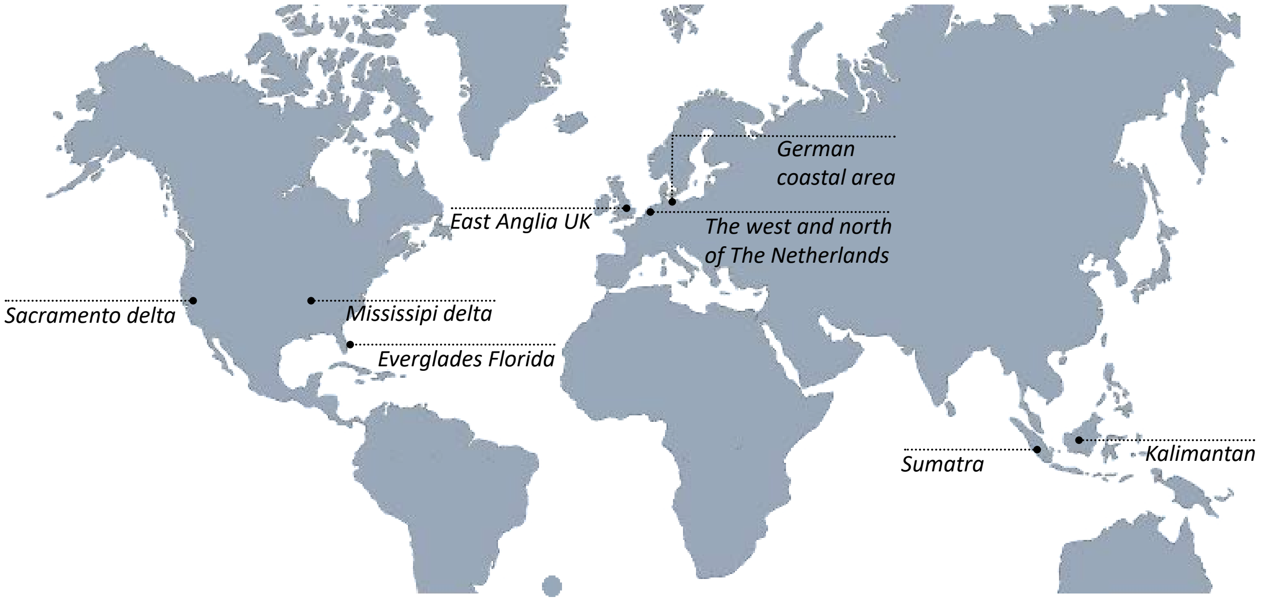


Figure 1 *Areas where soil subsidence in peat areas occurs (Deltares 2015)*

1.6 STUDY AREA

1.6.1 LOCATION

The main research area of this thesis is the Frisian peat area (figure 3). This area has a long history of farming and peat removal. The Frisian peat area has been characterized by the many lakes and waterways, but especially by the open views. The area forms the transition from the clay soils in the western part of Friesland to the sand soils in the eastern parts of Friesland as can be seen in figure 2.

***Figure 2** The location of peat in Friesland*

1.6.2 TYPE OF LAND USE AT THE FRISIAN PEAT AREA

HISTORIC LAND USE

The Frisian peat area has a long history when it comes to farming. For hundreds of years farmers are using the peat area to grow crops as food for their cows. Originally the peat area was a wet terrain. The water system was not yet controlled as much as it is today. Since the peat area was the lowest part of the province, water collected there. No large water pumping stations like the Woudagemaal at Stavoren were installed to eliminate redundant water of the province. At those times large parts of the agricultural areas in the peat area flooded every now and then during winter time. However, the floods were not only negative, they brought a fertile sediment layer on top of the fields. The grass of those wet areas could only be harvested during summertime and the hay comming of those areas was a fertile product as a result of the sediment deposition during winter time. In figure 4 the amounts of hay lands of 1832 is visible at the peat area.

CURRENT LAND USE

These hay lands included a high amount of plant species, since they were not used as intensive as today. So actually

***Figure 3** The Frisian peat area*

farmers were maintaining a form of nature management. Many animal species relied on this.

A dairy farmer owns or rents land to graze his cows and to obtain food for his cows. So the amount of land is very important. In the last decades much changed in the dairy sector in the Netherlands. Machines were introduced for milking and tillage, milk quota caused a regulation of the dairy sector and since january the 1th of 2016 a new measure set by the Dutch government was introduced: a AMvB: A general measure from the government. It means that farmers which have a phosphate surplus need a specific amount of land if they want to expand. In this way they can deposit the extra phosphate at their own land. Else farmers must take of their fertilizer at high costs.

At 1 January 2017 this AMvB will be translated in a new system of phosphate rights. A farmer then has based on his amount of cows at the 2nd of july in 2015 a certain number of phosphate rights. If he wants to expand his company he needs to buy phosphate rights from another farmer which for example sells his cows. In this way the Dutch goverment tries to stay under the phosphate limit of 84,9 millions of kg phosphate for the agricultural sector in the Netherlands (Wageningen University 2016). So the amount of land becomes very important to a farmer.

If we compare the type of land use of 1832 with the current type of land use at the Frisian peat area differents become visible. The water system in Friesland has developed to a strickt system. Former hay fields have almost all been transformed to permanent drained areas. Currently the peat area is 85.000 ha big, it exists of 62% from agricultural areas, 17% of nature, 17% of water and 4% of buildings and infrastructure. (Veenweidevisie 2015). Thus 52.700 ha of the Frisian peat area exists from agricultural terrains where mainly dairy farming takes place. The total numer of hectares of agricultural areas in Friesland is 234.151 ha (Elferink et al. 2009). Thus more than one fifth of the total of agricultural areas in Friesland is located at the Frisian peat area. Now we can not talk about farming as a way of nature management anymore compared with 1832. The peat area has become a production area in which grass production is the main type of land use.

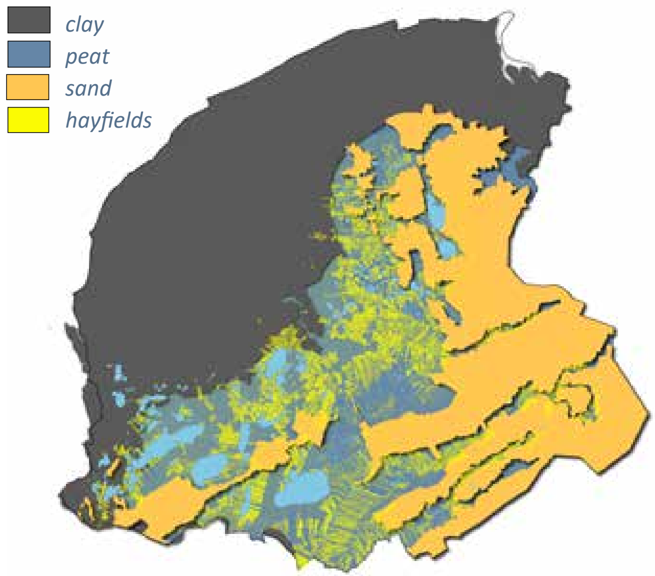


Figure 4 *Type of land use in Friesland in 1832*

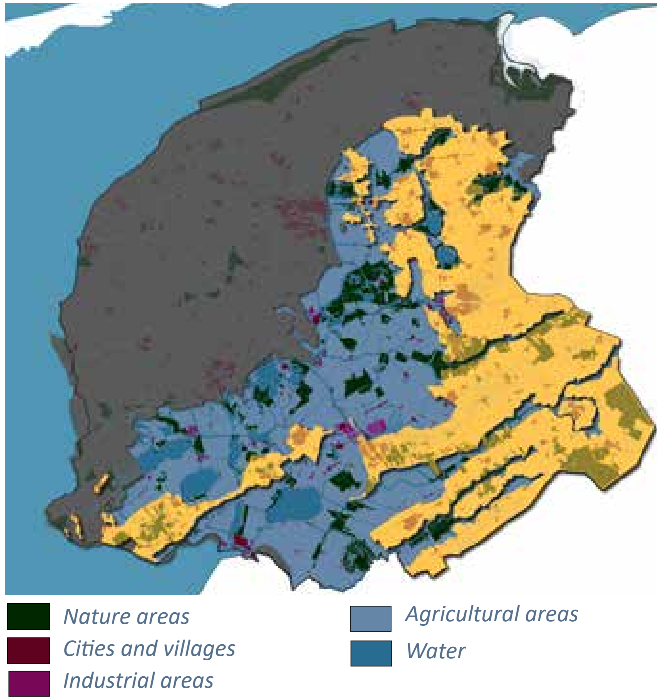


Figure 5 *Type of land use in Friesland in 2016*

1.6.3 SOIL TYPE AT THE FRISIAN PEAT AREA

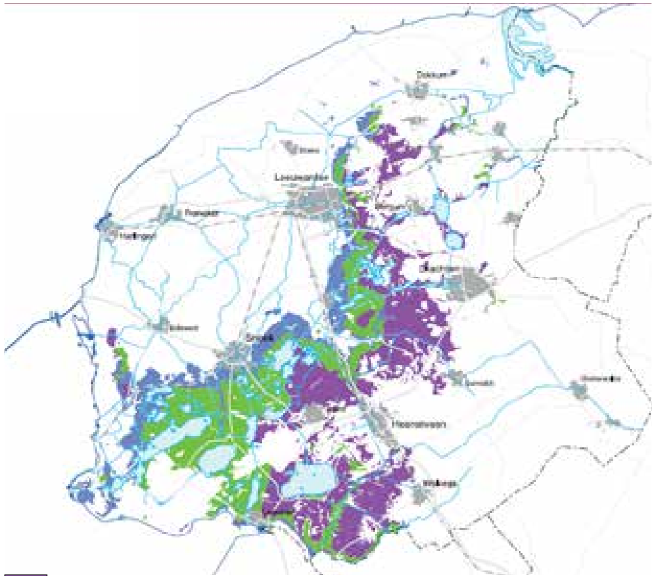
The current peat area exists of different types of peat soils. These soil types are related to the height of the area and thus they have effect on the water system. The province of Friesland and Wetterskip Fryslân define the peat area on the basis of the amount of peat in the soil:

‘The edges of the peat area are determined by the amount of peat in the soil. Peat soils exist of at least 40 cm of peat in the toplayer. The peat soils where clay has been deposited on the peat do also belong to the peat area’, (Provincie Fryslân 2015).

In figure 6 can be seen how Provincie Fryslân and Wetterskip Fryslân define the peat area in Friesland. The Frisian peat area is connected with peat areas in other provinces of the Netherlands (figure 8).

If you compare the height map in figure 7 with the peat area, the peat area and the different types of peat are related with the height. The lowest areas are areas where no clay as a top layer occurs. Those soils are situated at the western part of the peat area. However, also here the peat decreases up to 1 cm per year (Provincie Fryslân 2015). Those areas demolished and still demolish faster than areas with a clay deck or a clay top layer.

The demolishing of the peat is not the only cause of the current and predicted future problems at the Frisian peat area. Other problems and their causes will be analysed now.



Peat (without a layer of clay)
Peat with a top layer of clay
Clay with a peat layer in the underground

Figure 6 *Soil map of the Frisian peat area with three different types of soil (Peat area vision 2015).*

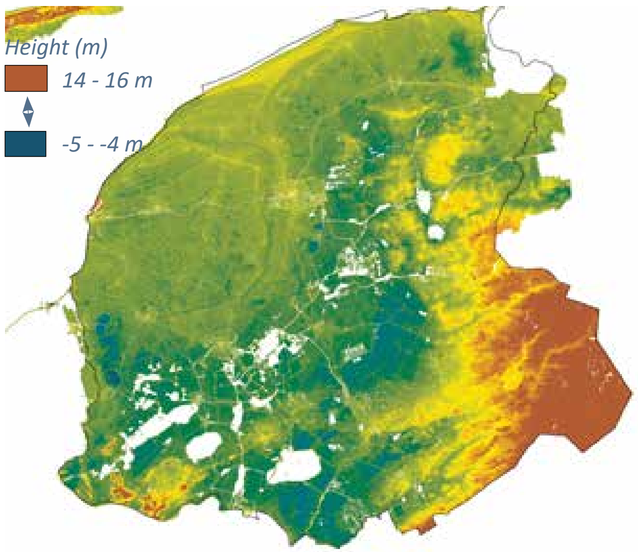


Figure 7 *Height map of Friesland with the lowest parts of Friesland at the eastern part of the Frisian peat area*

Peat area in the northern part of The Netherlands

Figure 8 *The Frisian peat area is connected with other peat areas at the Northern part of the Netherlands*

2. PROBLEM ANALYSIS

2.PROBLEM ANALYSIS

Some important problems at the Frisian peat area were introduced. Those problems are likely to continue and become more worse in the future. To find out how a robust water system can facilitate functions which do not enforce current problems, it is important to understand the causes of the current and predicted future problems. Therefore the problems will be illustrated by explaining its causes and effects.

2.1 INTENSIFICATION OF AGRICULTURE

During the 19th and 20th century the agriculture in Friesland and in the Netherlands in general changed. The Frisian peat area started to being used more intensive. This meant that former unused land was started to be used for agricultural purposes. It meant that large amounts of land at the Frisian peat area was impolderd during the 19th and 20th century.

One of the most important consequences of the impoldering of those former unprotected lands was the soil subsidence. Pursuing a fixed water level within the new developed polders lead to lower water levels within the polders. Together with the current system of manure, the natural sediment layer which was deposited during floodings was no longer needed to fertilize the land.

As a result of these lower water levels within the polders one of the biggest problems in the Frisian peat area became the subsidence of the soil. This process has started long ago by reducing the water level. Therefore the process and its effects is explained:

Soil subsidence occurs as a result of dehydration of the peat soil. The lower middle, as the Frisian peat areas is called as well, has a thick layer of peat (1 to 2,60 m). The current thickness of the peat is highlited in figure 9. When the water level in peat areas is being decreased, oxygen comes into contact with the peat. As a result the peat oxidases and the soil decreases. Agriculture is one of the most important functions of the peat area of Friesland. Therefore fertile land where machines are able to cultivate the land is important. This is why the ground water level in such areas is low, however in this way oxygen can easily access the peat.

- Demolition of the peat results in soil subsidence, an increase of greenhouse gasses and a decrease of the water quality (Davidson and Janssens 2006). Annually 30 tons of CO_2 per acre is being released into the atmosphere (Kwakernaak et al. 2010). This means around 255.000 million tons of CO_2 for the whole peat area per year!
- Climate change will lead to a fastening of the soil subsidence as a result of higher temperatures and lower water levels during summer time (Schothorst 1977; Davidson and Janssens 2006).
- Next to this there are indications that the inlet of water with a bad quality (silt, nutrients) could fasten the process of soil subsidence (Dettling et al. 2006).

Before the causes and effects of peat oxidation will be discussed, first it will be highlited how peat is composed. This gives a lot information about the speed of demolition and thus the soil subsidence. Peat exists of dead organic material from plants like sphagnum, Puntmos, Haarmos, sedge and Wollegras. A factor which slowly causes the demolition of the peat is the presence of oxygen. However, the absence of oxygen is not the only solution for the retardation of the peat, since there are other micro-systems which can force the process of peat demolition. Micro-organisms for example are able to use other electron acceptors like nitrate, iron en sulphate (Brouns and Verhoeven 2013)

Also the presence of phenol connections in the dead plant material of the peat causes a deceleration of the peat demolition. Phenols themselves hardly break of and they ensure that cell material of plants hardly demolishes since

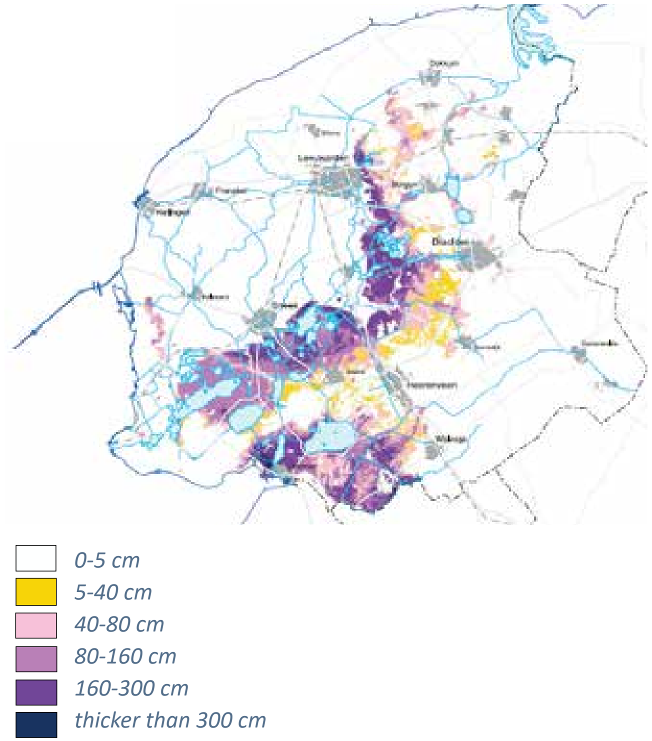


Figure 9 *Current thickness of peat in the Frisian peat area (Provincie Fryslân 2015).*

the phenols kind of encolse these. From an investigation of Freeman et al. appears that by adding oxygen to these phenol compounds the demolition is being accelerated. The enzyme phenoloxidase is being activated. So since oxygen can enter the peat, a process under aerobic conditions causes phenols in the peat and thus the phenol compounds and the enclosed cell materials of plants being demolished. As a result of this the whole peat area slowly demolishes and so the soil decreases. When the soil posesses a low acidity (pH) the enzym phenoloxydase is being inhibited. From a research (Brouns and Verhoeven 2013) appears that the concentration of phenols in drained peat areas is lower than in un-drained peat areas. This resembles the soil subsidence which occurs at the drained peat areas.

In the last 50 year the water level in ditches in the peat areas of Friesland have been lowered. This resulted in lower ground water levels in the Frisian peat area. The peat areas oxidezed faster, since oxygen got the chance to enter the peat as a result of the low ground water levels. If oxygen comes into contact with peat layers which managed to survive in a anaerobic climate the oxidation process starts after one till several weeks. If this peat layer is being rewet, the oxidation process will not stop, since the anaerobic climate has being disturbed.

This probably has to do with the cell material of the plant remains which has been released since surrounded phenols have been demolished. From the research of Brouns and Verhoeven (2013), it turns out that types of peat differ in vulnerability for phenoloxidase. Especially eutrophic reed and forest peat are vulnerable for exposure to oxygen.

The soil subsidence in peat areas is thus a consequence of the oxidase of the peat. However, as a result of the low water levels, there is another process which causes soil subsidence of the peat; klink. Klink occurs when the depth of dewatering is being increased. A thicker peat layer is then being dewatered and the floating capacity decreases. By the weight of the peat layer, the underlying layers are pushed together. (Schothorst 1977). Next to this aslo drought has influence on soil subsidence. As a result of drought water is being removed out of the peat and this is why the peat shrinks. Peat approximately exitsts for 90% out of water (Brouns and Verhoeven 2013).

Earlier it was mentioned that Sulfate can function as an electron acceptor too. In this way oxidation of the peat can occur. In natural conditions Piryte (FeS2) occurs in peat. As a result of Piryte oxidation Sulphate is being released. This elutes to the surface water. In anaerobic conditions of the surface water, Sulphate is being converted into Sulphide. This Sulphide attaches itself to Iron. This is how Ironsulphide arises. During this process Phosphate is being released. When there is much Ironsulphide in the water there is chance at Sulphide and Ammonia poisoning. This process in which nutrients like phosphate are being released as a result of peat demolition is also called intern eutrophication, since the Sulfate is being released by the soil and for a smaller part transmitted by the water (Hendriks et al. 2013).

An increase of nutrients like Phosphate in the water leads to a poor water quality. ‘Enrichment of water with mineral nutrients, such as nitrogen (N) and phosphorus (P) causes transformation of water bodies from oligotrophic to mesotrophic, eutrophic, and finally hypertrophic stage’ (Ansari and Gill 2014) As a result of this enrichment, water bodies are followed by an uncontrolled growth of primary producers (algae) and oxygen depletion caused by the decomposition of algae organic matter.

2.1.1 GREENHOUSE GASS EMISSION

Carbon and Methane are greenhouse gases which are being released and formed during the peat oxidation proces. Methane is being produced under anaerobic conditions. Peatlands are formed by the materials of dead plants and therefore they stortage a large amount of carbon.

'Approximately 400 to 500 million ha (about 3% of the land area of the world) is peatland. About 480 to 600 Gt of terrestrial carbon is locked in peatland, or twice the amount of carbon stored in the world's forests'(Bos et al. 2011).

So draining the peatlands has and will have a negative inpact on the carbon stock. It is possible to stop soil subsidence of the peatlands by rewetting them, although in Friesland this will be hard, since the peatlands are important for agriculture. Therefore a large amount of Carbon, Methane and other elements will be released in the future which will stimulate the climate change on a negative way.

As a result of the dehydration of the peat lands, also water has been extracted from the residual unprotected lands which lie along lakes and waterways outside of the polders within the peat area. That is why such lands became skewed. This process is explained in figure 10. This meant that those types of land became wetter and wetter and even here specific and valuable types of vegetation dissapeared. And thereby huge amounts of valuable ecology like Blue grass lands and Water lilly dissapeared.

However, larger nature areas have higher ground water levels and that is the reason why these type of areas lay higher than the agricultural terrains. The result is that the nature areas become high islands surrounded by low agricultural areas. Since they are hydrological connected, the effect is that the nature areas become dryer and dryer. And this has negative effect on the species living at the nature areas (Brouns and Verhoeven 2013). The same principle happens with houses. Many houses in the Frisian peat area are built on wooden poles. As a result of drainage at agricultural lands, the ground water level at near houses also declines. This leads to oxygen entering the area where the poles are situated. And this leads to rotten poles which can make the foundation of the houses unstable. Not only houses and nature areas sense the negative effect of the drainage of in particular agricultural areas, also infrastructure prolapses at certain places. This leads to higher costs for the Province and municipalities (Provincie Fryslân 2015).

2.1.2 COSTS OF THE WATER MANAGEMENT

The soil subsidence of the peat in general leads to higher costs for water boards to manage the water system (Brouns and Verhoeven 2013; Hartman et al. 2012). Wetterskip Fryslân inventorised how the water management changed in the Frisian peat area in the period of 1875 to 2010. The organisation used this information to predict the development of the water managment for the comming 40 years. The main expenses in the peat area are the enforcement of regional embankments and the development of pumping stations and sluices. Also the energy costs of the energy used by pumping stations is high. The costs for the water management in the Frisian peat area are compared to the costs for water management in the sand and clay areas. A couple sub-areas are researched and in figure 11 it becomes visible that the water management in the clay areas which are used for dairy farming is currently the most expensive, however, these are just the costs of the maintenance of constructions (pumping stations, damming constructions and sluices) and the maintenance of waterways (Hartman et al. 2012).

However as a result of soil subsidence, Wetterskip Fryslân assumes that more pumping stations and other damming constructions are needed to keep functions like agriculture possible in the Frisian peat area. More pumping stations, damming constructions means higher energy costs, higher maintenance costs and in general higher water management costs in the Frisian peat area.

Also the costs for the enforcement of regional embankments is likely to be much higher. Regional embankments along waterways and lakes also decrease, since they contain a layer of peat as well. Although they do not decrease as fast as the soil behind the embankments where agricultural

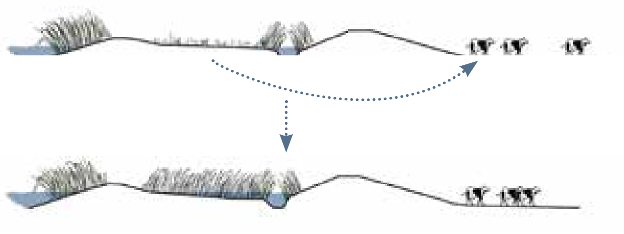
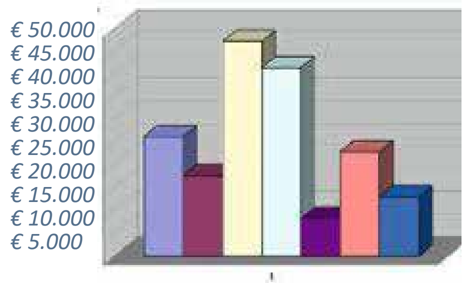


Figure 10 *Crooked boezemlands as a result of a high drainage at peat areas*

€ per 1000 ha



Peatpolders , peat 40 - 220 cm
Oldelamer, deep peat >120 cm
Hommerts 40 cm clay on peat
Koudum, 40-80 cm clay on peat
Northern - east of Friesland, clay, arable farming
Western part of Friesland, clay, agriculture
Southern - east of Friesland, sand

Figure 11 *The costs for the study areas in the peat, clay and sand terrains for the maintenance of constructions and waterways (Hartman et al. 2012)* activities take place. However when the soil behind the regional embankments decreases the embankment loses stability. To compensate this loss of stability, every 30 years the regional embankments must be enforced. However in reality this reinforcement takes place every 10-15 years. In scheme 3 the extra costs for the water management for the Frisian peat area in 2050 are visible compared to 2010. So all these extra measures means that there is an increased flood risk if no measures are taken to improve the regional embankments.

In the discussion of the article Wetterskip Fryslân mentions that they examined which developments according to the water management in the Frisian peat area were likely to happen if the policy of Wetterskip Fryslân would not change. This means that they assumed that they still maintain an optimal water management to make functions like dairy farming possible. Wetterskip Fryslân mentioned in this discussion as well that to reduce the costs of the water management, a decline of the load of kilometres of regional embankments or a reduction of the height of regional embankments would be the most efficient option.

With the continuation of the soil subsidence it will be harder to secure a good functioning of the agriculture in relation to the water management. This will probably lead to further problems in the near future, since the soil is still decreasing in the peat area. Together with a changing climate Wetterskip Fryslân must take important decisions about how to deal with the water management in Friesland. In paragraph 2.2.2 the effects of climate change in relation with soil subsidence will be highlighted.

2.1.3 NUTRIENT RUNOFF

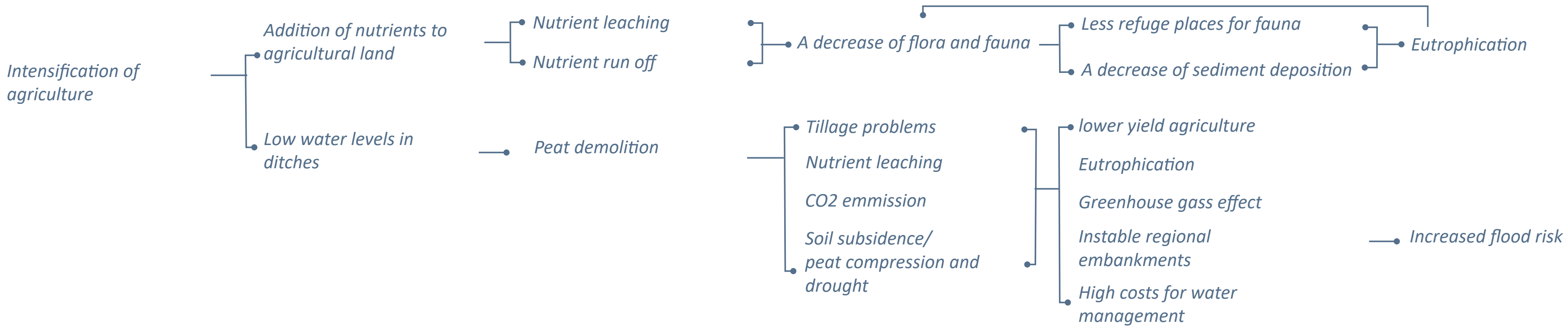
As a result of intensive agriculture, farmers in the Frisian peat area fertilize their land by using manure from the cows and fertilizer. A small part of these nutrients enter the water system as a result of nutrient runoff (Boekel et al. 2008). The most important sources which cause an increase of nutrients in the water system are nutrient runoff of the rural areas and the release of nutrients out of sewage treatment installations (Boekel et al. 2008). An increase of nutrients like Phosphate in the water leads to a poor water quality. 'Enrichment of water with mineral nutrients, such as nitrogen (N) and phosphorus (P) causes transformation of water bodies from oligotrophic to mesotrophic, eutrophic, and finally hypertrophic stage' (Ansari and Gill 2014).

So those two main processes: the dewatering of the peat area and the addition of nutrients leads to several problems. In the problem diagram at the next page the cause and effects are visible.

onderdeel	*toename van de jaarlijkse kosten in 2050 per 1000 ha*	*toename in % van de kostenpost t.o.v. 2010*	*toename in % van de kosten voor het waterbeheer t.o.v. 2010*
1. peilregulerende kunstwerken en jaarlijks onderhoud	*- € 2000 tot € 6000*	*- 8% tot + 33%*	*- 1,5% tot + 3%*
2. lokale keringen langs hoogwatervoorzieningen	*€ 23.000 tot € 57.000*	*nieuw*	*18%*
3. grotere afmetingen boezemwaterkeringen	*€ 18.400*	*15%*	*8%*
4. extra energiekosten bemaling	*€ 1250*	*20%*	*0,6%*
Totaal (gemiddelde schatting)	*€ 65.000*		*ca. 30%*

Scheme 3 *The development of the costs for the water managment at the Frisian peat area untill 2050 (Hartman et al. 2012)*

2.1.4 PROBLEM DIAGRAM INTENSIFICATION OF AGRICULTURE



Scheme 4 *Problem diagram with the effects of intensive agriculture at the Frisian peat area. The agricultural type of land use leads to problems related to the water management*

2.2 CLIMATE CHANGE

Next to the effects of intensive agriculture also the effects of climate change are taken into consideration. Climate change is going on and scientific research shows that its effects will have negative consequences on the Frisian water system. Therefore measures must be taken. However, first the effects must be clear.

2.2.1 THE ORIGIN OF CLIMATE CHANGE

The climate is important for humans, for their needs and for their wellbeing. 'Climate is the average state of the atmosphere and the underlying land or water, on time scales of seasons and longer' (National Research Council 2001). Humans influence the climate system. 'It has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (SPM)' (IPCC 2014). The human activities are one of the most important causes of the increase of greenhouse gases and therefore of the climate forcing (IPCC 2014). A climate forcing can be defined as an imposed perturbation of Earth's energy balance (National Research Council, 2001). A climate is sensible to such climate forcings. 'The sensitivity of the climate system to a forcing is commonly expressed in terms of the global mean temperature change that would be expected after a time sufficiently long for both the atmosphere and ocean to come to equilibrium with the change in climate forcing', (National Research Council, 2001).

Nowadays the quantities Carbon Dioxide (CO_2), Methane (CH_4) and Nitrogen (N_20) in the atmosphere are very high as a result of fossil fuel use and use of those gases in daily life. The particles of the gases absorb the infrared radiation from the sun. As a result of this, the heat stays in the athmosphere and causes a warming of the earth's surface. This direct climate forcing causes climate change. However, the climate changes also by indirect climate feedbacks. This means for example that the direct climate forcing, the increase of greenhouse gases causes the melting of the polar ice which causes an increase in greenhouse gases. In the polar ices a large amount of carbon dioxide and methane is depoted. These feedbacks also cause a growth of the mean temperature and the feedback loops will continue. There are much more human activities which cause climate change and nowadays the effects of these human activities together with the natural activities are getting noticeable in our daily life on negative ways. That is why governmental programmes are developed to stop the emission of greenhouse gases.

Global warming is the most familiar effect of climate change. The global warming results in an increase of extreme precipitation events (IPCC 2014). This trend is already going on as research bij the IPCC showed in its fifth assessment of the International Pannel of Climate Change (IPCC 2014) showed. It was already mentioned that the sea level will rise too as a result of global warming. However, this sea level rise will sometimes occur faster at certain places. (IPCC 2013). Relevant for this thesis is to understand what the concequences of global warming and climate change in general will be on the Netherlands and specificly on the Frisian peat area. This in order to develop a robust water system that deals with the effects of climate change.

2.2.2 EFFECTS OF CLIMATE CHANGE ON THE NETHERLANDS AND THE FRISIAN PEAT AREA

The KNMI institute developed for the Netherlands four climate scenarios on the basis of the IPCC data (figure 12). 'Every scenario gives a coherent picture of changes in twelve climate variables, like temperature, precipitation, sea level and wind' (KNMI 2014). By these climate scenarios the KNMI offers a guide to calculate the effects of climate change to choose the right strategies. The KNMI developed in 2006 already climate scenarios which at that time were included in the National Water plan. However as a result of new questions about the current climate and changes in this

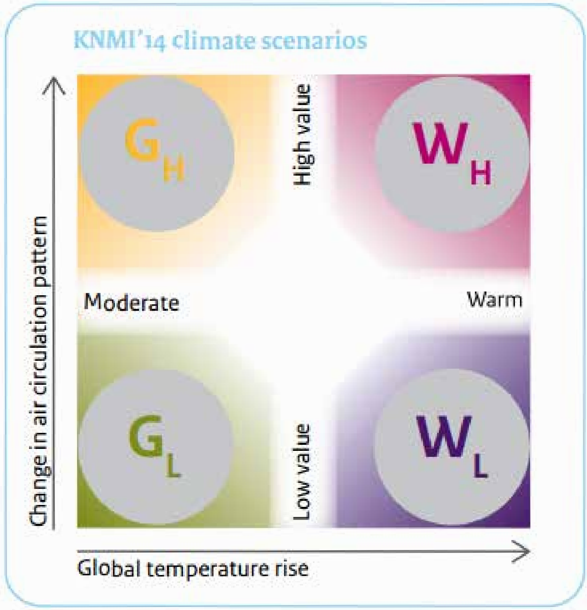


Figure 12 KNMI'14 climate scenarios, (KNMI 2014).

climate system and as a result of the fifth IPCC assesment, the KNMI developed new climate scenarios for the Netherlands. These scenarios are valid for 2050 and 2085 relative to the reference period of 1981-2010.

Overall the scenarios illustrate that the temperature will rise in the future and warmer summers and less cold winters will occur more often. There will be more precipitation events and more extreme precipitation events during winter and the intesity of precipitation events during summer will increase, however the scenarios show that within those general predictions, changes are possible. For example there are differences about how much the temperature is going to rise in the next decades. Therefore the scenarios give more detailed information.

The climate scenarios composed by the KNMI are being distinguished by global temperature rise and in air circulation pattern. Within the global temperature rise a distinction is made between G (medium) en W (warm). 'In the G-scenarios, the global temperature rise is 1 °C in 2050 and 1,5 °C in 2085 in relation to 1981-2010; In the W-scenario the global temperature rise is 2 °C and 3,5 in 2085 in relation to the period 1981-2010 (KNMI, 2014). Within the air circulation pattern a distinction is made between L (low) en H (high). 'In the low or L-scenarios (GL and WL) the influence of the changes is small, in the high or H-scenarios (GH and WH) the influence is large' (KNMI 2014). Next to this the KNMI has calculated 22 variables which are important for organizations like Wetterskip Fryslân. Such variables are the maximum precipitation per hour etc. The most important factor for this thesis next to temperature rise is the changes in the amount of precipitation.

PRECIPITATION

'In all scenarios, precipitation extremes increase throughout the year, even in the GH and WH scenarios with an overall drying in summer' (KNMI 2014). This is the consequence of a warming of the climate with more water vapour in the air. However it is likely that there will be differences between precipitation events during winter time and summer time. In figure 13 the precipitation scenarios are given for these two periods for 2050 and 2085.

SEA LEVEL RISE

The changes in sea level diverge between the different scenarios. Observations have shown that the world mean sea level rised with about 19 cm between 1901 and 2010. The average rise per year was about 1,7 cm a year. However this average rise between 1993 and 2010 was 3,2 cm a year. The sea level will rise in the future as well, only the tempo of this rise is dependent on several uncertain factors. According to the KNMI the speed of sea level rise will be higher than past decades. In figure 14 the predicted sea level rise per scenario is illustrated.

EFFECTS OF CLIMATE CHANGE ON REGIONAL EMBANKMENTS

So these changes show that Wetterskip Fryslân and The Dutch government in general must continue with taking decisions about how to deal with the water management, since these scenarios directly influence the water system. An important aspect of this is safety. If we look back to the subject of this thesis: regional embankments, these embankments shall play a huge role in the futural water managment. The question is how to deal with these. Next to the fact that as a result of climate change, there can be higher water levels during winter time in Frisian water system, climate change also accelerates soil subsidence in the Frisian peat area.

As mentioned before: Climate change will lead to a fastening of the soil subsidence as a result of higher temperatures and lower water levels during summer time (Schothorst 1977; Davidson and Janssens 2006). In figure 15 the speed of the soil subsidence in the Frisian peat area is visible. The

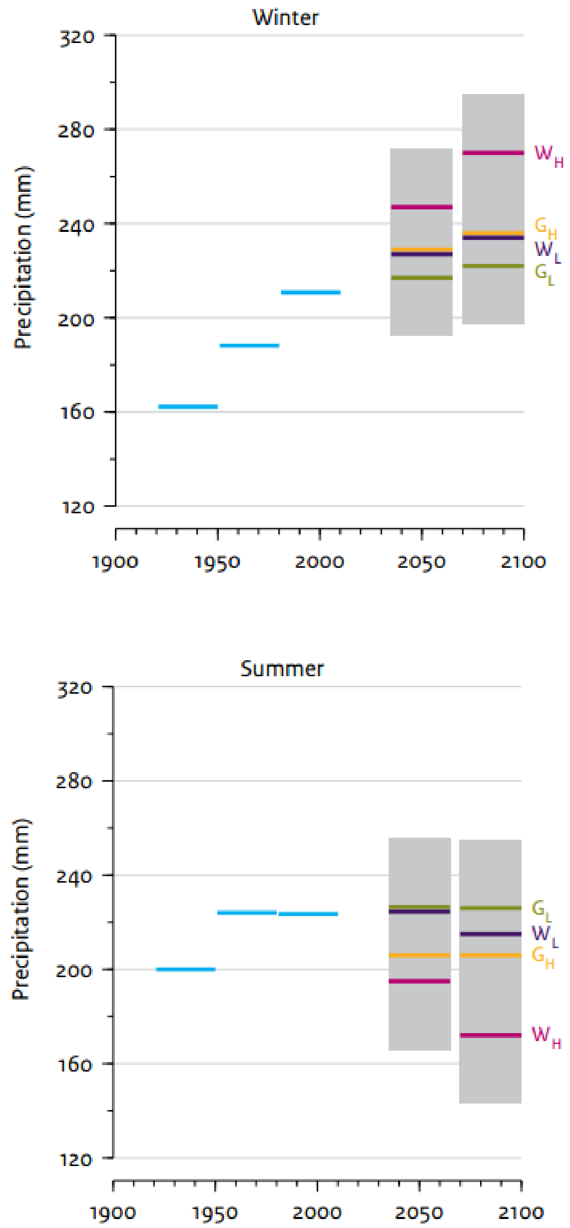


Figure 13 *Precipitation climate in the Netherlands: observations and KNMI'14 scenarios for 2050 and 2085 (KNMI 2014)*

decline is dependent on the type of peat. In general the subsidence means that the embankments get more instable every year. The inner side of the embankments gets more instable as a result of the decreasement of the agricultural land next to it. So what we see here is that together with the drainage of agricultural land, climate change is the cause of soil subsidence and thereby the cause of more instable embankments.

With the occurance of more precipitation events and more extreme precipitation events the Frisian water system has to deal with higher water levels during such events and afterwards. Higher water levels put more pressure on the regional embankments and therefore they get more instable. Next to this embankments must be high enough to prevent hinterlands from flooding.

Dryer periods during summer are able to cause a shortage of water. Since the main function of the Frisian peat area is agriculture, it is important that there is enough water to keep the grass growing and the keep the cows drinking. Therefore it is important that water can be retained in the Frisian water system during such warmer periods.

EFFECTS OF CLIMATE CHANGE ON AGRICULTURE

The most peatlands in Friesland are used for grass production for dairy companies. According to Rötter and Van de Geijn the dairy sector is being influenced by climate change on four different ways: 1: production of grass and silage, 2: prices of silage, 3: animal health, growth and reproduction and 4: diseases (Rötter and Geijn, van de 1999).

For the dairy sector it is important to obtain as much as possible milk from the cows. In the Frisian peat area, grass is the most important crop to reach this goal. However, global warming causes effects which can reduce the amount of grass cultivated in the peat area which also influences the profit of dairy companies. With the increase of more intensive precipitation events, floodings can cause troubles in the rural areas of the Frisian peat area. It could cause a farmer to mow more often when the land is wet. This can lead to tracks and as a result the grass field could deteriorated which leads to lower profits. Next to this, cows can easily worsen the grass quality by trampling it. When as a result of weather conditions the profit of grass decreases, there is always an option for farmers to buy food for their cows. However farmers are then dependend of silage prices which can go up if there is a high demand for silage. This can cause high silage costs and less profit for dairy companies.

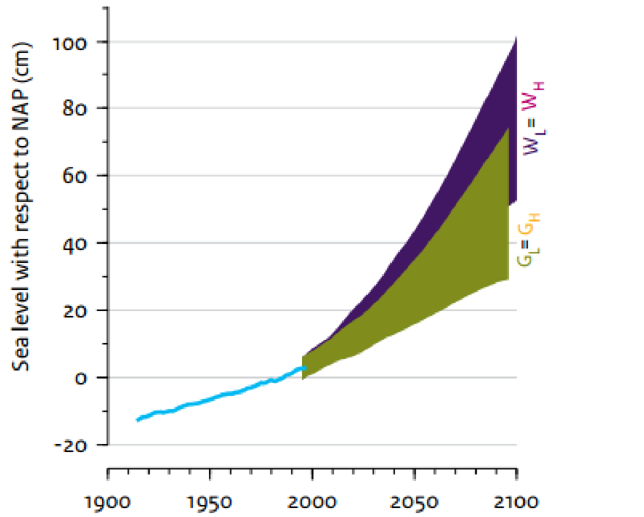


Figure 14 *Observed sea level at the Dutch North Sea coast and the projections in the KNMI'14 scenarios (KNMI 2014)*

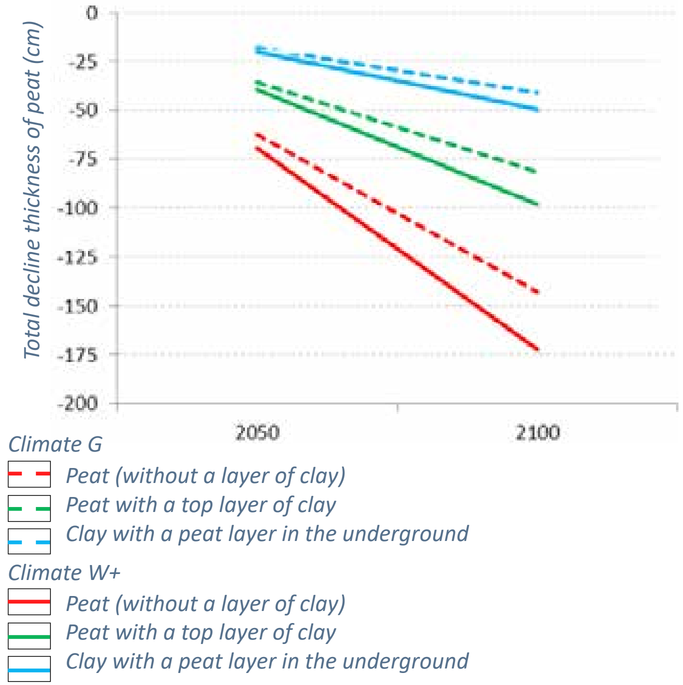
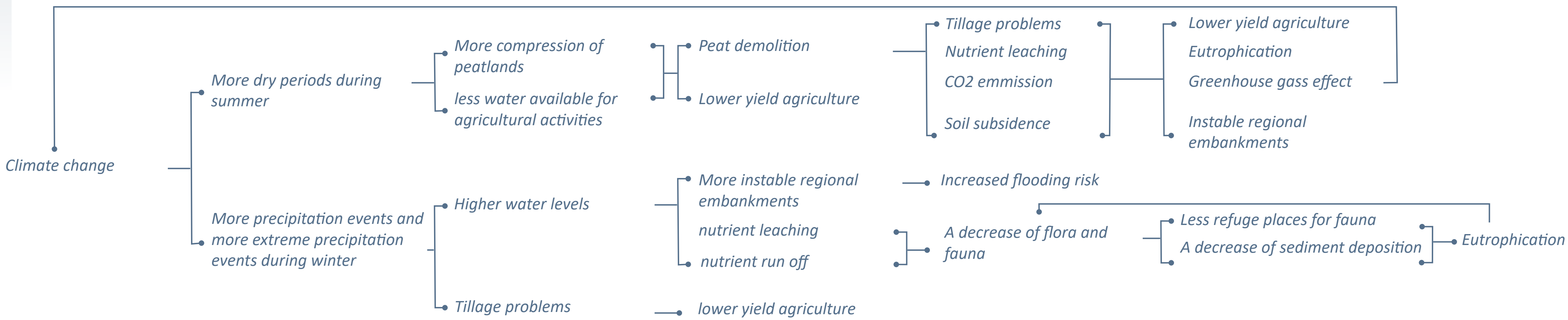


Figure 15 *Total decline thickness of peat for KNMI climate scenario's G and W+ (Osinga et al. 2014)*

2.2.3 PROBLEM DIAGRAM CLIMATE CHANGE

All the problems mentioned earlier are mostly related to each other. The diagram below shows the relations between several problems and causes.

When thinking about measures the challenge is to try to find solutions or to soften negative effects for more than one problem by excecuting measures. In this way, the maximum effect is tried to reached by the minimum of measures.



***Scheme 5** Problem diagram with the effects of climate change at the Frisian peat area. The effects of climate change lead to more problems according to the current type of agricultural land use at the Frisian peat area.*

2.3 REDUCTION OF THE FRISIAN SYSTEM OF RESERVOIRS FOR SUPERFLUOUS POLDER WATER

In the 19th and 20th century large parts of Friesland were flooded. These parts were unprotected lands. As a result of the low position of these lands in relation to the water level of Frisian the system of reservoirs for superfluous polder-water every winter the lands were flooded by mostly 45 cm of water. Farmers accepted these floods, since it brought a thin and fertile layer of silt full with nutrients. However, farmers started to built small dikes around these low areas to prevent the lands from flooding during the harvest season. In summertime the water level of the Frisian systems of reservoirs for superfluous polder-water was around 20 to 30 cm lower than the water level during winter time (Ter Haar and Polhuis 2004). Since it was hard to handle those strict water levels, the Province of Friesland encouraged the increasement of the small dikes around the lower lands. As a result such lands became polders, since it was easier to regulate the water management within the lands by using windmills as water pumping stations.

What happened was that farmers created their own polders with its own water management. As a result the Frisian system of reservoirs for superfluous polder-water became smaller since there no longer were those hundreds of hectares of land which could be flooded every now and then. This resulted in a a more intensive water management to keep the water level of the Frisian system of reservoirs for superfluous polder-water at a fixed level. Many farmers were dependent on this more fixed water level, since fluctuations would directly influence the water management within the polders. By this the Province of Friesland kind of created a new problem (Ter Haar and Polhuis 2005). Figure 16, figure 17, figure 18 and figure 19 show the decrease of the amount of land that could be flooded every now and then, the amount of unprotected land.

If we continue with discussing the effects of the impoldering of the hundreds of hectares of former unprotected land a huge consequence is the removal of a habitat for specific types of flora and fauna. Such former wet areas contained the perfect habitat for water vegetation like reed and swamp vegetation to grow. These specific types of vegetation at the wet lands and along the shores of such lands had a huge effect on different important processes within the Frisian water system:

- ‘Aquatic plants provide a refuge against planktivorous fish for phytoplankton grazing zooplankton (Timms and Moss 1984; Schriver et al. 1995; Stansfield et al. 1997).
- Structural complexity (provided by plants) promotes the piscivorous perch (Persson 1994) and pike (Grimm 1994) and deters the planktivorousbenthivorous bream (Lammens 1986), resulting in more top-down control of planktivores, and less fish-induced resuspension (Mehner et al. 2002).
- Vegetation reduces the availability of nutrients for phytoplankton, by uptake from the water and by promoting denitrification in the sediment’(Donk, van, et al. 1993; Gumbricht 1993).
- Wind - induced and fish-induced resuspension of sediments is reduced by vegetation (Jackson and Starrett 1959; James and Barko 1990), and shoreline erosion is prevented if littoral vegetation is well developed’ (O’sullivan and Reynolds 2005).

With other words, the reducement of sediment re-suspension leads to an increase of sedimentation. As a result of this, the water gets more clearer and hereby sunlight is able to penetrate to a greater water depth. ‘In clear shallow lakes or the edge of deep lakes, light penetrates tot the lake bed, allowing the growht of macrophytes and benthic algae’ (Dobson and Frid 2008).

By the change of these former unprotected lands which were flooded every winter into polders surrounded by embankments, water from the Frisian system of reservoirs

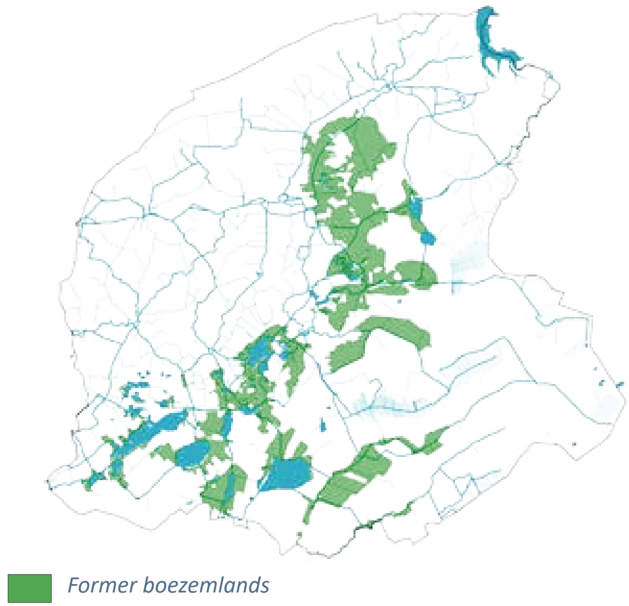


Figure 16 *Unprotected land in 1850 (Schotsman 1983)*

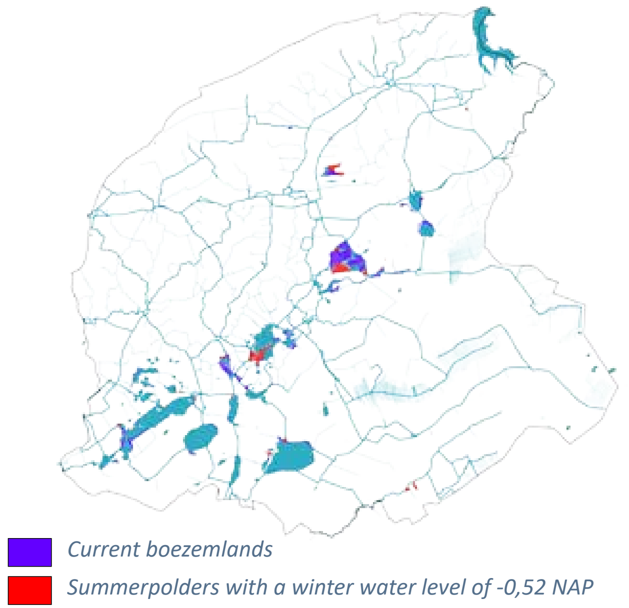


Figure 17 *Current polders with a winter water level of -0,52 NAP*

for superfluous polder-water could not find its way anymore to such polders. So it meant that in the whole Frisian system of reservoirs for superfluous polder-water the amount of water vegetation declined. As a result of this, sediment could not be deposited at such former unprotected lands and stayed mostly within the lakes. Sediment or SPM (Suspended particulate matter) contains nutrients. Sources of SPM in lakes in general are illustrated in figure 20. The key Sources of nutrients in in the Frisian water system are likely to be agriculutral activities, erosion, athmospheric paricles, wastewater and vegetation.

As a result of processes like sediment re-suspension by fish, the water quality declined, since nutrients become available again for phytoplankton. 'Sediment re-suspension is basically induced by wind fetch and wind force, and influenced by lake morphology, size and depth, and by the texture of bottom sediments' (Lick 1982). The sediment re-suspension may occur in shallow lakes over the total lake area whereas it occurs in deep lakes especially at the nearshore areas (O'Sullivan and Reynolds 2005). In figure 21 it is illustrated how sediment is being transported, accumulated and eroded at the bottoms in lakes as a consequence of wind fetch and water depth (Hakanson and Jansson 1983).

Since the decline of the amount of vegetation, the self-cleaning capacity of the Frisian system of reservoirs for superfluous polder-water declined as well. 'Enrichment of water with mineral nutrients, such as nitrogen (N) and phosphorus (P) causes transformation of water bodies from oligotrophic to mesotrophic, eutrophic, and finally hypertrophic stage' (Ansari and Gill 2014). Since for example phytoplankton is grow-limited by Phosphorus (O'Sullivan and Reynolds 2005). 'Inputs of very high levels of nutrients from human activities, such as fertilizer run-off and discharge of partially treated sewage, can lead to hypertrophy, the presence of nutrients at excessive concentrations. With nutrient availability removed as a limiting factor, photosynthesizers will increase in biomass untill they are constrained by space or shading. At such densities, they can disrupt the entire lake ecosystem, most notably through oxygen depletion' (Dobson and Frid, 2008). This process in which the water is being enriched with nutrients is called eutrophication. Within the Frisian water system, it has been experienced that the ecological water quality decreased as a result of this decreased of water or swamp vegetation areas. That is why currently Wetterskip Fryslân tries to create areas along the water sides where this vegetation can grow. However, this measure costs a lot of money (Wetterskip Fryslân 2015).

Such hypertrophic water areas are controlled by macrophytes or by phytoplankton. Both grow extremely well in waters where a high level of nutrients like phosphor and nitrogen are present. 'It is a common feature of many water bodies that clear water and a high density of macrophytes is replaced by turgid, algal dominated water as nutrient levels rise' (Dobson and Frid 2008). So it becomes clear that 'Sedimentation of suspended particulate matter (SPM) plays a key role in lake 'perturbation', management and rehabilitation' (O'Sullivan and Reynolds 2005).

The vegetation zone which at the same time is a transition zone from land to water is an important place for flora and fauna. With a smaller vegetation zone and cloudy water as a result of sediment re-suspension and phytoplankton, the problems are enforcing themselves. However, the reduction of the Frisian system of reservoirs for superfluous polder-water is not the only cause of just mentioned problems. The importance of water vegetation especially along the shores will be elaborated at paragraph 2.4.

The empoldering of the former unprotected lands also lead to the demolition of peat areas. How this lead to soil subsidence has already been explained. The consequences of the impoldering of former unprotected agricultural areas are still relevant. Nowadays these consequences are seen as problems. Some measures are taken to improve the water quality. This will be discussed later. So an effect

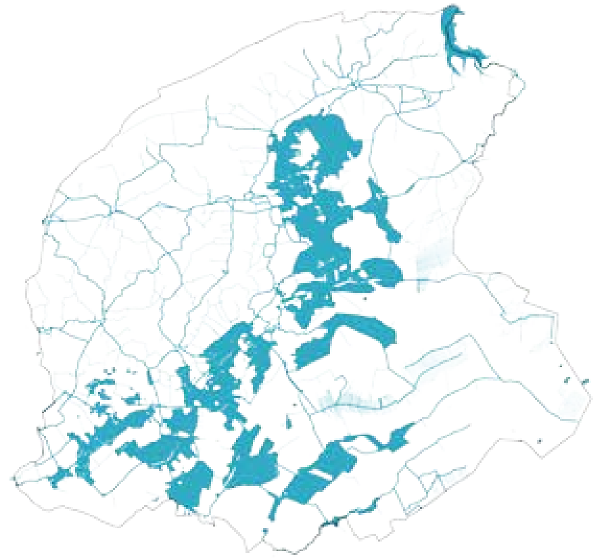


Figure 18 *Unprotected land at 1850 when flooded during winter time functioned as water storage areas*

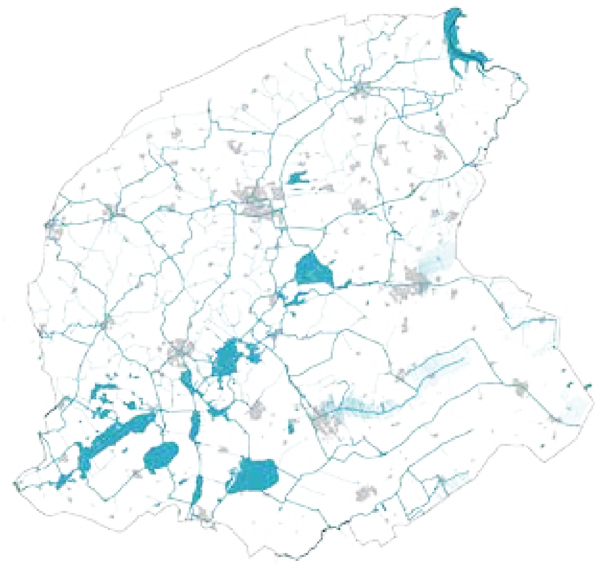


Figure 19 *Current unprotected land and polders with a winter water level of -0,52NAP funtion as a water storage area*

of the impoldering of the former unprotected lands is a more complex water management in Friesland with less space to store water compared to the 19th century. This lead to consequences like a decrease of water vegetation, more sediment resuspension within the water system and a need for more strict water levels in the Frisian system of reservoirs. In a simplified scheme ,scheme 6, the reduction of the Frisian system of reservoirs for superfluous polder-water and its effects is shown.

On the one hand, Wetterskip Fryslân wants to improve the water quality by creating habitat for flora and fauna and on the other hand, Wetterskip Fryslân wants to make functions like agriculture possible (Wetterskip Fryslân 2015) which means maintaining a type of land use that does not contribute to extra water storage or extra space for the development of water vegetation. Wetterskip Fryslân tries to find a medium in this, however it leads to high costs of the water management.

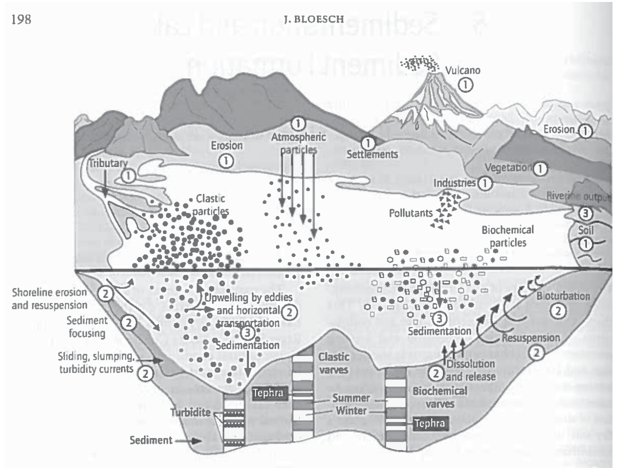


Figure 20 *The influence of external and internal environmental factors on suspended sediments, sedimentation and sediment formation in a lake basin: 1, sources of suspended particulate mater (SPM); 2, transportation and transformation of SPM; 3, removal of SPM (Modivied from Sturm and Lotter 1995)*

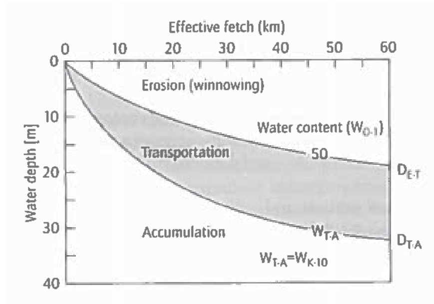
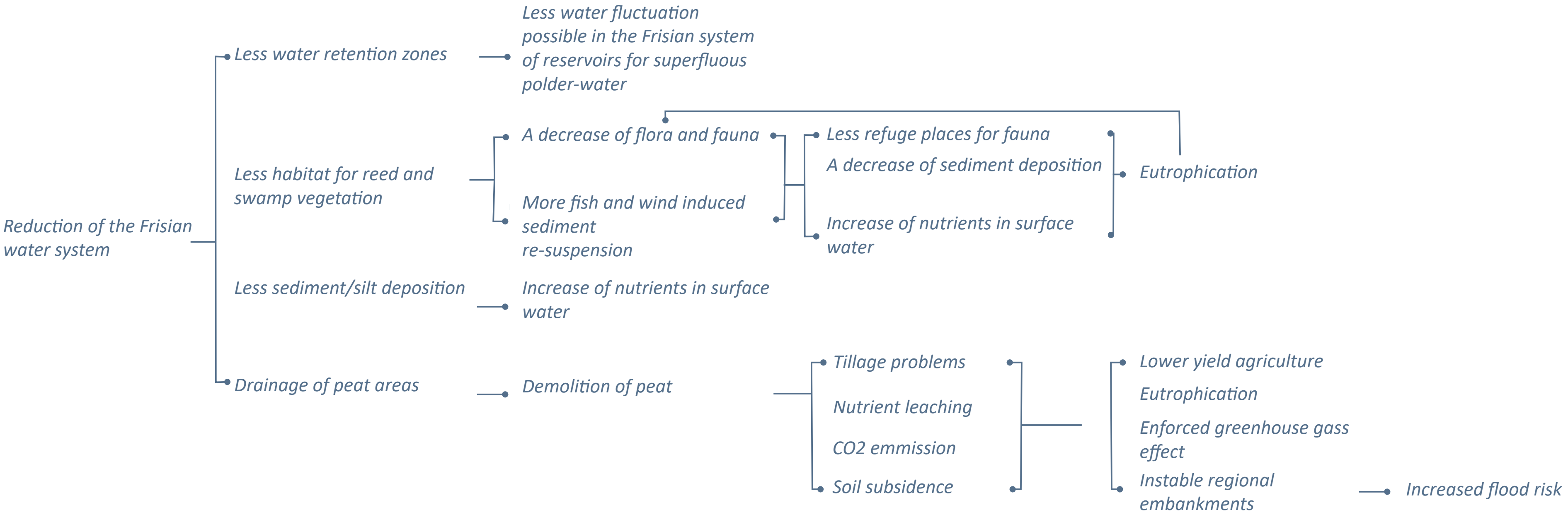


Figure 21 *The diagram shows the accumulation, transportation and erosion of sediments at the bottom of lakes (O'Sullivan and Reynolds 2005)*

2.3.1 PROBLEM DIAGRAM REDUCTION OF THE FRYSIAN SYSTEM OF RESERVOIRS



Scheme 6 *Problem diagram with consequences of the reduction of the Frisian system of reservoirs for superfluous polder-water.*

2.4 FIXED WATER LEVEL

Before the times of pumping stations, Friesland was dependent on locks to eliminate superfluous water out of Friesland during low tide. However, the commissioning of pumping stations meant a huge difference in the Frisian water management. In 1920 the ir. D.F. Wouda water pumping station at Lemmer was put into operation. This meant a decrease of water fluctuations in the Frisian system of reservoirs for superfluous polder-water since redundant water after intense periods of rain could be eliminated into Lake IJssel and the Waddensea much faster. Even if there were fluctuations, these were less intense. This also meant a reduction of flooded polders. And thus farmers were able to work the land without experiencing troubles as a result of flooded lands.

Together with the commissioning of the J.L Hoogland pumping station in 1967 at Stavoren, the creation of the Lauwers lake, the options to demolish water during low tide into the Waddensea at Harlingen and the creation of the Afsluitdijk the intensity of water fluctuations within the Frisian system of reservoirs with superfluous polder-water remaind nothing compared to the beginning of the 20th centrury where water level fluctuations could go to one meter (Brongers and Belle, van 2008). In appendix B the changes of water level fluctuations together with the changes in the water management of Friesland mentioned earlier are illustrated.

At the Provincial States in 1987 in the ordinance for the Frisian system of reservoirs for superfluous polder-water it was approved a fixed water level in the Frisian system of reservoirs for superfluous polder-water of -0,52 m NAP would be set. This meant that there were no huge water fluctuations in this system anymore which would occur as a result of (intense) periods of rainfall. Now there would be fluctuations of maybe 10 – 20 cm within this Frisian system of reservoirs for superfluous polder-water. This idea to have one fixed water level in the water system was already mooted at 1922 (Ter Haar and Polhuis 2004).

As a result of the fixed water level, less (intense) water fluctuations occured. The light penetration in the water area became smaller. An effect of this can be deteriorated circumstances for submerged water vegetation and the dissapearance of submerged water vegetation'(Brongers and van Belle 2008). The distribution of depth is the determining factor in this (Pot 2005). Submergend water vegetation take up nutrients like Phosphate and with their roots, they promote the sedimentation process. Next to this their roots prohibit silt re-suspension. This leads to a cleaner water quality. The sub-mergend water plants are also a hiding place for different fish species and smaller organisms (Dobson and Frid 2008).

By setting a fixed water level, large amounts of reed and swamp vegetation disappeared too. These types of vegetation occur at the transition zone at water to land. They, largely exist of different species of reed and they develop much better when every once in a while the shore gets dry (Pot 2005). In this way seedlings and young plants get the chance to develop and grow. However, with the decrease of the amount of water fluctuations in the Frisian system of reservoirs of superfluous polder-water and appearance of less intense water level fluctuations in this system, the amount of such reed and swamp vegetation along the embankments decreased (Brongers and Belle, van 2008).

A positive point of much water vegetation like reed in front of an embankment is that it protects the embankment. The vegetation dampens the water waves and as a result less soil demolishes from the embankment behind the vegetation. However with the fixed water level, there is less water vegetation and so there is less protection of the embankments, there is less accumulation of silt and there is less assimilation of nutrients.

Nowadays the vegetation zone along the shores in the Frisian lake area is only 2 to 3 m wide (Brongers and Van Belle 2008), while waves produced as a result of wind and ships concentrate themselves at the same places at the vegetation along the shore (O'Sullivan and Reynolds 2005). This causes an unstable reed and swamp vegetation zone along the embankments. The decline of shores and its vegetation is an effect of this process. What happened as a result of this in the past decades is that Wetterskip Fryslân protected the shores and the regional embankments with hard materials like rubble stone or sheet piling. This caused a decrease of flora and fauna at the shores along lakes and at the whole ecological system in such areas, since exactly such transition zones from water to land form the habitat for fish species, dragonflies, plants etc. Even for the waders who nowadays suffer as a result of the intensive agriculture this zone is an important habitat (Brongers and Belle, van 2008).

The riparian zone along lakes and water canals are important for the whole ecosystem of a lake; 'The littoral zone provides more benign environments with respect to exposure, light, oxygen supply and nutrient availability than does the body of the lake' (O'Sullivan and Reynolds 2008). Here an self-optimising structure is settled. Especially macrophytes are important here, since as already mentioned in other paragraphs, 'They maximise living space and bring close spatial and temporal coupling of substance decomposition and production, with feedback to the water and kmatter balance in their location. They increase the water retention capacity of the soil in the adjacent banks above the mean water level, through organic deposits and microclimatic sheltering. With increasing soil moisture, mineralisation processes are frequently restricted to the vicinity of the root zone, but where, through plant transpiration, drier phases may well arise. Matter cycling is locally restricted and losses are small, so materials are conserved and stored. Detritus is likewise enriched on the water side of the littoral interface. By positive feedback, the water becomes shallower and amenable to the establishment of further macrophytes.

Thus, the plants increasingly affect the material processes within the rooted zone. They mediate the water transport and oxygen supply in the former anoxic sediment through transpiration. Mineralisation near the roots is favoured and the nutrient supply to support herbal production is encouraged. Macrophytic development influences the production and distribution of littoral detritus, equalising water and matter balances and generally flattening the ecotone' (O'Sullivan and Reynolds 2005). In Figure 22 it is shown how the riparian zone is subdivided in different zones where specific vegetation species occur.

At the right side of this page scheme 7 shows the importance of water vegetation. At the next page a problem diagram including the consequences of a fixed water level is given. Less water level fluctuation within the Frisian water system was a huge advantage for farmers at the Frisian peat area, since less floods occur. However, at the long term it leads to a decrease of riparian zones and many other consequences. Nowadays Wetterskip Fryslân experiences the negative effects, since it must enforce embankments because no wide riparian zones are there with their positive effects.

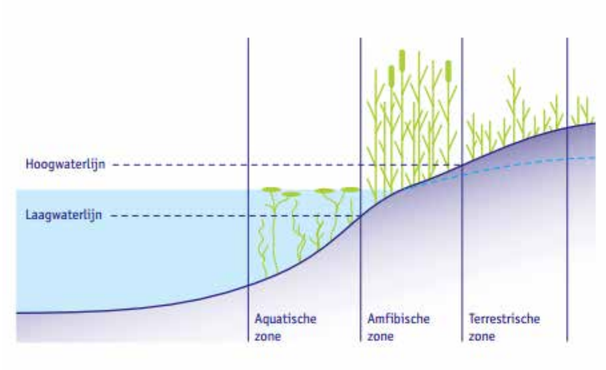
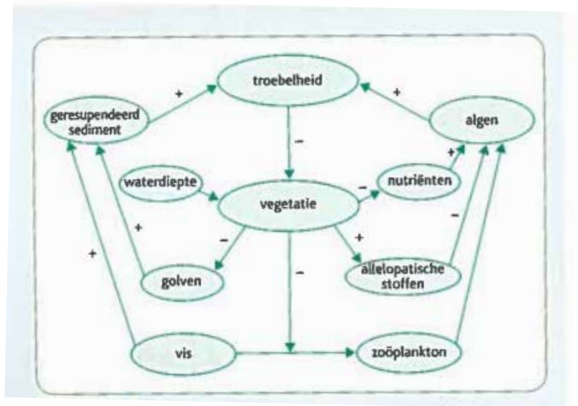
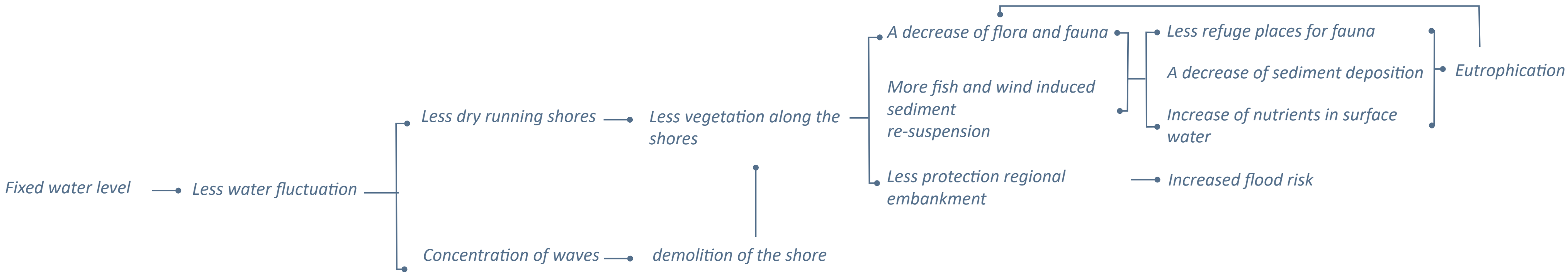


Figure 22 *Vegetation types along the riparian zone at Frisian waters (Goossenen et al. 1998)*



Scheme 7 *Feedback loops (Scheffer 1998)*

2.4.1 PROBLEM DIAGRAM FIXED WATER LEVEL



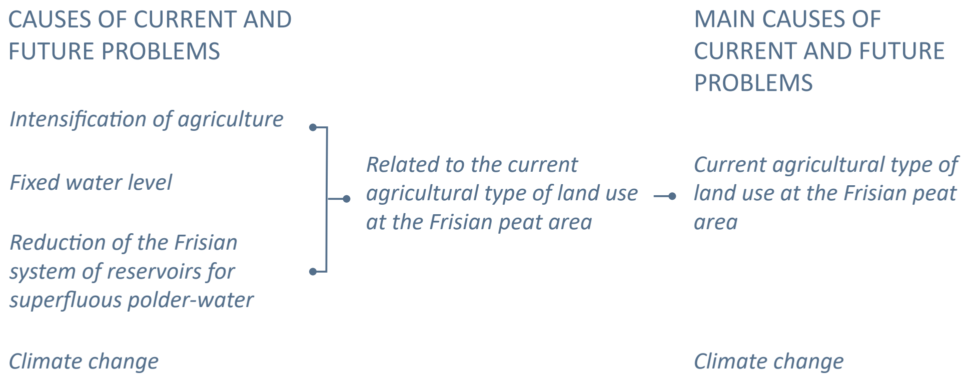
Scheme 8 *Problem diagram including the consequences of a fixed water level. Especially the ecological functioning of the Frisian water system decreased*

2.5 PROBLEM ANALYSIS - CONCLUSION

The problem analysis, including the problem diagrams, show that as a result of agricultural use of the Frisian peat area, now and in the past, many problems occur and will occur. Most causes mentioned at earlier problem diagrams are related to the current agricultural type of land use at the Frisian peat area. The fixed water level was set in order to prevent low peat areas from flooding. At this way, these peat areas could be used more intense for agricultural purposes. And the reduction of the Frisian system of reservoirs lead to more fertile peat land which could be used for agricultural purposes too. Next to this intensification of agriculture meant to optimize peatlands for higher yields.

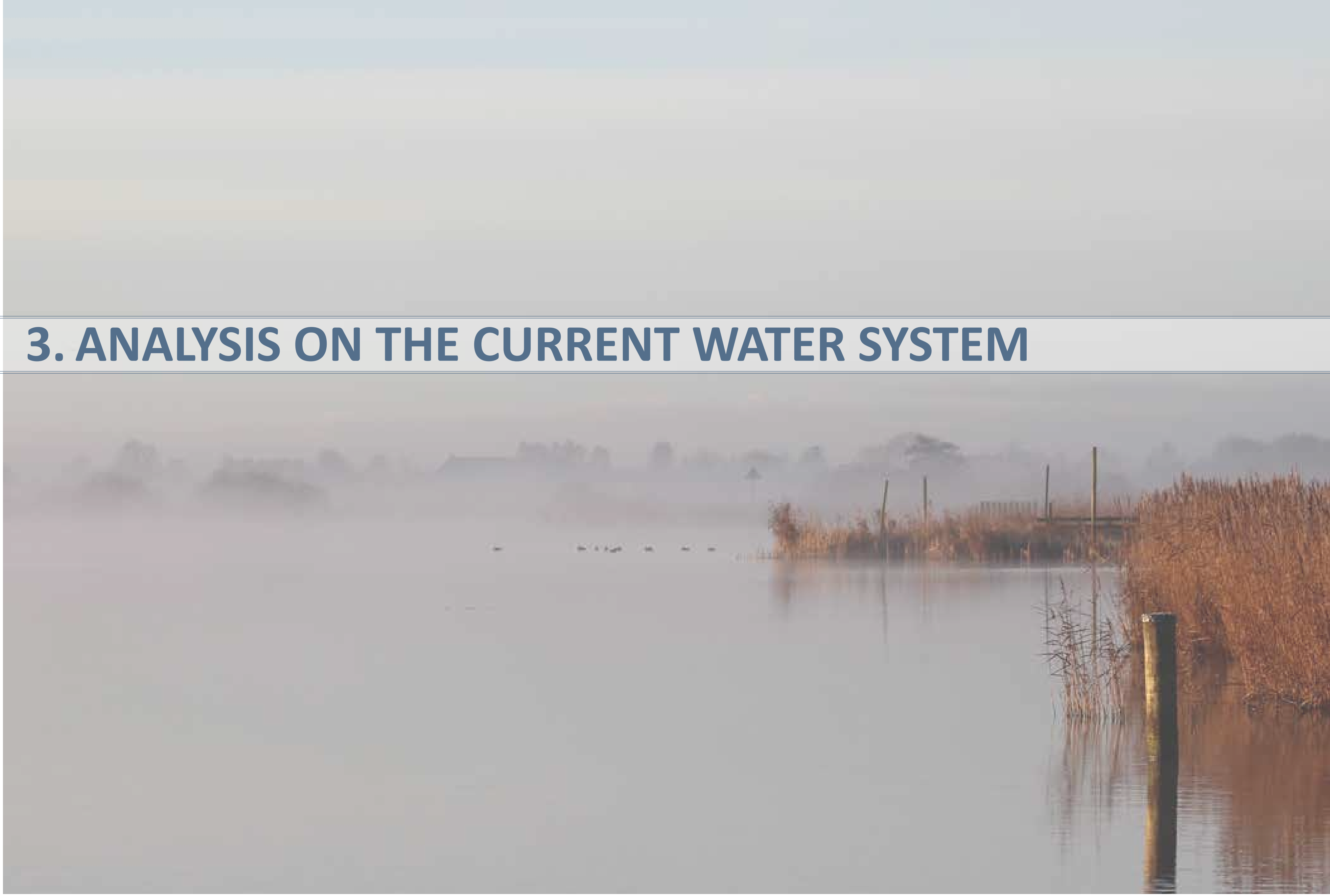
So actually we can conclude that the current type of agricultural land use at the Frisian peat area led and lead to problems and future problems mentioned in the problem diagrams together with climate change effects (scheme 9). Climate change and its effects are not related to the current agricultural type of land use in a way that it tries to remain or optimize this type of land use. Therefore climate change and the current agricultural type of land use at the Frisian peat area are seen as two main causes for the (future) problems at the Frisian peat area related to the water management. So the current type of land use is not sustainable and thus measures must be taken to create a sustainable type of land use in relation with the water management.

Now it is important to find out how the current water system actually functions. And find out what measures are actually taken to solve earlier mentioned problems. This will become clear at the next chapter.



Scheme 9 *Problem diagrams, overview*

3. ANALYSIS ON THE CURRENT WATER SYSTEM



3. ANALYSIS ON THE CURRENT WATER SYSTEM

3.1 THE FORMATION OF FRIESLAND

The water management as we know today is related to the geology, the climate and the physiography. The way in which the Netherlands is formed explains to a great extent why the Frisian water management is organized as the way it is.

The Netherlands as we know it today is particularly formed during the Pleistocene period (Ter Haar and Polhuis 2004). During this period between 2 million and 80.000 years B.C there were glacial periods in which The Netherlands was covered by a thick layer of ice and there were warmer interglacial periods in which the ice melted. During these times, the land was flooded by the sea. When the sea pulled back, it left behind a layer of fertile clay. During the later times of the Pleistocene period, the ice pulled back and grew again. This process repeated for several times. During these processes, materials especially originating from Scandinavia were transported by the ice. This is how the moraines like Gaasterland were formed.

During the last glacial period of the Pleistocene era, the ice did not reach The Netherlands anymore. However, the soil was almost permanently frozen. In this period sand was blown over the higher morraines. Already during the pleistocene period, stream valleys were formed which transported water out of those higher sand areas to the lower valley between the morains. Examples of such stream valleys are the Boorne, the Linde and the Tsjonger. The water comming from the higher sand terrains gathered itself in the lower areas. That is where the peat was formed.

Plants and trees found its way to such wet areas. During the Holocene period, the sea level rised, the ice in the soil melted and as a result of these actions the ground water level rised. This is why several swamps occured in the lower areas of Friesland and along the whole Dutch coast. In the middle and eastern part of Friesland, peat developed in those swamp areas. The ground water level in those areas was very high, since there was not yet a developed water system in the Province.

Around 4000 B.C the tides were able to enter some peat areas which were formed behind the sandy shorelines. They flushed away some peat areas and they deposited fertile clay. Sometimes peat was covered by clay. The tides flooded the western part many times and it explains how the clay area in the western part of the Province was formed. The seepage edge was displaced more and more in the eastern direction of Friesland. Meanwhile the peat grew and grew and it developed itself into a thick layer. Water found its way from the higher sand terrains in the east to the peat areas and at last to the lower clay soils in the west. Figure 23 shows the geology of Friesland at 2750 B.C.

However, today, with the soil subsidense, the 'old' water system where the clay area on the Western part of the Province was the lowest area of the Province has dissapeared. Now the peat area in the middle of the Province is the lowest part as a result of soil subsidence. This resulted in a new water management. The development of the Frisian water management has developed in the past centuries into a complex system where many functions rely on. Now some information about this development and the current landscape will be given. This will make it easier to understand the current water system.

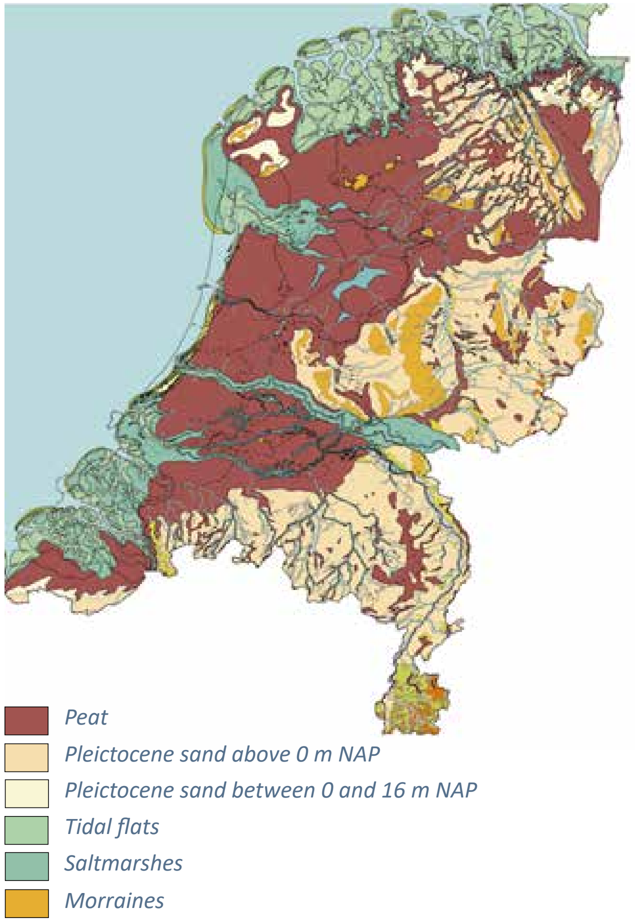


Figure 23 *The Netherlands at 2750 B.C. (Deltares 2015)*

3.2 HISTORIC VIEWS OF THE WATER MANAGEMENT IN FRIESLAND

The first people living in Friesland decided to live at the higher clay terrains, the salt marshes along the Wadden coast area. However as a result of floods people decided to built mounds to live on. This fertile clay area along the coast was being transformed into a developed landscape. The opposite was visible in the inaccessible peat areas and the less fertile sand terrains. Years later even the areas at the eastern side of the Province became inhabited.

To protect the fertile land, houses and people against floods, people started to built dikes. The first dikes were probably created around the 9th or 10th century (Ter Haar and Polhuis 2004). More dikes were developed like for example along the former Middle sea. Between the dikes there was still an open connection with the sea at some places. As a result of this, salt water affected the fertile land and made it less compatible for agricultural activities. That is why these exchanges with the open sea were also secluded. To remove inland surplus water to the sea, sometimes smaller openings called 'zijlen' or sluices were made in the dikes.

From the higher eastern part of the province some creeks (the Linde, Boarne and the Tsjonger) entered Friesland. First those creeks ended in the Southern sea, but later, as a result of the creation of the Helomavaart and the Chirstiaansloot, those creeks ended in the Frisian system of reservoirs for superfluous polder-water. The small river The Boorne was in the beginning responsible for the transportation of this water to the Middle sea. But when the Middle Sea became impoldered, the lakes in the peat area were responsible for the transportation of water to the sea. In the Western part of the province, the Franekervaart, the Bolswardervaart and the Makkumervaart started to have an important role in the removal of surplus water out of the province. In the eastern part of the province the Lits, de Lauwers and the Murk became important (Ter Haar and Polhuis 2004).

In the 18th century the water system in Friesland was not good yet. Especially during floods it was hard to remove water out of Friesland into the sea, since there were not yet spouces and water pumping stations like the ir. Wouda water pumping station. The Provincial States gathered about these problems and as a result measures were taken to improve the Frisian water system. Water ways were widened to make sure that water was able to find its way fast to the sluices and 'zijlen'. At 9 november 1871 the Provincial States stated that the Frisian system of reservoirs for superfluous polder water had to become one system. The system as we know it today.

In 1893 after the improvement of several water ways, the Provincial States concluded that there were still problems with the Frisian water system. Therefore they encouraged the impoldering of several areas within Friesland. As a result of this encouragement, farmers started to strenghten the dikes around these wet terrains. The areas became drained but the surface of the Frisian system of reservoirs for superfluous polder-water became more narrow, since water could not enter these drained areas anymore. It became again a problem to remove water out of the Frisian system of reservoirs for superfluous polder water fast, since it could only be removed out of Friesland during low tide. That is why in 1920 the ir. D.F. Wouda water pumping station was finished to remove water out of the Frisian water system also during low tide. In 1965 an extra water pumping station was established at Stavoren; the J.L. Hoogland spouce.

In the Northern part water was being eliminated out of the Frisian system of reservoirs for superfluous polder-water into the Lauwerssea. This was dependent on the tides. The conglomeration of silt in front of the outputs (sluices and water pumping stations) of the Frisian system of reservoirs made it more hard to remove the surplus water. Therefore in 1960 a new dike to cut off the Lauwerssea from the North sea was established including sluices at Lauwersoog. These made it possible to remove water during low tide.

This past water management could not prohibit that large parts of Friesland were flooded during winter time. ‘In the beginning of the 20th century during winter time almost 100.000 ha of land which was not protected by dikes flooded. These areas were called summerpolders and boezemlands. Boezemlands are fields at the Frisian system of reservoirs which are not protected by dikes. They are called summerpolders if they are being drained during summer time.

In the 80’s around 3000 ha of such fields were put under water during high water levels at the Frisian system of reservoirs for superfluous polder-water’. (Brongers and Belle, van 2010). Fluctuations of 1 m between winter and summer time were normal. Especially between 1930 and 1960 big amounts of areas became winterpolders (Schotsman 1983). Winterpolders are being drained all year long. It meant an increase in small windmills which dehydrated the new winter polders and later these were replaced by water pumping stations.

This decrease of summer polders and boezemlands lead again to a reversal of the surface of the Frisian system of reservoirs for superfluous polder-water. As a result of this the water storage capacity of the system of reservoirs for superfluous polder water has been decreased as well. So during havy rainfall periods, the water level in this system of reservoirs for superfluous polder water became higher and higher and therefore the dikes needed to be enforced, to prevent floodings.

So this historic development of the water system and its management lead to the current water system. How this current system functions will be explained now.

3.3 CURRENT WATER MANAGEMENT

The current Frisian water system is part of a wider catchment area; the Rhine basin. In figure 24 this Rhine basin is illustrated. Within this Rhine basin there are several subsystems. The system of reservoirs for superfluous polder-water in Friesland is a sub-system of this Rhine basin. This area is shown in figure 25. The total surface of the Frisian system of reservoirs for superfluous polder-water is 18.650 ha (Wetterskip Fryslân 2016a). Within this system there is a fixed water level of -0,52 m NAP. Water in the Frisian system of reservoirs for superfluous polder-water is mainly coming from rainwater and to a lesser extent from the streams Tjonger, Linde and the Alddjip (or the Boarne) and seepage water.

The Frisian system of reservoirs for superfluous polder-water contains six points in which the water from this system is being removed to the Waddensea, the Lauwers Lake or the Lake IJssel. These points are shown in igure 26. The most familiar and oldest water pumping station is the Ir. Wouda pumping station at Lemmer. This station has a capacity of maximum 6 million m3 per 24 hours. In Stavoren another important pumping station demolishes superfluous water into the IJsselmeer. Here the J.L Hoogland pumping station works with a capacity of 10 million m3 per 24 hours. Next to this there are four scouring sluices; the Dokkumer Nieuwe Zijlen, the sluice at Lauwersoog, the Tjerk Hiddes sluices at Harlingen and the sluices at Munnikezijl. There are also two inlet sluices; the inlet sluice at Tacozijl and Teroelsterkolk at Lemmer. Those let in water from the Lake IJssel during dry periods. There is one gray point visible; water pumping station Vijfhuizen. This planned pumping station is not yet finished.

Those points are most important for the regulation of the water level in the Frisian system of reservoirs for superfluous polder-water. If it rained for a couple of days, the scouring sluices and water pumping stations are eliminating the

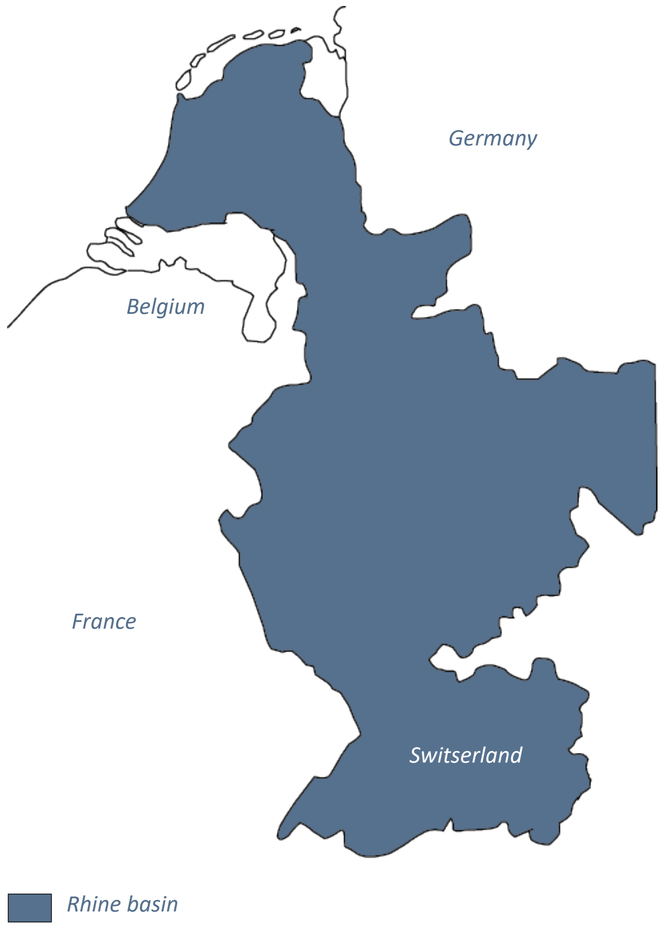
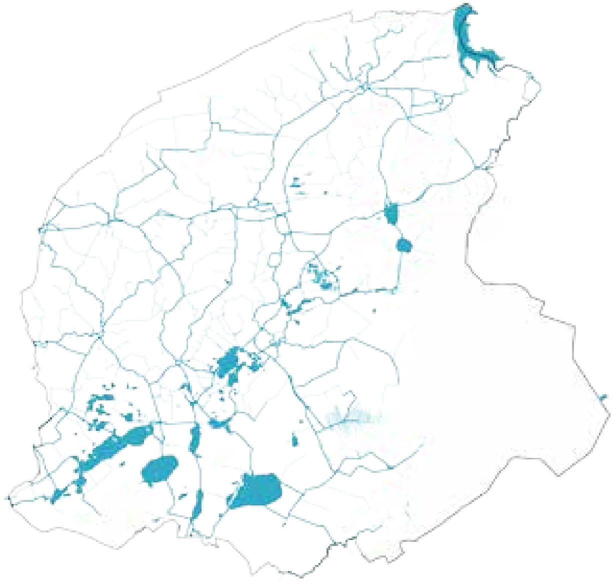


***Figure 24** The Rhine basin*

redunant water into the Wadden sea and Lake IJssel.

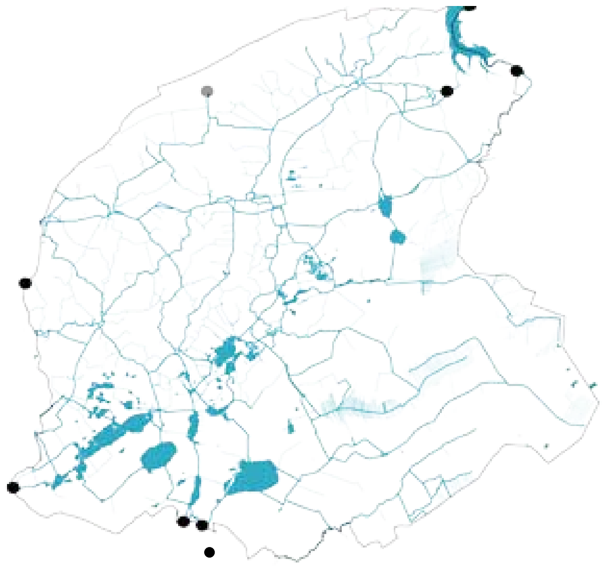
Next to the Frisian system of reservoirs for superfluous polder water, there are also polders which function as a subsystem. Within polders, there is often another water system functioning. Within the Frisian peat area, polders have often lower water levels than the fixed water level of the Frisian system of reservoirs for superfluous polder-water. This as a result of the low height of the area. Surplus rainwater in these polders is being removed by pumping stations into the Frisian system of reservoirs for superfluous polder-water. In figure 28 the principle of sub-systems in combination with the Frisian system of reservoirs for superfluous polder-water is shown.

The Frisian system of reservoirs is also connected with the gravitational discharge areas which are visible in figure 27. In these areas superfluous water streams under the influence of gravity to lower areas. They end in the Frisian system of reservoirs for superfluous polder-water.



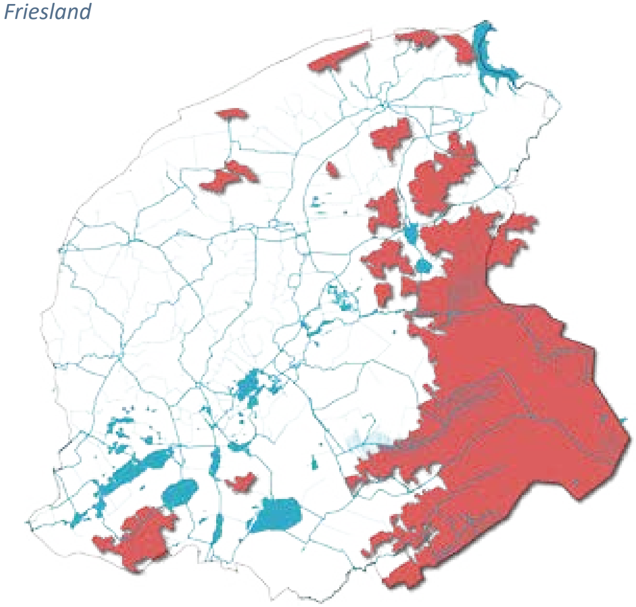
Frisian system of reservoirs for superfluous polder-water

Figure 25 *The system of reservoirs of superfluos polder-water in Friesland*



Water pumping stations and scouring sluices
Planned water pumping station

Figure 26 *Water pumping stations which discharge water out of the Frisian system of reservoirs for superfluous polder-water*



Gravitational discharge areas

Figure 27 *Gravitational discharge areas*

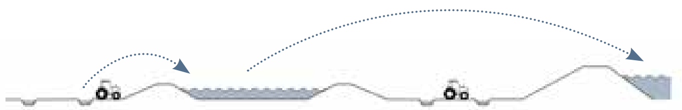


Figure 28 *Funtioning Frisian system of reservoirs for superfluous polder-water*

3.4 THE ROLE OF EMBANKMENTS

It was already mentioned that embankments were established to prevent polders and agricultural land from flooding. Embankments in the province of Friesland are part of the Frisian identity of the landscape. They have been there for hundreds of years and they show the actions taken to protect Friesland. One of the question remains; where are embankments located? To answer this question, it is useful to know that there are four different types of embankments in Friesland; Primary embankments, secundary embankments, regional embankments and local embankments. They all have the same function: to protect Friesland from flooding, however, they protect the hinterland at different degrees which is why they differ in layout.

3.4.1 PRIMARY EMBANKMENTS

The primary embankments are of great importance for Friesland, since they keep water from the Waddensea and Lake IJssel out of Friesland. Figure 29 illustrates where primary embankments are located. Primary embankments are part of a dike system which protects Friesland and beyond from flooding. In the Water law, a law in which the rules and regulations about water management are packed together, for every dike system the safety standards as the exceedence probability are mentioned. It means the probability of the exceedence of sea water or water of Lake IJssel into the mainland of Friesland. The exceedence probability for the mainland of Friesland is 1/4000 per year. This is why these types of embankments must be so strong.

3.4.2 SECUNDARY EMBANKMENTS

A secundary embankments is a former sea dike which becomes important if a primary embankment would fail. A couple of secundary embankments actually reduce the damage if a primary embankment would fail, that is why these secundary embankments are maintained.

3.4.3 REGIONAL EMBANKMENTS

Within Friesland lies the Frisian system of reservoirs for superfluous polder-water. This water storage system is separated from the hinterland by regional embankments. The purpose of regional embankments in Friesland is:

‘To protect against flooding from the Frisian system of reservoirs for superfluous polder-water’ (Wetterskip Fryslân, 2015b).

To pursue this goal, Wetterskip Fryslân enforces regional embankments to a certain height with a certain profile. Especially along the lower areas in the province, regional embankments are present. Just like at the primary embankments, also the regional embankments form a closed system since the water level in front of the embankments is often higher than the land which is behind the embankments. Sometimes roads and other higher elements in the landscape are identified as regional embankments. At the Frisian peat area, regional embankments surround the whole low lying polders. In appendix C images and a section of regional embankments are visible.

Regional embankments must apply certain norms. In figure 30 some risk categories within Friesland are shown with their exceedence probability of the normative water level. The Province of Friesland manages two risk categories for the regional embankments as norms for the safety of the embankments: Embankments with an exceedence probability of the normative water level of 1/100 and embankments with an exceedence probability of the normative water level of 1/300. The desired level of protection is dependent of the direct damage at the areas behind the embankement which can arise during floods. The higher the expected damage, the higher the risk category of the embankment (Wetterskip Fryslân 2014a).

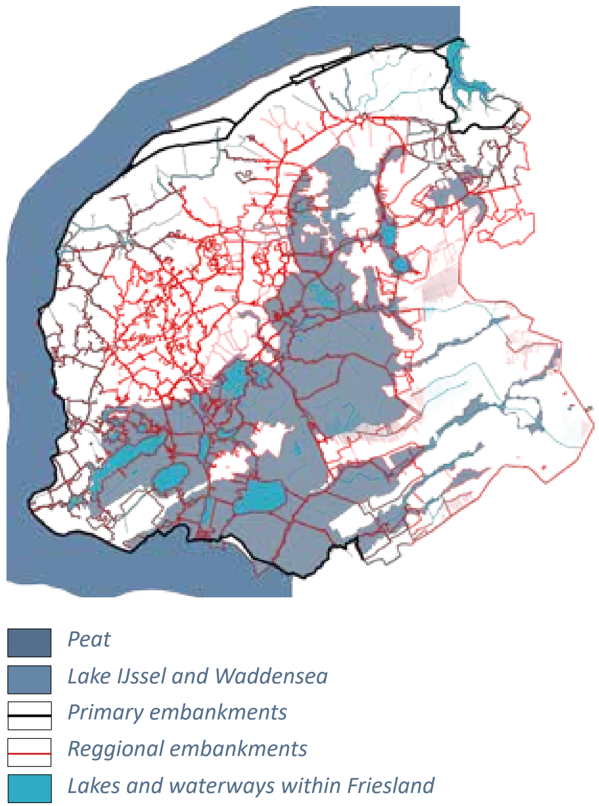


Figure 29 Primary and regional embankments in Friesland.

Next to the IPO standards there are more norms for regional embankments. Those rules are written down in the report; 'Technical Norms Frisian Embankments' (Wetterskip Fryslân 2010). The most important aspects for the design of an embankment are: the slopes of the embankment and the height of the embankment. Factors which are taken into account when measuring how a regional embankment must be enforced are:

- Wave run up
- Diffraction
- Width of the water body
- (Wind) set up
- Compression
- High rise

These factors are taken into account in the next formula to measure the height of the regional embankment:
Height of embankment = height of the Legger = Normative water level of the Frisian system of reservoirs for superfluous polder-water (MBP) + sigma + freeboard + local wind set up (Wetterskip Fryslân 2010).

The normative water level (MBP) for the Frisian system of reservoirs for superfluous polder-water is the water level which occurs once in every hundred years. This water level is calculated by using different models. Embankments thus must be higher than this normative water level. The normative water level in the province differs as a result of the wide of water bodies, wind effects etc. In figure 31 these differences are visible. Since a fixed water level is set for the Frisian system of reservoirs, differences in the MBP mean that in different areas of the province different heights for regional embankments are necessary.

The profile of an embankent is the result of calculations with factors mentioned earlier. However since everywhere in the province factors like the wide of a water body, the wave run up and the depth of the water bodies differ, there is no fixed design for a regional embankment. Also the soil of an embankment has influence on the type of construction of the embankment. For the construction of embankments with a peat layer, the slopes need to be much more slanted than at the construction of embankments with a clay soil. However, there are a couple of principles which help to stabilize an embankment at any time.

A riparian zone for example breakes the waves (figure 32). In this way, the waves loose their energy and therefore the embankments become extra stable and the height of the embankment can be reduced (Wetterskip Fryslân 2010). 'The riparian zone is the transition from land to water, the part at the normative water level which is being affected by frequent load '(Wetterskip Fryslân 2014b). Another aspect is the gradient of the outer slope (figure 32). If this gradient is higher, the wave run up will be lower and also the diffraction will be less. In this way the waves will affect the embankment to a lesser extent and therefore the embankment becomes more stable. The creation of a high ground (figure 32) works according the same principle. A high ground means that the embankment is so wide that the height of the embankment can be reduced, since waves will not reach the back of the embankment.

In summary: The just mentioned factors are part of the embankment. The borders of the regional embankments and embankments in general are mentioned in 'The Legger'. For the maintenance and upkeep of water system constructions Wetterskip Fryslân determined a Legger. 'The Legger exists of maps and writings which show who is responsible for which kind of water system construction, what this means and what the dimensions of the constructions must be' (Wetterskip Fryslân 2014b). The borders are formed by the embankment and the protection zone. The embankment is the width of the total object including the protection zone. As mentioned earlier, this width is dependent of several factors. The protection zone exists of the areas at both sides of the embankment which are mentioned in the Legger.

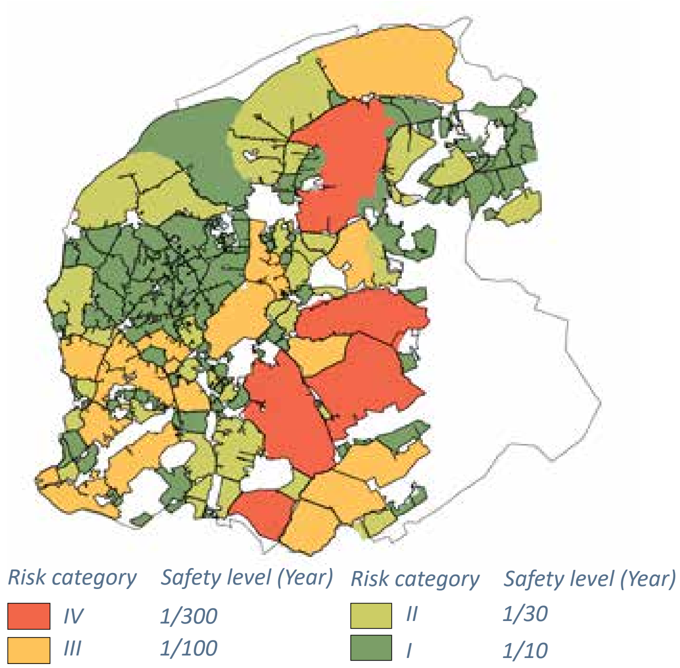


Figure 30 *Risk categories*

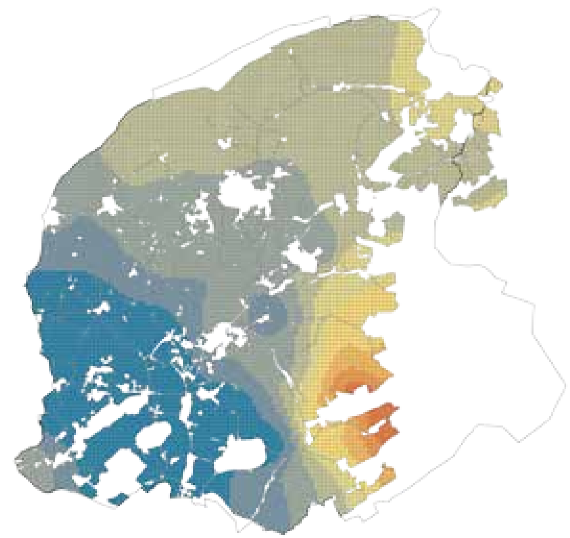


Figure 31 *Normative water level of the Frisian system of reservoirs for superfluous polder-water*

These zones are 5 m at both sides of the embankment.

Wetterskip Fryslân is responsible for the maintenance fo the regional embankments, when the goal of this maintenance is to improve the stability and/or the maintenance of the profile of the embankment. Owners of the regional embankments (mostly farmers) are responsible for normal maintenance, which means:

- Combating harmfull wild
- Recovering of small damage at the embankment
- Keeping the embankment free from garbage and brushwood
- The maintenance of vegetation which serves the functioning of the embankment' (Wetterskip Fryslan 2014b)

There are more important factors when designing an embankment, like the type of vegetation used at an embankment or the type of material used in front at an embankment at the riparian zone. Constructions in front of an embankment or on an embankment stabilize the embankment. The riparian zone in front of a regional embankment causes a deceleration of forces of the water in the Frisian system of reservoirs for superfluous polder-water which can damage the embankment. However this is dependent of the construction and use of materials in this riparian zone.

Often the design of the riparian zone is dependent of the result of technical calculations. However, sometimes other measures are being combined with the enforcement of regional embankments. An example of this is the measure to develop nature friendly shores at the Frisian system of reservoirs, imposed by the Kaderrichtlijn Water. This directive approved in 2000 imposes all the States of the European Union to improve the quality of the surface water to a certain level in 2015 (RIVM 2016). Also Wetterskip Fryslân and the Province of Friesland have to satisfy these norms. At paragraph 2.6 more information is given about this directive.

The location of the riparian zone when designing for example a nature friendly shore depends of land owners like farmers and the government, often Wetterskip Fryslân. It was already mentioned during this report that Wetterskip Fryslân wants to serve several goals during projects. This means that if they enforce regional embankments, sometimes they also want to establish nature friendly shores which could mean that the embankments must be moved. For example a farmer is often not happy with this, since he needs the amount of land for his bookkeeping so he can prove that he has enough land to drive out his fertilizer. In this way conflicts between several stakeholders can occur. At the next pages current materials, principles and nature friendly shores are shown to give an overview of what types of shores are designed by Wetterskip Fryslân.

3.4.4 LOCAL EMBANKMENTS

Local embankments can be divided into local embankments along the Frisian system of reservoirs for superfluous polder-water, called summer embankments and into local embankments outside the Frisian system of reservoirs for superfluous polder-water. Summer embankments are embankments along the Frisian system of reservoirs for superfluous polder-water which protect the lower lying summer polders against the higher water level of the Frisian system of reservoirs for superfluous polder-water. The summer polders are only drained during summer time. Local embankments outside the Frisian system of reservoirs for superfluous polder-water are embankments along an inner system of reservoirs for superfluous polder-water, embankments in barraged areas, or water level separating embankments. At local embankments the same rules are present as at regional embankments according to the maintenance of the local embankments. In appendix D images of a local embankment are visible.

Creation of a riparian zone/banks

Creation of 'high grounds'

Oblique of the outer slope

Figure 32 *Different design principles for regional embankments*

3.4.5 PROTECTION OF EMBANKMENTS

At appendix E some materials are shown which protect the embankment. Such materials prevent the embankment from eroding. Beneath in figure 33 nature friendly shores are illustrated which are developed by Wetterskip Fryslân. Such shores are especially designed to develop a new habitat for swamp and helophyte vegetation. Such vegetation helps to improve the water quality. Next to this, the vegetation helps to prevent the embankment from damage by wave run up. More about nature friendly shores at paragraph 3.7.1.

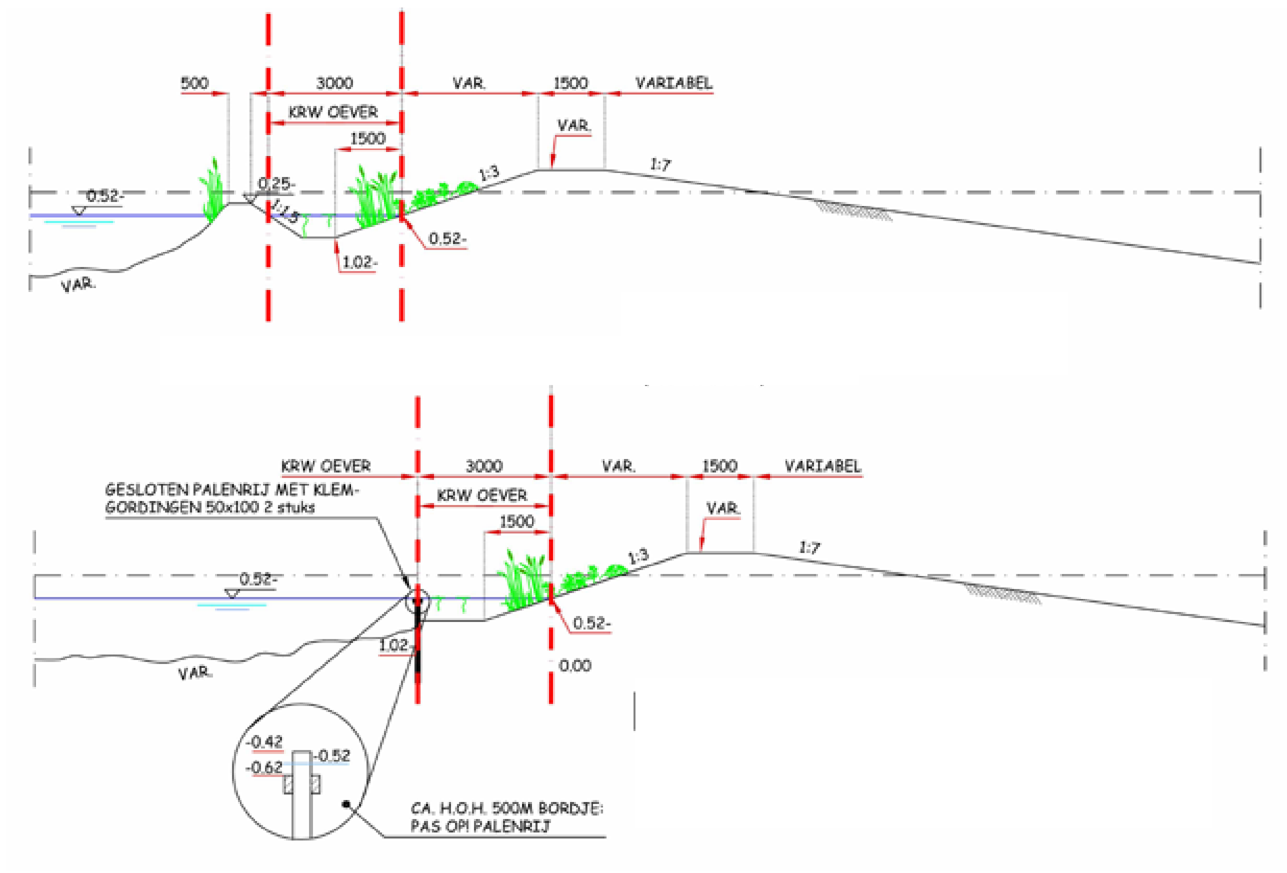


Figure 33 *Sections of nature friendly shores (Provincie Fryslân and Wetterskip Fryslân 2014)*

3.5 IMPORTANT FUNCTIONS

This water system makes specific functions possible. It was already explained that at the Frisian peat area dairy farming is the most important type of land use, and that is why Wetterskip Fryslân tries to adjust the water system to make this function possible. However also nature management is an important task of Wetterskip Fryslân. This function will be explained since it contributes to the quality and functioning of the water system in general.

3.5.1 NATURE AREAS

Nature areas in Friesland are mainainted by farmers or nature organisations like Staatsbosbeheer or It Fryske Gea. In figure 34 it is shown that nature areas are situated in the low lying areas of the Province, areas where water is available. In the stream valleys, nature nourishes itself with the seepage of the Drenths plateau and in the peat area nature benefits from the wet conditions. So these areas are mainly situated along water ways and lakes. As a result of drainage many areas in the Frisian peat area have declined, however nature areas or nature reserves have been drained less than agricultural areas and that is why nowadays the nature areas are the higher terrains in the Frisian peat area. Although, since the surrounded agricultural lands are still subject to intensive drainage, the groundwater in some nature areas often declines as well. As a result of this, specific swamp vegetation that helps with improving the water quality and other positive processes according to the functioning of the ecosystem dissapear. In figure 35 it becomes visible that many nature areas at the Frisian peat area are surrounded by areas with low water levels.

Wetterskip Fryslân tries to make several functions at the peat area possible. It becomes clear that serving all these functions leads to conflicting interests and negative consequences.

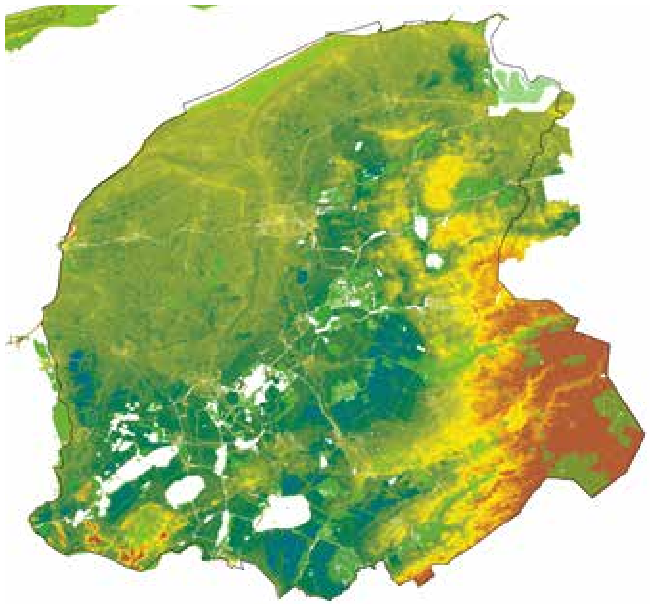


Figure 34 *AHN 2014 in combination with nature areas*

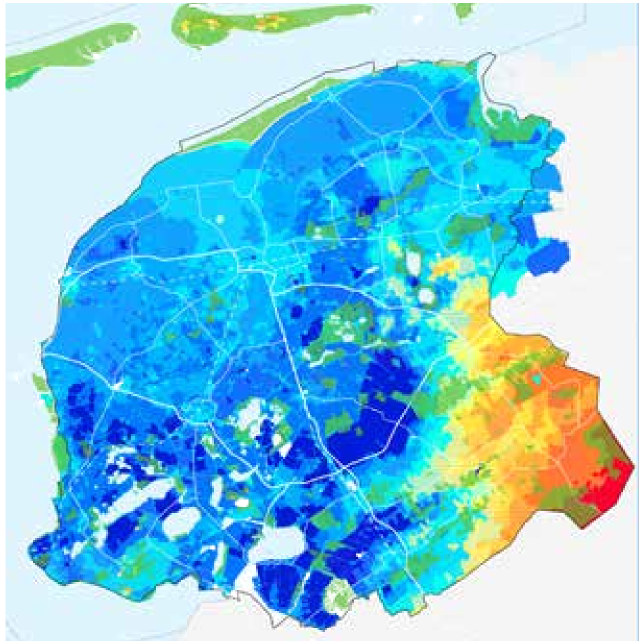


Figure 35 *Water level map in combination with nature areas.*

3.6 THE NEW WETTERSKIP FRYSLÂN

Around the turn of the century, the urge to think about how to deal with the effects of climate change, the soil subsidence and other changes in the Netherlands increased when it came to the water management of Friesland and the Netherlands. That is why in 1999 the State Secretary of Infrastructure and Traffic together with the chairman of the Union of waterboards asked the commission of Water Management for the 21th Century to give advise about future planning decisions about these challenges related to the water management. Also the floods of 1998 were an occasion for this ask for advise.

The Commission of Water Management for the 21th century did research to expected changes. Based on studies at the effects of for example climate change on the water management in The Netherlands, in May 2000 the second Water Maintenance Plan (Provincie Fryslân 2015) was published by the Province of Friesland. Also the first Integral Water Management Plan of Wetterskip Fryslân was based on the studies of the Commission of Water Management of the 21th Century. This Integral Water Management Plan is the further detailing of agreements made at the Water Maintenance Plan (Provincie Fryslân 2015) of the Province of Friesland. Also later studies of the Commission of Water Management for the 21th Century were taken into account while making decisions about the future water management of Friesland.

The Commission of Water Management for the 21th Century introduced a new way of thinking in the Dutch water sector: To retain water, to store water and after this, to eliminate water. This way of thinking was introduced to prevent waterboards to push off problems about the water management, since different waterboards are sometimes part of one catchment area. (Ter Haar and Polhuis 2004).

The challenges for the water management for the 21th century mentioned by the Commission of Water Management of the 21th Century were also the occasion to form the Nationaal bestuursakkoord water (NBW). The challenges needed a long term approach, since they could not be solved within a couple of years. In this 'bestuursakkoord' it was mentioned how the water management policy for the 21th century would look like. A starting point of this bestuursakkoord was that in 2015 enough measures were taken to cope with the problems like climate change effects, soil subsidence etc. and its effects on the Dutch water system. The parties who signed this bestuursakkoord were the Dutch Government, the Union of Waterboards (UvW), The Interprovincial Consultation (IPO) and the Association of Dutch municipalities (VNG). An important agreement was that measures taken by this cooperation of parties to cope with the problems and challenges mentioned earlier, should also lead to a better quality of soil and surface water as mentioned by the European Kaderrichtlijn water (KRW).

This new way of thinking to retain water at a certain place, to store it somewhere and then to eliminate it, lead together with the agreements mentioned in the National Bestuursakkoord Water to specific measures according to the water management in Friesland. This new way of thinking is first explained together with its specific measures within Friesland.

3.6.1 RETAIN WATER

It was predicted there would be more intensive periods of rainfall as a result of climate change. This would have direct effects on the water system. When retaining water at higher areas, like the gravitational discharge areas at the Eastern part of the province, a decrease of the water level at the Frisian system of reservoirs for superfluous polder-water could be realised.

3.6.2 WATER STORAGE

Water storage means that water is stored for a short period at retention areas. There are two types of water storage areas: retention areas and calamities areas. The first one is used during events which occur more than once in a hundred years and the second type is used no more than once in a hundred years. (Ter Haar and Polhuis 2004). As a result of the introduction of this measure in combination with the measure 'retain water' mentioned by the Commission for Water Management of the 21th Century Wetterskip Fryslân stated that 1400 ha extra retention zones needed to be created to assure that the water level of the Frisian system of reservoirs for superfluous polder-water did not cross the normative level of the Frisian system of reservoirs. Wetterskip Fryslân stated: 'Even if there is a limitation of eliminating water out of the Frisian system of reservoirs for superfluous polder-water, it will be possible to store water of this system by using this measure, without a high water level in the Frisian system of reservoirs, whereby damage could be possible' (Wetterskip Fryslân 2014a).

3.6.3 WATER ELIMINATION

To secure that water can be removed out of the Frisian system of reservoirs for superfluous polder water by using water pumping stations. During the presentation of the report 'waterbeheer 21e eeuw' developed by the Committee Water Management for the 21th century, there were already pumping stations which discharged water out of the Frisian system of reservoirs to theLake IJssel, the Waddensea and the Lauwers Lake. However, at that time an extra water pumping station in the North-eastern part of the province was already a wish. But based on calculations of the sea level rise, even with a new water pumping station, it would be hard to eliminate water by using gravity into the Waddensea. That is why the whole system to keep the water, to store the water and to discharge the water out of the Frisian system of reservoirs for superfluous polder-water is important to think about, since those have a huge influence on each other.

3.6.4 CURRENT WETTERSKIP FRYSLÂN

At 1 january 2004 a new waterboard was installed in Fryslân. Now Wetterskip Fryslân did not exist of one main organisation with several departments. No, now Wetterskip Fryslân existed of one organization who controlled the whole watersystem within Fryslân. But how would this new waterboard organize the watersystem?

Wetterskip Fryslân is a governmental organization which is responsible for the water management in the Province of Friesland. Its main tasks are to secure the safety behind the Frisian dikes, to secure enough water and to secure clean water. How Wetterskip Fryslân will manage to fulfill these tasks is written in the Water Management Plan 2016-2021. This document is tuned with the second Water Maintenance Plan of the Province of Friesland and it follows national policy about water management mentioned in the National Water Plan.

Since half of the Netherlands is situated below see level the Dutch government developed guidelines like the 'National Water Plan' (Rijksoverheid 2015) in order to cope with the climate changes. In this NWP five ambitions are mentioned:

1. 'The Netherlands have to stay the most safety delta of the world. To realize this, the safety standards are being renewed.
2. More attention is given to the improvement of the water quality to secure enough clean fresh water in the Dutch waters.
3. The Netherlands must be planned at a climate proof and waterrobust way.
4. The Netherlands is and stays one of the best countries at the level of watermanagment and waterinnovation
5. The Dutch must start living with more attention to the water they use' (Rijksoverheid 2015).

Those ambitions are pursued by those who are working on the environmental planning of the Netherlands, like governments, companies, knowledge organizations etc. Wetterskip Fryslân is a governmental organization which also must try to achieve those ambitions. Therefore the ambitions are translated by Wetterskip Fryslân into governmental documents. Two examples of such documents are The safety plan 2008, Safety plan II and 'Kaderrichtlijn Water' (also mentioned as KRW). Such documents are important for decisions about the environmental planning of Friesland. The measures taken by Wetterskip Fryslân are mentioned in such documents.

2.6.5 SAFETY PLANS

The urge to think about problems related to the water management in general and in the Frisian peat area increases and will increase. Changes in the climate system lead to sea level rise, more intense precipitation events and temperature changes (KNMI 2014). The Netherlands is a vulnerable country when thinking about these changes. More intense precipitation means more water in the Frisian water system. And more water which must be eliminated from cities and agricultural terrains. It also means that the chance on curled discharge of water of the Frisian system of reservoirs for superfluous polder-water into the Waddensea by souring sluices increases and the total discharge capacity of this water in the Waddensea becomes less (Wetterskip Fryslân 2014a). Two reports, Safety plan I and II, developed by Wetterskip Fryslân explain the approach of Wetterskip Fryslân about how to adapt the current water system in Friesland to such new climate conditions.

SAFETY PLAN 2008

The Safety plan is an important document since it contains importains decisions based on the study 'To retain, to store and to discharge the water'. This study was done in order to deal with the effects of climate change according to the Frisian water management (Wetterskip Fryslân 2008). The most effective measures of this study were translated into decisions which were documented in the Safety Plan 2008. The most important measures in this document for the Frisian system of reservoirs for superfluous polder-water were:

- The expansion of the Frisian system of reservoirs for superfluous polder-water with 1400 ha.
- The realisation of water storage areas (700 ha)
- Realisation of an extra pumping station at Harlingen.
- Realisation of an extra water pumping station called Vijfhuizen with a capacity of 4,3 m3 per second.
- Anticipating at the weather forecast.

Some important measures for the subsystems:
- Extra surface water in the subsystems (1650 ha)
- Extra capacity of the polder-water pumping stations (expansion of 20.000 ha with 10%)
- Steer with barrages (10.000 ha)

Currently 789 ha of the measure 'The expansion of the Frisian system of reservoirs for superfluous polder-water with 1400 ha' is realised. Next to this the total 700 ha of storage polders is realised and 400 ha of extra surface water in the subsystems of the 1650 ha. Also in the subsystems 10.000 ha is steered by barrages.

SAFETY PLAN II

Since in 2014 new climate scenarios by the KNMI were presented, an actualisation of the Safety Plan was necessary. This was an occasion to develop the Safety Plan II. The Safety Plan II is developed to give final desicions about the policy and measures to prevent Friesland from flooding. The plan contains calculations which take into account the newest climate scenario's. Those calculations are used to determine the normative water level of the Frisian system of reservoirs for superfluous polder-water 'MBP' in high water situations. By determining the MBP new insights were given about the current flood risk and the flood risk of the coming 34 years.

The current water level of the Frisian system of reservoirs for superfluous polder-water in Friesland complies the norms, however it does not comply the norms for 2050. With the current system the MBP in 2050 will be 12 cm higher than in the current situation and 10 cm higher than the medium heights of regional embankments in Friesland. So this brings enormous risks for the safety of Friesland. Therefore measures must be taken to be sure that the water level of the Frisian system of reservoirs also meets the standards in 2050. Therefore some measures are developed by Wetterskip Fryslân.

In the Safety Plan II Wetterskip Frsylân explains that 1 % extra water depository can compensate the effects of climate change. This means for example that extra space for water storage during intense precipitation events will be able to decrease the water level at the Frisian system of reservoirs. Another option is to create extra water pumping stations at the edges of Friesland. However, the expansion of the capacity of water pumping stations to discharge water from the Frisian system of reservoirs for superfluous polder-water into the Waddensea or the Lake IJssel does not have enough effect to prevent floods. However it can shorten the time of flooding periods.

For the year 2050 a mean water level of -0,06 m N.A.P is calculated for t100. This is a measurement for the water safety of the Frisian system of reservoirs for superfluous polder-water. It means that there is a chance of one on a hundred years that there will be a flood. This water level is 10 cm higher than the normative water level for the Frisian system of reservoirs for superfluous polder-water. This normative water level is used at calculations at the embankment enforcement projects which are currently going on under the name 'kadeherstelprojecten'. These projects enforce the regional embankments in Friesland to a certain dimension and stability. However, as a result of soil subsidence in the Frisian peat area, such embankments decrease and must be enforced, in theory, every 30 years. In reality this happens more often and suchs regional embankments are and will become huge expenses, since the process of peat demolition is not over yet. If then also the normative water level would rise in the future, suchs regional embankments must be enforced more intense, which would mean another huge expense and less guarantee for a safe water system. However, after during re-enforcement of embankments, the embankments are enforced to a higher level than necessary. This to compensate peat compression and soil subsidence.

For now the mean water level calculated for t100 pleases the safety standards of the Frisian regional embankments, however in the near future, the mean water level is higher than the safety standards of the regional embankments. That is why actions must be taken to keep the normative water level at -0,16 m NAP.

No single measure is effective enough to decline normative water level calculated for 2050. That is why it has been calculated which measures together can have enough effect to decline this normative water level calculated for 2050. The actions: developing an extra pumping station in Harlingen and creating more space for the Frisian system are together most effective to warranty a normative water level of -0,16 m NAP or even lower for 2050. So the realisation of 600 ha of extra space for the Frisian system of reservoirs for superfluous polder-water (800 ha is already realized), the planning of 1500 ha water depository areas in nature reserves and the realisation of a pumping station (gemaal) with a capacity of 30 cubic meters per second is calculated as the best set of options, to compensate the effects of climate change untill 2050.

The Safety Plan II sees the Frisian system of reservoirs for superfluous polder water as one system with one fixed water level. The measures which together are most effective in the long term are based on an analysis of the whole Frisian water system including the subsystems. As well as the Safety Plan 2008 as Safety Plan II do not mention where in the Province of Friesland expansion of the Frisian system of reservoirs for superfluous polder-water can be realised. It only mentions that it can be realised as the construction of nature friendly shores. In this way extra water retention is created and together something is done to improve the water quality in the Frisian water system. At appendix F it is shown where nowadays measures are taken which follow the decisions taken in the Safety Plan II.

So now it becomes clear what policy Wetterskip Fryslân maintains in order to develop a robust water system. A system which tries to serve current functions and which can deal with more and more extreme precipitation events, drought, etc. However, not only policy is made, also direct measures and related policy are developed which show how Wetterskip Fryslân tries to obey to this policy.

3.7 PAST AND CURRENT MEASURES

At the moment Wetterskip Fryslân and Provincie Fryslân are working on several programms to secure the safety of Friesland, to work on clean water in the Frisian water system and to work on measures which solve or soften current problems related with the Frisian water system. These are all related to earlier mentioned policy of Wetterskip Fryslân.

3.7.1 EMBANKMENT RECOVERY PROGRAM

The embankments in the province are of great importance for the safety of Friesland. Therefore they must stay strong. As a result of soil subsidence and other factors, especially regional embankments decrease and become less strong after a certain time period. Therefore Wetterskip Fryslân is currently enforcing 400 kilometers of regional embankments.

They hope to finish this job at the end of 2027. However, such embankments are enforced for a period of around 30 years, but in practise they must be enforced every 15 years at some places. This means that this process of embankment enforcing will continue also after 2027.

3.7.2 FUTURE PROOF WATER MANAGEMENT

The program future proof water management tries to develop a long term vision for a sustainable, robust and climate proof water system managed by Wetterskip Fryslân (Wetterskip Fryslân 2015a). The main occasion for this are the (predicted) changes of the climate and demolition of the peat which will cause in increase expenses to keep the water system safe and to serve functions like agriculture, living and nature.

For this program some studies have been executed to find out ways to reduce the increase of expenses for the water system while serving current functions. Studies at the Frisian rivers, the Tjonger and the Linde, showed that measures to retain or to store at the higher areas in Friesland (thus outside the Frisian system of reservoirs for superfluous polder-water) can reduce the normative water level of the Frisian system of reservoirs during periods of intense rainfall.

Most studies are focused to reduce the normative water level of the Frisian system of reservoirs which makes it for example possible to reduce the expenses for the reinforcement of embankments. No studies were executed yet to solve problems related to the soil subsidence at the Frisian peat, however, the Frisian Peat area Vision explained at page, will give more insight in current measures for problems at the Frisian peat area related to the water management.

3.7.3 GREEN BLUE SERVICES

Green Blue services focus at social needs related to nature, the landscape, recreation and water management. The Catalogue 'Green Blue Services' contains an overview of all green blue services which private land owners or land users can execute. (Europa decentraal 2016). 'The Catalogue, approved by the European Commission, is no arrangement, but it gives decentralized governments rules for compensation to companies that execute these Green Blue Services' (Europa decentraal 2016).

Wetterskip Fryslân uses Green Blue Services as a tool to acchieve their goals like water storage areas or KRW goals. For example farmers receive compensation for maintaining nature friendly shores. 'Next to this Wetterskip Fryslân also sees this measure as a tool to give stakeholders more responsibility. This can help to make small scale measures possible' (Wetterskip Fryslân 2015b).

3.7.4 PEAT AREA VISION

As a result of soil subsidence in the Frisian peat area many problems occured and many of those problems will be more worse in the future. In chapter 2 those problems were highlighted. Wetterskip Fryslân and the Province Fryslân are well aware of the impact of soil subsidence and therefore they developed the peat area vision. The Peat area vision was published at january 2015 and is therefore quite new.

'The vision for the Frisian peat area tries to provide visibility of a future for the area of an attractive living and working environment which enables people in the (far) future to live, work and recreate in the peat area' (Provincie Fryslân 2015).

The peat area is a working and living environment and therefore it is imporant that municipalities, the Province of Fryslân and Wetterskip Fryslân frame their futurual direction in relation to the water management and spatial developments. In this way, inhabitants and investors know what they can expect in the near future.

'The current peat are is 85.000 ha and exists for 62% of agricultural areas (mainly grass), 17% of nature areas, 17% of water and 4% of buildings and infrastructure' (Provincie Fryslân 2015). Much of this land is likely to decrease as a result of intense drainage for agricultural purposes. This leads to several problems (see chapter 2) The soil subsidence is not irreversible.

The peat area vision makes distinction between:

- Areas with a thin layer of peat; Especially in the eastern part of the Frisian peat area these areas occur. Measures to slow the process of soil subsidence hardly will have effect.
- Areas with a thick layer of peat; These areas occur mostly at the Western part of the Frisian peat area including the peat areas with a toplayer of clay and clay areas with a layer of peat. In these areas the process of soil subsidence is slower as a result of the presence of clay.
- Areas with a thick layer of peat and many opportunities when it comes to nature preservation, heritage, fundament problems, living environment etc.

According to the Province of Friesland and other developers of the Peat Area Vision there is no one package with measure, since 'the' peat area does not exists. There are several differences according to the soil, land use and landscape quality. However, they developed several 'no regret' measures which will be implemented in the whole peat area to slow the process of soil subsidence and to contribute to solutions for current problems occuring in the peat area as the result of peat demolition:

- The restriction of drainage of land to a maximum of 90 cm, also for areas whith a top layer of clay and underneath peat layers.

- Higher water levels during summer time at the clay on peat areas and the transition zones from clay to peat (ca 54.000 ha)

- Setting more zones with high water levels near builded areas when this will be cost efficient and effective.

In the Peat Vision, nine areas are mentioned where the Province of Friesland wants to discuss measures with the people living in those areas about how the values of those peat areas can be protected. In those areas it is about measures to rewet the nine specific peat areas. This rewetting is more intensive than it will be in other non specific peat areas. In these specific areas tests will be going on to see if there is a future for other crops which can sustain in wet areas. Or tests about under water drainage will be carried out here. Only with the cooperation of the people living in the areas.

The Peat vision is currently hot topic in the province of Friesland. It is clear what must be done to carry out the peat area programm, however it is not yet clear what the effects will be of the points mentioned the execution programm of the peat area vision. For example it is not yet clear which measures will be taken in relation to nature preservation in the peat area or how the peat area will look like in 50 or hundred years when executing measures. For now only some decisions are taken about how measures can slow the process of soil subsidence and also sustain the current type of land use.

Peat is entirely concerned with the water management of the Frisian water system. And therefore it is important to have a vision about how Friesland must look like in 50 or hundred years. Both governmental organizations (Provincie Fryslân and Wetterskip Fryslân) do not have a clear view yet of this, while this may be one of the most starting points of measures taken to preserve the Frisian peat area, or to create a robust water system.

3.7.5 WATER AREA PLANS

Wetterskip Fryslân understands the current problems occuring in the Frisian peat area and in Friesland in general when it comes to water management. Therefore at the time Wetterskip Fryslân is busy with developing 'water area plans'. For 20 area in Friesland such specific water area plans are being developed. Some are already finished. 'A water area plan contains the information about how Wetterskip Fryslân wants to carry out the water management in the area and how Wetterskip Fryslân wants to tackle problems in the area related to the water management' (Wetterskip Fryslân 2016b). Subjects which are being discussed during the development of a water area plan are:

Desirable water level management: Together with stakeholders Wetterskip Fryslân investigates if the water levels are tuned with the use of the soil. For example agricultural land needs lower water levels than nature areas.

Maintenance: To handle the right water management it is being discussed where for example an extra pumping station must be installed.

Problems: flooding problems and desiccation problems are analysed. Measures to prohibit these problems are being designed.

Clean water: to improve the water quality in the Frisian water system, Wetterskip Fryslân tries to create nature friendly shores. In every area Wetterskip Fryslân sees where such shores can be created in order to improve the water quality.

The steps taken for the development of a water area plan are as follows:

Step 1: What is going on in the area?
In this first step the area is being analysed to find out where problems occur. The results are discussed with the area managers of Wetterskip Fryslân.

Step 2: Solutions
Since the areas are quit large Wetterskip Fryslân does not come up with direct measures, it only highlights the direction in which the Wetterskip wants to go with the water management. These directions are discussed with stakeholders of the area (farmers, municipality etc.)

Step 3: Design
Together with all the information of the stakeholders and the anaylsis of the area a water area plan is being developed for the area.

Step 4: Final design
During this phase people living in the area or stakeholders can protest against the plan. Wetterskip Fryslân will react upon such protests.

Step 5: Realisation
In this last phase measures are taken to carry out solutions and decisions described in the water area plan.

CONCLUSION

What becomes clear is that such water area plans are focused on the water management and especially on the land use occuring at the areas in relation with the water management. Wetterskip Fryslân adapts the type of watermanagement to the type of land use occuring in the areas like dairy farming. However there is no overlapping vision about the water management in the province in which chances are explained in relation to the water management. Although, a starting point of Wetterskip Fryslân is to achieve several goals in different fields (ecology, recreation, etc.) when taking measures to improve the water management.

3.7.6 KRW MEASURES

To improve the Frisian water quality of the surface water, Wetterskip Fryslân has to satisfy the norms of the Kaderrichtlijn Water (KRW).

'Het doel van de Kaderrichtlijn Water (KRW) is een goede ecologische en chemische toestand in alle grond- en oppervlaktewateren in de EU in 2015. Onder voorwaarden is fasering tot uiterlijk 2027 mogelijk' (Provincie Fryslân and Wetterskip Fryslân 2014). Nowadays the water bodies in the Frisian water system do not satisfy the goals set by the KRW. To acchieve the goals of the KRW it is possible to phase measures untill 2027, since in this year the KRW goals must have been acchieved. Especially the ecological goals need some focus.

In 2009 the measures to reach the KRW goal in 2027 was set up. However every 6 years the measures in relation with their efficienty are evaluated. It means that there can be a change of the measures that will be taken to improve the ecological and chemical quality of the water bodies. For the comming 6 years Wetterskip Fryslân has written a KRW beslisnota. This means that they evaluated the measures taken in the past 6 years and they now give their adjusted measures and the argumentations to acchieve the goals set by the KRW.

To determine if the ecological situation in the waterbodies is good, several scales are used. Scales for the phytoplankton, macrofauna, water plants and fish. Since there is a high level of Brasem (fish species) in the water, the discernment has not yet reached the accepted level. Brasem routs the silt and as a consequence the water gets cloudy. This is also a result of the high phosphate level.

Every nation within the European Union has to provide 'stroomgebiedbeheersplannen'. The goals and measures for the water areas in the Netherlands must be mentioned in KRW factsheets. Those factsheets form the basis of the stroomgebiedbeheerplannen. Also Wetterskip Fryslân must provide such KRW factsheets together with the measures of how they want to reach the KRW goals (the good ecological quality and chemical quality of the bigger water areas). The factsheets are coupled on types of water bodies. There are four types of water bodies: M-types (meren- lakes), R-types (rivieren-rivers), K-types (kustwateren-coastal water areas) and O-types (overgangswateren, transition zones) (Ollie et al 2011). For this thesis the focus will be on the M-types.

The KRW judges water bodies on its physical and chemical and biological quality. Therefore different standards were developed. EKR, ecologische kwaliteits ratio.

A method often used by Wetterskip Fryslân to acchieve the goals of the KRW, natural friendly shores are often developed along the shores of lakes and water ways within Friesland, so also in the peat area of Friesland. They are also a measure to establish non-aquatic nature. For example to create ecological transition zones between land and water. Nature friendly shores are developed along the embankments. There is no direct distinction between the embankment and its adjacent shore, however the shores along an embankments often exist of three different zones as mentioned in chapter 3.

Natural friendly shores increase the ecological quality of the water body, since extra flora and fauna develops in the area, although another effect of natural friendly shores is that they purify the water. The macrophytes capture and remove nutrients from the water. As a result of this the chemical water quality will be improved. A part of the nutrient stays in the vegetation and will be transported into the rizosphere. Another part of the nutrients will come back into the water, since plant material will die. However the nature friendly shore also prevents re-suspension of dead organic material, since the shore largely exists of water and swamp vegetation. The more biomass, the more nutrients stored per unit area. By reducing the supply of nutrients from elsewhere, the water quality can be improved. Less nutrients in the water means a better water quality which is clearer. Much nutrients in the water means the water will be more clowdy.

Wetterskip Fryslân often tries to develop nature friendly shores at places where also other problems occur or where other interventions in the water system must be done. The approach the organisation follows is to create work with work. This is also the point with the current programme: The embankment recovery programme. At this programme regional embankments are enforced to a certain height, since they decline or become unstable as a result of soil subsidence or erosion. This re-enforcement takes more often place in the Frisian peat area than in the other areas of Friesland, since in the sand terrain embankments are missing and in the clay areas, embankments decline less hard as a result of the conditions of the soil. During the process of re-enforcing the embankments Wetterskip Fryslân tries to design nature friendly shores in front of the embankments.

3.8 IMPROVED PROBLEM STATEMENT

Water safety becomes a problem with the current and futural conditions. This mainly as a result of soil subsidence and climate change. If we want to increase the water safety in Friesland, huge expenses must be made. With the changing conditions, the costs of the water management in 2050 in the Frisian peat area will increase with 30%. And then the increase in expenses in other parts of the province are not even included. By preserving the current land use, large expenses must be done to create the right conditions, since there will be an increase of rain during winter together with more extreme precipitation events during summer. In the Frisian peat area this means for example higher costs for a freeboard of around 90 cm and fast removal of surplus water. However the biggest increase of expenses will be caused by the enforcement of the regional ebmankments. They need to be enforced which will be an increase of 18% of the costs of the water management in the Frisian peat area untill 2050.

And then the CO2 emission has not even been mentioned. Securing the current type of land use at the Frisian peat area maybe supports farmers, but what will the effect be of the millions of tons of CO2 in about 100 years? While current policies are all working on sustainability, it seems that Friesland does not share the same perspective on this.

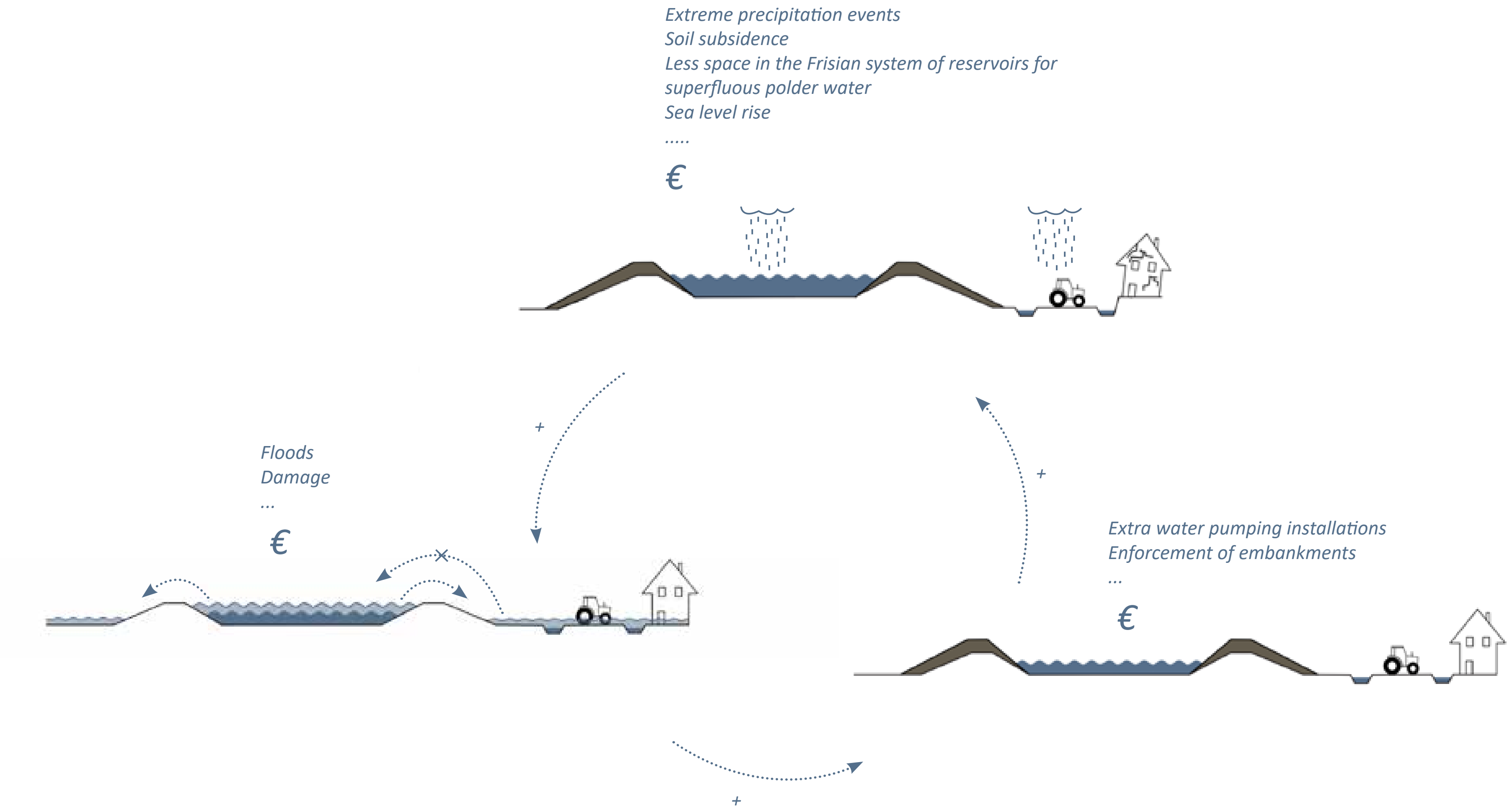
The question if we want to secure the water safety in Friesland is not hard to answer, however another question arises: Do we want or do we need to preserve current land use at the Frisian peat area? If this type of land use in the Frisian peat area causes problems which will be more worse in the future and if this type of land use as a result of these self-caused problems together with changing climate conditions causes an increase in the costs of the water management; is it then smart to preserve this type of land use? However, from this reflection, it almost seems that it would be smarter to create a peat area where the water management and current functions lead to a self sustaining system.

There are some other problems like the increased amount of nutrients in the surface water, however, these are all related to the type of land use, past activities of the type of land use (inpoldering of former boezemlands etc.) and climate change. So again, if we want to continue by having a safe environment with a decreased flood risk and an affordable type of land use there must be searched for measures which combine these goals. Measures which at the short or long term lead to a less expensive water system compared to the current water system. Without creating problems and solving these by placing extra water pumping stations and enforcing embankments.

If we relate this to the current policy of Wetterskip Fryslân we see that at the one side Wetterskip Fryslân wants to serve current types of land use, however at the other side they want to do something on current and future problems like the negative effects of climate change, negative effects of soil subsidence etc. While the current type of land use in the peat area; agriculture; is a huge cause of these problems. The scheme at the next page (scheme 10) clarifies the current vicious circle in which Wetterskip Fryslân is setteld. However, within this thesis the transition to a more suitable type of land use at the Frisian peat area will take a central place. This other type of land use seems the solution for current and future problems occuring at the peat area. scheme 11 illustrates this. How a transition to such a type of land use could take place will be explained in the following chapters.

3.8.1 CURRENT WATER MANAGEMENT IN FRIESLAND

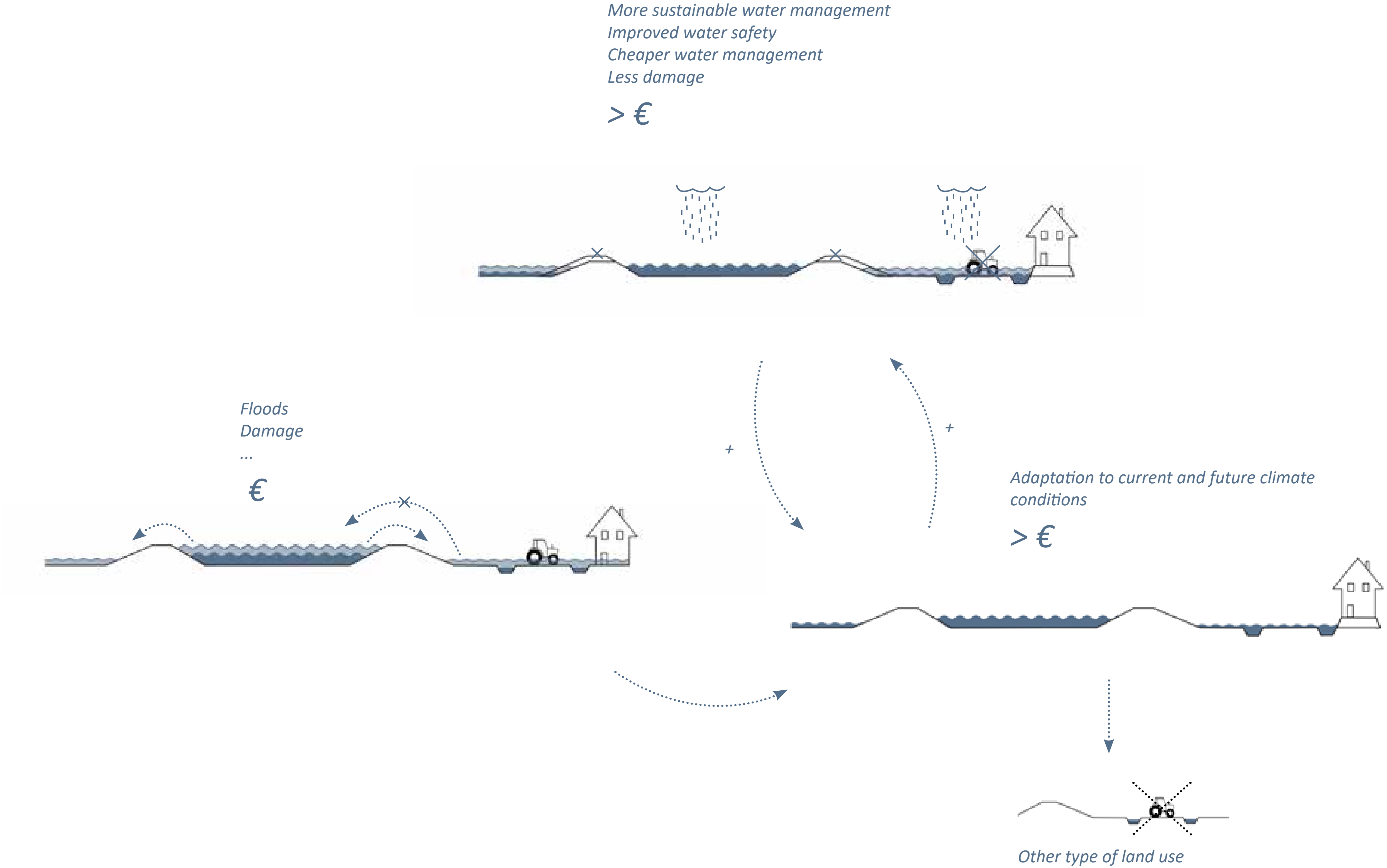
Serving the current type of land use



Scheme 10 *This vicious circle of Wetterskip Fryslân represents circle of problems at the Frisian peat area and measures taken by Wetterskip Fryslân to do something about the problem. However, this approach does not lead to a sustainable system*

3.8.2 FUTURE WATER MANAGEMENT IN FRIESLAND

Transition to another type of land use



__Scheme 11__ This scheme represents a possibility to escape the current vicious circle. The possibility is to adapt the type of land use at the Frisian peat area to current and future climate conditions.

4. DESIGNING A ROBUST WATER SYSTEM

4. DESIGNING A ROBUST WATER SYSTEM

4.1 INTRODUCTION

The main goal of this thesis is to find out what measures must be taken to let regional embankments be part of a robust water system at the Frisian peat area. To answer this question, it becomes important to understand what a robust water system is. How does Wetterskip Fryslân defines a robust water system and does this definition meets the information provided in previous chapters?

It already became clear that past and current activities as a result of the type of land use lead and still lead to problems. Problems like soil subsidence and a decreased water quality. In combination with changing climate conditions, the current water management must make huge expenses to serve the type of land use, dairy farming. Maybe at the short term these costs are incalculable, however, how about the costs in 100 years if we still want to serve the current type of land use? And is Wetterskip Fryslân then still able to provide an high level of water safety in the Frisian peat area?

A robust water system which contributes to current and future problems in the Frisian peat area means a transition to another type of land use, it means adaptation to the landscape in combination with adaptation to climate conditions.

First a definition of a robust water system will be given followed by the ingredients needed to design this system.

4.2 WHAT IS A ROBUST WATER SYSTEM?

First we have to understand what a robust water system exactly is. In the Cambridge dictionary robust means:

- Strong and unlikely to break or fail.

This is what the word robust means, but how does Wetterskip Fryslân sees the term robust water system? in the Water Maintenance Plan of 2016-2022 Wetterskip Fryslân mentiones that they ambition a robust water system:

- 'A water system (like a polder) which is able to prevent floods and dry periods, even during extreme weather conditions (Wetterskip Fryslân 2015b).

In chapter 3 it was already mentioned which measures Wetterskip Fryslân takes according to the Safety Plan II to reduce the water level in the Frisian system of reservoirs for superfluous polder-water during accidential situations.

When it comes to regional embankments there is another approach. In chapter 3 it was already mentioned that regional embankments are being enforced. Wetterskip Fryslân nowadays uses the approach 'risc oriented designing' when designing or enforcing regional embankments. This approach means:

- 'In a robust and resilient water system areas with big consequential damages will be protected more robust from flooding as a result of too much water in the Frisian system of reservoirs for superfluous polder-water than areas with less consequential damages' (Wetterskip Fryslân 2015b).

This new approach is focused on the regional embankments. In the study: 'Differentiatie Regionale Keringen', it was investigated if a more risk-oriented approach towards the protection of regional embankments would work. The outcome mentioned this new risk-oriented approach towards regional embankments as part of a robust water system.

There are a couple of reasons why Wetterskip Fryslân ambitions this more risk-oriented approach. Wetterskip Fryslân maintains hundreds of areas where different water levels are present. This in order to make specific functions like agriculture possible. This was and still is a very detailed way and thereby costly approach of maintenance. Next to this an important task of Wetterskip Fryslân is to maintain the current norms of regional embankments for the flood risk. However, with the rising water levels as a result of climate change, in many places in Friesland new adjustments are needed to secure the norms. 'At the long term, a more robust water system can lead to higher, but more acceptable risks for the control of various functions' (Wetterskip Frysân 2015a).

As explained before, Wetterskip Fryslân also developed the programme Future Proof Water Management. This programme tries to develop a vision of a sustainable, robust and climate proof organization of the water management. This programme still searches for measures to reduce the normative water level of the Frisian system of reservoirs for superfluous polder-water, while the type of land use at the Frisian peat area forms and will form the biggest problem according to the water management.

So now it becomes clear how Wetterskip sees a robuust water system for Friesland and how Wetterskip Fryslân tries to give meaning to this by taking measures mentioned in the Safety Plan II and the risc oriented approach related to the enforcement of regional embankments. Such measures maintain a system in which the type of land use is served. This, while the type of land use at the Frisian peat area is the biggest cause of current and future problems (higher expenses, soil subsidence, climate change etc.) Water will come out of the air, now and in the future. If this water already causes damage in the rural areas, how will this be in the future? Why then searching for solutions to serve this type of land use instead of changing the type of land use to a more compatible type of land use which increases the carrying capacity instead of decreasing it?

4.2.1 CARRYING CAPACITY

'The concept of carrying capacity implies that the improvement of the quality of live is possible only when the pattern and level of production-consumption activities are compatible with the capacities of the natural environment as well as with social preference' (Fulekar et al. 2014) With other words: the carrying capacity means that the pattern and level of production-consumption activities are compatible with the capacities of the natural environment as well as with social preference.

Currently we see that past and current agricultural activities led and will lead to problems in the Frisian peat area. This type of land use is thus not compatible with the capacities of the natural environment, existing of climate conditions and the physical landscape. However, to make another type of land use compatible to the natural environment also the conditions of the natural environment must be clear. This includes the physical landscape and climate conditions. One of the basic principles of this thesis is to respect the conditions of the physical landscape. To make the pattern and level of production-consumption activities compatible again, thus to increase the carrying capacity of the landscape for a certain type of land use, the type of land use must adapt to climate conditions in relation with the physical conditions of the landscape.

However, how does this type of land use exactly look like and to what conditions must this type of land use comply other than adaptation to the physical landscape and climate conditions? This will become clear at paragraph 4.4.1 Here design principles will be formulated based on the problem analysis.

This information brings us to a new definition of a robust water system:

'A water system (like a polder) which is able to prevent floods and dry periods, even during extreme weather conditions, by increasing the carrying capacity of the landscape'

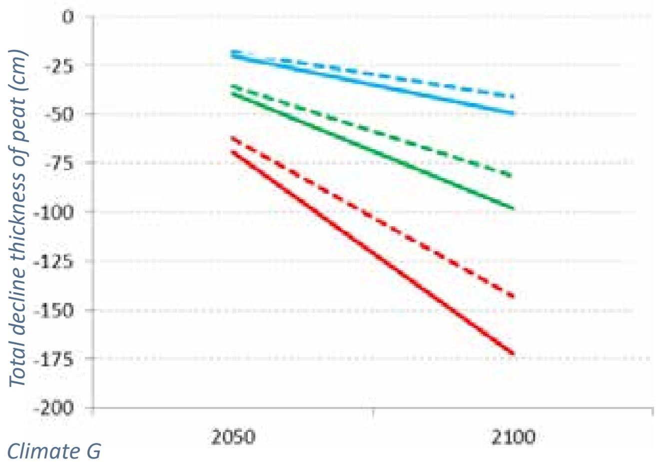
This thus has to do with:

- The physical landscape
- The type of land use
- The climate conditions
- Design principles

Those factors form the ingredients for the creation of a robust water system which contributes to solutions for current and future problems related to the water management at the Frisian peat area.

4.2.2 NECESSITY

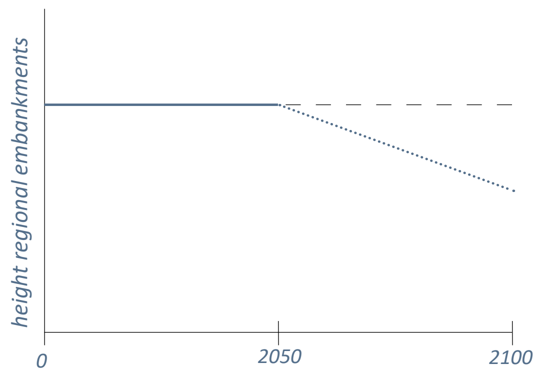
During the problem analysis it became clear what problems must be tackled during the next decades. Currently measures are carried out to keep Friesland protected untill 2050 (Wetterskip Fryslân 2014a). However, If we compare the speed of te processes like the soil subsidence (figure 36) with for example the current state of regional embankments (figure 37), we see that some interventions must be done before 2050 to compensate these negative processes and to keep Friesland safe. Thus a robust water system which contributes to solutions for current and future problems related to the water management in the Frisian peat area must be developed at 2050.



Climate G
- *Peat (without a layer of clay)*
- *Peat with a top layer of clay*
- *Clay with a peat layer in the underground*

Climate W+
- *Peat (without a layer of clay)*
- *Peat with a top layer of clay*
- *Clay with a peat layer in the underground*

Figure 36 *Total decline thickness of peat for KNMI climate scenario's G and W+ (Osinga et al 2014)*



- *Theoratical heigth of regional embankments*
- *Possible decline of regional embankments*
- *Standard heigth of regional embankments*

Figure 37 *The theoratical height of regional embankments at the Frisian peat area.*

4.3 APPROACH

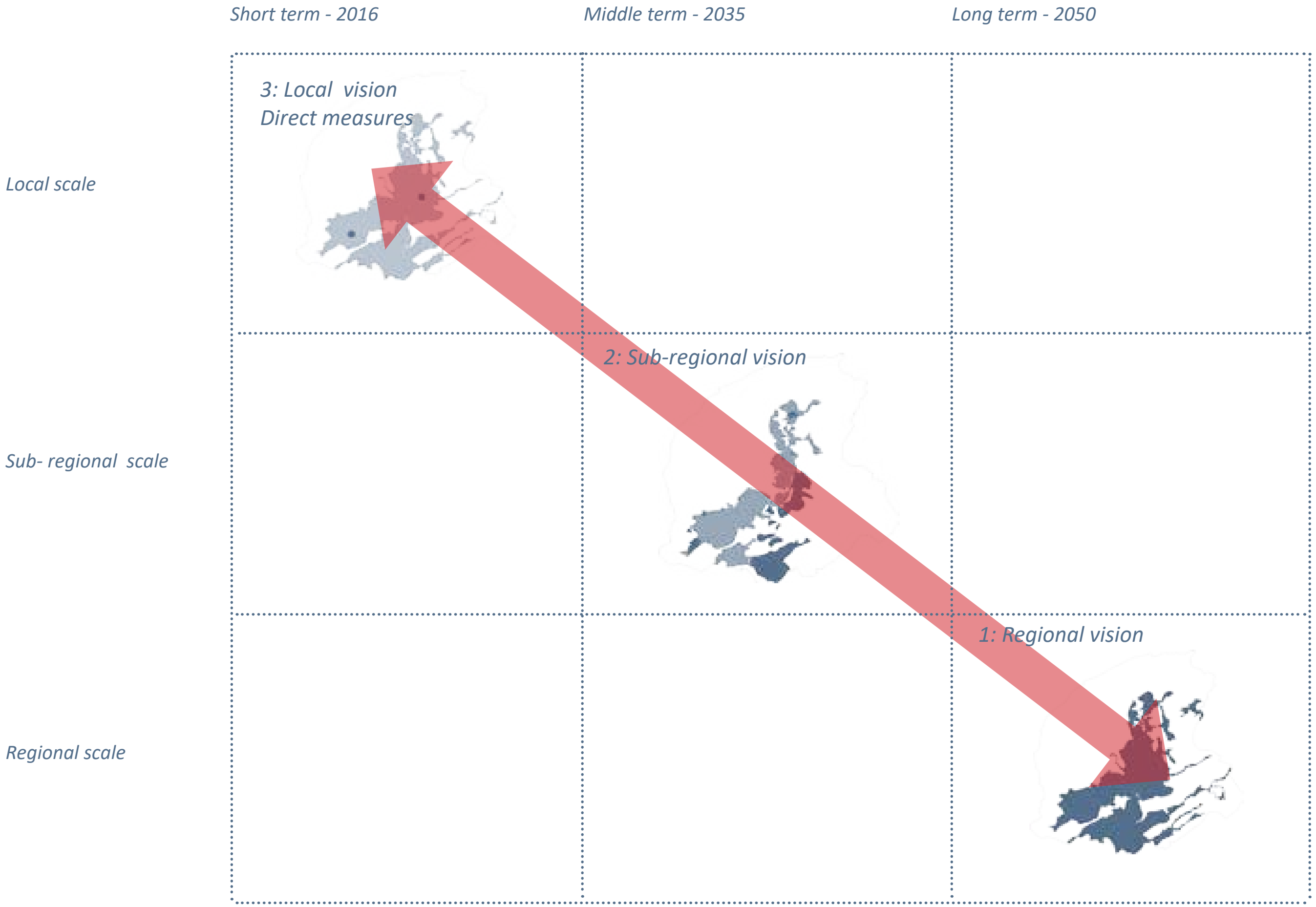
To design such a robust water system which means an increase of the carrying capacity of the landscape by developing a transition to another type of land use in the Frisian peat area, it is important to understand how this can be realised. Hereby the long terms starts to play a key role when thinking about taking measures today. The development of a robust water system must take into account the long term. In this way, no regret measures can be developed. Scheme 12 shows this way of thinking.

To increase the carrying capacity of the Frisian peat area in this case, means to make the type of land use compatible to the natural environment which includes the geomorphological conditions and climate conditions. So this means adaptation to climate conditions and to the physical landscape. Thus the new type of land use must comply this combination of conditions.

At the long term the physical landscape and the climate will change as partly became clear during the problem analysis. Since the physical landscape is a fixed factor, first these conditions must be clear in order to find out how adaptation to climate conditions will be possible there. Local and direct measures which can start today must take into account these changes. Therefore first a regional vision for the long term is developed which includes changes in the physical landscape and climate changes. It also includes the current situation of the Frisian peat area, since a transition to another type of land use starts at the current situation.

This general vision will be translated into a sub-regional vision and to local measures. These measures and visions will be related to each other. The starting point for possible measures is the current landscape and its adjacent landscape use. Therefore a flexible landscape must be designed where several developments are possible, since there is no one possible future. It means that current measures (step 3) must keep in mind the several possible changes in the future. This means that smart interventions must be done at the current landscape to create a flexible landscape in which the desired long term vision can be developed.

Next to different time scales also different areas will be taken into account (local - regional - sub-regional). At the next page the design process that will be used to design a robust water system will be explained.

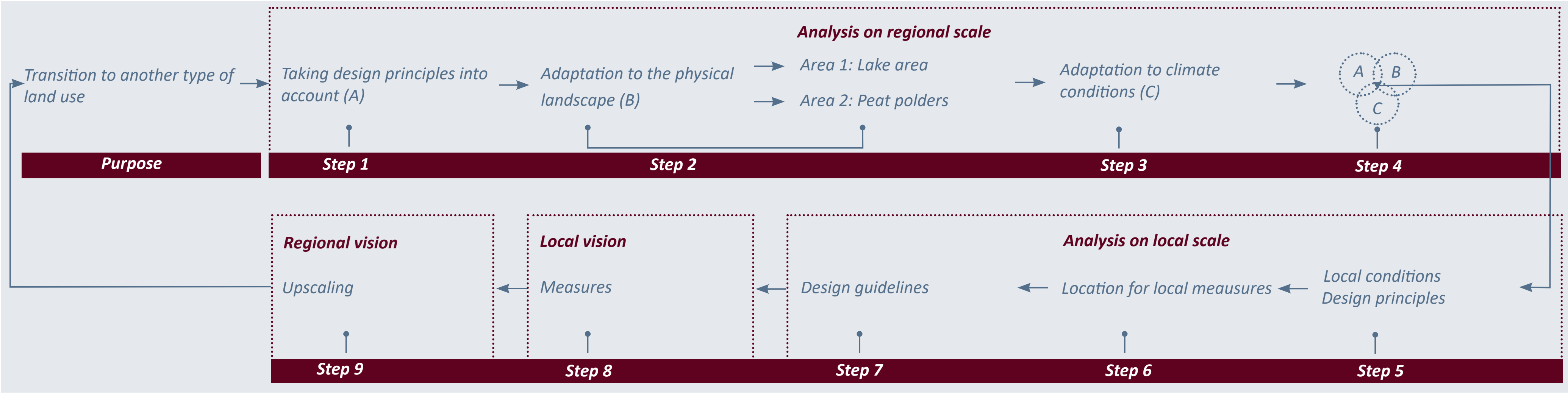


Scheme 12 *Approach for the development of a robust water system*

4.3.1 DESIGN PROCESS OF A ROBUST WATER SYSTEM

The design proces illustrates the steps that must be taken to design a robust water system and to gain answers to the main research question. The ingredients for the development of a robust water system mentioned at page 60 are incorporated in this design proces together with scheme 12 at the previous page. At the next pages and paragraphs every step of the scheme below will be highlighted.

DESIGN PROCESS OF A ROBUST WATER SYSTEM



__Scheme 13__ The design process of a robust water system. This scheme exists of several phases that will be elaborated at next paragraphs. The aim is to develop a robust water system to understand what measures/guidelines are needed to develop a robust water system at the Frisian peat area with regional embankments as part of this system.

4.4 SCALE ANALYSIS

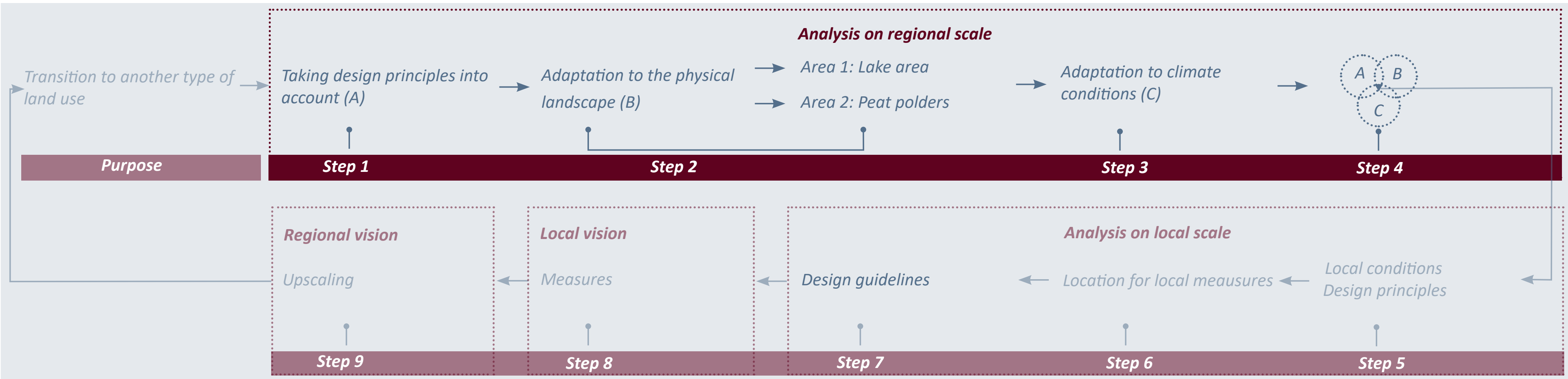
4.4.1 ANALYSIS ON REGIONAL SCALE

To find out how a robust system can be developed and how this will look, we start with analyzing the regional scale (figure 38).

Scheme 13 gives an overview of the steps that will be taken during the analysis of the regional scale. In the end it becomes clear to what set of conditions a type of land use must comply and how a regional vision for 2050 will look. This type of land use will increase the carrying capacity of the landscape.

Figure 38 *Regional scale*

DESIGN PROCESS OF A ROBUST WATER SYSTEM



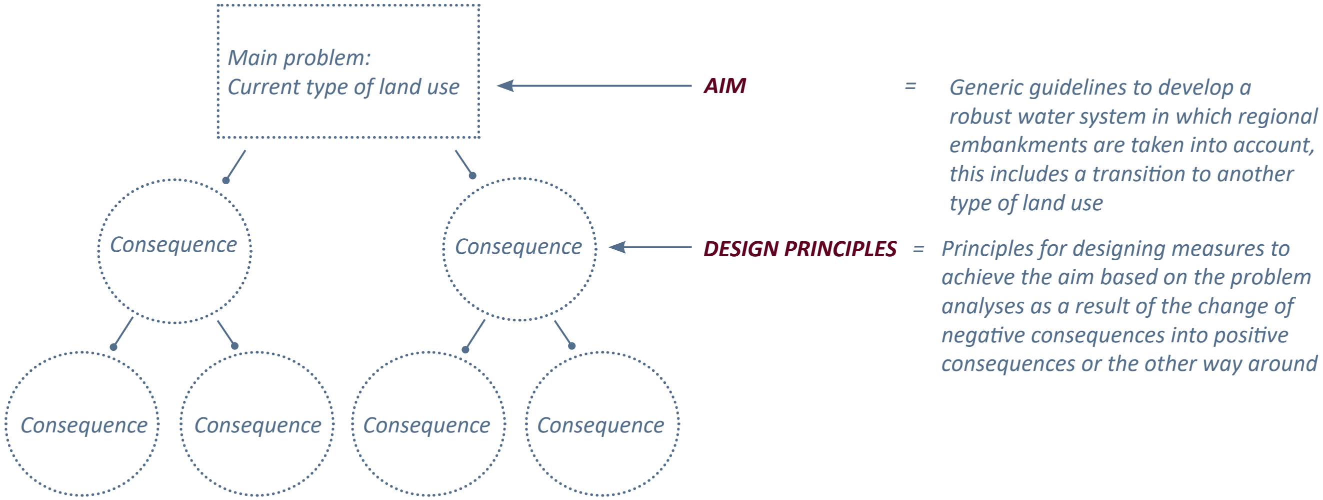
Scheme 13 *Design process of a robust water system*

STEP 1 DESIGN PRINCIPLES

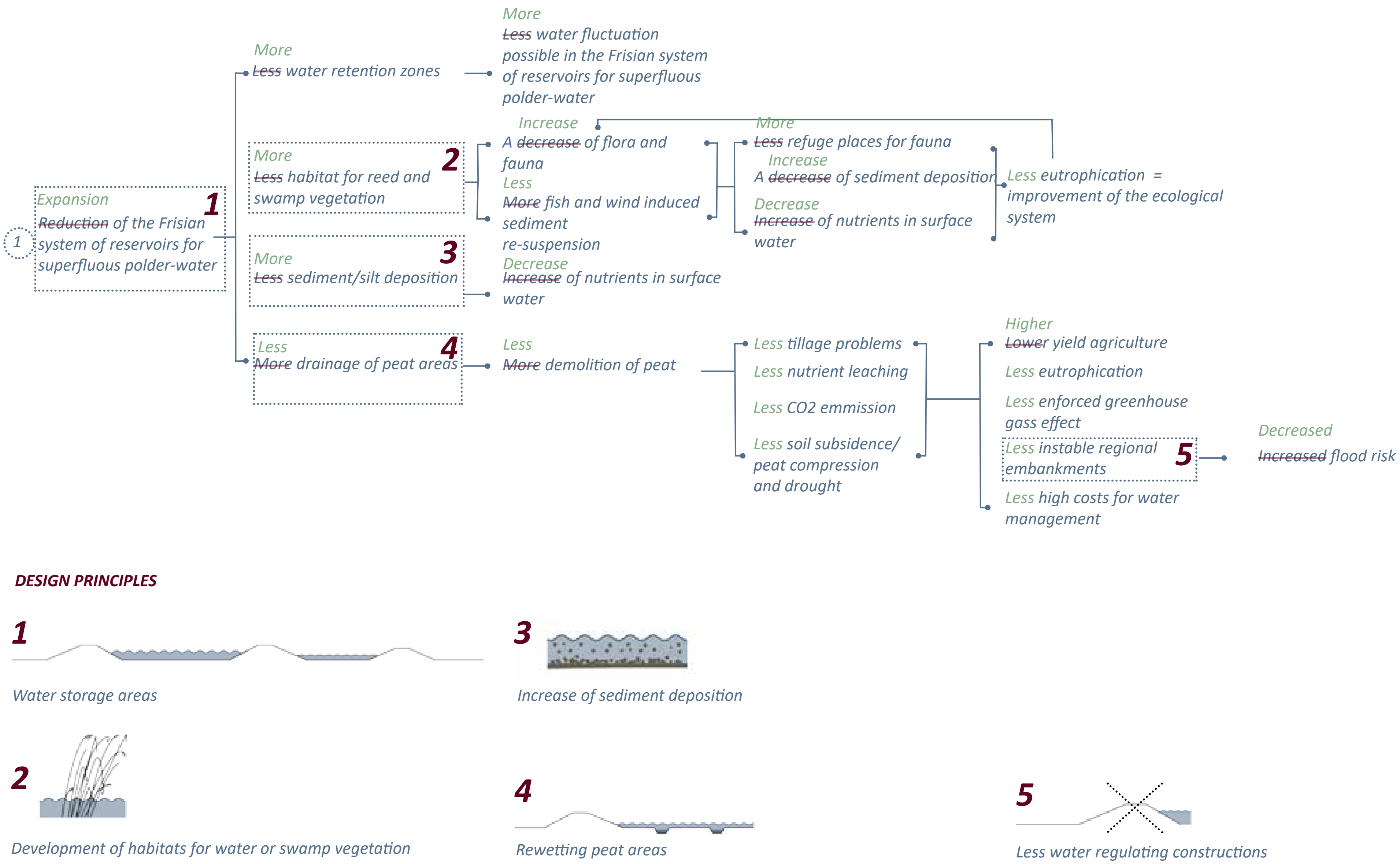
A transition to another type of land use is the main goal of the development of a robust water system. This became clear after investigating the problems at the problem analysis. The problem trees based on literature analysis and converations with experts showed the causes and its concequences.

A solution for the main problem seems clear: another type of land use. However, the question remains: what are the conditions for this other type of land use to make sure that the consequences dissapeare or reduce? Therefore design principles are developed based on the problem analyses and thus on conversations with experts and literature analysis.

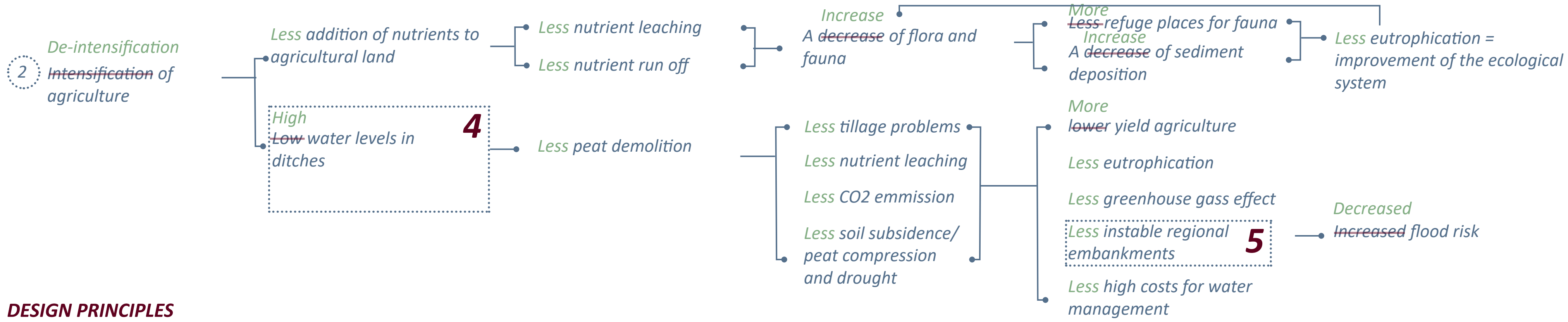
Scheme 14 shows how design principles are actually some sub-solutions for the main problem which will form the conditions for the type of land use in the Frisian peat area. At the next pages the problem diagrams of chapter 2 are analysed to develop design principles by turning positive consequences into negative ones and the other way around. Now these causes at the problem diagrams lead to negative consequences at the Frisian peat area. By turning those causes and consequences the other way around, some basic conditions for the design of a robust water system are being developed: the design principles.



Scheme 14 *Design principles used as measures to achieve the aim will be developed by turning consequences and causes at the problem diagrams the other way around*



Scheme 15 *Design principles obtained by analyses of the problem diagram that includes consequences of the reduction of the Frisian system of reservoirs for superfluous polder-water*

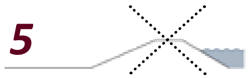


DESIGN PRINCIPLES

4

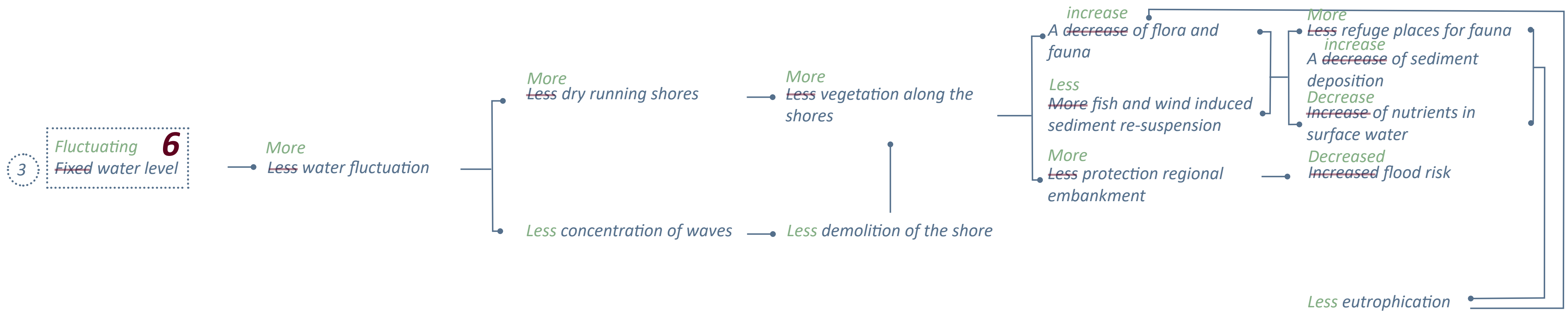
Rewetting peat areas

5



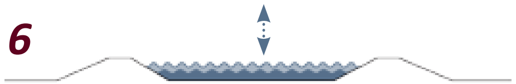
Less water regulating constructions

Scheme 16 *Design principles obtained by analyses of the problem diagram that includes consequences of the reduction of the intensification of agriculture*



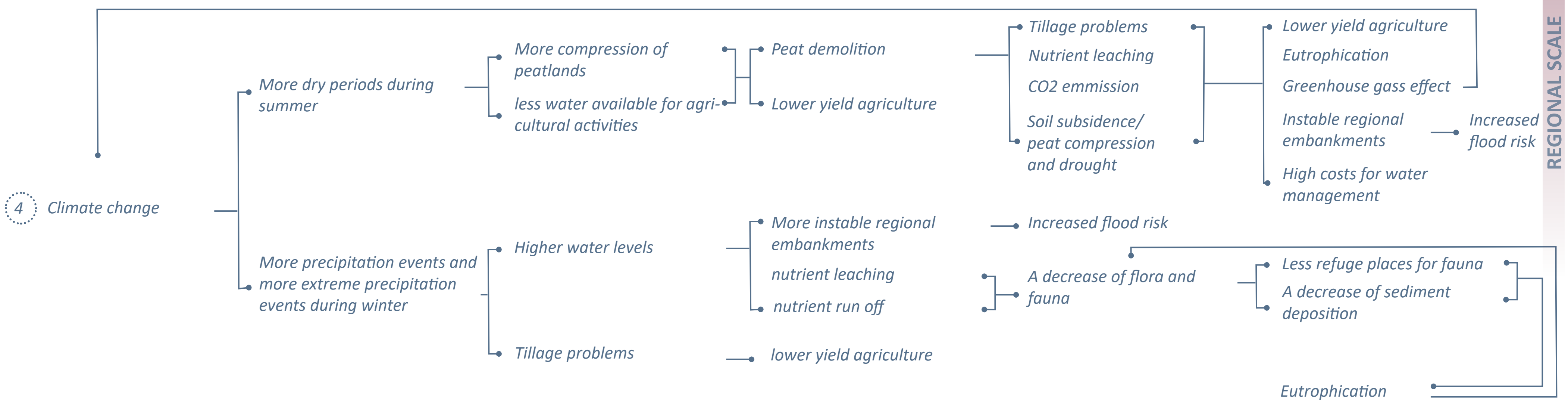
DESIGN PRINCIPLES

6



Water level fluctuation

Scheme 17 *Design principles obtained by analyses of the problem diagram that includes consequences of the determination of a fixed water level at the Frisian system of reservoirs*



Scheme 18 *Design principles obtained by analyses of the problem diagram that includes consequences of climate change*

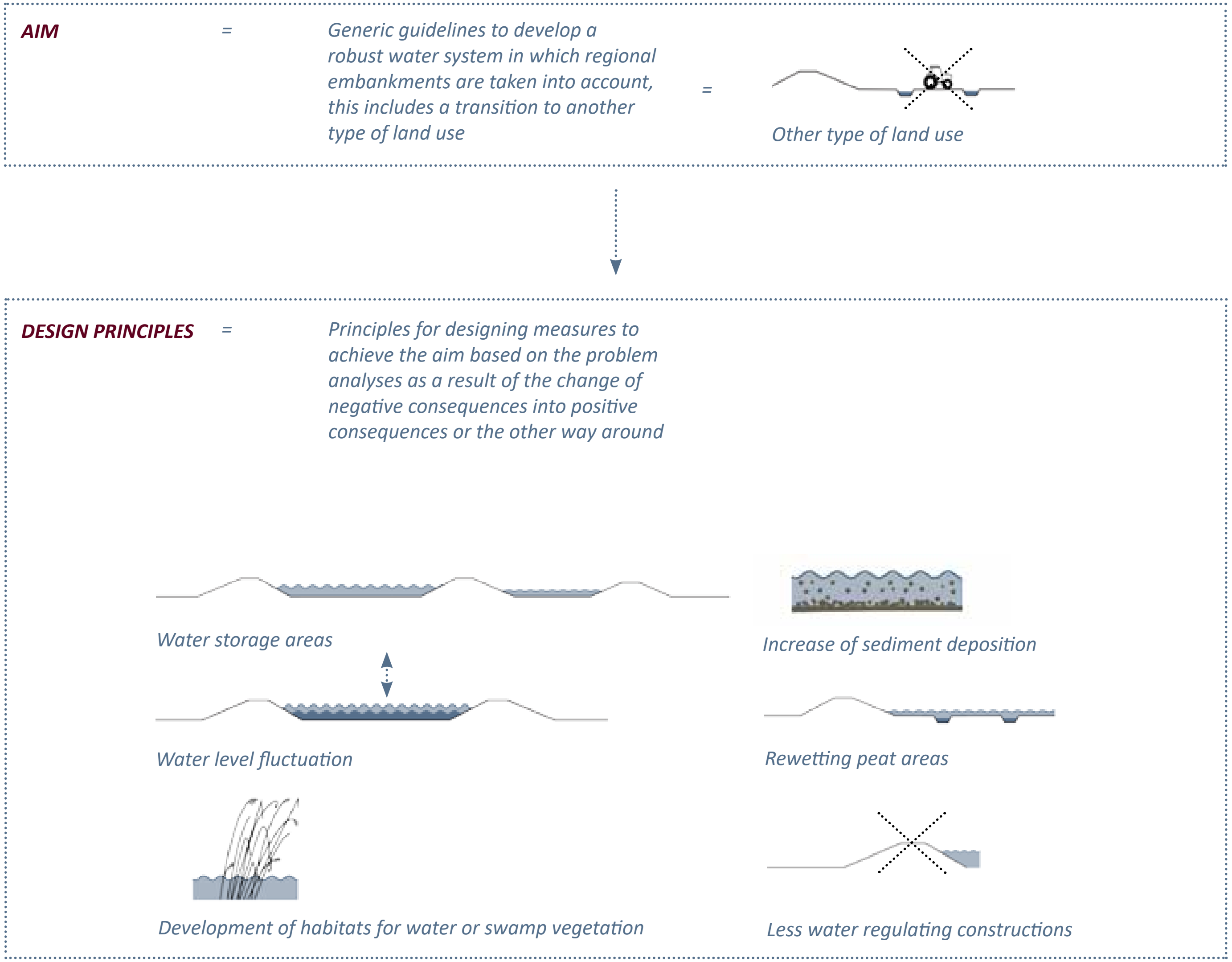
DESIGN PRINCIPLES

Since climate change is not only the effect of human actions, but also a natural process, this process is partly irreversible. Therefore no design principles are given here. However, the design principles given at other pages together can help to reduce the effects of climate change or to adapt to current and future climate conditions.

DESIGN PRINCIPLES BASED AT THE PROBLEM ANALYSIS

The problems occuring in the Frisian peat area in relation with the water management are shown in the schematic diagrams at pages 65 and 66. In the conclusion it was already mentioned how those problems and causes are related to each other and where the biggest challenges lies. To do something about the problems occuring in the peat area, the causes are important. Therefore design principles are formed. These principles together form conditions to which another type of land use must comply.

For the whole Frisian peat area, the aim is to develop a new type of land use. The design principles together with climate conditions and conditions of the physical landscape these principles form the basis for measures to create a system with another type of land use. Scheme 19 presents the design principles.

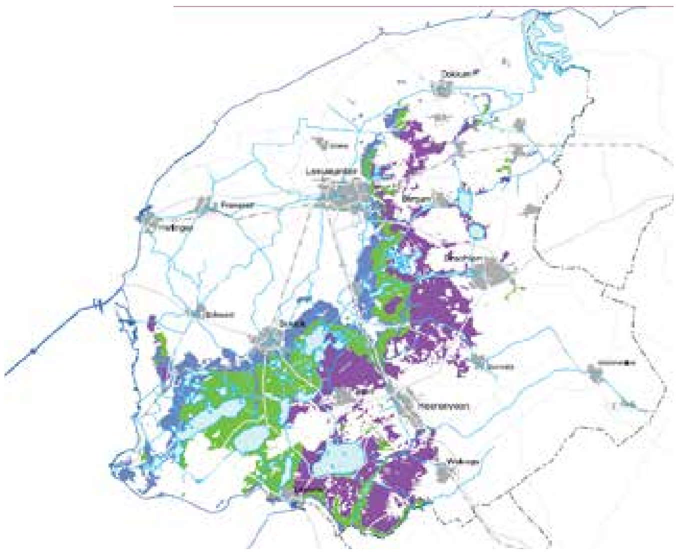


Scheme 19 *Design principles based on the problem analysis*

STEP 2. ADAPTATION TO THE PHYSICAL LANDSCAPE

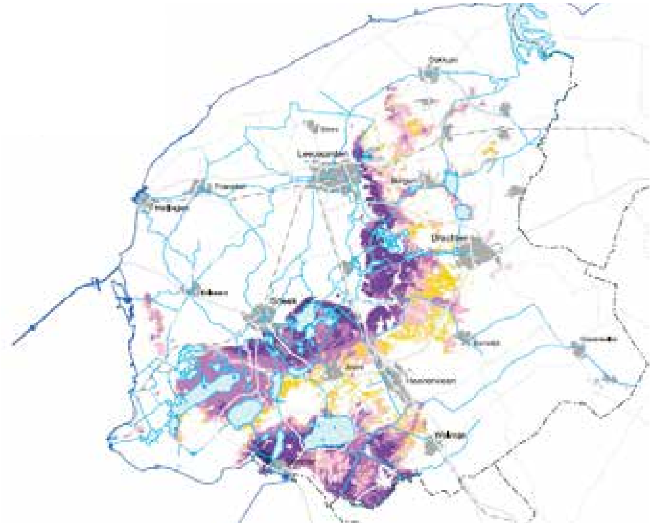
The peat area in the middle of Friesland can be sub-divided into three main sections. In figure 40 these sections are visible. As a result of drainage and climate change the soil decreases (Brouns and Verhoeven). This process will continue, since the peat area is mainly used for agricultural purposes. The peat areas without a top layer of clay decrease faster, since oxygen can easier come into contact with the peat. This is why such areas need a higher water level, since this causes higher ground water levels in the area. As a result of this, the speed of the soil subisidence reduces. The peat areas with a toplayer of clay (green) are better being able to handle lower ground water levels, since the clay prohibits contact of the peat with oxygen. However, the soil subsidence is not absent in these areas.

The current thickness of the peat is visible in figure 41. However as a result of intensive agriculture, the peat decreases with 1 to several centimeters a year in the whole peat area. As a result of this the thickness of the peat layer will be increasingly thinner at 2100. This is visible in figure 42. At the eastern part of the peat area there is less peat left than at the western part of the peat area. This means that the western part will mostly decrease to such an extent that it will become lower than the eastern part of the peat area, since this area 'only' will decrease another 40 to 100 cm.
In the paragraph about the peat area vision it was already mentioned that measures are taken to reduce the speed of soil subsidence, however, no measures were taken to stop the soil subsidence, since this would be a too costly process, since farmers make a living at the peat area. What becomes clear is that maybe nowadays the eastern part of the peat area is the lowest part of the province, however, in the future, the western part of the current peat area will become the lowest area of the Province, since the peat layer is much thicker here and will continue to decrease if no measures to stop the subsidence are taken. This will bring huge expenses for the water management as mentioned in the problem analysis.



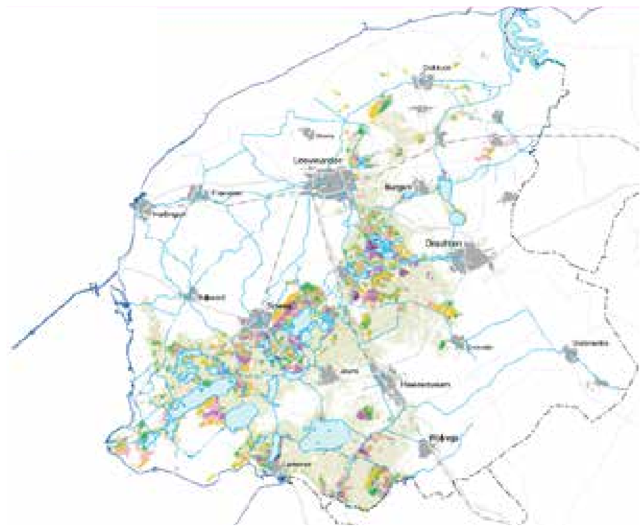
Peat (without a layer of clay)
Peat with a top layer of clay
Clay with a peat layer in the underground

Figure 40 *Soil map of the peat area (Provincie Fryslân 2015).*



0-5 cm
5-40 cm
40-80 cm
80-160 cm
160-300 cm
thicker than 300 cm

Figure 41 *Current thickness of the peat (Provincie Fryslân 2015)*



Peat dissapeared
Moerig
0-40 cm
40-80 cm
80-160 cm
160-300 cm

Figure 42 *The thickness of the peat in 2100 (Provincie Fryslân 2015)*

HEIGHT MAP

The height map shows the transition from the higher sand plateau, 'The Drenths plateau' to the low lying peat area. Next to this the transition from the peat area to the higher clay terrains is also visible. Originally the peat area was a couple of metres higher, but as a result of soil subsidence the peat area decreased. In the Eastern area of the peat area, which is visible as the lowest place of the province, the peat declined faster than in the Western part of the peat area.

Together with the sections it becomes clear that the lowest parts of Friesland are situated at the eastern part of the Frisian peat area next to the transition from the peat to the higher sand soils. In figure 43, figure 44 and figure 45 these low areas are highlited. Figure 43 is also visible in appendix G.

However, the other part of the peat area will decrease too. It means that another type of land use must adapt to these current and future low conditions.

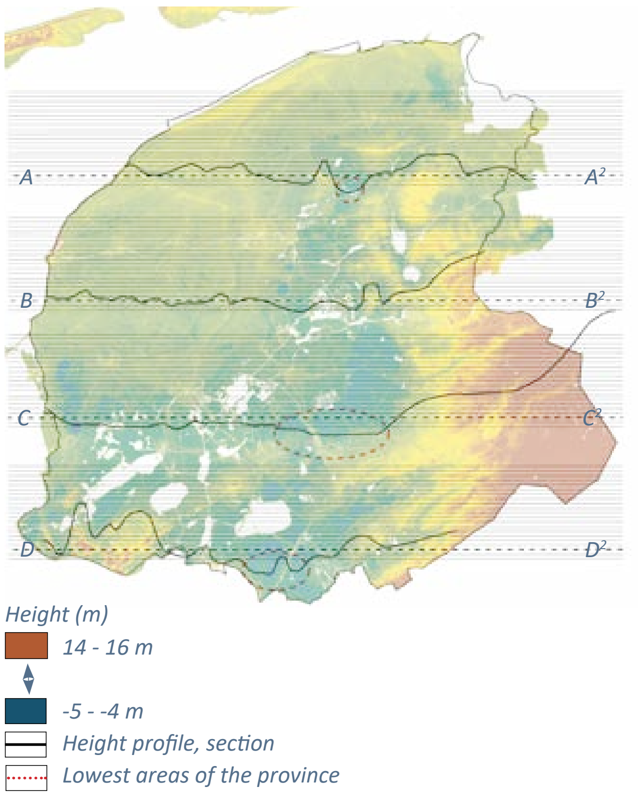


Figure 43 *Height map in combination with schematic sections based on the height map*

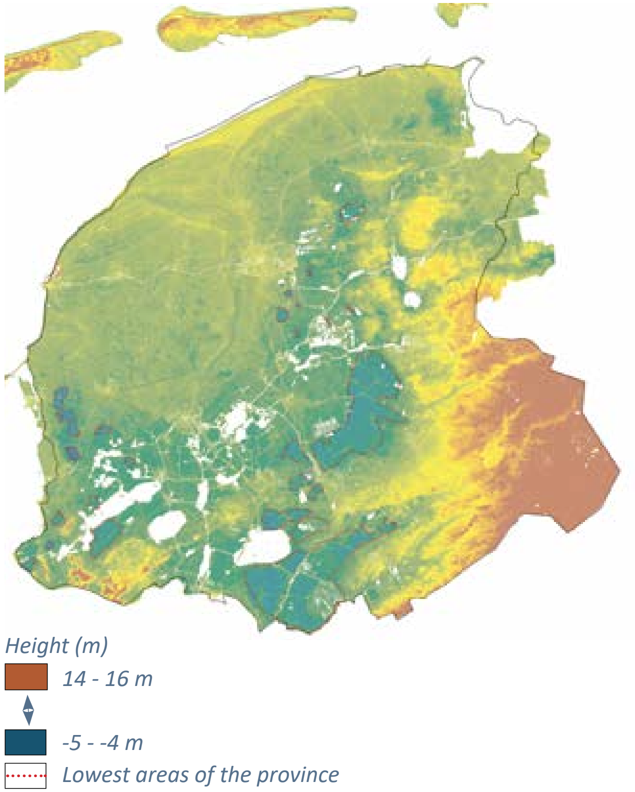


Figure 44 *The lowest areas of the province are situated at the eastern part of the peat area*

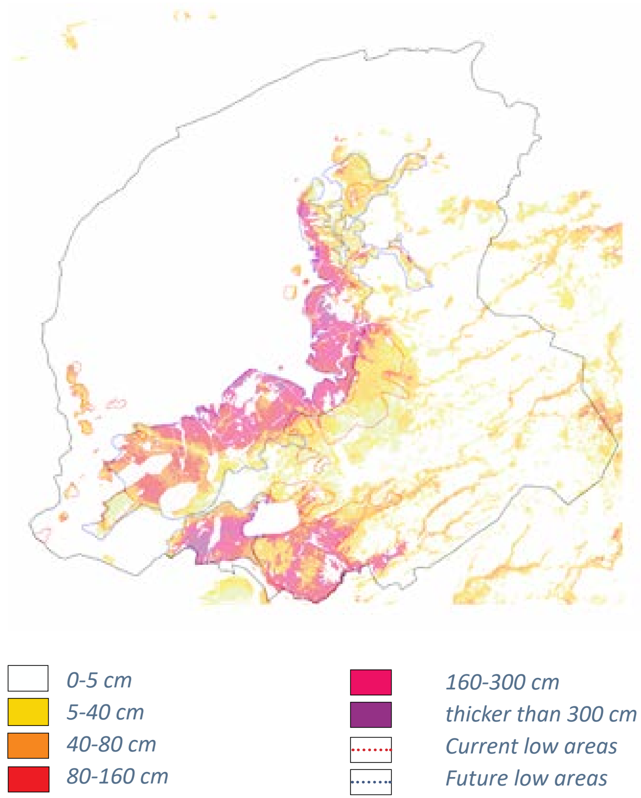


Figure 45 *Current low areas and futural low areas as a result of soil subsidence in combination with the curent thickness peat*

WATER LEVEL MAP

This map (figure 46) shows the water levels in Friesland. It becomes clear that the water levels at the peat area are lower than in higher areas like the sand and clay terrains. In these low peat areas, the water levels are also lower, since grass production for dairy farming is the main type of land use in these areas. This form of agriculture needs low water levels in ditches, since else crops will die as a result of high water levels. This grass must be harvested during spring and summer time. If the ground water level is too high, the areas are to wet to be entered by tractors or other machines.

So it is no coincidence that the current low areas contain the lowest water levels of the Province (figure 47). The two areas within the Frisian peat area show that there are two low areas (a current and futural low area) where different water level are present (figure 47). The red area within this image containes lower water levels than the blue area, since the peat at the red area has demolished faster.

Legend for images below:

Water level (cm - N.A.P.)

- 751-1260
- 401-750
- 251-400
- 151-250
- 101-150
- 51-100
- 1-50
- -51-0
- -99--52
- -149--150
- -219--150
- -390--220

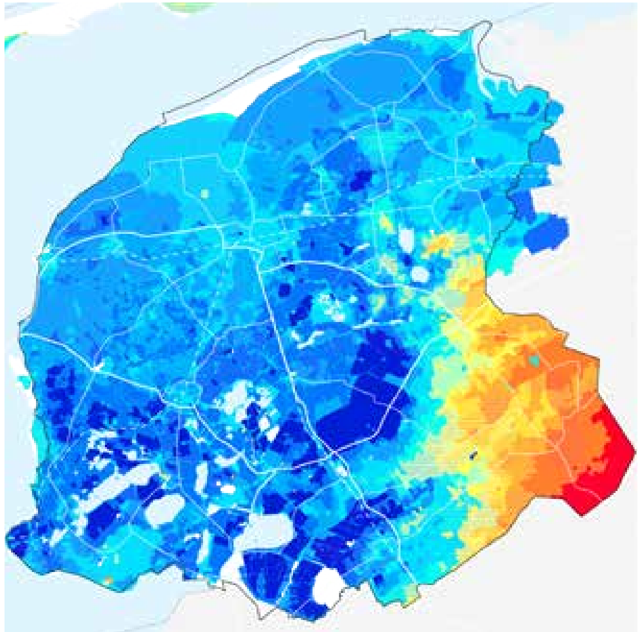
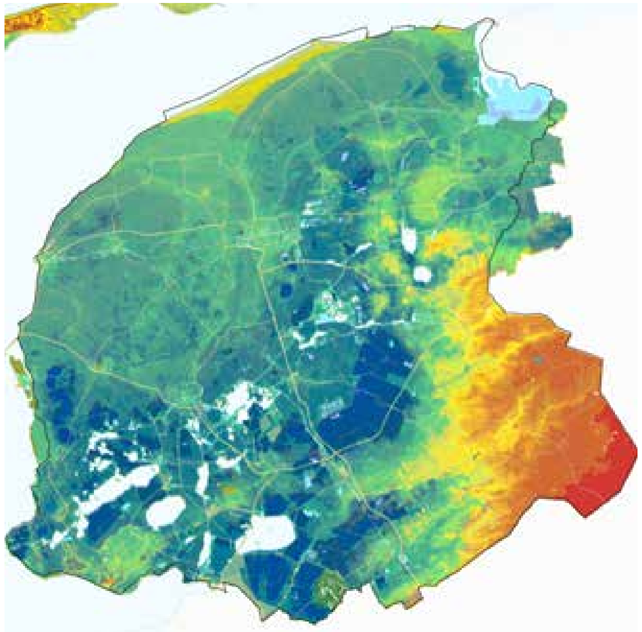


Figure 46 *Water level map of Friesland that illustrates that the lowest water levels occur at the Frisian peat area*

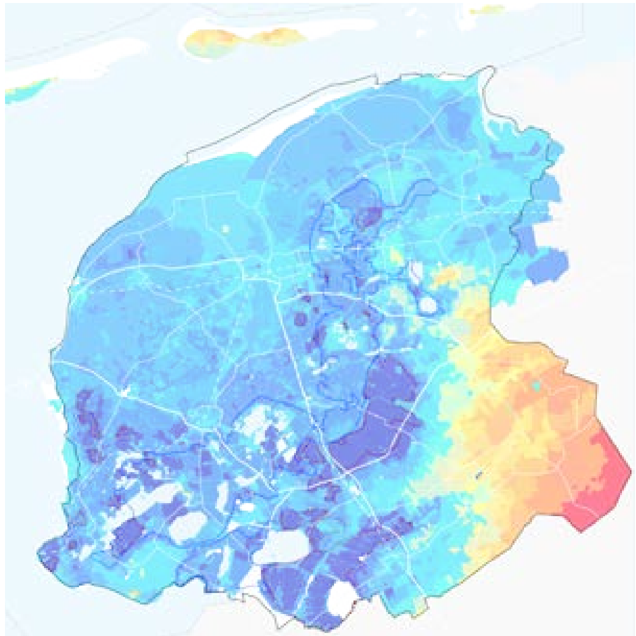


Height (m)

14 - 16 m

-5 - -4 m

Figure 47 *Water level map of Friesland in combination with the height map*



Current low areas

Future low areas

Figure 48 *Water level map of Friesland in combination with the current low areas and the futural low areas.*

CONCLUSION STEP 2

The physical landscape changes as a result of soil subsidence. However, within the peat area, differences occur when it comes to the demolition of the peat and the speed of this process. When developing a regional vision for a robust water system, these differences are important. Based on the previous analysis of the peat area, it becomes clear that the peat area can be divided in two main areas: areas which are already low, called the peat polders (figure 49) and areas which will become lower in the future, called the Lake area (figure 50). These two areas will take a central place in the next phases.

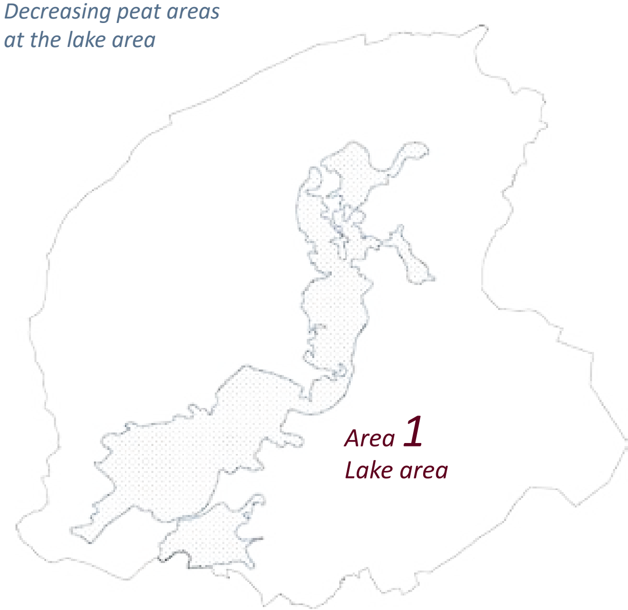
The difference in height and amount of peat will lead to different measures for both areas. It is likely that the Lake area will experience much more problems in the future since most places still contain a thick layer of peat that will demolish as a result of the current type of land use. This increases the need to think about a robust water system for this area. Therefore we continue at next paragraphs with thinking about appropriate measures for this area to develop such a robust water system to prevent problems related to the water management.

Peat polders at the east which are already low

Current low areas - Peat polders

***Figure 49** Lowest areas of the province*

Decreasing peat areas at the lake area



Future low areas - Lake area

***Figure 50** Futural low areas of the Province*

Current low areas - Peat polders

Future low areas - Lake area

***Figure 51** Current low lying areas and futural low lying areas in the Province of Friesland*

STEP 3. ADAPTATION TO CLIMATE CONDITIONS

The differences at the physical landscape have become clear. However, the question which becomes interesting is: How is it possible to adapt another type of land use to climate conditions? Therefore we need to understand the current and future climate conditions and an analysis of the current type of land use. In this thesis we want to design a robust water system, which means a transition to another type of land use. The starting point for this transition is the current situation in both specific peat areas (area 1 and 2). Thus it becomes important to understand the current land use and the stake of people executing this type of land use in order to start a transition.

CLIMATE CONDITIONS

In the problem analysis the climate conditions were already discusssed, however, here a short summary is given at scheme 20. These climate conditions state that the type of land use must deal with a certain amount of water. Next to this also enough water must be available during dry periods.

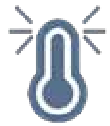
CONCLUSION STEP 2

So actually adapting the new type of land use to climate conditions means a type of land use which can stand the climate conditions now and in the future mentioned at scheme 20. Especially long and intense periods of rain and drought are important conditions to handle since those are problems at the current type of land use. Thus a permanent wet Frisian peat area would be the best way to adapt to climate conditions. In this way oxigene will not be able demolish peat and rewetting the peat will give lots of possibilities for extra water storage, water vegetation development etc. to create a robust water system that does not enforce problems occuring at the Frisian peat areas, but which lead to a sustainable water and agricultural system.

OVERALL CHANGES / SCENARIO DIFFERENCES AND NATURAL VARIATIONS

Overall changes

- *temperature will continue to rise*
- *mild winters and hot summers will become more common*



Scenario differences and natural variations

- *changes in temperature differ between the four scenarios*
- *changes in 2050 and 2085 are greater than the natural variations at the 30 year-time scale*

Overall changes

- *precipitation in general and extreme precipi-tation in winter will increase*
- *intensity of extreme rain showers in summer will increase*
- *hail and thunderstorms will become more severe*

Scenario differences and natural variations

- *more dry summers in two (GH and WH) of the four scenarios*
- *natural variations in precipitation are relatively large and thus the scenarios are less distinct*

Overall changes

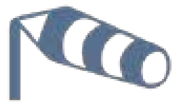
- *sea level will continue to rise*
- *the rate of sea level change will increase*

Scenario differences and natural variations

- *rate of sea level rise greatly depends on global temperature rise*
- *there is no distinction between scenarios with different air circulation*

Overall changes

- *changes in wind speed are small*

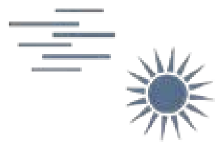


Scenario differences and natural variations

- *more frequent westerly wind in winter in two (GH and WH) of the four scenarios*
- *the wind and storm climate exhibits large natural variations*

Overall changes

- *number of days with fog will diminish and visibility will further improve*
- *solar radiation at the earth's surface will increase slightly*



Scenario differences and natural variations

- *natural variations differ for different climate variables*

Scheme 20 *KNMI climate scenario's summarized (KNMI 2014)*

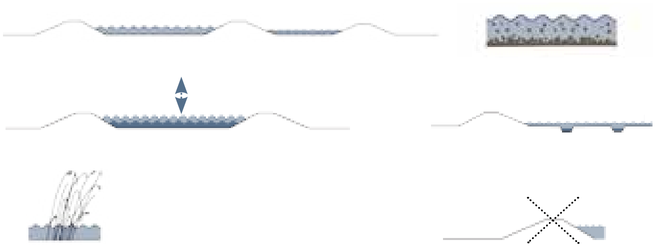
STEP 4 CONDITIONS FOR A TYPE OF LAND USE

There are two areas in the Frisian peat area. Area 1 is low and area 2 will become lower in the near future. A transition to another type of land use in the Frisian peat area exists of translating the design principles in measures which take into account the conditions of both areas and the conditions of the climate (scheme 13).

Since the amount of peat at area 1, the Lake area is much higher than at area 2, and since area 1 is higher too, the need to think about measures for area 1 is also more relevant. Here it is likely that huge problems related to the water management will occur in the (near) future. Therefore at next paragraphs to focus will be at this area, to find out how the type of land use at this intensive agricultural area can change.

However, this transition to another type of land use will not go easy. Why and how will be explained now.

A CONDITIONS FOR ANOTHER TYPE OF LAND USE: DESIGN PRINCIPLES

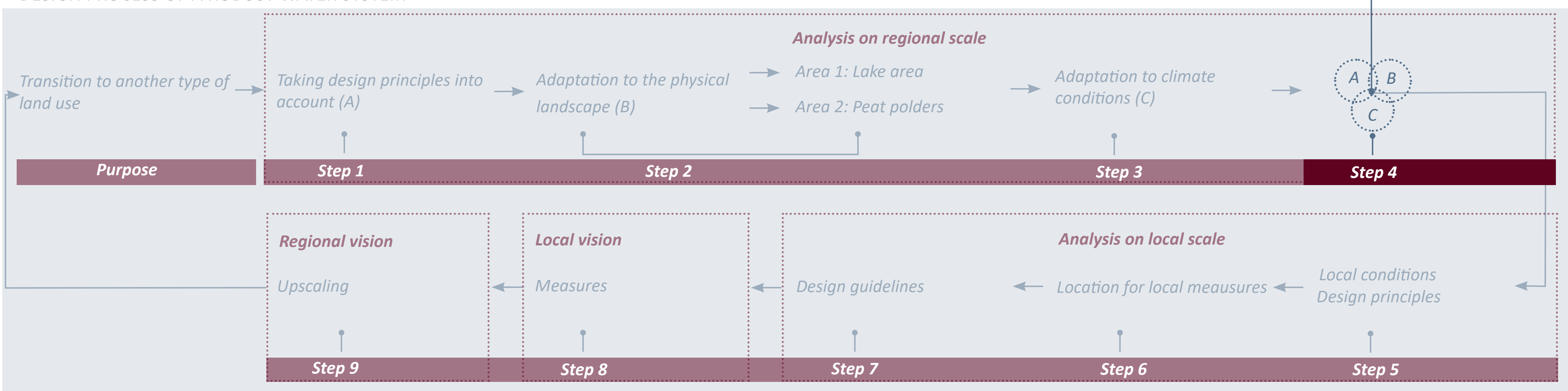


B PHYSICAL LANDSCAPE

C CLIMATE CONDITIONS

Type of land use

DESIGN PROCESS OF A ROBUST WATER SYSTEM



Scheme 13 *Design process of a robust water system*

OTHER TYPE OF LAND USE

A farmer tries to gain money with his company, by using his land. If his land must be rewetted to a certain degree it means that this same farmer must gain the same or a higher profit for crops harvested at his land. Why will they else turn into another type of land use? Changing the type of land use to a form which functions in permanent wet conditions would be the ideal situation. However, what type of land use suits these conditions at the Frisian peat area? An option would be to rewet areas for the development of nature reservers with governmental funding. However transforming 85.000 ha into nature reserves would not be a sustainable type of land use at the long term. Therefore paludiculture is being explained.

PALUDICULTURE

'Paludiculture means the cultivation of biomass at wet or rewetted peat areas while maintinaing the current profit' (Riet, van de et al. 2014) The two differences with the current type of land use is that with paludiculture the soil subsidence at the peat area stops and that the emission of greenhouse gasses is being reduced (Van de Riet et al. 2014; Abel et al, 2013). There are also other advantages of paludiculture:

- 'Ground biomass can still produce peat
- The biodiversity will be able to increase and the peat area will be preserved better
- Recovery of ecosystem services
- Paludiculture can be combined with water storage' (Abel et al. 2013)
- According to Abel et al. (2013), paludiculture can help to preserve current nature areas if paludiculture areas are being placed along such nature areas. Waterlogged vegetation and related animal species will have benefit from this, since in this way less water from nature terrains will leave the area as a result of seepage and less water from outside such terrains has to be brought in which stimulates vegetation and animal species in the nature areas (Riet, van de et al. 2014).

There are around 814 species currently identfied as potential paludiculture species (Abel et al. 2013). Some species grow at best with a low water level, while other may grow with a higher water level. Abel et al. developed the DPPP (Database of Potential Paludiculture Plants) (Abel et al, 2013).

Abel et al. 2013 based the potential of the species at the condition of the peat, the stability of the peat, the market potential and the current implementation. However, the research was done for the area 'Pomerania' where the peat area differs from the Frisian peat area. This means that for the Frisian peat area specific research must be done to find out which species have the most potential in Friesland. However, some promising plant species are given which will be used during later phases in this thesis.

- Typha latifolia (Cat tail)
- Shpagnum (Peat moss)
- Phragmites australis (Common reed)

Cattail can be used as building or isolation material (Fritz et al. 2014). Sphagnum can be used as 'growing media' (horticultural potting soil) and Phragmites australis can be used as a bioenergy crop or as an industrial raw material (Wichtmann and Schäfer 2007). Many more plant species are likely to be used in rewetted peat areas, but research must be done to find out if it is profitible.

The ideal situation, which is a permanent wet Frisian peat area, will be hard to fulfill based at the current land use. Farmers and land owners must cooperate to rewet their land and the type of land use compatible with wet conditions must at least be as profitable as the current type of land use. Why else would farmers invest and change the current type of land use? So changing the type of land use to another type which adapts to the current and future climate conditions

Figure 52 *Typha latifolia (Stichting Flora Nederland 2016)*

Figure 53 *Sphagnum (Avanced Nutrients 2016)*

Figure 54 *Phragmites australis (BeMidbar 2016)*

and which suits the design principles not only exist of simply rewetting the Frisian peat areas.

DEGREE OF REWETTING

To transform an area from an intensive drained agricultural area into a permanent rewetted area will probably take several steps. Therefore three degrees of rewetting are developed. These three degrees of rewetting are illustrated in figure 55. These are based on degrees of water storage mentioned in the Safety Plan II (Wetterskip Fryslân 2014a) and the report: 'Afvoer en berging van water in Fryslân' (Klopstra 2001). In the reports Wetterskip Fryslân describes water storage areas as retention zones, as expansion of the Frisian system of reservoirs for superfluous polder-water and as water storage in the sub-systems and water storage in summer polders during winter time.

Many factors are able to slow the transition to another type of land use which suit a high degree of rewetting, a permanent rewetted lake area. Therefore a certain level of flexibility is necessary. That is why next to different degrees of rewetting a type of land use will be coupled to a degree of rewetting, called a degree of adaptation. The ideal situation is a permanent degree of rewetting with for example a form of paludiculture. This starts with the current situations and with current land users and owners. If they do not cooperate with measures to acchieve this high degree of rewetting, another degree or rewetting must be possible to still develop a robust water system to a lesser extent. This lower degree of adaptation can step by step be turned into a higher degree of adaptation which makes it possible to still develop a robust water system with areas permanently rewetted. This also gives a certain level of flexibility.

Nowadays many farmers at the Frisian peat area expand their company. New stables are built to produce more milk. However, the new phosphate regulation causes farmers to be more dependent of the amount of land they own or use for the production of food for their cows (Wageningen university 2016). Still farmers expand their company. 'Larger agricultural companies achieve a higher profitability than smaller companies' (Meulen, van der et al. 2011). Next to this also the cost price of milk decreases with the increase of the size of the company (Meulen, van der et al, 2011). This makes it more likely that farmers continue with expanding their companies in the future. With the current regulation, it means that farmers need every cm of their land for the deposition of fertilizer. This also means that farmers need their amount of land for the production of grass, corn or other crops for their cows to be market independent. If their is a high demand for food, prices of food go up (Schaap et al. 2014) which lead to high costs for farmers if they must buy this food to feed their cows.

Since land owners need their land for the production of grass for their expanded dairy company I assume also at the basis of experience that these land owners do not tolerate a degree of water storage. However, to develop a degree of adaptation, the first step is to keep the land functional for current purposes. This is why a sporadic degree of rewetting can be combined with the current type of land use. In this way, farmers or land owners can use their land. However, there will be a small chance that their land will be covered with a small layer of water during intense periods of rain. This can affect their yield, but the water will be pumped into the Frisian system of reservoirs as fast as possible. To reduce the costs by compensating damage, water must be eliminated as fast as possible from agricultural areas.

If Wetterskip Fryslân decides to stop with taking measures that keep the current type of land use at the Frisian peat area profitable or if a form of paludiculture gains more profit than the current type of land use, the areas with a sporadic degree of rewetting must be able to be transformed to permanent rewetted areas where a form of paludiculture can take place. At pragraph 4.5 it will be explained how measures could function when designing areas for a transition to another type of land use.

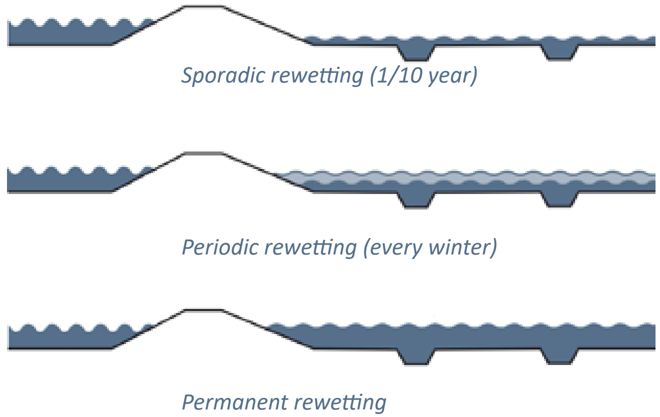
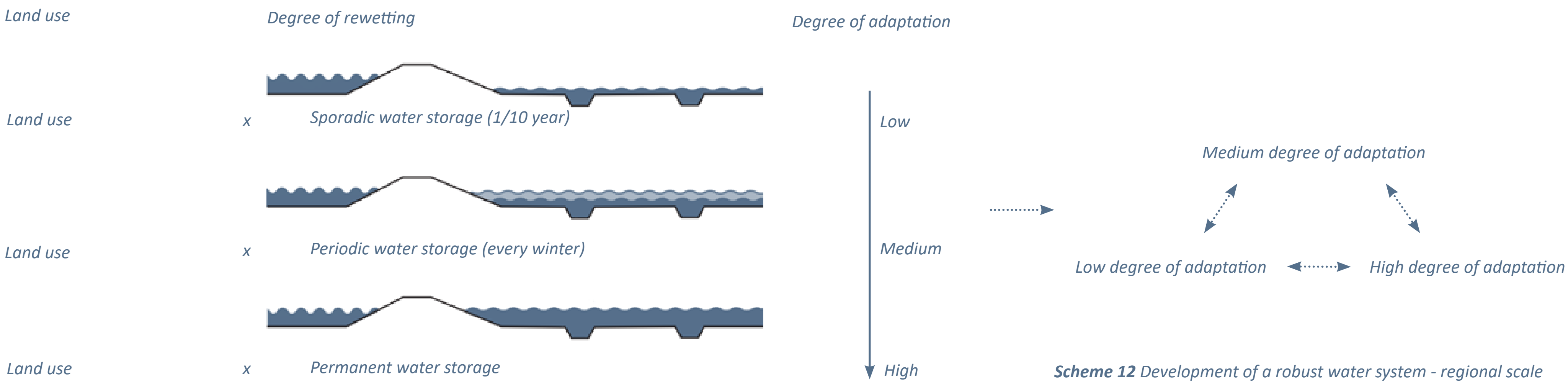


Figure 55 *Degree of water storage as a degree of rewetting*

CONCLUSION STEP 4

Recently three degrees of adaptation where explained. The ideal situation would be high degree of adaptation at scheme 13 below. However, this means a huge transition from the current type of land use to a type of land use which can stand permanent wet conditions. The speed of this transition will also depend on the policy of for example Wetterskip Fryslân and research to forms of paludiculture and their profitabililty. Since such factors will remain unsure if no direct steps are taken, therefore the degree of flexibility is important.

DEGREES OF ADAPTATION



***Scheme 12** Development of a robust water system - regional scale*

4.4.2 POTENTIAL OF THE LANDSCAPE

'The functioning of landscapes is the result of the interaction between physical structures, which are the basis for natural processes and human actions' (Termorshuizen and Opdam 2009). 'Functions can be translated into services when valued by people'(Termorshuizen and Opdam 2009).

That is what Termorshuizen and Opdam call landscape services. The type of land use gives certain services. "Change in land use or management will therefore cause a change in service supply, not only for specific services but for the complete bundle of services provided by that (eco)system" (De Groot et al. 2010).

By trying to create rewetted peat areas with an appropriate type of land use, we try to adapt the landscape to provide better services. This can be defined as sustainable landscape development; people change the landscape to create added value (Termorshuizen and Opdam 2009) which leads to an increase in landscape services. Termorshuizen and Opdam 2009 use the term landscape services in the context of collaborative planning processes designed to change landscapes with the purpose of generating added value'(Termorshuizen and Opdam 2009).

In figure 56 the interaction between actors capable of supplying landscape services and the actors using these services, linked by financial arrangements, is visible'. Ideally, the suppliers earn income and incur the costs of changing the landscape and managing it; the users gain profit in the form of quality of life (health, recreation) or save money because the landscape takes over regulatory functions (e.g., water supply, waste treatment)' (Termorshuizen and Opdam 2009).

The current landscape shows that in the rural areas especially agriculture and ecology form the main function. They provide landscape values like food security, recreation and heritage preservation. So actually the landscape is multifunctional. The landscape provides several functions valued by people. A multifunctional landscape concept, which includes both the aesthetic aspect and the services it provides to humans (Bastian 2001; Fry 2001; Tress et al. 2001; Musacchio and Wu 2004; Potschin and Haines-Young 2006) recently has been adressed. Termorshuizen & Opdam, 2009 incorporate both natural and cultural aspects when talking about multifunctional landscapes. 'In this view, landscapes are spatial human–ecological systems that deliver a wide range of functions that are or can be valued by humans because of economic, sociocultural, and ecological reasons (Chee 2004; DeFries et al. 2004; De Groot 2006).

Changing the structure of the peat area into a rewetted area gives opportunities for nature development, the preservation for cultural heritage and more which could result in a creation of value, in recreational activities and thus income or profit. That is why at the next pages some important structures in Friesland are highlighted like nature areas, cultural heritage etc. In this way certain areas in a rewetted peat are could be more focused on for example nature development to connect nature areas. This could lead to an ecological structure which creates opportunities for recreational activities and thus income. With this perspective now some structures will be highlighted.

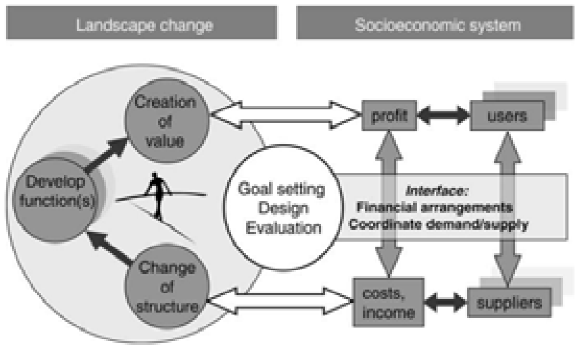
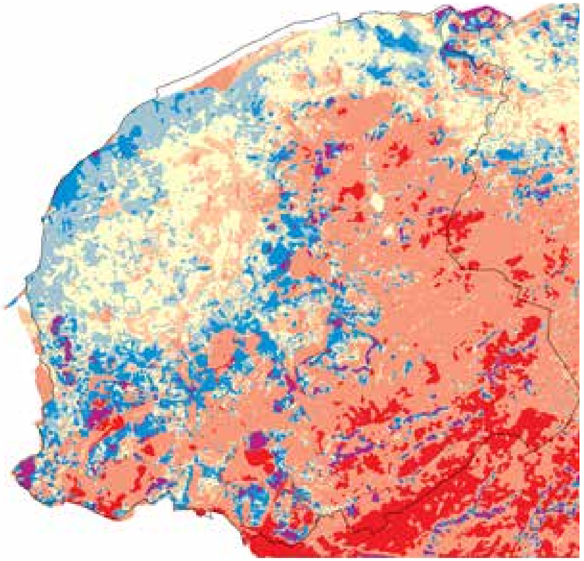


***Figure 56** A conceptual framework for collaborative landscape development (Termorshuizen and Opdam 2009).*

SEEPAGE AND INFILTRATION

Seepage (figure 57) from great depts helps to improve the water quality. As a result of this, specific vegetation develops. Seepage is a specific type of groundwater. Broadly speaking there are two types of seepage here in the province; seepage as a result of water level differences between for example the Frisian system of reservoirs for superfluous polder-water and the water level in ditches on the other side of embankments which separate these two types of water. And seepage which comes from greater depths (tens of metres) to the surface. This is the case next to the Drenths platea in the eastern part of the Frisian peat area (figure 59). Here water which infiltrated many years ago in the sand soil of the Drenths plateau comes to the surface in the current lower peat areas (figure 59). This seepage zone next to the Drenths plateau can help to improve the water quality and vegetation development (Goossensen et al 1998). Often many different plant species occur in these areas. Such nature reserves are therefore perfect habitats for for example several bird species (Brongers and Belle 2008).

If in some parts of this seepage zone the type of land use in a rewetted area would be combined with nature development, already existing nature reserves in seepage areas could be connected which could result in an increase of value.



Strong seepage
Medium seepage
Weak infiltration
Intermediary
Weak infiltration
Veenweide
Strong infiltration

Figure 57 *Seepage map (Wetterskip Fryslân 2016)*

Current low areas - Peat polders
Future low areas - Lake area
Strong seepage zone

Figure 58 *Seepage area especially appearing at the current lowest areas of the province.*

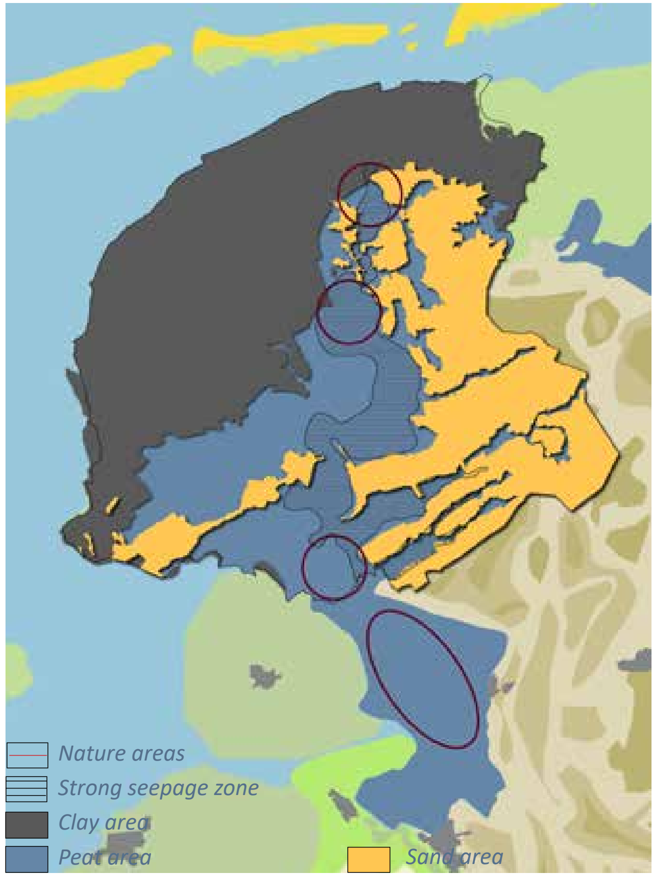


Figure 59 *Nature areas at seepage areas along the transition from sand to peat soils*

NATURE AREAS

In Friesland many nature areas situated (figure 60). If such areas could be linked with each other by developing new ecological structures, or maybe these structures could be linked to the Ecological Main Structure in the Neterlands (figure 61). This could lead to an increase of biodiversity, extra functions of the landscape and and extra creation of value. This again gives opportunities for activities and thus also for gaining extra income for people living nearby.

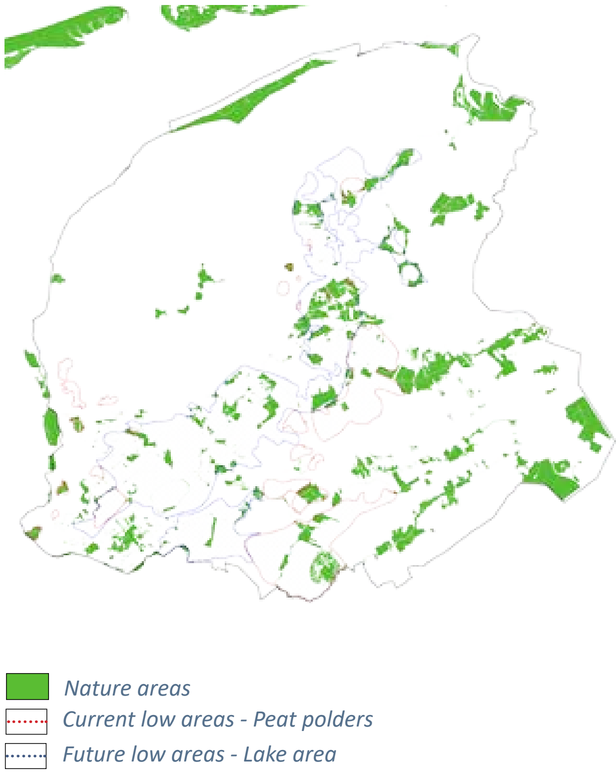


Figure 60 *Nature areas and current low lying and futural low lying areas of the Province*

Figure 61 *EMS; ecological main structure*

LANDSCAPE TRANSITION

The landscape types map (figure 62) shows where specific types of landscape are situated within the province of Friesland. This map is taken over from the landscape type map of the Province of Friesland.

Based on the research of Goosens et al. people like to experience different types of landscapes within a small area (5 km). To live, work or recreate in (Goosens et al. 2006). At the Frisian peat area the landscape transforms where the peat soil changes into the sand or clay soils (figure 63). Here differences in height and soil occur and thus differences in vegetation and use since these are related to the soil and height. These 'landscape edges' could be used to develop an attractive landscape with potential for recreational activities, living and working since these are areas where people can experience different types of landscapes within small distances.

Legend figure 62 and 65

- *Moraine landscape*
- *Heather reclamation*
- *Frisian Ash landscape*
- *Woud reclamation*
- *Peat bogs*
- *Peat moor*
- *Peat*
- *Saltmarsh wall*
- *Saltmarsh plain*
- *Clay on peat area*
- *Clay mound landscape*
- *Droogmakerijen*
- *Stream valleys*
- *Young sea polders*
- *Plains*
- *Outer saltmarshes*
- *Old sea polders*

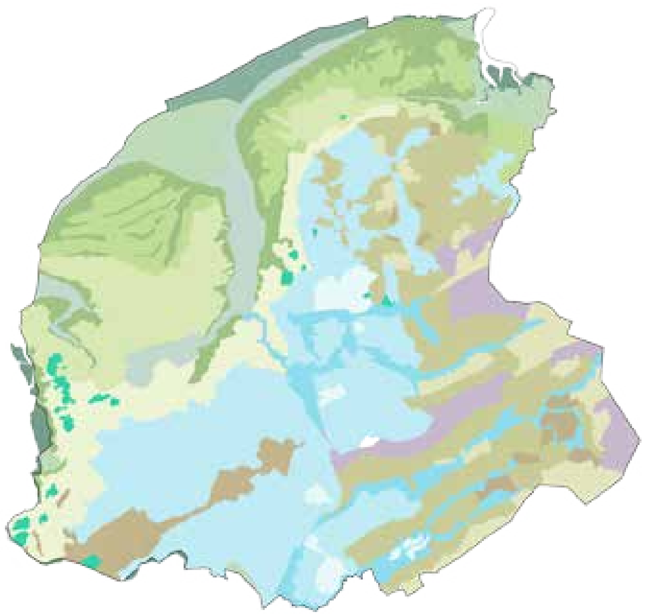
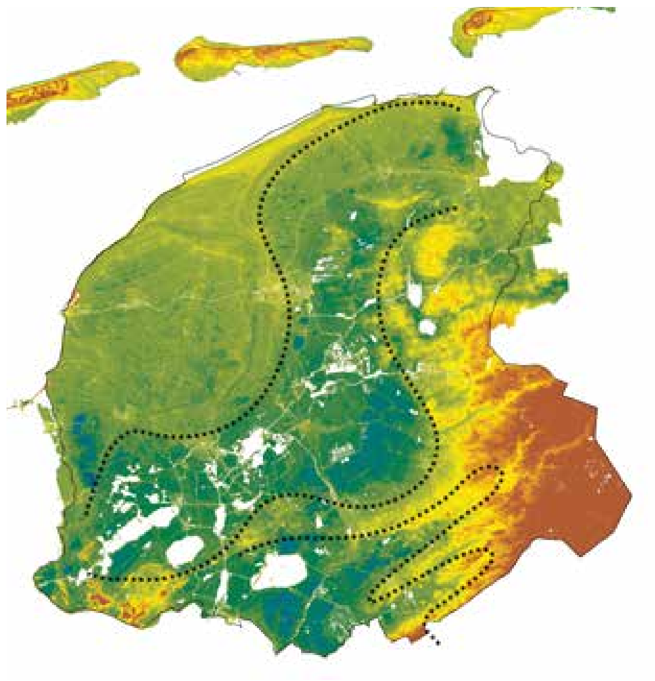


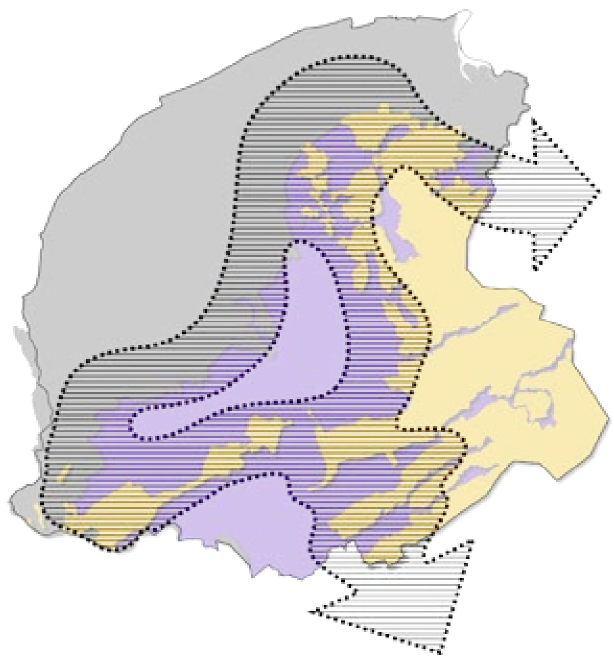
***Figure 62** Landscape types map*



Height (m)

- *14 - 16 m*
- *-5 - -4 m*
- *Landscape type transition*

***Figure 63** Transition from landscape types combined with height map*



Landscape type transition areas

***Figure 64** Potential connection to other peat landscape transition areas*

HERITAGE

In figure 65 and figure 66 it becomes visible that heritage like old landscape parks, static houses and churches are mostly situated on the edges of landscape types. Especially along the transition of the fertile clay area to the peat area. When people settled in Friesland, the clay terrains were much higher and easier to use for agricultural activities than the wet peat areas in the middle of Friesland. In the eastern part of the Province, most heritage is situated on the higher morains. Those were the higher and drier areas to use for agriculture and other activities. These ribbons of heritage are again situated on the transition of landscape types.

Thissen en Engelsdorp Gasteren, van. (2000) state that 'Beauty of nature, recreational services and a high cultural historic level, make the living environment attractive'.

Cultural historic embankments (figure 67) at the peat area give possibilities for the development of recreational activities and for upgrading the attractivity of the landscape. Together with the landscape transitions at the edges of the peat area, the potential for extra use of the area could be enforced. This could mean extra income for people in such areas by the developments of bed and breakfast, restaurants etc.

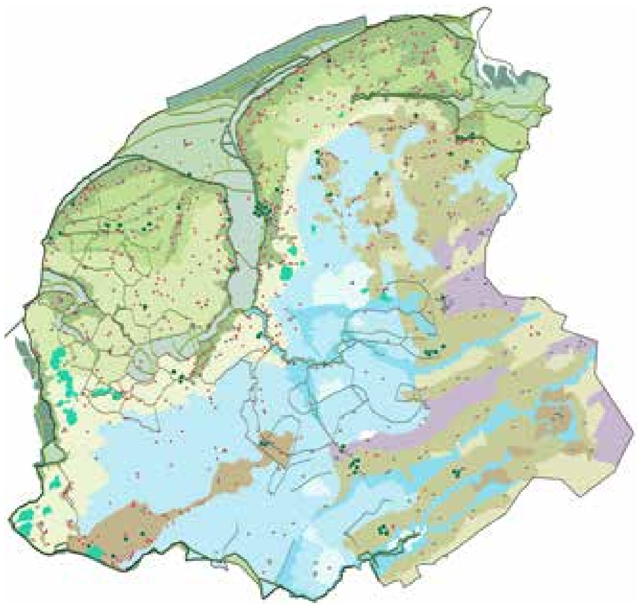


Figure 65 *Cultural heritage (Provincie Fryslân)*

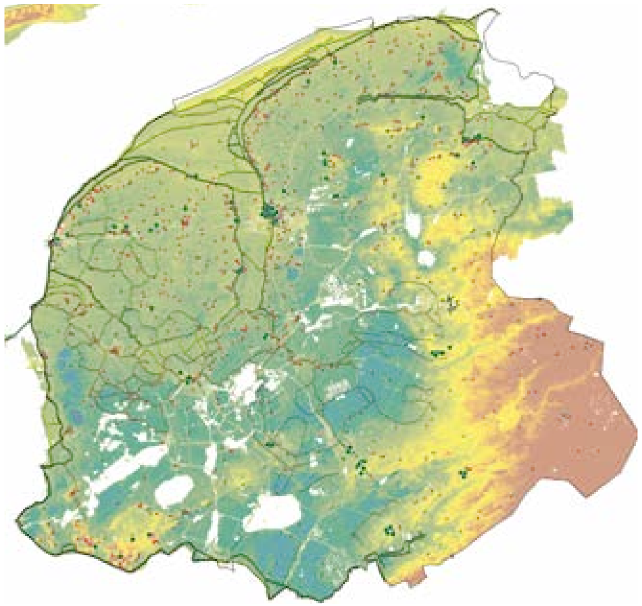


Figure 66 *Cultural heritage in relation with the AHN*

Figure 67 *Cultural heritage in the Frisian peat area (Provincie Fryslân 2014)*

OPPORTUNITIES

The structures mentioned at the previous pages can be developed during the transition to another type of land use. If all those opportunities are combined in a map, it becomes visible how several opportunities overlap each other. Figure 68 shows such a map. This map can be designed in several different ways, however, for this thesis there is only one possiblility given. For now it is not most important to develop the opportunties, but to show what opportunities are there if a robust water system with a rewetted peat area would be developed.

SUB-REGIONAL SCALE

With such a development it is important to take into account the landscape characteristics at a sub-regional level. They could help to determine where exactly measures could be taken to improve for example regional recreational or ecological structures. In this report those characteristics at a sub-regional scale will not be taken into account, however during further research about the development of a robust water system these sub-regional characteristics can be taken into account.

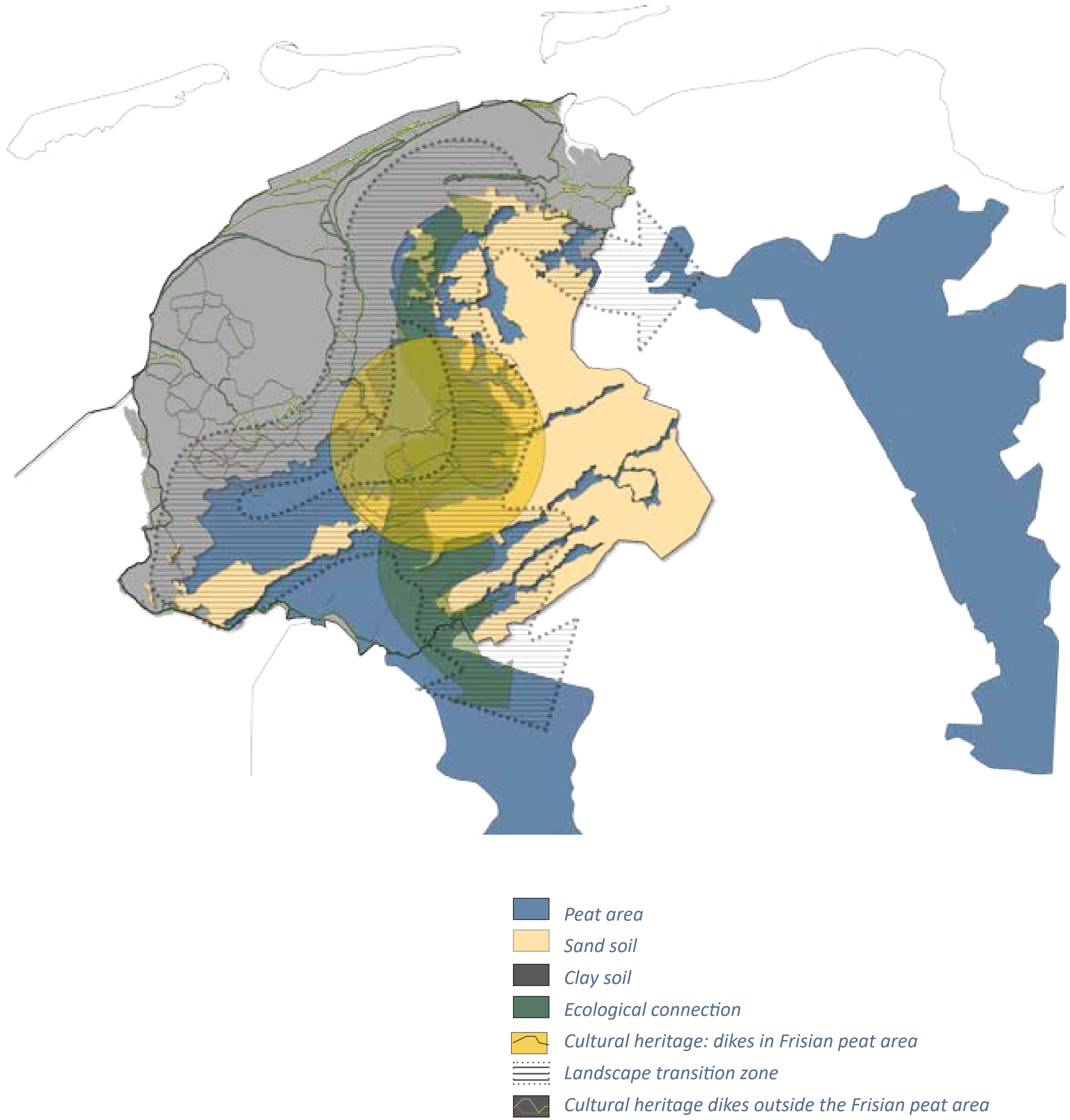


Figure 68 *Opportunities*

4.4.3 ANALYSIS ON LOCAL SCALE

The analysis on the regional scale resulted into general conditions for the development of a robust water system for the Frisian peat area. However, the starting point for the creation of a robust water system with another type of land use is the current landscape. Therefore the conditions at the regional scale for a robust water system mentioned at the regional vision must be translated into direct measures. To find out what these measures will be, local conditions are important. Conditions like the lowest places of the area, the ownership pattern etc. But also the incorporation of the design principles must taken into account.

A specific location at the Lake area, area 1 will be analysed (Figure 69). This area needs the most attention since about 2-3 m of peat is left here. More problems will occur here if nothing is done to slow or stop the problems related to the water management in this part of the Frisian peat area. For this case/area it will be researched how local conditions and design principles can be taken into account when designing measures to develop a robust water system. At the end it will be shown how the landscape could be transformed with these measures and how this could lead to the ideal situation of a rewetted peat area with a form of paludiculture.

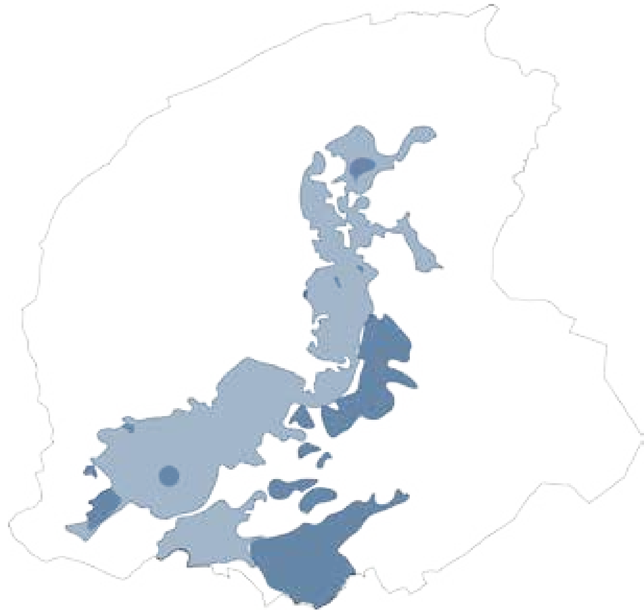
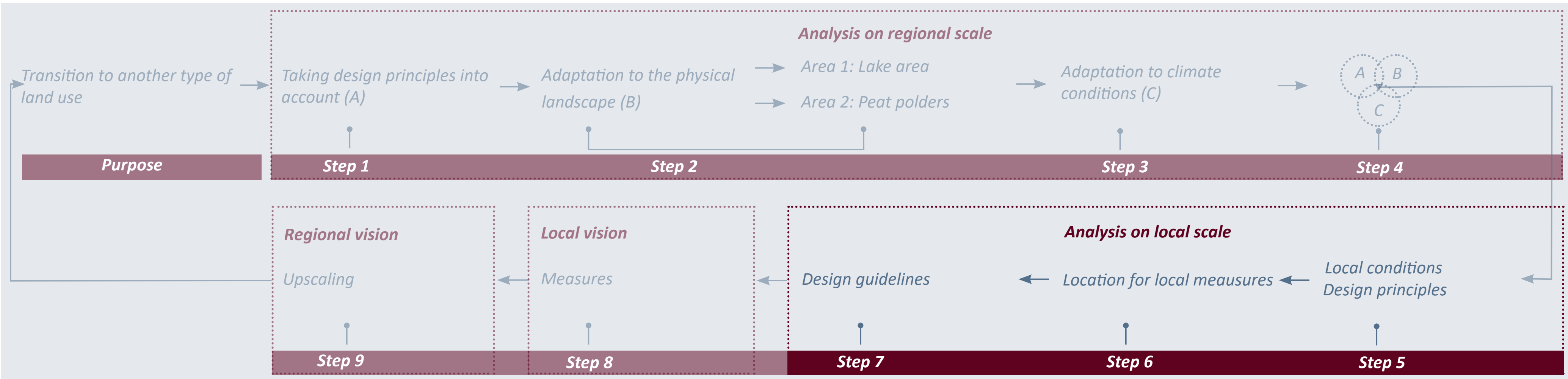


Figure 69 *Local scale*

DESIGN PROCESS OF A ROBUST WATER SYSTEM



Scheme 13 *Design process of a robust water system - local scale*

LOCATION OF THE CASE

The case is situated at Ypecolsga in Friesland. Around 70 people live in te village Ypecolsga (Gemeente Súdwest Fryslân 2016). In figure 70 this location in the middle of the Frisian lake area is visible. This area is part of a wider agricultural area where mainly dairy farming takes place. That is the reason why this area has been chosen. The specific area exists of an intesive agricultural polder situated next to a lake. This lake is surrounded by regional embankments. At the next pages the area will be analysed to find out what local conditions must be taken into account when developing local measures to create a robust water system.

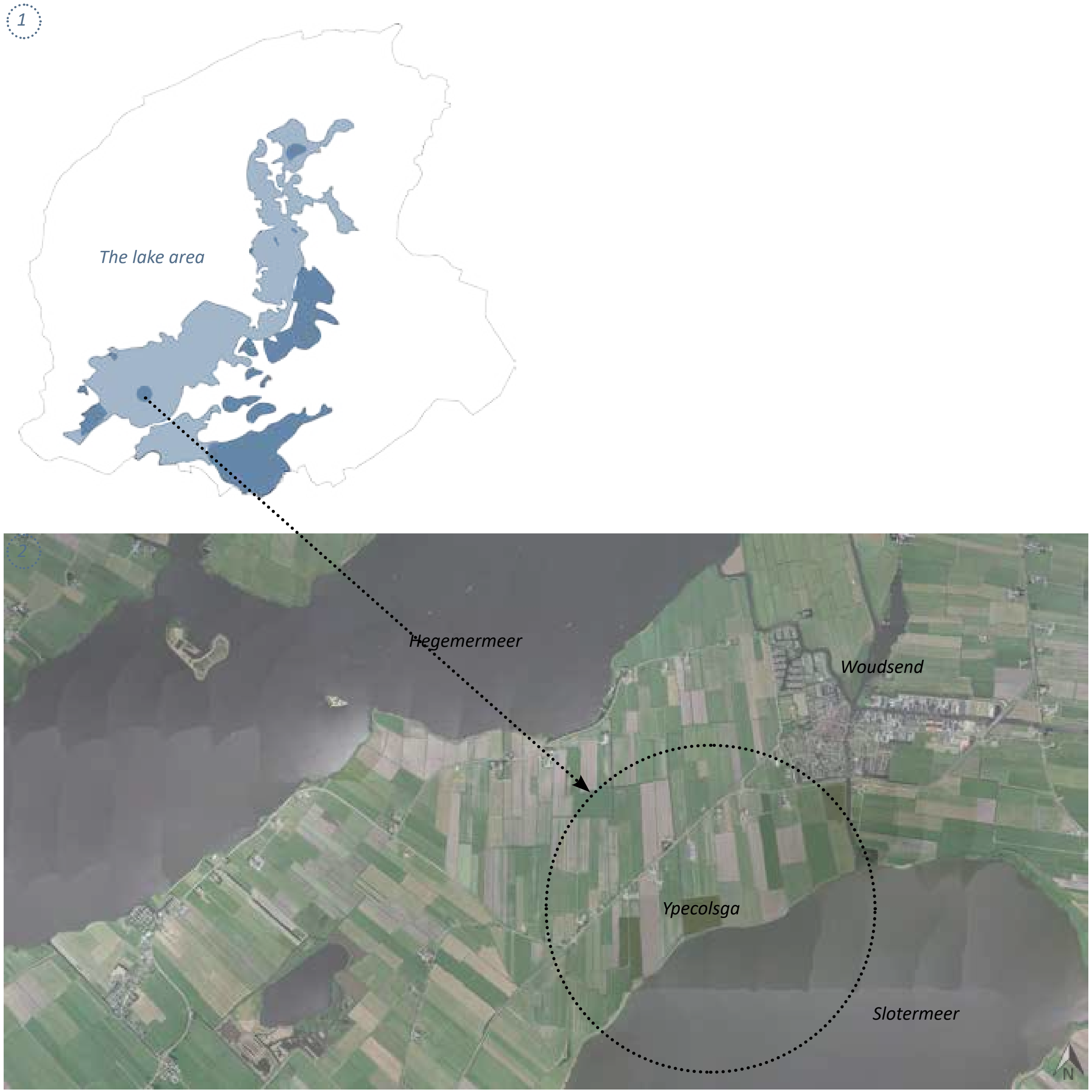


Figure 70 *Location of the case*

At this page, images of the current state of the case are visible. The field is mainly used for gras production. Big stables are developed where cows are kept. Also the lake is visible.

Figure 71 *Images of the area.*

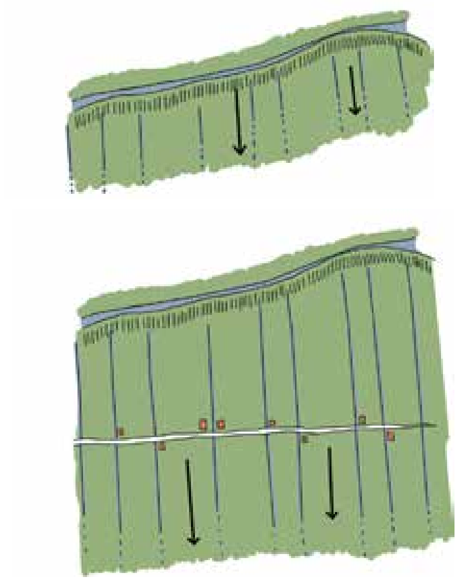
HISTORICAL DEVELOPMENT

Agricultural areas at the Frisian peat area often have a specific allotment pattern. This is the result of the historical development of the area. In past centuries the peat area contained a thick layer of soaked peat. However, people started to live in this area by reclaming the land around the 10th century (Provincie Fryslân 2014). This happened from a small peat river or a natural embankment (figure 72). The allotment pattern was placed traverse on this reclamation base. The reclamation base moved more landwards to turn more wet peat into fertile agricultural land (figure 73).

As a result of the drainage of these new formed agricultural areas, the soil declined. During storms sometimes those lower areas flooded and washed away. Lakes arised (figure 74). To prevent the agricultural areas from flooding, embankments were established (figure 75). These regional embankents surround the lakes and water systems in Friesland. They show the long history of the area. The illustrations at the right represent the development of a nonexistent place to illustrate the reclamation of the Frisian peat area.

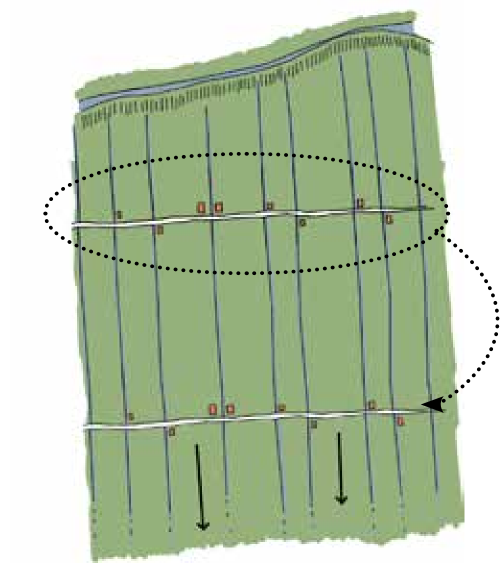
1

__Figure 72__ Around the 12th/13th century the peat areas were reclaimed. Often starting from a small peat river or levee.



2

__Figure 73__ After a while the reclamation went more landwards. This is why the reclamation basis was moved more landwards too.



3

__Figure 74__ The lower subsudenced areas sometimes dissapeared during storms

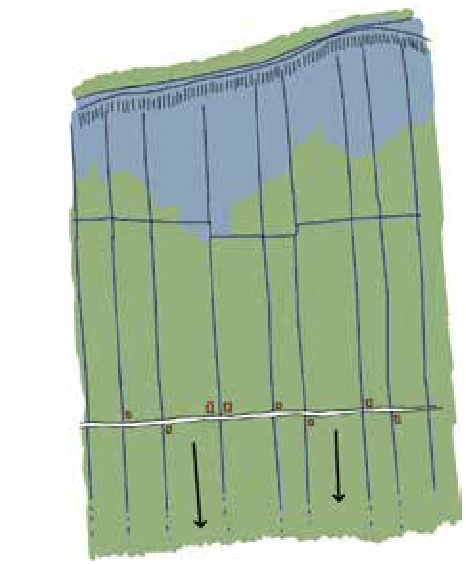


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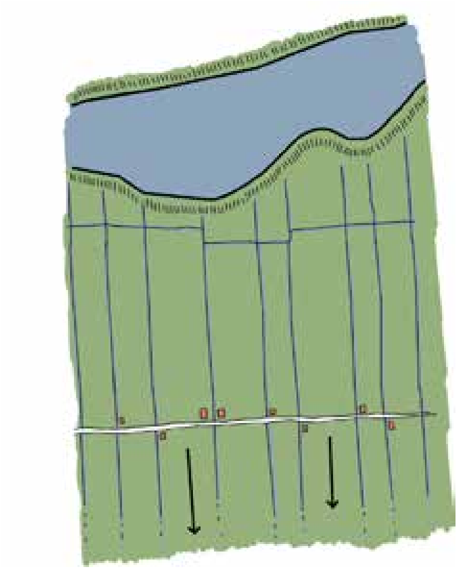
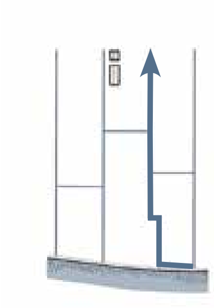
__Figure 75__ To protect reclamated areas from water of the arised lakes, embankments were developed.



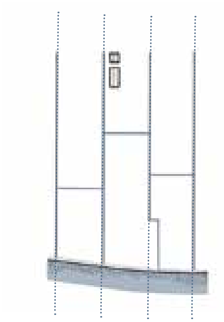
STEP 5 - LOCAL CONDITIONS

The local conditions represent together with the design principles the conditions for the development of a robust water system at the area based on analysis of the case area. Site specific facets are analysed like the ownership pattern, or the allotment pattern. This in order to design a robust water system which is practical and functional. At the next pages this analyses is visible.

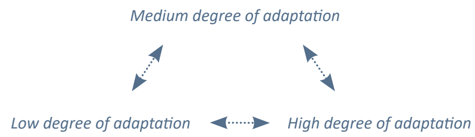
Start taking measures at the lowest areas when developing a certain degree of rewetting



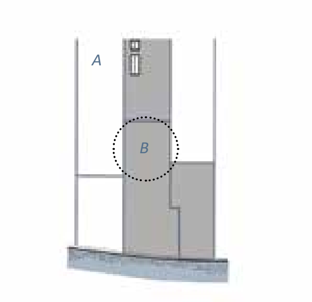
Take into account the current functioning of the water system. Measures to develop another type of agricultural land use must fit into this system to avoid unnecesary expenses.



Take into account the landscape characteristics which means for agricultural areas taking into account the allotment pattern.



Keep in mind that the type of land use will be able to swich from one type to another, to increase the feasibility.



Take into account the ownership pattern of agricultural areas

LANDSCAPE CHARACTERISTICS

The reclamation of the peat area lead to a specific pattern (figure 76). This rectilinear pattern determines to a great extent the identity of the Frisian lake area. Since lakes appeared sometimes after the reclamation of peat areas, the pattern often crosses lakes as illustrated in figure 77.

The developed embankments around such lakes have become higher and higher as a result of the soil subsidence (figure 78). Nowadays, the high embankments form a clear unform element in the landscape. The curves and their irregulare riparian zones make the embankments as a diversified unity (figure 79).

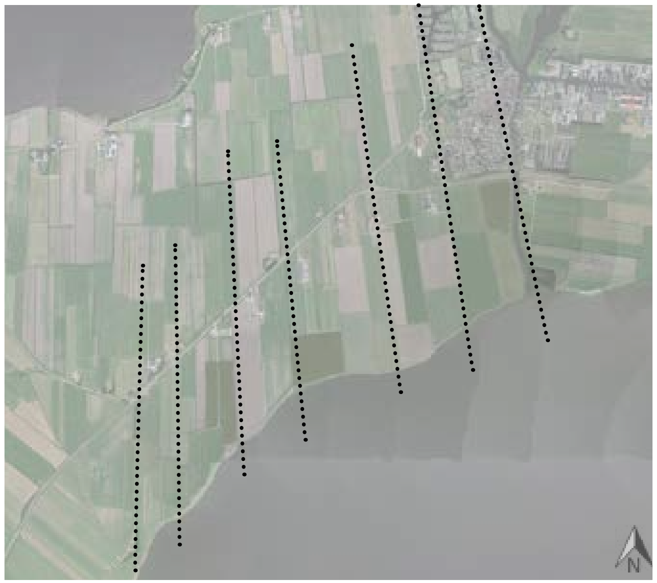


Figure 76 *Rectilinear allotment pattern*

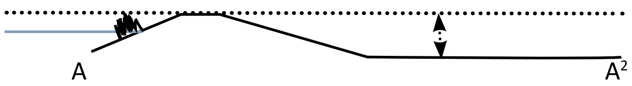


Figure 78 *Embankments have become high elements in the landscape*

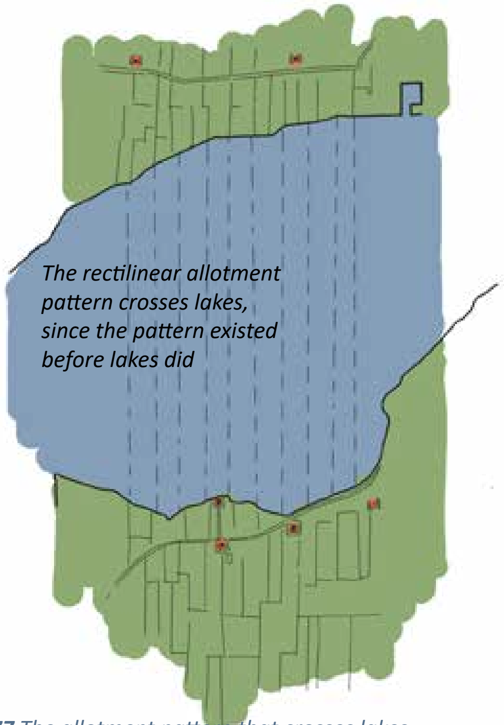


Figure 77 *The allotment pattern that crosses lakes*

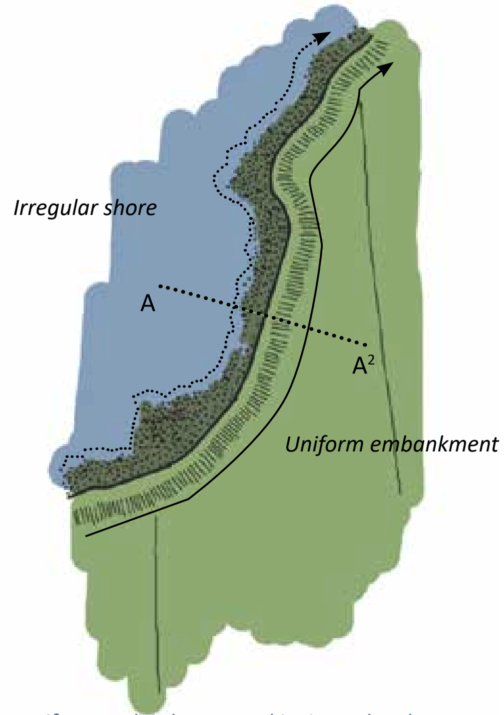


Figure 79 *The uniform embankment and its irregular shore*

Another characteristic in the landscape is the availability of high vegetation around farms (figure 81). This vegetation, existing from trees, highlights the places where farms occur.

When designing measures which form the transition to another type of land use in the Frisian lake area, it is important to take into account the landscape characteristics (figure 82, figure 83 and figure 84). These characteristics are part of the identity of the Frisian peat area. This identity determines to a large extent the attractiveness of the landscape. The reason why tourist come here, why people live and work here. Below in figure 80 this local condition to take into account the landscape characteristics is illustrated below.

Figure 81 The occurance of high vegetation around farms

Figure 82 Open landscape

Figure 83 Rectilinear allotment pattern

Figure 84 Irregular shores, uniform embankments

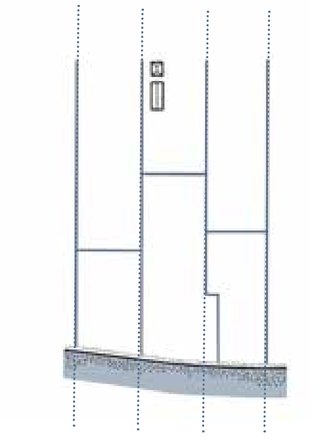


Figure 80 Take into account the landscape characteristics when designing measures to develop another type of land use.

PHYSICAL CIRCUMSTANCES - HEIGHT

At the regional scale it became clear that the lake area is an area with sometimes up to 3 meters of peat. This means that the area shall decrease as a result of soil subsidence if the current type of land use will be continued. Within the peat area the height differs. It determines together with the occurance of peat the necessity of adaptation to geomorphological and climate circumstances.

At figure 86 and figure 87 it becomes visible that areas further away from lakes and waterways are lower. This is the result of drainage and the absence of seepage. Areas next to waterbodies often contain a higher ground water level which leads to a slower peat demolition.

Lower areas will earlier experience the negative effects of peat demolition in combination with an increase of precipitation events. This is why those areas have a priority when it comes to rewetting the peat and transforming the type of land use. Figure 85 shows this condition.

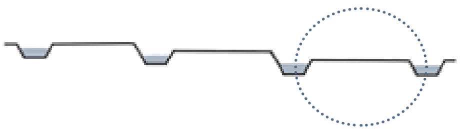


Figure 85 *Use the most low areas to start a transition to another type of land use.*

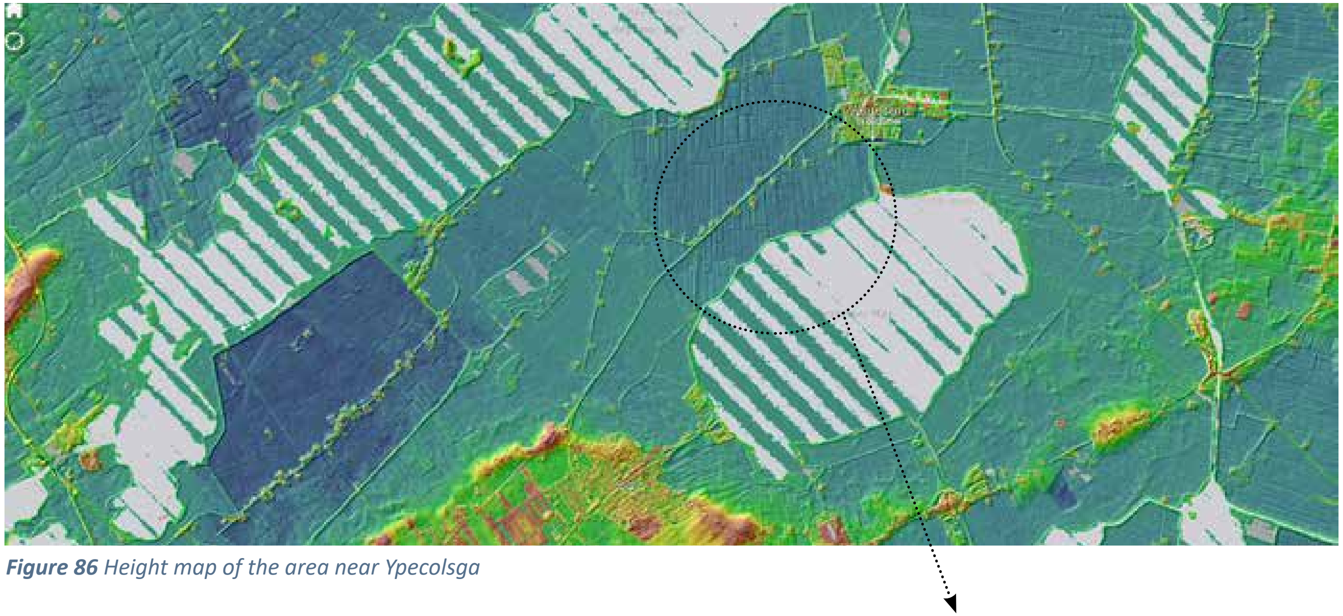
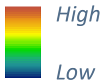


Figure 86 *Height map of the area near Ypecolsga*

Legend for figures 86 and 87



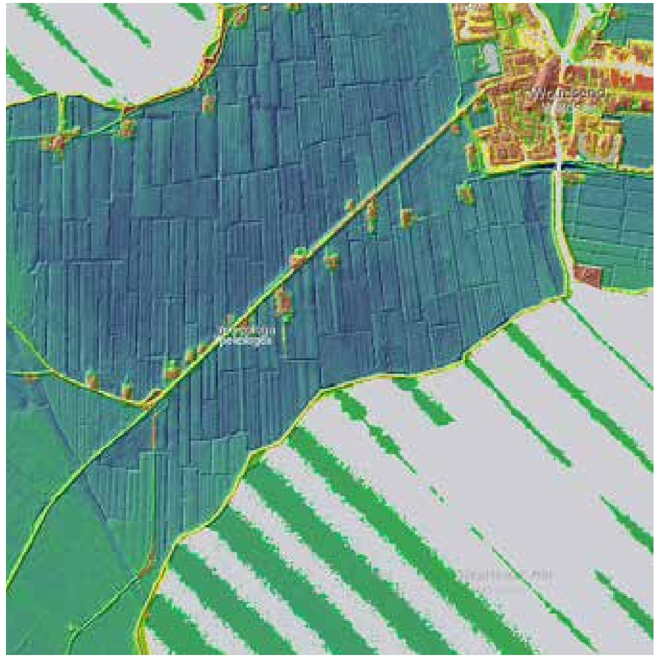


Figure 87 *Height of the case area, Ypecolsga*

SUITABILITY INTO CURRENT SYSTEM

A problem for the future when serving the current type of land use will be the huge expenses to secure the water safety. When taking measures to develop a landscape suited for another type of land use to adapt to climate circumstances and the physical landscape now and in the future, no huge expenses must be made to transform the landscape. Therefore a condition for taking measures is the suitability of measures into the current system.

REGIONAL EMBANKMENTS

The regional and local embankments are visible in figure 88. These embankments protect the area against surplus water of the Frisian system of reservoirs for superfluous polder-water. The water level of the Frisian system of reservoirs for superfluous water is -0,52 m NAP. The agricultural terrains outside the Frisian system of reservoirs protected by regional embankments are lower (-1/-3 m). Without the embankments, these areas would flood.

As mentioned in chapter 2 a lot of effort is being done to keep the regional embankments strong and safe. Based on this information it would not be logic to displace these but rather use these constructions.

Figure 88 *The location of regional embankments in the area.*

Figure 89 *The location of regional embankments in the area.*

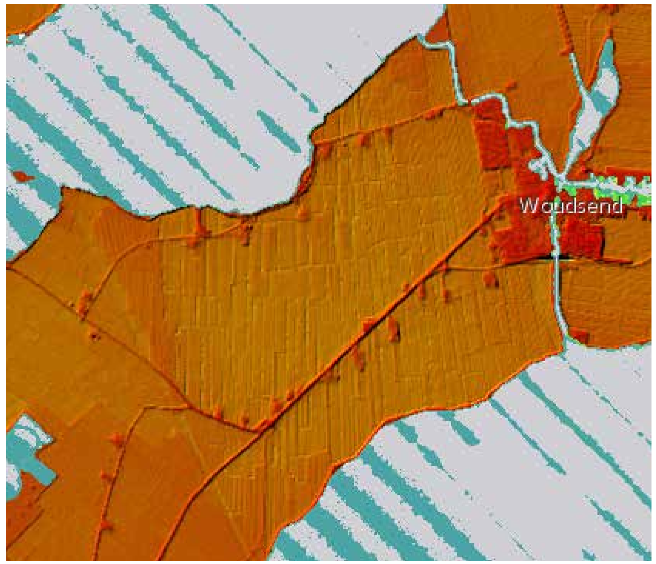


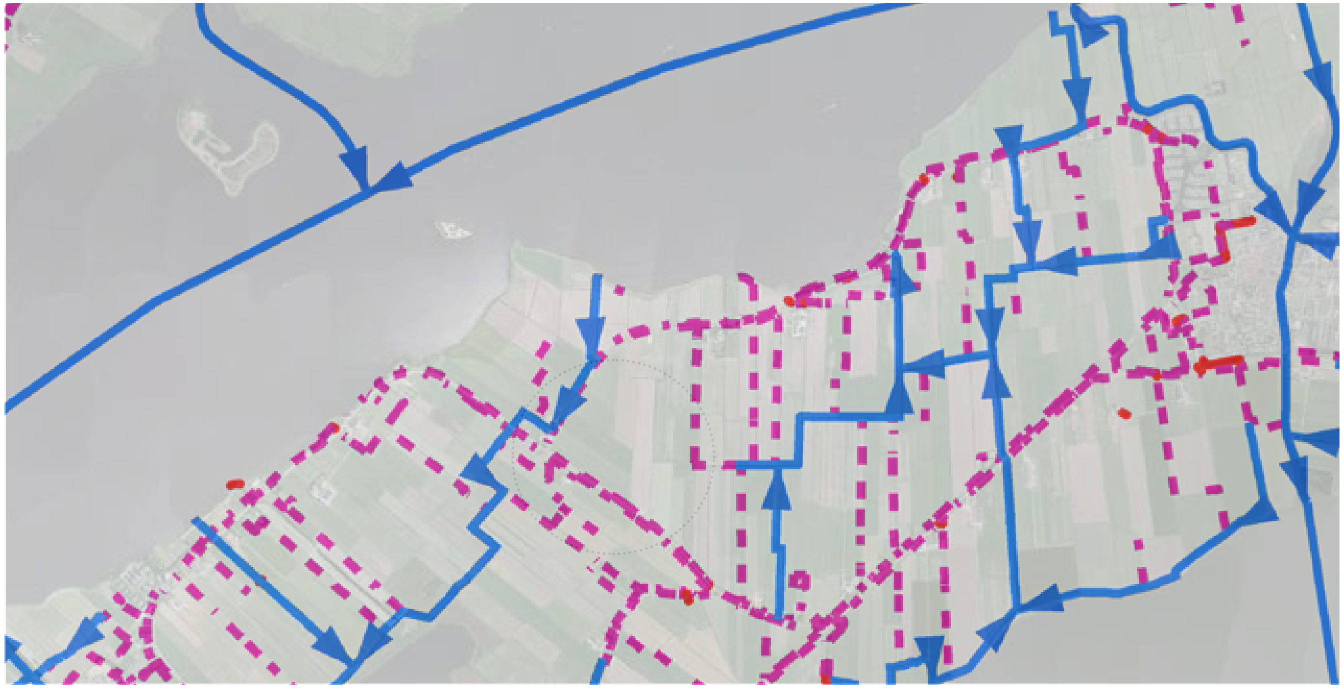
Figure 90 *Embankments form the highest places of the area together with the roads and houses*

DRAINAGE

A polder contains ditches. In the ditches redundant water from the area is being collected. This water is being discharged out of the polders by a system of small and wider ditches which end at a water pumping station. These water pumping stations pump the redundant water into the Frisian system of reservoirs.

The water level within these sub-systems; the polders is lower than the polder itself. This as a result of the high freeboard at the ditches in the polders for agricultural purposes. This freeboard generally varies from 30-150 cm. In figure 92 it is shown how this system of ditches functions at the investigated area. These small ditches determine the allotment pattern of the area which is so specific for the Frisian peat area. Ditches are also boundaries between field of different farmers.

Again it would not be cost efficient to first remove all the ditches in an area before places could be rewetted. Measures must fit in this drainage system to prohibit that areas can not get rid of redundant water. The illustration below stands for the suitability of measures into the current system.



Direction in which redundant water is being eliminated out of the area

Routes used to eliminate redundant water out of the area

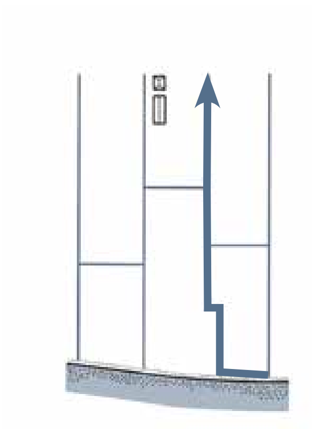


Figure 91 *Measures must fit into the current water system.*

Figure 92 *Drainage system at the area.*

OWNERSHIP

In the peat area and in the rural areas of Friesland in general, especially farmers own the land. Sometimes farmers rent it from churches or other organizations. In figure 94 an example is given of how in an area the land could be owned by several farmers. It forms a kind of patchwork. Nowadays with the new regulation according to the phosphate rights system, farmers try to remain their amount of land (chapter 1) Farmers also try to gain a high yield from their land.

From conversations with project leaders of Wetterskip Fryslân and from my own experience I know that owners of agricultural areas often not want to cooperate at the first place with water related projects. The more owners must cooperate to finish a certain project, the longer it often takes. The longer a project takes, the more expensive it gets.

If measures must be taken to increase the water safety or to develop a system for a whole new land use, the faster this will go if one land owner must cooperate instead of ten. That is why in the design phase we try to take measures which at the first place only affect one land owner.

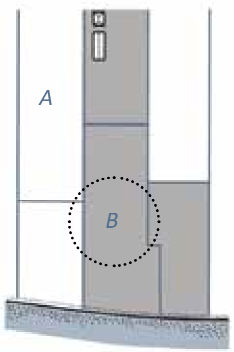


Figure 93 *Start measures in cooperation with one land owner*

Figure 94 *Ownership*

FLEXIBILITY

The aim is to increase the carrying capacity of the landscape by the transition to another type of land use at the Frisian peat area. The best option is to rewet areas at a permanent level, however factors like the circumstances of the physical landscape, the climate circumstances and political conditions influence the speed of the transition to another type of land use. These factors together with the local conditions mentioned earlier show the need for a degree of flexibility. A high degree of adaptation will need time to develop. However, to start with measures soon to develop this high degree of adaptation, probably the first step will be the development of a low degree of adaptation. If all these degrees of adaptation can be developed with the same measures, it means that the measures incorporate a degree of flexibility. This flexibility (figure 95) will probably increase the feasibility of the development of a robust water system.

DEGREES OF ADAPTATION

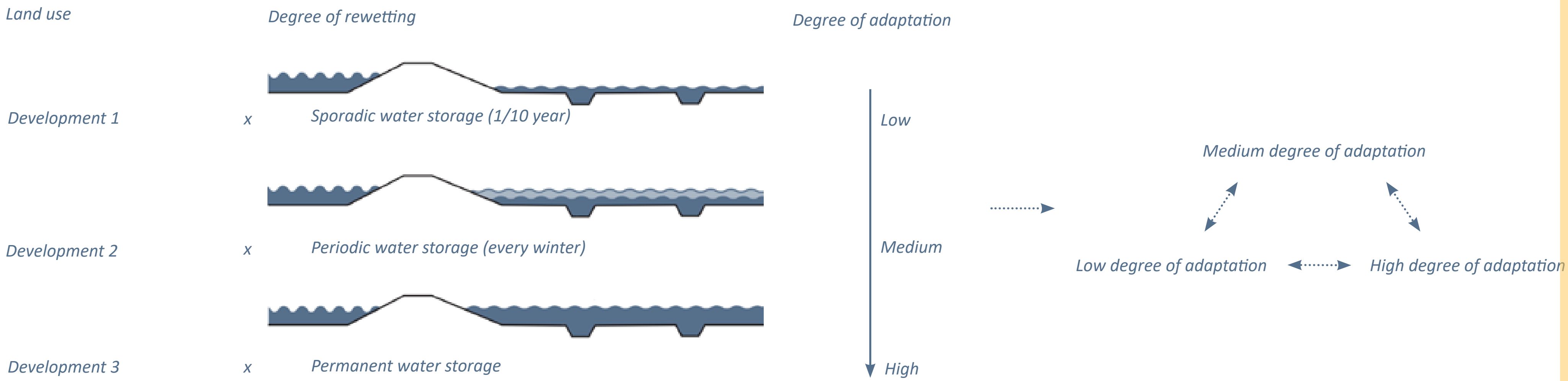


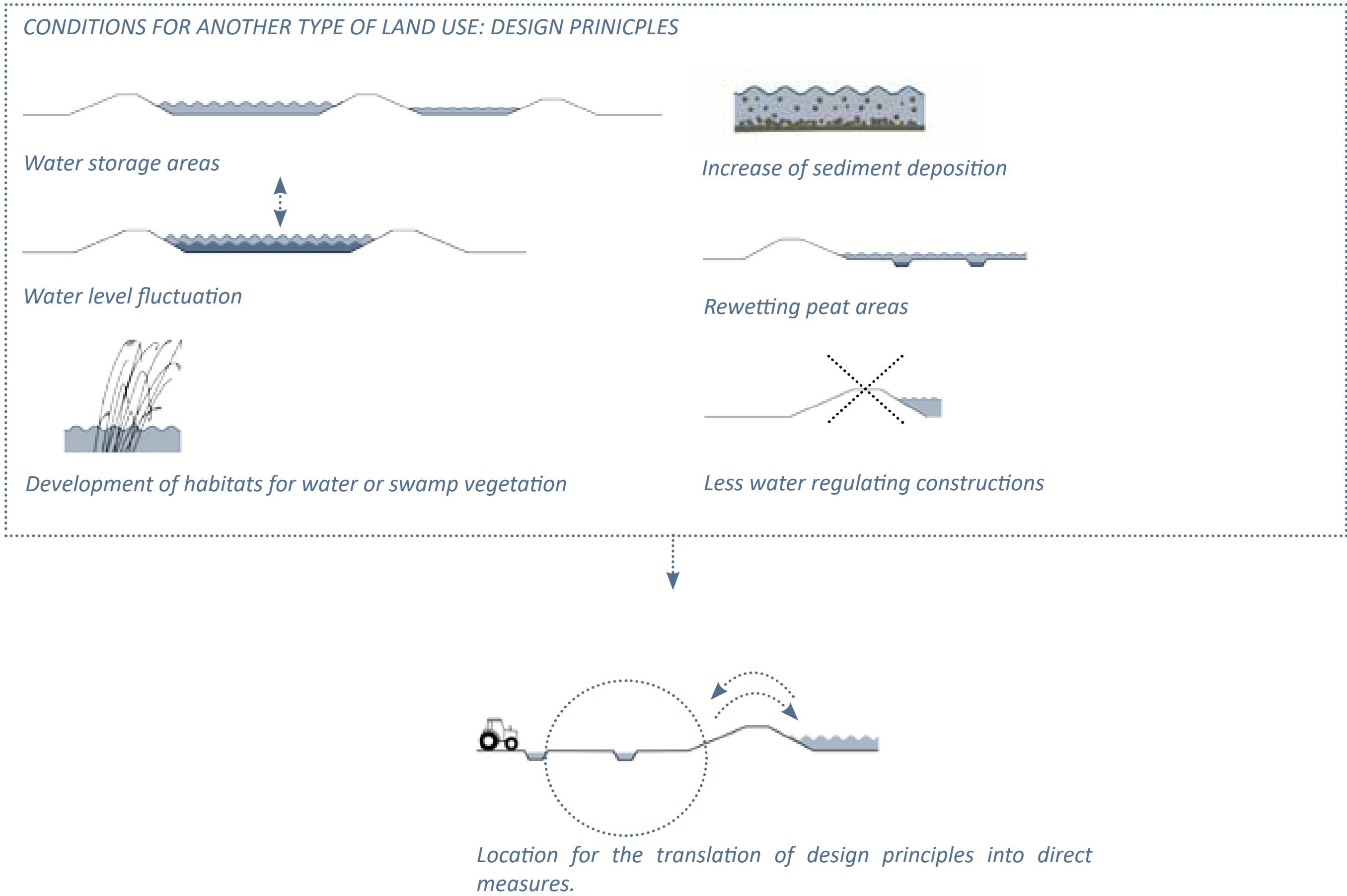
Figure 95 *Create flexibility*

STEP 5 DESIGN PRINCIPLES - LOCATION

The conditions for local measures are clear. The location where measures must be taken at the regional scale is clear, however at the local scale this location depends at the local conditions combined with the design principles. Therefore scheme 21 shows how this location becomes clear. When this location is clear, the next step will be to develop measures for this location.

The design principles given in paragraph 4.5.1 now become important. They will determine to a large extent the measures that will be taken to design a transition to another type of land use in the lake area. Here the design principles are repeated. The local conditions determine to another extent the local measures.

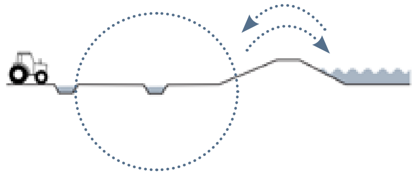
If all design principles will be taken into account during the transition to another type of land use, the best location for measures based on these design principles would be next to the Frisian system of reservoirs at the lowest area of a polder. In this way redundant water of a polder can be gathered here in order to remove it direct into the Frisian system of reservoirs. This area can also function as a retention zone for redundant water out of the Frisian system of reservoirs.



***Scheme 21** Location for measures based on design principles*

STEP 6 - LOCATION FOR LOCAL MEASURES

If we combine the local conditions that determine to a large extent the location for local measures with the best location based at the design prinicples, scheme 13 shows where at best local measures can be taken when developing a robust water system. The next step, step 8 will be to develop measures which make the current landscape suitable for another type of land use which adapts to current and future climate conditions and the physical circumstances of the landscape.



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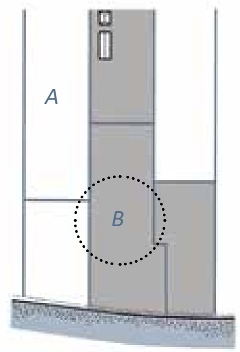
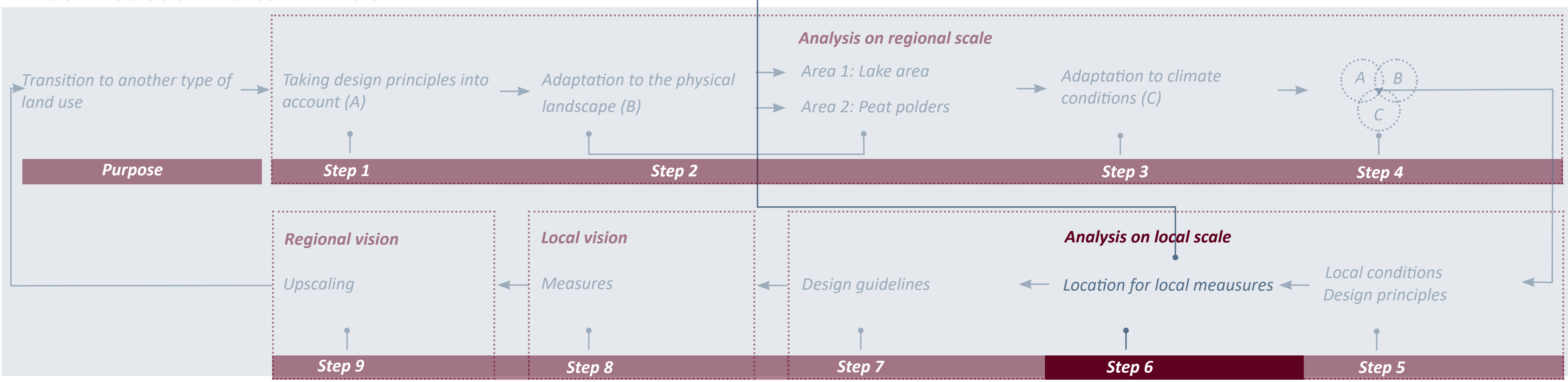


Next to the Frisian system of reservoirs for superfluous polder-water

At the lowest parts of the surrounding area

At the agricultural terrains of a single farmer

DESIGN PROCES S OF A ROBUST WATER SYSTEM



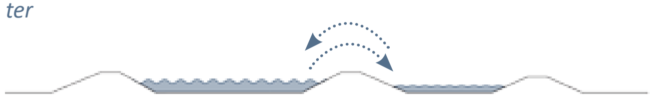
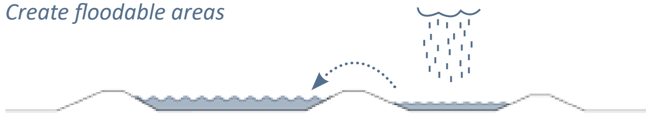
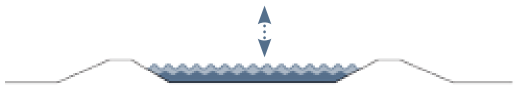
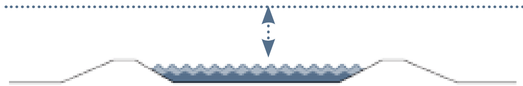
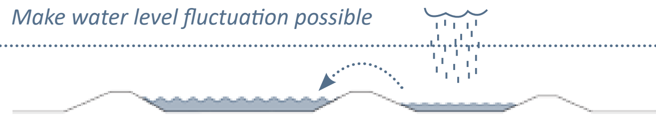
Scheme 13 *Design process of a robust water system - local scale*

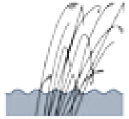
STEP 7 - DESIGN GUIDELINES

It has become clear what the design principles are. They are a kind of conditions for another type of land use. Scheme 22 repeats this again. However the implementation of these design principles can be excecuted on several ways. There are several ways in which a specific design principle can be implemented. At scheme 23 several ways are visible. At paragraph 4.5 it becomes clear how these design principles lead to specific measures.

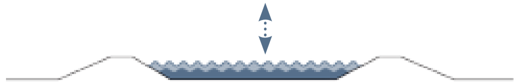
AIM	=	*Generic guidelines to develop a robust water system in which regional embankments are taken into account, this includes a transition to another type of land use*
DESIGN PRINCIPLES	=	*Principles for designing measures to achieve the aim based on the problem analyses as a result of the change of negative consequences into positive consequences or the other way around*
DESIGN GUIDELINES	=	*Ways to realise the design principles*

Scheme 22 *Design guidelines as ways to realise design principles*

DESIGN PRINCIPLES	***DESIGN GUIDELINES***
 *Create water storage areas*	 *Expand the Frisian system of reservoirs for superfluous polder-water*
 *Rewet peat areas*	 *Create floodable areas*  *Create water retention areas*  *Make water level fluctuation possible*
 *Make water level fluctuation possible*	 *Create water retention areas*  *Rewet peat areas*

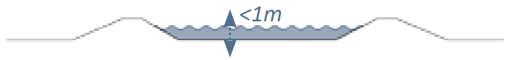


Create habitats for water or swamp vegetation



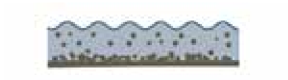
Make water level fluctuation possible

Create riparian zones

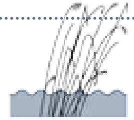


Create shallow areas untill 1m below the water level

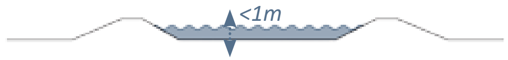
Create sedimentation zones



Increase the possibility for sediment deposition

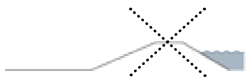


Create habitats for water or swamp vegetation



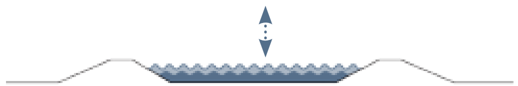
Create shallow areas untill 1m below the water level

Create sedimentation zones



Reduce the need for water regulating constructions

Rewet peat areas



Make water level fluctuation possible

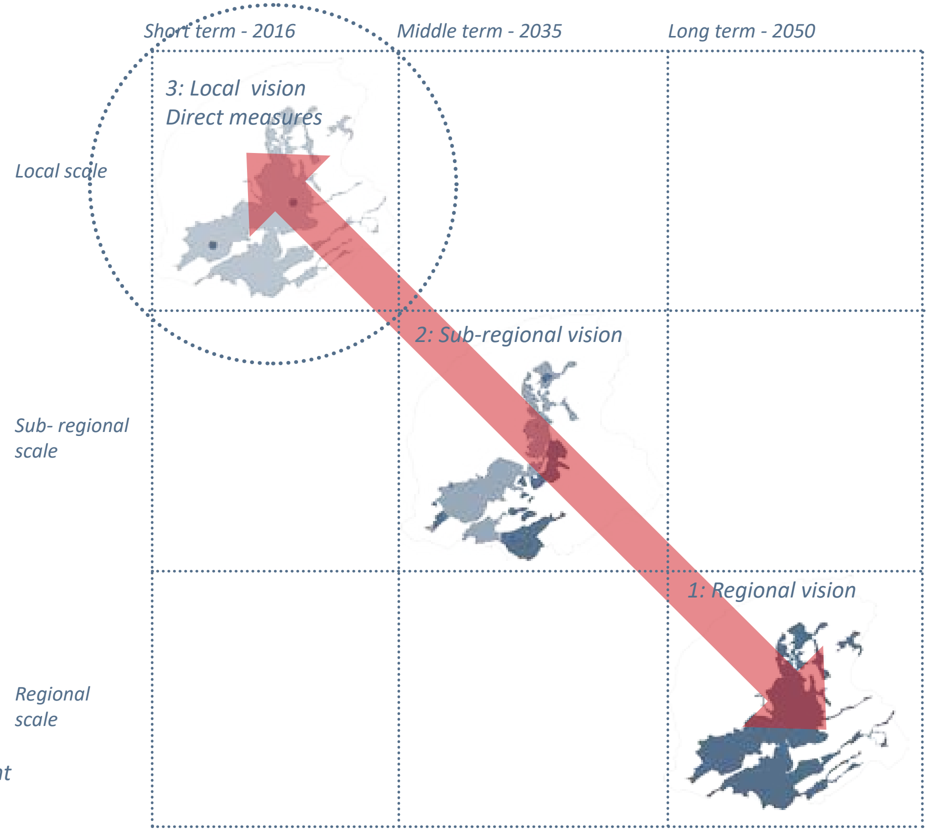
Create floodable areas

Scheme 23 *Different design guidelines to implement design principles*

4.5 STEP 8 - LOCAL VISION

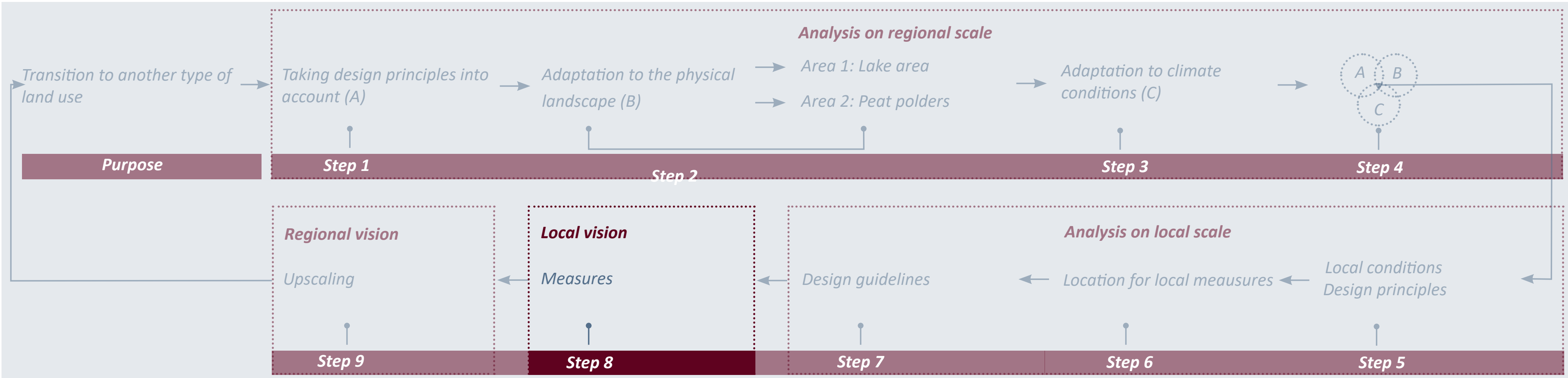
Different scale levels have been analysed to investigate the conditions for a robust water system at the Frisian peat area. Now measures are developed which take into account these conditions. Scheme 13 below explains where this development of measures takes place during the development of a robust water system. Together the measures shape the local vision; the development of the local area. The starting point for these measures will be the current landscape. From this current landscape measures eventually will lead to a robust water sytem at the long term.

However, the measures here are developed for this site. At the end these measures are extrapolated to the regional scale to develop the regional vision, the result of these measures at the long term. First local measures will be explained on the basis of 2 specific sites within the case area. At both areas it will be shown how measures can lead to a robust water system, to a permanent rewetted lake area.



Scheme 12 *Approach for the development of a robust water system*

DESIGN PROCESS OF A ROBUST WATER SYSTEM



Scheme 13 *Design process of a robust water system - local vision*

4.5.1 LOCATION FOR TAKING MEASURES

Now it is time to show what measures can be taken in order to comply to the design conditions. Also to show how a transition to another type of land use can take place and how this looks. The area has already been analysed. Now some more specific illustrations will be given at the next pages which will explain certain measures.

Two locations will be used within the polder to show how measures will look. In figure 96 and figure 97 a section shows where these locations are exactly situated.

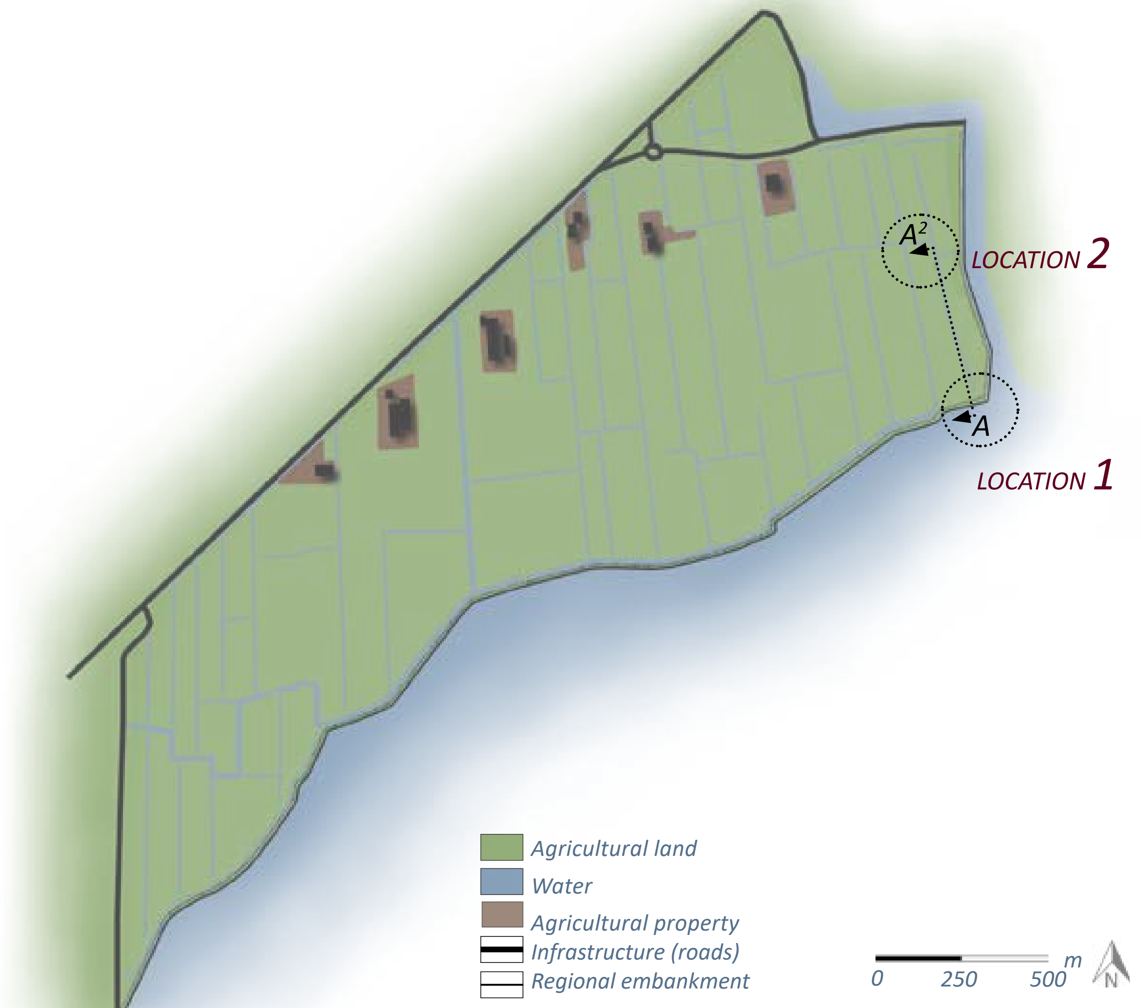


__Figure 96__ Area where the section is taken

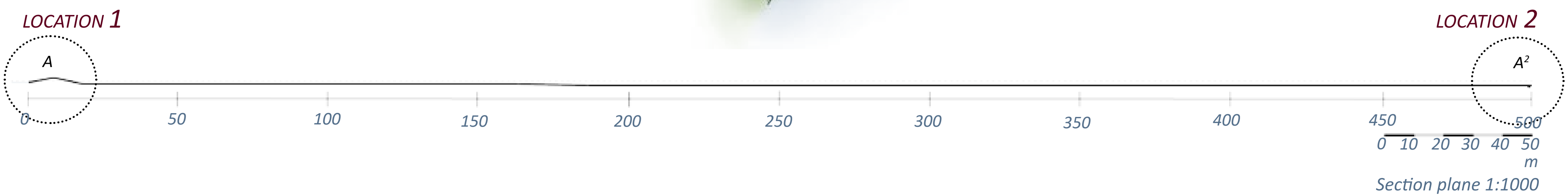


__Figure 97__ Two locations where measures will be illustrated

WHY THESE LOCATIONS?

The local design conditions and design principles showed the best location where measures can be taken to start the transition to another type of land use; near the Frisian system of reservoirs for superfluous polder-water, at single allotments and at the lowest places of the local area. The figures figure 98, figure 99 and figure 99 at this page show that locations 1 and 2 comply these conditions.

PHASING

This first phase will exists of measures which make it possible that a field can function as a sporadic water storage area, a periodic or a permanent water storage area. However, to achieve the ideal situation, these measures must be extended to other fields (phase 2) where as well sporadic, periodic and permanent water storage can take place. This second phase will be also explained by illustrations. Scheme 24 represents the different phases.

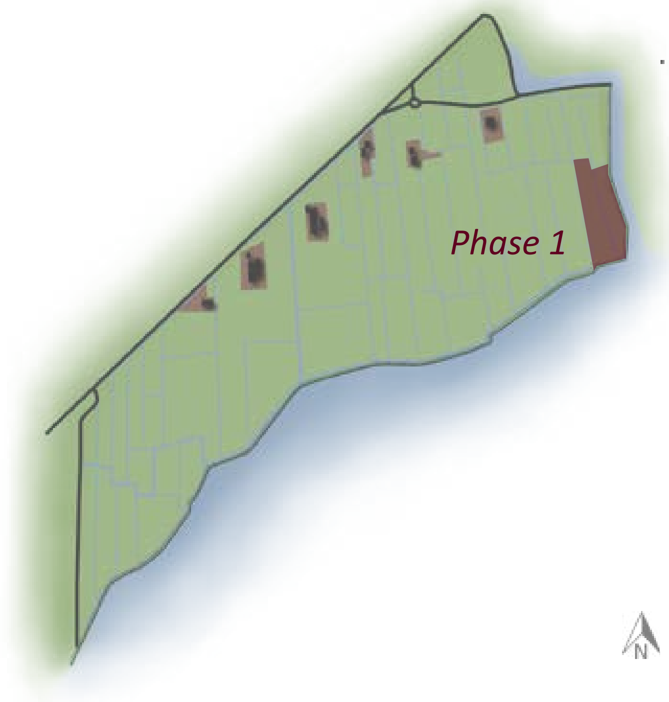


Figure 98 *Phase 1 - measures taken at single fields*

Figure 99 *Phase 2 - measures taken at several fields*

4.5.2 MEASURES

MEASURES AT LOCATION 1

At a chronological order the transition from the current landscape into a landscape with a robust water system will be shown. This means the transition from grass production areas into areas with a type of paludiculture. The captions will explain what happens at every stage and what is being achieved. The starting point will be the current situation.

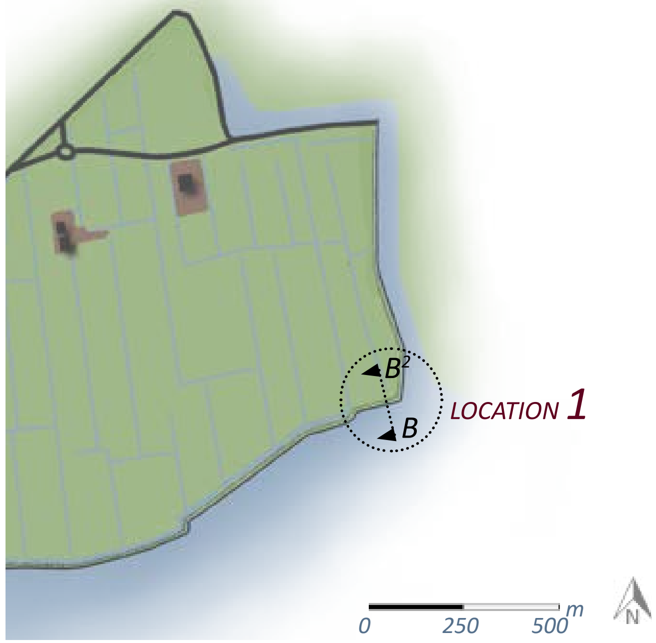


***Figure 100** Location of a section at area 1*

STAGE 0 - CURRENT SITUATION

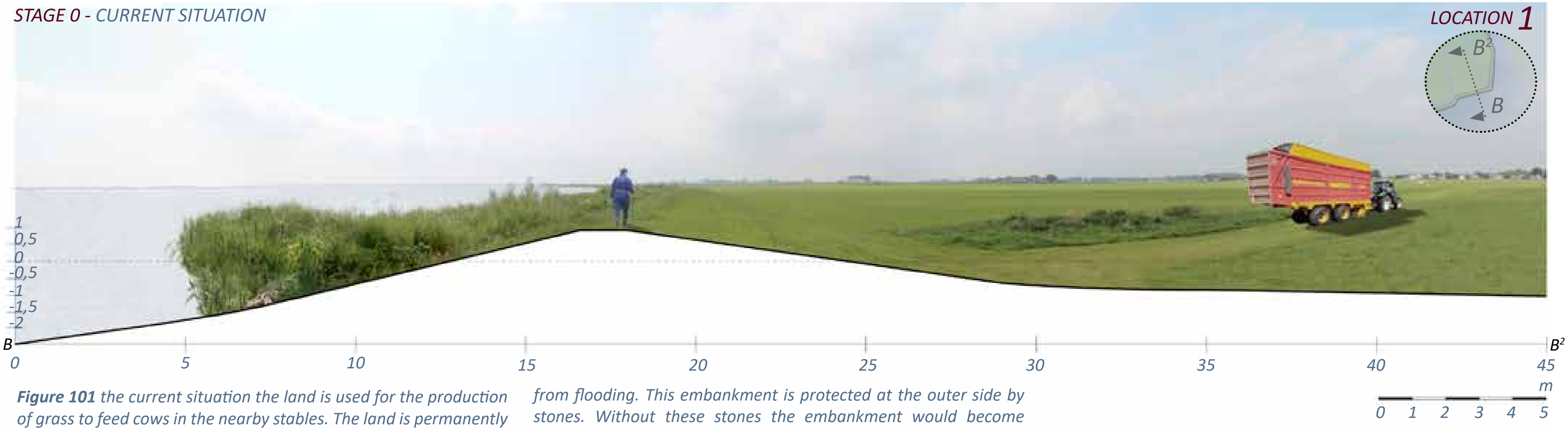


***Figure 101** the current situation the land is used for the production of grass to feed cows in the nearby stables. The land is permanently being drained in order to prevent grass roots from rotting. Next to this the land cannot be entered by tractors and tillage instruments if the area is wet. The regional embankments protect the hinterland from flooding. This embankment is protected at the outer side by stones. Without these stones the embankment would become instable as a result of erosion by waves.*

Figure 102 The water retention zone is visible at this image. During dry periods the water pumping station at the area is able to eliminate surplus water. However after periods of extreme rainfall, the retention area can be filled with water out of the polder where the rain falls. In this way the medium water level in the ditches at the area becomes lower and people working and living in the area experience less floods or high water levels which can affect their properties.

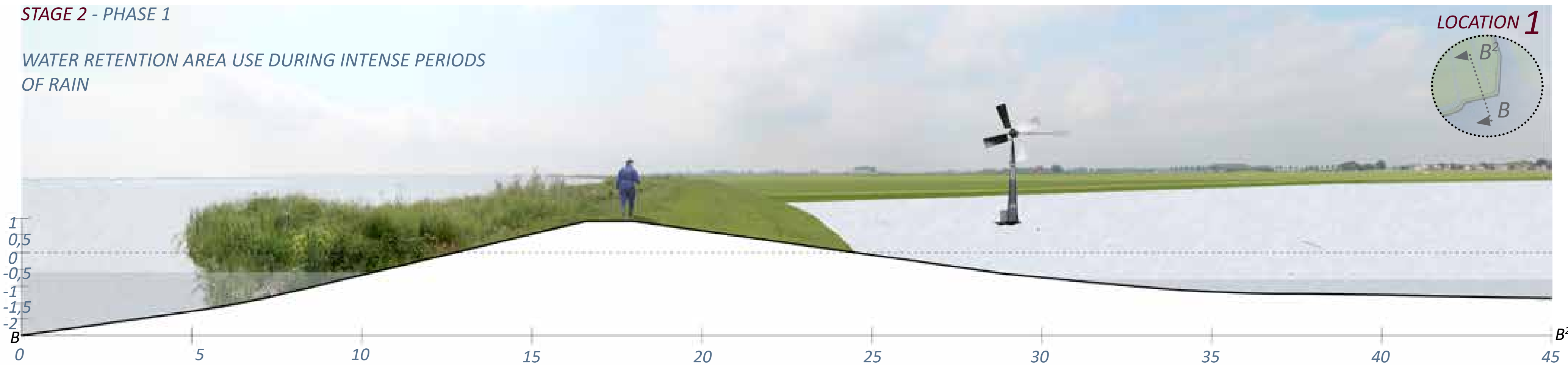
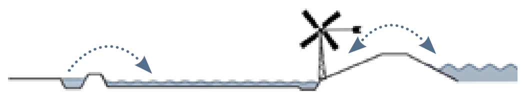


Figure 103 In this figure it is visible how the area will function. The windmill will be able to eliminate redundant water into the Frisian system of reservoirs for superfluous polder-water. If this principle of local rewetting will be applied at several places in the peat area, the lower areas together will lead to a lower normative water level in the Frisian system of reservoirs. This could lead to less strict norms for the height of regional embankments and thus to a reduction of costs for the enforcement of such dikes. The farmer which is the owner of these lower areas will possibly experience negative effects, however, not if he adjusts the type of land use to such wet condiotions.



DESIGN PRINCIPLES

By developing water retention areas at the former agricultural terrains water can be stored. In this way the peat is also rewetted.

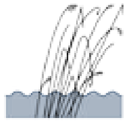
The water level can fluctuate. This also can have positive effect at the vegetation development and thus the purification of the water in the whole Frisian water system.

The rewetted areas are habitats for water and swamp vegetation. Especially the transitions from wet to dry areas are good habitats for different types of vegetation and thus also places where sediment deposition could take place, since water vegetation improves this proces.

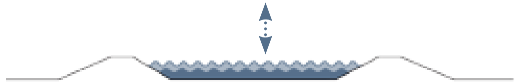
At a rewetted peat area less water pumping stations, sluices and dams are necessary.

Create water storage areas

Rewet peat areas



Create habitats for water or swamp vegetation



Make water level fluctuation possible

Reduce the need for water regulating constructions

Increase the possibility for sediment deposition

STAGE 3 - PHASE 1

OTHER TYPE OF LAND USE COMBINED WITH WATER STORAGE

Figure 104 *The ideal situation is a permanent rewetted area. This situation will delay the soil subsidence as a result of peat demolition, since oxigen will no longer be able to come into contact with the peat. Also less nutrients will be necessary to fertilize the crops at the wet terrains. Next to this vegetation will be able to purify the water. This combined with a permanent degree of water storage. In this way the area pursues the highest degree of adaptation as mentioned in table... Also water level fluctuation will be possible in such areas.*

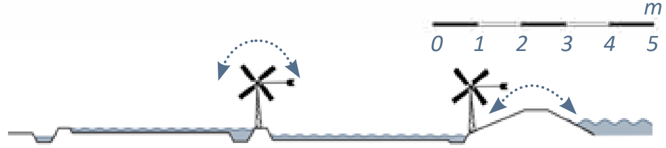


Figure 105 The ideal situation of a permanent rewetted field can be extended to nearby fields. This will only be possible if farmers agree to harvest other crops than grass. The policy of governmental organisations like the Province of Friesland or Wetterskip Fryslân are determined in this.

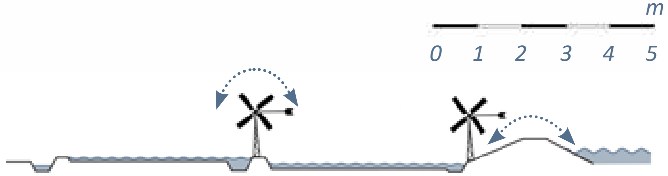
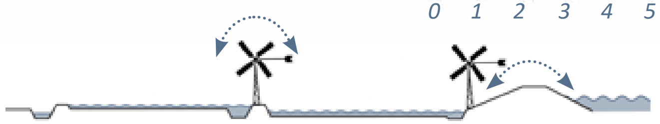


Figure 106 If at the peat area the type of land use will change in combination with rewetting the area, there is a chance that grass will not be interesting to harvest anymore. If the type of land use changes, the type of farming will proably also change and maybe dairy farming, the most common form of farming at the Frisian peat area, will not be interesting anymore. Then grass will also not be beneficial. Therefore some options of other crops at regional embankments are given. Regional embankments will stay high and dryer places at the peat area where other conditions occur than at areas that will be rewetted. An example is to have a flowerish embankment which stimulates the ecosystem. This could be realised for example with funding of governments to acchieve certain nature goals.

STAGE 5 - PHASE 2

OTHER POSSIBLE VEGETATION AT (REGIONAL) EMBANKMENTS

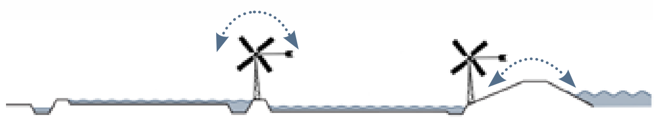
Figure 107 Another variant is a regional embankment with grape vines. Grape vines normally grow at hill slopes at southern areas, however, there are some examples of grape vines in The Netherlands. Grape vines need dry places and regional embankments will certainly provide these. In this way farmers could be able to harvest grapes and the grape vines will protect the regional embankment from erosion.



STAGE 5 - PHASE 2

OTHER POSSIBLE VEGETATION AT (REGIONAL) EMBANKMENTS

Figure 108 The last example of another crop is rapeseed. Rapeseed can be used for the production of oil. The waste of this process is often being used as cattle feed. It is an easy product to harvest. Next to this the yellow colour of rapeseed indicates the location of the regional embankment in the landscape. This could lead to a higher appreceation of the landscape which is an ingredient for the development of tourism.



MEASURES AT LOCATION 2

At a chronological order the transition from the current landscape into a landscape with a robust water system will be shown for location 2. This means the transition from grass production areas into areas with a type of paludiculture. The captions will explain what happens at every stage and what is being achieved. The starting point will be the current situation.

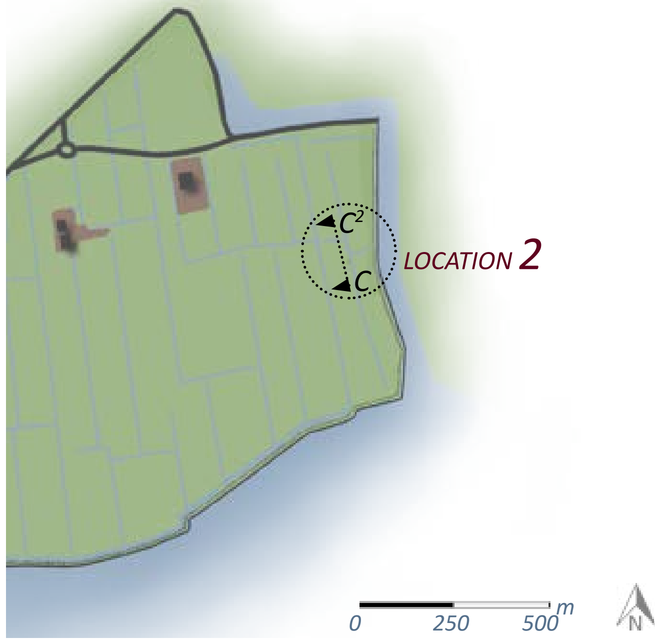


Figure 109 *Location of a section at area 2*

STAGE 0 - CURRENT SITUATION AT LOCATION 2

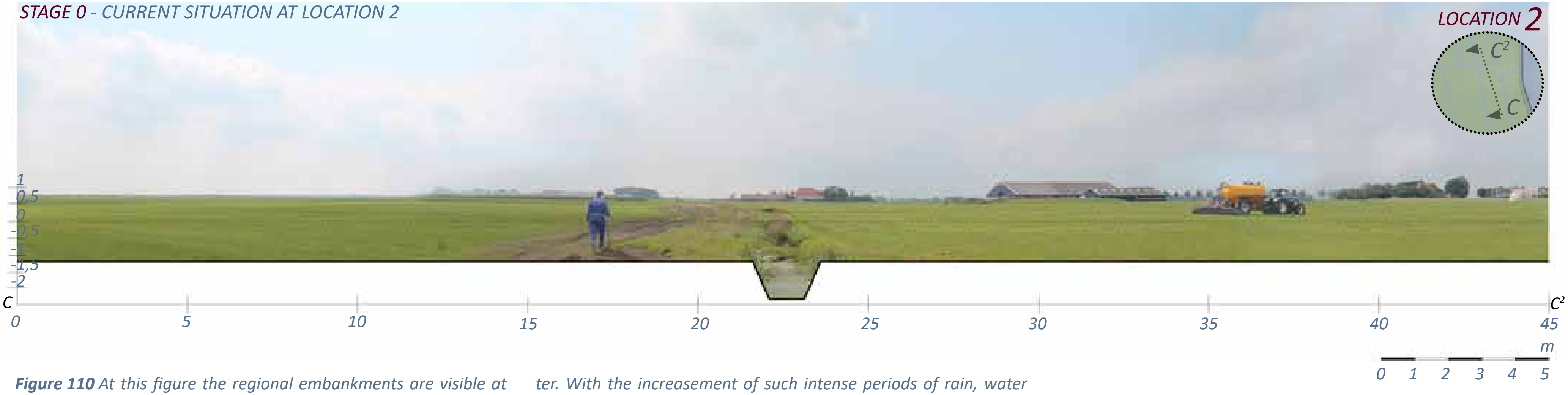


Figure 110 *At this figure the regional embankments are visible at the back. The ditches at the area function as drains which make it possible that the areas can be occupied by farmers. During intense periods of rain the water level at the ditches rises. Water pumping stations are therefore placed at such polders to eliminate surplus water to the Frisian system of reservoirs for superfluous polder-water. With the increasement of such intense periods of rain, water pumping stations do not have the capacity to eliminate surplus water within a certain time (a couple of days). That is why in the future more problems with the water management will occur.*

STAGE 1 - PHASE 1

WATER RETENTION AREA USE BETWEEN INTENSE PERIODS OF RAIN

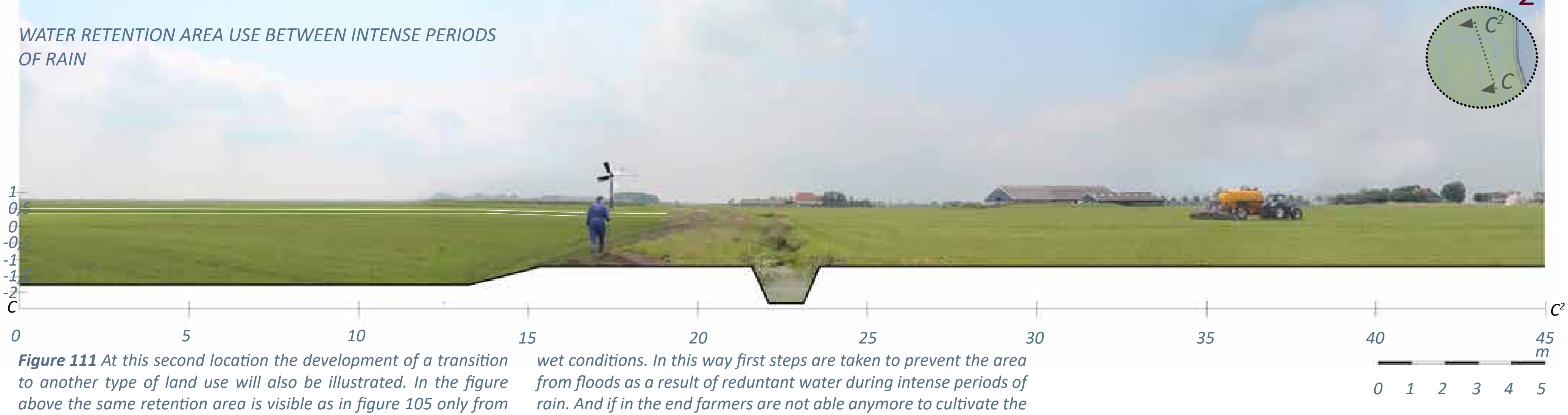


Figure 111 At this second location the development of a transition to another type of land use will also be illustrated. In the figure above the same retention area is visible as in figure 105 only from another perspective. Here it is visible that the field is reduced to be able to store redundant water of the area at the lower field. This field is then already shaped to contain crops which can deal with wet conditions. In this way first steps are taken to prevent the area from floods as a result of reduntant water during intense periods of rain. And if in the end farmers are not able anymore to cultivate the land as a result of climate conditions combined with soil subsidence etc., they can easily adapt their practices to changing climate conditions in such lower fields.

STAGE 2 - PHASE 1

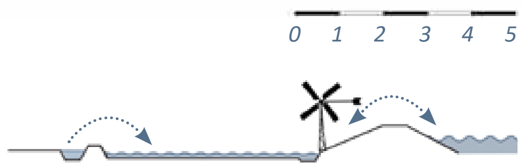
WATER RETENTION AREA USE DURING INTENSE PERIODS OF RAIN

Figure 112 In this illustration it becomes clear how the local retention zone could function. Redundant water from the area can flow into the lower excavated fields. It depends at the capacity of the local water pumping stations how deep such fields must be excavated in order to reduce the water level in nearby ditches. The deeper such excavated fields, the more water they can retain. Such fields will be situated next to the Frisian system of reservoirs. If the water level at the Frisian system of reservoirs is too high, these excavated fields can also function as water storage area for the Frisian system of reservoirs for superfluous polder-water. Small windmills wil be able to eliminate the redundant water into the Frisian system of reservoirs for superfluous polder-water.

STAGE 3 - PHASE 1

OTHER TYPE OF LAND USE COMBINED WITH WATER STORAGE

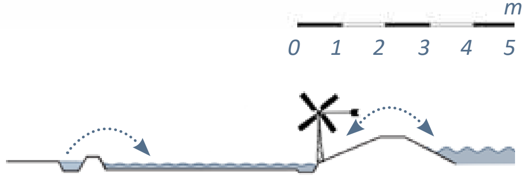
Figure 113 In a further stage a farmer can decide to adapt the type of land use to wet conditions. This is the ideal situation for the Frisian peat area. In this way, the peat demolition delays and a farmer will be able to cultivate his land even if this is wet. The question is if at this stage crops which can stand wet conditions are economical beneficial. Therefore research must be done. In this figure, cat tail is shown. This crop can handle wet conditions and it is used for the production of for example wooden floors.



STAGE 4 - PHASE 1

CREATION OF NEW EMBANKMENTS

Figure 114 If a farmer decided to harvest another crop at his or her land, it may be possible to enforce the sides of his excavated field. In this way, he can more easily enter his field and the sides become more stable and dry for tractors and other machines. After a couple of years of enforcing the sides it could become possible than a new embankment is formed. This embankment does not need active maintenance, because if it breaks, no water wil rinse out, since it does not stop water at the normal situation as illustrated here above. However, this small embankment could function as an extra safety system if a regional dike would break.

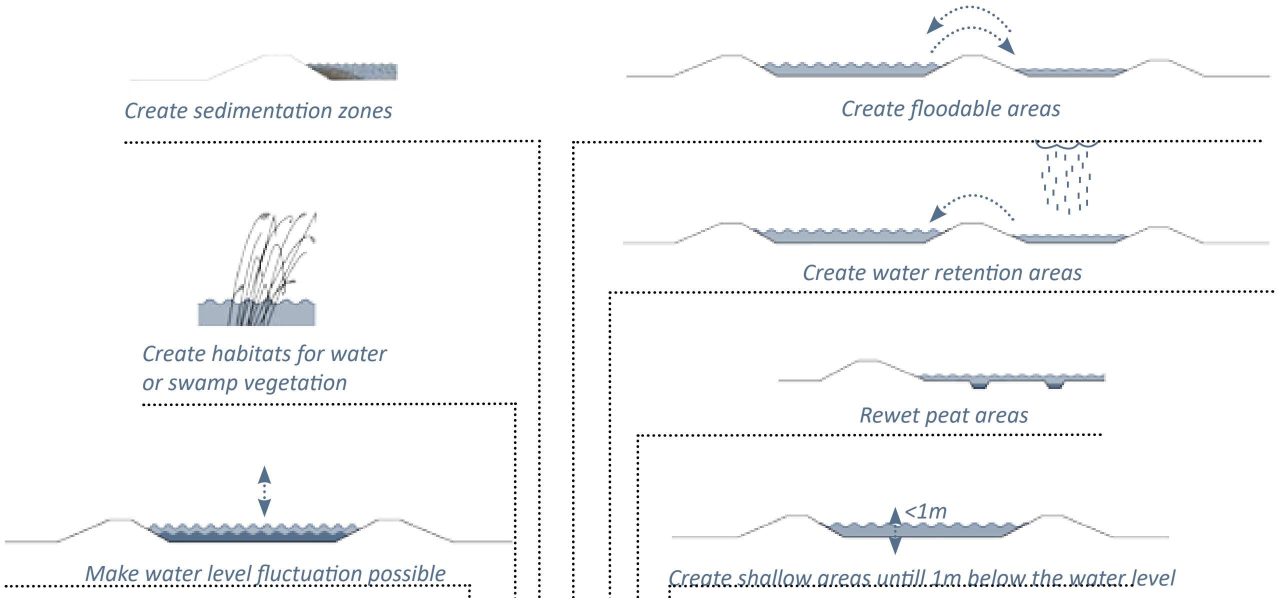


DESIGN GUIDELINES

At 98 the design principles were illustrated. Now the incorporated design guidelines are presented.

The rewetted peat areas function as retention zones which should be able to stand floods, if the water level of the frisian system of reservoirs rises beyond the height of the regional embankments.

Next to this, the rewetted areas function as habitats for water or swamp vegetation where sediment deposition can take place if water from the Frisian system of reservoirs is brought in to the rewetted areas.



STAGE 5 - PHASE 2

EXPANSION OF AREAS WITH ANOTHER TYPE OF LAND USE AT PERMANENT REWETTED AREAS

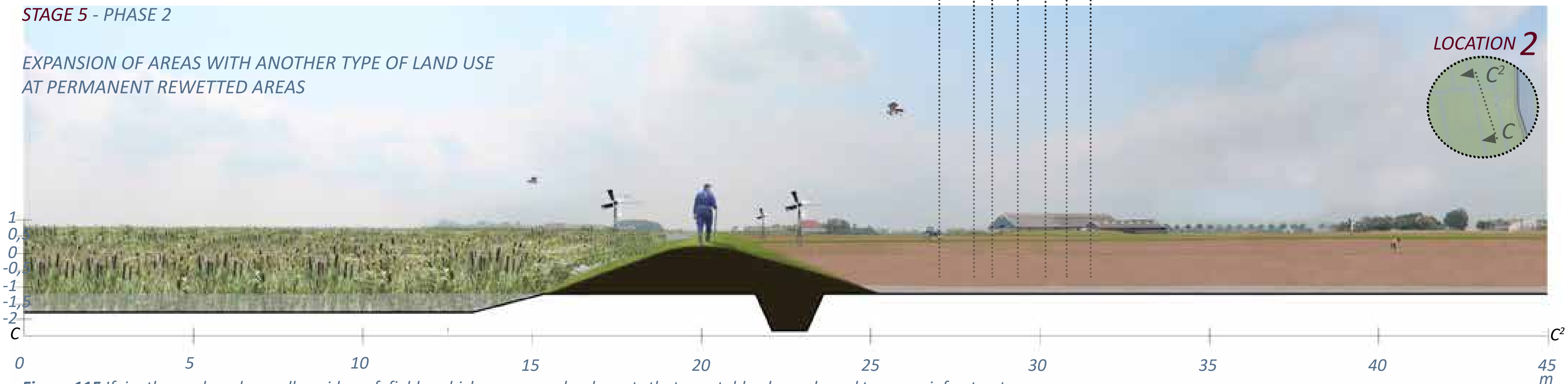
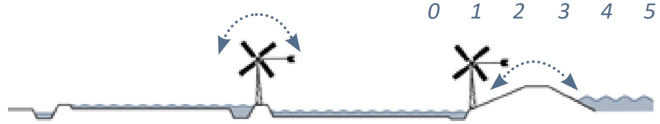


Figure 115 *If in the end such smaller sides of fields which are periodic or permanent rewetted are heightened every year or once in a couple of years, it could be possible to design new regional embankments. If the time is their when crops of a permanent rewetted area give more profit than the original form of dairy farming, it will become more easy to develop such new (regional) embankments that are stable, dry and good to use as infrastructure to enter the rewetted areas. Such new embankments could form a new type of safety system or the amount of kilometres of regional embankments could be reduced.*



4.5.3 THE LAKE AREA - MEASURES - SCHEMATIC

PHASE 1 - MEASURES AT SINGLE FIELDS

Here some schematic figures show how the transition to another type of land use could look in the area. The illustrations at the right match the schematic images below.

1

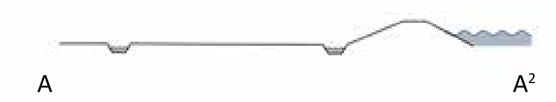


Figure 116 *2016 - Current situation*

2

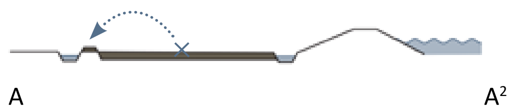


Figure 117 *Excavation of the land to create water storage areas*

3

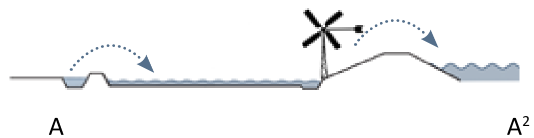
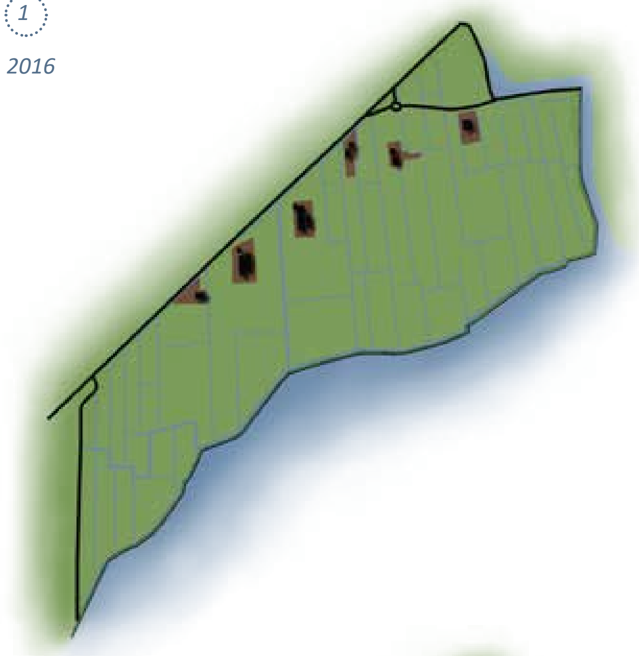


Figure 118 *The water storage area becomes the drain of the area, since it floods under free discharge. Windmills will eliminate water out of the lowered area when necessary.*

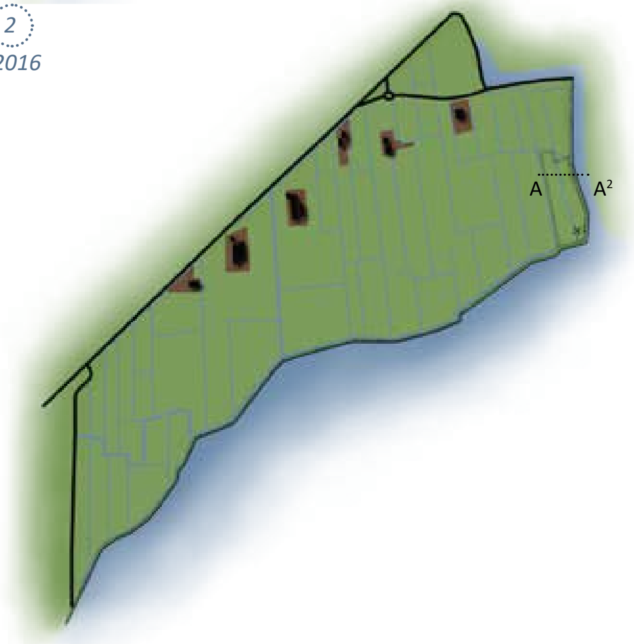
1

· *2016*

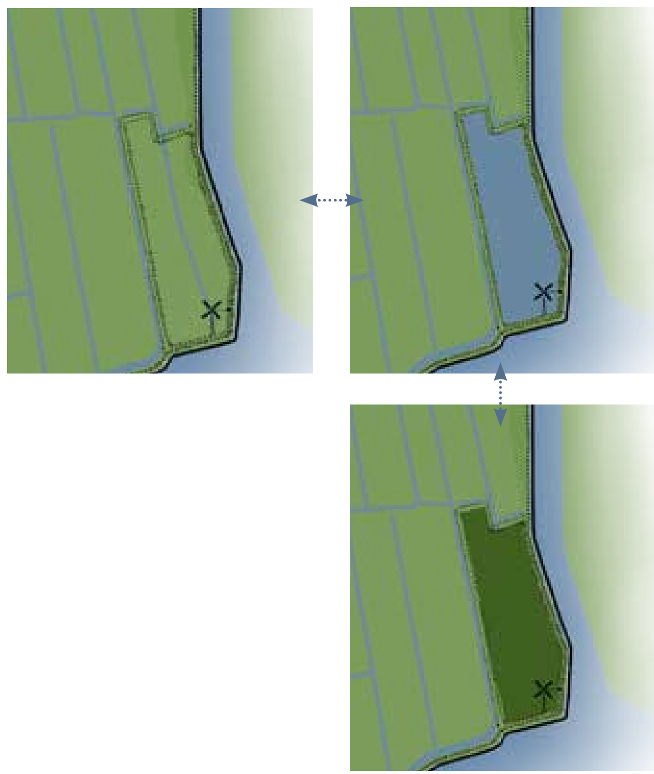


2

· *2016*



3



Legend for schematic images (page 112 and 113)

- Agricultural land
- Water
- Agricultural property
- Wet areas
- Infrastructure (roads)
- Regional embankment

0 500 1000 m N

PHASE 2 - MEASURES AT SEVERAL FIELDS

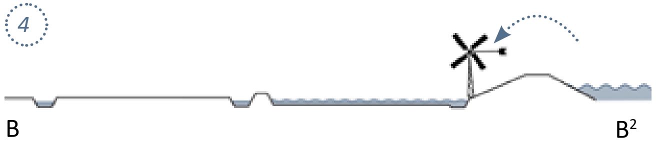


Figure 119 *The area can also function as a retention zone for water of the Frisian system of reservoirs for superfluous polder-water. The degree of rewetting can be adjusted when the time is right. At the end a permanent wet area is the ideal situation to have a robust water system which contributes to solutions for current and future problems related to the water management in the Frisian peat area.*

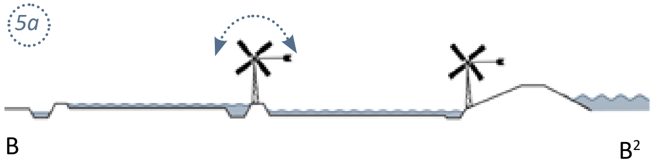


Figure 121 *A way to expand the system is to create small local embankments. These embankments retain water at the field. A negative aspect of this is that Wetterskip Fryslân will be responsible for the condition of such embankments. If an embankment breaks, redundant water wil come into the ditches behind the water storage area and could cause flooding problems in combination with periods of intense rainfall. Therefore another option to expand the system is given beneath. However during the rest of this report this variant will be used to explain the transition to another type of land use.*

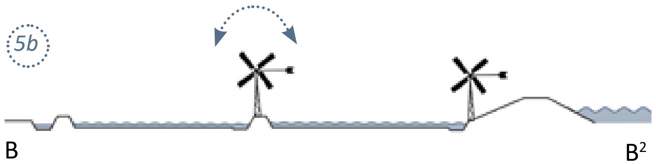
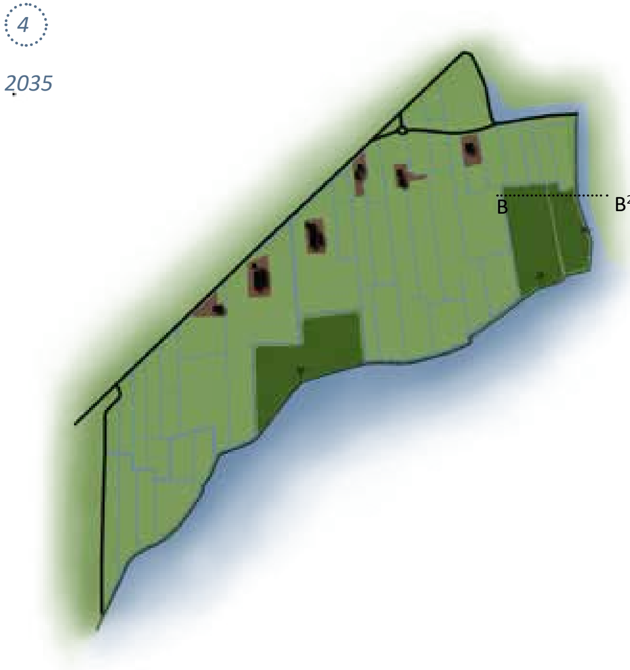
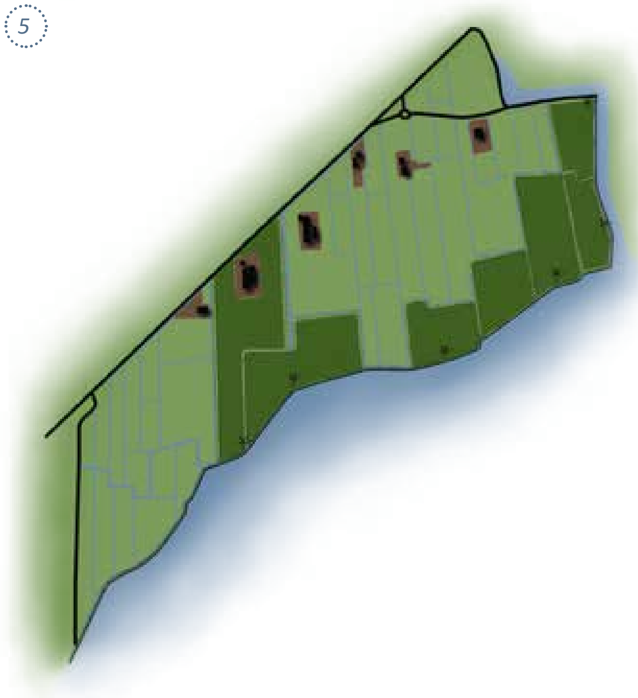


Figure 120 *The system can be expanded by excavating other terrains. Again excavated soil can be used to enforce the flanks of the excavated fields.*





POSSIBILITY OF A REWETTED AREA

The ideal situation would be to rewet the whole Frisian peat area. In schematic illustrations this was shown. However, the transformation to another type of land use has a potential for the whole area. This will be explained at page 125. This potential could lead to recreational activities, to an increase of people that want to live in the area etc. This is one of the reasons to preserve some agricultural areas in its present form. Therefore some areas near houses are reserved to serve different functions, like housing areas, recreational areas or areas where several types of activities could be organised to generate extra income (figure 122 and figure 123).

Another positive point of such open spaces near housing areas, is the preservation of the openness. The current openness around housing areas and villages is valuable. It is part of the identity of the Frisian peat area. However, it also depends on the crop type which will be grown at rewetted areas whether the openness will dissapear. At the next page a possible view of a rewetted area is shown. Here some fields near houses are not rewetted. These are places where other developments can take place.

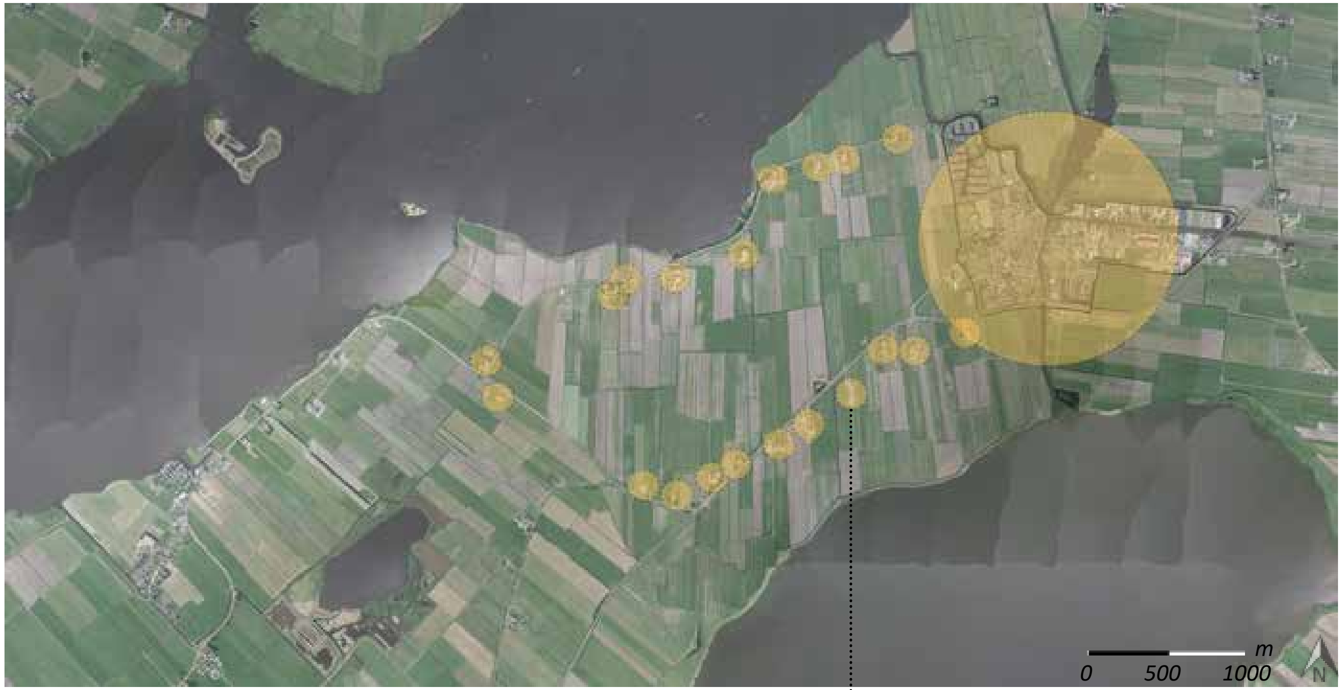


Figure 122 *Preserve open spaces near housing areas*

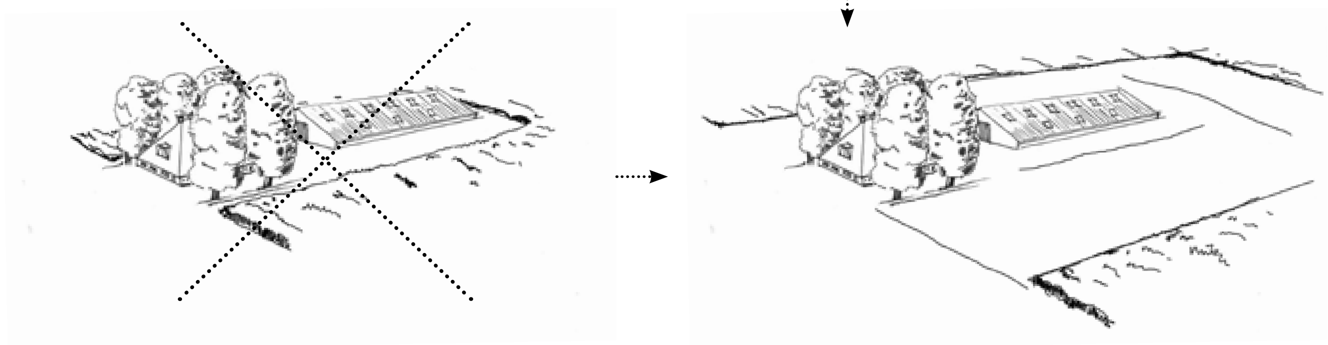


Figure 123 *Preserve open spaces near housing areas*

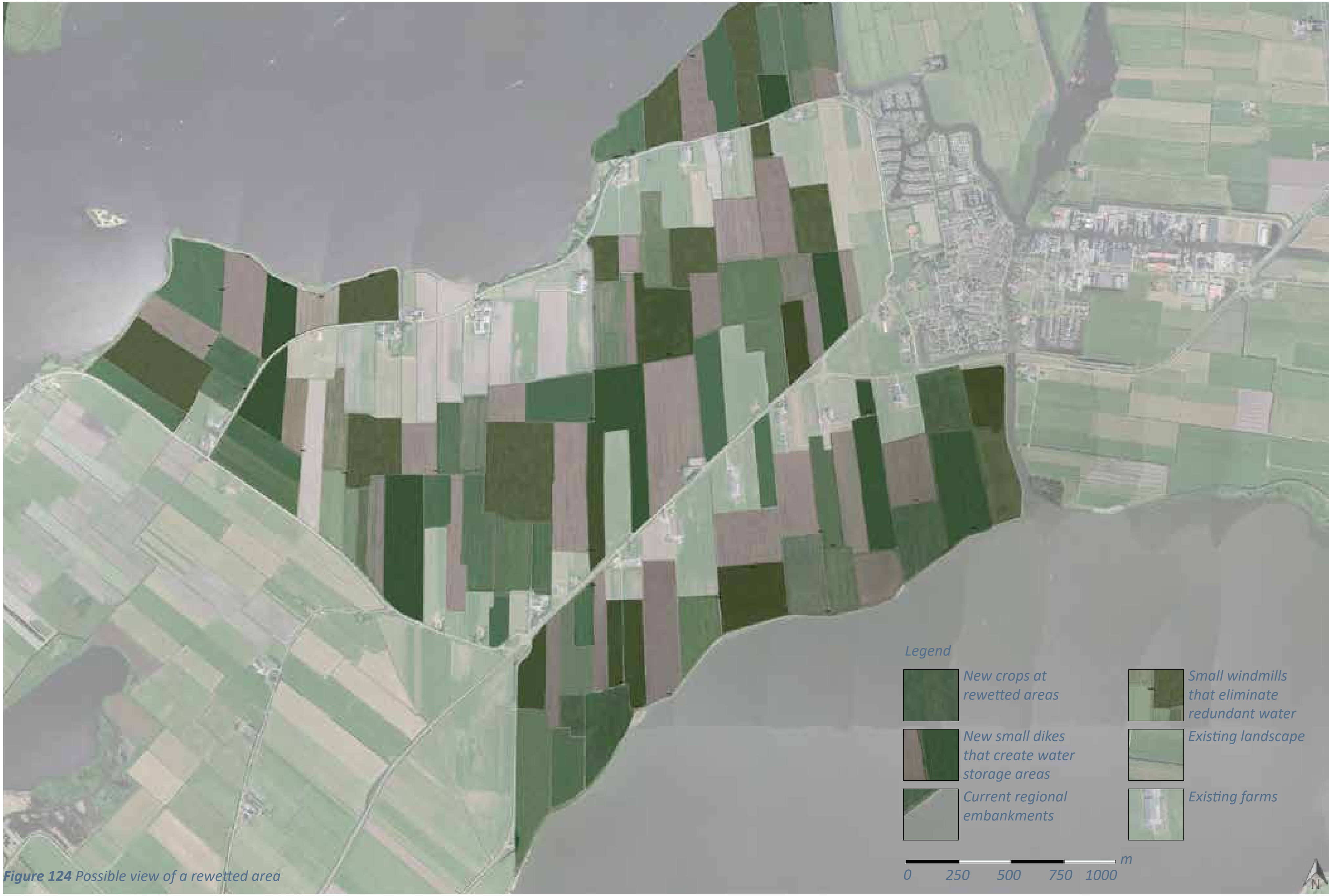


Figure 124 *Possible view of a rewetted area*

4.5.4.POSSIBILITIES AS A CONSEQUENCE OF LAND USE TRANSFORMATION

The previous pages give a possibility of a transformation to another type of land use at the Frisian lake area. This transformation gives possibilities to increase the feasibility of the transformation.

A farmer would probably only consider this other type of land use if he can gather the same or a higher income than he used to do, if the current type of land use becomes harder and harder as a result of tillage problems on his land or if Wetterskip Fryslân together with the society not want to invest again to preserve the current type of land use. The possibilities that will be explained could functions as a kind of 'green blue services'. That if a farmer executes the services, he gets money in return. Next to this, the possibilities can help to reach several goals in the fields of water safety, biodiversity and liveability too. By this the feasibility could be increased.

These possibilities are explained at the next pages under the headings:

1 *EMBANKMENTS 2.0*

2 *ECOLOGICAL ZONES*

3 *RECREATIONAL USE*

1 *EMBANKMENTS 2.0*

If an area would be reweted to a permanent level, why protecting these with a high regional embankment as in the current situation (figure 125), while the areas can stand wet conditions? With this perspective the amount of regional embankments in the area at figure 126 has been decreased. The red areas are now no longer drained areas surrounded with an enforced regional embankment, but areas protected by a smaller embankment.

Farmers can develop such embankments themselves as illustrated in figure 127, figure 128 and figure 129. The dark red line illustrates how such smaller embankments can form a closed embankment system together with the higher infrastructure in the area.

Figure 125 *Current regional embankments*

Figure 126 *Possible future embankment system*

In this figure the amount of kilometers of regional embankments has been reduced with 1,7 kilometer at an area of 1000 ha. If we extrapolate this number, at the whole Frisian peat area (85.000 ha) with 1000 km of regional embankments, 14,7% could be reduced. Imagine that this could lead to less investments to secure the water safety in Friesland. Although costs for creating the new regional embankments are not taken into account.

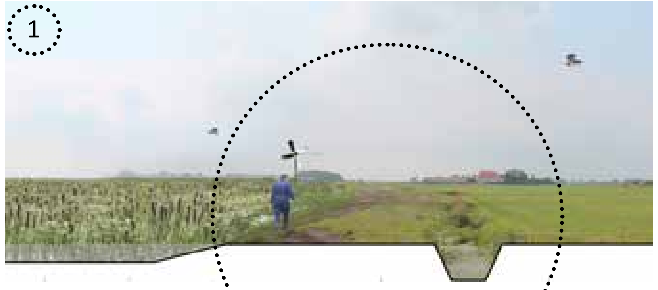


Figure 127 *The current height of the landscape, a flat landscape protected by a regional embankment.*

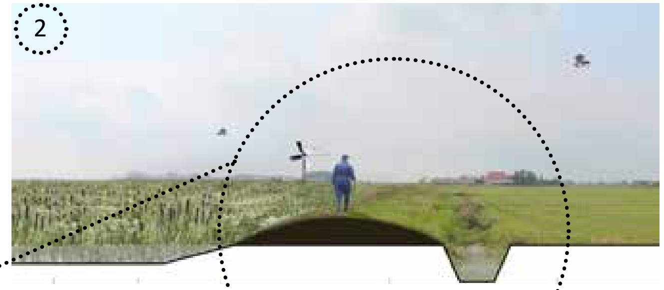


Figure 128 *Soil can be added to increase the sides to use those sides as infrastructural roads for agricultural machines and to develop new regional embankments.*

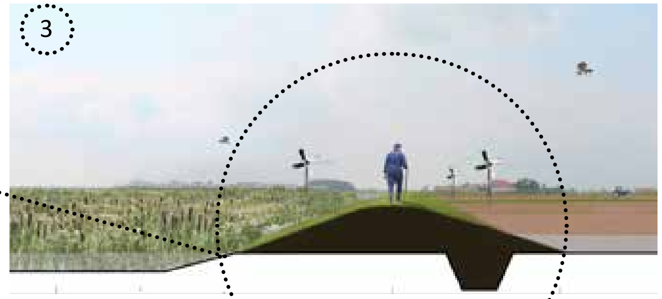


Figure 129 *After some decades, dependent of the speed of the transition to another type of land use, the addition of soil to the sides of rewetted areas could lead to the devleopment of new regional embnakments. This could cause a reduction of the amount of kilometers of regional embnakments.*

NEW REGIONAL EMBANKMENTS

The sections below in figure 130 show the current and the ideal situation in which a new regional embankment has been developed. The current regional embankment will protect the new regional embankment and the hinterland. The new regional embankment leads to a decrease of maintenance costs for regional embankments, since there are less kilometers of regional embankments to maintain.

The fields between both embankments could function as a huge foreshore if the old regional embankment is reduced as a result of less maintenance. No maintenance is needed anymore, since the old regional embankment does not need to protect houses and dry agricultural areas. The areas between both embankments will be permanently rewetted and can deal with a certain amount of water. It will take some deccades before the current regional embankment has been reduced to the status of a local embankment which could be maintained by farmers to stop waves entering their wet terrains which could affect their crops.

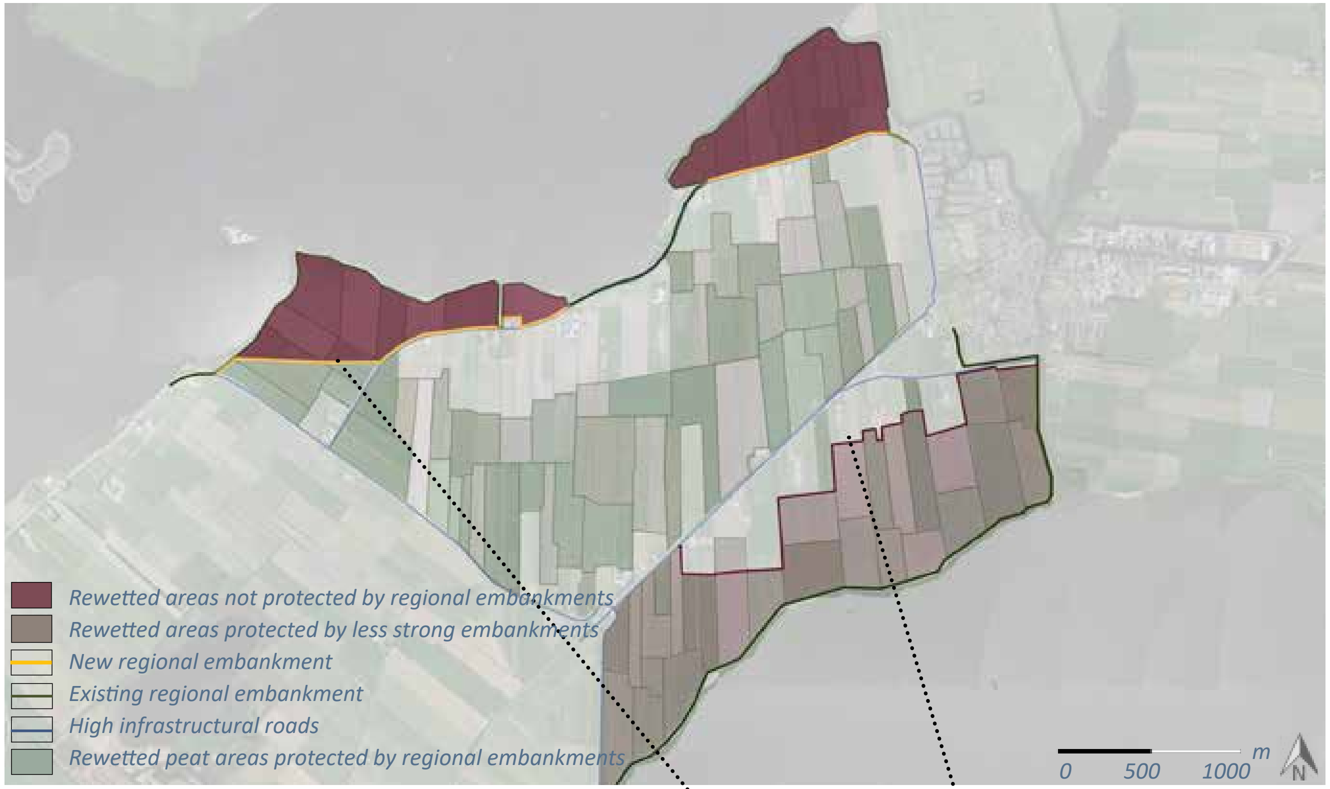
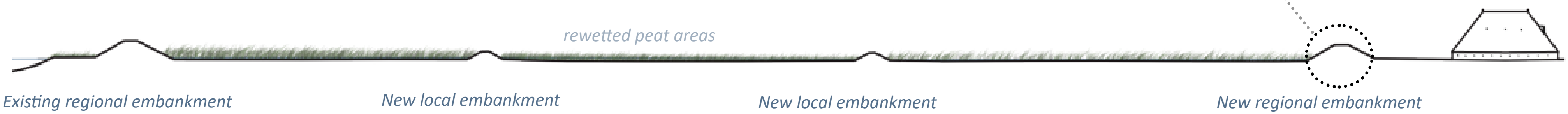


Figure 126 *Possible embankment system*

By developing a rewetted peat area, new embankments could be created too. This schematic image shows how such embankments could lead to extra water safety. If the first existing regional embankment would break, water from the Frisian system of reservoirs can be retained by the new local embankments. As a result of this 'back up' system the regional embankment does not have to be so heavily enforced.



Permanent rewetted peat areas can handle wet conditions, which would make it possible to reduce the level of enforcement of the regional embankment. The regional embankment could be developed elsewhere in order to reduce the amount of kilometers of regional embankments.

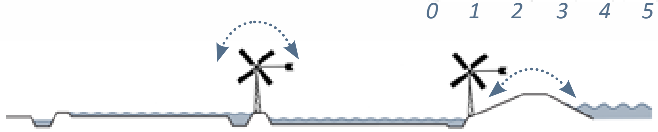
Figure 130 *Extra safety as a result of new developed embankments*

2 ECOLOGICAL ZONES

OPTION 1 - RIPARIAN AREAS AS ECOLOGICAL ZONES

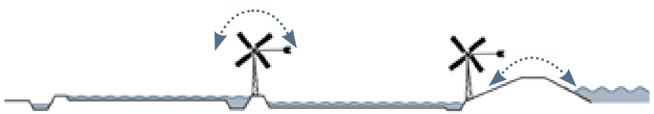
This second possibility is about the development of ecological zones. A central principle for this possibility is te development of places where specific water, swamp or helophyte vegetation can develop and where sediment deposition can take place. The figures below and at the next page highlight this.

Figure 131 *This new developed rewetted peat area gives the perfect circumstances for different water vegetation species to develop. Therefore the inner side of (former) regional embankments could be used for the development of ecological zones. Here vegetation could develop at the transition from land to water. This could lead to a high amount of different plant species, since plant species often have different requirements for their stand. With the maintenance of an ecological zone, the biodiversity could as a result be increased.*



OPTION 1 - RIPARIAN AREAS AS ECOLOGICAL ZONES

Figure 132 *Also at the inner sides of new developed embankments ecological zones can be developed. Such zones could help to improve the water quality at the areas where crops are being grown. Next to this the zones could help to improve the living conditions for protected animal species at the Frisian peat area. Birds like the lapwing feed themselves with animals that occur at such wet areas.*



OPTION 2 - ECOLOGICAL RIPARIAN ZONES AS SEDIMENT DEPOSITION AREAS AFTER REALISATION

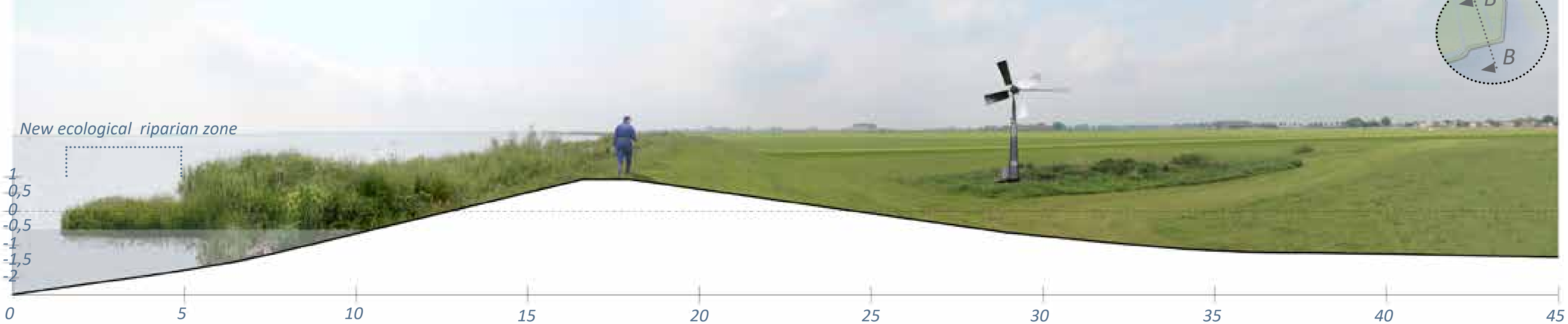
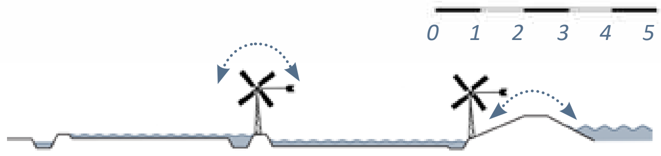


Figure 133 At the outer side of regional embankments constructions could be created to create a riparian zone which at the same time functions as a sediment deposition area. At this floating riparian zone, vegetation could develop, which helps to purify the water and reduces the wave attack at the embankment. Currently no riparian zones at the outer side of an embankment are developed, without re-positioning the embankment, since this affects the water storage capacity of the current water system. However, in this plan, agricultural terrains will be rewetted, which means an extra water storage capacity. And thus even at the outer sides of embankments constructions could be created to prevent erosion and to create a habitat for helophyte vegetation and specific animal species.



OPTION 2 - ECOLOGICAL RIPARIAN ZONES AS SEDIMENT DEPOSITION AREAS LONG AFTER REALISATION

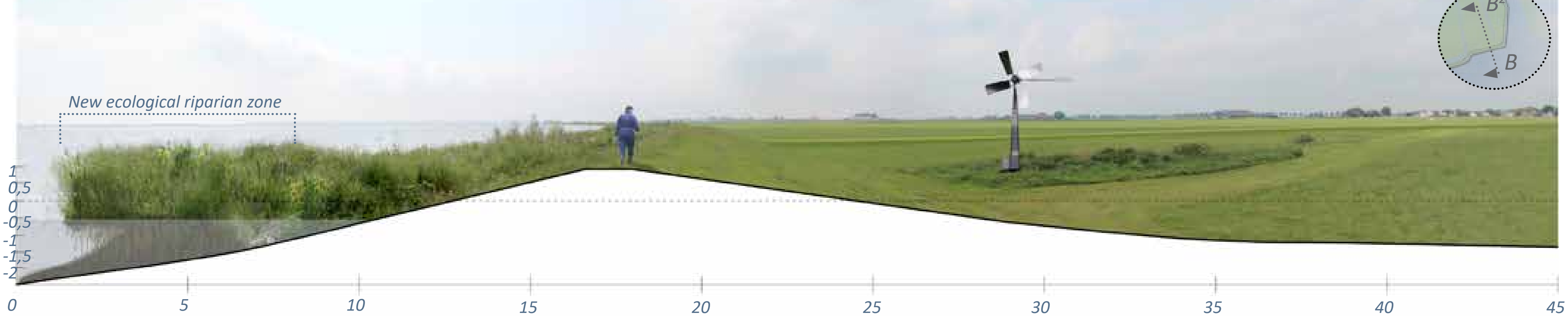
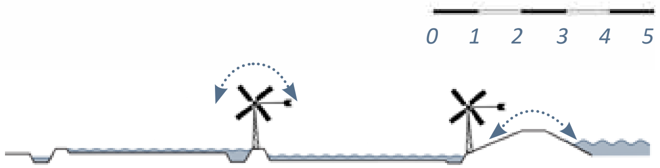


Figure 134 At the end this floating ecological zone could also function as a natural embankment protecting system. The sediment could be used to enforce the dikes or it could be transported to the smaller embankments at the rewetted areas to enforce those with the sediment.



ECOLOGICAL STRUCTURES

If embankments would be used for the development of ecological zones, a whole new ecolgocial structure can be developed in an area. Figure 135 at the right shows a possibility of such a structure in the area.

Why should a farmer want to develop such an ecological zone at the edge of his lands? By placing the ecolgical zone at the edge between dry land and water at a gradient, different vegetation species can develop that attract different animal species. By this the biodiversity could be increased and thus the functioning of the whole ecosystem in the area. Next to this also the water quality is likely to improve, since water vegetation purifies the water.

Wetterskip Fryslân nowadays for example designs nature friendly shores to improve the water quality. This measure costs millions of euro's and a lot of time, since farmers often not want to cooperate. Farmers need their land for the production of grass in the current system. However, if their land is rewetted, if they produce crops at such rewetted areas and if such an ecological zone could be developed and maintained by farmers for some funding by Wetterskip Fryslân, it would seem a logic step to develop such ecological zones.

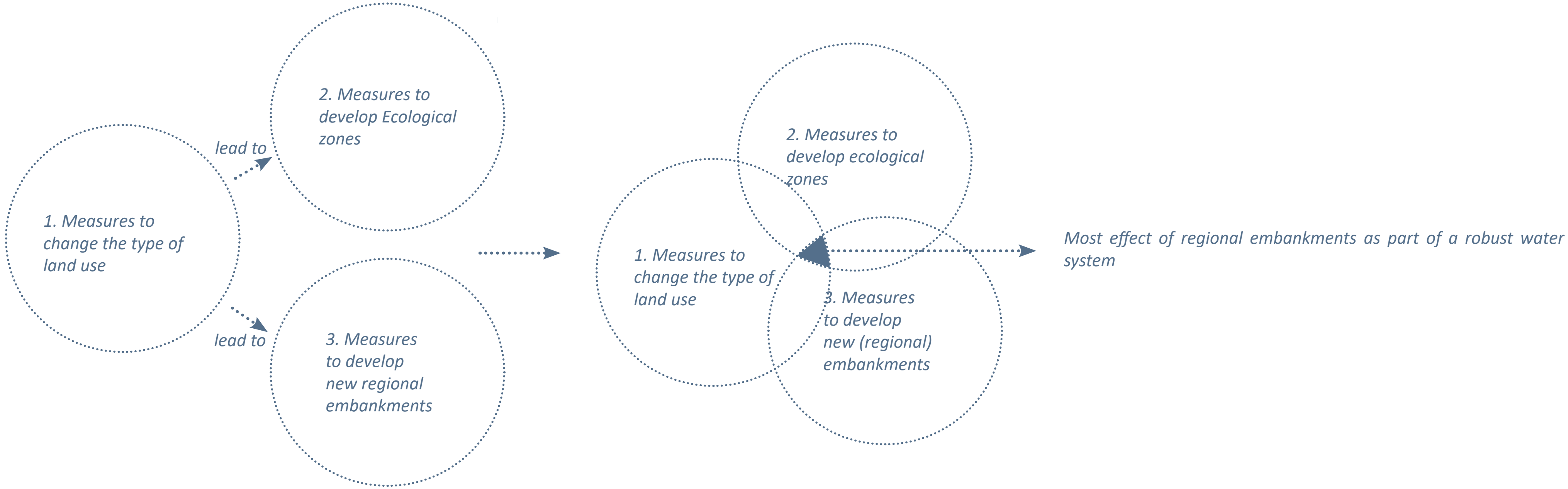
By this, Wetterskip Fryslân becomes the manager and the farmer becomes the maintainer. And together they work on a sustainable system, a robust water system.

Figure 135 *Possible ecological structure*

COMBINING MEASURES

At the previous paragraphs measures have been illustrated which can lead to a robust water system that contributes to solutions for current and future problems related tot the water management at the Frisian peat area. If measures are being combined, a more effective system can be developed (scheme 24).

In the ideal situation all measures would be excecuted in order to develop a robust water system. However, it will probably depend of several factors if all these mentioned measures will be taken at areas. Factors like politics, financial situations and ownership will probably affect the decion making process. At the next page figure 136 illustrates a possibility of a permanent rewetted which includes all measures.



Scheme 24 *Combining measures*

Figure 136 A possible view of a permanent rewetted area which includes all possibilities

3 RECREATIONAL USE

Nowadays the regional embankments at the agricultural areas are not accesible for townspeople or tourists. Farmers often do not want people in their land and at embankments, since farmers need it for grass production. People also can pollute the areas and their dogs could transfer disseases to agricultural fields which serve as food for the cattle.

However, with the illustrated transformation of agricultural terrains, (regional) embankments could be used for other purposes. The main type of income will be the crops at the rewetted areas. This could leave space for the development of walking or cycling routes at the new developed and current embankments.

The Frisian peat area has many elements which attract tourists and inhabtants. Also the local case area next to 'Woudsend' has such like shown at the figures at the right. More potential places for the development of recreational activities could help to develop the tourist sector or the liveability in the area. A possitive effect of this could be more income for local people by managing small bed and breakfasts, restaurants etc. Places where such developments could take place were already mentioned at page 115.

For the local area I analysed two special points. I show how and why these points have a potential to be developed for recreational goals. I design possible use of these places to illustrate that embankments can serve other goals than functioning as flooding defences.

Figure 137 *The village Woudsend*

Figure 138 *A farm at Ypecolsga*

Figure 139 *Vacation houses at Woudsend*

Figure 140 *Skûtsjesilen at the Hegemer lake*

Recreational route via the water
Provincial road
Sub-provincial roads
Optional route to detail location
Village
Location for detailled design

Figure 141 *Routing through and around Woudsend*

RECREATIONAL USE

In figure 143, figure 144 and figure 145 two areas are visible, area 1 and area 2. The embankments and especially the embankment along the lake give possibilities to experience both water and land (figure 142). However, areas 1 and 2 in are places where an other degree of complexity is present. What this other degree of complexity is will be explained at the next pages. However precisely this variation of different degrees of complexity can increase the potential for development of recreational purposes at such places. I want to show how such places may lead to the development of possible routes along the embankments and thus extra use of the area.

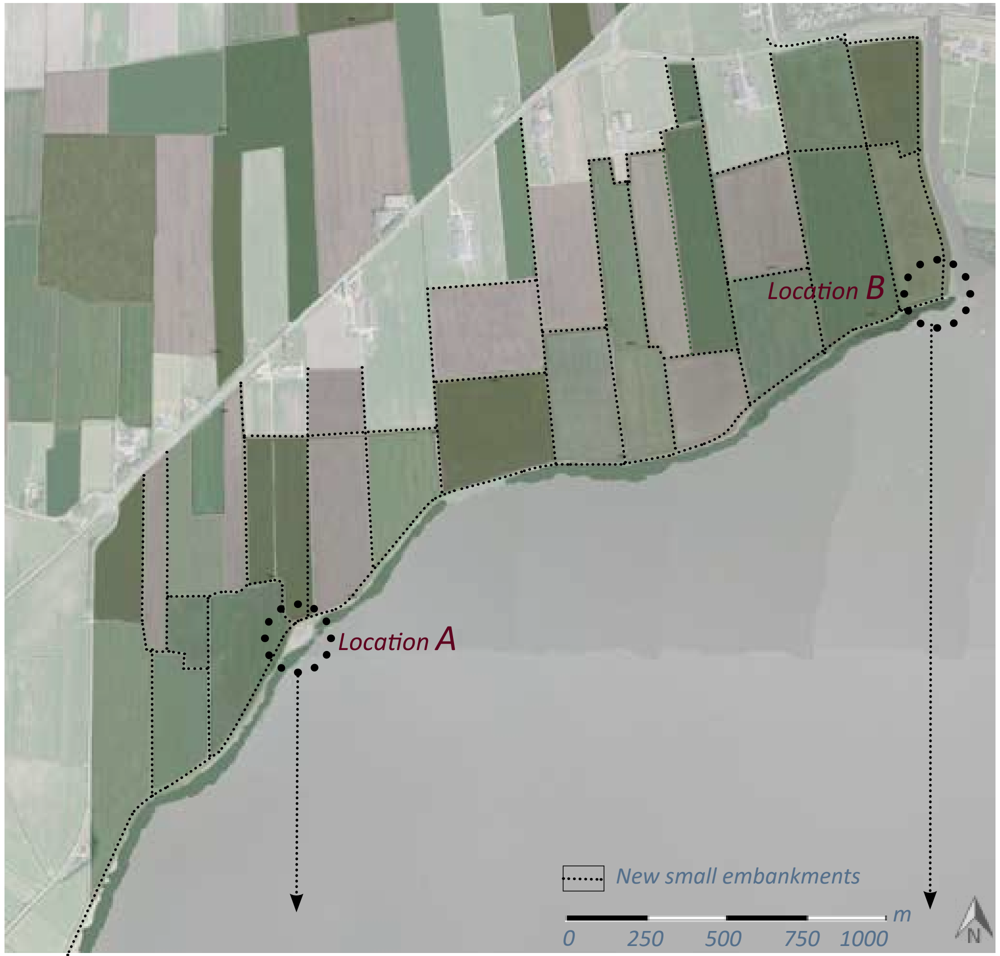


Figure 143 *Two areas wih a higher degree of complexity*

Figure 144 *Location A*

Figure 145 *Location B*

Figure 142 *Experience both land and water*

LOCATION A

This area differs from other places at the embankments, since it contains a wide riparian zone. This means the distance from the embankment to the water differs compared with other places at the same embankment (figure 149). Also different vegetation occurs here, since parts of the riparian zone are higher than others (figure 150). To increase the potential for developments for possible recreational developments, the degree of complexity could be increased. A higher degree of complexity increases the variability in the area. And a higher variability can be experienced as more attractive. For example a tree could be planted in the situation when a new robust water system would be realised like in figure 151. This tree would create variety. Also embankments could be used to create new sightlines (figure 152).

How the potential for recreational developments could be stimulated is shown in figure 153 at page 128.

Figure 146 *Current views at detailled area*

Figure 147 *Current views at detailled area*

Figure 150 *Possible situation in a robust water system*

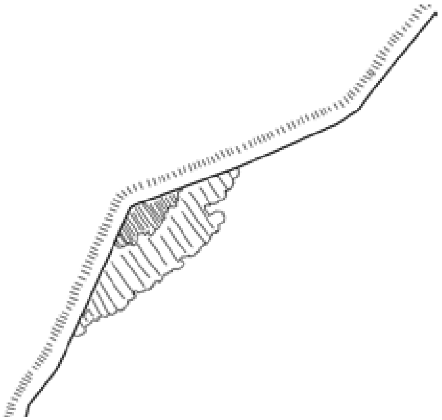


Figure 148 *Different heights*

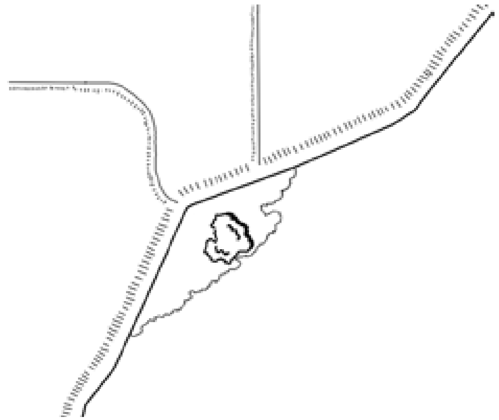


Figure 151 *Addition of a tree to increase the degree of complexity*

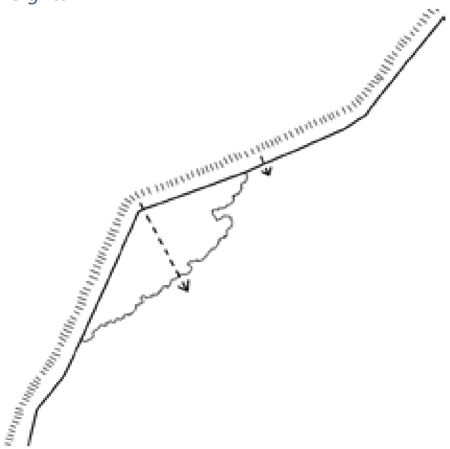


Figure 149 *Distance from the embankment to the lake*

Figure 152 *Creation of new sightlines*

Figure 153 *Possible developments at the area*

LOCATION B

This area (figure 156) also contains a higher degree of complexity. Here a wide foreshore is visible across from a small forest (figure 157). The water in front of area 2 is a busy water way where boats gather to enter the village 'Woudsend'. The degree of complexity of area 2 could be enforced by planting a tiny forest at the area. In this way even an entree for water recreationists is designed. This high degree of complexity ccould lead to a higher potential for possible developments as shown at next pages.

Figure 154 *Current views at detailled area*

Figure 155 *Current views at detailled area*

Figure 156 *Area 2*

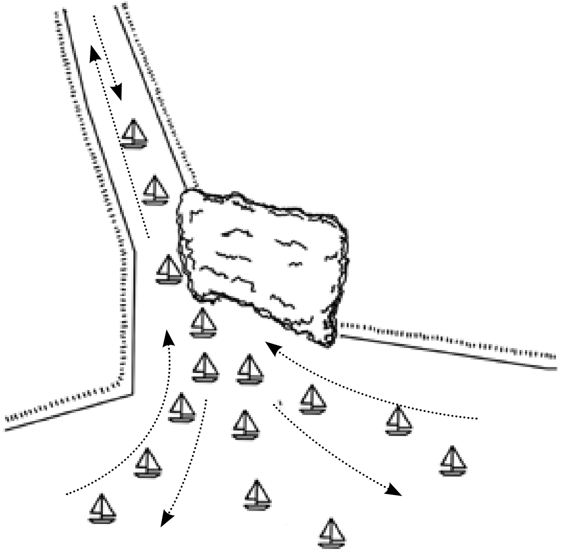


Figure 158 *Boats come along to enter the nearby village*

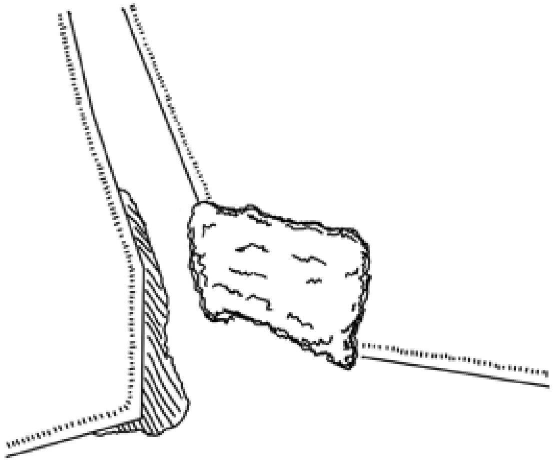


Figure 157 *Occurence of a wide riparian zone and a small forest*

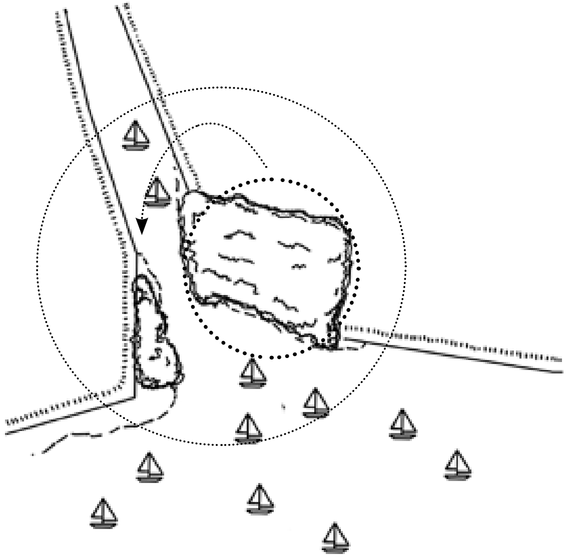


Figure 159 *Add extra trees to create a gateway*

The section below illustrates a possible development at location b as a result of an increased degree of complexity at the area. Such developments could stimulate the creation of new walking routes at embankments and other parts of the area. It gives possibilities to experience the area from the land instead of experiencing the area from the water.

Figure 161 *Location B; area where the section is situated*

Figure 160 *Possible developments at area 2 as a result of creating a higher degree of complexity than at other areas*

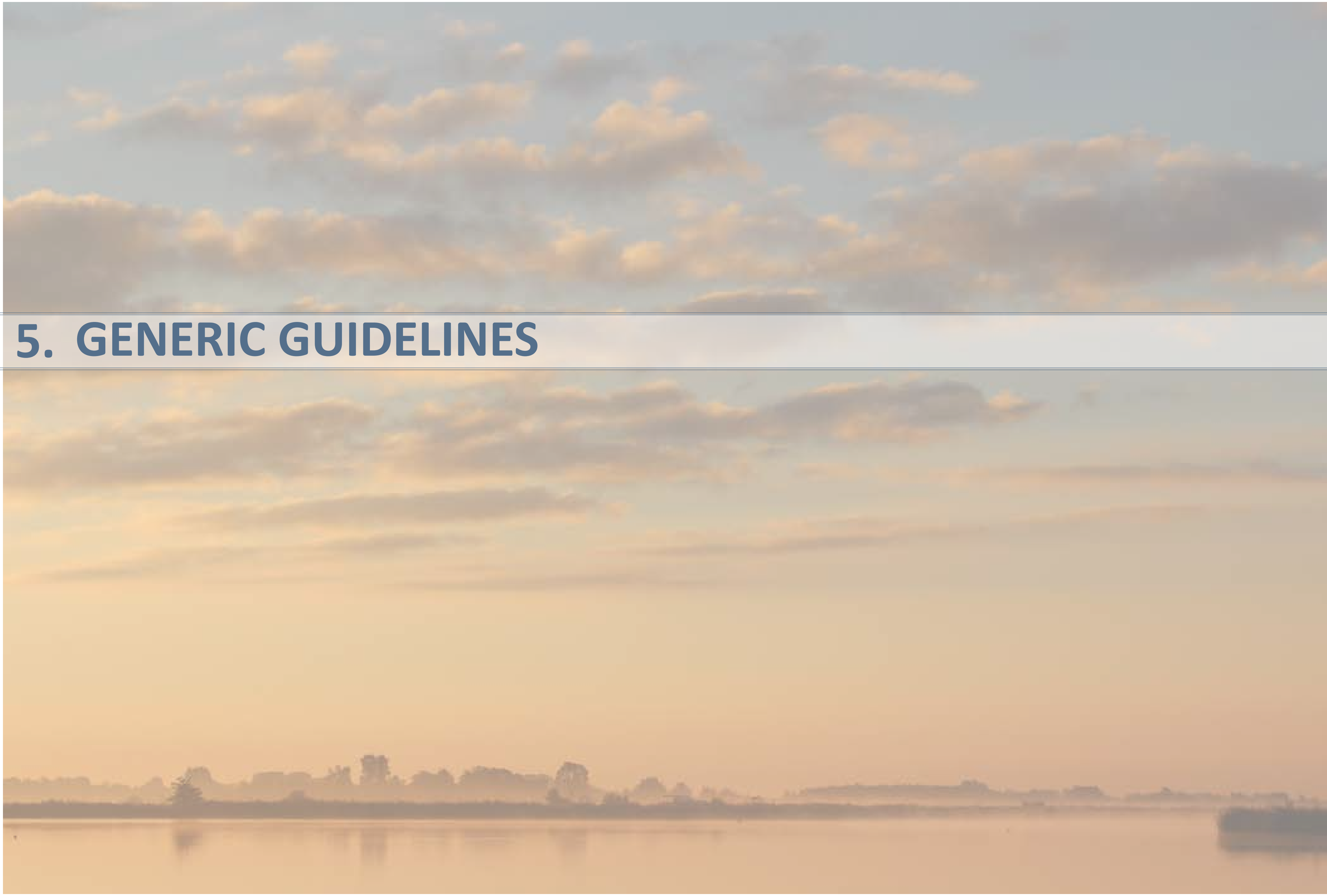
4.6 CONCLUSION

Analysis at different scale levels together with the analysis of the current water system and the problem analysis lead to the development of several measures during the design process. This design process leads to a robust water system for the local case area. Measures like rewetting the peat area and creating water retention zones make another type of agricultural land use, like paludiculture, possible. The measures incorporate design principles and guidelines which are based on the problem analysis and different scale analyses. This means that they contribute to solutions for current and future problems.

The measures let regional embankments be part of a robust water system at the local scale whereby several possibilties have been developed which can increase the feasibility of the development of a robust water system at the Frisian peat area. Together the measures and possibilities of the system lead to a system in which the water safety is not only enforced by regional embankments and water pumping installations, but in which the whole transformed area as part of robust water system helps to secure the water safety, to reduce current problems and to achieve goals in the field of biodiversity, water quality and recreation.

However, the next step is to find out if measures at local scale could lead to a robust water system at the whole Frisian peat area. This will be elaborated at chapter 5.

5. GENERIC GUIDELINES

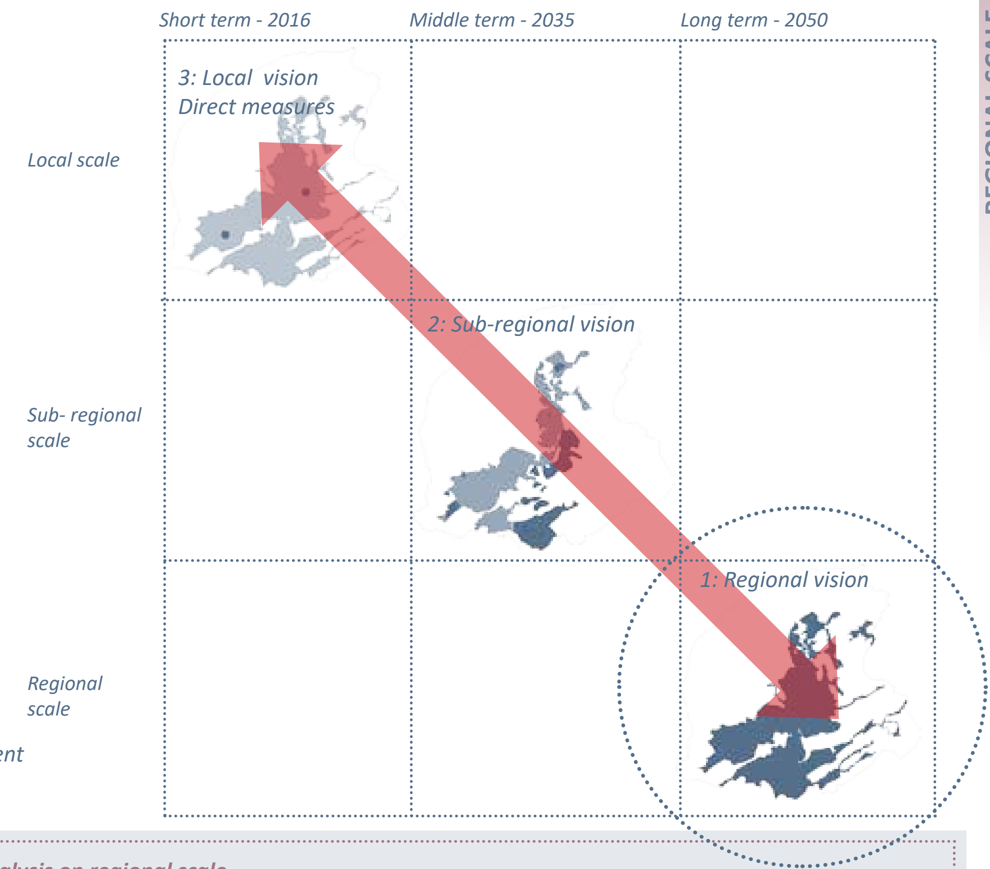


5 GENERIC GUIDELINES

5.1 STEP 9 - REGIONAL VISION

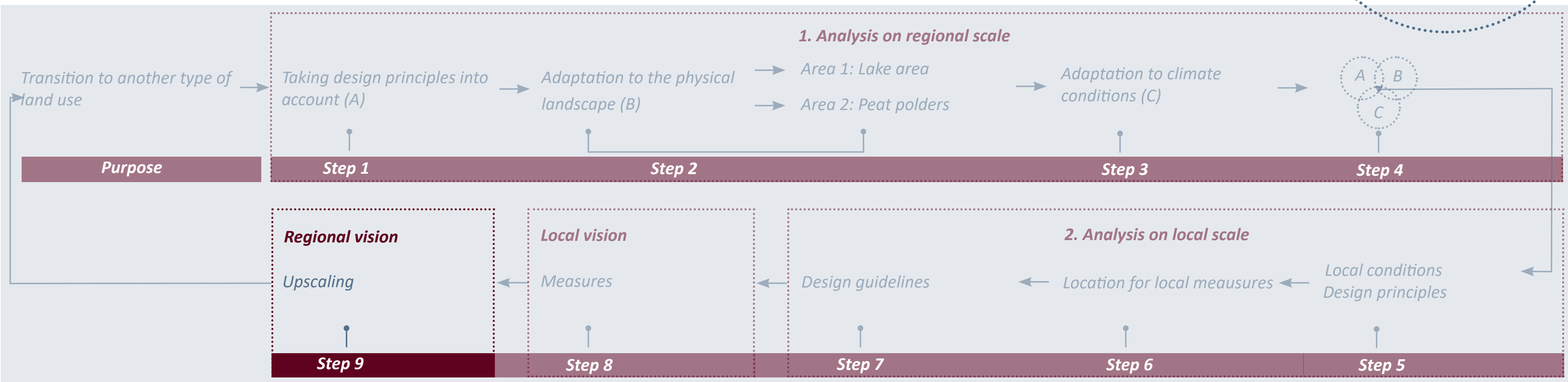
A local vision has been established with information about how small scale measures could lead to the transformation of the type of land use at local level. However, the question remains: what are the generic guidelines for the Frisian peat area to transform the current water system into a robust water system?

The local measures established in chapter 4 have been extrapolated to the regional scale at the long term (scheme 12). The map at page 133 shows how such measures lead to a robust system for the Frisian peat area. Also the possibilities of this system as the development of new ecological structures along embankments and the development of wide riparian zones are taken into account.



Scheme 12 *Approach for the development of a robust water system*

DESIGN PROCESS OF A ROBUST WATER SYSTEM



Scheme 13 *Design process of a robust water system - regional vision*

5.1.1 REGIONAL VISION - 2050

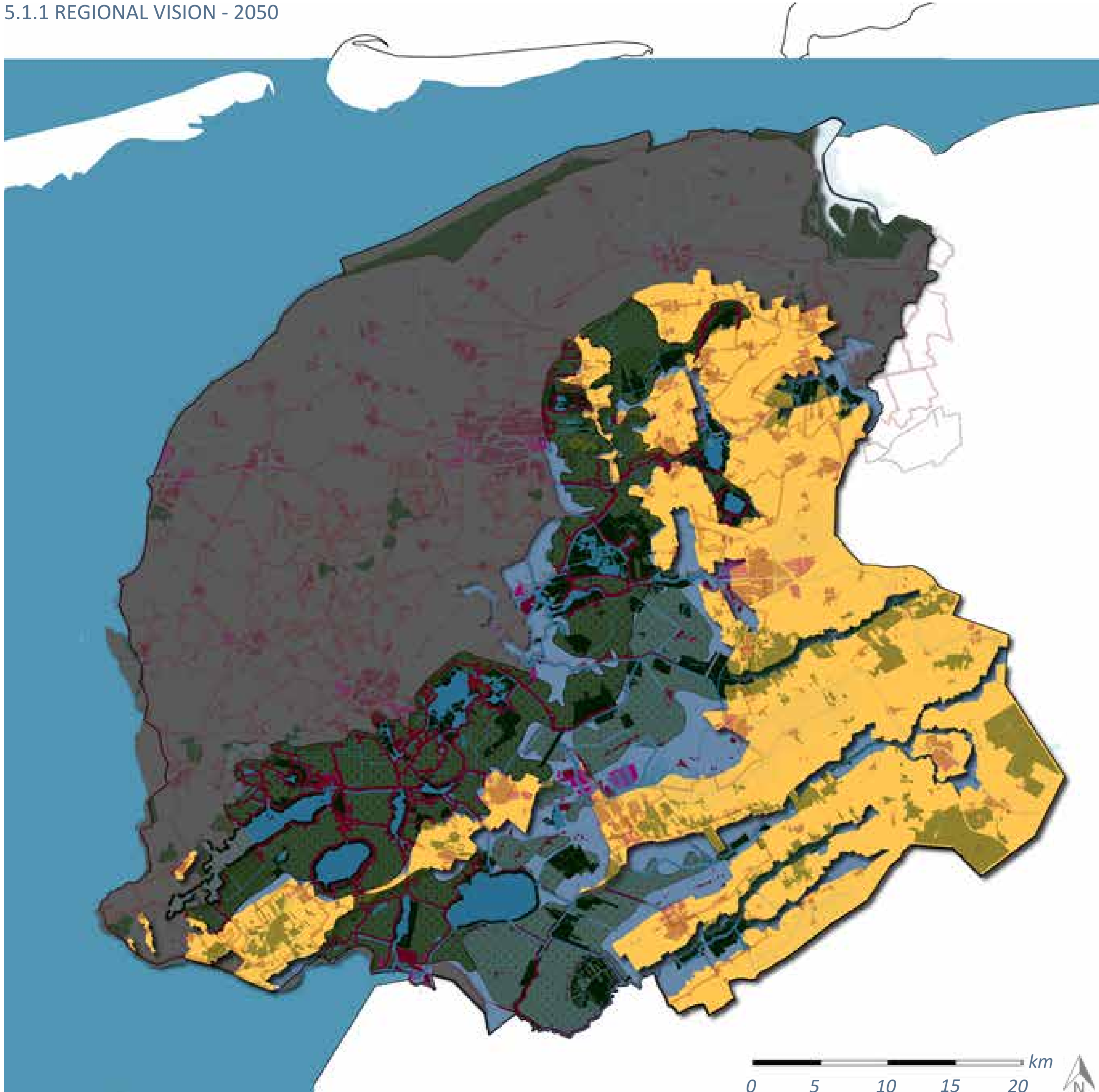


Figure 162 Regional vision for the Frisian peat area based on measures developed at chapter 4

Legend

Permanent rewetted peat areas at the Lake area with paludiculture as agriculture type of land use.

Permanent rewetted peat areas at the Peat Polder area with paludiculture as agricultural type of land use.

Riparian zones as ecolgical zones along regional embankments

Riparian zones as sediment deposition areas along lakes

Existing nature areas in the current Frisian peat area

Exisiting housing area at the Frisian peat area

Waterbodies and waterways within the Frisian peat area

Area with a clay soil where no measures are taken

Area with a sand soil where no measures are taken

Areas with less than 40 cm of peat

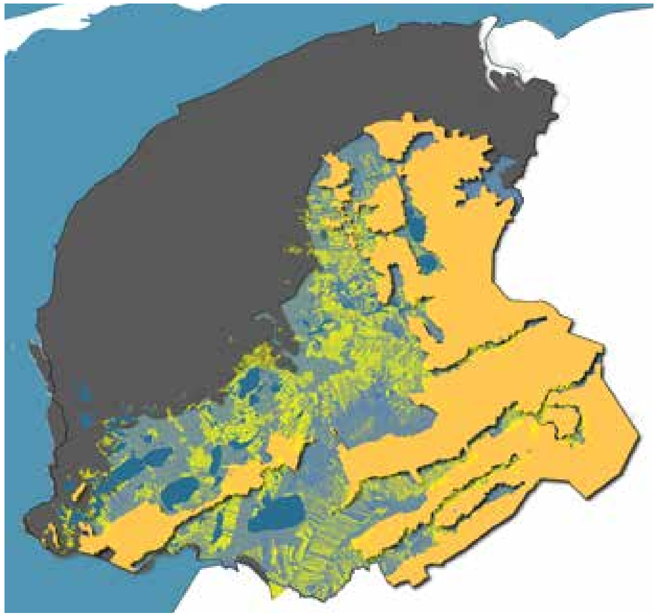
The map illustrates two areas as higlihted at paragraph 4.4.2: the Peat Polder area and the Lake area. In this thesis we analysed the lake area, since it is likely that more problems will occur there as a result of the thick layer of peat which is still present there. Now, local measures based on analysis of The Lake area have been scaled up to the regional scale and thus to the Peat Polder area as well to illustrate the effects of measures taken at local scale on a regional level. Since the Lake area consists of other characteristics than the Peat Polder area, it would be necessary during furhter analysis to analyse the Peat Polders also on a local scale. This in order to develop appropriate measures for the Peat Polder area. Next to this some areas are mentioned as 'peat areas with less than 40 cm of peat'. It is likely that the peat has been dissapeared at 2050 before measures can be taken to preserve the peat in these areas.

5.1.2 CONCLUSION REGIONAL VISION

The local measures extrapolated to the regional scale result in a robust water system in which regional embankments are incorporated. Not only the 1000 kilometers of regional embankments protect cities and villages from flooding, also the agricultural areas (which exist of 62% of the total peat area) at the Frisian peat area are able to increase the water safety and to reduce the negative effects of the current water management.

It will depend on several factors like the cooperation of farmers, the policy of governmental organisations like Wetterskip Fryslân and the Province of Friesland and research to new crop types wheter and how fast a robust system as explained in this thesis will develop. However, these measures illustrated at figure 162 are the basis for the development of a robust water system. If we put this map in a timeline compared to the type of land use at 1832 and 2016, we actually go back to a peat area that consists of wet terrains. In 1832 those wet terrains were hayfields that flooded every winter and in 2050 those will be areas with forms of paludiculture. That this form is suitable for the Frisian area was already understood before this thesis, however, now it is understood how this type of land use can be accomplished as part of a robust water system.

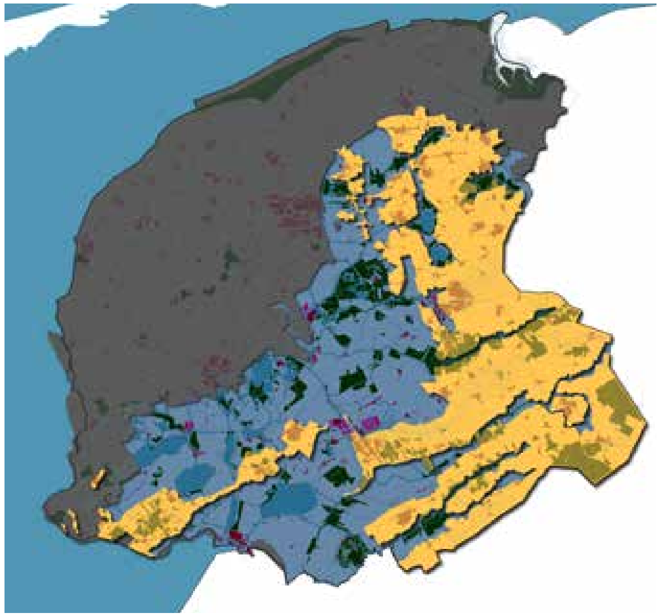
1832



Clay
Peat
Sand
Water
Hayfields

Figure 163 *Type of land use in Friesland in 1832*

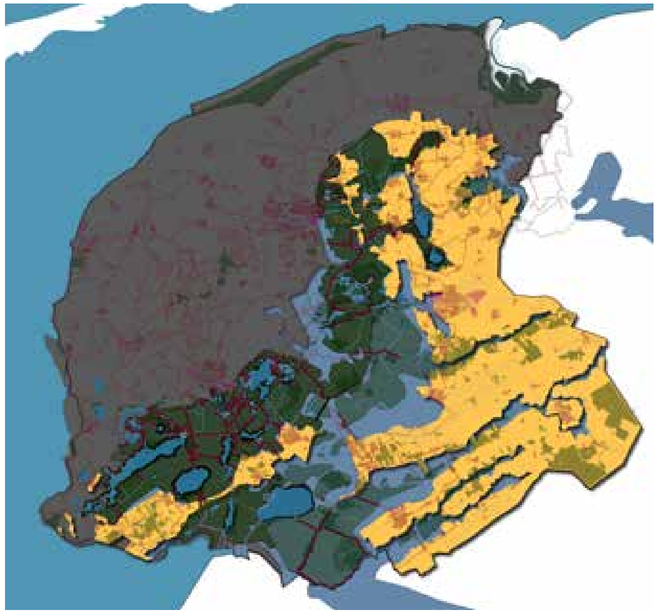
2016



Nature areas
Cities and villages
Industrial areas
Agricultural areas
Water

Figure 164 *Type of land use in Friesland in 2016*

2050



See legend at page 133

Figure 163 *Type of land use in Friesland in 2016*

6. DISCUSSION

6. DISCUSSION

A development of a robust water system for the Frisian peat area has been explained. The main question arises: Why should a farmer cooperate with a transition to another type of land use? And if he does, what does this mean for the farmer himself and the role of Wetterskip Fryslân?

The problems that occur and will occur at the Frisian peat area have become clear. These problems and their consequences will lead to investments to keep the current type of land use in the Frisian peat area possible. Nowadays a farmer pays, like all the inhabitants of Friesland, a certain amount of money, a tax, to Wetterskip Fryslân. In return Wetterskip Fryslân maintains the water system and thus makes current functions like the type of land use possible.

If huge investments must be done, payed by all the inhabitants of Friesland, in order to ensure that a farmer can continue to work his land and produce grass, would this still be acceptible? It would seem more acceptible for Wetterskip Fryslân to stop with funding huge investments which actualy seems a way of sponsoring farmers with community money. If Wetterskip Fryslân actually would stop with doing investments to ensure the current type of land use, farmers probably experience huge troubles in the near future when it comes to the production of enough grass for their cows and bringing their fertilizer at these agricultural terrains.

And even if Wetterskip Fryslân would be able to make investments to secure the type of land use possible at the Frisian peat area, farmers maybe are not able to gain enough harvest as a result of too wet terrains and thus unproductive terrains. This could increase the need for a robust water sytem. This thesis tries to create a realistic development of such a robust water system in which the rural peat areas can remain profitable and whereby single investments could lead to a sustainable system withouth a continuation of investments to secure safety and a functional area.

In this thesis the feasibility of the production of crops that can deal with permanent wet conditions is a point of discussion. Since how long will it take before such a crop would be produced at the Frisian peat area? This has to do with the need. If an area cannot be made suitable for the production of grass, the need for a crop which can stand wet conditions will increase. However, the need for such a crop can also be increased, if Wetterskip Fryslân does not want to invest in extra measures to secure the current type of land use.

And if we assume that such a robust water system as explained at chapter 4 would become reality, the role of a farmer and of Wetterskip Fryslân would change. Nowadays a farmer maintains the small waterways at his own territory and Wetterskip Fryslân is responsible for the maintainance of the embankments and the larger waterways. However, if agricultural terrains become productive areas where water storage takes place and where for example ecological zones are being maintained in return for subsidize, a farmer becomes responsible for the functioning of the water system too. Wetterskip Fryslân seems to become a kind of manager and the farmer the maintainer. And what if a farmer does not keep his new established embankments at a certain height? Who will be the one responsible for this? So do we like to see these new roles or would it be more wisely to shape areas in such a way that a farmer does not become the responsible person for the functioning of the water system.

These and other points must be investigated. In this thesis a specific design process has been used in which one case area has been studied. This case area included an intensive agricultural area where people live and where regional embankments were present. However in further research it would be usefull to study several case areas which differ from each other. This in order to find out if measures produced at local scale in one area can be used at another local case area, or if they have similarities.

This thesis only presents one possible way for a robust water sytem. However, it would have been better if several ways would have been investigated based on conversations with different parties at different areas. Parties like farmers, nature organisations, recreational organisations and governmental institutions. I could have spend another year to find out how this form of a robust water system could be implemented by taking other opinions into consideration. However, the aim of this thesis is to show that there are other solutions for problems at the frisian peat area than to invest in extra water punping installations, embankment enforcement and scouring sluices. Further research must be done to find out how such a system can be financed exactly, how the exact implementation could be imposed and if such a system would give the expected results in reality.

7. CONCLUSION

7. CONCLUSION

The current agricultural type of land use at the Frisian peat area is not sustainable. Huge investments must be done to keep the Frisian peat area safe and to keep the water management at this area functional for the agricultural type of land use, since the effects of soil subsidence and intense periods of rain will become worse. A large part of such investments must be done by Wetterskip Fryslân to enforce regional embankments. Regional embankments protect the 85.000 ha of peat from flooding. These embankments keep the peat area safe and they secure the current agricultural type of land use here.

The aim of this thesis is to design generic measures which result in the development of a robust water system. This means a transition to a sustainable type of agricultural land use at the Frisian peat area which does not lead to problems like a decreased water safety, tillage problems or huge expenses by Wetterskip Fryslân to secure the water safety and the functioning of the type of land use. Therefore the main question for this thesis is:

What measures could be taken to let regional embankments be part of a robust water system at the Frisian peat area?

Rewetting the Frisian peat area forms the main answer to this question. Rewetting in such a way that the Frisian peat area can function as a (temporary) water storage area where water vegetation development can take place together with sediment deposition areas and the possibility for water fluctuation. The design proces of a robust water system shows a way in which these measures are being developed based on analyses of current and future problems at the Frisian peat area and analyses on different scale levels. A suitable and thus sustainable type of agricultural land use for these conditions is paludiculture.

With these measures it becomes clear that not only the current regional embankments are able to secure the water safety at the Frisian peat area, but that the whole area where a sustainable agricultural type of land use is being maintained together with the current regional embankment becomes important when it comes to water safety and the reduction of problems related to the water management at the Frisian peat area.

With this robust water system as explained in chapter 4 the tide of increasing problems at the Frisian peat area could be turned into possibilties. For a farmer to develop a sustainable way of living in which current problems do not lead to huge investments, but to possibilities to gain the same or more income. And for Wetterskip Fryslân a possibility to prevent huge costs for the water managment in the near future and a way to achieve several goals in the field of water management, ecology and human wellbeing.

This development of a robust water system could lead to a decentralized type of agricultural water management at the Frisian peat area. In which farmers are being responsible for the water management at their own agricultural areas. This means that they are less dependent on measures and investments taken by Wetterskip Fryslân. At the same time farmers help Wetterskip Fryslân to reduce problems like a decreased water safety by maintaining the sustainable type of land use as part of a robust water system. So a win-win situation is being developed.

Next to this this robust water system can contribute to goals which are maybe not the main task of Wetterskip Fryslân like the development of a landscape with potential for tourism and recreation. A system that in the end can help to improve the attractiveness of the area and thus the liveability. Or for example the increase of biodiversity. This robust water system does not limits itself to only the water management. It goes beyond this.

SOURCES

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Figures without citations are designed by using GIS-data from Wetterskip Fryslân

APPENDICES

APPENDICES

A. GLOSSARY

The explanations are originating of the study: 'Verklarende hydrologische woordenlijst' (Gesreksgroep Hydrologische Terminologie 1986).

English and Dutch	Explanation
Boezemlands *Boezemlanden*	Areas which are not protected by regional embankments
Ditch *Sloot*	General term for a water course of limited width which contains stagnant or slow moving water
Drainage *Ontwatering*	The discharge of water over and through the ground and by the waterways system
Drainage sluice *Spuisluis*	Sluice to remove redundant water
Embankment/dike *Kering/dijk*	A dike located along open water
Freeboard *Drooglegging*	The height difference between the water level in a watercourse and the soil surface
Frisian water system *Friese water systeem*	The water system managed and maintained by Wetterskip Fryslân
Frisian system of reservoirs for superfluous polder-water *Friese boezem*	A system of open connected waterways and lakes. Water from lower polders is pumped into this temporary storage area untill it is being eliminated into the Waddensea or Lake IJssel.
Gravitational discharge area - *Vrij lozend gebied*	An area where redundant water can flow by gravity
Groundwater *Grondwater*	Water below the ground surface, usually limited to water below the water table
Riparian zone **Oever**	Transition zone from water to land
Settlement *Zetting*	Subsidence as a result of shrinkage and the construction of artworks, incrementing of the ground or the application of any other material.
Seepage *Kwel*	The withdrawal of groundwater
Subsidence by lowering of the piezometric head *Inkllinking*	Decrease of the ground surface as a result of lowering of the groundwater level
Subsidence by shrinkage *Krimp*	Decrease of the soil as a result of dehydration of the soil.
Soil subsidence *Bodemdaling*	Decrease of the ground surface by oxidation or other geological processes.
Surface water *Oppervlaktewater*	The water flowing over or staying in the Earth's surface.
Water pumping station *Gemaal*	Technical installations that displace redundant water.

B. WATER LEVEL FLUCTUATIONS

Water level fluctuations image from the report:
Peildynamiek voor een vitale Friese boezem
(Brongers and Belle, van 2008).

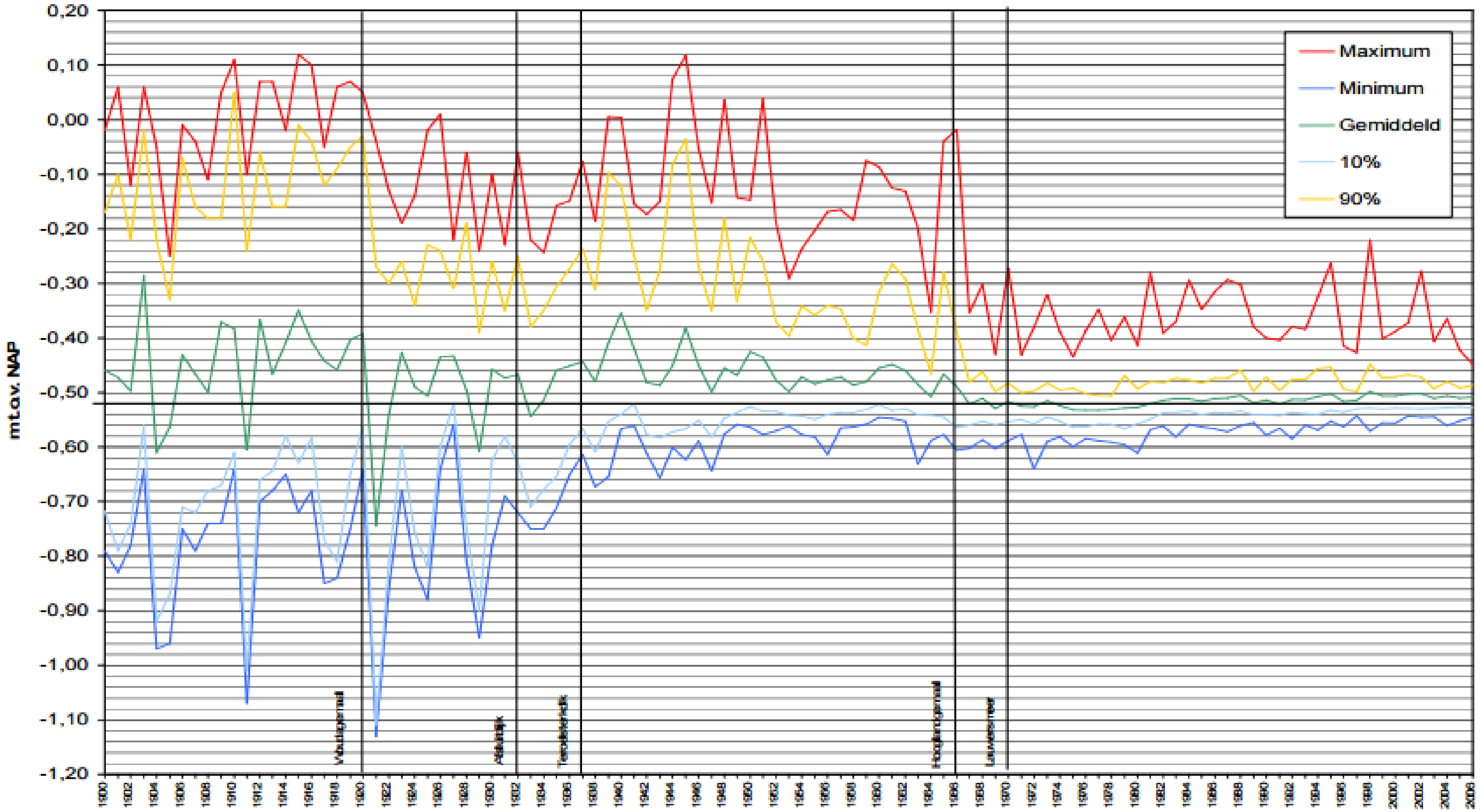


Figure 165 *Water level fluctuations (based on average water levels of the Frisian system of reservoirs for superfluous polder-water) at the Frisian system of reservoirs between 1900 and 2006 (Claassen 2008) Moments when dramatic changes in the water system took place are illustrated with a vertical line (Brongers and Belle, van 2008).*

C. IMAGES OF REGIONAL EMBANKMENTS

Figure 166 *Photo of a regional embankment from the top of the embankment*

Figure 167 *Photo of a regional embankment taken next to the regional embankment*

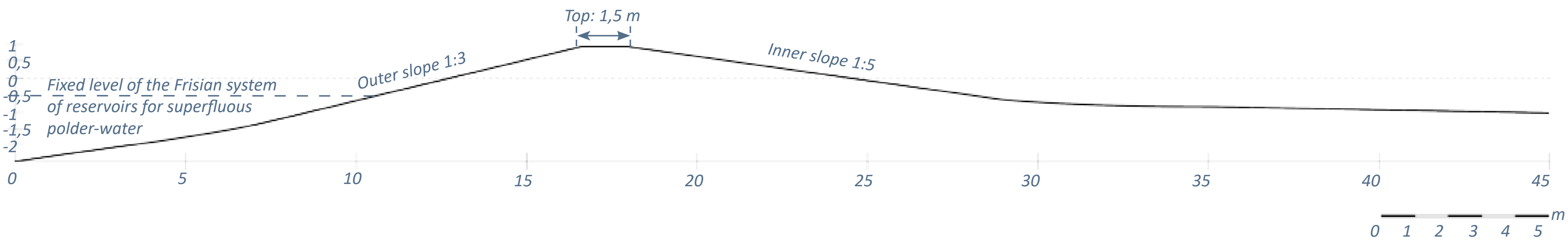


Figure 168 *Section of a regional embankment*

D. IMAGES OF LOCAL EMBAKMENTS

Figure 169 *Photo of a local embankment*

Figure 170 *Photo of a damaged local embankment*

E. PROTECTION OF EMBANKMENTS - MATERIALS


Rubble, recently created


Rubble, recently created


Rubble, recently created


Rubble, created some years ago


Rubble, created some years ago


Rubble, created some years ago


Wooden sheet piling of a couple years old


Wooden sheet piling, new


Sheet piling of concrete

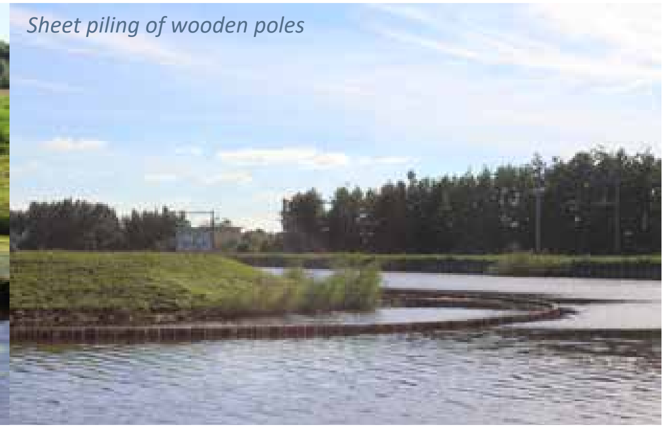

Sheet piling of steel


Sheet piling of wooden poles


Coconut mats


Wooden poles


Wooden poles


Sheet piling of wooden poles

F. SAFETY PLAN II

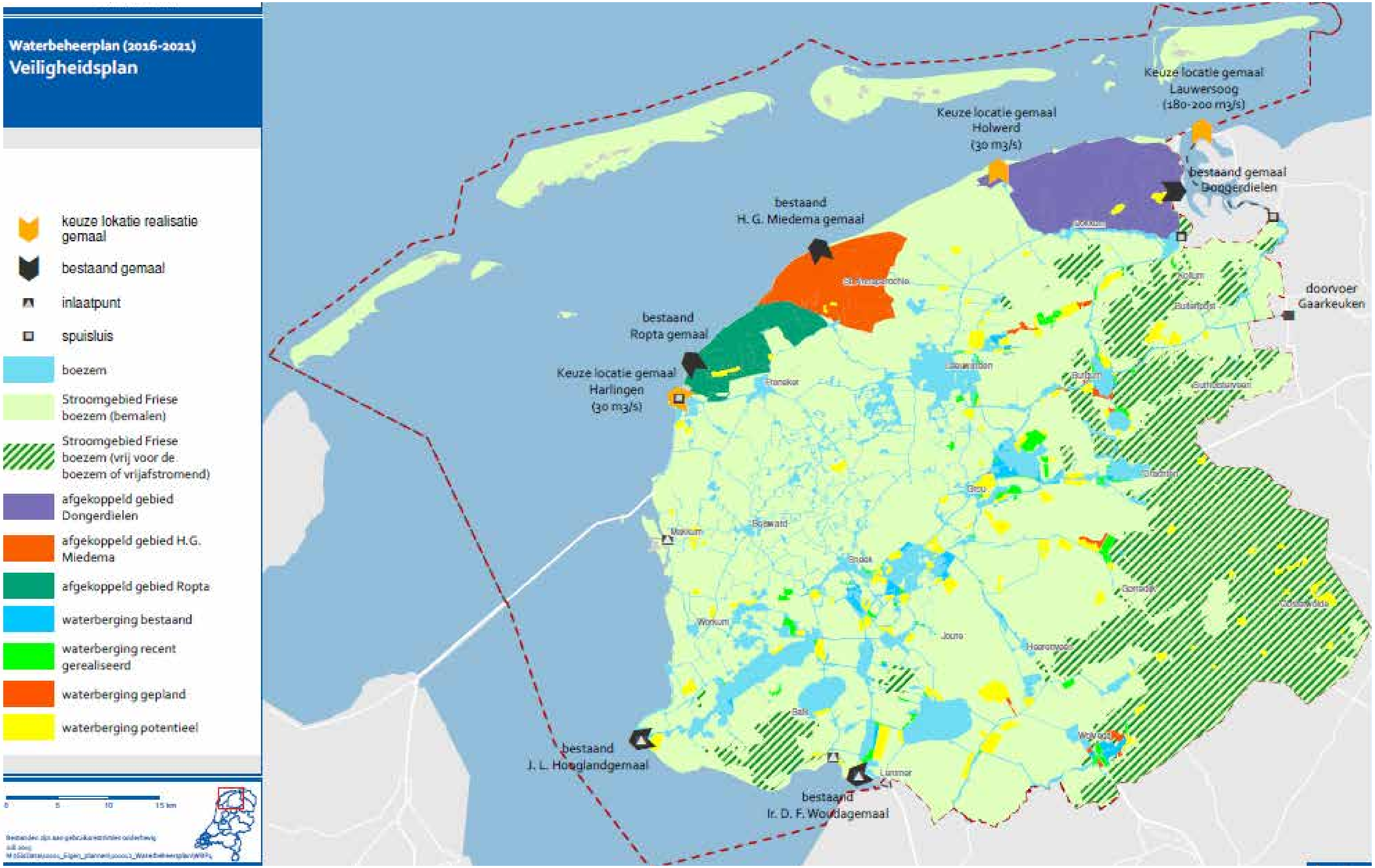
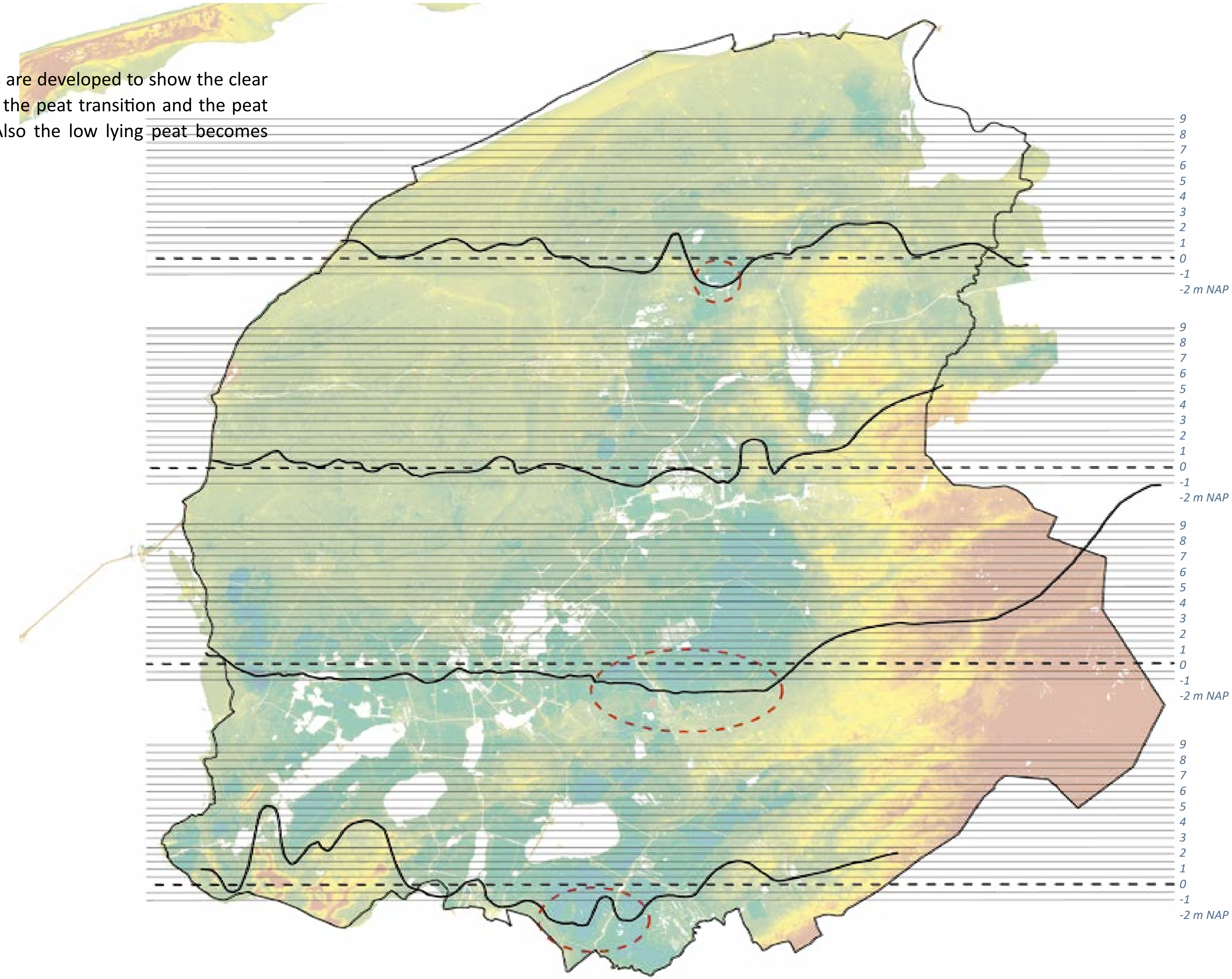


Figure 171 Safety plan II (Wetterskip Fryslân 2014a)

G. SECTIONS

These schematic sections are developed to show the clear transitions of the clay to the peat transition and the peat to the sand transition. Also the low lying peat becomes visible.




2050