PALUDICULTURE LANDSCAPE MACHINE

REGENERATION OF THE RAISED BOG LANDSCAPE

a case study in the Bargerveen landscape system

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"A while ago I saw in an art gallery a ... picture ... of a swamp.

A repulsive, forbidding thing.

One felt like taking a dose of quinine every time one looked at it.

If ugliness is real beauty they have yet to prove it to a very large mass of the assembled public."

This critic, Hector Charlesworth, was referring to the now world-famous painting by Lawren Harris, entitled Beaver Swamp, Algoma (1920). This critic's comments reflects the perspective of a bygone era. It seems that globally we now recognize the swamp and other peatlands no longer as horrific wastelands that need to be drained and colonized, but as valuable ecosystems and as things of beauty or sublimity.

Colophon

Paludiculture Landscape Machine: regeneration of the raised bog landscape
a case study in the Bargerveen landscape system

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Preface

Climate change is a global threat to planet and the landscape must be redesigned in order to slow down climate change and to adapt to the changing climate. This global challenge is explored in the setting of the Bargerveen landscape system – a raised bog remnant in an agricultural landscape. A new regenerative agricultural system is designed in which nature and agriculture intertwine, that can support the restoration of raised bog remnants. I found this to be an extremely interesting and informative challenge. It rekindled my love for the profession of landscape architecture and the role it can play in the global challenge called climate change.

I would also like to grasp this opportunity to thank a few people. Most of all I would like to thank my supervisor Michaël van Buuren for the critical feedback, good supervision and pleasant conversations regarding this topic and others. Gert-Jan van Duinen for his time, knowledge and invitation to the symposium 'Bargerveen 50 jaar Grenzeloos Groeiend'. Bill Reed for his correspondence, inspiration and permission for the use of the image of regeneration. Kevin Raaphorst for his help on the research proposal. Fellow landscape architecture students for their feedback, input and curiosity. I want to thank friends and family for supporting me during the process of this thesis. Special thanks to Pascal Storck for printing my posters and Juliët Bruijne for transcribing the interview.

I hope that this report can provoke people to see the possibilities and opportunities of creating such a regenerative agricultural system in the raised bog landscape.

Ruud Hesselink
Wageningen, February 2019

Abstract

The current agricultural land use and drainage of peatlands causes peat oxidation which results in CO_2(-eq) emissions, soil subsidence, lowering of water- and soil quality and a lesser biodiversity. This degradation of peatlands is especially problematic around raised bog nature reserves such as Bargerveen because they require wet conditions for their conservation. To restore this valuable raised bog ecosystem and its services, surrounding lands need to be rewetted and the problem of nutrient overloading needs to be solved. This thesis explores the implementation of large-scale paludiculture, the productive use of wet peatlands by agriculture, to support the restoration of the raised bog ecosystem and to create a regenerative raised bog landscape. This is done by using the design theory of Landscape Machines in which the landscape is envisioned as a living system. Analysis revealed how the raised bog landscape functions, how it is degrading and what interventions can be taken to regenerate it. The most promising paludiculture crops for the raised bog landscape were cattail, reed, willow and peat moss. With the proposed interventions in the designs and the simulation of a *Moorausbruch*, the hydrology can be improved and the problem of nutrient overloading solved. With the designs, a landscape can arise in which agriculture and nature complement each other and where new possibilities and opportunities arise. The results are two models for two landscape types that can regenerate the raised bog landscape with paludiculture.

Keywords: landscape architecture, paludiculture, peat oxidation, raised bog ecosystem, ecosystem restoration, Bargerveen

Samenvatting

Het huidige agrarische landgebruik en drainage van veengronden veroorzaakt veenoxidatie wat resulteert in CO_2(-eq) uitstoot, bodemdaling, vermindering van water- en bodemkwaliteit en minder biodiversiteit. Deze degradatie van veengronden is vooral problematisch rond hoogveenreservaten zoals Bargerveen omdat deze natte omstandigheden nodig hebben om goed te kunnen functioneren. Om dit waardevolle hoogveenecosysteem met zijn ecosysteemdiensten te herstellen, moet omliggend land worden vernat en het probleem van nutriëntenoverschot worden opgelost. Deze scriptie verkent de implementatie van paludicultuur, het productieve gebruik van natte veengrond door landbouw, op grote schaal om het herstel van het hoogveen ecosysteem te ondersteunen en om een regeneratief hoogveenlandschap te maken. Dit wordt gedaan door de ontwerptheorie van Landscape Machines te gebruiken, waarin het landschap wordt gezien als een levend systeem. Uit de analyse komt naar voren hoe het hoogveenlandschap functioneert, hoe het degradeert en welke ingrepen nodig kunnen zijn om het te regenereren. De paludicultuur gewassen met de meeste potentie voor het hoogveenlandschap zijn lisdodde, riet, wilg en veenmos. Met de voorgestelde ingrepen in de ontwerpen en de nabootsing van een *Moorausbruch* kan de hydrologie worden verbeterd en het probleem van nutriëntenverschot worden opgelost. De ontwerpen laten een landschap zien waarin landbouw en natuur elkaar aanvullen en waarin nieuwe mogelijkheden en kansen ontstaan. Dit resulteert in twee modellen voor twee landschapstypen die het hoogveenlandschap kunnen regenereren met paludicultuur.

Trefwoorden: landschapsarchitectuur, paludicultuur, veenoxidatie, hoogveenecosysteem, ecosysteem restoratie, Bargerveen

Table of contents

1 Introduction

1.1 Context

During the 2015 United Nations Climate Change Conference the Paris Agreement was negotiated, a global agreement on the reduction of climate change. Countries that signed the agreement should set their own goals. The Netherlands set the goal to limit the amount of emitted greenhouse gasses with 49% in 2030 and with 95% in 2050. Specifically, this means a total of 48,7 megaton CO_2-equivalence (CO_2-eq) should be reduced by 2030. In the 'Klimaatakkoord' different sectors have assigned goals for reducing their output of CO_2-eq among which the agricultural sector. Their set goal is to reduce 3,5 megaton (3.500.000 ton) CO_2-eq by 2030. On the one hand there is an assignment to reduce the amount of CO_2-eq in the agricultural sector by 3,5 megaton, but on the other hand the current agricultural use of peatlands leads to an emission of 7,0 megaton CO_2-eq a year (CBS, 2017). This is the result of a process called peat oxidation which is caused by the drainage needed for conventional agriculture. Especially the bog peatlands in the north-eastern part of The Netherlands emit a lot of CO_2-eq because of the deep drainage (Mens, 2017). One hectare can emit up to 40 tons a year (Figure 1) (de Vries *et al.*, 2008; CBS, 2017). It is in these lands that a fair amount of CO_2-eq reduction can and must take place.

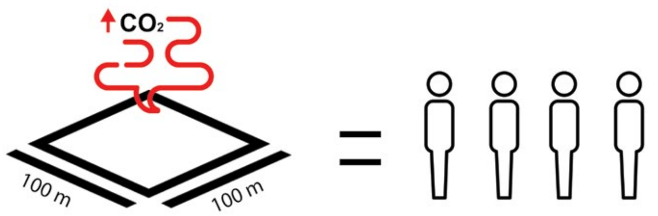


Figure 1: CO_2-eq emissions from one hectare bog peatland is the equivalent of four persons

1.2 Project area

The location of this thesis is the raised bog landscape on the border between The Netherlands and Germany (Figure 2). The project area is a cluster of nature reserves that are raised bog remnants of the largest raised bog complex in Northwestern Europa called Bourtangerveen (Casparie, 1993). These remnants form an international nature reserve by the name of Moor-Veenland. The main focus of this thesis is Bargerveen, the only Dutch nature reserve in this international nature park, and the system in which it is embedded.

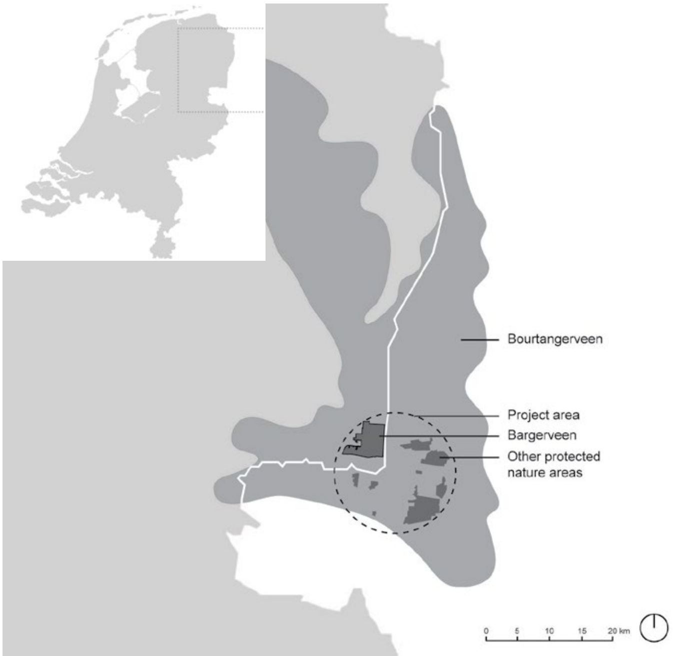


Figure 2: Project area, cluster of nature reserves including Bargerveen

1.3 Problem statement

The emissions that are produced by the agricultural drainage of bog peatlands are caused by peat oxidation. This creeping process also results in a lot of other problems such as soil subsidence, slowly decreasing biodiversity and poorer soil and water quality (Joosten, 2017; Mens, 2017; Waterschap Hunze en Aa's, 2017). Climate change amplifies the process of peat oxidation (van Eijk *et al.*, 2015). As a result of peat oxidation, the total area that classifies as peatlands (soils with >40 cm peat) in Drenthe has shrunken with 21.000 ha to a total of 33.000 ha between 1965 and 2005 (de Vries *et al.*, 2008). When the current agricultural drainage continues, the peat will disappear in the future (Fritz *et al.*, 2014). Therefore it can be stated that the agricultural use of peatlands is per definition unsustainable (Townsend, Begon and Harper, 2008). The problems of peat oxidation are also noticeable in the project area. Bargerveen as nature reserve benefits from high water levels but an extensive drainage network is in place for the surrounding agriculture, having a strong draining effect on Bargerveen. This causes a dysfunctional ecosystem where the most crucial plant of the raised bog ecosystem, peat moss or *Sphagnum*, will barely grow. Concluding, the problem is peat oxidation which causes the degradation of the raised bog landscape around Bargerveen and the effect it has on this nature reserve. The landscape should be used in a more sustainable way to ensure the continuation of the raised bog ecosystem and to limit peat oxidation and the CO_2-eq emissions connect to it. The objective is to steer away from degradation and turn towards regeneration of the raised bog landscape and thus contribute to CO_2-eq emission reduction. A possible solution that is explored in this thesis is the concept of paludiculture, the productive use of wet peatlands by agriculture.

1.4 Knowledge gap

The concept of paludiculture is relatively new. Nevertheless, there has been a lot of research on this subject of productive use of wet peatlands, especially in Germany by the university of Greifswald. The book *Paludiculture – productive use of wet peatlands* by Wichtmann *et al.* (2016) gives principles on how to implement paludiculture on a large scale but fails to incorporate it in the larger landscape system, on different levels of scale and specifically in the raised bog landscape. This is acknowledged by one of the authors, Prof. Dr. Dr. h.c. Hans Joosten, in his presentation on the conference *Omhoog met het Veen* (2017) as he states that the knowledge is bundled in this book but large-scale implementation is missing. These knowledge gaps are important to fill because they are a bridge between science and implementation in the real world, which is where landscape architecture research can contribute by producing design guidelines. To fill this knowledge gap and to explore the landscape architectural potential, the concept of paludiculture is used together with the design theory Landscape Machines for designing a regenerative raised bog landscape and thus contribute to CO_2-eq emission reduction. Therefore the objective of this thesis is to propose a set of design guidelines (models) for the large-scale implementation of paludiculture to contribute to the regeneration of the raised bog landscape.

1.5 Research questions

To reach the objective and therefore fill the knowledge gap identified in this thesis, research questions have been made. The main research question overarches the entire research and the sub-research questions help to answer the main question.

Main research question:

What design guidelines for a paludiculture Landscape Machine can help to regenerate raised bog landscapes?

Sub-research questions (SRQ):

1. What is the potential of Landscape Machine theory for designing a regenerative raised bog landscape with paludiculture?

This needs to be answered to gain insight in paludiculture and Landscape Machine theory and which role their combination can play in the regeneration of the raised bog landscape. Relevant data of paludiculture is gathered. Aspects of Landscape Machine theory that are relevant for analysis (SRQ2) and designing (SRQ3) are noted.

2. How does the raised bog landscape of the Bargerveen landscape system function?

This question is essential for this thesis because it is aimed at creating an overview of the development of the raised bog landscape of Bargerveen. This is necessary for fully understanding the landscape, its functioning, genesis, current state and possible future state. Special attention is given to ecology and hydrology.

3. What would be a way to create a regenerative paludiculture Landscape Machine in the Bargerveen landscape system?

This question is about testing the theory of Landscape Machine and concept of paludiculture in the raised bog landscape of Bargerveen. By designing, new insights occur and the research can be deepened. The answer to this question are multiple 'fully' integrated designs.

1.6 Relevance

The starting point of this thesis is the climate problem. Not only the CO_2-eq emissions need to be reduced to mitigate climate change, the landscape should also be adapted to the changing climate which often means more buffering of water to mitigate drought and heavy rainfall. Beside this, the relevance of this thesis also lies in exploring a mixture between nature and agriculture, or nature-inclusive agriculture. In concrete terms, this thesis explores the possibilities of paludiculture in the regeneration of the raised bog landscape by using Landscape Machines theory. Lately, a lot of research is being done on the restoration of remnants of raised bog ecosystems such as Bargerveen. Underlined is the importance of thinking and steering on higher levels of scale (van Duinen *et al.*, 2011). This lies within the framework of Landscape Machines theory. The design of buffer zones around the raised bog remnants is THE challenge for future research and management of raised bogs (Limpens *et al.*, 2016). This challenge is also being accepted in this thesis. With the designs of the project area, a future scenario is given of how a regenerative raised bog landscape can be designed and how it can function. This is relevant because the current raised bog landscape functions in an unsustainable way and a regenerative raised bog landscape is climate adaptive and can even play a role in climate mitigation. CO_2-eq emissions can be reduced and sequestration is even possible, thus contributing to mitigating the climate problem. With the generation of design guidelines this knowledge is transferable and can be used in designs for paludiculture systems in other raised bog landscapes. With these guidelines, an addition to the body of knowledge on paludiculture in the raised bog landscape is made.

1.7 Structure of the report

This report consists out of 12 chapters. In the first chapter, the theoretical framework is set out in which relevant theories, concepts and definitions are given. In chapter two, the methods that are used to answer the research questions are explained. In the third chapter, the concept of paludiculture and Landscape Machines theory and their potential in the regeneration of the raised bog landscape are discussed. Chapter five, six and seven are describing different phases of the raised bog landscape (of the Bargerveen landscape system). The intact ecosystem is described, then its degradation and restoration. After that, in chapter eight, the regeneration phase is described, in which the designs are presented which are abstracted in two models. In chapter nine the conclusion is given and the results and limitations are discussed in chapter ten together with recommendations for further research. The references are given in chapter eleven and appendixes in twelve.

2 Theoretical framework

In this chapter Landscape Machines theory and the concept of paludiculture are introduced. Definitions are given for a raised bog, the raised bog landscape and regeneration. This theory, concept and definitions are linked together to form the theoretical framework which serves as a theoretical starting point for this thesis.

Landscape Machines

Landscape Machines is a design theory introduced by Roncken, Stremke and Pulselli (2014) and further refined by Roncken (2018). It is built upon the systematic approach developed by McHarg (1969) and Van Leeuwen (1973) which is later refined in the field of landscape architecture by McHarg's student Meto Vroom. The typical 'Wageningen-approach' of landscape analysis is immortalized in the triplex model by Kerkstra, Struik and Vrijlandt (1976). Within the perspective of Landscape Machines theory, the landscape can be visualised as a literal machine with gears, levers, pipes and meters. The malfunctioning of this machine is pivotal as parts of the machine can be missing, rusting or damaged as the machine is over- or misused to produce certain goods and services. To create a desirable, functioning landscape these parts of the machine should be dealt with. Roncken, Stremke and Pulselli (2014) state that a Landscape Machine is also defined as a productive landscape that, by a design intervention, will resolve an existent malfunction in the physical environment. This is an important reason why this design theory is chosen within this thesis, to resolve the problems revolving around peatland drainage. Furthermore it states that the landscape can be seen as a living system and it proposes a framework of how to design a Landscape Machine to improve the current situation in the development of the landscape. Landscape Machines theory is mainly focussed on understanding the landscape, its functioning and interactions. The design interventions that are made in the landscape are tools to tweak certain processes, resulting in unscripted system responses from the landscape (Roncken, 2018).

Paludiculture

Paludiculture originates from the Latin word 'palus', meaning 'mire' or 'marsh' (Wichtmann *et al.*, 2016). Paludiculture is the agricultural or silvicultural use of wet and rewetted peatlands. It uses spontaneously grown or cultivated biomass from wet peatlands under conditions in which the peat is preserved or newly formed (Wichtmann *et al.*, 2016). Species used for paludiculture are bound to soil and water properties. Biomass is harvested and can be used in several ways such as bioenergy and fodder.

Raised bog

A living raised bog is defined in *Ecosysteemvisie Hoogvenen* by van Wirdum *et al.* (1993) as: "a horizontal and vertical confined unit in the landscape in which:

- A body of peat water has been formed by local precipitation which is above the regional water level;
- The production of plants is primarily dependent on nutrients from the atmosphere;
- The wet conditions slow down the decomposition of organic material in such a way that peat is being formed"

A living raised bog has the following characteristics:

Vegetation: Consisting mostly out of different species of peat mosses (*Sphagnum*). This peat moss layer covers at least 50% of the peat surface. Plant species which are being fed by ground- or surface water or point to mineralisation are few.

Soil: A raised bog needs to have at least 50 centimetres of peat which is formed under ombrotrophic (getting its nutrients from the air) circumstances in which at least the upper 20 centimetres is not or weakly humified.

Landscape: The raised bog complex is confined in a natural way or wedges out against the surrounding landscape (van Wirdum *et al.*, 1993).

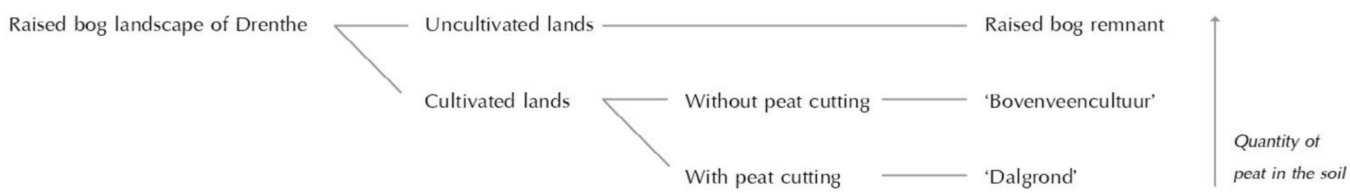


Figure 3: Definition raised bog landscape, lands that are still raised bog or once were raised bog, often still with a quantity of peat in the soil.

Raised bog landscape

The raised bog landscape consists out of a raised bog complex and the landscape in which it is embedded and is also referred to as the macro-scale (van Duinen *et al.*, 2017). An undisturbed raised bog landscape no longer exists in The Netherlands (van Duinen *et al.*, 2011). Therefore the term raised bog landscape is used to describe the areas that once were raised bog (Figure 3).

Regeneration

Regeneration in general means to 'create anew', a higher and more worthy state. It embodies the co-evolution of natural and human processes (Reed, 2010). In the Figure below, regeneration is placed within a framework for ecological design. In this framework for sustainability, several types of design are set out against their cost in energy. It can be seen that conventional and green design require greater costs and are degenerating life, which is defined as a whole evolving system. Sustainable design is design which has zero (negative and positive) impact on life. But to repair the damage that humans have done to the environment, sustainable design is not enough. Restorative design is needed to restore the environment and the life in which it is embedded. Regenerative design seeks not to restore a certain state but to create new possibilities within life and thereby regenerating it (Reed, 2010). Regeneration seems to share a philosophical background similar to paludiculture and Landscape Machines.

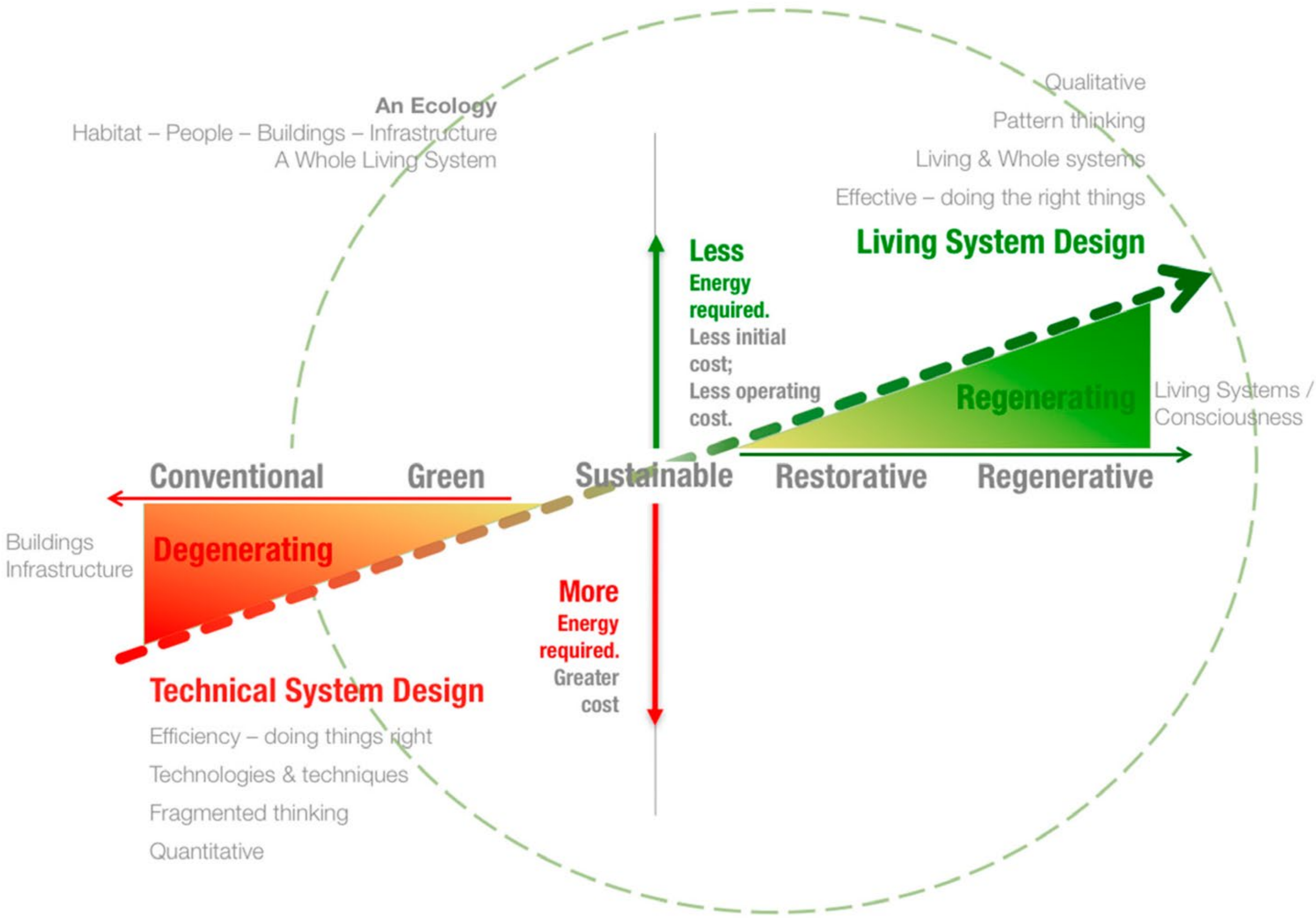


Figure 4: Trajectory of Ecological Design (Reed, 2010)

3 Methods

This chapter describes the process of the thesis and the methods used to answer the sub-research questions. The first sub-research question is descriptive and comparative, the second descriptive. In the third sub-research question, multiple 'fully' integrated designs are made which are the result of designing with the combined and applied insights of the first and second question. These designs envision an imagined future state of the landscape.

This thesis employs a case study in the Bargerveen landscape system to test the possibilities of the concept of paludiculture for the regeneration of the raised bog landscape while using Landscape Machine theory. The end result of the case study are multiple 'fully' integrated designs which are abstracted into two models for the large-scale implementation of paludiculture in the regeneration of the raised bog landscape. The landscape system of Bargerveen is chosen as a case because the problems of peat oxidation in the raised bog landscape are the most visible here. Therefore this is a paradigmatic case and the conclusions can be relevant in future regional raised bog landscape designs (Swaffield, 2017).

In order to answer the **main question**:

What design guidelines for a paludiculture Landscape Machine can help to regenerate raised bog landscapes?

Multiple methods are used, divided over three sub-research questions (Table 1).

SRQ1: What is the potential of Landscape Machine theory for designing a regenerative raised bog landscape with paludiculture?

First the regeneration of the raised bog landscape is discussed. Second, a literature study is conducted on paludiculture and Landscape Machines to describe both and discuss their potential for the regeneration of the raised bog landscape. Third, the differences and similarities between Landscape Machine theory, paludiculture and regeneration are described and how they complement each other. The method of literature study is chosen to comprehend the concept of paludiculture and Landscape Machines theory and filter the relevant information for this thesis.

SRQ2: How does the raised bog landscape of the Bargerveen landscape system function?

A literature study is conducted to find out what other authors write about this particular landscape during its multiple phases. The site analysis is informed by SRQ1 and the theoretical framework, certain data should be given extra attention such as soil and water because these are important elements in the context of raised bog landscapes. When specific design-knowledge is needed this analysis can be further deepened. During this reflective iterative process, data can be collected by means of a literature study. For collecting specific information that is not available in literature, semi-structured interviews with experts will be implemented. The interviews are guided by a set of predetermined open-ended questions, which allows new insights to occur. The data collection method of field observation will provide this research with contextual descriptions of the observable and characteristic elements within the field setting (Silva *et al.*, 2015). Photographs and field notes will be made during multiple visits. This is important for understanding the landscape, its workings and dimensions.

Table 1: Used methods

Research question	Methods	Expected results
What is the potential of Landscape Machine theory for designing a regenerative raised bog landscape with paludiculture?	Literature study on 'landscape machine' and paludiculture	Insight in both theories, gathering relevant data, discussing the combination of both theories for the raised bog landscape
How does the raised bog landscape of the Bargerveen landscape system function?	Literature study, field observation, site analysis, semi-structured interview	An overview of the development of the raised bog landscape of Bargerveen
What would be a way to create a regenerative paludiculture Landscape Machine in the Bargerveen landscape system?	Research through designing, development of models	Full design and two sets of design guidelines (models)

SRQ3: What would be a way to create a regenerative paludiculture Landscape Machine in the Bargerveen landscape system?

This SRQ deals with how to apply the gathered data in SRQ1 from paludiculture and Landscape Machines in a landscape design in the Bargerveen landscape system, which is analysed in SRQ2. To reduce this gap between academic knowledge (research) and applicability (design), designing is employed as a research tool with the method 'Research Through Designing' (RTD) (Lenzholzer, Duchhart and Koh, 2013). By integrating RTD into a case study design, it can contribute directly to answering the critical questions of the discipline of landscape architecture (Swaffield, 2017). RTD is a process to generate, test and prove new knowledge and is concerned with the solution of problems and application within a specific context (Lenzholzer, Duchart and van den Brink, 2017). To achieve the answer to this sub-research question, complex and comprehensive design-relevant knowledge is needed due to the design criteria of paludiculture and Landscape Machines, therefore a pragmatic worldview is embraced as it is most suitable for answering the sub-research questions 1 and 2. This worldview draws from many ideas, employs 'what works', does not obey to fixed theories and by combining knowledge claims and methods from different worldviews, the overall outcome can be improved (Lenzholzer, Duchhart and Koh, 2013).

SRQ1 and SRQ2 are what is called 'Research For Design', it supports the design product or process (van den Brink *et al.*, 2017). The designing itself consists of applying the data from paludiculture and Landscape Machines in designs on the specific site and evaluating these design against the acquired knowledge. In this reflective iterative process new knowledge should be gathered in SRQ2 as more specific questions arise considering the site. This pragmatist RTD process will result in 'fully' integrated designs which are the product of accumulated knowledge (Lenzholzer, Duchhart and Koh, 2013). These 'fully' integrated designs are made for two areas around and are the manifestation of a paludiculture Landscape Machine which regenerates the raised bog landscape. These designs are then abstracted into two models, or sets of design guidelines. These two models are then tested in the larger landscape system of Bargerveen resulting in another 'fully' integrated design on a larger scale. The creation of the two models is the knowledge gap that this thesis bridges and the answer to the main research question. An overview of the whole research and design process can be seen in Figure 5, this is not a literal linear process. The preliminary designs and sketches are shown in Appendix 8, as they are part of the designing process.

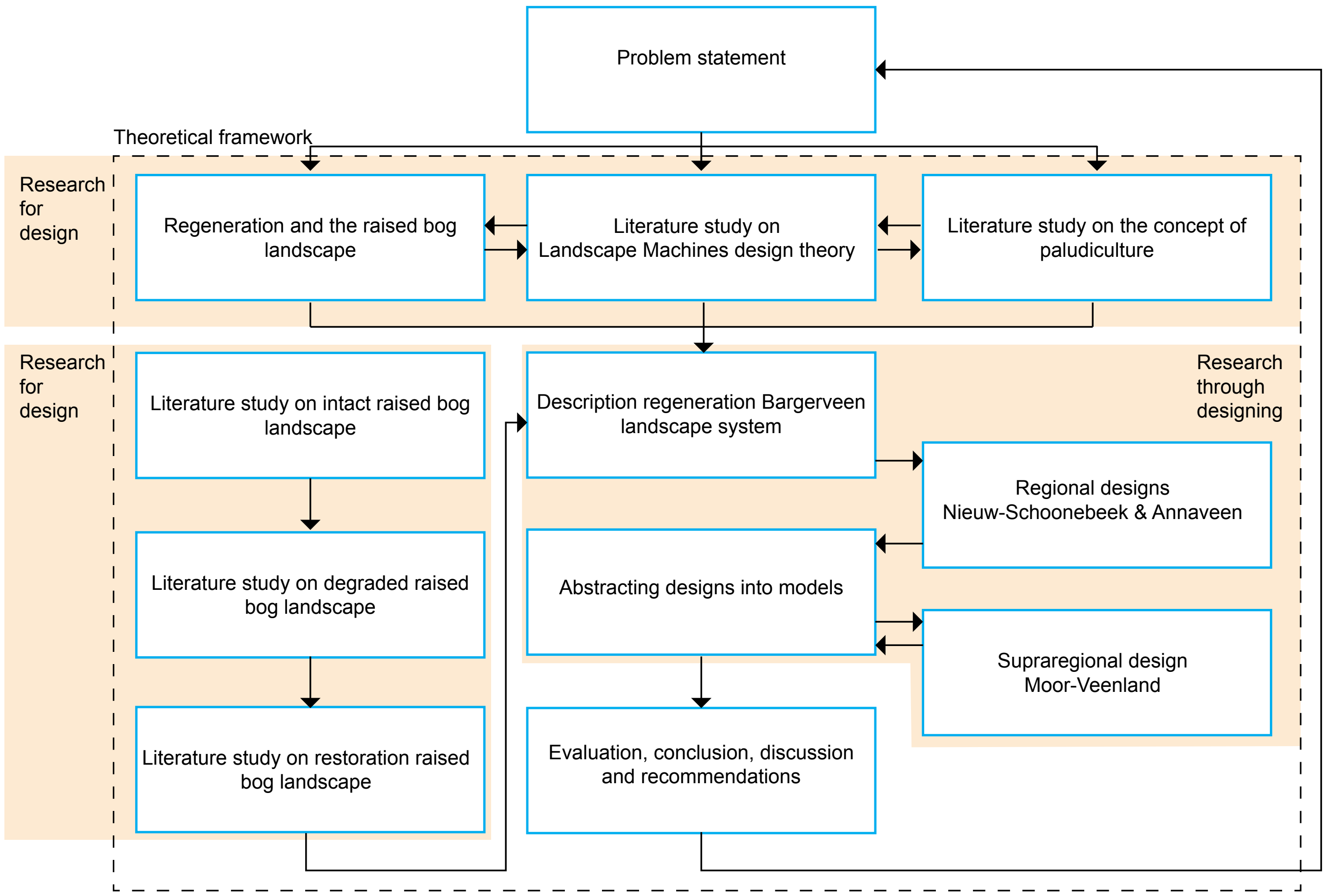


Figure 5: Flow chart of the thesis process

4 Paludiculture & Landscape Machines

When looking at both Landscape Machines and paludiculture, in the light of regenerating the raised bog landscape, it becomes clear that they are interconnected. Regeneration embodies the co-evolution of natural and human processes. Paludiculture makes a strong case for the mixing of nature and agriculture and the designing of this marriage between agricultural innovation and habitat development is exactly what Landscape Machines is all about. Therefore it can be stated that Landscape Machines and paludiculture have the same approach. Both share the same philosophical background but are from different fields of expertise. Paludiculture can be seen as a proven technology, there is a lot of hard data to support the productive use of wet peatlands. But while paludiculture is studied extensively over the course of many decades and in many facets, it is mostly explored in an ecological-modernist way by Wichtmann *et al.* (2016) and fails to translate it in workable spatial concepts or to embed it in the larger system of the raised bog landscape. While the theory of Landscape Machines takes a more holistic approach and sees the landscape as a living system. Although this is an abstract theory, it also offer guidance on what to analyse and what the outcome of the designed Landscape Machine should be. It considers a more systemic approach which also deals with dynamic and succession, especially because the landscape will evolve towards a dynamic steady-state stage. Landscape Machines is used in several design theses and one of the critiques was that a lot of the assumptions made were considered wishful thinking and thus lacking the scientific validity (Roncken, personal communication, April 2018). By combining the concept of paludiculture and Landscape Machine theory, both shortcomings can be resolved and a better outcome can be achieved. Because the scientific validity and concreteness of paludiculture can prove useful within the holistic but merely theoretical approach of Landscape Machines while designing a regenerative raised bog landscape. Concluding, the potential of Landscape Machines for designing a regenerative raised bog landscape with paludiculture is high. In this chapter the statement above is further clarified, the theory of Landscape Machines and concept of paludiculture are both explained and their potential to regenerate the raised bog landscape is discussed.

4.1 Regeneration of the raised bog landscape

During this research it became clear that the raised bog landscape is degrading as discussed in Chapter 6. To salvage the raised bog landscape and to adapt it for the future, a 180 degree turn is necessary. Instead of exploiting the landscape and thereby degrading it, we should work towards the regeneration of this landscape. Regeneration is different from restoration as can be seen in Figure 4. Where restoration seeks to restore the original state of a landscape, watershed or ecosystem, regeneration seeks to 'create anew' by including people and human interactions as part of nature (Reed, 2010). In other words, with the regeneration of a landscape, human and natural systems should actively co-evolve as one. The regeneration of the raised bog landscape is easy to argue in the perspective of sustainability (Figure 4), climate mitigation and climate adaptation. Because the basic principle of regeneration of the raised bog landscape is that water-levels are raised. In this condition peat will accumulate once again and the ecosystem can perform and provide its services. So instead of releasing CO_2 in the atmosphere due to peat oxidation, CO_2 is captured (climate mitigation). As for climate-adaptation, the ability to store and retain water in these rewetted peatlands is an effective measure for diminishing the peak-discharge in case of heavy rainfall. Also in case of drought, the raised bog landscape system of Bargerveen can store and retain water so it does not have rely on external water that has to be pumped from the IJssel lake. In times of abundance, water can be released to downstream areas. This increases the self-sufficiency of water supply in Drenthe.

The regeneration of the raised bog landscape should be centered around the parts of the raised bog ecosystem that are still in a semi-original state because these areas benefit extra from raised water-levels and the effects thereof. These are often assigned as raised bog nature areas and organisations responsible for these areas struggle to restore these raised bog remnants which is explained in Chapter 7 Restoration of the raised bog landscape. These areas should be the starting point for the regeneration of the raised bog landscape. Bargerveen is such an area and is therefore used in a case study to demonstrate how the regeneration of the raised bog landscape can be done. By restoring this raised bog remnant, surrounding agricultural lands need to be rewetted. This excludes the current agricultural use as land use. This loss of productive land should be countered with the introduction of the – economically viable – concept of paludiculture: the productive use of wet peatlands. It can be concluded that the regeneration of the raised bog landscape should begin by restoring the raised bog remnants with the implementation of paludiculture in surrounding areas. By doing this, a regenerative paludiculture landscape emerges.

4.2 Landscape Machines

In Figure 4 it is visible that regeneration is linked to Living System Design (thinking). Thus to create a regenerative design with paludiculture for the raised bog landscape, living systems theory and thinking is necessary. Such a design theory for living systems is proposed by Roncken, Stremke and Pulselli (2014) and further refined by Roncken (2018) under the name of Landscape Machines. The theory of Landscape Machines is based on the regained interest in the functional value of landscapes and its design. It integrates the knowledge of ecological systems into landscape design and therefore builds upon theories proposed by McHarg (1969) and Hough (1995).

Roncken, Stremke and Pulselli (2014) state that there is a paradigm shift from *beautification* and *preservation* to landscape-related *production*. This shift is part of a more general turn towards sustainable development by arguing that natural processes can contribute to economic and geopolitical benefits. This can be seen as a holistic approach to ecosystems and biodiversity by putting it in a larger framework (Roncken, Stremke and Pulselli, 2014).

Landscape Machines explores a type of design that is concerned with the dynamics of self-organizing systems and is a fit between general knowledge, proven technologies and a local situation. It is a theory for the design of living systems such as ecosystems or landscapes. The general idea is to develop a new kind of semi-wilderness that is a product of ecological and technical interventions (scripted design interventions) and the allowance of new habitats to arise (non-scripted responses and interferences). Roncken (2018) states that a Landscape Machine may be conceived as a futuristic machine that is both natural and man-made.

Landscape Machines serve both natural development of ecosystems and habitats and the harvestable resources of enhanced natural environments. The designed area must therefore be suitable for agricultural yields and ecosystem restoration. This marriage between agricultural innovation and habitat development creates a performing landscape. The physical performance of the landscape is expressed in crops, animal populations and in resilient systems to cope with a new climate regime. The aesthetic performance is characterized by a continuous shifting sense of place and sense of self and by arising recreational opportunities. This performance will change over time as the system is dynamic and is rhythmically disturbed by harvesting crops, in and outflow of nutrients and water. It can be concluded that this new semi-wilderness will be a dynamic place, as it will slowly be colonized in response to a series of shifting landscape performances (reaction of the landscape on changing circumstances) and will organize itself towards a higher complexity and organization (Roncken, Stremke and Pulselli, 2014; Roncken, 2018). To design a landscape with this approach, inter and transdisciplinary knowledge is needed and thereby question the unique qualities of landscape architecture as a specialized field (Roncken, 2018, p. 222).

4.2.1 Characteristics

Roncken (2018) defines a Landscape Machine in the following four main requirements see Figure 6:

(1) There is a distinction between scripted design interventions and unscripted system responses. The development over time of both constitutes the whole of the Landscape Machine. The audience, which consists out of humans, animals and plants interact with this new landscape system.

(2) This scripted design intervention (input) should be non-endemic to provoke a strong new system response. This is best described as *Fremdkörper*: a technological or resource-related element within the landscape that is non-endemic and thereby stimulates systemic responses. The performance over time by the landscape and its audience responses (human, animal, plant) is the mechanical part of the Landscape Machine. The machine produces a controlled amount of food, resources, energy and other services.

(3) The machine will develop for the most part according to the unscripted system responses. The responses will gain in complexity as they continuously interact with each other, affecting the shape, scale and position of components and audience responses within the landscape. There is an additional disturbance by scripted harvesting of crops, water or other resources. The introduced conditions need to be quantified in order to be able to describe the material interactions (see section 4.2.2 Metabolism) and qualified in order to be able to monitor the type of aesthetic interactions that change the audience responses. The functionality of the design is expressed in the form of input/output ratios in a book-keeping model for both the quantitative aspects (metabolism) and qualitative aspects (aesthetics) of the system to provide a means for evaluating performance. The quantitative aspects include amounts of water retention and biomass production. The qualitative aspects include human, animal and

plant responses, physical well-being, sense of place and sense of self.

(4) The overall development process can be simplified by breaking it down in four stages: an initial stage, a growth stage, a yield stage and a steady state stage. During the initial stage a scripted design intervention is made which relates to the societal/biotic/abiotic types of engagement. In the growth stage, the landscape is under the influence of various interacting parallel successions. During the yield stage the Landscape Machine regulates itself entirely, is powered by renewable resources and will provide a maximum amount of ecosystem services and goods. The steady state stage is the ideal state of the Landscape Machine because the continuous harvesting of products coincides with continuous shifts within the landscape while maintaining an abundance of biodiversity. Dynamic steady state systems are, for instance, mangrove forests, wetland systems and highland peatlands. Landscape Machines may also evolve in to a steady state that is no longer harvestable, this would mean a failure in terms of productivity but a success when taking aesthetics in account because it can develop into a state with a high complexity and diversity (Roncken, 2018).

Additional to this, Roncken, Stremke and Pulselli (2014) state that the machine aspect consists of ecologically described processes that are either enlarged or stimulated to perform (Roncken, Stremke and Pulselli, 2014).

4.2.2 Metabolism

According to Roncken (2018), a Landscape Machine can be designed follow this procedure:

Examine

(1) Examine the confinement of the Landscape Machine

(2) Examine potential ecosystem services

(3) Examine the systemic history of the site and past/present audience engagement

(4) Examine external and internal metabolic relationships and note how they can be measured

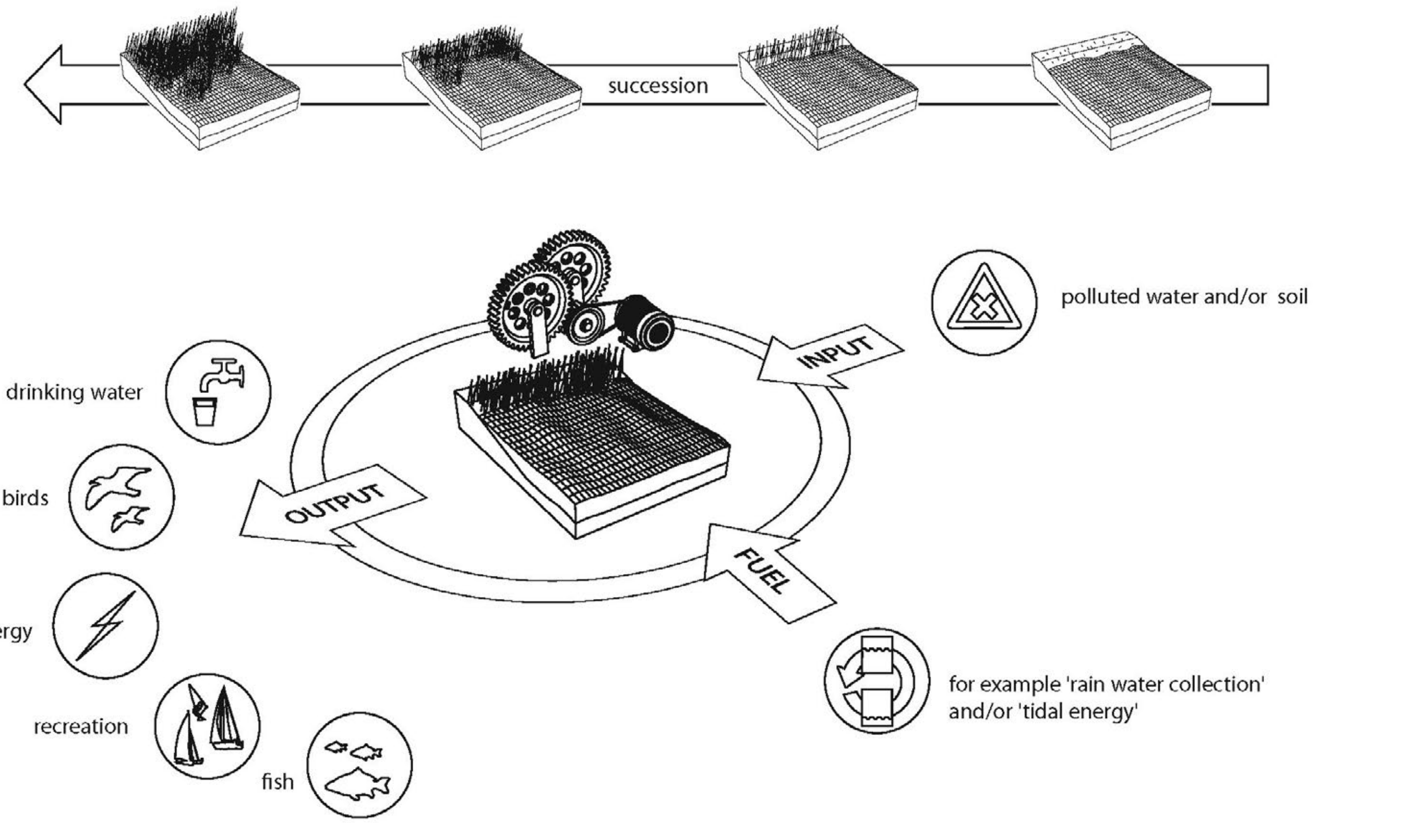


Figure 6: Schematic representation of the components of a Landscape Machine (Alexander Herrebout, 2011). The inputs are the scripted design interventions, the landscape reacts to this by changing its performance and audience responses. The fuel is the energy or resource that drives the machine. The output are the goods and services the machine produces.

Define

(1) Define desirable nutrient cycles and feedback systems (recycling)

(2) Define nutrient cycles geographically and describe what has to be connected/isolated

(3) Define desirable human, animal and plant life involvement (affordances and landscape ecology)

(4) Define what type of yield is possible over what timespan

Besides this, visualisations should be made of the Landscape Machine that have a high degree of empathy (Roncken, 2018). This is to stimulate the senses of how the Landscape Machine, which is for a great part quite theoretical, can look like for the visitor.

A rather pragmatic part of the procedure when designing a Landscape Machine is to draw up an input-output scheme of the metabolic (quantitative) and aesthetic (qualitative) interactions. This scheme, together with accompanying cross-sections showing the dimensions in the landscape, indicates what types of relationships may develop (Roncken, Stremke and Pulselli, 2014; Roncken, 2018). Tiezzi (2011) proposed a concept to describe the properties of living systems under the name of COOS or Confined Ontic Open System. Roncken, Stremke and Pulselli (2014) adapted this in such a way that it is applicable to a Landscape Machine to serve as a framework and common ground for designers and scientists. In Appendix 1 the four key concepts of COOS are defined and specified how to apply them in a Landscape Machine. The Landscape Machine that is designed in this thesis will be assessed according this table (see Chapter 10 Discussion).

4.2.3 Conclusion

Concluding, Landscape Machines is a theory that sees the landscape as a living system and applies living system theory and thinking in landscape design. The starting point of this design theory is a malfunction in the landscape or a dysfunctional situation which is exactly what is happening in the Bargerveen landscape system as stated in Chapter 6 Degradation of the raised bog landscape. When looking at the landscape as a machine and analysing it, it becomes clear where the 'machine' stopped working, what caused it to stop working and what needs to be repaired or newly created in order for the 'machine' to start working again. Furthermore a Landscape Machine is defined by Roncken (2018) in four points and it can be designed by following a procedure in which eight points need to be examined or defined. These definitions and requirements are used as a guideline to design a regenerative raised bog landscape. The concept of COOS by Tiezzi (2011) is used as a tool for understanding the properties of living systems but also as a reflection on how the designed Landscape Machine fits within this framework of the description of properties from living systems. This living systems theory emerges clearly when Roncken is writing about the so-called dynamic steady state stage, or in other words: how the 'machine' will develop over time in which it traverses different stages (initial, growth, yield) and finally reaches a sort of dynamic equilibrium or the dynamic steady-state stage. This theory can be applied to ecosystems and landscapes as well, because they also can be seen as living systems.

4.3 Paludiculture

While the design theory of Landscape Machines is quite theoretical, the concept of paludiculture is very concrete. Paludiculture is used in the Landscape Machine that will be designed for the regenerative raised bog landscape. In the following sections the concept of paludiculture is explained in the light of regeneration and the raised bog landscape.

4.3.1 Regenerative paludiculture landscape

Paludiculture is the productive use of wet peatlands by cultivating specific crops that prosper in these conditions. By raising water levels, it is mimicking the conditions in which this landscape or ecosystem once was formed and flourished. Translating this into more practical terms, it means that peat oxidation will be stopped and it can therefore be seen as a form of sustainable land use. Paludiculture is especially promising in buffer zones that are needed around raised bog nature reserves. The goal of using paludiculture in this way, is to support the regeneration of the raised bog landscape as a whole. This is done in three ways.

Firstly, the paludiculture landscape is a hydrological buffer around the raised bog remnant that transitions from nature to conventional agriculture (see Figure 52b). The rewetting of drained peatlands achieves a reduced hydraulic gradient which is important for the groundwater stock (Wichtmann *et al.*, 2016). This helps with restoring the external hydrology of the raised bog remnant by achieving stable water levels, which is a precursor for peat moss to grow. With the growth of peat moss, the raised bog ecosystem will start to restore as the self-regulating capabilities and resilience of this plant are of great importance to this ecosystem. When restoring, the raised bog ecosystem will provide ecosystem services as seen in Figure 19.

Secondly, the introduction of paludiculture on the rewetted agricultural peatlands conserves the remaining peat in the soil and can result in new peat formation. Under the right circumstances and with the introduction of certain species, peat will form. This is because the peat is mostly formed underground, by the roots and rhizomes (Figure 7). The plants can be harvested without damaging the formation of new peat (Joosten, 2017). Important is that the buffer capacity exceeds the precipitation deficit during the growth season to prevent water levels from decreasing too much. If water levels are too low during summer, the process of peat oxidation can set in.

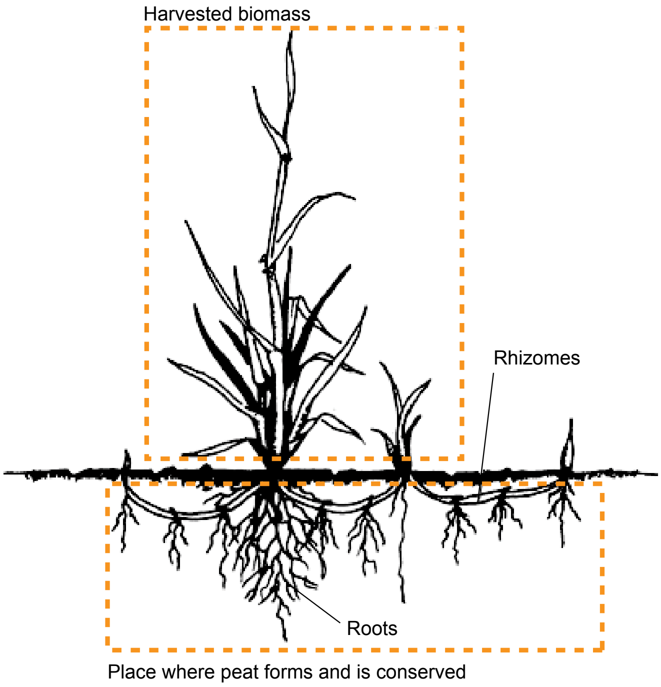


Figure 7: Harvesting, conserving and forming peat

Thirdly, paludiculture leads to useful production. By cultivating crops that prosper in these conditions, the harvestable biomass of paludiculture can match conventional agriculture (see section 4.3.3 Productivity and possible revenue models). Paludiculture can potentially replace conventional agriculture in the raised bog landscape, which is a big factor for the demise of this landscape and the raised bog ecosystem.

Paludiculture thereby offers perspectives for: the conservation and (possible) regeneration of the raised bog ecosystem, the reduction of CO_2-eq emissions and (possible) sequestration and as an alternative for conventional agriculture in the raised bog landscape.

4.3.2 Land use change and sustainability

Decisions about the use of land are often based on short-term, cost-benefit considerations, current preferences, and knowledge. Ecological, social and (total) economic effects are usually not taken into account or at least not their long-term aspects. However, the concept of sustainability demands that precisely these effects are addressed in decision making. The use of land has also ecological, social and economic effects that often work beyond the utilised area itself (Foley *et al.*, 2005). This should be evaluated when the sustainability of land use is assessed. Wichtmann *et al.* (2016) state that as the usability and productivity of peatlands declined and knowledge of the ecological function of intact and drained peatlands increased, questions arose about how to deal with peatlands in a sustainable way. Societal priorities widened in the face of biodiversity loss, eutrophication of water bodies and climate change (Wichtmann *et al.*, 2016). Instead of reclaiming peatlands they are preserved or even restored.

Wichtmann *et al.* (2016) evaluated the land uses of grassland, maize, undisturbed fen peatland and paludiculture with reed and willow. In this evaluation for sustainability, ecological, social and economic aspects are brought together and it was clear that the land uses of paludiculture (cultivation of reed and willow) scored the best in this assessment. For the results of the evaluation see Appendix 2.

To achieve land use change is very difficult and not within the scope of this thesis to research, but some recommendations will follow. In agricultural areas with low income, the willingness to change current land use will be higher than on profitable arable land (Wichtmann *et al.*, 2016). The price per hectare for agricultural land in Drenthe is relatively low compared to other lands in The Netherlands (Boerderij, 2018; NVM, 2018) so this might be a good indicator that land use change could be possible. The change from conventional agriculture to paludiculture is very impactful and need to be done on a large scale that corresponds with hydrological units. Farmers need to be stimulated to work together and form collectives. This can be done by guaranteeing their income and giving them subsidies for the ecosystem services that paludiculture provides. Also land funds can be involved, one of these initiatives called 'CommonGround' buys up land and rents it out to farmers for a low price under the condition to implement nature inclusive agriculture. This way investors have a real impact with their investment and farmers can change their current business model. The way this new business model for paludiculture can work is explained in the next section.

It can be concluded that paludiculture on peatlands scores high on the scale of the sustainability of land use. There are several ways to achieve land use change. More importantly, paludiculture offers perspectives for the stated problems.

4.3.3 Productivity and possible revenue models

Although little data exists of paludiculture practices on (former) raised bog peatlands, it can still be seen as a proven technology because there is a lot of hard data to support the productive use of other peatlands with paludiculture (Geurts *et al.*, 2017; Joosten, 2017; Lamers and Smolders, 2017). Former agricultural lands are being converted to paludiculture fields without digging away soil, these are good quality soils with high nutrient availability for paludiculture crops. While paludiculture is less intensive than the current form of agriculture, that does not necessarily mean that the yields (tonnes dry mass per hectare per year) are less than agriculture. With the cultivation of cattail, reed and willow new opportunities arise. Farmers need to organize themselves in collectives because their land may consist out of a fraction willow, cattail and reed which are not profitable when exploited by only themselves. These crops have different harvest times and may require different management and agricultural machinery, thus a form of cooperation between the farmers may be necessary. Biomass seems like an obvious goal of these crops, which is understandable because these crops are fast-growing, can be harvested every year with high yields and have a lower heating value (LHV) between 17-19 MJ/kg (Wichtmann *et al.*, 2016).

Also the local infrastructure for biomass seems to be good, there is a large manufacturer in Germany who can process it (Klasmann-Deilmann) and there are glasshouse-complexes in the area who can use the biomass for heat.

But besides harvesting for biomass, these crops can be used in other ways. Cattail is suited for brewing beer and production of insulation material, for reed the most economic one is thatching and willow can be harvested for wood production (Wichtmann *et al.*, 2016). Although the cultivation of these crops may produce less gross revenue, these crops also require less maintenance costs because they do not need fertilisation, pesticides or herbicides. One can think of implementing a regional production chain with the harvested biomass, for example the production of recreational houses (Figure 8). This can be for the economic benefit of farmers and local industry. The renewable raw materials of reed and willow are being transported to Solidus Solutions, a cardboard factory in Coevorden. The reed and willow are being transformed to pulp and cardboard is made from it, this cardboard is the main material used for the so called wikkelhouse. These houses can then be located in the area of Bargerveen to serve as temporary housing for nature-lovers and rest-seekers. By doing this there is a substantial addition to regional value, because the products are harvested, transported and manufactured in the same region. To top this off, the produced goods (Wikkelhouses) are then placed back in the area where the raw materials are harvested, adding even more value to the region. Other possibilities are extensive livestock farming with water buffaloes or transforming agricultural buildings on the farmyard to recreational or residential buildings. An economic comparison between old, current and new land use is available in Appendix 5. The main conclusion is that reed is reasonably profitable when harvested for thatching and direct combustion. This is certainly the case when looking at the Bargerveen area because there are local markets available. Besides profitability, ecosystem services and sustainability play an important role that cannot always be expressed in economic terms. Although the profitability of paludiculture fields may be lower than normal agriculture, it seems evident that paludiculture provides better and more ecosystem services and is more sustainable.

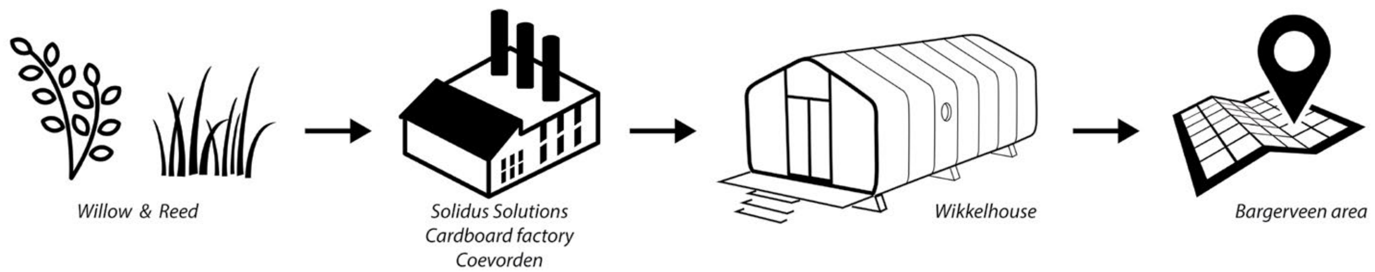


Figure 8: Possible regional production chain

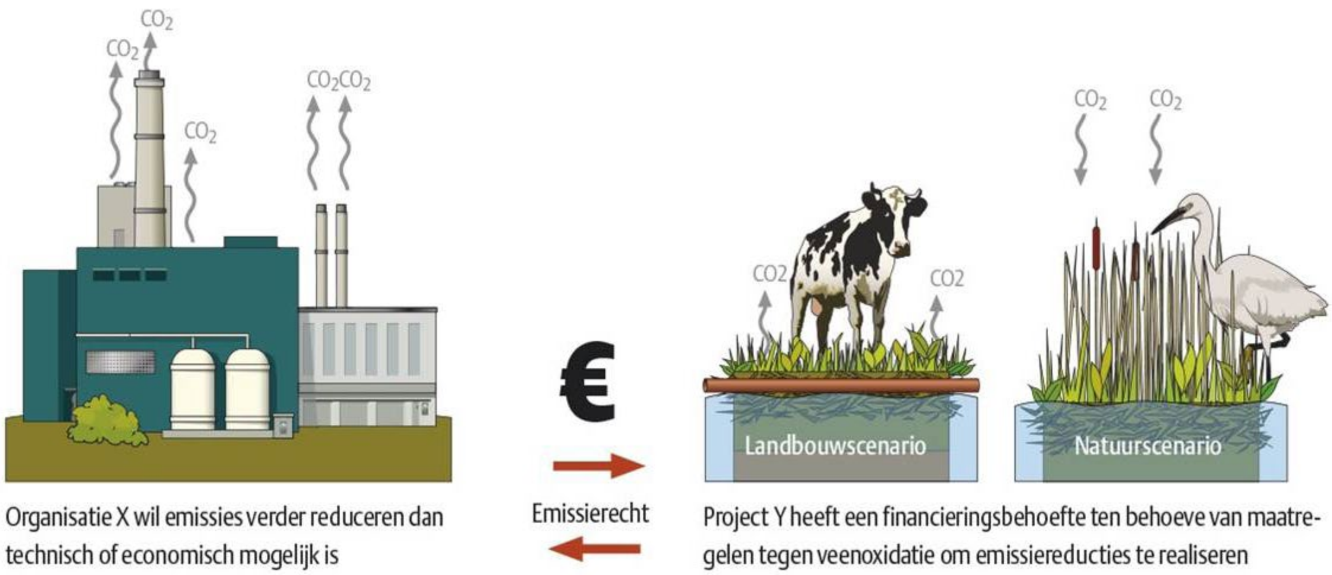


Figure 9: Revenue model for rewetting of peatlands (FMF, 2017)

Another way of compensation is demonstrated by the project 'Valuta voor Veen', in which the CO_2 emissions from peat oxidation are stopped or CO_2 is even sequestered by raising the water levels (Figure 9). The cost of raising the water levels for the farmers is then compensated by citizens, companies and authorities that pay a voluntary contribution for each tonne of saved CO_2-eq (FMF, 2017). A similar project in Germany, MoorFutures, has been successful since 2011 (Joosten, 2017).

Besides the revenue from yields, other ways of economic compensation can be given to the farmers. Because their lands contribute to the restoration of the raised bog of Bargerveen, stop the degradation of peatlands and implement a sustainable agricultural system. Further criticism on the productivity of paludiculture is discussed in Chapter 10 Discussion.

4.3.4 Implementation of paludiculture

Rewetting is a precondition for paludiculture on degraded peatland areas. For the implementation of paludiculture changes in water regulation and infrastructure may be necessary (Wichtmann *et al.*, 2016). Wichtmann *et al.* (2016) state that the assumption that peatlands can easily be rewetted and then used for paludiculture is rarely appropriate. Differences in surface relief can be reduced by levelling the area before rewetting or by dividing the area into different subsections, with different water levels. Considerable spatial variation in water level needs to be avoided as the water level needs to be near the surface during the whole year. This is to ensure the preservation of the peat body, the stored carbon and nutrients and to provide optimal growth conditions for the cultivation of paludiculture crops. This may require regulation and technical measures. Passive and active water management measures can be implemented such as: blocking ditches, filling-in ditches, dikes, adjustable and fixed weirs and pumps. Passive water management measures serve to keep the water in the peatlands and active water management measures allow for regulation of the water table. These active measures are necessary because the water table will lower significantly in the summer. To ensure optimum water tables for paludiculture in the summer, the level of water retention in winter must be high or additional water must be added. It is estimated that the level of retention in winter must be +12 centimetres, for water tables not to drop below the surface (+/- 0 centimetres). If this level of retention is not possible than the amount of water that is necessary to maintain optimum water tables (mean water table of -20 centimetres) in the summer is 110 cubic metres per hectare. The more additional water is available, the easier it is to balance seasonal demands and keep water tables constant. When comparing this to conventional agriculture which is draining up to 1 meter deep in the area (Schunselaar, van der Hauw and Dik, 2014) and discharging excess water it will mean that paludiculture buffers extra water because of limited drainage and will result in an overall increase in water tables which is favourable for the restoration of the raised bog ecosystem.

When rewetting, the difference in site conditions has to be taken into account. A mosaic of different crops and land use practices can help to respond to this. This might be more challenging with respect to managing these sites but it creates a resilient system with regional added value and biodiversity. Moreover, new infrastructure might be needed for management on site and for transport of the harvested biomass. No conventional machinery can be used to harvest the biomass but this challenge can be met with technology as seen in Figure

10. Other infrastructural measures may be necessary such as the adaptation of existing infrastructure to high water levels, construction of paved transport routes and biomass transfer sites. These biomass transfer points must be accessible via paved roads that are suitable for transport vehicles (Wichtmann *et al.*, 2016).

Figure 10: Harvesting Reed biomass with specialized machinery (http://www.hanzewetlands.com/)

Summarizing, a successful implementation of paludiculture requires water management measures to limit the fluctuation in water levels. Additional water needs to be available to keep water tables constant to balance seasonal demands. Implementing paludiculture will result in an overall increase in water tables which is favourable for restoring the raised bog ecosystem. When implementing paludiculture, differences in site conditions can be met with a mosaic of different crops and land use practices. New infrastructure might be required. When designing with paludiculture these measures need to be taken into account.

4.3.5 Crops

There are many species that are suitable as crops for paludiculture. The database for potential paludiculture plants (DPPP) describes more than one thousand species that can be used. These include species that thrive on different kind of peatlands and in different kind of environments. A model was made by Van Duinen (2016) to narrow down the amount of useful species in a certain situation (Appendix 3). This model takes a holistic approach to the selection of species, it takes into account socioeconomic and ecological aspects but also climate, water and tourism. In the situation of the raised bog landscape, the crops with the highest potential for large scale paludiculture are Common Reed (*Phragmites australis*), Common Cattail (*Typha latifolia*), willow (*Salix*) and peat moss (*Sphagnum*) (Van Duinen, personal communication, June 21, 2018). This is supported in the work of Wichtmann et al. (2016) and in the thesis of Schepers (2018) on a paludiculture buffer on a plot of land nearby Bargerveen. In the following sections these plants are described further in the context of this thesis and are linked to soil and water properties.

Willow – *Salix*

Willow is well adapted to fluctuations in water levels and can handle inundation as drying-out (van Duinen *et al.*, 2017). It flourishes when the water level is between 0 and -20 centimetres, thus in the parts where cattail and reed cannot grow properly (Schepers, 2018). Under ideal conditions, peat can be formed. Within the designs it is also used as a windscreen for atmospheric deposition of nitrogen to relieve the raised bog nature reserves from excess nutrients. Willow also has high filtering capacities for water, even better then reed, but the capacity of capturing nutrients from the soil is distinctively lower than cattail and reed. Willow can be harvested for multiple purposes and in different intervals. A short rotation is best for bioenergy, fodder and paper/cardboard. A longer rotation (20-40 years) can harvest more quality wood for construction (Schepers, 2018).

Common cattail – *Typha latifolia*

Wichtmann *et al.* (2016, p. 226) state that cattail is very tolerant of water table fluctuations (from 150 cm to 0-10 cm above surface), extremely competitive and can reach heights of 2 meters. It is a highly productive plant, that sequesters large amounts of CO_2 from the atmosphere and plays a significant role in the mass balance of wetlands by assimilating nutrients in its biomass. It removes nutrients and toxins that cause eutrophication in aquatic systems and is therefore used in engineered constructed wetlands for wastewater treatment. Cattail can produce significant biomass within a single growing season which has superior qualities as material for insulation and light weight construction. Optimum water levels for biomass production are between 20 – 40 centimetres above surface (Schepers, 2018). Because of these wet circumstances, peat will be formed. In times of drought, water needs to be supplied to maintain the required water level. Harvesting captures nutrients such as nitrogen and phosphate and remove them from the nutrient cycle. If nutrient rich water is available, it can be used for irrigating fields of cattail, which needs a large nutrient supply. However, in many cases only a small area may profit from this extra nutrient supply because of the high nutrient uptake by the plants. Sites that are not close to the inlets can be cultivated with crops with less nutrient demand or used to produce special qualities. The best time for harvesting is the end of the growing season. Because of the high nutrient uptake, Cattail can be cultivated to create oligotrophic environments in which rare habitats can develop (Wichtmann *et al.*, 2016; Schepers, 2018). It can be concluded that cattail thrives in wet, eutrophic conditions.

Common Reed – *Phragmites australis*

Common Reed is a very versatile plant which can grow in nutrient-rich to nutrient-poor conditions and from dry to extremely wet conditions. It can handle water levels from -50 to 200 centimetres above the surface. Depending on the availability of nutrients it can reach heights up to 4 meters. Under permanently wet circumstances peat can be formed. Reed has just like cattail a high capacity for filtering nutrients from the soil and water (van Duinen *et al.*, 2017). When planted, it takes about three years for it to be harvestable. The harvest time depends on the use of biomass. In nutrient-rich conditions the biomass can be used for bioenergy and in nutrient-poor conditions it can better be used for thatching (NBD, 2017). Both are economically successful (Wichtmann *et al.*, 2016, p. 119). Other use can be construction material, paper/cardboard and fodder. It can be concluded that Reed is very versatile, thrives in a broad spectrum of conditions and can be used in several ways.

Peat moss – *Sphagnum*

Where the previous crops flourish well in nutrient-rich circumstances and under influence of ground- or surface water, the cultivation of peat moss is bound to oligotrophic conditions and limited to water supply by precipitation. The hydrological conditions that are needed for the cultivation of peat moss are practically the same as the raised bog nature reserves, namely a high and constant water table (Wichtmann *et al.*, 2016, p. 36; Schepers, 2018). Therefore the implementation of peat moss as a paludiculture crop is bound to a set of conditions. The soil of the site does not need to be enriched with nutrients from conventional agriculture, if so, the soil needs to be dug away. The site needs to be limitedly influenced by groundwater and cannot be inundated by surface water. There needs to be controlled irrigation and drainage which can be solved by a water basin, to achieve optimal growing conditions. When this is implemented, the first moss harvesting is possible after 3-4 years (Wichtmann *et al.*, 2016, p. 36). Given this set of conditions, only a few areas are suitable for peat moss farming and it is a costly option to implement this. However, in a paludiculture system in the raised bog landscape, peat moss cultivation can have a distinctive place as is shown in the supraregional design. The efforts of cultivation peat moss may be worthwhile because peat moss biomass offers a sustainable alternative to fossil peat in professional horticulture (Biancalani and Avagyan, 2014).

These four plants can create an interesting mosaic when they are implemented in the raised bog landscape. Each plant can fulfil a specific function and place within the landscape and thrives in different conditions.

4.3.6 Conclusion

The concept of paludiculture can be used to restore the raised bog ecosystem and to regenerate the raised bog landscape as it is compatible with rewetting measures that are needed as concluded in the problem statement. Paludiculture scores high on land use sustainability. The implementation of paludiculture requires measurements in water management. Difference in site conditions of paludiculture areas can be met with the cultivation of different species. Willow, reed, cattail and peat moss are the species that are implemented in the regeneration of the raised bog landscape with a specific function and place within the landscape, each of them linked to soil and water properties. This is why I choose to elaborate a landscape plan based on the exchange of conventional agriculture by paludiculture as a major part of this thesis research.

5 Intact raised bog
a well-oiled machine

For a successful regeneration of the raised bog landscape, it is essential to understand what a raised bog ecosystem is and how this type of peatland functions. Therefore, in this chapter a classification of peatlands is made. The type of peatland within the study area is then studied on a general level; how is it formed, how did it develop and how does this intact ecosystem function. Special attention is given to the hydrological characteristics. Discussed are the services this ecosystem provides and the role of this ecosystem in the perspective of climate change and climate adaptation. After this general description a more detailed and site-specific description is given of the Bargerveen landscape system with the purpose of giving background information and insight in the processes that have formed this raised bog.

5.1 Classification of peatlands

A classification of peatlands is made to make a clear distinction between the types of peatland and to show which type of peatland this thesis is focussed on (Figure 11) (National Wetlands Working Group, 1997). This makes it easier to find specific sources or information and enhances the reach of the results. Peatlands are organic wetlands that have accumulated more than 40 centimetres of peat, which is defined as partially-decomposed organic matter, on which organic soils develop (National Wetlands Working Group, 1997). The Canadian Wetland Classification System (CWCS) distinguishes four classes of peatlands: bog, fen, swamp and marsh (Mahdavi *et al.*, 2017). Peatlands where peat is currently forming and accumulating are called mires (van Duinen, 2013). The class of peatland that this thesis focusses on is called bog. Bogs receive water, minerals and nutrients from precipitation, are limitedly influenced by groundwater and its vegetation is dominated by peat mosses, also called *Sphagnum* (National Wetlands Working Group, 1997). Within the bog-class there are different types, whereas this thesis explores the raised bog (Dutch: hoogveen) type. This is a type of bog which rises in height due to peat formation and is dependent on a precipitation-rich, temperate climate with a precipitation surplus (van Guldener *et al.*, 2017, p. 43). Within the raised bog type there is a differentiation which is dependent on climate and geographical location. In North-West Europe the raised bogs take on the classical lens shape and are called plateau raised bogs (Limpens *et al.*, 2016). In the following section a detailed description is given of the formation, development and characteristics of the plateau raised bog.

Figure 11: Classification of peatlands. Based on Mahdavi et al. (2017)

Box 1: Trophic degree

The trophic degree constitutes the amount of nutrients in the water or soil. Nitrogen and phosphate are important nutrients as they are nutrition for plants. Within the trophic degree there is a scale division. Oligotrophy is a state with low amounts of nutrients, mesotrophy a state with medium amounts and eutrophy with large amounts of nutrients. Within the study area there are different trophic degrees. The raised bog remnants thrive in extreme oligotrophic conditions, whereas the agricultural lands are eutrophic because of decades-long fertilization. The stream valley of Schoonebeekerdiep forms a gradient from mesotrophic to oligotrophic conditions. These trophic degrees are not used in a quantitative manner but are purely used in a qualitative way to distinguish different soil and water properties within the study area.

5.2 Formation and development of a raised bog

Different stages of succession are needed before a raised bog is formed. According to Geel (2015), the first stage is an open lake created by meltwater of ice caps from the last ice age, approximately 10.000 years ago, and by precipitation due to the changing climate. This open lake will slowly overgrow with plants like reed and sedge that thrive in nutrient rich environments that are fed by groundwater, creating a fen peatland. Often this succession of species leads to a swamp forest. The next step in the succession, if there is a precipitation surplus, is the formation of a raised bog which is a oligotrophic (see Box 1: Trophic degree) environment that is solely fed by precipitation (van Geel, 2015). The hydrological situation of this peat development is seen in Figure 13. These raised bogs start their formation on the fen peatland and expand in a horizontal direction on the adjacent slightly higher grounds that have acidic soils (Jongmans *et al.*, 2013). Raised bogs have a differentiation between strongly decomposed peat (Dutch: zwartveen) and weakly decomposed peat (Dutch: witveen) which has to do with altering climate conditions. *Sphagnum* (Figure 12) plays an important role in the bog ecosystem, they can store up to 40 times their own weight in water and can outcompete other species by actively acidifying their environment (van Geel, 2015; Limpens *et al.*, 2016).

During their growth, *Sphagnum* accumulates nutrients and CO_2 (in the form of carbon) in peat, making the ecosystem poorer in nutrients and minerals (Limpens *et al.*, 2016). Both factors lead to a vertical gradient in nutrient and mineral richness as seen in Figure 14 (Limpens *et al.*, 2016). Crucial for the growth of *Sphagnum* and development of a raised bog is a humid and steady climate. The amount of precipitation must exceed the loss of water by discharge and evaporation (Jansen, 2015). Furthermore, the precipitation should be evenly distributed during the year.

Figure 12: *Sphagnum* plays an important role in the raised bog ecosystem (Assen, 2014).

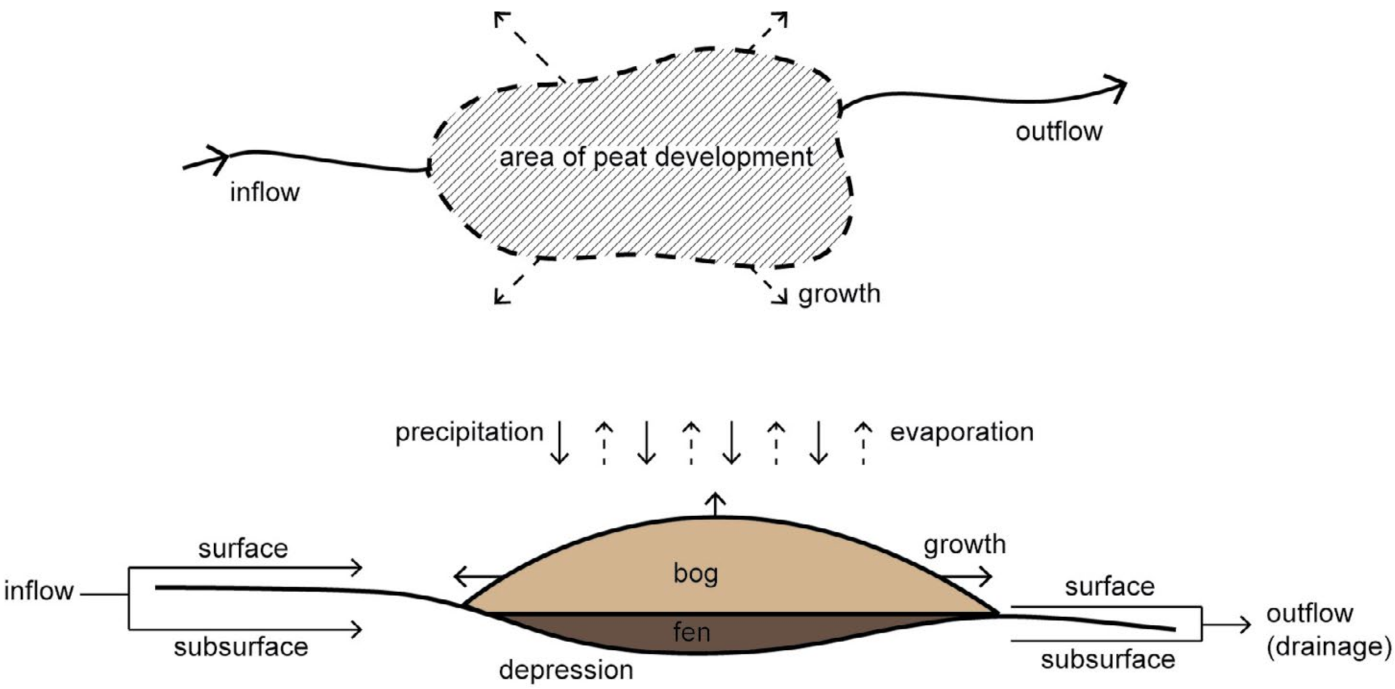


Figure 13: Fundamental hydrological situation of raised bog development. Based on Andriesse (1988).

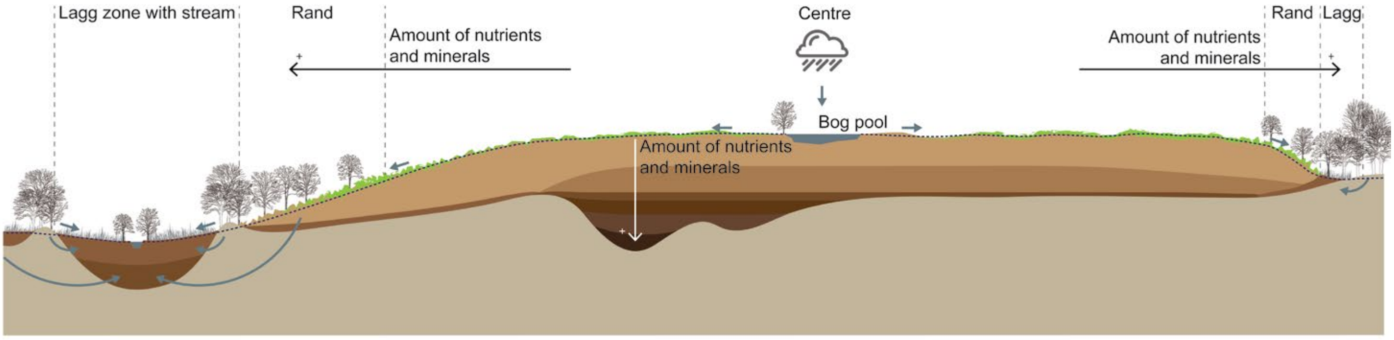


Figure 14: Schematic representation of an intact raised bog

5.3 Characteristics of a raised bog

Peatlands are one of the most important ecosystems of the world because their biodiversity, regulation of climate and water supply (van Duinen, 2013; Biancalani and Avagyan, 2014). Jansen (2015) states that other characteristics of the raised bog are its wetness and own water regime, relatively high altitude and the dome-shape. The centre of the bog consists out of bog pools (Dutch: meerstallen) and lawns (Dutch: vlakten) of *Sphagnum*, guaranteeing sufficient water supply in the growth season (Casparie, 1993). The slopes of the bog are characterized by small streams that discharge excess water and a mosaic of hummocks (Dutch: bulten) and hollows (Dutch: slenken) with different types of *Sphagnum* that create a micro relief (Jongmans *et al.*, 2013; Jansen, 2015). The hummocks and hollows permits maximal use of the water for the process of peat formation (Casparie, 1993). On these slopes, also called rand, the water levels are relatively low, making it suitable for trees and shrubbery to grow (OBN Natuurkennis, 2018c). The edges of the bog, often referred to as lagg, are a wet transition zone where bog- and groundwater mix with each other and thereby creating swampy areas with forest, reed or sedge, these contact zones play a role in maintaining the waterlogged state of the bog complex (Casparie, 1993; Limpens *et al.*, 2016). These horizontal gradients in acidity, wetness, availability of minerals and nutrients along the edge of the raised bog harbour a high biodiversity (van Duinen, 2013). In Figure 14 an intact raised bog can be seen.

The soil of intact raised bogs is often divided in two layers with their own hydrological characteristics (Figure 16), the acrotelm and catotelm (Ingram, 1978). These layers, when intact, have a high degree of hydrological self-regulation with *Sphagnum* playing a key-role (van Duinen, 2013). Jansen (2015) states that the acrotelm, the upper layer of the bog, is 30-70 centimetres thick, consists mostly out of living *Sphagnum* and weakly decomposed peat. This layer has a high capacity to store water and has a high water permeability that decreases exponentially downwards because of the increasing decomposition of plants. The acrotelm has the capability to swell and shrink corresponding to water levels, this process is called 'bog breathing' (German: Mooratmung). The layer beneath the acrotelm is called catotelm, this layer is permanently saturated with water, has a low permeability and consists out of strongly decomposed peat. Because of this low permeability of the catotelm and the 'bog breathing' of the acrotelm, a resilient and self-regulated hydrological system arises with little variation in water levels, even in times of a precipitation deficit (Jansen, 2015). According to Casparie (1993) a number of spatial structures develop during the formation of a raised bog: the hummock-hollow systems, the domed complexes, bog pools, contact zones and bog streams. These structures ensure a water surplus in the acrotelm which feeds peat formation, a water supply in the catotelm so that the bog can survive in dry periods and the maintenance of oligotrophy. In order for the bog to grow, an appropriate water supply is required. The bog should not be too wet or too dry but balanced, thus requiring a regulated water discharge (Casparie, 1993). This self-regulation of the acrotelm is shown in Figure 15, where the discharge controls the water level, the water level controls the permeability of the acrotelm and the permeability controls the discharge (van Duinen *et al.*, 2017). The productivity of an intact raised bog is very high when considering the oligotrophic conditions, according to Jongmans *et al.* (2013) about 8 ton dry weight per hectare. Which is comparable to the productivity of a temperate deciduous forest but productivity declines when forests grow older, which is not the case for raised bogs. The growth of *Sphagnum*, that is determined by the amount and distribution of precipitation, is 30-50 mm per year, which is regarded as a high value of accumulation (Jongmans *et al.*, 2013). This does not mean that the peat will accumulate with these numbers each year. Because the dead plant material will be decomposed and compacted, it is estimated that the growth of peat is around 1mm/year. To ensure the maximum productivity, and thus the maximum CO_2-uptake, of *Sphagnum*, several conditions must be met. Jansen (2015) states that the optimal growth conditions for *Sphagnum* are stable water levels (<30 centimetres fluctuation) near ground level, gradual surface runoff and availability of sunlight and carbon. Supplementary to this, the water should be nutrient-poor and *Sphagnum* will not grow in water that is deeper than 50 centimetres (Limpens *et al.*, 2016). The process of CO_2-uptake is explained in Box 2. The maximum height of a bog is around 10-12 meters. It will still grow when reaching this height and thus capturing CO_2, but there will be a balance between the formation of new peat and the compaction of peat due to the load on top (Van Duinen, personal communication, June 21, 2018).

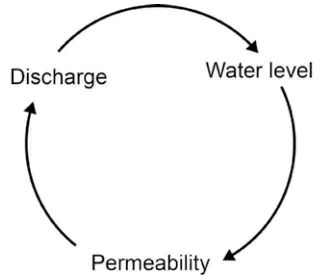


Figure 15: Self-regulation of the acrotelm. Control loop of the acrotelm.

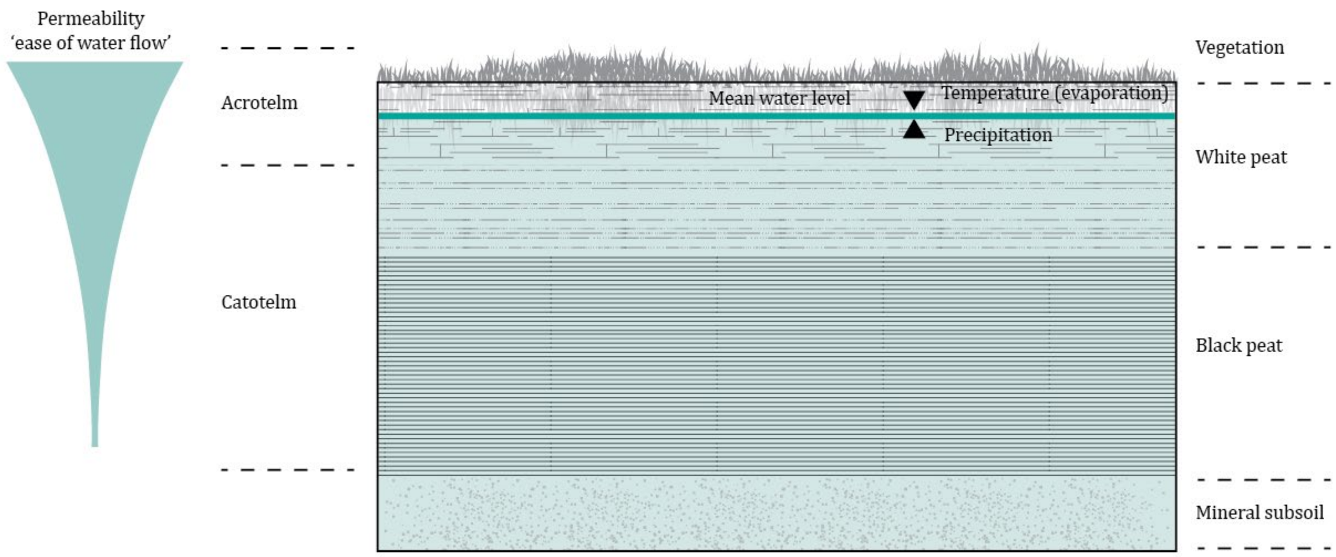


Figure 16: Schematic representation of the layers of the raised bog

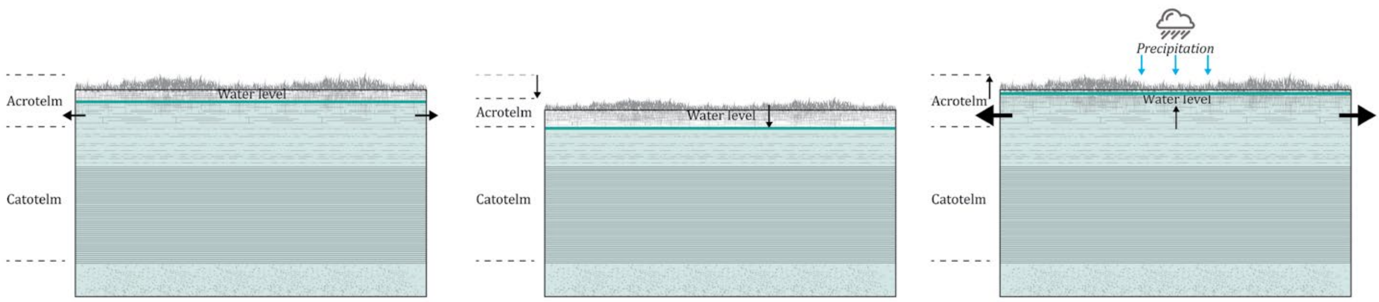


Figure 17:Bog breathing illustrated. The bog reacts to precipitation and drought.

5.4 Ecosystem services

Ecosystem services are the benefits people obtain from ecosystems (Millennium Ecosystem Assessment, 2005), in this case the raised bog ecosystem. The Millennium Ecosystem Assessment (2005) divides ecosystem services into four categories: provisioning, regulating, cultural and supporting services as seen in Figure 19. Whereas the first three are the main categories, the fourth is supporting services which are necessary for the production of other ecosystem services. All these ecosystem services have different impacts on several aspects of the well-being of humans. In a broader sense, ‘everyone in the world depends on nature and ecosystem services to provide the conditions for a decent, healthy, and secure life’ (Millennium Ecosystem Assessment, 2005). This framework is used for the important services that ecosystems, like raised bogs, provide and cannot always be valued in monetary terms. Further in this thesis (in section 5.4.1, 6.6 and Figure 94) , this framework is used to assess the services provided by the past, current and future landscape.

5.4.1 Ecosystem services of raised bogs

Intact raised bog ecosystems provide numerous ecosystem services as can be seen in Figures 19 and 20. These services are mostly in the regulating category and have a stabilising effect on local hydrology: attenuating the peak-discharge of heavy rainfall by water retention and storage, purification of water and the exertion of a cooling effect on local climate through evaporation (Wichtmann *et al.*, 2016). The continuous peat formation of this ecosystem leads to a relative high sequestration of carbon - the process of removing CO_2 from the atmosphere and storing it in peat - and mineral components of plants, which is also a regulating service. Lamers and Smolders (2017) state that bogs have a broad range of carbon sequestration, from 3 to 160 grams of carbon per square meter per year. Other sources define the maximum net carbon accumulation rate as 300-400 kg per hectare per year (Lamers, Bobbink and Roelofs, 2000). A provisioning service of a raised bog is the production of fresh water because of the filtering characteristics of the peat body. In these ecosystems, which have a long developmental history, current and past natural processes can be observed and studied. As places of wilderness, bogs play an important role in science, recreation, inspiration and education which are cultural services (Wichtmann *et al.*, 2016). Important supporting services are habitats and biodiversity. Bogs have gradients in nutrient-richness and acidity which extent to extremely nutrient-poor

Box 2: Carbon cycle raised bog ecosystem

The carbon cycle (Figure 18) in the raised bog ecosystem is driven by photosynthesis. CO_2 is converted to carbon compounds such as carbohydrates. The sequestered CO_2 is processed in different parts of the plant. At the same time a part of the CO_2 is released in the atmosphere by respiration. In the oxic layer, which is not always under water, organic material is converted to CO_2 by micro-organisms. In the anoxic layer (catotelm), which is permanently saturated with water, organic material is stored and the decomposition rate is extremely low. CH_4 (methane) is produced through other processes in this layer. Although this is a relatively strong greenhouse gas (34 times the equivalent of CO_2), the amount of produced methane is low. The total amount of carbon stored is larger than the amount emitted by this ecosystem when intact, thus the raised bog ecosystem is a carbon sink (Tuittila, 2000).

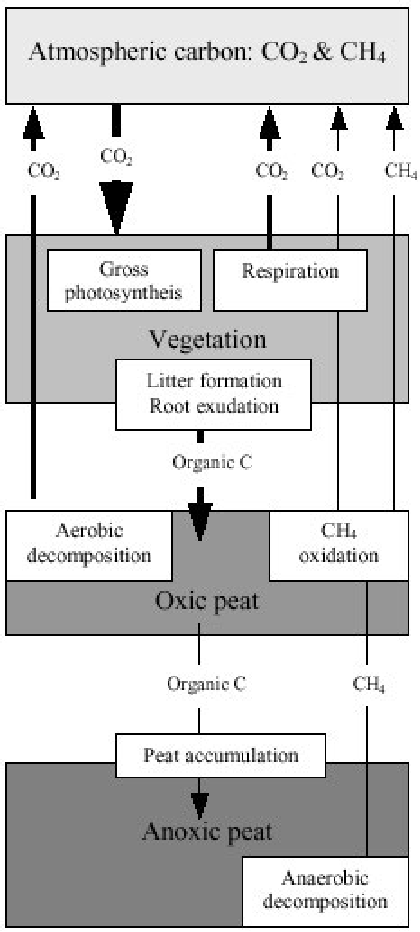


Figure 18: Gaseous carbon cycle, typical of a intact raised bog ecosystem (Tuittila, 2000).

and acid. A considerable part of biodiversity is found in these special habitats, even when they cover only a small area of the landscape (Wichtmann *et al.*, 2016). Other supporting services are the production of biomass and the formation of peat.

Provisioning	Regulating	Cultural
Goods produced or provided by ecosystems	Benefits obtained from regulation of ecosystem processes	Non-material benefits from ecosystems
- Fresh water	- Water retention - Water storage - Water purification - Cooling effect - Carbon sequestration	- Science - Recreation - Inspiration - Education
Supporting		
Services necessary for production of other ecosystem services		
- Biodiversity - Habitats - Production of biomass (plants) - Peat formation		

Figure 19: Ecosystem services of a raised bog. Based on Lamers and Smolders (2017)

5.4.2 Ecosystem services and climate change

The raised bog ecosystem, when fully functional and intact, is a resilient self-regulating ecosystem with valuable ecosystem services. When taking into account climate change, considering the climate scenario W_H which is most likely to happen (meaning: temperature rising, more extreme precipitation events, more dry summers, smaller precipitation surplus), raised bogs can play an important role in climate adaptation (Klein Tank *et al.*, 2015). With services such as water storage and retention it can help mitigate extreme precipitation, to a certain degree, so it does not constrain the drainage network. In times of extreme drought, the raised bog ecosystem will not be damaged, it will merely be on sleep-mode, waking up when there is rainfall. This will limit its growth so enough water needs to be buffered in the wet season to bridge this gap (Bijlsma *et al.*, 2011). The main contribution is the long-term storage of water in the catotelm and the storage of water during the wet season and in cases of heavy precipitation events. Also when considering climate mitigation, raised bogs have an important role to play. Raised bogs are carbon sinks, storing carbon in organic material (peat). This means when growing, the raised bog (*Sphagnum*) takes up CO_2 and converts it into carbon (C) and thereby reducing the amount of CO_2 in the atmosphere (Fritz *et al.*, 2014). These properties coincide with important policy objectives such as CO_2 reduction and increasing the regional self-sufficiency of water supply, making the raised bog ecosystem particularly valuable asset.

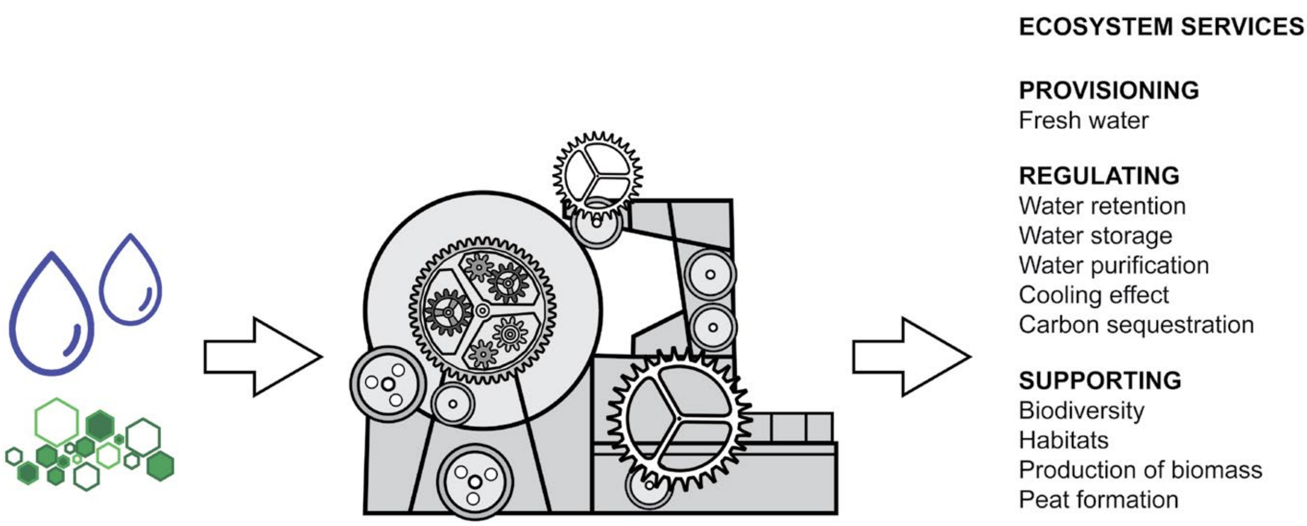


Figure 20: The functioning landscape of the intact raised bog. In conditions which are wet and nutrient-poor, the machine (intact raised bog) provides numerous ecosystem services.

5.5 Formation, development and characteristics of Bargerveen

The area of Bargerveen was once part of a larger raised bog complex called Bourtangerveen, which was the largest raised bog area in Western Europe (Figure 21). This bog complex is situated in the north-eastern part of The Netherlands and constituted the natural border with Germany over a considerable distance (Casparie, 1993). Van Guldener *et al.* (2017) state that Bargerveen developed itself as part of the Bourtangerveen on the intersection of the old stream valleys of the rivers Vecht and Hunze. These valleys were formed during the second-last ice age as they eroded in the boulder clay that was deposited in the same ice age. Bargerveen is situated on a high sandy ridge that is part of the Hondsrug and the hydrological separation is therefore still present. The water in the north-eastern part follows the path of Runde – Westerwoldse Aa – Dollard and the water in the south-western part flows towards Schoonebeekerdiep – Vecht – IJssel. This high sandy ridge has a thick layer of boulder clay, making it hard for water to infiltrate deeper layers, this leads to seepage in areas located directly next to the ridge. The layer of boulder clay is missing in the valleys.

The formation of peat started in the upper basin of the Hunze where water stagnated. At first a fen peatland was formed under the influence of groundwater creating a minerotrophic (mineral-rich, groundwater fed) environment. Due to the growing influence of rainwater the vegetation changed and an ombrotrophic (mineral-poor, rain fed) environment arose. *Sphagnum* began to take over and a thick, rainwater-saturated peat-layer expanded across the surrounding area that consisted out of acidly sandy soils. These were good conditions for the expansion of the raised bog, it crept up to higher grounds and swallowed whole forests doing so. Peat was also formed in local depressions on the flanks of the Hondsrug, because of the boulder clay the water stagnated and by that creating a suitable environment for *Sphagnum* to grow – this is how parts of the Bargerveen area are formed (Figure 22). These raised bogs grew together and formed a large complex, the Bourtangerveen. North of the Bargerveen area, a bog pool (Zwarte Meer) was formed during the growth of the peat body. When there is too much excess water, these ponds burst open (German: *Moorausbruch*), discharging water and nutrients (Casparie, 1993). During these outbreaks and the erosion it caused, a new stream was formed: de Runde (van Guldener *et al.*, 2017). In the south of the Bargerveen area there are two other bog streams that are located on the slope of the bog, the Bargerbeek and Ellenbeek. Both streams flow towards the Schoonebeekerdiep, which originates a few kilometres upstream in the same raised bog complex in Germany. The Schoonebeekerdiep is also the border between Germany and The Netherlands.

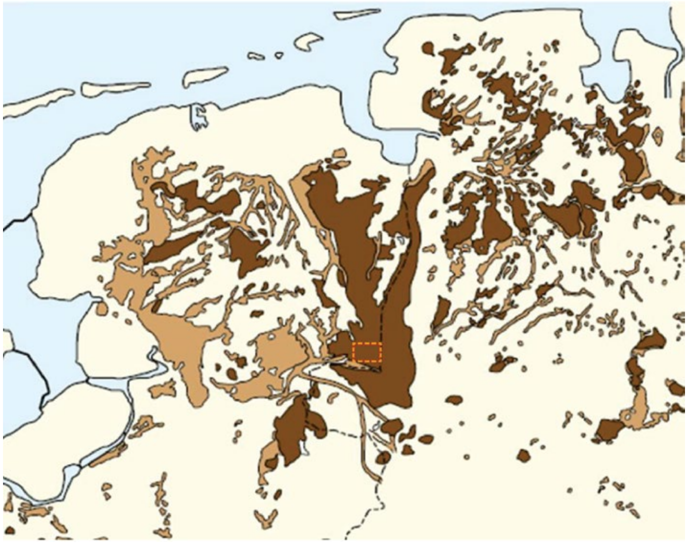


Figure 21: Peatlands in the northern parts of The Netherlands and Germany around 1500 AD. Light brown are fen peatlands and dark brown raised bogs. The large raised bog complex in the middle is Bourtangerveen, Bargerveen is indicated with the orange square (van Guldener *et al.*, 2017).

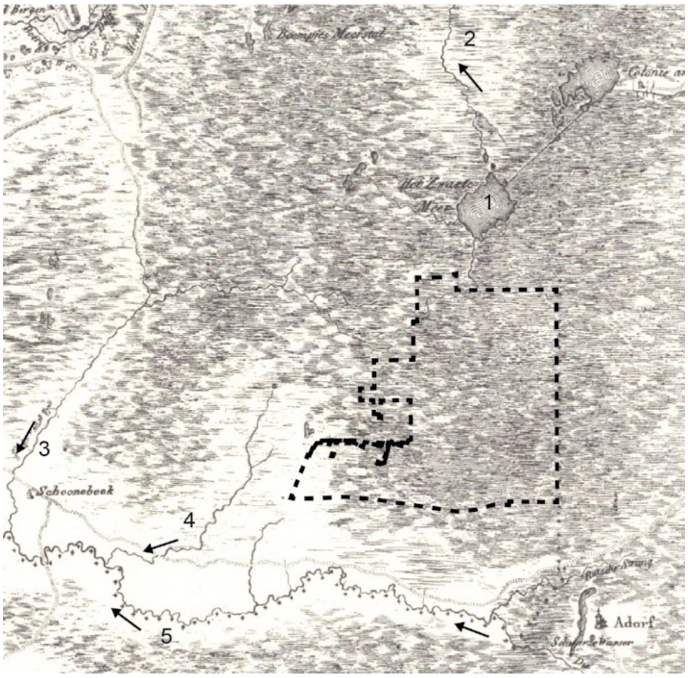


Figure 22: Historical map of the area 1820, the arrows represent the flow direction. 1: Bog pool Zwarte Meer. 2: de Runde. 3: Bargerbeek. 4: Ellenbeek. 5: Schoonebeekerdiep. (http://www.topotijdreis.nl/)

5.6 Conclusion

The raised bog ecosystem is an important ecosystem that is formed thousands of years ago and has developed itself ever since. Due to the extreme conditions and gradients in wetness, acidity and trophic degree it harbours highly specialized plants and animals. It is a resilient, self-regulating and highly productive ecosystem with peat moss or *Sphagnum* playing the main role. Besides the biodiversity, the raised bog ecosystem provides numerous other ecosystem services. When considering climate change and the adaptation to it, the ecosystem services of water storage and retention are valuable. The raised bog ecosystem has a relatively high carbon sequestration in comparison to other ecosystems and acts as a carbon sink, which seems like an important ecosystem service in times of high CO_2 emissions and when considering climate mitigation. It can be concluded that this ecosystem, when intact, is a well-oiled machine with important services (Figure 14 and 20) certainly when taken climate change into account.

6 Degradation of the raised bog landscape

demolishing the machine

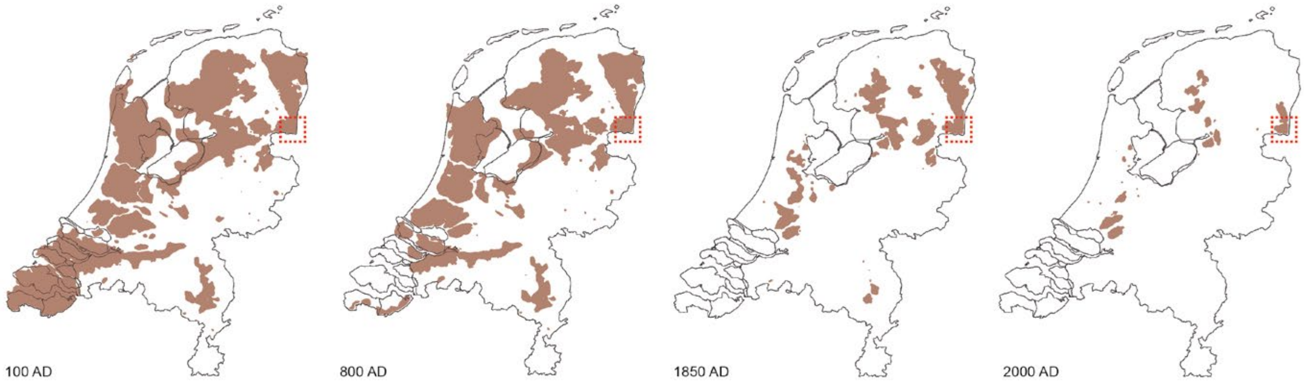


Figure 23: The loss of peatlands in The Netherlands over the centuries. Project area indicated with red square. Based on Bazelmans *et al.*, 2012.

Over the centuries the amount of peatlands in The Netherlands has decreased significantly (Figure 23). In this chapter the degradation of the Bourtangerveen and in particular the Bargerveen area is described. Explained is how during many centuries the raised bog was used by people, in which a distinction is made between the small-scale cultivation of lands around the edges of the bog and the large-scale reclamation by peat cutting. Special attention is given to an ingenious historical agricultural system the farmers used in the area south of Bargerveen. Descriptions are given how the Bourtanger- and Bargerveen are exploited and how the current drainage of agricultural peatlands will lead to a dead-end.

6.1 The early use of Bourtangerveen and Bargerveen

The raised bogs were mostly uninhabited areas until the medieval period. Before this time the bog had a ritual function which is concluded by archaeologists with the findings of timber trackways (Figure 24a), a wooden temple (Figure 24b), corpses and pottery (de Vries, 2012). It was a vastly desolate landscape, only accessible by a few roads situated on the higher sandy ridges. For many years, bogs were avoided and seen as inaccessible wildernesses and wastelands (Wichtmann *et al.*, 2016). Pijnacker (1634) describes the area as: *desertum, ob paludes et aquas in accessum* which can be translated into: wasteland, inaccessible because of swamps and water (Figure 25). In the Middle Ages the first settlements were established at the edges of the bog near the stream valleys. Schoonebeek is such a settlement, situated on the higher sandy ridges along the Schoonebeekerdiep and next to the road leading to Germany. These first settlers were farmers that cultivated the harsh landscape with hard work. Elerie (1982) describes the agricultural system that these farmers used, the so called 'oude bovenveencultuur', which relies on colonising the bog to perform permanent agriculture by draining it with ditches. This type of reclamation is characterised by small irregular strips of land, is called 'randvervening' and is practised along the stream valley of the Schoonebeekerdiep as seen in Figure 26 (Slabbers and Ulijn, 1994). In the next section an in-depth analysis on the agricultural system of the 'oude bovenveencultuur' is given. In more recent times the bog was used in unsustainable farming practices characterised as 'jonge bovenveencultuur'. By draining the bog and burning the vegetation, crops could be cultivated (Elerie, 1982). This land was only arable for a short period of time while it became exhausted and had to regenerate for 25-30 years, during this time sheep flocks were grazing on the heather that grew on the drained bog surface (Slabbers and Ulijn, 1994). It can be concluded that up until the 20th century, the raised bog was used – and misused – for agricultural practices. Although the edges of the bog were slowly degrading by the drainage of the 'randvervening', the majority of the bog and peat body remain relatively untouched.

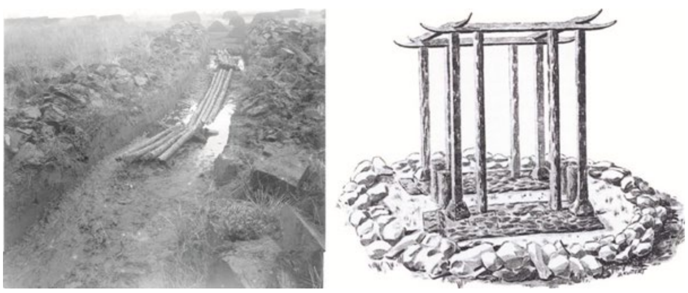


Figure 24: Timber trackways and wooden temple, both found north of Klazienaveen and dating back to the Bronze Age (de Vries, 2012).

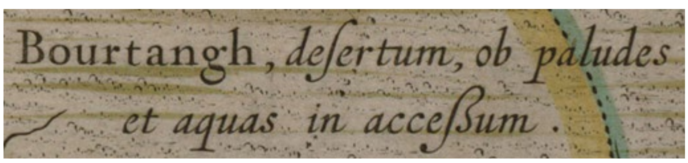


Figure 25: In his map of Drenthe, Pijnacker (1634) describes the area of Bourtangh (Bourtangerveen) as wastelands which are inaccessible due to swamps and water.

6.2 'Oude bovenveencultuur'

The agricultural system of the 'oude bovenveencultuur' was a mix form of land uses and consisted out of meadows, vegetable gardens, fields, heather and bog as can be seen in Figure 27. The farmyard is built upon sandy ridges along the Schoonebeekerdiep, these grounds are most favourable for agriculture and have the highest land use intensity. Also the wetness of the ground increases in both directions; towards the Schoonebeekerdiep and the bog. This is paired with the decrease of land use intensity in both directions. Concluding, one can state that the farmyard was the centre of 'culture' and from there towards the Schoonebeekerdiep and the bog there was a gradient towards 'nature'. Every part in this ingenious agricultural system contributes to achieve the main goal of performing permanent agriculture – the cultivation of rye – on peatland. The problem of permanent agriculture on peatland is that the peat layers will shrink and oxidate due to drainage which will also lead to a decreasing fertility. To counter these processes, a heavy fertilisation system was implemented (Figure 28). Sheep and cattle grazed on the heath and meadows during the day and at night they were stalled in special buildings called 'potstal'. Their manure was mixed with the topsoil from the bog/heath (sods) and then every once in a while the 'potstal' was cleaned out and the mixture of sods and manure was put on the fields and gardens to keep the soils fertile. Over the centuries, a humus-rich mineral top soil of 35 centimetres developed on top of the peat because of the large quantities of applied manure and sods, making the soil less subject to oxidation and subsidence. The mixed farming system of the 'bovenveencultuur' may have disappeared with the introduction of artificial fertiliser in the beginning of the 20^{th} century, making the fertilisation system of manure and sods outdated – and leading to specialisation. This in combination with the deeper drainage to support the heavy machines that cultivate the land, can lead to further oxidation of peat and subsidence. Nowadays, in many areas of the 'bovenveencultuur' there is still a large layer of peat in the soil, which is subject to degradation (Figure 29). The current landscape structure can be seen in Figure 30 and 31.

When looking back upon the agricultural system of the 'oude bovenveencultuur' it can be concluded that this diverse and irregular mosaic of land uses was dependent upon the soil properties of the landscape. The gradients that were present seem to be interesting and are used as inspiration further in the design.

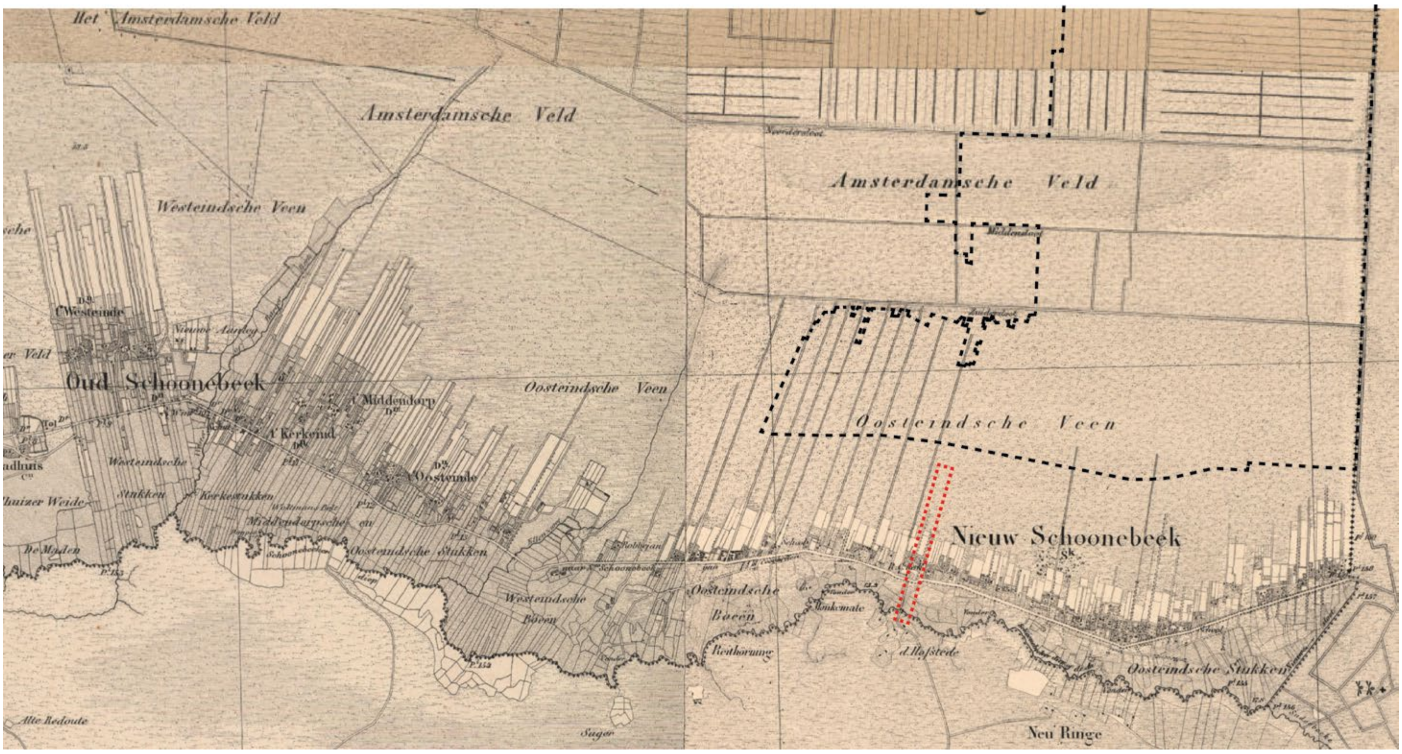


Figure 26: Topographic map of the area around 1895. The meandering Schoonebeekerdiep in the south and parallel to this the villages of Oud and Nieuw-Schoonebeek with the 'oude bovenveencultuur' which is characterised by the small irregular strips of land. The current boundaries of the Bargerveen are indicated with black. The area indicated in red is where the cut-out of Figure 27 is taken (http://www.topotijdreis.nl/).

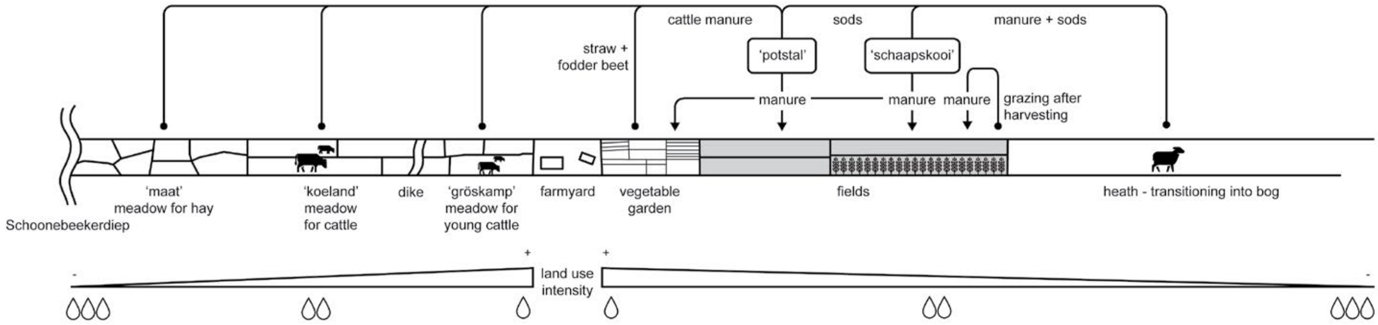


Figure 27: Schematic representation of the 'oude bovenveencultuur' as of 1895. Indicated is the land use, land use intensity, the gradients in wetness and the flow of nutrients. Based on Elerie (1982).

Figure 28: Schematic representation of the fertility of the soils. The meadows for hay along the Schoonebeekerdiep excel in their fertility because of the mineral-rich seepage water and the deposition of nutrients from the stream (Elema, 1928). When getting closer to the dike the fertility becomes less because of the declining influence of nutrients and minerals. The vegetable gardens were fertilised the heaviest because these provided food directly for the farmers. Besides that, the fields where rye was cultivated are heavy fertilised with a mixture of sods and manure to ensure the productivity of these lands. The heath is low in fertility and when it transitions into the bog the fertility of the soil is even lower.

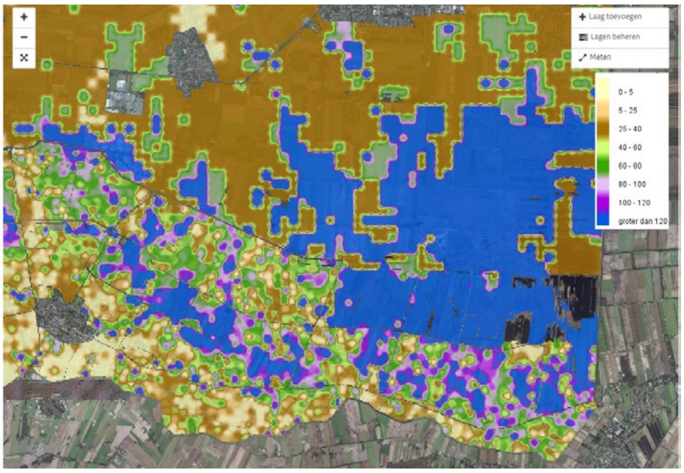


Figure 29: Thickness of the remaining peat layer. In the raised bog remnant of Bargerveen generally a large layer of peat is still present. In the areas of 'oude bovenveencultuur' the remaining peat layer is quite large and heterogeneous, from >120 centimetres to 5. In the areas of the 'dalgronden' the remaining peat layer is often smaller and more homogeneous, large areas have between 5 and 25 centimetres of peat left (which is used for 'moerige gronden') (https://data.overheid.nl)

Figure 30: Landscape structure 'oude bovenveencultuur' near Nieuw-Schoonebeek (http://www.topotijdreis.nl/).

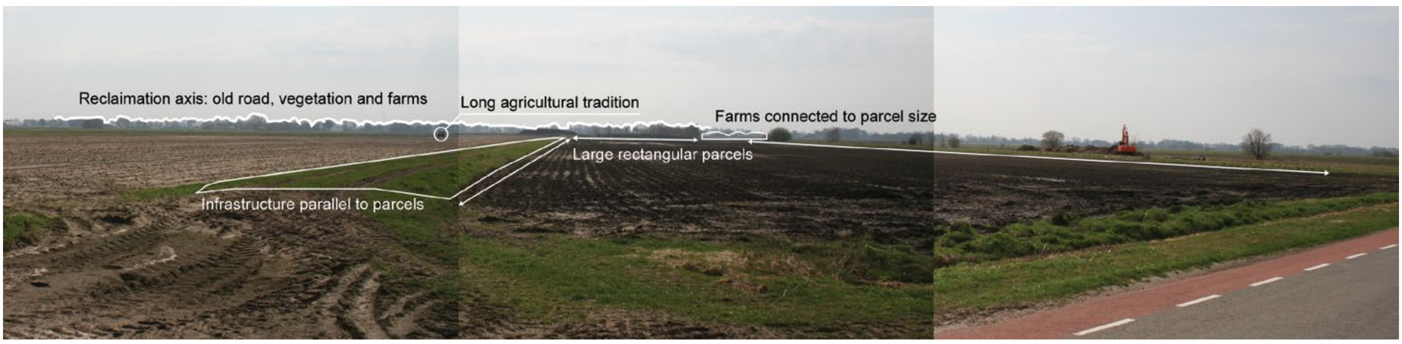


Figure 31: Panorama landscape structure 'oude bovenveencultuur' near Nieuw-Schoonebeek

6.3 Systematic peat cutting (1850-1960)

The raised bog of Bourtangerveen gained importance when it was reclaimed by drainage and was used for agriculture, forestry, fuel peat extraction and as settlement area. The main focus of attention was its production function (Slabbers and Ulijn, 1994; Wichtmann *et al.*, 2016). The area of Bargerveen was the last area in The Netherlands that fell prey to peat cutting, reclamation and colonization, which was at the end of the 19th century (Slabbers and Ulijn, 1994). This had to do with the desolated location of the area and the lower quality (heating values) of peat (Gerding, 1995). The peatlands in the north belonged to a collective of farmers from smaller towns near Emmen and was often sold to large companies that cut away the peat and developed it to agricultural lands (Slabbers and Ulijn, 1994). In the south the farmers of Schoonebeek and adjacent villages owned the peatland situated behind their farms (Gerding, 1995). From the north the colonisation was handled in a systematic way. A network of waterways and roads was made with a clear hierarchy (Figure 32) that functioned as a starting point for the cultivation of these peatlands (de Vries, 2012). These waterways drained the raised bog from water and at the same time provided an infrastructure for the transportation of peat. The peat was mostly transported back to the west to serve as fuel for the industry and for domestic use. Towns were founded along the waterways and roads, consisting out of people who (a) made a living by cutting, owning or transporting the peat, (b) built the infrastructural network or (c) farmed the (un)cultivated land (de Vries, 2012). When an area was cleared with peat, the top layer of the peat body – which was not suitable as fuel – was deposited back and mixed with the mineral subsoil, creating the so-called 'dalgronden' (Figure 33). After fertilisation this was good agricultural land (Slabbers and Ulijn, 1994). Originally the agricultural system in this area consisted of a mixed form of several land uses, as shown in Figure 27, but with the arrival of large quantities artificial fertiliser, this system changed to monocultures of beet, potato and grain. Although these artificial fertilisers enlarged the productivity, the quality of the soils deterred. The peat that was deposited back had already disappeared from the soil and no new humus was added to these 'dalgronden', resulting in a diminished capability of the soil to store water and more susceptibility to wind erosion (Slabbers and Ulijn, 1994). The landscape structure can be seen in Figure 34 and 35.

From 1920 onwards, the peat was excavated by machines and transported along roads or by small trains, no longer needing waterways. Gerding (1995) states that also around this time the market for peat as fuel collapsed, with coal and later oil and gas taking over the primary role. This had huge implications for this region as it was largely built upon the peat industry. The market kept fluctuating the next thirty years, with subsidies, laws and the overall shortage of fuel promoting the use of peat but shortly after the second world war peat was only locally used as fuel. After this the peat was still excavated for other products such as activated carbon (NORIT), potting soil and substrate for plants (Gerding, 1995). The area around Bargerveen was especially suited for this because of the large layer of 'witveen' (Figure 16). In 1968 the national government bought a small area uncultivated raised bog because of its important botanical value (van Guldener *et al.*, 2017). In 1992 – as the last area in The Netherlands – the peat digging in Bargerveen stopped and 'Staatsbosbeheer' became the manager of the area, starting a new phase for the raised bog ecosystem - or what's left of it.

1920 1940 1960

Figure 32: Development of the Bargerveen area from 1920 until the present. In the map of 1920 a clear structure of roads and waterways, to drain the bog, are visible. Also towns appear on the map. In 1940 it is clearly visible which lands are already in agricultural use. From 1960 onwards the trends are; the shrinking amount of peatland and the increasing size of the towns.

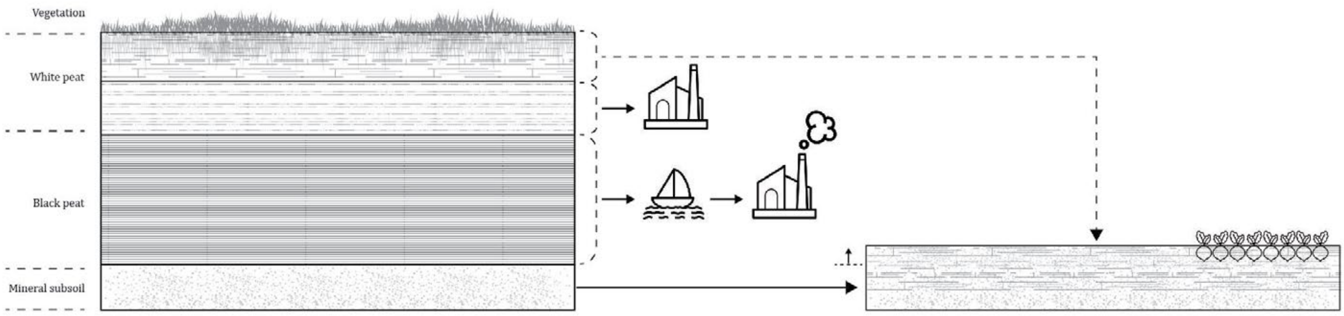


Figure 33: Creation of 'dalgronden'. Firstly, the top layer of the white peat is set aside to deposit back later on. The rest of the white peat layer – that was relatively large in this area – is processed by local companies and sold as horticultural or agricultural products. The black peat layer is cut away and shipped to the western part of The Netherlands to serve as fuel for factories and households. When the useful peat was extracted, the top layer of white peat is deposited back and mixed with the mineral subsoil. This resulted in fairly good agricultural grounds (Slabbers and Ulijn, 1994).

Figure 34: Panorama landscape structure 'dalgrond' near Weiteveen

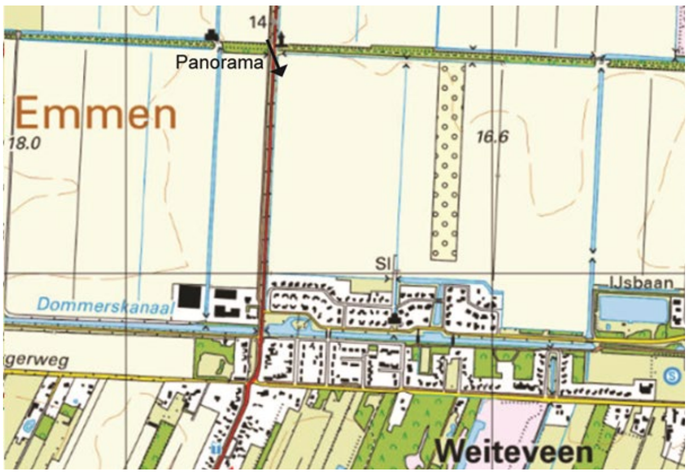
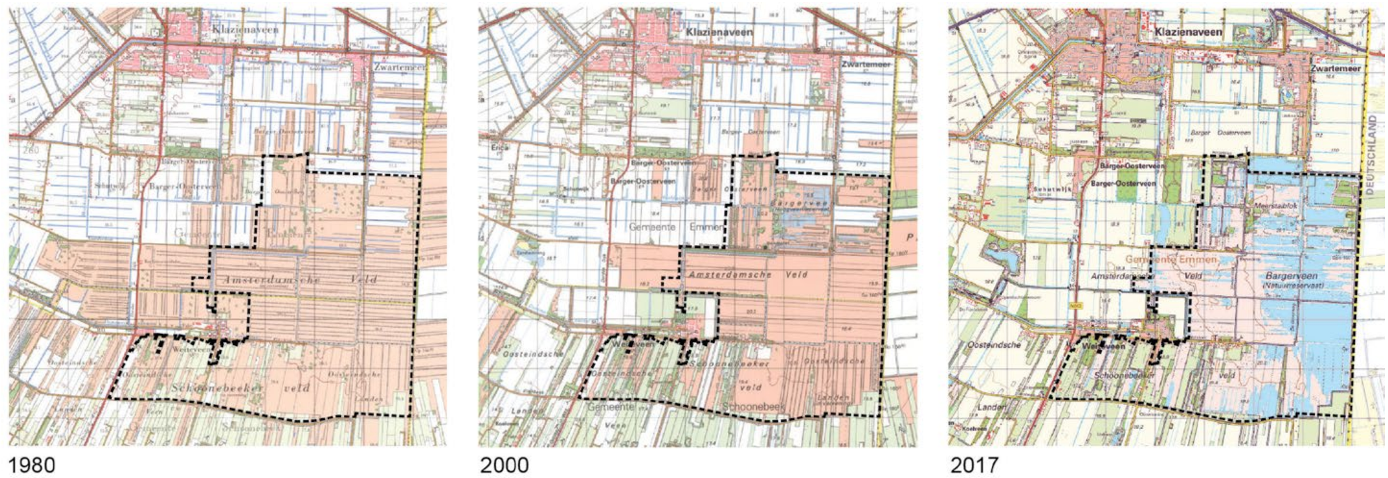


Figure 35: Landscape structure 'dalgrond' near Weiteveen (http://www.topotijdreis.nl/)



From 1980 onwards there is large-scale planting of trees and other measures to enlarge the aesthetic value of this landscape. In 2000 and especially in 2017 the measures to restore the Bargerveen are visible which translates itself to more areas of water. (http://www.topotijdreis.nl/)

6.4 The people and their landscape

Schoonebeek is the oldest villages in this area, dating back to the 14th century. Its name means clean or bright stream (referring to Schoonebeekerdiep), which was a peculiar sight back in the day because most of the water and streams were black because of the bogland. Schoonebeek is an old colonist village, meaning that the people needed to actively bend the landscape to their will as discussed in section 6.2 'Oude bovenveencultuur'. Most colonists came from the neighbouring villages and from Germany. Schoonebeek existed out of four separate parts, all situated on sandy ridges along the stream. From 1947 onwards the village grew rapidly thanks to the oil industry.

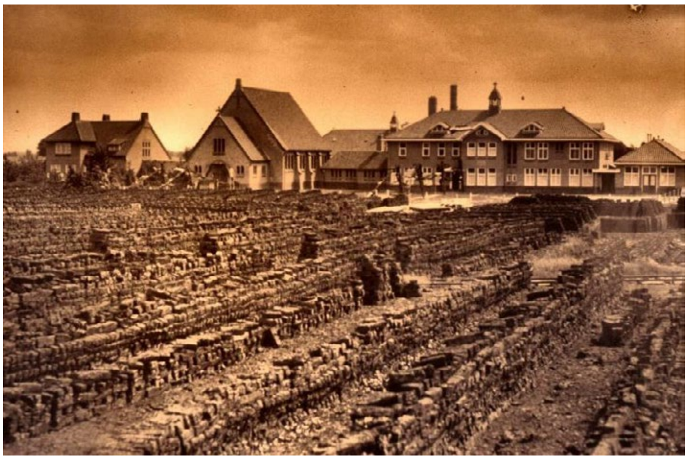


Figure 36: Village of Weiteveen surrounded by peat (http://www.orgelsindrenthe.nl)

Nieuw-Schoonebeek is also a colonist village, situated along the Schoonebeekerdiep. It was founded as an agrarian settlement in the 19th century with a mixed population of people from Schoonebeek and Germans. These settlers formed a tight-knit community.

Weiteveen, also called Nieuw-Schoonebekerveld back in the day, was formed on the border between the municipalities Schoonebeek and Emmen in the beginning of the 20th century (Figure 36). On the backend of the lands from the farmers of Nieuw-Schoonebeek, people from Schoonebeek and Germany settled themselves, often working in the peat industry or as small-scale farmers. Nieuw-Schoonebekerveld is renamed to Weiteveen in 1954, derived from the frequent cultivation of 'boekweit' (*Fagopyrum esculentum*) in this area.

Figure 37: Historical map of 1945. Visible is the stream valley of Schoonebeekerdiep with its meadows (green), the towns parallel to it, the fields perpendicular to it (white) and the peatlands behind it (purple). (http://www.topotijdreis.nl/)

Along the stream valley of the Schoonebeekerdiep in Germany, towns like Neuringe, Adorf, Rühlertwist, Hesepertwist and Twist share a similar history and genesis as Nieuw-Schoonebeek which can be seen in old maps (Figure 37). These German towns were disputed areas when the border was set up between Germany and The Netherlands which can be derived from their names (Twist – *betwist*) (Gerding, 1995).

In the northern part of the area, which was bog for a long time, the villages are founded along the canals. Klazienaveen was founded as a peat-colony in 1884 by a rich industrialist, it consisted mostly out of people who made living of the peat.

Zwartemeer (1871) was originally located at a bog pool called Zwarte Meer, which was the origin of the Runde stream. Later when the bog pool was drained and canals were made, the village was re-located along the canal. The colonists from Zwartemeer originated from Twente and Germany.

It can be concluded that the rugged landscape and isolated location had a huge impact on the formation of villages and the culture. It was not easy making a living on the peat, which is reflected in the relatively late (14th century) occupation of the area. These first inhabitants were dependent on the high sandy grounds along the stream for a suitable place to practice agriculture. From these sandy ridges they cultivated the landscape, through hard work they created permanent agricultural land on the bog. After that it was quiet for a long time, in the 19th century the colonization along the stream of Schoonebeekerdiep continued while these were the best lands in the area for agriculture. With new technologies and cultivation methods, the raised bog was used for temporary agriculture and the edges were slowly drained, cultivated and used for permanent agriculture. When the large-scale digging of peat in the area started at the end of the 19th century – as the last area in The Netherlands, because of the poor quality of the peat for fuel – it brought with it the destruction of an old landscape and the creation of a new one. In the northern part a grid of canals and roads was constructed and villages appeared along it. These villages consisted out of a mix of people from the neighbourhood and other regions that were attracted to the work of the peat digging industry and everything that encompasses it. Slabbers and Ulijn (1994) characterised the landscapes of peat-diggers and small-scale farmers as the landscapes of 'turf, jenever en achterdocht'* or peat, gin and suspicion. Landscapes of poverty, not only in an economic sense but also when considering the quality of the landscape. A lot was being extracted from the landscape and not much put back. Although this might be the case, the people have embraced their newly formed landscape and there is a strong sense of community in these villages. For instance in a survey in the local paper for the most important person of the 20th century in Klazienaveen, the (anonymous) peat-digger was chosen. Because this landscape was the last colonized and intact raised bog in The Netherlands, it can be characterised as remote, isolated, rugged and wide. Characteristics that certainly influenced the local population but also characteristics that have become rare in The Netherlands and can therefore be considered as valuable.

**The complete proverb goes: 'Uit turf, jenever en achterdocht heeft onze lieve heer de Drent gewrocht'*

6.5 Peatland drainage

After the reclamation of the raised bog for agricultural land, the drainage which is necessary for performing the current form of agriculture lead to a further degradation of the raised bog landscape. De Vries *et al.* (2008) state that the volume of peat consists out of a large part of water and a small part partially-decomposed organic matter. When this water is drained from the peat, the peat will be dried out and compacted because its volume decreases. This process of soil compaction is irreversible, so when the peat is drained from a certain amount of water and the soil has compacted, the peat cannot take up the same amount of water because the dried out peat has lost this property. Another problem of drained peat soils is the process of oxidation. Because the partially-decomposed organic matter is now subjected to oxygen, organisms in the soil will digest most of the peat, causing CO_2-eq emission and an ever decreasing volume of the peat. This process is shown in Figure 38. This slow process leads to further land subsidence (de Vries *et al.*, 2008). It is estimated that the peat soils subside 1-2 centimetre each year due to drainage for agriculture (Waterschap Hunze en Aa's, 2017). It is estimated that the peatlands around Bargerveen produce between 20 and 30 tonnes CO_2-eq per hectare per year because of peat oxidation (de Vries *et al.*, 2009) in comparison to 12 tonnes CO_2-eq per hectare in the peat meadow landscape of The Western Netherlands (stowa, 2014). These relatively high emissions are the result of deep drainage in Drenthe, sometimes even a meter below the surface, thus a larger part of peat is subject to degradation (de Vries *et al.*, 2009; Mens, 2017). This deep drainage also has a negative influence on Bargerveen, due to its elevated position in the landscape it is losing a lot of water due to the drainage of surrounding agricultural land (van Guldener *et al.*, 2017).

De Vries *et al.* (2009) state that the amount of emitted CH_4 (also known as swamp gas) and CO_2 in mesotrophic peatlands such as the stream valley of Schoonebeekerdiep is relatively high. This has to do with the amount of nutrients captured in the peat. When drained, the rate of oxidation is high and so is the amount of CO_2 emitted. When re-wetted, the oxidation of peat will stop but the amount of emitted CH_4 will not decrease. This is because of the anaerobic decomposition of mesotrophic peat will continue and is larger than in oligotrophic peat (see Box 2: Carbon cycle raised bog ecosystem). But when rewetted, the vegetation can sequester CO_2 and produce peat which can compensate the CH_4 emission, also when taking into account the difference in global warming potential. It can be concluded that these peatlands can also function as carbon sink, although not as efficient as the raised bog ecosystem (de Vries *et al.*, 2009).

The processes illustrated in Figure 38 continue until the peat has disappeared from the soil, leaving soils that contain only sand with low organic content. As a result of peat oxidation, the total area that classifies as peatlands (soils with >40 centimetres peat) in Drenthe has shrunken with 21.000 hectares to a total of 33.000 hectares between 1965 and 2005 (de Vries *et al.*, 2008). This 'sandification' of the raised bog landscape can be seen in Figure 39. In the long term, these changing soil properties lead to a decline in productivity (Wichtmann *et al.*, 2016). Also the biodiversity which is connected to these peatlands is under pressure or will disappear. Climate change will amplify these processes and their effects (van Eijk *et al.*, 2015).

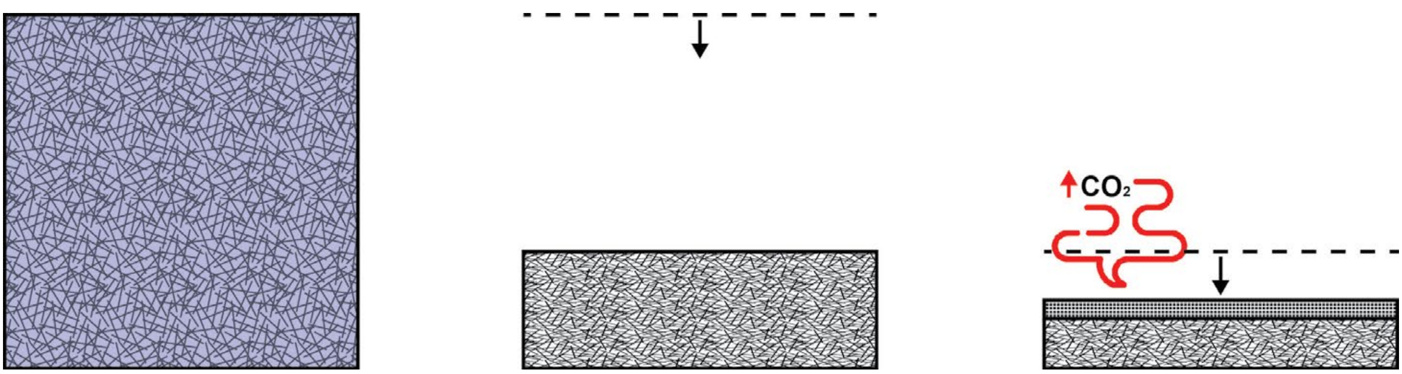


Figure 38: Drainage of peat and its consequences. Peat in its original state, saturated with water. When drained from water, the peat will compact which decreases its volume which causes soil subsidence. When drained, the peat becomes subject to oxidation, soil organisms digest the peat causing CO_2-eq emissions and more soil subsidence. These processes will continue if the peat is drained until it completely disappears.

When the current drainage of water from these peatlands continues, the peat will disappear in the future and the quality of the soils will deter (Fritz *et al.*, 2014; Wichtmann *et al.*, 2016). This degradation of peat soils leads to an overall deterioration of soil quality which is outlined in the research report on peatlands in Drenthe by de Vries *et al.* (2008). Due to the oxidation of peat, the capacity of the soil to store water and the quality of the stored water will decrease. The heterogeneity of soils will also increase because in some parts of the fields there is still a peat layer present whereas in other parts this layer has disappeared, leading to large differences in dryness and wetness which translates itself in decreasing yields as can be seen in Figure 40. Another negative effect is the susceptibility of sandy soils for wind erosion (de Vries *et al.*, 2008).

In the long-term the process of peatland drainage and the effects thereof are a problem because of increasing infrastructural costs, extra costs for water boards that need to manage the water level, and a deterioration of the future perspective of farmers and their land (Waterschap Hunze en Aa's, 2017). The current form of agriculture and drainage is also a limiting factor for the restoration of Bargerveen (van Guldener *et al.*, 2017). This current form of agriculture is schematized in Figure 41 and 42.

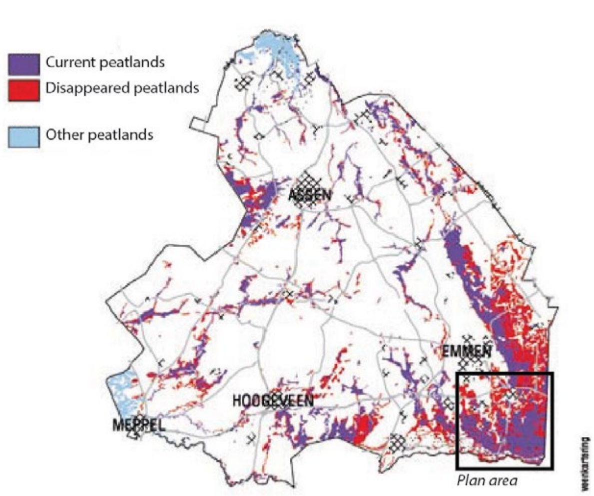


Figure 39: Disappearance of peatlands in Drenthe between 1965 and 2005, after updating soil data (van Kekem, Hoogland and van der Horst, 2005).

Figure 40: Heterogeneity in agricultural lands, resulting in differences of crop growth

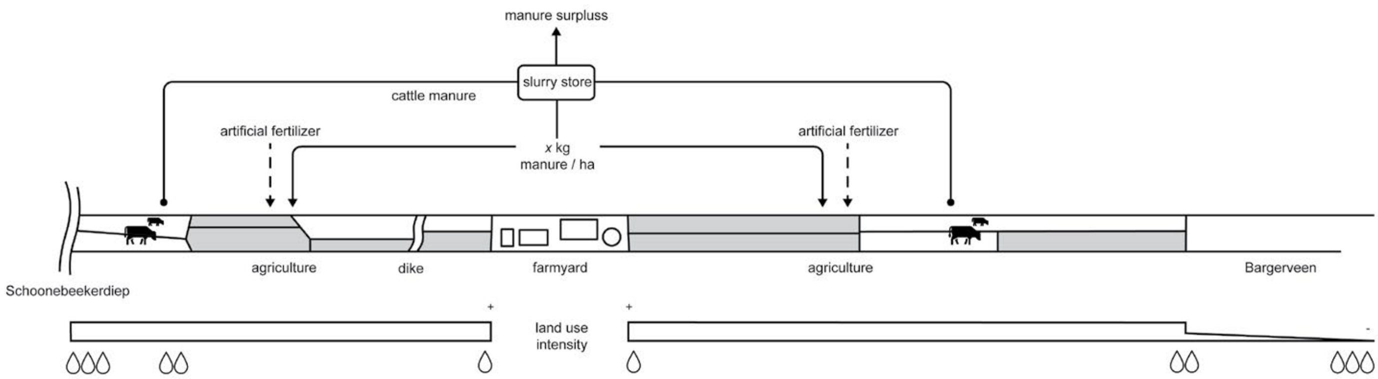


Figure 41: Schematic representation of the current form of agriculture. Indicated is the land use, land use intensity, the gradients in wetness and the flow of nutrients. It can be concluded that the agricultural system is globalized, resulting in specialisation of livestock farming. The amount of nutrients is no longer a limiting factor for productivity, thus every plot of land – no matter the differences in site conditions – is used in the same way. This results in an overall high land use intensity. Also due to the drainage the gradients in wetness have disappeared. The current form of agriculture produces too much manure, which is the result of overcapacity. This agricultural land use conflicts with the raised bog of Bargerveen.

Figure 42: Schematic representation of the fertility of the soils, a maximum amount of manure is being applied to the land, resulting in an highly productive unilateral environment. The raised bog of Bargerveen receives too much nutrients because of atmospheric deposition.

6.6 Ecosystem services

With the degradation of this landscape, the quality and quantity of provided ecosystem services will diminish. While the intact raised bog provided numerous regulatory ecosystem services, as seen in Figure 19, which had a stabilising effect on local hydrology, the degraded raised bog ecosystem provides mostly provisioning services. These provisioning services are at the expense of other services such as regulating, cultural and supporting as seen in Figure 43. The raised bog provides fuel, raw material and new agricultural land that produces food. These provisioning services are not sustainable because they either actively destroy the ecosystem (with its services) or continue to degrade it.

Wichtmann *et al.* (2016) explains the continued degradation as follows: when peatlands are drained, the peat is subject to oxidation and nutrients sequestered in the peat are released, the hydrological balance is severely disturbed, and the habitats of specialised bog organisms disappear to make place for those of more ordinary species. Carbon sinks turn into sources that very rapidly release considerable amounts of carbon and other substances that had been sequestered over a very long time span, resulting in large greenhouse gas emissions. The filter and buffer function is dramatically reduced (Wichtmann *et al.*, 2016).

Provisioning	**Regulating**	**Cultural**
Goods produced or provided by ecosystems	Benefits obtained from regulation of ecosystem processes	Non-material benefits from ecosystems
~~Fresh water~~ - Fuel - Raw materials - Agricultural land	~~-Water retention~~ ~~-Water storage~~ ~~-Water purification~~ ~~-Cooling effect~~ ~~-Carbon sequestration~~	- Science - Recreation - Inspiration - Education

Supporting
Services necessary for production of other ecosystem services
- Biodiversity - Habitats - Production of biomass (plants) ~~-Peat formation~~

Figure 43: Ecosystem services provides by a degraded raised bog. Ecosystem services in red are under pressure and ecosystem services crossed out are no longer provided.

6.7 Conclusion

The degradation of the Bargerveen area can be distinguished in three phases. Namely, the early agricultural use of the bog's edges called 'randvervening', the systematic peat cutting and subsequently agricultural reclamation of the so-called 'dalgronden' and the drainage of peatlands which continues up until this day. These two types of agricultural landscapes are stereotypical for the Bargerveen landscape system. The landscape of 'randvervening' is characterised by a reclamation axis, often an important road, with farms and accompanying vegetation. The landscape has a long agricultural tradition and the parcels are small irregular strips of land. The other agricultural landscape of 'dalgronden' is a young landscape and characterised by its wide open fields and grid of infrastructure and vegetation.

The raised bog of Bourtangerveen is degraded in such a way that only relatively small bog remnants continue to exist, such as Bargerveen (Figure 44). These raised bog remnants have lost the capability to function like a proper raised bog ecosystem because only a small percentage of the area is covered with peat moss. There are also still a lot of agricultural lands within the raised bog landscape that are defined as peatlands which are subject to degradation because of drainage. It can be concluded that the current raised bog landscape is strongly degraded and continues to degrade because of agricultural drainage. This dysfunctional landscape is shown in Figure 45. If the raised bog landscape should be saved from 'sandification' and should harbour a functioning raised bog ecosystem once again, measures need to be taken. Measures that stop the unsustainable agricultural use of peatlands and implement a more sustainable form of land use for the sake of restoring the raised bog ecosystem and its services.

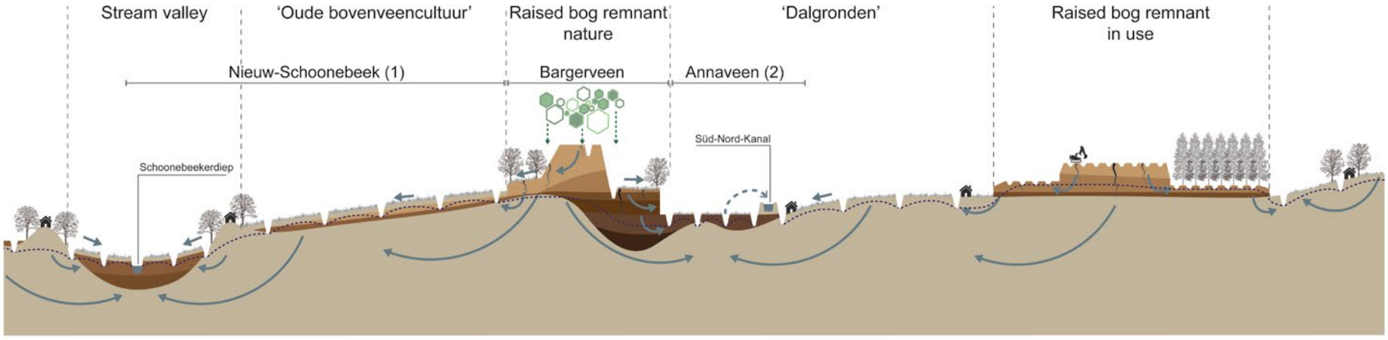


Figure 44: Schematic representation of the degraded raised bog landscape

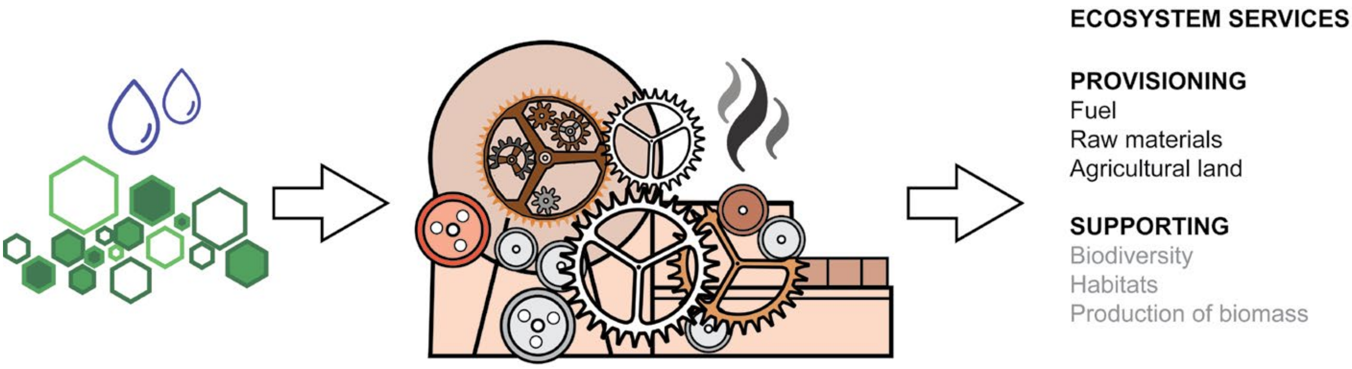


Figure 45: The dysfunctional landscape of the degraded raised bog. Conditions have changed from nutrient-poor to nutrient-rich and from wet to dry. The machine (degraded raised bog landscape) has been changed in set-up and is used in an unsustainable way, it produces more provisioning ecosystem services which is at the expense of other ecosystem services.

7 Restoration of the raised bog landscape

repairing the machine

Hydrology and nitrogen deposition are the most crucial factors for preserving raised bog ecosystems (Bijlsma *et al.*, 2011). In this chapter the measures that have been taken to restore the ecosystem of Bargerveen are described. The goals for Bargerveen as Natura 2000 are explained and future plans are laid out. Later in this chapter the relationship between Bargerveen and its surroundings is described, especially the juxtaposition between nature and agriculture. Gradually it becomes clear that for the restoration of this ecosystem interventions should be made outside the area of Bargerveen.

7.1 Current measures and goals Bargerveen

Since the purchase of the 'Meerstalblok' (Figure 46) in 1968 by the national government the conservation of the raised bog landscape has started. This area still had the original *Sphagnum* vegetation although it did not grow actively, it was defined as a resting bog (van Guldener *et al.*, 2017). The first condition for *Sphagnum* to grow is water, thus the water level needed to be raised. This was done by constructing dikes to retain water in the area and by filling in waterways so the raised bog remnant did not lose water to drainage of the surrounding area (Provincie Drenthe, 2006). After the ceasing of peat-digging activities in 1992, 'Staatsbosbeheer' became the manager of the whole Bargerveen area, consisting out of the 'Meerstalblok', 'Amsterdamsche Veld' and 'Schoonebekerveld', an nature reserve of 2.100 hectares and the only raised bog remnant in The Netherlands of this size. While the 'Schoonebekerveld' and 'Amsterdamsche veld' only have a peat layer of 0.5-1 metres, the 'Meerstalblok' still has a peat layer of maximum 5.5 metres. In 2003-2006 the dikes in this area were upgraded and extended and two water basins were made to improve the hydrological conditions in the northern part of Bargerveen. Bargerveen is part of Natura 2000 since 2013, an European network of protected nature reserves. This means that the national government of The Netherlands is obligated to preserve and develop the characteristic values of this area (van Guldener *et al.*, 2017). The core task for the raised bog landscape is stated as followed: "For restoration and quality improvement of remnants of the raised bog landscape it is essential for the hydrology (intern and extern) to be in order. Formation of functioning raised bogs by improving the quality of raised bog remnants and restauration of the edge zones, enlarging the internal and external cohesion for the purpose of fauna." (Ministerie van LNV, 2006). Besides these core tasks for the raised bog landscape, area-specific core tasks are also appointed. For the Bargerveen these are: expansion in quality and quantity of the active core of *Sphagnum*, initiating the formation of peat and development of edge zones in the raised bog landscape (including lagg-zones) (van Guldener *et al.*, 2017). This means that from 2013 onwards, active measurements are taken to preserve the raised bog remnant of Bargerveen and restore it into a living raised bog.

To achieve this, several measures have been taken in the last few years such as the revival of the Runde with a buffer zone on the north side and a buffer zone between the village of Weiteveen and Bargerveen with a stable for the sheep that graze on Bargerveen. But still, after all these interventions, the area of living raised bog is only growing slowly, estimated on three hectares in 2007 and situated in the northern part (van Guldener *et al.*, 2017). In the Natura 2000 management plan by van Guldener *et al.* (2017) it is stated on page 168 that the current hydrological knowledge and models are not sufficient to predict if the hydrological conditions for a living raised bog – the growth of *Sphagnum* – are being met.

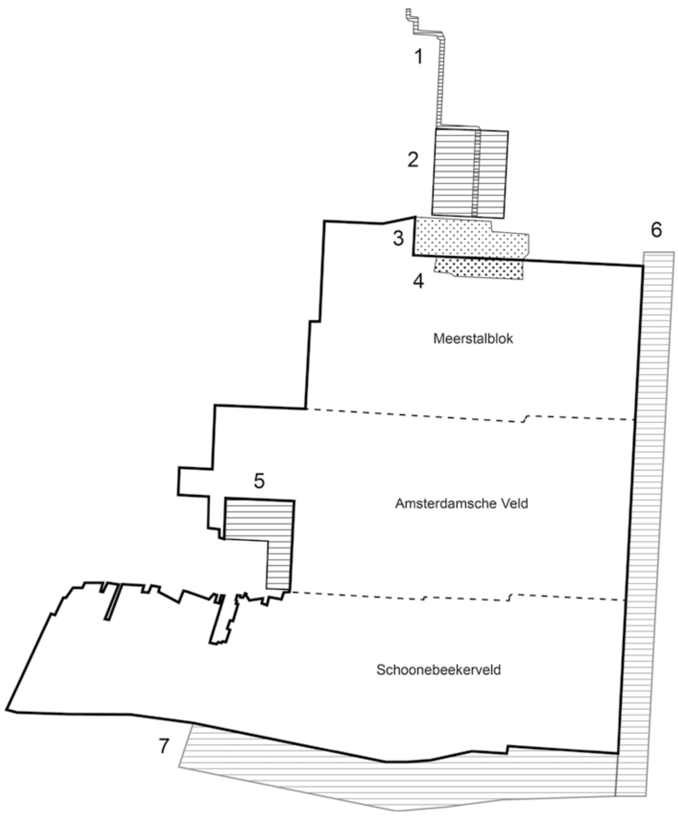


Figure 46: Bargerveen consist out of three areas and buffer zones.

1: Reconstruction of the Runde

2: Buffer Noord – Zwartemeer

3: Low water basin

4: High water basin

5: Buffer zone Weiteveen

6: 'Wiedervernassungszone' – rewetting zone (not yet con structed)

7: Buffer Zuid – Nieuw-Schoonebeek (not yet constructed)

Underlined is the importance of the groundwater level reaching the bog footing (Dutch: veenbasis); the layer that forms the most important hydrological resistance, obstructs infiltration to the mineral subsoil and by degradation enlarges the amount of water loss to its surroundings (Sevink *et al.*, 2014; van Guldener *et al.*, 2017). According to Sevink *et al.* (2014), the bog footing of Bargerveen consists of a mineral layer with low hydrological resistance. The groundwater level only reaches the bog footing in parts of the Bargerveen (Figure 47) because of the surrounding drainage, a further increase in the groundwater level is needed so it reaches a larger area of the bog footing, resulting in a stop to the degradation of the bog footing, less water loss due to infiltration, less horizontal runoff and stable groundwater levels in the peat body which are necessary for the development of a well-functioning acrotelm and therefore a living raised bog ecosystem (Sevink *et al.*, 2014). To achieve this increase in groundwater levels, large buffer zones are often needed, certainly when water levels need to permanently – so also during summer – reach the bog footing (Sevink *et al.*, 2014). Besides this, due to its relatively high location and soil subsidence at the edges, a lot of water is seeping away to the surrounding area (van Guldener *et al.*, 2017). This results in dried out areas where the layer of peat is subject to degradation. This loss of water is especially the case in the Amsterdamsche Veld and Schoonebekerveld (Sevink *et al.*, 2014). It is also in these areas where the remaining peat layer is thin (0.5 – 1 metre) and degraded, that the effect of groundwater reaching the bog footing is the highest because it results in more stable water levels (OBN Natuurkennis, 2018a). This relation between Bargerveen and the regional groundwater system can be described as the external hydrology of the raised bog. With the internal hydrology being the water system within the raised bog.

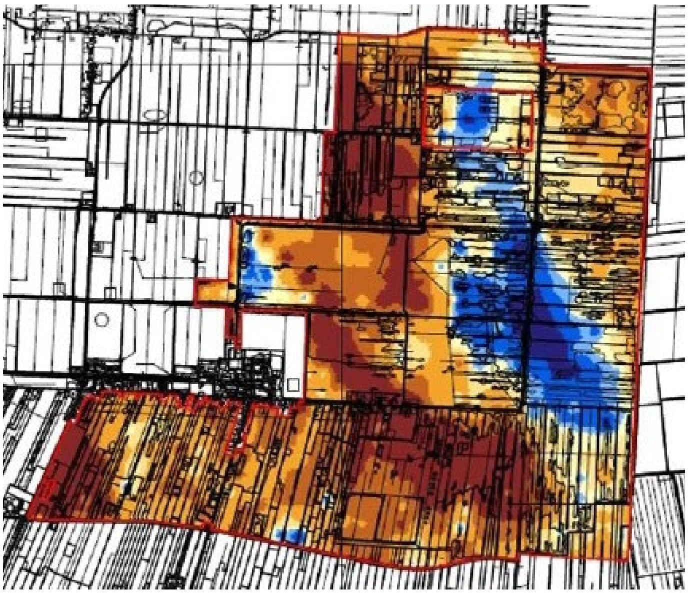


Figure 47: Map of Bargerveen that shows in which parts the groundwater reaches the bog footing (blue) and in which parts not (red). This is the situation in a very dry year (van Guldener *et al.*, 2017).

7.2 Future plans Bargerveen

In the Natura 2000 management plan by van Guldener *et al.* (2017) it is stated that in the near future two more buffer zones are planned as can be seen in Figure 46. One buffer zone is along the whole south side of Bargerveen with the dimensions of 500 by 4500 meters. The other buffer zone is situated along the border with Germany on the German side and is planned to be a strip of 300 meters that is approximately 7 kilometres long. These buffer zones should limit the amount of water that is lost by seepage to nearby areas with counter pressure and provide water in times of drought.

These buffer zones are very big in size when compared to the other ones but they still only seem to focus on keeping the raised bog wet and restoring the internal hydrology. This is confirmed by the Ministry of agriculture, nature and food quality (Ministerie van LNV). They state that the new local hydrological conditions, that are the result of the buffer zones, lead to local restoration of the original state of the bog. Restoration on landscape-scale is dependent on the establishment and re-wetting of buffer zones (Ministerie van LNV, 2018). These buffer zones are made by converting productive agricultural land to unproductive nature, which is a time-consuming and expensive process because land needs to be acquired and exchanged. For restoring the external hydrology of Bargerveen and therefor the regional groundwater system which seems necessary for restoration of the raised bog landscape, this is nearly impossible. Therefore, other options should be considered.

There are currently no specific plans for the development of edge zones. It is important that a gradual transition is being achieved for maximum biodiversity and resilience. These edge zones should gradually melt into the surrounding – agricultural – landscape and thereby creating gradients in wetness, nutrients and intensity of land use. This cannot be done by converting agricultural land to nature because of loss of productive land and obvious economic reasons, it has to be done by mixing both into a new form of land use where these edge zones are multiple kilometres wide and serve to restore the external hydrology of the raised bog ecosystem.

7.3 Restoring the hydrology

As stated in the previous sections, one of the main reasons the raised bog of Bargerveen is degrading is because of the disturbed hydrology. In this section the hydrology of the raised bog ecosystem of Bargerveen is explained and the requirements for hydrological restoration are being given.

For the growth of *Sphagnum* and therewith the restoration of the raised bog ecosystem with its acrotelm, several hydrological conditions should be met:

- Water level should be near ground level during the whole year (Jansen, 2015; van Guldener *et al.*, 2017)
- The seepage to other areas should be less than 40 millimetres a year (Jansen, 2015; Limpens *et al.*, 2016)
- Gradual lateral runoff on the peat surface during most of the year (Sevink *et al.*, 2014; Jansen, 2015)
- Ground water should reach the bog footing throughout the whole year (Sevink *et al.*, 2014; Jansen, 2015)

Van Duinen *et al.* (2017) state that when a raised bog is intact, the amount of seepage is not important because the ecosystem is constructed in such a way that it is self-sufficient in its water supply. This can be different in a raised bog where the peat is cut away and the remaining peat layers are strongly degraded. When such a degraded bog must be restored, it is possible that the hydrological dependence on its surroundings is too high to ensure the right conditions for the growth of *Sphagnum*. Usually this has to do with the lower ground water levels relative to when the intact raised bog grew because of the artificial drainage of the land. This means that the bog is losing too much water to its surroundings due to seepage (van Duinen *et al.*, 2017). The restoration of the hydrology and therewith the restoration of the raised bog ecosystem and growth of *Sphagnum* can be achieved by limiting the amount of seepage, this can be done in two different ways which are explained below. The basic hydrology of raised bogs is shown in Figure 48 and Appendix 6.

7.3.1 Internal hydrology

The OBN, a Dutch knowledge network for the development and management for quality of nature, has a website dedicated to the restoration of raised bogs. In the chapter explaining about restoring the hydrology of raised bogs they state the following: For restoring a raised bog the right hydrological conditions in the area are essential. For the restoration of the core and edges of the bog, the internal hydrology should at least be alright. The realisation of stable water levels in the raised bog often requires measures around it, for example the construction of dikes or a hydrological buffer zone, as seen in Figure 49. For restoring a complete raised bog landscape, the complete hydrology of the area and the surroundings must be restored. Buffer zones are meant to decrease the mutual hydrological influence of the raised bog remnant and its surroundings to create better conditions in the bog remnant for the development of *Sphagnum* and thus the creation of a peat-forming ecosystem. For the restoration of a raised bog that has lost its hydrological independence due to degradation, hydrological buffer zones are needed. A hydrological buffer zone stimulates the restoration of the bog by decreasing the hydrological influences that the surrounding area exercises on the bog and thus increasing its hydrological independence. This concerns mostly the reduction of water seeping from the bog to its surroundings. On short term the primary function of buffer zones is to support the development of *Sphagnum* by reducing the seepage from the raised bog. Besides that, buffer zones can have an important function in creating a buffer between the nutrient-poor wet nature and nutrient-rich dry agricultural land. At the same time buffer zones can also function as water storage, so in times of peak rainfall the surrounding surface water system will not be overburdened (OBN Natuurkennis, 2018a).

7.3.2 External hydrology

Besides restoration of the internal hydrology, the restoration of the external hydrology is necessary for the restoration of the raised bog remnant of Bargerveen and the regeneration of the nearby raised bog landscape. This should be done by raising the regional water level which is possible by limiting the drainage of the area and giving the water more time to infiltrate the soil. This more or less buffered groundwater that is enriched with minerals is essential for the regeneration of the raised bog landscape in three ways.

Firstly, when water levels are raised the ground water will reach the bog footing, thus creating a water regime that is more resilient and less susceptible to seepage and drought. Especially when the remaining peat layer is thin and degraded, for instance in the Schoonebeekerveld and Amsterdamsche Veld, the vertical permeability is high and a lot of water will seep away (Sevink *et al.*, 2014). Therefore by raising the water level to such a height that it reaches the bottom of the peat layer (i.e. bog footing), the seepage will be reduced severely which is favourable for realising a stable water level in the raised bog for the growth of *Sphagnum* (OBN Natuurkennis, 2018a). This can be seen in Figure 50.

Secondly, the groundwater plays a role in the carbon supply of *Sphagnum*. Carbon dioxide can be supplied by the groundwater, which is necessary for the growth of *Sphagnum* in restoring raised bogs under wet conditions (OBN Natuurkennis, 2018b).

Thirdly, the influence of the groundwater is essential when maintaining and restoring gradients, such as the rand or lag-zone, from the raised bog core to its surroundings (OBN Natuurkennis, 2018b). The possibilities of the restoration of gradients can be determined by analysing the geo-hydrological situation of the wider area. On the basis of an analysis of historical maps, existing height difference, groundwater levels, groundwater flow and soil-type an assessment can be made about the possibilities of restoring a rand- or lagg-zone (OBN Natuurkennis, 2018a).

It can be concluded that for restoring the external hydrology, the regional groundwater level needs to be raised. By doing this, rand and lagg-zones can be developed and conditions for *Sphagnum* to grow within the raised bog remnant can be improved.

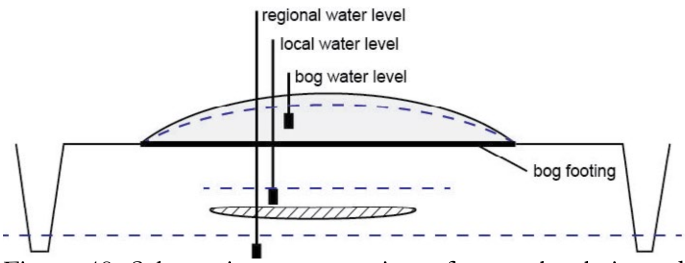


Figure 48: Schematic representation of water levels in and below an intact raised bog. Based on Sevink *et al.* (2014).

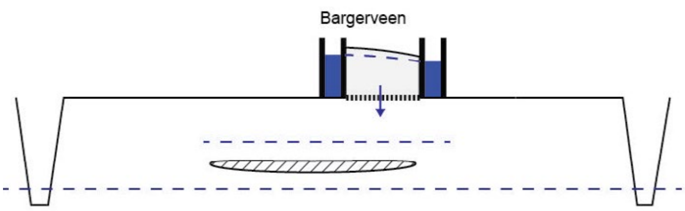


Figure 49: Current situation Bargerveen: peat is cut away bog footing is degraded, large seepage to underground because of the low water levels needed for agriculture.

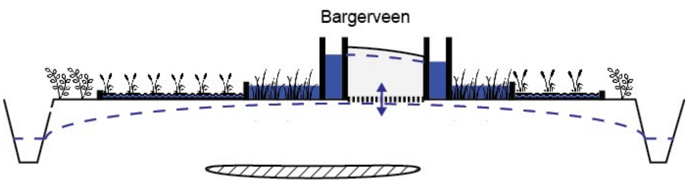


Figure 50: New situation: regional water level raised so it reaches the bog footing so the seepage is less. Surrounding lands are now paludiculture.

7.3.3 Current agricultural use and external hydrology

To restore the raised bog according to the goals as stated in the management plan of Bargerveen for Natura2000, it is essential to implement measures outside of the designated Natura2000 area. The current measures are focused on the internal hydrology by keeping the raised bog remnant of Bargerveen wet by containing the rainwater with dikes and by limiting the seepage of water to nearby areas with counter-pressure of buffer zones (Figure 49 and 52a). These measures are not enough to accomplish the goals because the requirements of active living raised bog, peat formation and gradient restoration are not being met. It seems that the Bargerveen area is still losing too much water due to seepage to other areas, this causes the peat to dry out which leads to compaction and oxidation of the peat layer (Figure 51) (van Guldener *et al.*, 2017). This is especially the case in the Amsterdamscheveld and Schoonebeekerveld because of the thin (0.5 – 1 metre) and degraded peat layer (Sevink *et al.*, 2014; van Guldener *et al.*, 2017). Van Guldener *et al.* (2017) states that in the eastern part of the Bargerveen the large water loss is caused by a strong flow of water to the nearby polder of Annaveen in Germany (Figure 58). Although this part is inundated, it seems that too much water is lost to this polder so that the groundwater won't reach the bog footing, causing oxidation and subsidence of the lower lying peat layers. In the southern part, the Schoonebeekerveld, the oxidation and subsidence

Figure 51: Silent witness of peat compaction and oxidation on the border between The Netherlands and Germany.

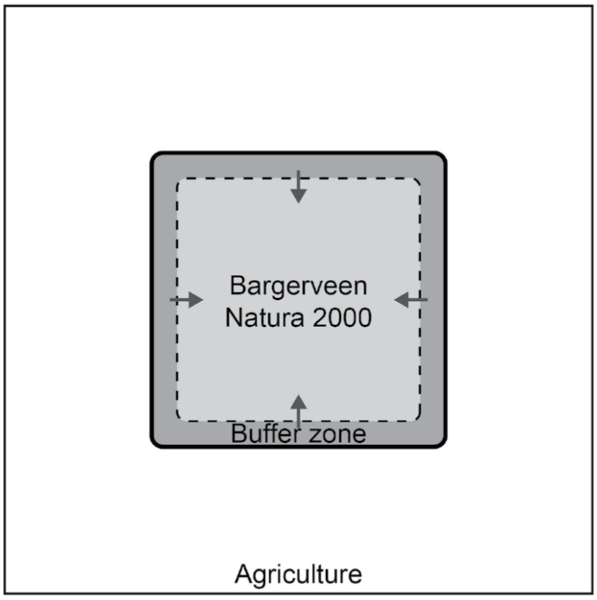


Figure 52a: Current strategy = restoration internal hydrology

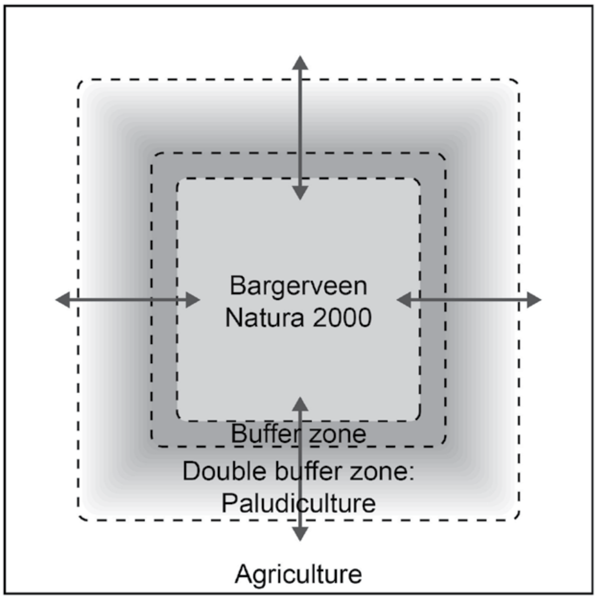


Figure 52b: Proposed strategy = restoration external hydrology by creating a double buffer zone with paludiculture

is caused by the surrounding agricultural land that requires lower water levels (van Guldener *et al.*, 2017). It is in this juxtaposition of extremely wet conditions that are necessary for the raised bog and the dry conditions for agriculture that most problems arise (Figure 53. Because there is no buffer zone at the south side of Bargerveen to provide counter-pressure, the amount of seepage is high towards Nieuw-Schoonebeek and the Schoonebeekerdiep because of the natural drainage path (Figure 54). This means that the goal of restoring the raised bog cannot be achieved unless a buffer zone for the internal hydrology is realized. This buffer zone will be realized in the future as plans are currently being made. When looking at Figure 55, it becomes clear that both the area of Nieuw-Schoonebeek and Annaveen (Figure 56 and 57)) have a significant influence on the amount of seepage from Bargerveen. This is supported in the hydrological model of MIPWA which shows a large flux in local, intermediate and regional flow systems in the areas of Annaveen and Nieuw-Schoonebeek (Appendix 4).

It can be concluded that to restore the raised bog, a buffer zone that focusses on the internal hydrology is not enough. A second – more extensive – buffer zone is necessary which is larger and shows a gradual transition into the surrounding agricultural landscape to restore the hydrological conditions that are required for the restoration of the living raised bog and its edge zones (Figure 52b).

Figure 53: Juxtaposition between agriculture and nature. Schoonebeekerveld, the southern part of Bargerveen, on the right and agricultural lands of Nieuw-Schoonebeek from the 'oude bovenveencultuur' on the left.

Figure 54: Hydrological units and direction of water flow Bargerveen. The dark blue area is drained towards the south. Here are no water basins to limit the amount of seepage (van Guldener *et al.*, 2017).

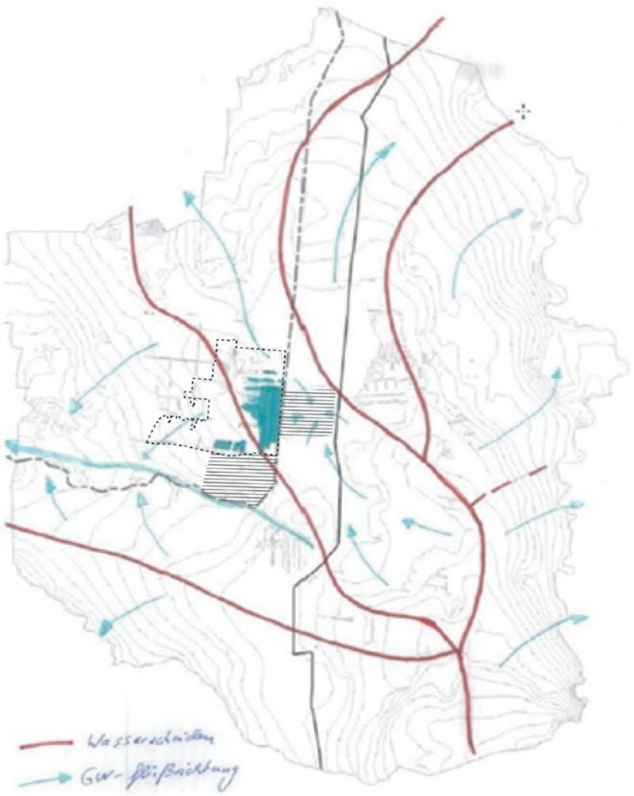


Figure 55: Isohypses, direction of water flow and watersheds. Bargerveen and plan areas indicated. Based on van Guldener *et al.* (2017).

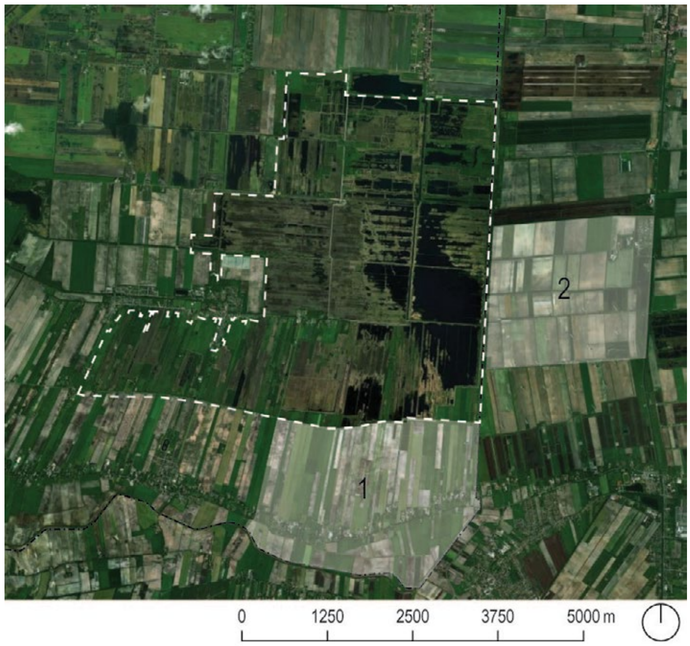


Figure 56: Location of plan area for regional designs, Nieuw Schoonebeek (1) and Annaveen (2).

7.4 Dealing with nutrient overloading

Another problem for the restoration of this ecosystem is the amount of nutrients, especially nitrogen and phosphate. Raised bog ecosystems are very susceptible to atmospheric nitrogen pollution (Lamers, Bobbink and Roelofs, 2000). Due to atmospheric deposition and guanotrophy, the amount of nutrients in this ecosystem is too high. This is especially problematic for the composition of *Sphagnum* species and the functioning of the hummock-hollow complex (van Guldener *et al.*, 2017). Besides this, other vegetation arises such as Birches which leads to further groundwater depletion and eutrophication which worsens the conditions for the growth of *Sphagnum* (OBN Natuurkennis, 2018b). To keep the conditions for the growth of the raised bog and therewith *Sphagnum* optimal, the oligotrophic state of this ecosystem should be maintained. The water in the bog will collect nutrients because of guanotrophy and atmospheric nitrogen deposition (OBN Natuurkennis, 2018b). This creates a nutrient rich environment in which *Sphagnum* growth is not optimal and other species can take over, leading to a deterioration of the ecosystem (van Guldener *et al.*, 2017). Casparie (1993) states that the raised bog ecosystem has a self-cleaning capability in which it discharges its excess nutrients, the bog burst or *Moorausbruch*. By doing this, it ensures a natural dynamic and succession in *Sphagnum* species and an overall growth of the ecosystem (Casparie, 1993). This ability of the raised bog can no longer be performed because all that remains are remnants of the once intact ecosystem. However, these remnants will get the same problem of accumulating too much nutrients because a lot of the area is open water. This undesirable enrichment of nutrients in the water of the raised bog ecosystem can be flushed out by simulating a single *Moorausbruch* in which a lot of nutrients are discharged from the system and thus maintaining the oligotrophic state in which the raised bog ecosystem can thrive (Streefkerk and Casparie, 1987).

7.5 Conclusion

It can be stated that Bargerveen is a dead ecosystem. In only 3 of the 2100 hectares, *Sphagnum*, the most crucial plant of the raised bog ecosystem, is present. To restore this ecosystem according to Natura 2000, the following goals are set: expansion in quality and quantity of the active core of *Sphagnum*, initiating the formation of peat and development of edge zones (gradients) in the raised bog landscape. These goals are not being met and it can be concluded that this has to do with the hydrological conditions and a surplus of nutrients. The construction of buffer zones and water basins around Bargerveen help to restore the internal hydrology but the areas of Schoonebeekerveld and Amsterdamsche Veld need to have their external hydrology restored in order to increase the possibility of *Sphagnum* to grow. To accomplish these goals, interventions should be taken outside of the nature area, to restore the external hydrology and to create possibilities for gradient restoration. Two areas in particular come forward when examining the hydrological influence on Bargerveen, which are Nieuw-Schoonebeek and Annaveen (Figure 57). It is in these areas, which have the largest hydrological influence, that measures need to be taken. With the implementation of a paludiculture Landscape Machine in the areas of Nieuw-Schoonebeek and Annaveen, these goals can be accomplished while regenerating the raised bog landscape, which is explained in the following chapter.

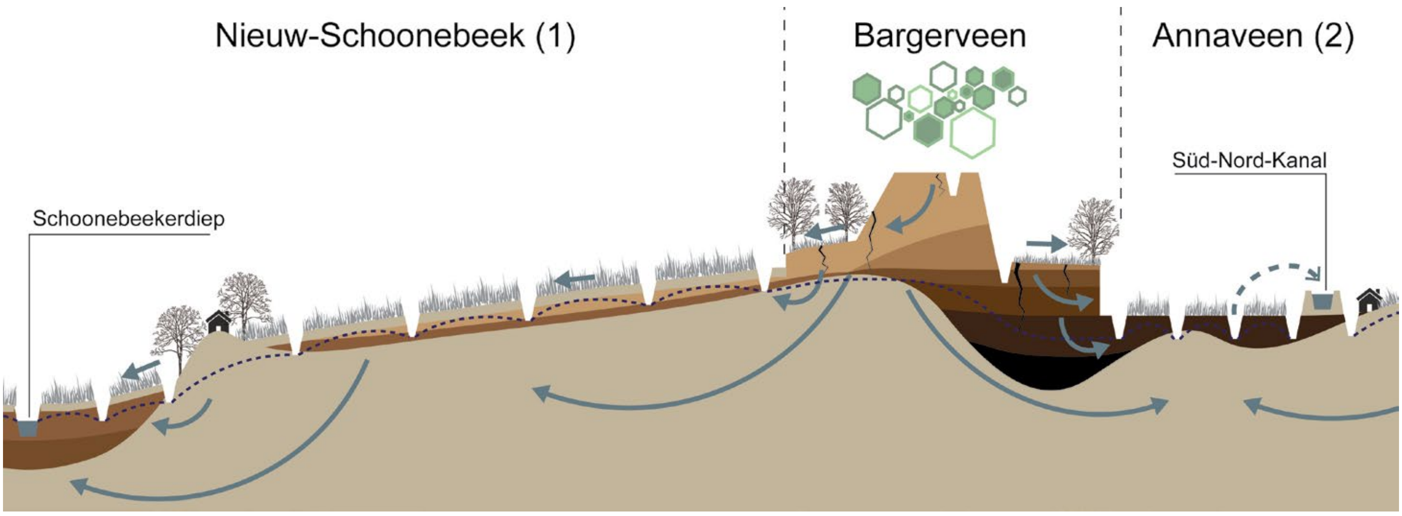


Figure 57: Schematic representation of the current situation and the two areas selected for designing.

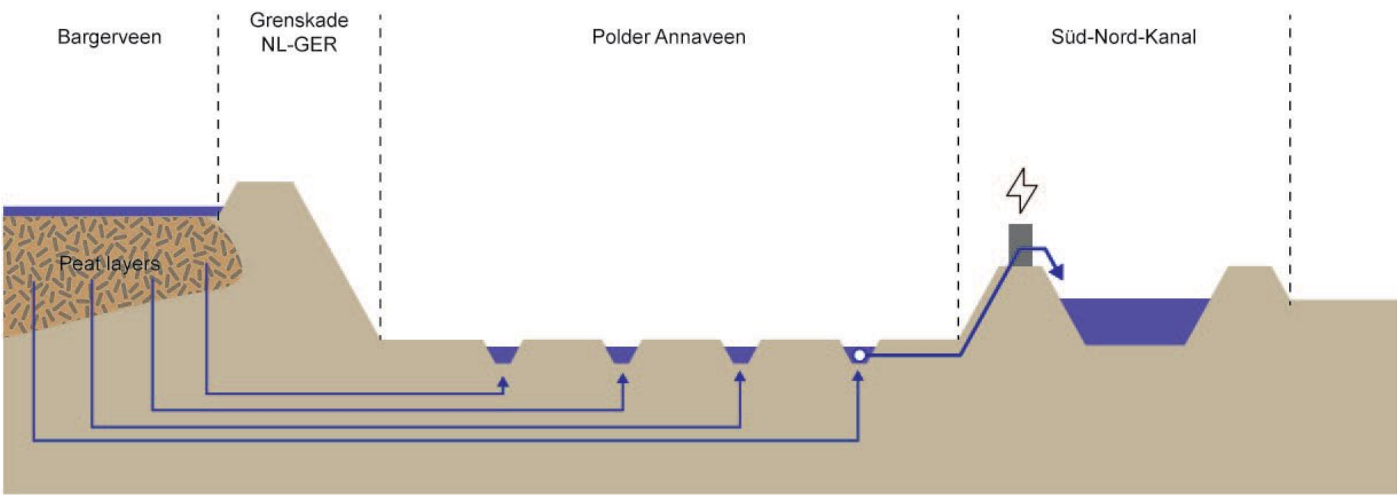


Figure 58: Detailed schematic representation of Bargerveen losing water due to seepage to the polder Annaveen

8

Regeneration of the raised bog landscape creating a new machine

In this chapter the regeneration of the raised bog landscape in the Bargerveen landscape system is presented. First, the case study design is explained. Then, two regional designs for Nieuw-Schoonebeek and Annaveen are presented. After that a supra regional plan is made of nature reserve Moor-Veenland with a system that copes with the surplus of nutrients. With these designs the regeneration of the raised bog landscape in the Bargerveen landscape system is accomplished. With the abstracted design guidelines into models, other raised bog landscapes can be regenerated as well.

8.1 Case study Bargerveen landscape system

The concept of paludiculture is implemented in a case study on the Bargerveen landscape system to test their possibilities to regenerate the raised bog landscape while using the design theory Landscape Machines (Figure 59). In the previous chapters the raised bog ecosystem, Bargerveen, its goals and its relationships are studied. It became clear that the areas of Nieuw-Schoonebeek and Annaveen both have a large hydrological influence on Bargerveen. These two areas, which are exemplary for the types of agricultural landscapes (Nieuw-Schoonebeek = 'oude bovenveencultuur' and Annaveen = 'dalgronden') in the raised bog landscape, need to be designed to improve the external hydrology. This can lead to accomplishing the goals of gradient restoration, peat formation and improving the quantity and quality of peat moss in Bargerveen. The information gathered on paludiculture and the development of the raised bog landscape (of Bargerveen landscape system) are used in the process of designing for the areas of Nieuw-Schoonebeek and Annaveen. In both areas the relief of the landscape is rather homogenous which is positive when implementing paludiculture. The differences in relief that are present are embraced to create this mosaic of different crops and land use practices as will be shown in both designs. From both designs, a model – or a set of design guidelines – is abstracted and is tested in the supra-regional design that is made for a part of the former Bourtangerveen which is designated as an international nature park called 'Natuurpark Moor – Veenland' (Figure 90). The designated raised bog nature areas should be restored and the models that are implemented in the surrounding landscape should facilitate this, which results in a regenerative raised bog landscape. This supra-regional design also solves the problem of the nutrient surplus in the raised bogs in an integrative way.

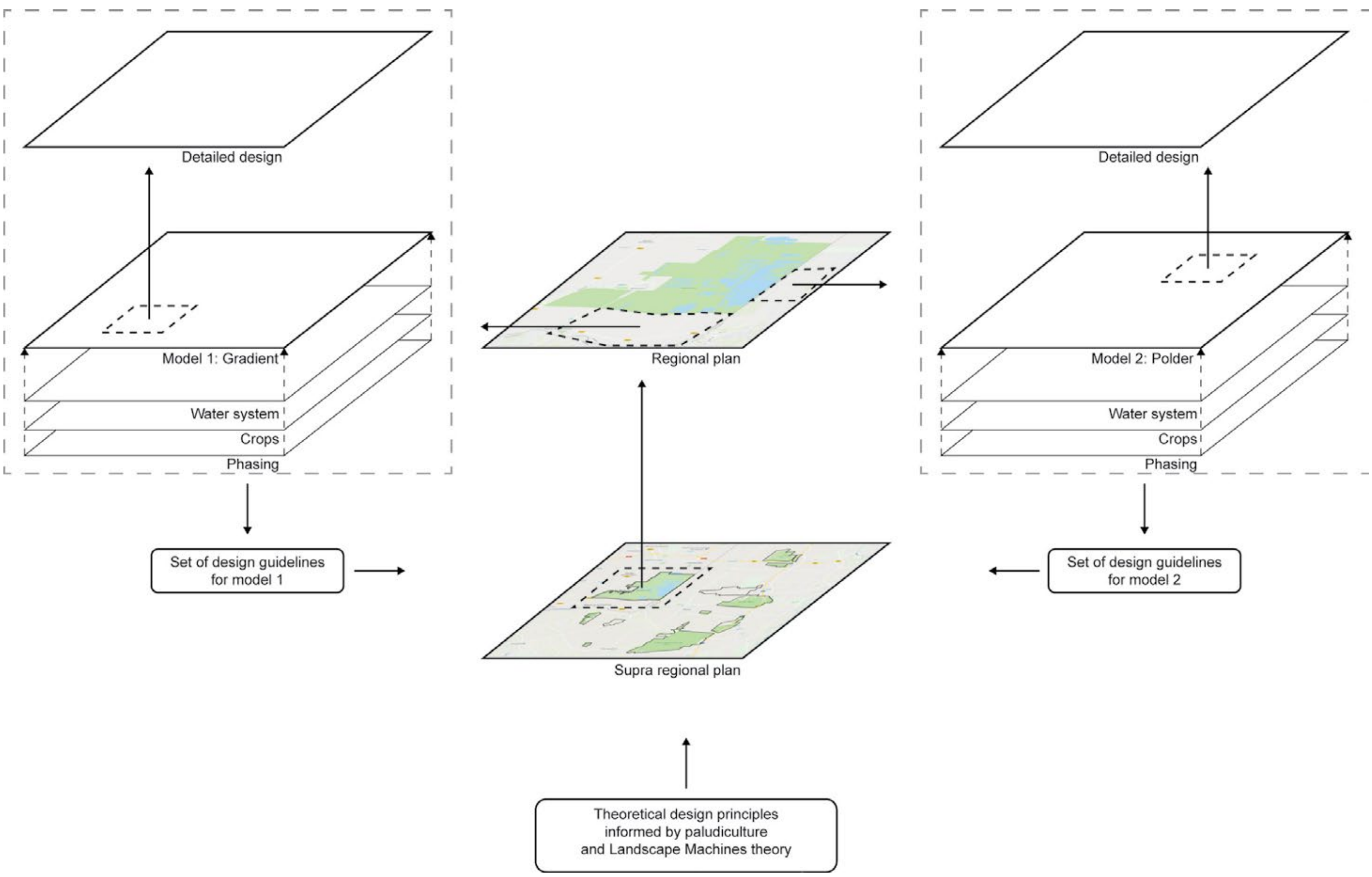


Figure 59: Case study design framework

8.2 Regional design Nieuw-Schoonebeek

Nieuw-Schoonebeek originated alongside an important route to Germany and is situated on the edge of the stream valley of the Schoonebeekerdiep. Back in the day the farmers had an ingenious system (see section 6.2 'Oude bovenveencultuur') which made use of the natural properties of the landscape and in which every plot of land had its own specific function. During the last century most of the peat was dug away (see section 6.3 Systematic peat cutting) and the land reclaimed for agriculture. Only Bargerveen, mostly excavated and degraded, remained from the once grandiose raised bog complex in this area. Now, with the design of this area, the once reclaimed agricultural lands are used for paludiculture and serve the restoration of Bargerveen (by restoring its external hydrology), creating a regenerated raised bog landscape.

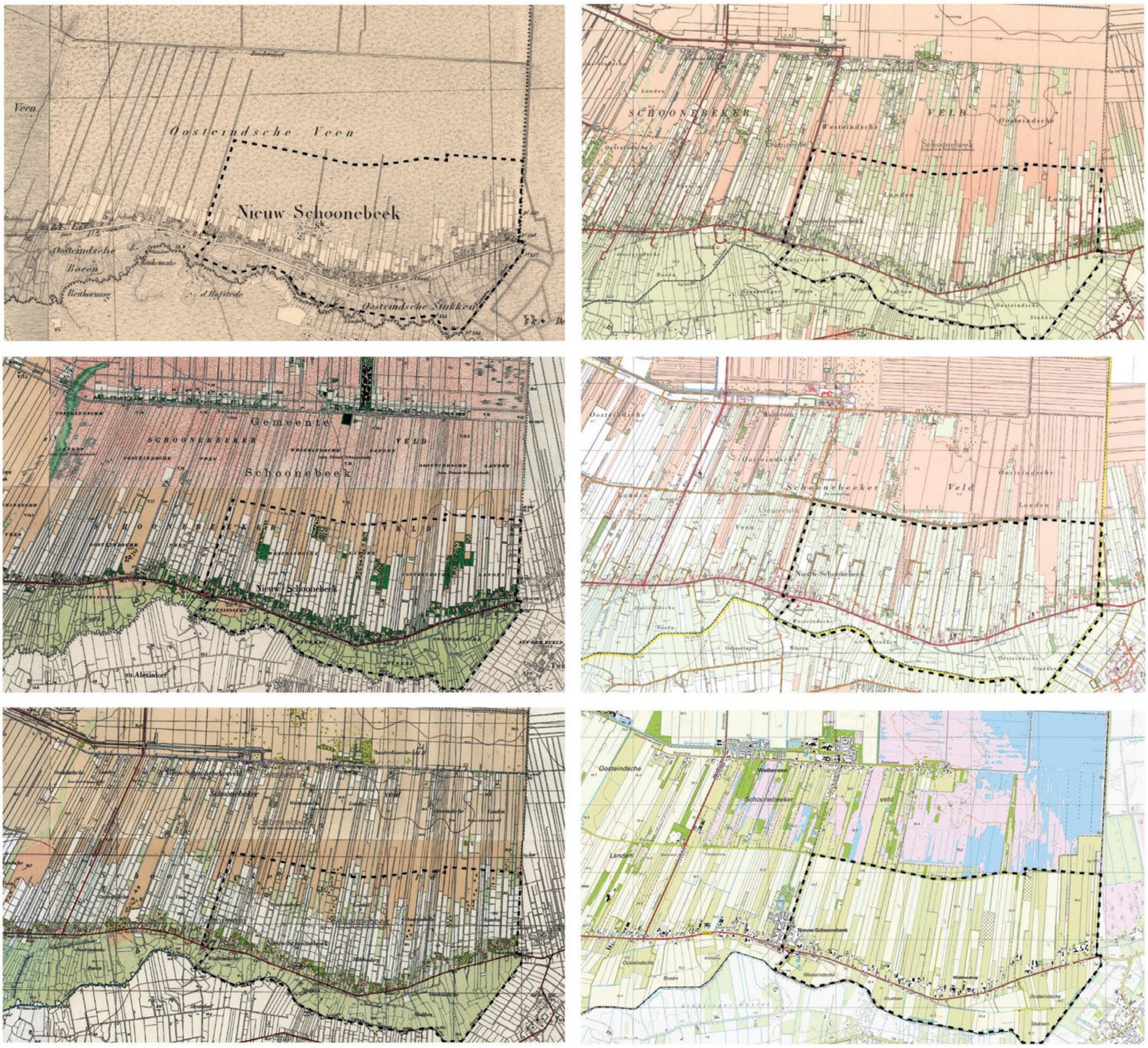


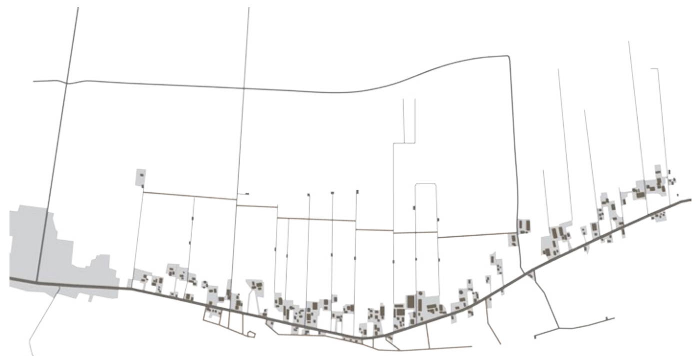
Figure 60: Nieuw-Schoonebeek in 1895, 1920, 1940, 1960, 1980 and 2016 (http://www.topotijdreis.nl/)

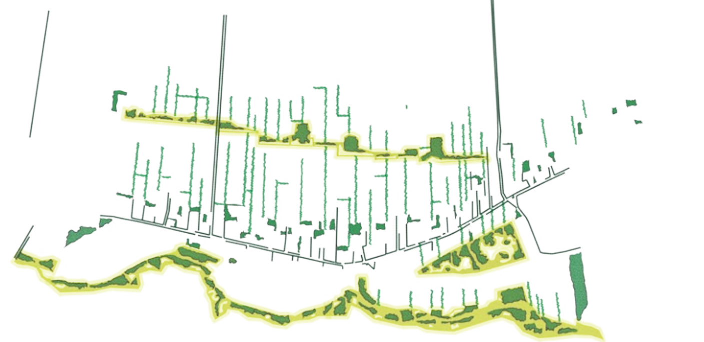
In the design (Figure 61a) multiple interventions are made. The first and most obvious intervention is the implementation of paludiculture with willow, reed and cattail. Water basins are designed along the edge of Bargerveen to improve the internal hydrology of the raised bog (Figure 67). Willows are planted to visually separate Bargerveen from its surroundings. These willow fields will be harvested with different intervals, creating patterns of younger, smaller trees and older, larger trees. The fields are penetrated by infrastructure which is embedded in formal rows of trees. The willow fields follow the structure of the parcels, creating interesting edges (Figure 66). The parcel size will remain intact but the amount of drainage will be reduced by filling in ditches and making them more shallow. Vegetation can arise alongside the ditches. Old infrastructure and platforms from the pumpjacks are maintained to serve as routes and biomass loading points for the harvesting of willow and reed. A dike-ditch system is implemented to collect water from different qualities, creating opportunities for flora and fauna (Figure 65). The old farmyards along the dike are situated higher in the landscape, this is accentuated by wrapping them in native vegetation so they become an island of green in a sea of reed (Figure 65). The dike with road and bicycle path is accentuated as a cultural component by planting oak trees. When using this dike it will feel intimate while providing wide views on the landscape (Figure 64). Large water storage structures are constructed alongside the dike in the stream valley. These collect water from the reed and willow fields. The water is used for the cattail fields in the summer when they require water. Interesting vegetation can arise in these water storage structures, also called battery's, because they 'charge' up water during the wet season and release it during the dry season. A water-meadow system is implemented in the cattail fields, ensuring an adequate water and nutrient supply. The Schoonebeekerdiep is remeandered according to its old structure. Alongside the stream there is place for recreation and nature development (Figure 63). The structures implemented in the stream valley are seen in bird's eye perspective in Figure 62.

Figure 61a: Regional design of Nieuw-Schoonebeek


Figure 61b: System: water buffering, restoring external hydrology and providing water and nutrients for cattail fields.

Land use: cattail, reed and willow


Infrastructure: roads, village and farms


Green structure: formal lanes of trees, natural vegetation, (wet) woodlands

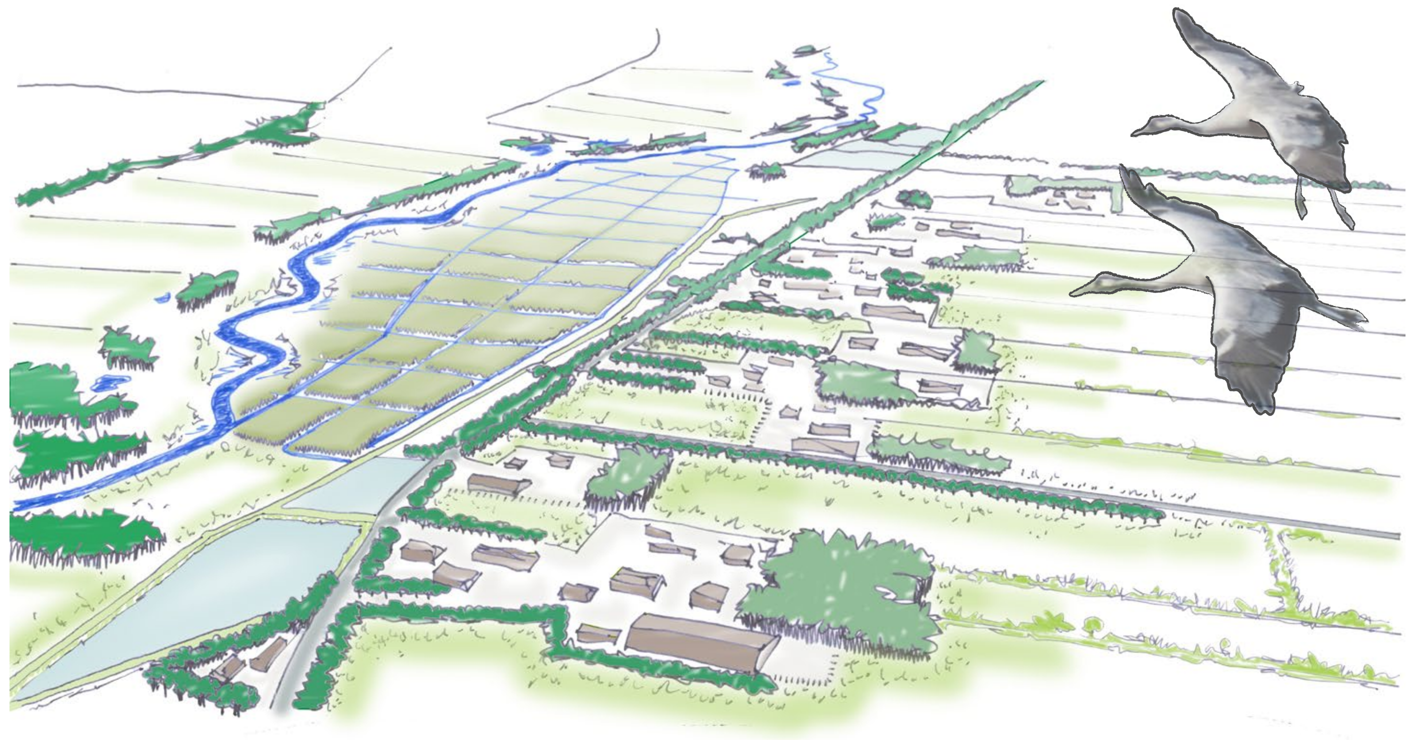


Figure 62: Bird's eye perspective of the stream valley near Nieuw-Schoonebeek

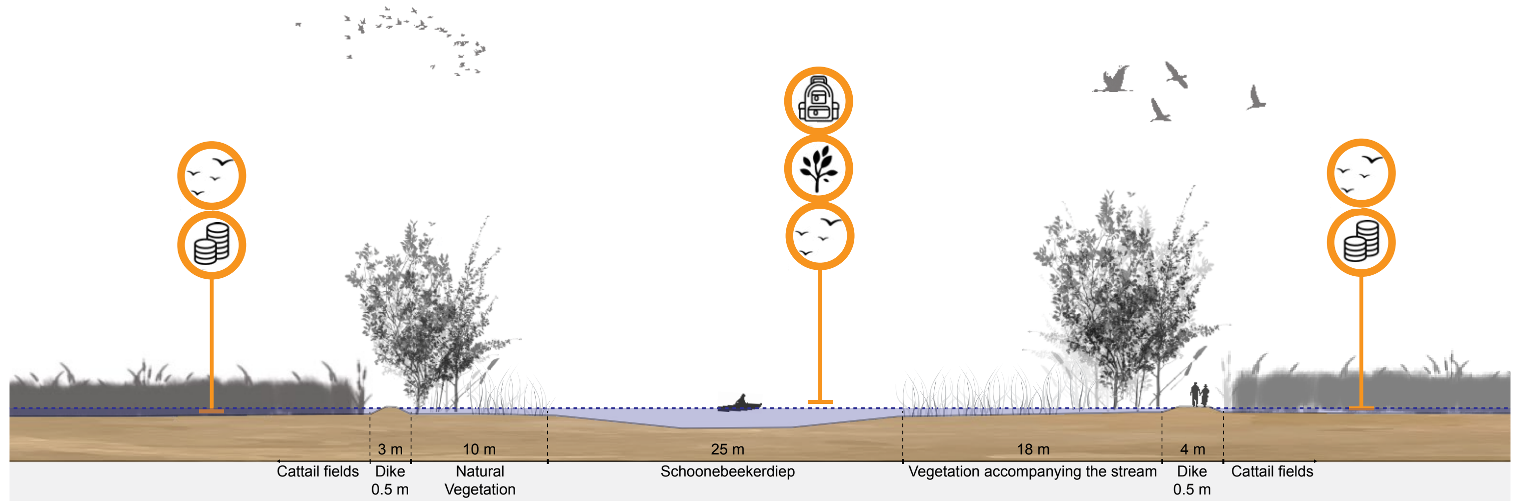


Figure 63: Section A-A': Remeandering Schoonebeekerdiep

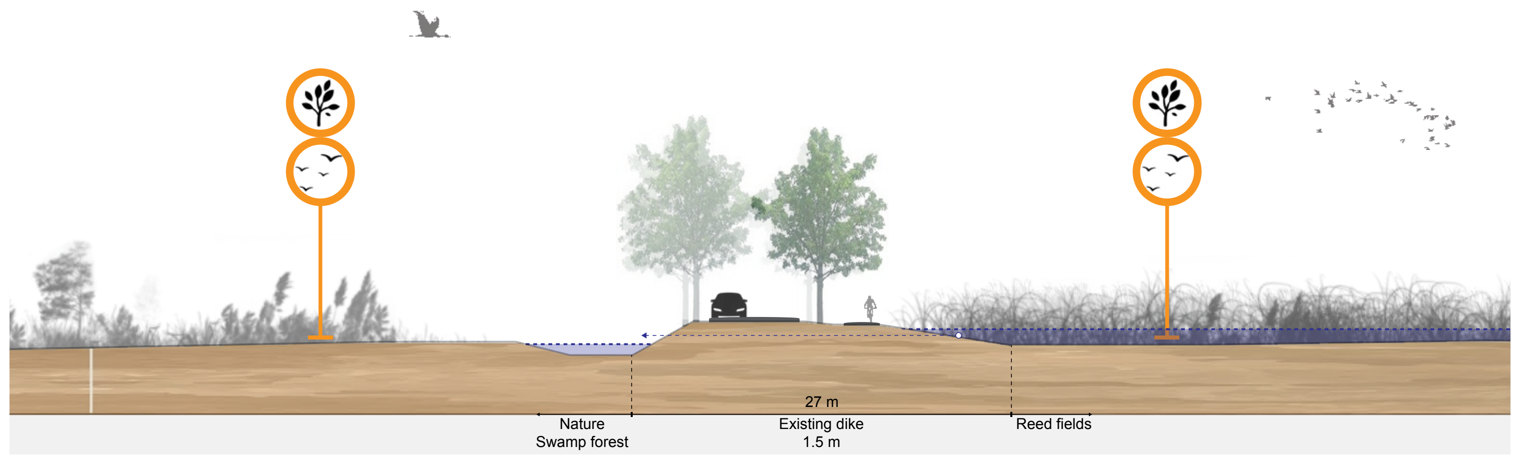


Figure 64: Section B-B': Old dike (Europaweg) as cultural component in a wild landscape

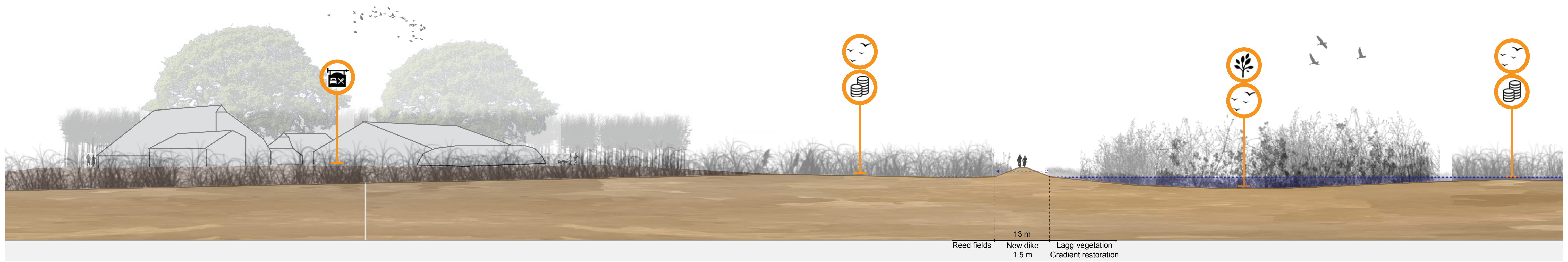
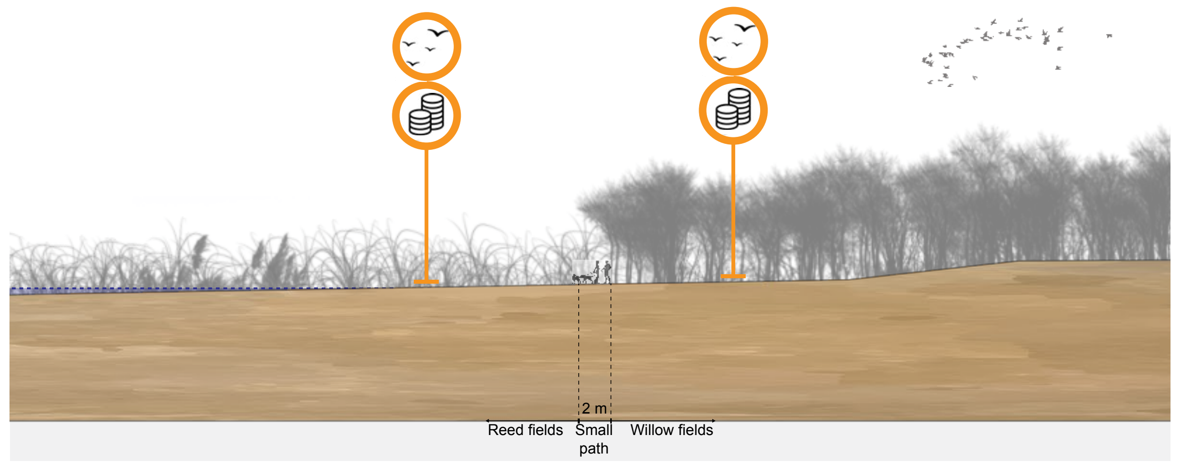


Figure 65: Section C-C': Farm as a green island in a sea of reed. Dike-ditch system with water collection and gradient restoration



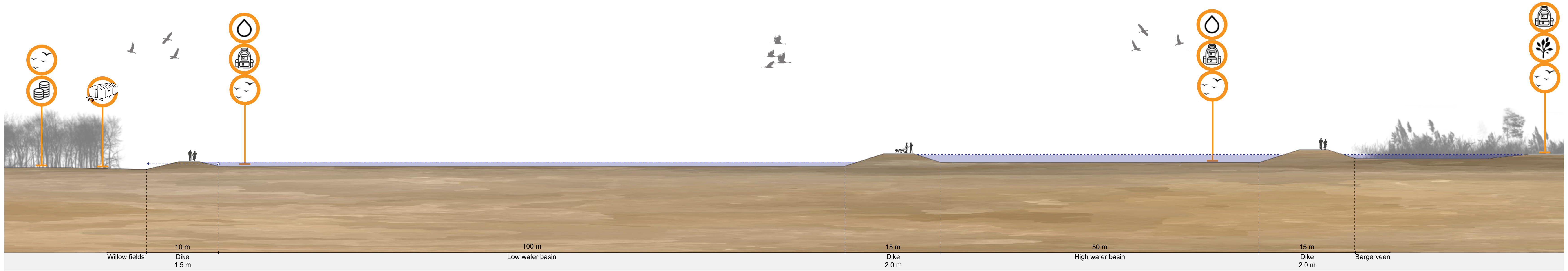


Fig 66: Section D-D': Transition between reed and willow, interesting edges with gradients in wetness

Figure 67: Section E-E': The embedded water basins of Bargerveen. Large open spaces between the willow fields and Bargerveen.

8.2.1 Rainwater and mixed system

The design principles of this design are explained from the Bargerveen to the Schoonebeekerdiep. The whole system is seen in Figure 61b and 68.

The first design intervention is the construction of a buffer zone with two basins to decrease the mutual hydrological influence of the raised bog remnant and its surroundings to create better conditions in the bog remnant for the development of *Sphagnum*. The basin closest to Bargerveen is the high water basin in which rain water is collected. The function of this basin is to provide counter-pressure to the water levels in Bargerveen so that the amount of seepage from the Bargerveen will decrease. Also when the water level in Bargerveen is lower than the buffer zone, water will seep from the buffer zone towards Bargerveen. The second basin is the low water basin, this basin is also filled with rainwater and will provide counter-pressure for the high water basin. This basin also functions to attenuate the peak discharge in case of heavy rainfall. This rainwater and mixed system will work as follows:

When it rains, the raised bog can take up a lot of water which is needed for its growth. The high water basin fills with water to ensure the rain that is falling in the raised bog will stay there as long as possible. Excess water will flow from the high water basin to the low water basin. The low water basin has overflow drains so when the water level is too high, the water will gradually be released towards the lower-lying fields of willow. These fields are not permanently under water because they receive water from precipitation and from the overflow of the low water basin. There are no ditches in the willow (*Salix*) fields so it won't drain Bargerveen and the water basins. These are good conditions for willow to grow because they need dry situations in the summer, which is when the water levels are lowest and Bargerveen needs the most water thus the willow fields get little to no excess water from the basins. The water then enters the reed (*Phragmites australis*) field that is divided in two parts. This division is because the slope from the willow fields to the old dike is approximately 1 metre and reed can grow as deep as 50 centimetres under water, but also to ensure maximum infiltration. So halfway along the slope is a small dike that can support a water body of maximum 50 centimetres. This dike has overflow drains, when the water level is too high excess water is released to lower lying reed fields. Along this dike is a ditch that is situated perpendicular to the water flow. This ditch collects rainwater and local groundwater. The mixing of these two types of water can create conditions that are similar to a lagg-zone. The reed fields have changing water levels, while some areas are permanently under water, others are only temporary, which is no problem for this plant. The constant flowing of water eliminates the problem of mosquitos. The principle of overflow drains is also implemented in the old dike for the other (lower lying) reed field. So when the water level is high because of precipitation, which is likely the case in the winter, the water will flow through the old dike to the buffer zone, or battery, in the stream valley of the Schoonebeekerdiep. Here the water enters the water system of the Schoonebeekerdiep.

8.2.2 Groundwater system

The Schoonebeekerdiep water system relies on the supply of seepage water from higher located areas, therefore the quality of water is different from the raised bog water system. While the water from the raised bog ecosystem consists mostly out of rainwater which is oligotrophic and acidic, the water from the Schoonebeekerdiep water system is more mineral-rich and basic. With a shallower and meandering stream, the Schoonebeekerdiep can store more water and the discharge rate will decrease, keeping the water longer in the area. Where the stream fans out into a side streams there are large productive fields (water-meadows) of cattail (*Typha latifolia*), which is to ensure a maximum supply of water and nutrients because this plant grows best under wet and nutrient-rich conditions. Cattail takes up nutrients quickly and can function as a helophyte

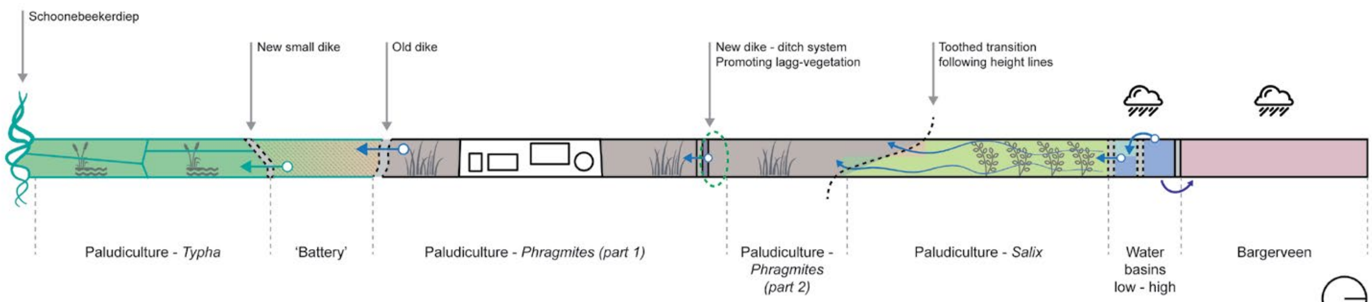


Figure 68: Rainwater, groundwater and mixed system

filter, filtering the water from nutrients and contributing to a better water quality for nature downstream. Soon enough the nutrient supply in the soil will be exhausted and the productivity of cattail will decline. When there is a bog burst (or *Moorausbruch*) and an excess of nutrients enter this system, there will be an increase in productivity of cattail. These processes ensure a certain dynamic in the size, location and productivity of cattail fields. Cattail needs to be under water also in summer, to ensure enough water supply, the battery or buffer zone has a large water supply which the cattail fields can use. In the rest of the stream valley there are reed fields.

In this system there is also room for nature to grow (Figure 69). When the nutrient supply in the soil is exhausted due to the continuous harvesting of reed other vegetation may arise. Or in case of unsuitable harvesting conditions the reed are not harvested. It may be possible that a vegetation arises that was originally present such as swampy forests. Once again, the process of the bog burst ensures a dynamic in biodiversity when considering the trophic degree.

8.2.3 Impact of the design

The design focusses on the restoration of the internal and external hydrology of Bargerveen and therewith the regeneration of the raised bog landscape. With the water basins, the internal hydrology of the southern part will be improved by limiting the amount of seepage with counter pressure. With measures like the meandering of the Schoonebeekerdiep, the removal of ditches and the construction of dikes, the water level is raised. This improves the external hydrology because with a raised regional water level, more water reaches the bog footing which improves the condition of *Sphagnum* to grow.

Besides restoring the external and internal hydrology of Bargerveen, the design stops the degradation caused by drainage of peatlands in the area because of the raised water levels. The generation of peat is even possible in places that are under water throughout the whole year.

The design has a strong focus on restoring and making new gradients in the landscape. This is done by creating two water systems and mixing them together, creating different places with different water qualities and thus different vegetations. The one water system is that of oligotrophic rainwater, which is the bog water system. The other one is that of mineral-rich seepage water that surfaces in the stream valley of Schoonebeekerdiep and is collected there. The paludiculture fields are planted with species that thrive in the different conditions that are linked to the soil and water properties.

With the creation of the two water systems, the one of the raised bog which is focussed on rainwater and the one of the stream valley which is focussed on groundwater, two different environments are created. Both systems rely upon different qualities and quantities of water. In the mixed system, both groundwater and rainwater is mixed to ensure a high biodiversity in which a lagg-like vegetation can develop. The system as a whole ensures a gradient in availability of nutrients, water and extensiveness of land use with the chance of developing a high biodiversity over time with the dynamic of the bog burst. With the increase of the water level in the area, peat degradation by drainage is halted. The peat that is left in the soil is preserved and the generation of new peat is even possible in areas that are wet during the whole year. This implies that the emission of CO_2-eq that is connected to peat oxidation can be converted to the sequestration of CO_2. Of course when the conditions for *Sphagnum* to grow are being met, a lot of CO_2 will be sequestered because of the high productivity of this ecosystem.


Figure 69: Winter in the stream valley

CO_2 reduction

The lands around Nieuw-Schoonebeek emit around 20-30 tonnes CO_2-eq per hectare per year (de Vries *et al.*, 2009). The designed area is around 800 hectares. Thus when these lands are rewetted for paludiculture it can be assumed that once drained peat layers are no longer subject to peat oxidation, thus reducing the amount of emitted CO_2 to zero. This is considering optimal water levels and disregarding possible carbon sequestration in the formation of new peat on paludiculture lands. This way, 0.176-0.264 megaton CO_2-eq is reduced until 2030. This is 17% of the total 1.5 megaton reduction for agricultural land use as stated in the 'klimaattafel landbouw en landgebruik' which is a very sizable amount.

More interesting is the possible carbon sequestration of Bargerveen if it restores to a functioning ecosystem. The Netto Ecosystem Exchange from raised bogs ranged from -3 to -160 g C m^{-2} y^{-1} (Fritz *et al.*, 2014). This results in -11 to -587 g CO_2 m^{-2} y^{-1} or -0.11 to -5.87 tonnes CO_2 per hectare per year. Possible sequestration in Bargerveen (2100 hectares) until 2030 range from 2,541 to 135,597 tonnes CO_2 or 0.025 to 0.136 megaton CO_2. Concluding, CO_2 can be reduced by a sizeable amount when these lands are rewetted for paludiculture and CO_2 sequestration is possible in Bargerveen if restored.

8.2.4 Conclusion

By implementing principles from paludiculture and using Landscape Machines theory in the design for Nieuw-Schoonebeek, a diverse and irregular mosaic of land uses will occur that is connected to soil and water properties. This design creates new opportunities for farmers and the region as a whole. The internal and external hydrology of the raised bog will be improved and gradient restoration can be achieved, which are both goals of the Natura 2000 management plan. The cattail-fields have a prominent role in the design. More important, a regenerative landscape arises that has the potential to be a keystone in the regeneration of the raised bog landscape. In the following section the design guidelines are distilled from the design and put together in a model.

Model gradient (1)

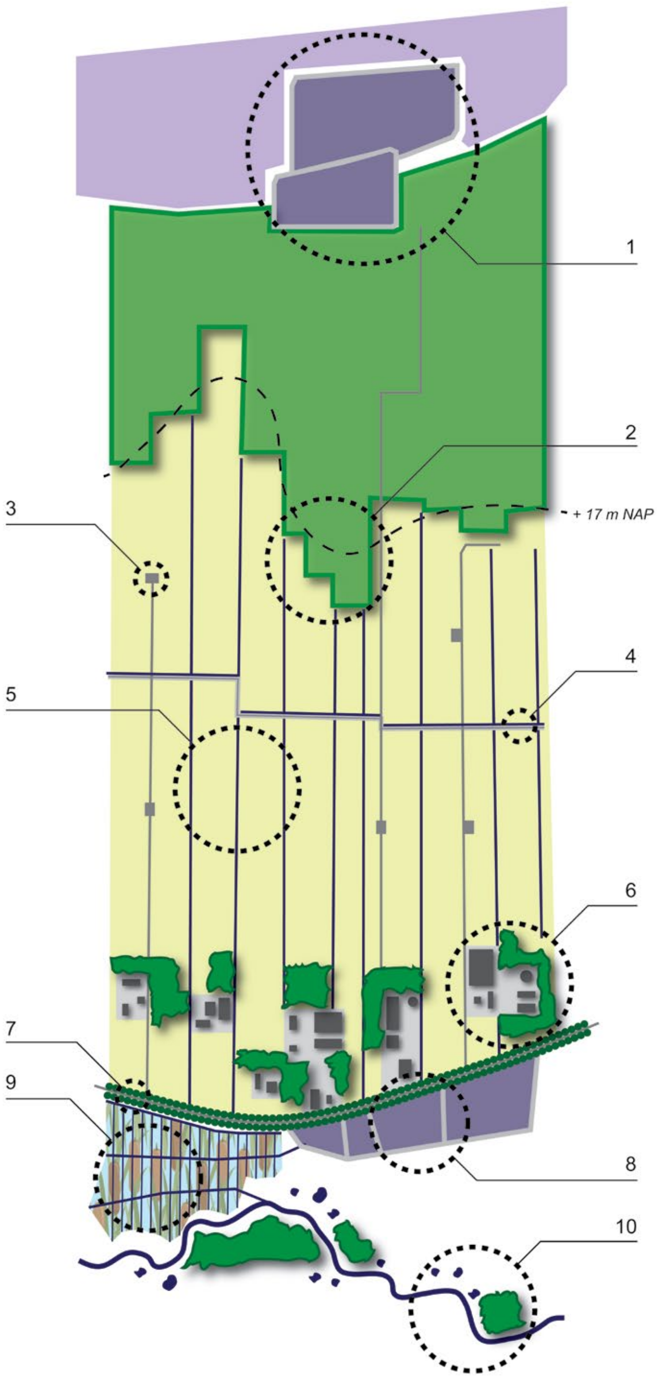


Figure 70: Design guidelines model 1

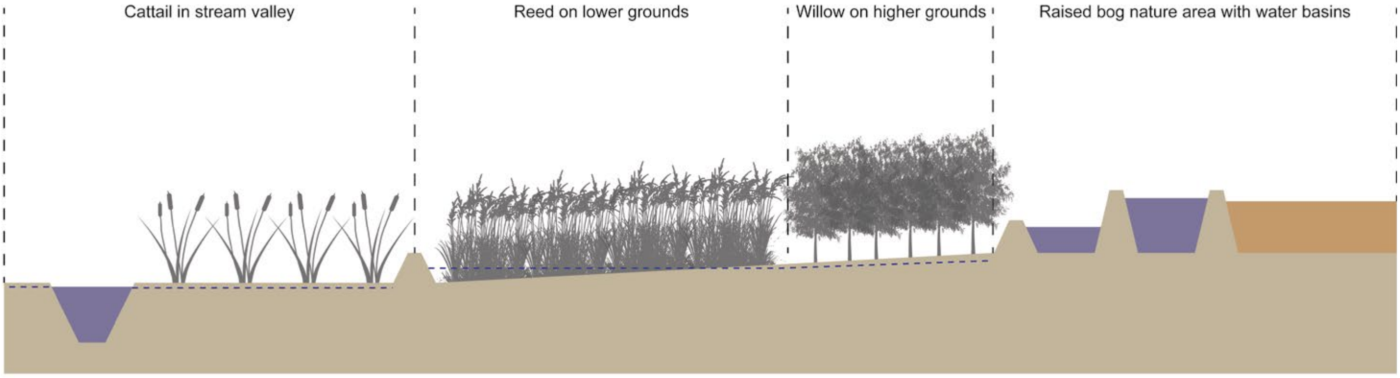


Figure 71: Land uses in model 1

The hydrology in the design is constructed in such a way that the growth of cattail is being stimulated. Cattail fields are planted in the stream valley to ensure water and nutrient supply. Reed is planted on the lower grounds that can get under water when necessary. Willow is planted on the higher grounds near the raised bog nature area without drainage, to serve as a visual separator, windbreaker and to limit the deposition of nitrogen (Figure 71). The guidelines are explained according to Figure 70.

(1) Water basins are corresponding in size to the raised bog area that it is supporting and should be encapsulated and integrated in the area. It should follow the landscape structure of the supported area which is often massive, erratic and open. The landscape structure can differ per area, resulting in a differentiation of water basins.

(2) The willow fields are planted in a toothed form that is a reference to the old agricultural system. The irregular toothed line corresponds with the height line and parcel structure which creates interesting edges. Parcels of willow can be harvested in different intervals (1, 5, 20 years), creating a pattern of coppice forests and full grown forests (Figure 72).

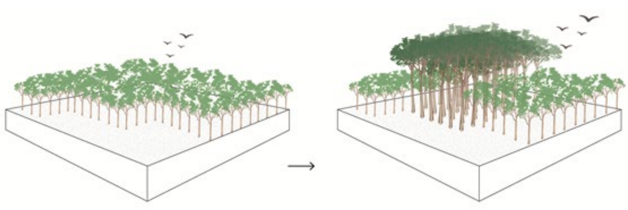


Figure 72: Willow fields in different stages

(3) Infrastructure leading to the parcels and biomass loading points will be kept intact or should be constructed to ensure the transport of harvesting and transporting machinery.

(4) The dike-ditch system is implemented in a formal way perpendicular to the parcel structure. The dike is constructed in a straight line and will make sharp turns at every other parcel. The straightness of the dike will form a sharp contrast in the landscape as a man-made structure, while the rest of the landscape will slowly be naturalised, creating an interesting contrast (Figure 73). The visitor will enter different worlds when crossing from parcel to parcel as the vegetation around the ditches will act as a screen – visually separating each parcel. The dike-ditch will collect water from different qualities, which can result in the emergence of an interesting vegetation (Figure 74).

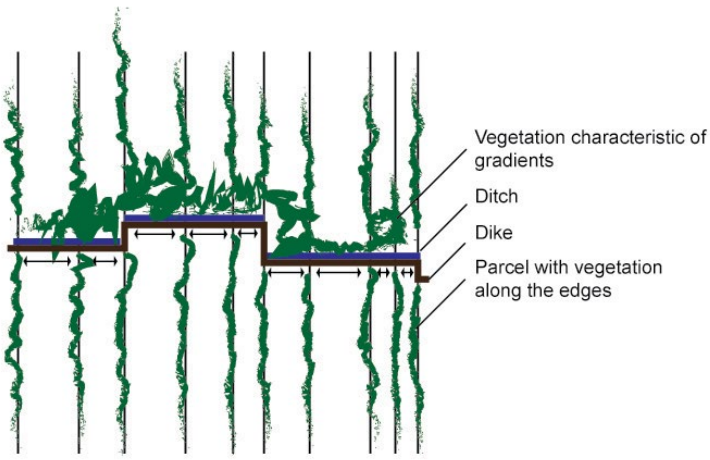


Figure 73: Top view dike-ditch system, clear contrast visible between this formal designed structure and the naturalised landscape surrounding it.

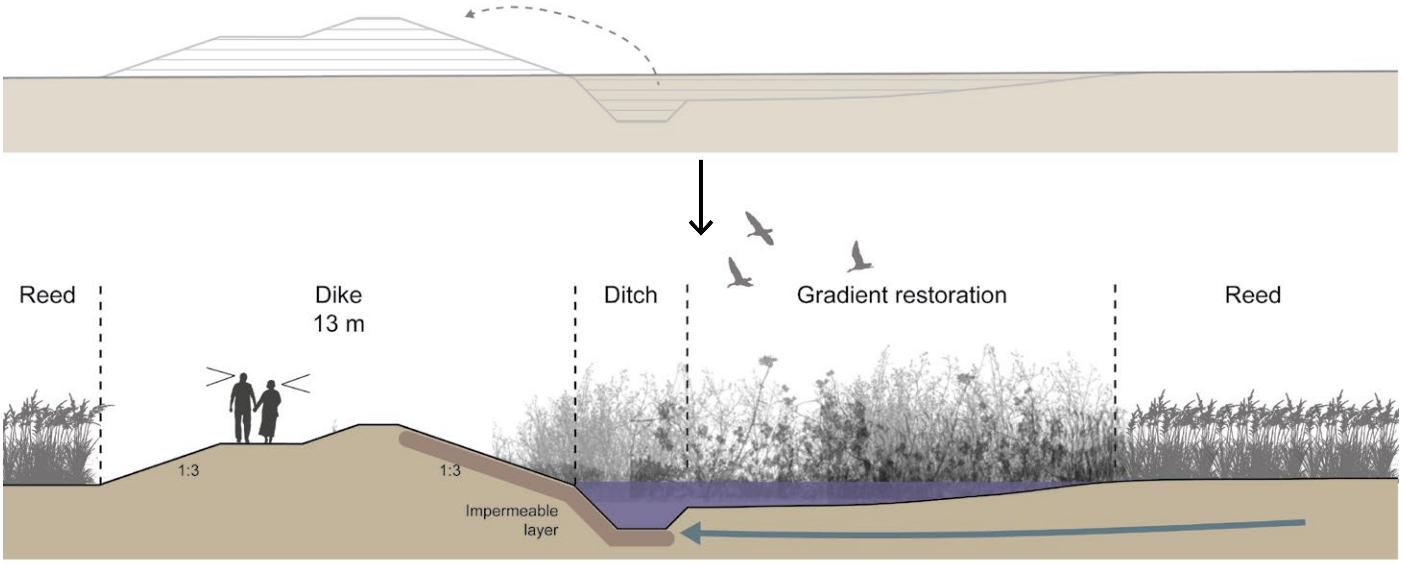


Figure 74: Design and implementation of the dike-ditch

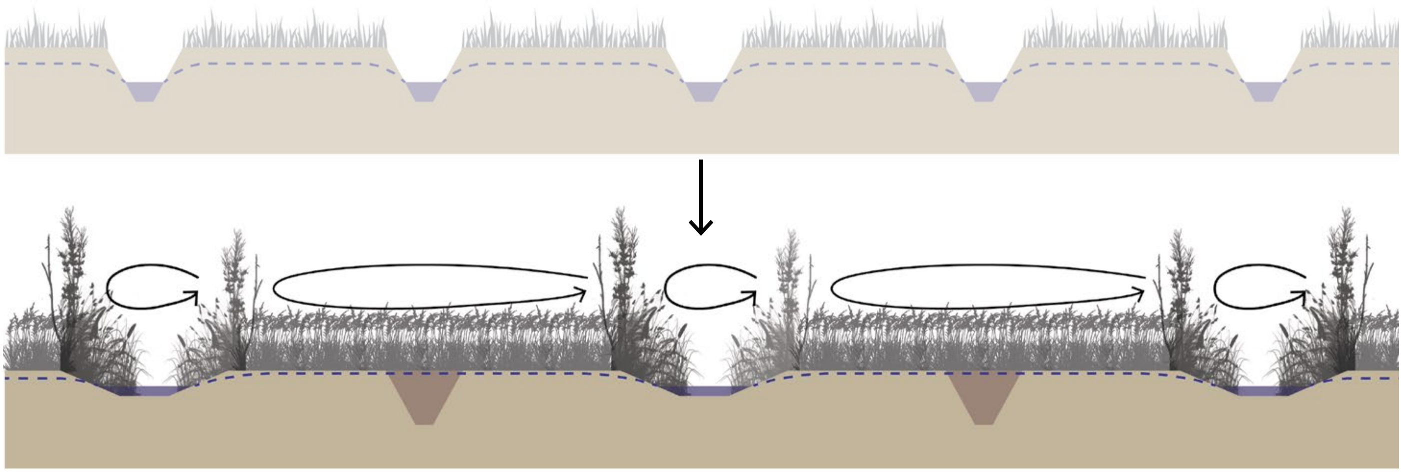


Figure 75: Old and new parcel structure and land use

(5) The parcel structure will be kept intact but the amount of drainage will be reduced by filling in ditches or making them more shallow and broad. Vegetation that arises around these shallow and broad ditches is maintained to separate the large fields of reed (Figure 75).

(6) The farmyards, which are elevated above the surrounding landscape, should be wrapped in native vegetation according to the scale and parcel size. To accentuate that it is part of the cultural component. This will look like a green island in a sea of reed.

(7) Accentuate important roads with rows of native trees to create an imposing green structure that leads through the landscape.

(8) The water buffer or 'battery' is integrated in the dike on the side of the stream valley. These should be constructed on the most logical location where the water will naturally enter the stream valley. The 'battery' is a structure of dikes that collect water, it consists out of multiple spaces with perpendicular dikes that can overflow when buffering water. The different site conditions in the multiple compartments of the 'battery' can result in the emergence of a gradient in the vegetation.

(9) In this water-meadow systems, located in the stream valley, the cattail is cultivated (Figure 76). This system ensures water and nutrient supply and is extensively studied by Baaijens *et al.* (2007). These systems should reflect a highly productive environment. The water-meadow system is constructed with three ditches parallel to the stream. The first ditch is the deepest, collecting the seepage water from higher grounds that normally end up in the stream. The second ditch is connected to the 'battery' and will gain its water from there. The third ditch is connected to the stream and will receive a constant inlet of water. All these ditches are then connected by a series of smaller ditches

that are constructed perpendicular to the three main ditches. The water-meadow system is clearly recognisable as a man-made structure and thus forms a contrast with the meandering stream and naturalised stream valley.

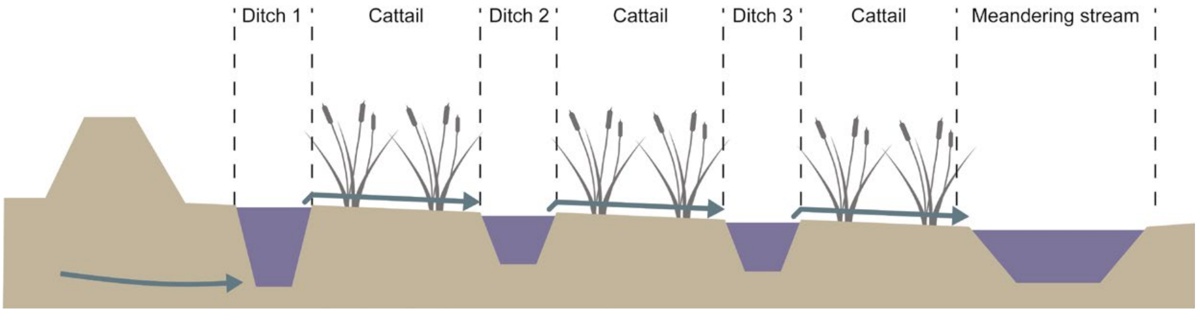


Figure 76: Schematic representation of the water-meadow system

(10) The stream in the stream valley is re-meandered while this ensures water retention and a dynamic in the system. The re-meandering should be done by studying historical maps and doing soil research to re-create the natural state. The organic meandering stream forms a contrast with the rest of the area when looking at the water structure. The stream is assembled by smaller ponds and wet areas where swampy forests can arise.

Conclusion

This model, or set of design guidelines, focusses on the transition from a raised bog nature area to a stream valley. The system is characterised by gradients in wetness and water quality. The stream valley is a distinctive structure in the landscape, framed by the dike with formal rows of trees. With these design guidelines a diverse small-scale landscape arises with clear man-made structures that form a contrast with the emerging nature. The improved hydrological situation is seen in Figure 77.

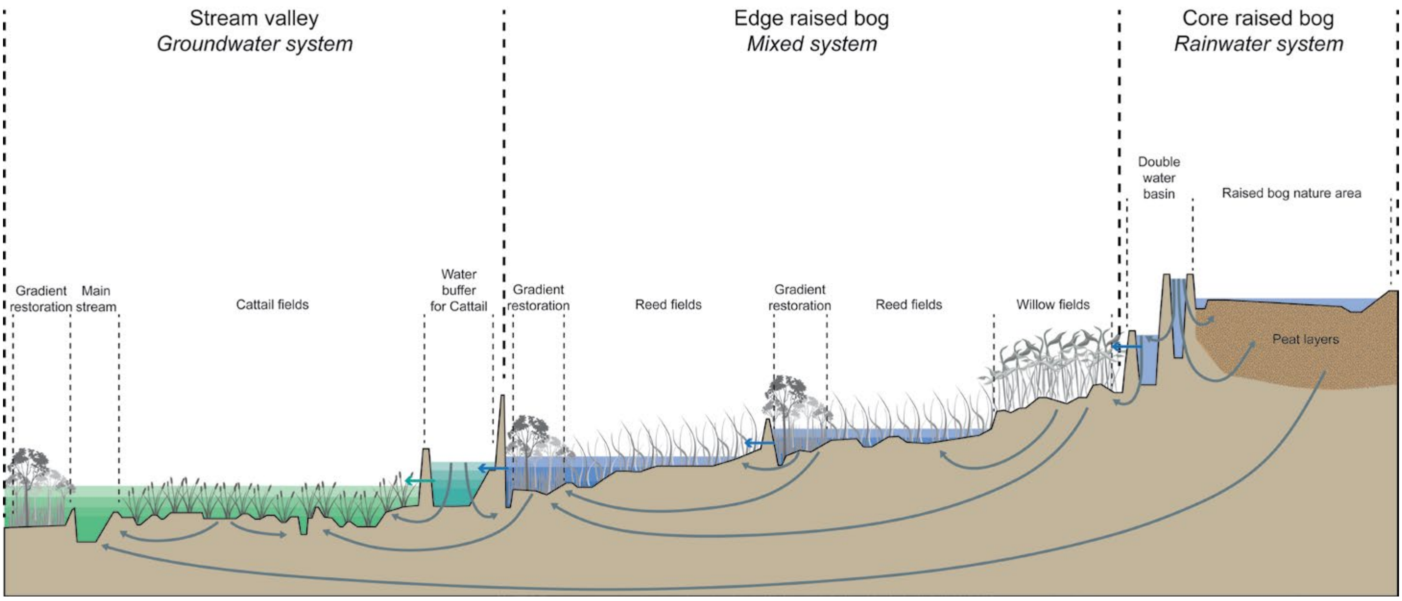


 Figure 77: Schematic representation hydrological situation model 1. Hydrology based on Tóth (1963)

8.3 Regional design Annaveen

The polder Annaveen is located on the border between Germany and The Netherlands (Figure 78). In the map of 1895 it was still wilderness. In 1920 the Süd-Nord canal was constructed and the area of Annaveen became a distinctive unit. The land was cultivated from the nearby village of Rühlertwist in a similar way as Nieuw-Schoonebeek. In 1940 new patterns and a small railway arise, this indicates the systematic peat cutting. This grid used for peat cutting is still in place during 1960 and in 1980 the first lands of Annaveen are reclaimed for agricultural use. During the 90's the polder was designed and it remained this way up to 2019 (Figure 79 and 80). The designed area of Annaveen has a strong grid lay-out with roads and ditches. There are two farms and a small village next to the canal. There is also a grid pattern of windmills with according infrastructure. Because all the peat was dug away, the polder is quite low and water needs to be pumped to the canal which is elevated above the landscape (Figure 81). Now, with the design of this area, water levels are increased by limiting drainage, buffering water and the inlet of water from the canal. The lands are used for paludiculture and serve the restoration of Bargerveen (by restoring its external hydrology), creating a regenerated raised bog landscape.

Figure 78: Polder Annaveen in 1895, 1920, 1940, 1960, 1980 and 2016 (http://www.topotijdreis.nl/).

Figure 79: Panorama landscape structure 'dalgrond' Annaveen

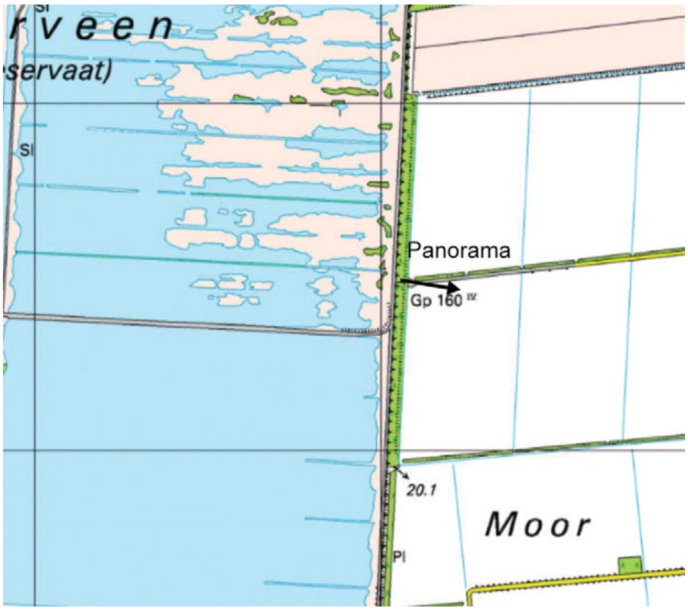


Figure 80: Landscape structure on the border between Bargerveen and Annaveen: strongly juxtaposed (http://www.topotijdreis.nl/).

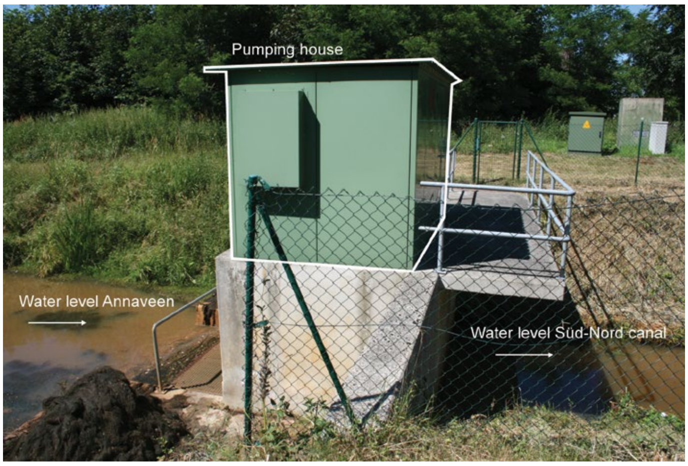


Figure 81: Water levels Annaveen and Süd-Nord canal, water is pumped from Annaveen to the canal. In the design water can be transported from the canal to the polder.

In the design (Figure 82a), the strong grid lay-out with the roads and ditches is kept intact and accentuated by adding formal rows of trees to some roads and by planting vegetation alongside some parcels and ditches. Cattail is planted on parcels alongside the ditch-infrastructure which are easily accessible for the inlet of nutrient-rich water from the canal. Reed is planted on other low-lying parcels and willow on the parcels which that are elevated such as near the village and canal. The main ditch (in the middle) is accentuated with accompanying natural vegetation. There is place for wet woodlands and a lake, which can harbour the functions recreation and water buffering. The strong grid of infrastructure and drainage which is embedded in green forms a strong contrast with the grandiose cattail and reed fields. The mixing of land use can also provide interesting combinations as seen in Figure 83. These components make for an interesting landscape for recreation (Figure 84), routes can be constructed alongside these edges.

On the north side of the polder a 'renatureriering fache' is situated. This is designated as a nature area thus the land use is adjusted on this side. This translates to more water buffering (to achieve stable water levels), cultivating reed and no inlet of nutrient-rich water. On the east the polder is attached to the canal, the canal is embedded in a strong green structure composed of woodlands and rows of trees. On the south side it is confined by a hard border with willow fields, these fields below to another area similar in structure to the area of Nieuw-Schoonebeek. On the west side it is confined by the elevated 'grenskade' which is a dike structure, the border between Germany and The Netherlands, a strong recreational route and also the edge of Bargerveen.

8.3.1 System

The system is shown in Figure 82b. The paludiculture fields are planted with crops that thrive in the different conditions that are linked to the soil and water properties. The Süd-Nord canal crosses the supra-regional design from south to north. This canal is filled with nutrient-rich water and was used to drain the area. In the winter the water will be buffered here and in the summer the water will be distributed to the areas that are (hydrologically) connected to this canal and have a water shortage. This can be done very efficiently because the water level in the canal is higher than in the areas surrounding it. When doing this, water and nutrients will reach the areas that are grown with cattail, providing it with the resources that it needs to be cultivated productively. Adjustable weirs are needed to direct the water to the fields.

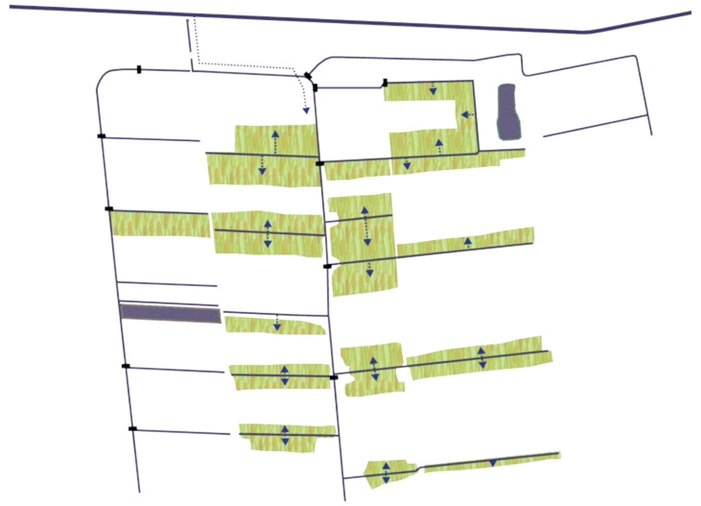


Figure 82b: System: water buffering, water inlet, restoring external hydrology and providing water and nutrients for cattail fields.

8.3.2 Impact of the design

The area of Annaveen has a large influence on the external hydrology of Bargerveen. Meaning that a lot of water is lost to this polder. This has to do with the low location and the high level of drainage. This design limits the amount of drainage and thus increases water levels and a more gradual hydraulic gradient is achieved. By doing this the external hydrology of Bargerveen is improved. Besides this, the design stops the degradation caused by drainage of peatlands in the area because of the raised water levels. The generation of peat is even possible in places that are under water throughout the whole year.

This whole system is implemented for the improvement of the external hydrology of Bargerveen. By decreasing the amount of seepage from raising the water levels so that it reaches the bog footing, the conditions for *Sphagnum* to grow are much better.

Figure 82a: Regional design Annaveen, turned a quarter to the left (see North arrow)

Infrastructure: roads, village, industry, farms and windmills

Land use: cattail, reed and willow

Green structure: formal lanes of trees, natural vegetation, (wet) woodlands

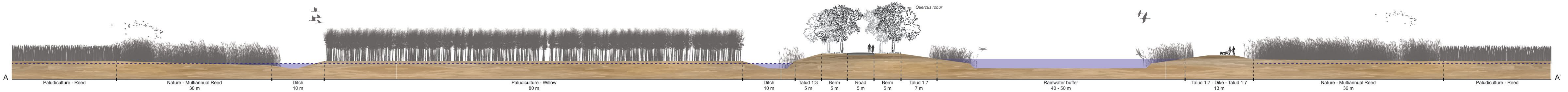


Figure 83: Section A-A': Mosaic of multiple paludiculture crops, road, dikes and a rainwater buffer, resulting in a diverse, productive landscape.

Figure 84: Cattail fields in the summer

8.3.3 Conclusion

By implementing principles from paludiculture and using Landscape Machines theory in the design for Annaveen, a diverse mosaic of land uses will occur that is connected to soil and water properties. This design creates new opportunities for farmers and the region as a whole. The external hydrology of Bargerveen will be improved. The cattail-fields have a prominent role in the design. More important, a regenerative landscape arises that has the potential to be a keystone in the regeneration of the raised bog landscape. In the following section the design guidelines are distilled from the design and put together in a model.

Model polder (2)

Figure 85: Design guidelines model 2

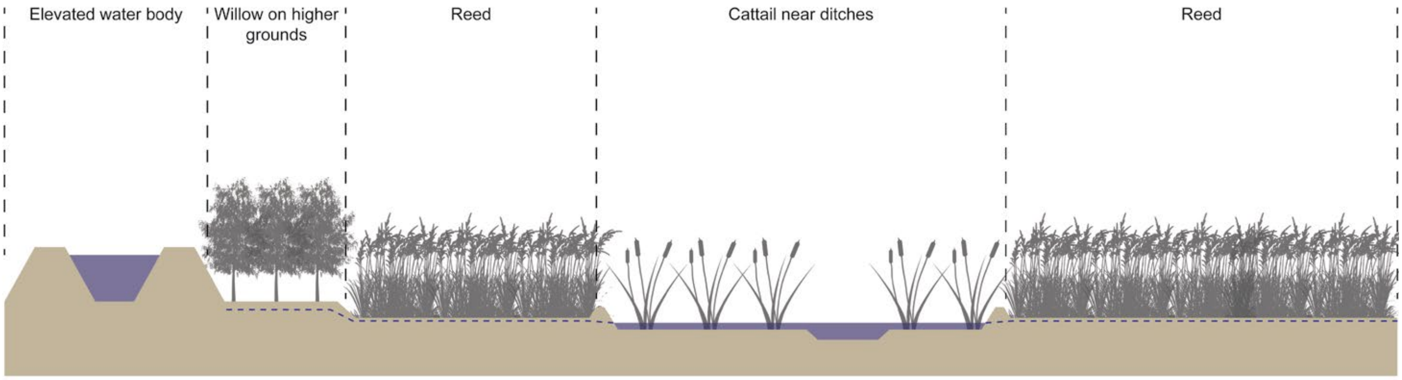


Figure 86: Land uses in model 2

The hydrology in the design is constructed in such a way that the growth of cattail is being stimulated (Figure 86). Fields of cattail are planted near the main ditch to ensure water and nutrient supply. Reed is planted in the other fields. Willow is planted on the higher and dryer grounds – which are rare. The guidelines are explained according to Figure 85.

The leading structure of this model is the system of ditches (Figure 87). A distinction is made between the main ditch (2) and the other ditches (3,4). The main ditch is designed in such a way that it can handle large amounts of water in an efficient way. Other ditches are shallowed and broadened for the purpose of supplying nutrients and water to cattail fields. The ditch system is controlled by weirs and sluices to actively manage the water. The main ditch is connected to a higher water body such as a canal (1), this ensures a plentiful water and nutrient supply. The importance of the main ditch is accentuated by the accompanying green structure which consists out of natural vegetation (Figure 88).

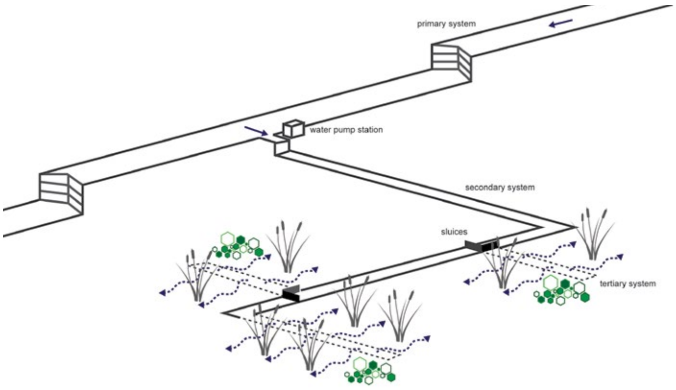


Figure 87: Hierarchy in drainage system of model 2, supply of water and nutrients to cattail fields

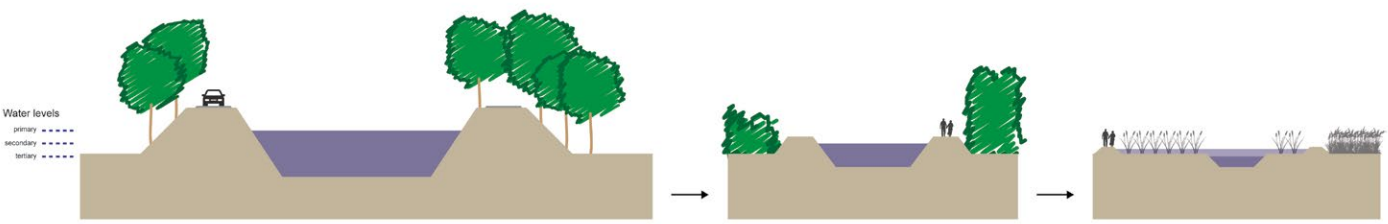


Figure 88: Design guidelines for primary, secondary and tertiary drainage systems

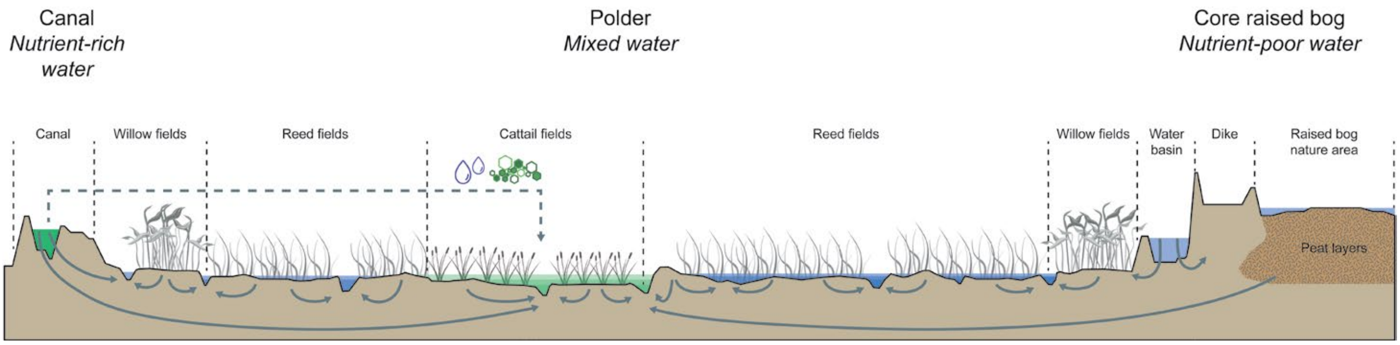


Figure 89: Schematic representation hydrological situation and nutrient distribution model 2. Hydrology based on Tóth (1963)

(5) The edges of the polder should be in stark contrast so the polder will become a clear distinctive unit.

(6) Appropriate land use near raised bog nature areas. No cultivation of cattail with inlet of nutrient-rich water.

(7) The present grid of infrastructure is maintained and embedded with large formal rows of trees to accentuate the cultural component.

(8) Water buffers – if necessary – are placed in strategic locations near cattail fields and designed according the parcel structure.

(9) The farmyards, which are often large-scale, are embedded in corresponding vegetation so that these elements are clearly visible in the landscape.

Conclusion

This model focusses on the large-scale reclaimed raised bog areas for agriculture. The system is characterised by a clear hierarchy in land use and drainage. The grid and openness of these polders is accentuated by hard edges of higher vegetation and large, productive open spaces in between. With these design guidelines a clearly man-made landscape emerges with possibilities for nature along the water structures. Over time the cultural component of the landscape fades as productivity declines and opportunities arise for a more natural vegetation. The improved hydrological situation is seen in Figure 89.

8.4 Supra-regional design nature reserve Moor-Veenland

When designing for Bargerveen it turned out that it was part of a larger landscape system, a part of the former raised bog complex of Bourtangerveen. Within this entity, multiple raised bog remnants such as Bargerveen exist. An international cooperation between The Netherlands and Germany exists that connects these raised bog remnants, called Natuurpark Moor-Veenland (Figure 90). After analysing the area, it became clear that the landscape was of the same typology as the created models (Figure 91 and 92). In this design exercise the models were tested within this landscape, resulting in a variation of designs that can be elaborated further. This design exercise (Figure 93) also made the models better because of the constant reflection. A bigger and improved Landscape Machine is created, instead of regenerating one raised bog remnant and its surroundings, multiple raised bog remnants are linked together, forming an unity that is connected with the stream valley. In the following sections the design and possible developments over time of this Landscape Machine are described.

Figure 90: Boundaries of Natuurpark Moor – Veenland, Bargerveen is part of this international nature area.

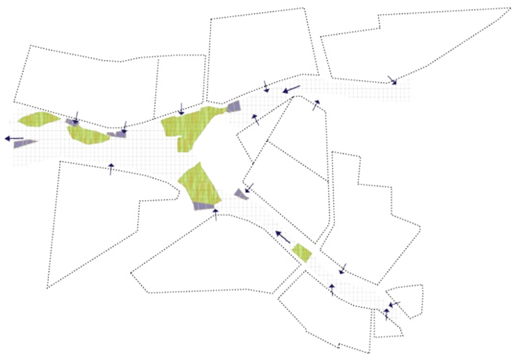


Figure 91: Model gradient (1) areas

Figure 92: Model polder (2) areas

(1) Süd-Nord canal, embedded in green, as entrance to the area

(2) Important infrastructure leading to the area embedded in the surrounding landscape

(3) Existing lay-out is kept within the raised bog nature areas as cultural history

(4) Water retention in stream valley

(5) The company Klasman-Deilmann plays an important role in the design. It played a large role in the reclamation of agricultural lands in the area. It has multiple establishments and a rail infrastructure throughout the area. This company and its infrastructure can play a role in the harvesting and transportation of biomass. The main location is located prominently at the edge of the plan area near the highway.

(6) Historical components are accentuated with trees such as this 'road for sheep'

(7) The stream valley as a clear distinctive unit

(8) Large-scale peat moss production fields with water basins. These peat moss farming sites are implemented in areas that are limitedly influenced by groundwater because they are on border of two watersheds. These sites used to be peat-extraction sites so the soil is not enriched with nutrients from decades of fertilisation.

(9) Differentiation between large and small-scale polders. This polder is relatively old which is reflected in its structure

(10) The canal forms a hard edge (visual and hydrological) between the design and surrounding landscape

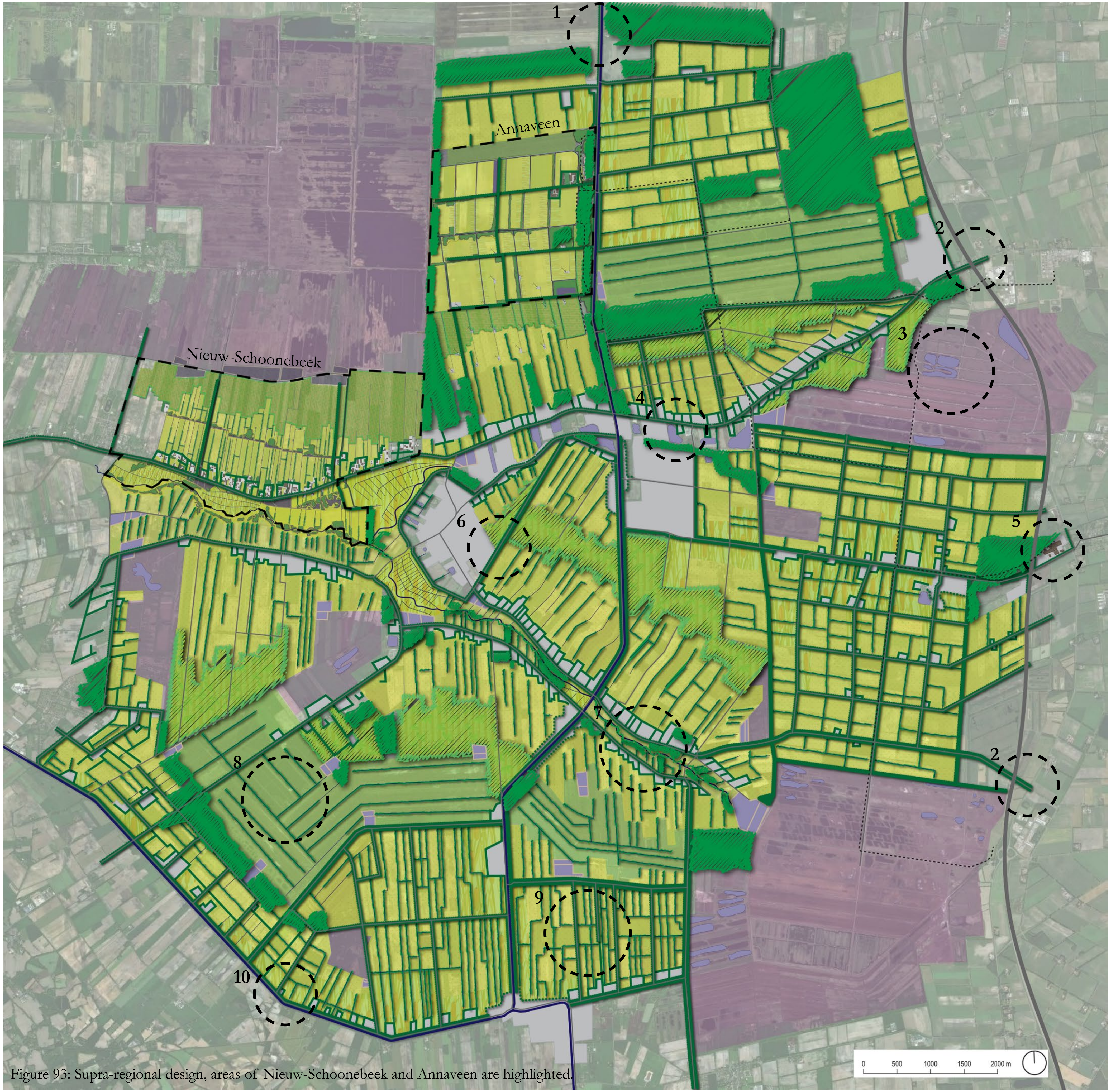


Figure 93: Supra-regional design, areas of Nieuw-Schoonebeek and Annaveen are highlighted.

Infrastructure: roads, highway, villages and farms

Land use: cattail, reed, willow and peat moss

Green structure: large lanes, woods and vegetation around farms

Conclusion

By implementing the models in the larger area of the supra-regional design, a diverse paludiculture landscape can arise with cattail, reed, willow, peat moss and the emergence of other species. The Landscape Machine is illustrated in Figure 94. The regenerated raised bog landscape is shown in Figure 95.

8.5 Succession

With the designs of Nieuw-Schoonebeek and Annaveen, the created models and the implementation of the models in the supra-regional design of Moor-Veenland the landscape will change because of the implementation of paludiculture and interventions in hydrology (ditches, weirs, dikes, remeandering). These changes are the scripted design interventions. When the scripted design interventions are being made, the landscape changes over time due to unscripted system responses. For instance, the amount of nutrients in the soil decreases, leading to a changing vegetation and productivity. This succession is simplified in four different stages, the initial, growth, yield and steady-state stage. In the following section these stages are shown (Figure 96-102) and described.

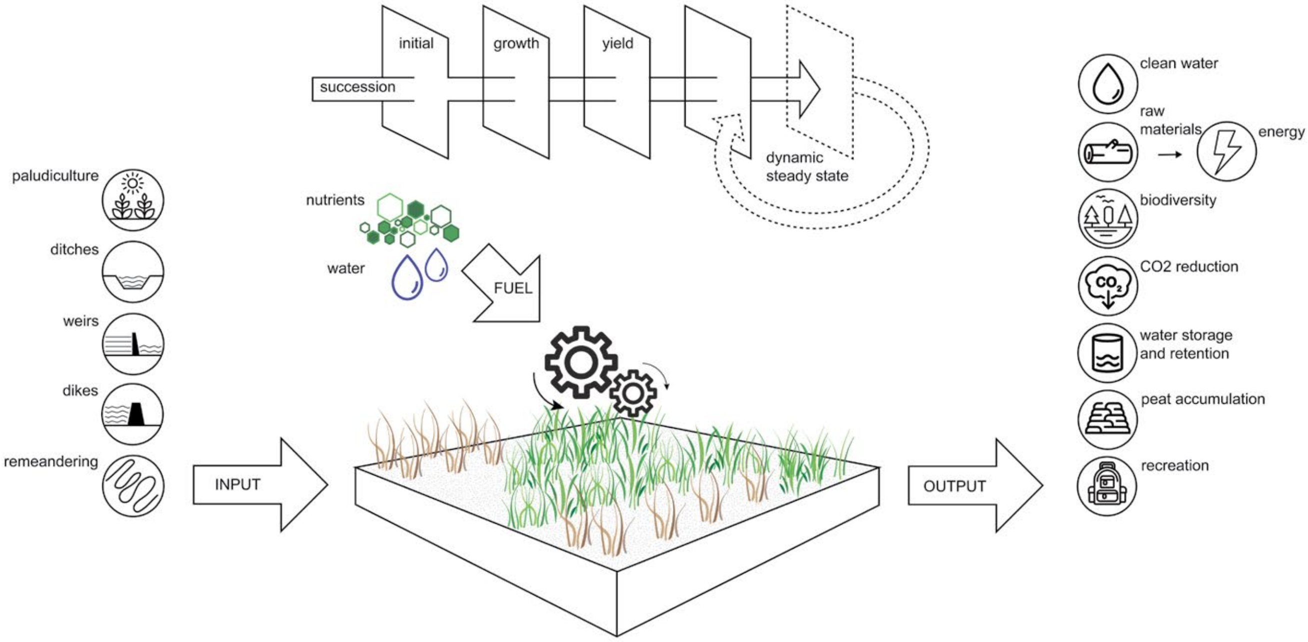


Figure 94: Metabolism of the paludiculture Landscape Machine in the Bargerveen landscape system. The Landscape Machine of the raised bog landscape. The input are the design interventions, the machinery of the landscape (natural processes) is fuelled by water and nutrients. The outputs are the ecosystem services and the succession is the way the landscape changes over time as a result of the input and fuel, which results in a changing output.

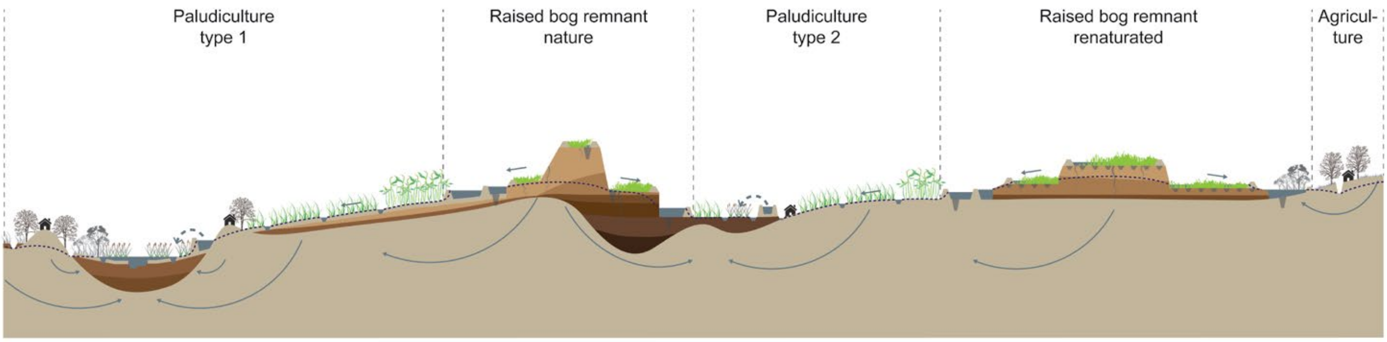


Figure 95: Schematic representation of a regenerated raised bog landscape

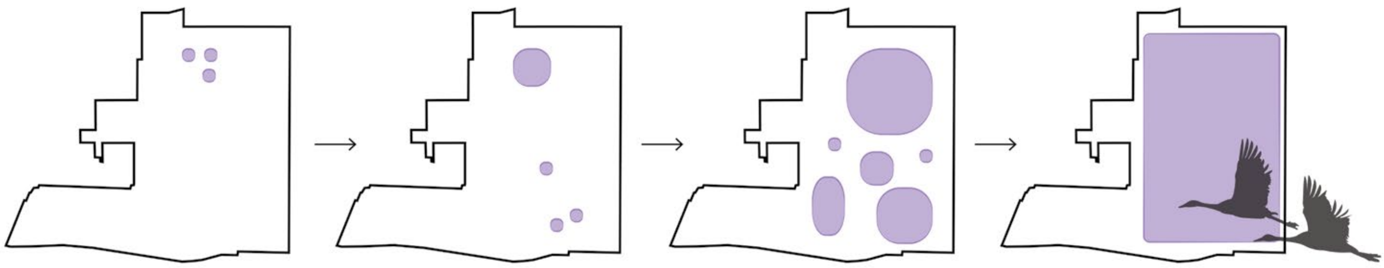


Figure 96: Succession of *Sphagnum* in raised bog nature areas

8.5.1 Initial stage

The scripted design interventions that are implemented in the models and in the supra-regional design are all related to hydrology. The change in land use, from conventional agriculture to paludiculture is the largest scripted design intervention. Four species are implemented in the designs, all of these are linked to soil and water properties. Another large scripted design intervention is the limiting of drainage by filling in ditches or making them more shallow and with less steep banks. The Schoonebeekerdiep stream will be re-meandered and shallowed to limit the draining factor, to improve the water storage and to add more dynamic in the system. In the areas where cattail will be cultivated, the Schoonebeekerdiep will spread out over a larger area to support the need for water and nutrients of this plant. In many parts of the design water basins are constructed, especially in the stream valley, raised bog nature areas and *Sphagnum* fields. The purpose of these water basins is to keep the area wet, either by buffering water or by providing counter pressure to limit the amount of seepage. In other areas small dikes will be constructed to stop the lateral flow of water and maximize the amount of infiltration. When these scripted design interventions are implemented in the right areas and in the right way, the regional water table should rise and the external hydrology of the raised bogs should be restored, resulting in the growth of this ecosystem (Figure 96).

8.5.2 Growth stage

During this stage the scripted design interventions will react with their surroundings. The growth stage is different for each implemented paludiculture crop. Reed for instance can be harvested for biomass after 3 years, cattail after 1 year. While *Sphagnum* takes a longer time to grow before it can be harvested in a sustainable way, approximately 3-4 years (Wichtmann *et al.*, 2016). The growth stage of willow is dependent on the use, when harvested for bioenergy a rotation of 2-4 years is most efficient but when harvested for twigs it can be done every year and for wood (furniture) it can take up to several more years. During this growth stage the plant will take up nutrient from the top layer of the soil, which is enriched with nutrients from decades-long fertilisation, and from the water. The amount of nutrients in the system will stay the same because there is not being harvested. The biodiversity will increase because new habitats are created and get the chance to grow. Because of the restoration of the external hydrology of the raised bogs, these ecosystems can grow once more and produce peat – which is not harvested.

8.5.3 Yield stage

During the yield stage the paludiculture plants are harvested. With the continuous harvesting of these plants, the amount of nutrients in the soil will decrease. This results in a decreasing productivity which can lead to a shift in production. For instance, the paludiculture fields with reed can now be harvested for thatching instead of biomass energy. Because of the more oligotrophic conditions, the quality of the reed is more suitable for thatching than for biomass energy (NBD, 2017). Also the continuous harvesting of plants and removal of nutrients from the system can lead to an increasing biodiversity. New habitats can arise, especially in areas that don't have excess nutrients in the soil, good water quality and a diverse set of other conditions. When looking at the design, these areas might be the so-called lagg-zone near the dike-ditch system as seen in model 1. In this permanently wet area, local groundwater will mix with rainwater, creating conditions that mimic the lagg-zone in an intact raised bog as seen in Figure 14. The vegetation that can emerge is seen in Figure 97 and illustrated in Figure 101. Also around the newly constructed wide and shallow ditches, new vegetation can arise when the nutrient availability will decrease. These areas are difficult to harvest because of their wetness and farmers can choose to cultivate these spots for a maximum biodiversity. Another area that can harbour a high biodiversity is the stream valley. Around the Schoonebeekerdiep there is space for the growth of swampy forests, with a highly diverse water quality and gradients in wetness, acidity and nutrient availability. When eutrophic conditions are present these vegetation consists out of alder (*Alnus*) swamp woods with *Phragmites*, *Typha* and *Carex*. In mesotrophic conditions there will be more *Salix* and in oligotrophic conditions Birch (*Betula*) woodlands.

Figure 97: The vegetation of this lagg-zone in Nigula (Southwest Estonia) consist out of: *Phragmites, Calla palustris, Betula, Salix, Alnus* and *Polytrichum* (van Duinen *et al.*, 2018).

8.5.4 Dynamic steady state stage

The steady state stage will be achieved when the amount of excess nutrients is removed from the soil and an equilibrium is achieved in biodiversity, the productivity of paludiculture crops and in the ratio between productive land (paludiculture) and unproductive land (nature). The dynamic in this system (Figure 102), apart from weather and climate conditions, comes from the manipulation of water and nutrient distribution as described in the following section.

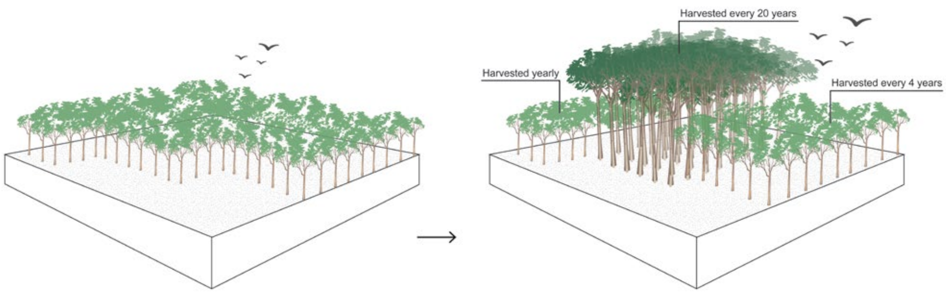


Figure 98: Succession of willow fields

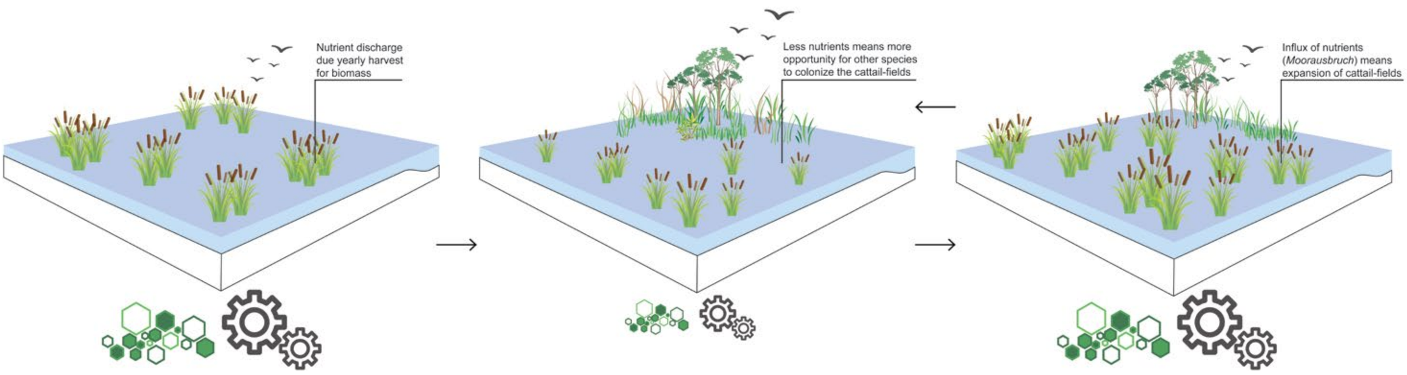


Figure 99: Succession of cattail fields in the stream valley

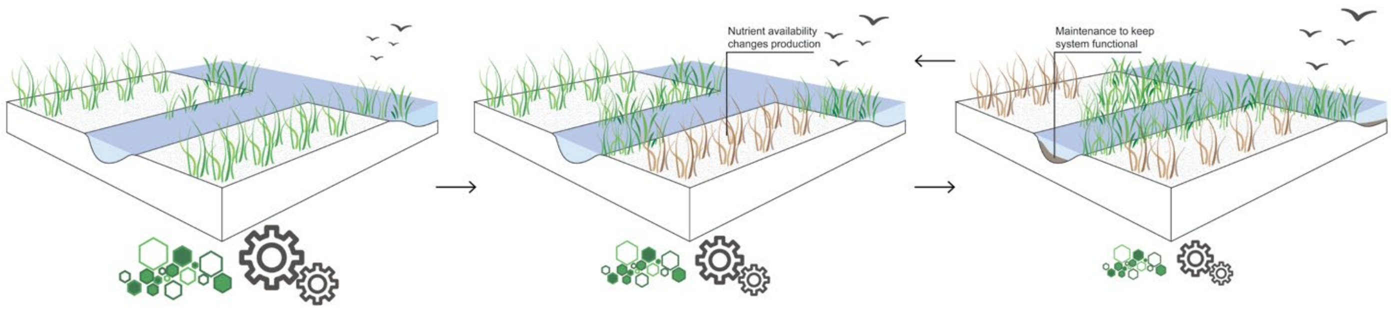


Figure 100: Succession of reed fields

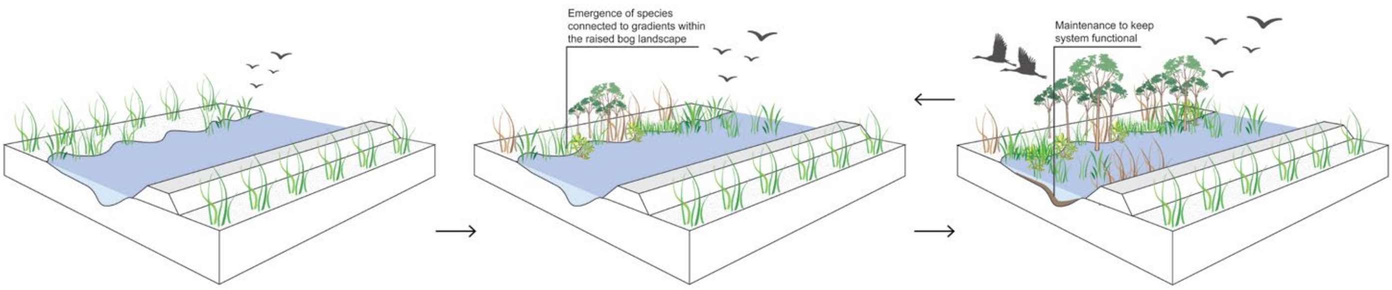


Figure 101: Example of natural succession in a lagg-zone

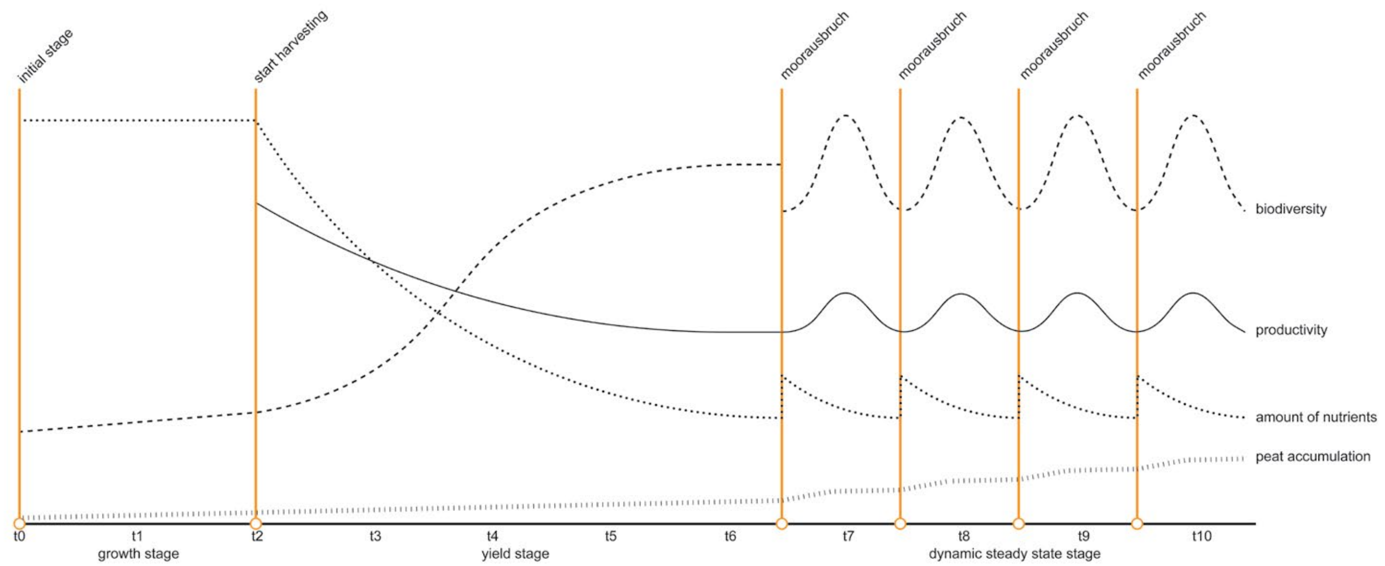


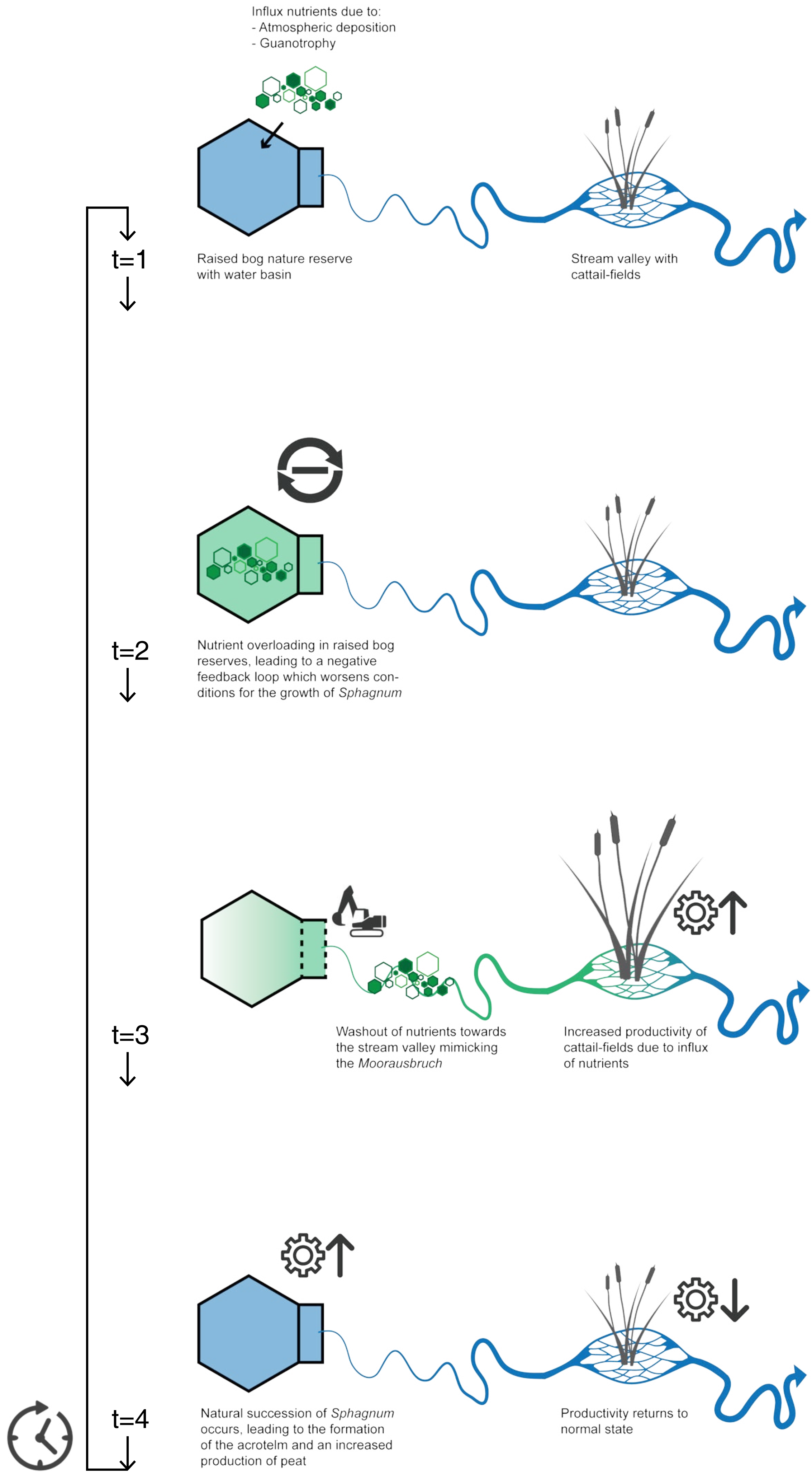
Figure 102: Dynamic development of the raised bog landscape.

8.6 Moorausbruch

The principles of the *Moorausbruch* or bog burst are implemented in the supra-regional design in all the nature areas that are raised bog remnants. The raised bog areas of Rühler Moor and Dalum-Wietmarscher Moor are the source of water for the Schoonebeekerdiep as can be seen in Figure 93 and 103, other areas are connected to the Schoonebeekerdiep valley with ditches. Once every decade or so, the water supply of a raised bog and its water basins is cleared by flushing it all out towards the stream valley of Schoonebeekerdiep. This should be done when heavy rainfall is expected so that the water supply will be replenished as soon as possible to prevent the drying out of peat. By clearing the water supply of nutrients in these raised bogs, the oligotrophic state is maintained and excess nutrients leave the ecosystem towards the stream valley in the Schoonebeekerdiep. In this stream valley the nutrients are then used for the production of cattail. When doing this, a certain dynamic will take place. When there is a bog burst, the nutrients will leave the raised bog nature area and enter the stream valley. This increases the growth of *Sphagnum* and therewith the rate of peat accumulation. The nutrients will be taken up by the cattail fields, increasing. Species along the Schoonebeekerdiep connected to eutrophic conditions will thrive. After a while the productivity of the cattail fields will decrease and the area of cattail may even shrink when other species, more adapted to mesotrophic conditions, will take over. With the implementation of this ecological process, the raised bog landscape will transform into a dynamic steady state system with a recycle system for nutrients. This process of *Moorausbruch* is illustrated in Figure 104.

Figure 103: Raised bog areas connected to the stream valley.

> Figure 104: Process of *Moorausbruch* illustrated. 1: Raised bog nature areas gather a surplus of nutrients over time due to atmospheric deposition and guanotrophy. 2: Too much nutrients in the raised bog ecosystem, resulting in a shift of vegetation and declined productivity of *Sphagnum*. 3: The water supply of the raised bog with its nutrients is flushed out by human involvement towards the stream valley where the water and nutrients are used for the cultivation of cattail, resulting in an increased productivity. 4: Water supply is refilled, maintaining oligotrophic conditions. Cattail fields decline in productivity while nutrient supply declines.



Influx nutrients due to:
- Atmospheric deposition
- Guanotrophy
t=1
Raised bog nature reserve with water basin
Stream valley with cattail-fields
t=2
Nutrient overloading in raised bog reserves, leading to a negative feedback loop which worsens conditions for the growth of *Sphagnum*
t=3
Washout of nutrients towards the stream valley mimicking the *Moorausbruch*
Increased productivity of cattail-fields due to influx of nutrients
t=4
Natural succession of *Sphagnum* occurs, leading to the formation of the acrotelm and an increased production of peat
Productivity returns to normal state

9 Conclusion

The objective of this thesis is to contribute to the regeneration of the raised bog landscape by proposing a set of design guidelines (models) for the large-scale implementation of paludiculture. This objective is reached by answering the main research question which is: what design guidelines for a paludiculture Landscape Machine can help to regenerate raised bog landscapes? To answer this main research question, a case study is done in the Bargerveen landscape system in which multiple sub-research questions are to be answered. The first one is about the potential of Landscape Machine theory for designing a regenerative raised bog landscape with paludiculture. The second is about the functioning of the Bargerveen landscape system. The third one is about the implementation of a paludiculture Landscape Machine in the Bargerveen landscape system. In the following sections these questions are answered and conclusions are drawn.

SRQ1: What is the potential of Landscape Machine theory for designing a regenerative raised bog landscape with paludiculture?

When looking at both Landscape Machines and paludiculture, in the light of regenerating the raised bog landscape, it becomes clear that they are interconnected. Regeneration seeks to 'create anew', a higher and more worthy state. It embodies the co-evolution of natural and human processes. Paludiculture makes a strong case for the mixing of nature and agriculture, and the designing of this marriage between agricultural innovation and habitat development is exactly what Landscape Machines is all about. Therefore it can be stated that Landscape Machines and paludiculture share the same philosophical background but are from different fields of expertise. The concept of paludiculture can be seen as a proven technology, but while it is studied extensively over the course of many decades and in many facets, it is mostly explored in an ecological-modernist way by Wichtmann *et al.* (2016) and fails to translate it in workable spatial concepts or to embed it in the larger system of the raised bog landscape. While the theory of Landscape Machines takes a more holistic approach and sees the landscape as a living system, applying living system theory and thinking in landscape design. The starting point of this design theory is a malfunction in the landscape or a dysfunctional situation which is exactly what is happening in the Bargerveen landscape system. Therefore, paludiculture and Landscape Machine theory complement each other when designing a regenerative raised bog landscape (in the Bargerveen landscape system). One of the critiques on Landscape Machines is that a lot of the assumptions made were considered wishful thinking and thus lacking the scientific validity. The scientific validity and concreteness of paludiculture can prove useful within the holistic but merely theoretical approach of Landscape Machines while designing a regenerative raised bog landscape. By combining the concept of paludiculture and Landscape Machine theory, both shortcomings can be resolved and a better outcome can be achieved. Concluding, the potential of Landscape Machines for designing a regenerative raised bog landscape with paludiculture is high. This is especially the case when considering the restoration of raised bog nature reserves.

SRQ2: How does the raised bog landscape of the Bargerveen landscape system function?

For a successful regeneration of the raised bog landscape, it is essential to understand how the Bargerveen landscape system currently functions and how it functioned in the past. Therefore it is researched how the raised bog ecosystem functions, how it is degraded and what is being done to restore it.

The raised bog ecosystem is an important ecosystem that is formed thousands of years ago and has developed itself ever since. Due to the extreme conditions and gradients in wetness, acidity and trophic degree it harbours highly specialized plants and animals. The raised bog consists of a catotelm, an almost impermeable layer of decomposed peat saturated with water, and an outer shell, the acrotelm which consists out of living plants. Due to these characteristics, it is a resilient, self-regulating and highly productive ecosystem with peat moss or *Sphagnum* playing the main role. Besides the biodiversity, the raised bog ecosystem provides numerous other ecosystem services such as production of fresh water, water retention and carbon sequestration. The area of Bargerveen was part of the larger raised bog complex of Bourtangerveen, the largest one in North-western Europe. This raised bog complex was a combination of individual raised bogs with clear boundaries and patterns. Bargerveen is a part of such a raised bog. It can be concluded that this ecosystem, when intact, is a well-oiled machine with important services, certainly when taken climate change into account (Figure 105 and 106).

The degradation of the Bargerveen area can be distinguished in three phases. Namely, the early agricultural use of the edges of the bog complex called 'randvervening', the systematic peat cutting and subsequently agricultural reclamation of the so-called 'dalgronden' and the drainage of peatlands which continues up until this day. These two types of agricultural landscapes are stereotypical for the Bargerveen landscape system. The landscape of 'randvervening' is characterised by a reclamation axis, often an important road, with farms and accompanying vegetation. The landscape has a long agricultural tradition ('oude bovenveencultuur') and the parcels are small irregular strips of land. The other agricultural landscape of 'dalgronden' is a young landscape and characterised by its wide open fields and grid of infrastructure and vegetation.

The raised bog complex of Bourtangerveen is degraded in such a way that only relatively small bog remnants continue to exist, such as Bargerveen. These raised bog remnants have lost the capability to function like a proper raised bog ecosystem. There are also still a lot of agricultural lands within the raised bog landscape that have remaining peat layers in the soil, which are subject to degradation because of drainage. This causes the process of peat oxidation with many negative effects such as soil subsidence and CO_2-eq emissions. It can be concluded that the current raised bog landscape is strongly degraded and continues to degrade because of agricultural drainage (Figure 107 and 108).

It can be stated that Bargerveen is a dead ecosystem. In only 3 of the 2100 hectares, *Sphagnum*, the most crucial plant of the raised bog ecosystem, is present. This plant is essential for restoring the acrotelm which is responsible for the functioning of this ecosystem. To restore this ecosystem according to Natura 2000, the following goals are set: expansion in quality and quantity of the active core of *Sphagnum*, initiating the formation of peat and development of edge zones (gradients) in the raised bog landscape. These goals are not being met and it can be concluded that this has to do with the hydrological conditions and a surplus of nutrients. The construction of buffer zones and water basins around Bargerveen help to restore the internal hydrology but the areas of Schoonebeekerveld and Amsterdamsche Veld need to have their external hydrology restored in order to increase the possibility of *Sphagnum* to grow. To accomplish these goals, interventions should be taken outside of the nature area, to restore the external hydrology and to create possibilities for gradient restoration. Two areas in particular come forward when examining the hydrological influence on Bargerveen, which are Nieuw-Schoonebeek ('randvervening') and Annaveen ('dalgronden'). It is in these areas, which have the largest hydrological influence, that measures need to be taken.

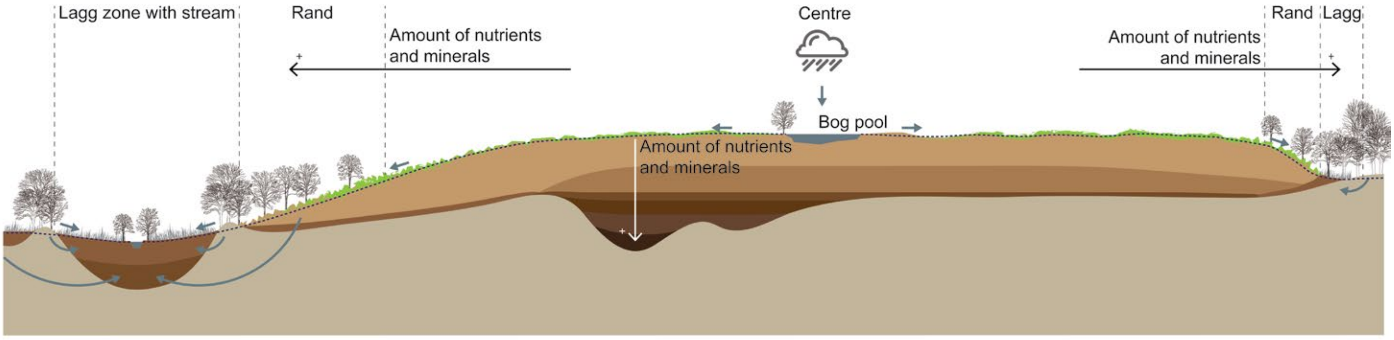


Figure 105: Schematic representation of an intact raised bog

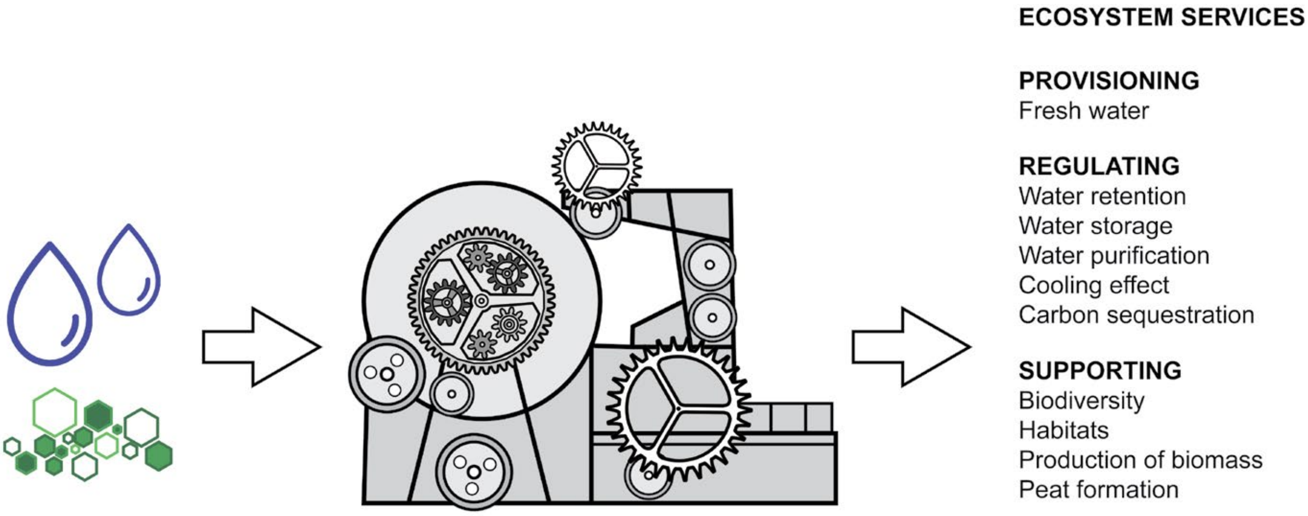


Figure 106: The intact raised bog landscape, a well-oiled machine with important ecosystem services which functions best under wet and nutrient-poor conditions.

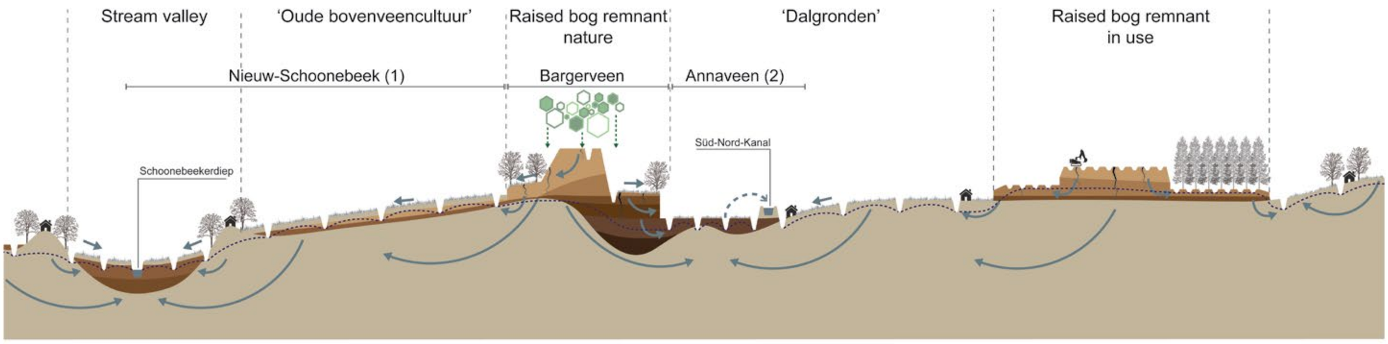


Figure 107: Schematic representation of the degraded raised bog landscape

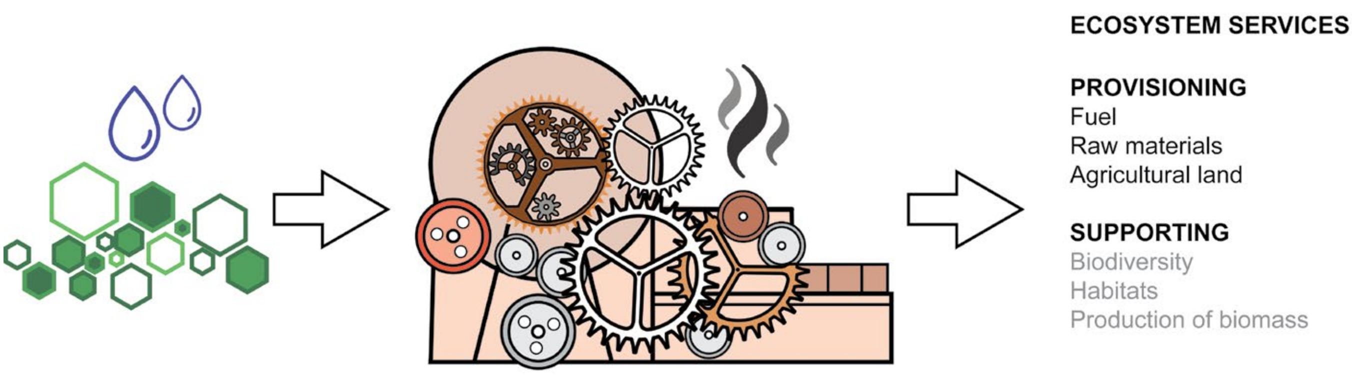


Figure 108: The degraded raised bog landscape. Conditions have changed from nutrient-poor to nutrient-rich and from wet to dry because of agricultural use. The machine (degraded raised bog landscape) has been changed in set-up and is used in an unsustainable way, it produces more provisioning ecosystem services which is at the expense of other ecosystem services.

SRQ3: What would be a way to create a regenerative paludiculture Landscape Machine in the Bargerveen landscape system?

Research through designing (RTD) was used to combine and apply the knowledge and insights that were gained during the research for design process (answers of SRQ1 and SRQ2). This results in an exploration of a possible regenerative paludiculture system in the raised bog landscape as designs in the landscape system of Bargerveen. This is done by designing in the area of Nieuw-Schoonebeek ('randvervening'), Annaveen ('dalgronden') and in the nature reserve Moor-Veenland.

The raised bog landscape is regenerated by restoring the (internal and external) hydrology of raised bog remnants and the implementation of a paludiculture system to ensure productivity and biodiversity (gradients) as seen in Figure 109. This ensures a sizeable CO_2-eq reduction (0,176-0,264 megaton CO_2 until 2030 when looking at the design for Nieuw-Schoonebeek which is 17% of total reduction for agricultural land use when looking at the climate table). CO_2 sequestration is possible when peat moss begins to grow in the raised bog nature areas or on lands that are permanently under water. Possible sequestration in Bargerveen (2.100 hectares) until 2030 range from or 0,025 to 0,136 megaton CO_2. Concluding, CO_2-eq emissions can be reduced by a sizeable amount when these lands are rewetted for paludiculture and CO_2 sequestration is possible in Bargerveen if restored. Even the goals stated in the N2000 management plan can be met as shown in the design of Nieuw-Schoonebeek. Outside of CO_2-eq reduction or possible sequestration and meeting the goals of management plans, the regenerated raised bog landscape provides numerous other services like: production of biomass, fresh water, biodiversity, water retention and storage, nutrients filtering, peat accumulation and recreation (Figure 110).

With – simple – design interventions such as paludiculture, filling in ditches and making them more shallow, remeandering of the stream, dikes and weirs which ensure hydrological manipulation and nutrient distribution, the problematic situation of the degrading raised bog landscape can be solved. With the two designs for Nieuw-Schoonebeek and Annaveen, Bargerveen and the surrounding landscape can be regenerated. When these designs are abstracted into a set of design guidelines (models) and these models are implemented in the larger landscape system of nature reserve Moor-Veenland; a larger, more sophisticated regenerative raised bog landscape can emerge by linking multiple raised bog remnants together that form an unity which is connected to the stream valley. The succession of this regenerative landscape is described in four stages. With the manipulation of water and nutrients, a dynamic steady state system can emerge, resulting in a constant change in biodiversity, productivity, amount of nutrients and peat accumulation. This can be done by simulating the process of *Moorausbruch* which ensures optimal conditions for the growth of *Sphagnum* in raised bog remnants and supplies nutrients to the cattail fields in the stream valley.

With this regenerative paludiculture Landscape Machine (Figure 111), the landscape system of Bargerveen is made climate adaptive (water buffering) which increases the self-sufficiency in water supply. This regenerated landscape can even play a role in climate mitigation (CO_2-eq reduction and sequestration) and provides opportunities for biodiversity, recreation and sustainable production chains. But most of all it can create a landscape in which nature and agriculture go hand in hand because the cultivated crops are bound to soil and water properties that complement the restoration of the raised bog ecosystem of Bargerveen according to the goals stated in the N2000 management plan.

MRQ: What design guidelines for a paludiculture Landscape Machine can help to regenerate raised bog landscapes?

The objective of this thesis is to contribute to the regeneration of the raised bog landscape by proposing a set of design guidelines (models) for the large-scale implementation of paludiculture. This is done by implementing the concept of paludiculture in a case study on the Bargerveen landscape system while using the design theory Landscape Machines, to test the possibilities to regenerate the raised bog landscape. As is shown in SRQ3, the goal of regenerating the raised bog landscape can be accomplished, according the designs and accompanying text.

With the creation of two models, consisting out of abstracted guidelines from the designs, for two stereotypical agricultural landscapes within the raised bog landscape, general applicable knowledge is gained that can be used in future plans or research that encompasses the use of paludiculture in the raised bog landscape or the restoration of raised bog remnants. The model for type 'randvervening' is called *gradient* and can be found in section 8.2.4, Figure 70. The model for type 'dalgronden' is called *polder* and can be found in section 8.3.3, Figure 85. This answers the main research question.

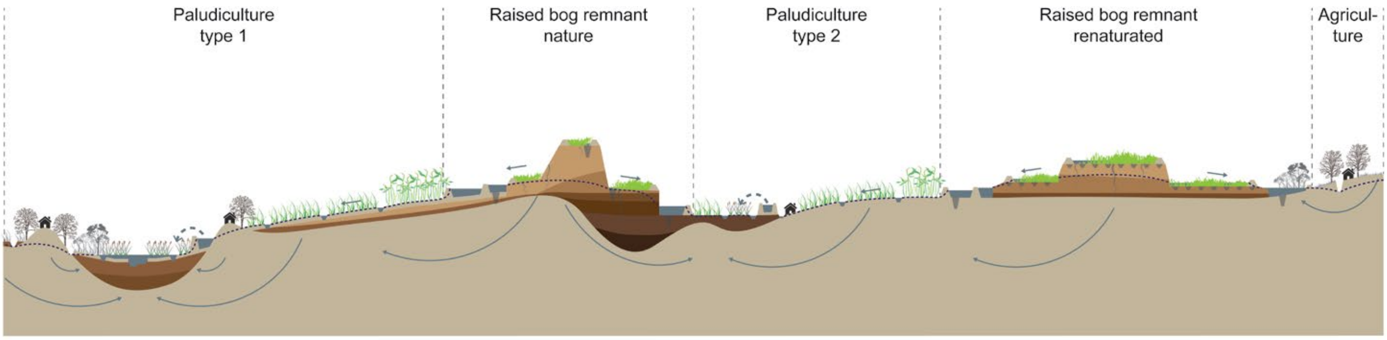


Figure 109: Schematic representation of a regenerated raised bog landscape

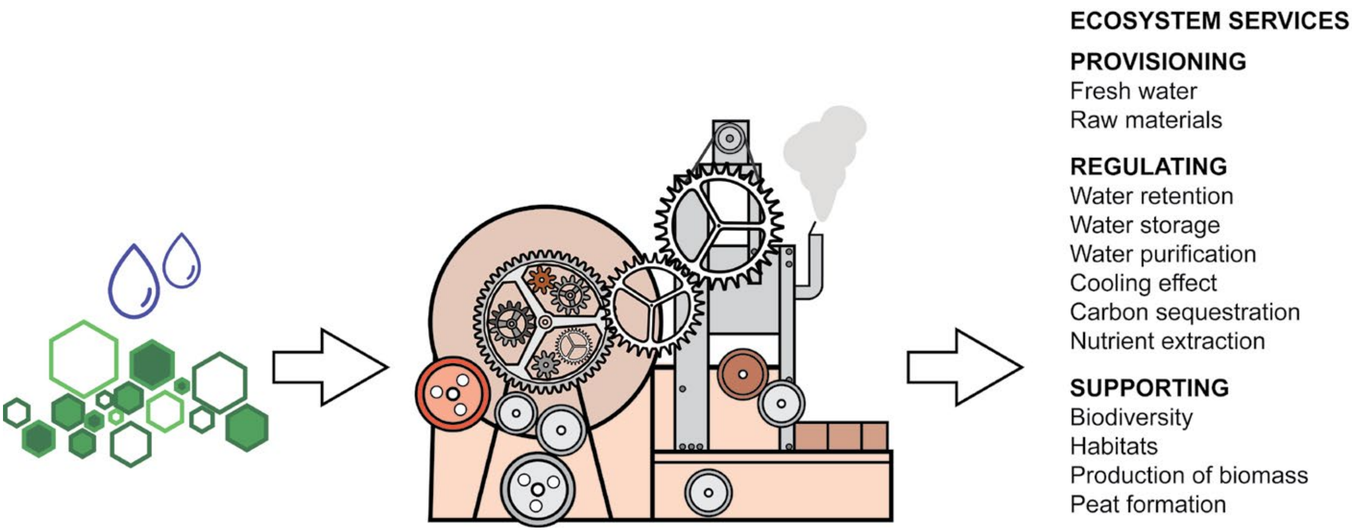


Figure 110: The regenerated raised bog landscape. The dry and nutrient-rich conditions have not changed. The machine (the landscape) needs to be regenerated, by demolishing and adding parts to the machine it can be used in a sustainable way. When regenerated, the machine can provide an extensive amount of ecosystem services.

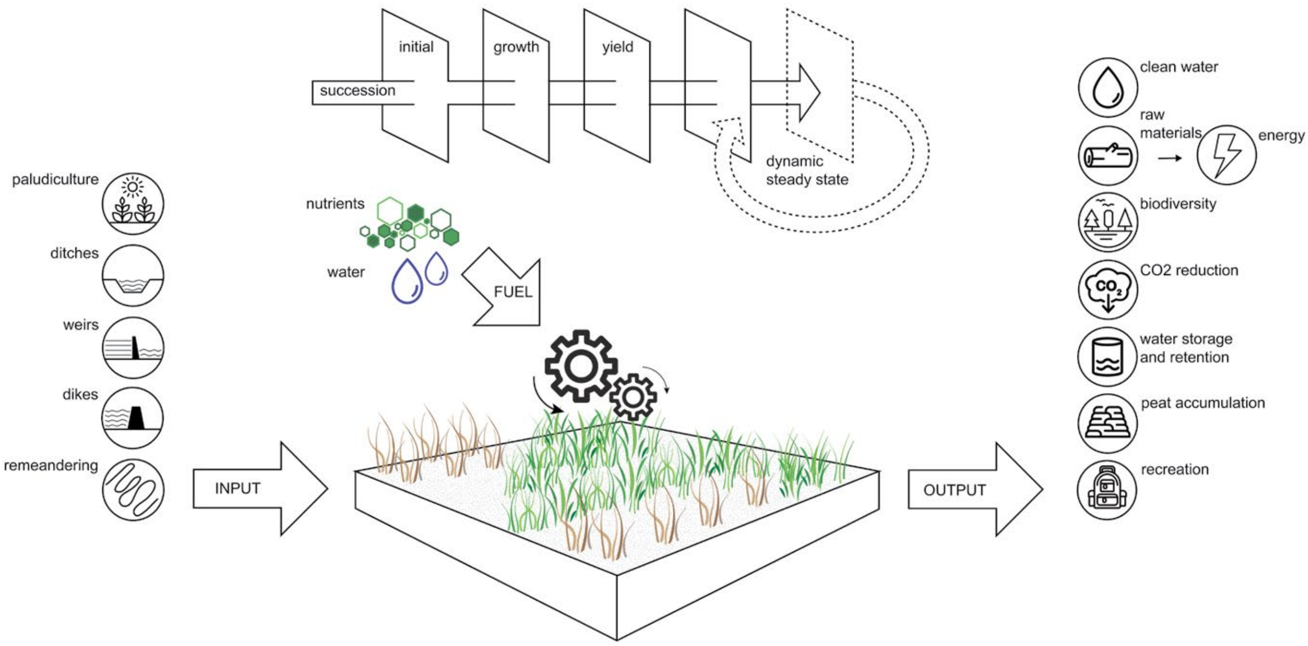


Figure 111: Metabolism of the paludiculture Landscape Machine in the Bargerveen landscape system. The Landscape Machine of the raised bog landscape. The input are the design interventions, the machinery of the landscape (natural processes) is fuelled by water and nutrients. The outputs are the ecosystem services and the succession is the way the landscape changes over time as a result of the input and fuel, which results in a changing output.

10 Discussion

In this chapter the main results are discussed and a reflection on reliability and validity is given. Furthermore, the concept of paludiculture and Landscape Machine theory are reflected and some footnotes are given. This thesis was written to contribute to landscape architecture research and practice, and to society in general. This contribution is threefold. Firstly, this thesis shows how buffer zones around raised bog nature reserves can be designed for productive use. Secondly, it shows how, with the use of Landscape Machine theory and the concept of paludiculture, the regeneration of the raised bog landscape can look like and what possible outcomes it can provide. Thirdly, it gives a possible outcome of how the CO_2 problem can be tackled in the raised bog landscape and how this can create exciting possibilities and opportunities, something which does not include the loss of productive land.

Methodological reflection: reliability

The reliability of this thesis is ensured by documenting the used sources and methods to collect and analyse data in the research for design part (SRQ 1 and 2).The design theory of Landscape Machines also gives a framework on what is important and what to research. In the design process (SRQ 3), reliability is ensured by using the design theory of Landscape Machines, documenting sketches and by clearly stating the train of thought and the direction in which the design goes. Full reliability can never be assured because designing is a creative process which is influenced by personal experience. Another reliability issue is that the interview was semi-structured thus different interviewer could get different results. Other shortcomings in the work are discussed below. This includes a discussion on Landscape Machines theory, the selected crops of paludiculture and its economic feasibility and productivity.

Landscape Machines theory

Like every other scientist, the makers of Landscape Machine theory stood upon the shoulders of giants. Their theory is built upon that of McHarg (1969) and Hough (1995) as stated by the authors. It is possibly further influenced by the 'Wageningen-approach' practised by Meto Vroom and Klaas Kerkstra. Also the systemic approach by Van Leeuwen (1973) may have been an inspiration. It was certainly inspired by H.T. Odum (1994), who developed Systems Ecology, because they use his type of diagrams. Roncken, Stremke and Pulselli state that their theory adds to that of McHarg and Hough's because it is not the current or past landscape that forms the foundation for future developments but a new, artificial, landscape system. Other than that, Landscape Machines borrows theory from the field of evolutionary thermodynamics. Landscape Machine is also a design theory, serving as a middle ground for designers and scientist, contributing to making landscape architecture more scientific and systems theory more applicable in practise.

By seeing and analysing the landscape as a machine with and input, reaction and output a certain insight occurred in how the machine once worked, how we overused and misused the machine and how the current landscape is a result of this. By understanding the machine and what's wrong with it, it also became clear which gears and levers of the machine to add or remove in order to regenerate it.

It is incredibly brave, or risky, to reduce something as complex as a landscape to a simple diagram of a machine (or living system) with an input, reaction and output. The complexity of the landscape is enormous and so are the interactions within the landscape. For example: important parameters of Bargerveen are not known such as infiltration resistance, water balances, the variable resistances of the bog footing and the thickness and location of boulder clay layers. It is therefore impossible to know every interaction in the landscape and the data can never fully cover the complexity of it. The same applies when describing the four phases of succession. There is no data about the quality and quantity of nutrients in the soil, thus it remains a mystery how long the crops can stay highly productive – although this will probably be decades as shown in research by Geurts *et al.* (2017). By understanding the landscape and reducing it to a simple living system as described in Landscape Machine theory, it can give insight in which processes and which inputs need to change in order to regenerate the landscape. This is a very refreshing insight in which the reductionism is necessary to comprehend the complex relations in the landscape. This theoretical approach of the landscape is described by Roncken, Stremke and Pulselli (2014); "Landscape Machines are only developed within academia and are purely speculative: they are paper realities only".

Paludiculture: willow, reed, cattail and peat moss

The choice of selecting these crops for designing a regenerative paludiculture landscape is based on the model of Van Duinen (2016) for selecting the right paludiculture crops for the specific situation (Appendix 2). It uses species from the database for potential paludiculture plants (DPPP) in which more than 1.000 species are appointed. The model of Van Duinen takes into account water levels, soil, nutrients, economy and ecology for selecting the best crops. Because this is a whole study on its own, I made a shortcut for selecting the best crops. Because of his extensive knowledge of the raised bog landscape, both theoretical and practical, I interviewed van Duinen directly and asked him which species are the best for large-scale implementation of paludiculture in the raised bog landscape. His answer was reed, cattail, willow and peat moss. These crops were also extensively described in the book *Paludiculture – productive use of wet peatlands* and other sources, granting me a good overview of how these crops function. These species are also 'best practice' crops, they are 'proven' to work. They can be cultivated in a productive way under wet circumstances in the raised bog landscape and be economically profitable (Appendix 4). An argument you could make against these selected paludiculture crops in this case, is that land which is used for food or fodder (these lands used to be meadows or maize land) is transformed into land which is not. It is true that large-scale implementation of these crops decrease the amount of land that produces food. Although some products can be used as fodder for cows and other products can be potentially processed for human food. Other paludiculture crops can be implemented that can be used for human food such as cranberries or water buffaloes can even graze the wet peatlands, producing milk, cheese and meat. However, the chosen crops have other benefits that weigh more heavily and fit better within the conditions of the site.

Paludiculture: economic feasibility and productivity

Paludiculture seems like a good solution for specific landscapes – such as the landscape around Bargerveen. The productive use of wet peatlands is however difficult to achieve when looking at economics. The plants which are cultivated (reed, cattail, willow and peat moss) do not qualify as agricultural crops within the framework of the European Union. This means that it is not likely farmers will switch from agriculture to paludiculture because 1) their income directly decreases because of ceasing subsidies 2) the initial costs (planting, machines) are high 3) the first and second year no harvest can take place because the crops need to grow 4) the market for these crops and their products is uncertain on the long term 5) productivity of the crops and thus income on the long term are uncertain. Over and above this, paludiculture only works in large consecutive areas thus if landowner A agrees, landowner B should also agree. This is making bottom-up initiatives quite a challenge. Possible solutions can be innovative farmers, land funds that invest in nature-inclusive agriculture or the government buying up land and leasing it to farmers. It is not unthinkable that these problems will be addressed in the future considering the climate policy and the agricultural policy of the European Union, making it more culturally, socially and financially accepted. The new minister of agriculture, nature and food quality; Carola Schouten, already presented a new, more sustainable, vision on agriculture in which paludiculture can certainly perform a role. Legislation should be made considering paludiculture, their crops and possible production chains to make it economically more feasible. When looking at the larger perspective it seems crooked that the European Union economically supports conventional agriculture on peatlands, which is anything but sustainable (Appendix 1) but blocks the path of a possible solution, paludiculture. As the general consensus is towards sustainability, the concept of paludiculture as a form of sustainable land use on peatlands will gain traction. As the current degrading use continues, more and more negative effects will become visible and steps are to be taken towards sustainable development of the raised bog landscape.

Another point of discussion is the possibility of declining production. The plant get their nutrients from the soil which is enriched with nutrients from decade-long fertilisation. Especially reed and cattail are high productive plants and can take lots of nutrients from the water and soil (van Duinen *et al.*, 2017). By harvesting these plants, nutrients are removed from the system. The limiting factor for nature development on enriched soils is the discharge of nutrients, especially phosphate. Paludiculture can be a stepping stone from conventional agriculture to nature development by discharging nutrients from the system. Reed and cattail can discharge phosphorus very efficiently, up to 80 kg/ha/y (Geurts *et al.*, 2017). Even then it can take up to decades before the soil can be characterised as nutrient-poor. Furthermore, nitrogen is the leading factor for the growth of cattail. A supply of nitrogen-rich water improves the filtering capacity and biomass production of cattail and reed. But also with a low supply of nitrogen a biomass production can be assured which is comparable to grasslands (10 tonnes dry matter/ha/y), this low supply of nitrogen is always available because of atmospheric deposition. In some cases, if it limits growth, it might be necessary to add potassium, magnesium or calcium (Geurts *et al.*, 2017). Concluding, paludiculture crops like cattail and reed can be highly productive due to nutrient availability in the soil, atmospheric deposition and supply of nitrogen-rich water. Declining productivity can be dealt with in threefold, adapt: switch to new production type (e.g. harvest reed for thatching instead of biomass energy), fight: add nutrients to keep production on level, evolve: switch from production use to nature use.

Methodological reflection: internal validity

To answer the main research question, different methods of data collection were used: collecting data from literature, making observations in the case study area resulting in photographs and notes during multiple fields visits during multiple seasons, interviewing expert and visiting a symposium. This triangulation of what does the literature state, what is the situation on the ground and what does an expert say, supplied with enough accumulated evidence to support the train of thought that is laid out in this thesis. However, there are limitations on the quality of my answer to my main research question. The main points are discussed below and include the selected areas for design and the lack of (appropriate) data.

Paludiculture: main source is focused on fen peatlands

For the concept of paludiculture I used the book *Paludiculture – productive use of wet* peatlands' by Wichtmann *et al.* (2016) as the main source. This book is largely based on the productive use of fen peatlands, which are intrinsically different from bog peatlands. Because knowledge of paludiculture in bog peatlands is limited, careful assumptions have been made when assessing the applicability of paludiculture in the raised bog landscape. These assumptions are also informed by my knowledge of the raised bog landscape. Additional literature study and an interview with an expert (Appendix 6) are employed to further strengthen the claim of paludiculture in the raised bog landscape.

Bog footing (veenbasis)

The bog footing (veenbasis) is a relatively unknown concept and little research is done on this subject. One thing is certain and that is its importance in the restoration of the hydrology of raised bog remnants. The groundwater should reach in the bog footing to provide stable water levels in the raised bog. It is claimed that damage to the bog footing because of drought is an irreversible process which is disadvantageous when looking at the amount of seepage from raised bog remnants. This seems to me like an extra reason to restore the hydrology because otherwise the damage will be worse, which reduces the changes of restoring the raised bog remnants. The entire bog footing of Bargerveen and the amount of damage to it is not known, but educated guesses are being made by Sevink *et al.* (2014). The lacking of data is underpinned by van Guldener *et al.* (2017) as they state that a complete geohydrological model of the area is missing. The educated guesses are used as data for this thesis.

Choice of selected location designs

I am quite certain that the locations of Annaveen and Nieuw-Schoonebeek are two good locations to design for the purpose of restoring the (external) hydrology of Bargerveen as they have a large hydrological influence on Bargerveen. This is the conclusion I made after analysing the landscape, height maps and isohypses. Supporting evidence are the hydrological models in Appendix 3. In the supra-regional plan with other raised bog remnants this analysis to pinpoint the areas with largest hydrological influence is not done because of the lacking of data (these are not Dutch areas) and time.

Methodological reflection: external validity

The usefulness of the results are discussed below.

Validity of created models

The models which consists out of a set of design guidelines. Design guidelines have their limitations and uncertainties as described by Prominksi (2017). He states that due to their innovative character it is impossible to provide a list of criteria which is valid for all design guidelines. However, both models are representative for a type of landscape which can be found in the raised bog landscape. Their validity is tested when I abstracted the designs of Nieuw-Schoonebeek and Annaveen into models and implemented these models in the larger landscape system in the supra-regional plan. The created models could be implemented without much trouble and were improved to local conditions where necessary. These models can be used for the restoration of raised bog remnants and the regeneration of the raised bog landscape. It can be possible that these models are representative for other raised bog landscapes as well because they derive back to two types of reclamation, the small-scale at the edges and the large-scale at the centre. The models probably have the most success when examining the landscape of the same type of bog peatland (*Plateauregenmoore*), which appear in north western Europe. Another point Prominski (2017) is making is that design guidelines have to be adapted to the specific situation of the site, thus they can only be used by skilled landscape architects to produce good designs.

Reflections

In the first section, this research is positioned within the existing body of knowledge. In the next sections Landscape Machines theory is reflected upon, was it a useful theory, what elements were not used and how did the designs fit within the framework of COOS. Then the need to restore raised bog ecosystems is discussed within the light of climate change. In the next section an argument is discussed that might be used against paludiculture. The last section gives recommendations for future research.

Position of this research in the existing body of knowledge

This research is about the large scale implementation of paludiculture in the raised bog landscape. It can therefore be seen as an addition or extension of the research done on paludiculture at the University of Greifswald. The comprehensive book *Paludiculture – productive use of wet peatlands* is mostly focussed on fen peatlands and the little to no principles are given of how to design with paludiculture and certain crops (especially in the raised bog landscape).

During the research it comes forth that large scale implementation of paludiculture can be extra beneficial when coupled to the restoration of raised bog nature reserves. In the report *Duurzaam herstel van hoogveenlandschappen* of van Duinen *et al.* (2017) they reason the other way around. They state that the buffer zones, which are needed to restore the raised bog nature reserves, can have secondary functions such as biomass production (which is basically paludiculture). In the proposed designs, this buffer zone (or paludiculture fields) is so extensive that it is not really a buffer zone anymore but has a primary function of production and a secondary function as (hydrological) buffer for the raised bog nature reserve. This might be the difference between internal hydrology and external hydrology as described in section 7.3 or the difference between the meso-scale of the raised bog ecosystem and the macro-scale of the raised bog landscape in which it is embedded. Therefore the research in this thesis can be seen as a 'buffer zone' with a primary production function on macro-scale that restore the external hydrology.

Halfway through this research, a thesis report was published on a paludiculture buffer around Bargerveen, called Pilot paludicultuur by Schepers (2018). This thesis explores the organisation of paludiculture crops on a plot of land next to Bargerveen by providing three scenarios. The thesis of Schepers is focussed on the small scale implementation of paludiculture and uses strong analytical tools to support its claims. This thesis is focussed on the large scale implementation of paludiculture, using a holistic approach to support the results. The other difference is that this thesis provides a long term vision and is more conceptual, while Schepers his thesis is more technical.

Landscape Machines theory: Fremdkörper and COOS

Fremdkörper, non-endemic resources, need to be introduced in the machine to provoke new system responses according to Roncken, Stremke and Pulselli (2014). In several theses that use Landscape Machine theory, this Fremdkörper is some dramatic element that should be imported to get a certain reaction in the landscape such as oil rigs or polluted soil. In this thesis it is shown that this Fremdkörper is not necessary in the sense of introducing some external element, the way to get new system responses can also be as subtle as a few weirs and dikes, altering the ditch structure and remeandering of the river.

Assessment COOS

Confined *Boundaries*: clear boundaries/units based on hydrology. Confined mostly by the canal, stream, dikes or roads. Within the Bargerveen landscape system multiple identifiable features exist such as the stream valley, agricultural lands and raised bog remnants. Input/output can be specified qualitatively and quantitatively.

Open *Connectivity*: Inflow/outflow water – canal

Outflow clean water – stream

Inflow (atmospheric deposition + guanotrophy) /outflow (water + biomass) nutrients

Outflow paludiculture products

Permeable system boundaries for water and nutrients.

Ontic *Historical dimension*: Existing infrastructure as functional part, agricultural history as inspiration for future developments, recreating natural conditions to restore raised bog ecosystem.

Steady state future: New equilibrium will be reached when nutrient availability declines. Dynamic will be ensured by the nutrient recycling of the *Moorausbruch*.

Systemic *Self-consistency*: Clear configuration for the created models. Cohesive organization as a whole.

Multifunctionality: Multifunctional system that provides diverse ecosystem services and goods. Diversity of species and land uses increased.

Continuity: Nutrient recycling of the *Moorausbruch*; output nutrient raised bog, input nutrients cattail-fields. Production chains to support local economy. Constant water production and peat production (CO_2 sequestration).

The designed landscape of Moor-Veenland is one big Landscape Machine in which multiple smaller Landscape Machines can be distinguished. The configuration of the big Landscape Machine is such that the sum is greater than the parts. The Landscape Machine can be seen as a production type (paludiculture), a waste treatment type (clean water due to nutrient filtering from cattail and reed) and a system repair type (restoration raised bog ecosystems and peat moss).

Raised bog ecosystems and climate change

The PBL (Planbureau voor de Leefomgeving) stated that the development of raised bogs in The Netherlands will probably be critical when taken into account the climate scenario W+ (comparable to Wh; the most extreme scenario). This led to questions about the necessity and advantage of continuing the restoration measures for raised bogs. Bijlsma *et al.* (2011) researched the current developments and future perspective of raised bogs while taken climate change into account. Their conclusion was that raised bogs do have a future perspective even under climate scenario W+. An import condition for this is an optimal hydrology. This means a high enough water table in the mineral soil beneath the peat and in the bog footing in combination with an impermeable (peat)layer and/or a supply of local groundwater. For the preservation and restoration of raised bogs on the long term under climate scenario W+, hydrological interventions are needed such as buffer zones, compartmenting and increasing seepage. The reduction of the precipitation surplus rising temperature are not an issue if measures are taken to upgrade the hydrology to optimal. This is exactly what is done with the proposed design interventions in this thesis.

Land use change to paludiculture – loss of food-production

Some reactions from stakeholders concerning conflicts of interest related to land use change are that agricultural land should be used for food production, rewetting causes water trouble for citizens and rewetting leads to more mosquitos (Kleinhückelkotten and Neitzke, 2016). It is true that most uses for paludiculture do not include food production, it could be possible in the form of cultivating cranberry or other products directly consumable for humans. Cattail and reed can be harvested as fodder for livestock to support food production indirectly (Biancalani and Avagyan, 2014). But the most effective way of using these crops for rewetting peatlands seems to be bioenergy or construction materials. It can be true that rewetting causes water trouble for citizens, this should be taken into account when implementing paludiculture in an area. Measurements should be taken if necessary. The problem of mosquitos can arise in open areas with stagnant water. Around the water basins of the raised bog this could be a problem. But in the paludiculture fields this shouldn't be a problem because of variable water levels. Mosquitos are also part of the raised bog ecosystem and serve as food for birds. The mosquitos that live in Bargerveen are not a problem for nearby villages according to researcher Arjen Strijkstra (van Schilt, 2015).

Recommendations

Additional research can be done on the missing data such as the creation of new models for the soil fertility and geohydrological conditions in the area of Bargerveen to support the claim of paludiculture, its productivity and impact on hydrology.

New paludiculture models can be made for raised bog landscapes with other systems, crops and design interventions. An in-depth research can be done on how to create production chains for paludiculture products, how this land-use change can be achieved (with legislation or bottom-up initiatives) and how to create other interesting mosaics of crops, biodiversity, harvest times and methods.

Paludiculture pilot projects can be started in the raised bog landscape to support the claim of paludiculture in the raised bog landscape.

The implementation of a paludiculture Landscape Machine in other peatlands such as the peat meadow landscape by the means of a case study.

The topic of paludiculture and the problems revolving the raised bog landscape are chosen for their relevance in the larger scientific and societal realm such as reduction of CO_2 emissions, ecosystem restoration and exploring nature-inclusive agricultural systems. I would like to see my thesis as an inspiration for a holistic approach to solving the problems of the degrading raised bog landscape by creating a regenerated raised bog landscape with a paludiculture Landscape Machine.

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12 Appendixes

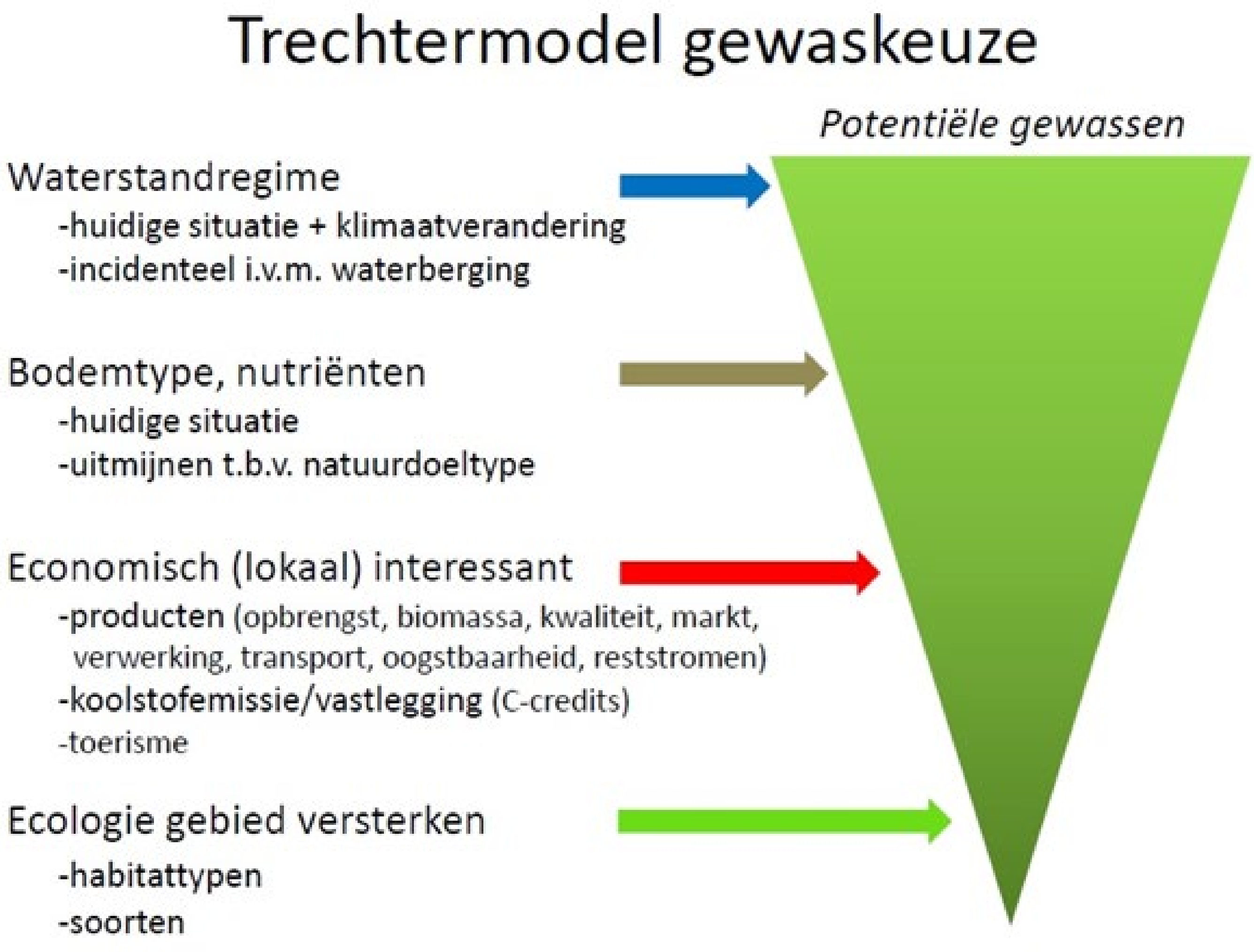
Appendix 1: Overview of the four key concepts of COOS and specified in more detail how these apply, in general terms, for a Landscape Machine by Roncken (2018)

Key concept	Specification
Confined	*Boundaries*: permeable–non-permeable 'barriers' perform functions of control, linkage and communication, such as those performed by membranes, filters and interfaces, in order to regulate/constrain/monitor relations and exchanges with other systems and the external environment, for example to ensure consistency/perception of in/out limits and to specific filter and control processes/functions (e.g. noise, in/out flowing water, wind, movement of animals and people, connections to the local/global market). The boundary also indicates the boundary of a sense of place, i.e. the delineation within the landscape that relates to identifiable features within the landscape.
Open	*Connectivity*: in/out flows allow the system to grow and develop, fed by energy, materials, water and other resources (also people as workers, recreational visitors and trespassers, imported goods, information), and discharge waste, emissions and water outflows (also export food, symbols that represent a sense of place or sense of self, materials and goods to the market). This implies the system behaves like a node (and plays a role) in a wider, even global network of processes with a proper physical consistency and space-time rhythms.
Ontic	*Historical dimension*: combination of choice and chance, (eco)systems, co-evolution and emergence of novelties. Events that occurred in the past may be indicators of the present state of the system and present sense of place and sense of self. Elements are developed in accordance with the availability of local resources as well as the aesthetic/historical/climate/cultural/social/economic context. *Steady state future*: new dynamic equilibrium will influence the settlement of plants, animals and human involvement, indicated by monitoring of developing capacities for affordances.
Systemic	*Self-consistency*: the system has a coherent configuration and recognizable functions/services. A cohesive system of actors/elements derives not only from an identifiable physical structure (within given boundaries) but also from the whole organization, which implies the sharing of intentions, aims and future perspectives and the emergence of a unique identity. *Multifunctionality*: the system is made of interacting elements/processes that perform different functions/services (with different space-time rhythms and different aims and users), but cooperate and co-evolve in an integrated whole. The organization/configuration mirrors this biocultural diversity and heterogeneity – instead of monofunctional homogeneity – as a combination of structures/functions in the same place, resulting in an enhanced land-use intensity and augmented chance for combinations, self-organization and emergence of novelties. *Continuity*: interactions between elements in a network of processes in which, for example, outputs from one side become inputs to another (e.g. energy/matter exchanges, health-related phenomena, sense of place/self) enhance the diversity and specialization of elements and their cohesion/unity/continuity in space and time. Examples are production chains, networks of resources (e.g. energy, water, community services), means of communication (e.g. wired and wireless), discharged energy/matter collection and treatment (e.g. grey water, waste, heat), people and goods transportation.

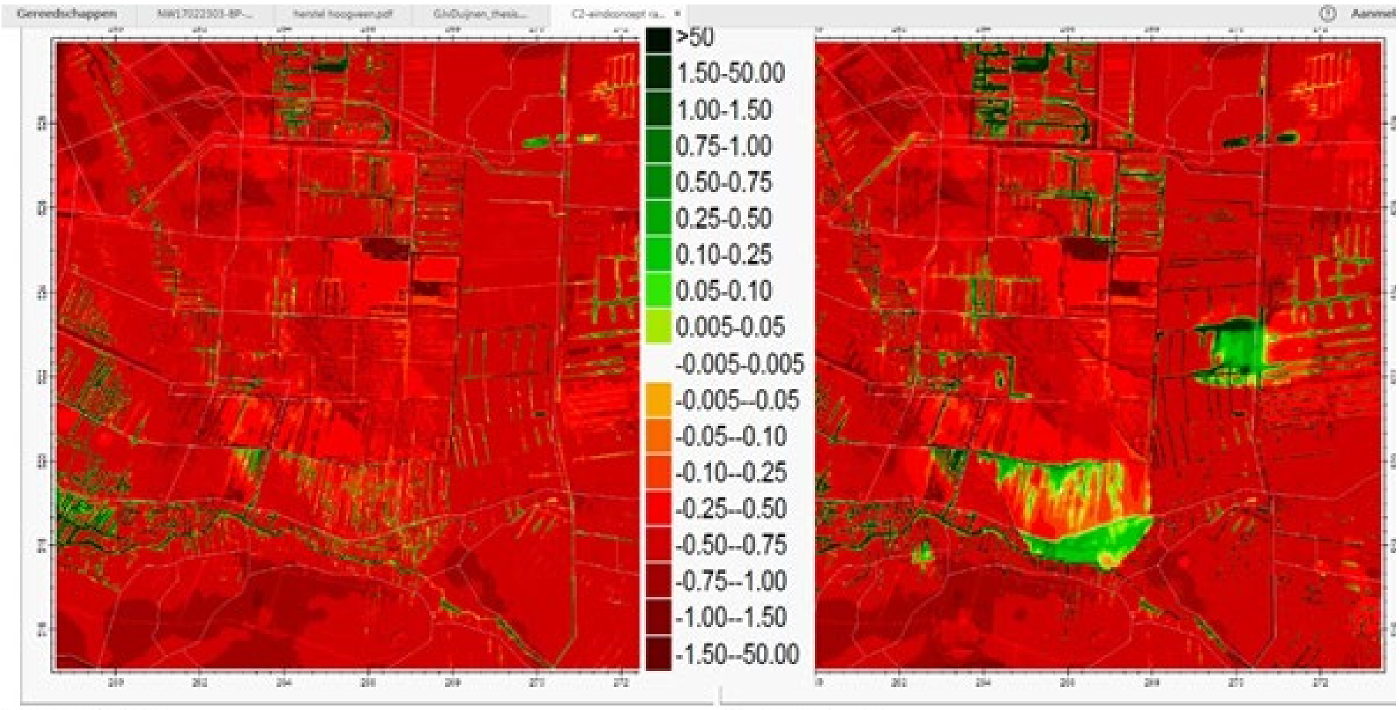
Appendix 2: Evaluation (ecological, social, economic) of land uses (Wichtmann et al., 2016, p. 177)

Superior objectives	Weight	Land use options 1 Grassland	2 Maize	3 Paludicultre: Common Reed	4 Short rotation coppice: Willow	5 Undisturbed fen peatland
Ecological aspects						
N1 Area: Conserve or restore areas	2.9	-2.2	-9.1	5.0	2.8	10.1
N2 Soil: Conserve or restore soil properties	2.8	-3.8	-10.2	7.4	4.1	9.8
N3 Groundwater: Conserve or restore	2.7	-5.8	-10.4	6.9	4.6	10.4
N4 Inland waters: Conserve or restore	2.7	-1.5	-6.8	4.1	2.7	7.0
N5 Coastal waters: Conserve or restore	2.8	-0.6	-8.6	4.2	2.0	8.3
N6 Global climate: Mitigate climate change	2.0	-3.2	-7.2	4.6	2.0	5.4
N7 Local climate: Conserve or restore	2.2	-0.7	-4.1	4.3	4.1	6.5
N8 Air quality: Conserve or restore	2.0	0.2	-3.6	3.2	3.5	5.2
N9 Biodiversity: Habitats, species, genetic resources	2.8	2.5	-7.5	4.2	3.1	7.4
N10 Landscape: Conserve or restore diversity and typical character	2.9	3.7	-6.9	6.6	3.7	3.3
Social aspects						
S1 Population: Promoting an optimal population development	2.1	1.3	-2.0	-1.3	0.7	-1.1
S2 Material living conditions	2.4	1.4	4.9	2.2	1.9	-3.0
S3 Health	2.4	6.2	-11.3	0.3	2.2	5.2
S4 Culture: Strengthen culture, education and local identity	2.4	10.2	-3.6	4.1	3.1	1.2
Economic aspects						
W1 Local economy/business: Improve or stabilise economic situation	2.5	-0.3	18.1	8.0	8.9	-14.0
W2 Public budget: Improve or stabilise financial capacity	2.3	-1.6	9.9	4.3	4.0	-11.4
W3 Resources: Guarantee availability	1.9	1.5	-1.8	11.0	10.6	-9.4
Ecological aspects		**-11.4**	**-74.4**	**50.4**	**32.7**	**73.4**
Social aspects		**19.1**	**-12.0**	**5.3**	**7.9**	**2.3**
Economic aspects		**-0.4**	**26.2**	**23.3**	**23.5**	**-34.8**
Total		**7.3**	**-60.2**	**79.1**	**64.1**	**40.9**

Appendix 3: Model for selecting paludiculture species (Van Duinen, 2016)

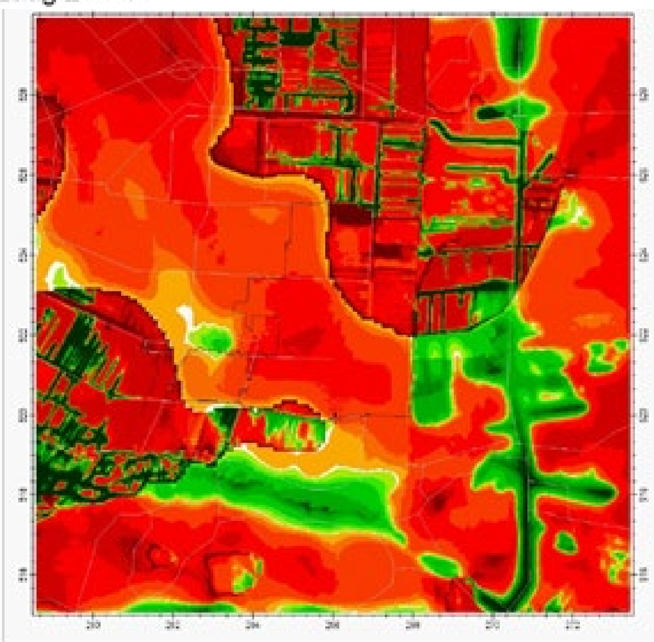


Appendix 4: Hydrological model MIPWA (Schunselaar, van der Hauw and Dik, 2014)

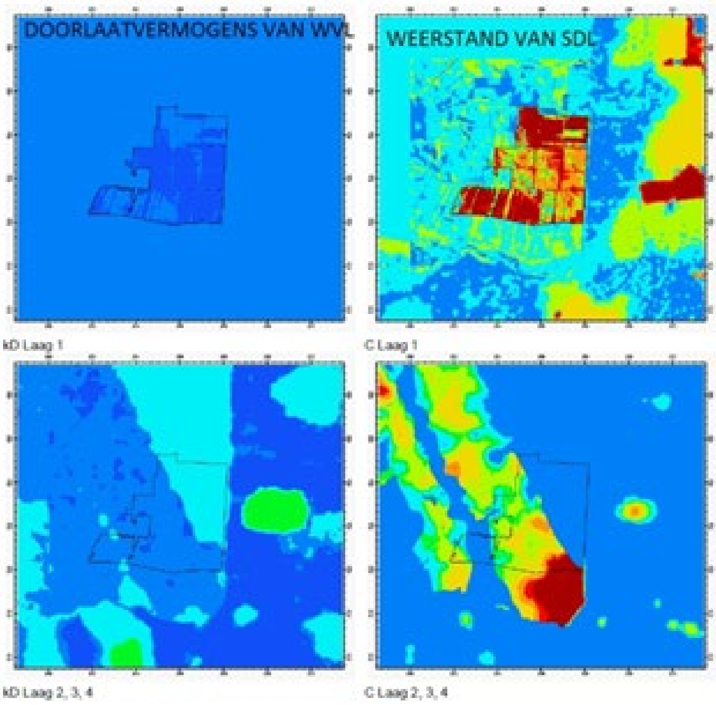


Laag 2 -> 1

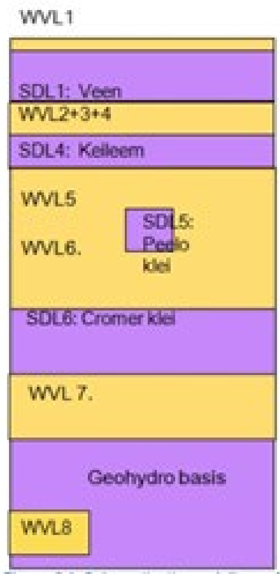
Laag 5 -> 4



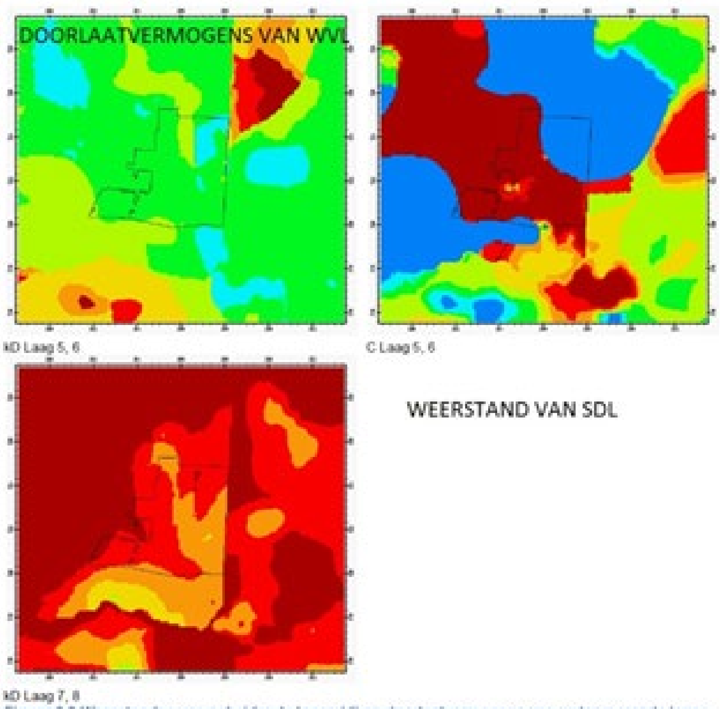
Laag 7 -> 6



De schematisatie van de modellagen is weergegeven in onderstaande Figuur 2.1..

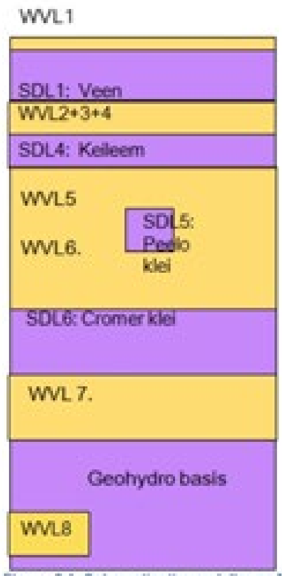


Figuur 2.1. Schematisatie modellagen MIPWA Bargerveen



Figuur 9.9 Weerstanden van scheidende lagen (d) en doorlaatvermogens van watervoerende lagen (m2/d)

De schematisatie van de modellagen is weergegeven in onderstaande Figuur 2.1..



Figuur 2.1. Schematisatie modellagen MIPWA Bargerveen

In his extensive report on four centuries of peat digging, Gerding (1995) states that a total of 142,000 hectares of peatland was converted to dry peat fuel, representing a combustion value of 3.5 x 109 gigajoules (GJ). This is an average of 24,600 GJ per hectare. For the current yield of agricultural lands, the average yield of a grassland was taken because this is common in parts of the area. The average yield of grass is 10 tonnes dry mass per hectare (Groen Kennisnet, 2015). The average price per kilo dry mass in 2017 was 21.3 cents (BIJ12, 2017). This results in a gross revenue of €2,130 per hectare per year. But this number says nothing about the profitability because the land needs to be fertilized, cultivated and sprayed with pesticides and herbicides. For the yield of the paludiculture field with reed, its production is estimated between 4.6-15 t dry mass per hectare per year by Wichtmann et al. (2016). These numbers are depend on site conditions and reed genotype. For this instance the average of 9.8 tonnes per hectare is chosen. The average lower heating value (= net calorific value) of Common Reed is 17 MJ/kg (Wichtmann et al., 2016). So when a hectare reed is harvested, 9,800 x 17 = 166,600 MJ or 167 GJ energy is yielded. This can be converted into heat with a efficiency of 75-80 percent, or to energy which is only 20-25 percent efficient (Biomass Energy Resouce Center, 2009). There are local markets available for biomass, such as Klasmann-Deilmann: a company specialised in substrates, potting soils, raw materials and renewable energy. Reed can also be used to heat the nearby greenhouse complexes of Rundedal, Erica or Klazienaveen. There is also a market for the thatching of roofs, The Netherlands are the biggest importer of reed for roof thatching. With a possible large production base and mechanized harvesting, we don't have to import our reed from China. The economic value is hard to calculate but from the analysis by Wichmann, who used a Monte-Carlo-simulation model based on deterministic calculations using realistic single values to compare the profitability of three ways of utilising reed-dominated vegetation, it can be concluded that the risk of loss for utilising reed for direct combustion is 18% and utilising it for bundles for thatching roofs is <1% (Wichtmann et al., 2016, p. 114). This means that both uses, thatching and direct combustion, are reasonably profitable. Besides profitability, ecosystem services and sustainability play an important role that cannot always be expressed in economic terms. Although the profitability of paludiculture fields may be lower than normal agriculture, it seems evident that paludiculture provides better and more ecosystem services and is more sustainable. The Figure (a) below gives an insight in the economic comparison between old, current and new land use.

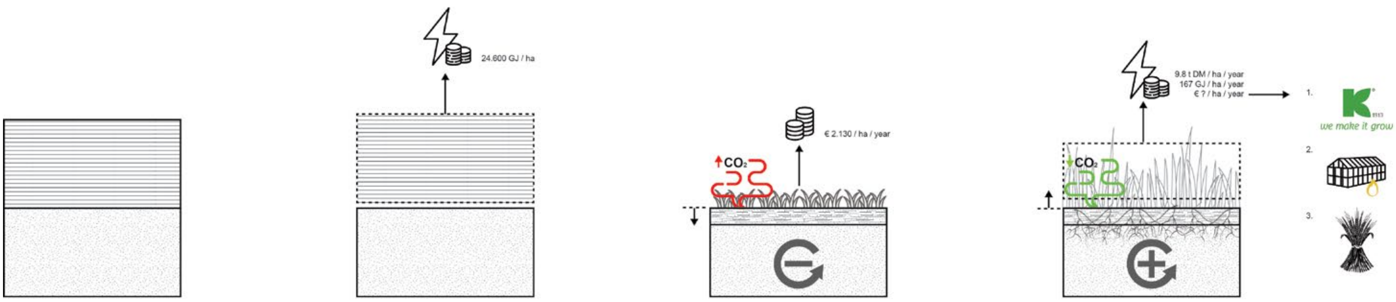
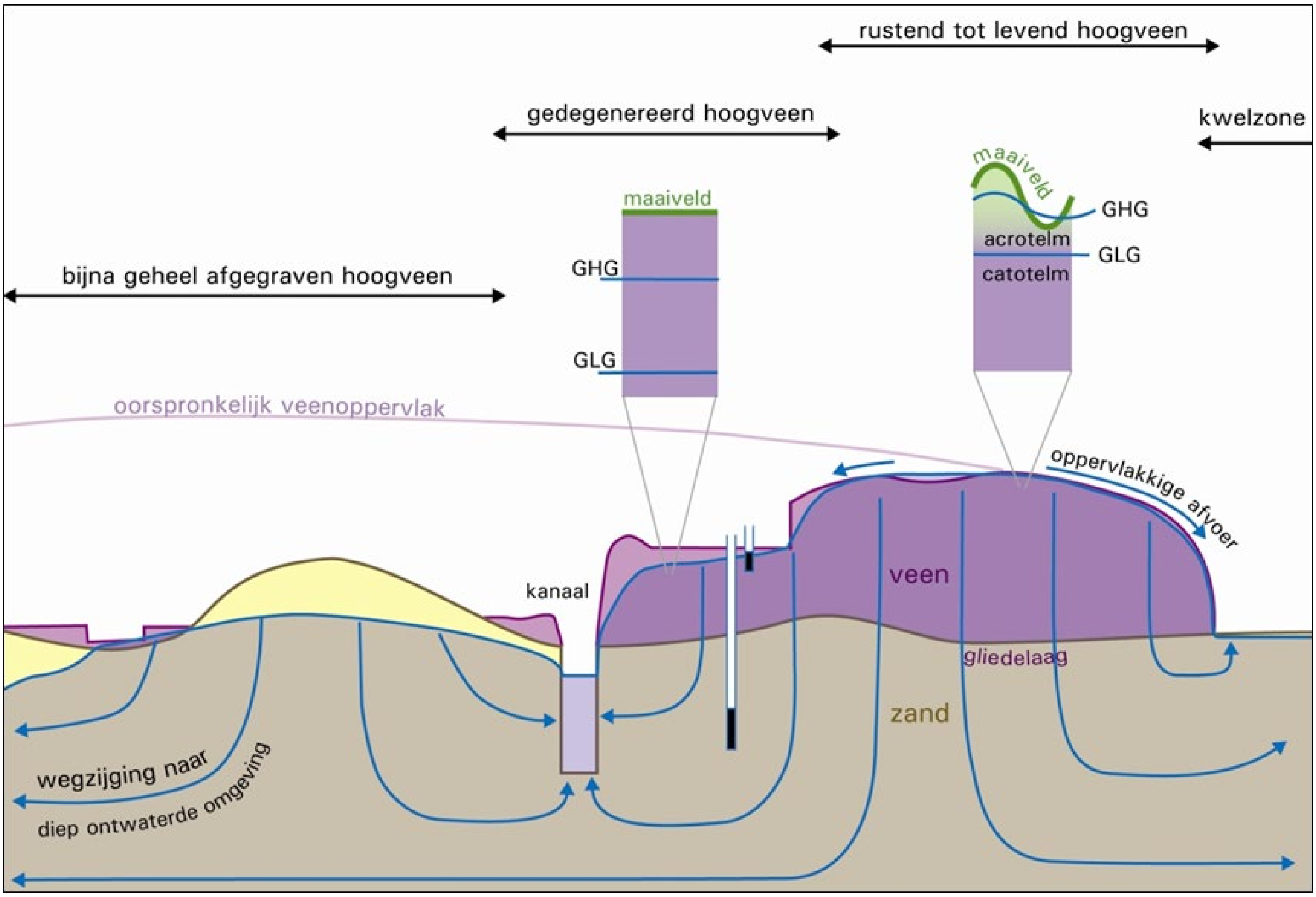


Figure a: old, current and new land use

Appendix 6: Hydrology of a raised bog (Witte, Aggenbach and Runhaar, 2007)



R: "Zou je iets over jezelf kunnen vertellen en jouw rol bij stichting Bargerveen?"
GJ: "Ik ben dus Gert-Jan van Duinen en ik werk als onderzoeker/projectleider bij stichting Bargerveen 20 jaar bijna. Ik ben ooit begonnen als stagiair met onderzoek naar ...(?) en hun voedsel op het waddeneiland Ameland. Toen ik daarmee klaar was en afgestudeerd was, kwam er een project wat gericht was op het herstel van hoogvenen, dus toen ben ik daar op aangenomen. En sindsdien uh.. Ik zeg altijd hoe langer je in het veen zit, hoe erger je er aan vast gezogen wordt, daar kom je niet meer van los.. Dus-ja, we hebben verschillende projecten rondom hoogvenen, dus ik ben gepromoveerd op onderzoek aan het herstel van hoogvenen en de effecten daarvan op de fauna, ook de effecten van aantastingen. Eén van de dingen die daaruit naar voren kwamen is dat veel soorten die nu in het hoogveen voorkomen, dat die daar van nature eigenlijk niet voorkwamen. Ik heb ook onderzoek gedaan in intact hoogveenlandschap, ook in Estland.. en dan zie je dus dat een aantal soorten die we nu – in grote aantallen soms – in het hoogveen zien, dat die van nature eigenlijk alleen maar aan de randen van het hoogveen voorkomen. En wat je dus ook ziet gebeuren is dat door de vernattingsmaatregelen die genomen worden, dat een aantal van die soorten die dus vanuit de randen – die randen ontgonnen, dus daar konden ze niet meer leven en door de degradatie konden ze uiteindelijk toch een plek vinden in dat restant van de hoogveenkern.. maar wat je nu dus ziet is dat door de hoogveenkern dat die soorten het ook moeilijk krijgen, dat die dus een aantal van die leefgebieden die ze nu hebben in de kern, dat die verdwijnen en in kwaliteit achteruit gaan. Dus dat je eigenlijk in feite soorten die thuishoren in het hoogveen landschap kwijt dreigt te raken, omdat die randen er van nature niet meer zijn. dus je moet iets aan die randen doen.. Tegelijkertijd zie je dus dat externe invloeden op het hoogveen groot zijn, met name drainage, landbouw, st..(?2:28) effecten, verstoring.. om die reden worden dus ook bufferzones aangelegd, die zijn belangrijk om de hoogveenkern te behouden, of eigenlijk de kwaliteit daar te verbeteren.. Maar misschien kan je die bufferzones wel zo inrichten dat je behalve het doel om het hoogveen te ondersteunen, dat je wellicht ook wel iets van de elementen van de rand een plek zou kunnen geven. "
R: "Een soort gradiënt in de bufferzone?"
GJ: 'Ja, precies'
R: "En die gradiënt is er nu niet in bijvoorbeeld de hoog- en laagwaterbekken en in het gedeelte van Weiteveen?
RJ: "Nee, het zijn harde randen hè. Er zijn kades, aan de ene kant staan de maïs(?3:10) en de aardappels en aan de andere kant heb je een bak zuurwater. Dus ja, die gradiënten zijn er heel erg weinig, terwijl ze van nature wel aanwezig zijn geweest en het op sommige plekken wel iets te herstellen valt waarschijnlijk."
R: "Dus de huidige maatregelen zijn gericht op het in stand houden en uitbreiden van het areaal levend hoogveen?"
GJ: "Ja, klopt ja"
R: "En is dat positief voor die soorten die gedijen in die gradiënten of is dat juist negatief?"
GJ: "Voor de soorten van gradiënten is het over het algemeen negatief, kun je zeggen.. hoewel het aan de andere kant natuurlijk wel zo is, voor een duurzaam hoogveen landschap waarin dus zowel – hoogveen wordt natuurlijk vooral gekenmerkt door dominantie van veenmossen, dus dat moet je sowieso hebben, dus dat levend hoogveen heb je al per definitie nodig. Dus ook voor die gradiënten heb je ook de uitersten nodig, dus als je dat hoogveenkern niet herstelt, heb je ook geen duurzame situatie waarin die soort op die andere gradiënt gaat zitten, een goede plek hebben."
R: "En zoals ik het heb gelezen in heel veel documenten dat zo'n gradiënt vooral te maken heeft met een soort van gradiënt in de voedselrijkdom van bijvoorbeeld kwelwater en de lage voedsel rijkheid in bijvoorbeeld veenwater. En zoals in het gebied van het Bargerveen zoals het nu is, is er kans tot gradiëntherstel, of moet je dat buiten het gebied zoeken?"
GJ: "Het kan voor een deel binnen het gebied, je hebt een uitloper van de Hondsbrug, die in het Amsterdamse veld aan de oppervlakte komt, daar zijn wat overgangen tussen zand en veen. Daar zit natuurlijk al iets van een gradiënt in, maar dat zand is ook heel voedselarm en zuur. En verder zie je richting de randen het gebied wel delen die minder nat zijn, of een wat sterkere fluctuatie van de waterstand kennen, daar zijn ook gradiënten in ieder geval in droogte en in voedselrijkdom. En verder heb je natuurlijk de bovenveen graslanden, verspreid in het ..(?5:50) blok en met name in het Schoonebeekerveld.
… (dingen laten zien op de kaart)
R: "Dus dat zijn van boeren die daar vroeger hebben geboerd, zonder het veen af te graven?"
GJ: "Ja. Dus er werd mest en waarschijnlijk ook maaisel vanuit het Bekerdiep opgebracht – dat zal met name hier geweest zijn – Om dat voedselarme veen geschikter te maken voor teelt of voor vee om te grazen. Dus dat zijn de wat rijkere plekken die er toch nog steeds zijn. en je hebt bijvoorbeeld een …(soort 6:40) die in het hoogveen eigenlijk van nature niet voorkomt, maar het Bargerveen het wel de grootste … populatie van de ... Veluwe. Dus dat zijn toch dingen die belangrijk zijn. Je kan natuurlijk zeggen 'mijn doel is om hier het hoogveen te herstellen dus die soort hoort hier niet thuis, dus wegwezen..', dan heeft die niet meer de luxe een ander gebied te vinden buiten het hoogveen, dus daarmee raak je een populatie kwijt. Dat geeft dus aan dat je naast je doel voor het landschap ook andere doelen hebt waarvan je wel moet kijken in hoeverre je ze kan combineren. Dan moet je keuzes maken, hoe lastig die ook kunnen zijn.. zeker voor die bovenveen graslanden, met name hier.. waar de kansen voor de ontwikkeling van hoogveen eigenlijk niet zo groot zijn, kun je juist voor die soorten het leefgebied verbeteren. Dus dat betekent dat je wel binnen reservaatsgrenzen ook mogelijkheden hebt voor gradiënten of mozaïken, misschien dat je dan niet van die overgangen van zuur naar het voedselrijke hebt, maar wel in de vorm van mozaïken en die hebben net zo goed een functie."
R: "Oké. En hier heb je ook een waterscheiding van het systeem dat afvoert naar de Eems en hier naar de Vecht – eerst naar Schoonebeekerdiep – en hier ligt dan ook die zandbrug.. dus eigenlijk wat je zegt is dat die gradiënt of die zandrug van het hoogveen.. hier zou je een soort gradiëntzone kunnen maken? "
GJ: "hier zit iets van gradiënt maar omdat dus dat die zandbodem daar dus ook heel zuur is, heb je in zuurgraad en voedselrijkdom niet echt een gradiënt, maar dus wel in droogte en vegetatie."
R: "Ik pas dus die natte landbouw toe in de omgeving van het Bargerveen in een soort van visie.. ik heb drie gebieden zien en laat ik in elk gebied een andere vorm zien van natte landbouw. Eén gebied wat ik bijvoorbeeld wil gaan doen is vanaf het hoogveen tot het Schoonebeekerdiep en dan ook nog een stukje van de Duitse kant meenemen. Wat ik hier bijvoorbeeld wil gaan doen, is – want hier heb je de bovenveen cultuur … - een gradiënt maken van verschillende soorten, dus je zou bijvoorbeeld in het Schoonebeekerdiep dal riet kunnen doen, of Lisdodde en dan verder naar boven kan je soorten doen die gedijen in voedselarme gronden en voedselarm water.."

GJ: "En wat voor soort denk je dan aan?"
R: "uuh, daar heb ik nog niet over nagedacht.. "
GJ: "Voor teelt voor productcultuur, zit je natuurlijk op voormalig landbouwgronden die voedselrijk zijn als gevolg van het inbrengen van mest, dus dan kunnen riet en Lisdodde daar ook prima groeien, Wild kan eventueel ook. Willig gedijt eigenlijk het beste als het droog ligt in de zomer, dus niet permanent onder water. Voor Lisdodde is permanent water wel belangrijk voor een goede opbrengst. Dus dat je dan van nature het beste rondom de beek zit.. maar als je het voor elkaar krijgt om in deze zone permanent natte situaties te creëren, kan het ook daar groeien. Omdat je natuurlijk zit met de historie van het inbrengen van mest door de akkerbouw. Als je dus niet de bouwgrond gaat afvoeren, blijven daar natuurlijk nutriënten zitten, dus maak je daar in die zin voor de productnatuur gebruik van, dat daar dus een meststof is. En daarnaast wat je zou kunnen doen, is natuurlijk water in laten, dat kan sowieso nodig zijn om de waterplant op orde te krijgen – om voldoende nattigheid te houden ook in de zomer – maar dat zorgt er ook voor dat je voedselrijk water met nutriënten invoert, waarmee je bemesting geeft. Aan de andere kant als dat water ook weer kan uitstromen, dan gaat het als een helofytenfilter werken en dan krijg je dus uiteindelijk voedselarm water wat uitstroomt en in die zin kun je dus zorgen voor een afname van de voedselrijkdom in je waterloop bijvoorbeeld van het Schoonebeekerdiep. Wat dus interessant kan zijn voor de kadering van water. Dus de doelstelling om schoner water te creëren, zou paludicultuur een functie in kunnen hebben."
R: "Dus daar heb ik nog niet over nagedacht namelijk, dat is wel een goed punt wat je zegt. Dus als je dit gebied riet gaat maken en dan zegt 'dan zuiveren we dat water wat hier komt', dan heb je hier uiteindelijk ook goede kwaliteit water wat weer beter is voor de rest van de beek. Oké, zo heb ik er nog niet over nagedacht. In eerste instantie wat ik wou doen met het gebied hier is ook een soort bufferzone maken en dat water kan je gebruiken voor de pauludicultuur hier. En hier is een klein verval dus hier moet je ook werken met duikjes of dammetjes, dus dat je bijvoorbeeld compartimenten binnen deze zone krijgt met verschillende planten soorten."
GJ: "Riet kan wel droog vallen, maar Lisdodde eigenlijk niet, tenminste het kan het wel overleven, maar voor een goede productie moet het wel echt nat blijven in de zomer ook. Riet kan ook permanent nat zijn, maar kan wel iets beter tegen de droogte."
R: "Heb je enig idee – want daar ben ik nog niet echt achter gekomen – hoe snel het gaat dat veen word gevormd door de wortels van verschillende planten?"
GJ: "Ik weet niet precies hoe snel dat gaat, maar wat er natuurlijk gebeurt is dat je de bovenste biomassa oogst, dus alles wat ondergronds groeit, blijft zitten. Dus al de koolstof die daar in op is geslagen, die conserveer je."
R: "Want wat ik bijvoorbeeld hier wil doen – in mijn tweede gebied bij het zwarte meer, waar ik me iets meer wil richten op de recreatie, dat je een noord-zuid verbinding hebt tussen het Bargerveen en Klooster Ter Apel en het watersysteem daar – is de meerstal proberen te maken. Hier heb je bijna geen restveen meer, dus ik wil het eerst uitmijnen door Lisdodde te oogsten en dit zorgt ook voor veenvorming en dan na 20-30 jaar is er een veenlaag waar veenmos op kan groeien. Maar ik weet niet zeker of dat mogelijk is."
GJ: "Ja, in theorie is dat mogelijk. De vraag is natuurlijk krijg je het voldoende nat en zeker voor veenmos is het zo dat dat natuurlijk heel sterk afhankelijk is van voldoende water, regenwater, dus dat moet je wel op peil houden ook in de zomer. En zeker in de eerste fase als het veenmos zich moet vestigen, is dat wel van belang en later als het veenmos dan een pakketje hebben gevormd, dan kunnen ze dat ook beter vasthouden, dus dan gaat het allemaal wat makkelijker. Maar zeker in die eerste fase moet je zorgen dat de waterstand tot aan het maaiveld zit, want dan kan de ontwikkeling van het veenpakket daarbij helpen, ook al is het laagveen – eutroveen. Dat kan opzich wel een goed matras zijn voor de veenmossen, maar dan moet je het wel voldoende nat kunnen houden."
R: "Hoe zou je dat kunnen doen? Zou dat kunnen door die bufferzone te vergroten? Dat bij neerslag het water wordt opgeslagen en bij droogte dit (benedenstrooms) nat kunt houden?"
GJ: "Ja, dat zou kunnen, ja. En wat je natuurlijk ook al aangaf, is dat er nu water wordt ingelaten en vanuit het Ijsselmeer heel Drenthe ingepompt wordt, dus dat betekent dat er in die zin water genoeg is. Dat water kan je natuurlijk ook gebruiken om het hier natter te houden. Niet dat je dat meteen als oppervlakte water inlaadt, maar misschien wel dat het in sloten ingeladen wordt, zodat de waterstand op peil blijft.
R: "Ik kan me voorstellen dat dat dan heel voedselrijk water is..?"
GJ: "Ja, dat is zo"
R: "Is dat dan wel geschikt voor het veenmos?"
GJ: "Nee, sowieso voor het veenmos niet. Die veenvorming gaat in eerste instantie via Lisdodde en riet enzo, dat gaat natuurlijk het beste als het ook nat is. Als het steeds in de zomer droog valt, stimuleert dat ook weer de afbraak. Je wil het altijd zo nat mogelijk houden, dus zeker in die fase kan dat water een rol spelen en als dan dat veenpakket zich opgebouwd heeft, kun je dat veenpakket ook wellicht van onder nat houden met dat 'vieze water', waarbij de veenmoskussens daarboven liggen en het oppervlaktewaterpeil niet boven de veenmossen komt."
R: "Oké, akkoord"
GJ: "Dus dat is eigenlijk compensatie voor de versterkte wegzijging. Zegmaar via een infuussysteem de veenconstructie op gang brengen en als dan voldoende dik veenpakket zich gevormd heeft, dan kan natuurlijk het infuus af, maar dat is wel een termijn van vele decennia."
R: "Ja dat denk ik ook, het groeit niet heel snel. Nog iets over het Ijsselmeer water.. want dat is ook een ding voor de toekomst, want klimaatverandering is meer hitte en meer hevige neerslag. Nu is in Drenthe in de zomer nog heel erg afhankelijk van het Ijsselmeer water, maar als je straks een hele droge zomer hebt, dan kan er misschien niet voldoende water worden gepompt uit het Ijsselmeer. Kan in de toekomst het Bargerveen of het veengebied hier in de buurt straks een rol spelen in de waterhuishouding?"
GJ: "Het is nu zo dat het water wat nu in de retentiegebieden hier in het noorden wordt ingeladen, dus bij neerslag overschot of bij piekbuien wordt dat water vastgehouden en in droge perioden wordt dat weer in deze slenk gepompt, om daarmee de ontwatering – als gevolg van drainage in de omgeving – te compenseren. Nu is het natuurlijk zo als de omgeving natter wordt, dat je minder water kwijt hoeft te raken dus dat je ook minder water nodig hebt om de boel weer nat te houden. Dus als de drainage in de omgeving verminderd – dan kun je denken aan de polder waar heel veel water naar weg lekt – en het daardoor natter wordt, dan zou het Bargerveen wel voor de afvoer van water kunnen gaan zorgen."
R: "Oké, dat is wel interessant om aan te geven. Vooral ook omdat het advies was dat Drenthe de zelfvoorziening van water moest verhogen, dus dan kan het bargerveen daar misschien ook

een rol in spelen."
GJ: "Maargoed, de opslag van water in het Bargerveen kan niet echt, dus vandaar dat die retentiebekkens zijn aangelegd, want als je water in het Bargerveen zelf opslaat, dan gaat dat ten kosten van de hoogveen ontwikkeling omdat dan de waterstand te sterk gaat fluctueren. Zo is het natuurlijk ook in het hoogveen dat als er heel veel neerslag is dat dat op een gegeven moment ook gewoon afgevoerd wordt. Er wordt natuurlijk wel gezegd van het hoogveen is een spons, maar als een spons vol is, voert die ook water af."
R: "Als er heel veel neerslag valt, dan gaat dus het water niveau omhoog, maar tegelijkertijd gaat de zijwaartse afwatering omhoog, dus eigenlijk hoe meer regen er valt, hoe hoger het waterlevel stijgt, hoe sneller het water wordt afgevoerd. Dus bij heel veel regen is eigenlijk de retentie van hoogveen niet heel hoog."
GJ: "Nou alleen als de waterstand laag is. Dus als je natuurlijk in een droge zomer bent en de waterstand is laag en dan is er veel regen, dan kan het nog vrij veel opnemen, maar is het in de winterperiode en staat het water tot het maaiveld, dan neemt het niet veel water op."
R: "Kun je een inschatting geven van hoeveel water hoogveen per hectare kan opnemen? Als het een droge zomer is en het water staat iets boven catotelm."
GJ: "Dat durf ik zo niet in kuubs uit te drukken, dat hangt natuurlijk heel sterk af van de eigenschap van die acrotelm, dus hoe dik is die, hoeveel poriën zitten daar in. En op dit moment is het zo dat met het hoogveen herstel je in feite zit met een restje van de catotelm en daar bovenop probeer je een acrotelm te ontwikkelen. Nou, dat gaat heel moeizaam en er zijn nu een paar stukjes in het Bargerveen waar dat heel goed gaat. Ook delen waar nog witveen aanwezig was, dus minder vergaan veen met een groot porie volume, dus wat betere spons zegmaar, dus dat heeft een wat hogere capaciteit om water op te slaan. Want eigenlijk is het dus afhankelijk van hoe dik die acrotelm is en daar is op dit moment natuurlijk nog nauwelijks sprake van. Dus dan heb je het over een termijn van decennia waar dat eventueel een rol zou gaan spelen, dus voor de komende tientallen jaren moet je daar niet echt wat van verwachten."
R: "Mh, ja dat is jammer.. Want die catotelm is ook in het Bargerveen aangetast, toch?"
GJ: "Ja"
R: "Want van onder uit, zegmaar de waterstand is zo laag dat het water niet tot in de veenbasis reikt."
GJ: "Nee, op een aantal stukken een deel van het jaar wel. En de bufferzones die aangelegd worden zijn bedoeld om dat gedurende langere periode in het jaar zo te hebben."
R: "En als dan dat water in de veenbasis reikt, dan is automatisch de wegzijging minder?"
GJ: "Ja, ja. Nou kijk die catotelm en acrotelm is natuurlijk een theoretisch begrip, uiteindelijk is er niet een keiharde grens tussen catotelm en acrotelm. Het zijn meer begrippen om het begrip van het systeem te ondersteunen."
R: "Ja, hoe ik het ook zie is dat het niet een harde scheiding is, maar een geleidelijke overgang tussen witveen en zwartveen."
GJ: "Nu is het wel zo dat als je een veenprofiel maakt van boven naar beneden, dat daar soms wel duidelijke grenzen in zitten. Dat heeft te maken met de klimaatomstandigheden in die periodes of bijvoorbeeld een brand die geweest is, dat soort dingen. Daar kan je opzich wel een harde overgang zien. Of ook als het een nattere periode is, je een ander veenmos krijgt met een andere structuur en andere eigenschappen. Dus dat soort grenzen kan je wel zien, maar bijvoorbeeld 'hier stopt acrotelm en hier begint catotelm', dat is niet zo."
R: "Nog een ding waar ik in geinteresseerd in ben is de teelt van veenmos. Kun je veenmos oogsten? En in hoeverre blijft dan bijvoorbeeld de acrotelm in stand?"
GJ: "Ja, veenmos kan je inderdaad oogsten en dan groeit het ook weer verder – tenminste als je het niet al te rigoureus doet natuurlijk. En zolang het verder kan blijven groeien, houdt het ook iets van die acrotelm in stand. Er ontwikkelt zegmaar een veenpakket en afhankelijk van wat je daarvan afhaalt, haal je een aantal centimeters over. Maar het is afhankelijk van je inzijging in het gebied of kwel... (en nog wat gebrabbel, 31:50)"
R: "en dit gebied, het Anaveen is eigenlijk een polder met onderbemaling.. Eigenlijk wat ik daar wil doen; ik wil paludicultuur gebruiken in plaats van landbouw." GJ: "In plaats van maaisel Lisdodde" R: "ja bijvoorbeeld, of in ieder geval iets wat productief is, want dit zijn hele grote vlakken en je hebt hier ook infrastructuur, bijvoorbeeld het kanaal en een railtje loopt er en heel veel aanvoer van water vanuit het Bargerveen. Dus eigenlijk is dit een hele goede plek om als bufferzone te dienen, maar ook omdat je hier genoeg wateraanvoer hebt."
GJ: "Ja, door dit nat te maken, zal het verlies en de aanvoer vanuit het Bargerveen minder worden. Maargoed omdat het nu natuurlijk een polder is met onderbemaling, tenzij je de bemaling stop zet, loopt het vanzelf voor. En dan is het natuurlijk een voedselrijke situatie vanwege de mest die in de akkers gelegen heeft, dus dat is prima voor Lisdodde en riet enzo, die zullen heel productief zijn."
R: "Dat is mooi want Klaas is ook bezig met turf en veenmos en witveen, maar ook met biomassa. Dus dat is wel een mogelijkheid."
GJ: "Ja, ze zijn inderdaad bezig om te kijken wat de mogelijkheden zijn om bijvoorbeeld Lisdodde of andere plantenmaterialen als vervanging van turf. En nu is het natuurlijk zo dat turf uit de Baltische Staten gehaald wordt voor het leveren van substraten, dus ja als je inderdaad naartoe kunt voor alternatieven daarvoor, zijn we natuurlijk heel geïnteresseerd in."
R: "Ja, oké. Dus dat zijn drie gebieden die ik ga ontwerpen, met paludicultuur in een verschillende rol en functie. Verder maak ik ook een regionaal plan. Ik ga ook een stuk Duitsland in, bijvoorbeeld. Want wat me heel erg opviel was dat het Bargerveen zich heel erg focust op het Bargerveen en niet op het omliggende gebied, terwijl Anaveen eigenlijk prioriteit nummer 1 is, omdat veel water daar naartoe stroomt en het ligt pal naast het Bargerveen, maar daar schrijven jullie eigenlijk niet zo heel veel over. Wat ik eigenlijk wil gaan doen is – want hier kun je heel goed die structuur zien van hoe het veen vroeger in het landschap heeft gelegen en dat is natuurlijk mooi met het Schoonebeekerdiep er in, wat eigenlijk gewoon de veenbeek is, want hij begint hier en dan met het herstel van Runde, dan heb je eigenlijk gewoon een heel veengebied met twee veenbeken en dat kan wel wat worden, lijkt mij."
GJ: "Je kent het internationale natuurpark Moor?"
R: "Ja, daar heb ik iets over gelezen."
GJ: "Dat heeft ook een beetje die grenzen. En we hebben dit jaar voor het internationale natuurpark een bekende studie gedaan, naar de mogelijkheden van paludicultuur en daar hebben we het Anaveen ook aangegeven als een mogelijke plek om iets te gaan doen. En daarmee twee vliegen in één klap te slaan; de ontwatering vanuit het Bargerveen verminderen en een alternatief bieden voor de landbouw die daar nu is."
R: "Ja, want ik kwam eigenlijk ook uit op die plek. Een beetje raar dat het wordt onderbemalen en dat er zoveel water wegzijgt."
GJ: "Het is ook dat ze in deze omgeving last hebben van te veel water, dus als er veel neerslag is, kunnen ze het water eigenlijk heel lastig kwijt. Ze hebben ook gedacht van misschien moet het peil van het kanaal dan omlaag, zodat je dus meer water kwijt kunt. Dus ze zitten met een nattigheidprobleem daar. Gebruik

dan een polder zoals Anaveen en andere lagere stukken en sla daar het water in op."
R: "Je had het net over het veenpark, heb je daar documenten van ofzo? Aangezien dat in Duitsland zit en ik vooral Nederlandse data heb."
GJ: "Ja er zijn eigenlijk alleen maar verouderde data, dat is de .. service. Daar kan je wel allerlei kaarten van veen enzo vinden. En LPEG en NIBIS. Maar dat is verouderd, ze zijn nu bezig met een nieuw Moor-kadaster te maken. En er zijn nog wat geologische rapporten."
R: "En heeft dat Moorpark (internationaal natuurpark Moor) gegevens die een uitspraak doen over het hele gebied?"
GJ: "Ja op hun website zijn wel wat publicaties te vinden."
R: "De boswachter had het ook over dat jullie misschien een testveld wilden inrichten voor paludicultuur, was dat dit veld? Wat is jullie doel daar dan?"
GJ: "Het is niet zo dat wij dat uitgekozen hebben, het is meer dat prolander in de provincie is aangegeven dat dat wel een geschikt perceel zou zijn, want dat heeft al een bestemming als ecologische bufferzone dat is al een aantal jaren geleden aangewezen van 'dat moet een ecologische bufferzone worden', dus daar kun je wel die proeven uitvoeren. Zo is dat eigenlijk gegaan. En die hebben dus niet zozeer een hydrologische functie, mooi dat die functie het ook heeft, maar het heeft ook een ecologische functie. Dus nu is het even de vraag van hoe kan dit het beste ingericht worden? We hebben in dat rapport van het natuurpark ook wat schetsen gemaakt van zo zou het er uit kunnen gaan zien. Enerzijds is dat je kan zeggen de focus ligt op paludicultuur en maakt het optimaal voor die gewassen, maar wat ook een ecologische functie heeft, kun je zeggen ecogeen gaat voorop en je wil vooral de biodiversiteit stimuleren. Dus de vraag is inderdaad van hoe nat kun je het krijgen? Door wat maaiveld te verlagen kun je wel een areaal krijgen waar wat riet en Lisdodde kunnen groeien, maar verder is vooral voor Wilg geschikt, omdat grote delen toch te droog zijn."
R: "Dus wat ik je hoor zeggen zijn het in dit gebied vooral riet, Lisdodde en Wilg en veenmos."
GJ: "Ja je hebt zonnedauw, als je daar een hectare van hebt dan heb je de markt voor heel Europa al te pakken. Daar wordt een stof uitgevonden voor een medicijn voor het hart. Maargoed, daar heb je niet zo heel veel voor nodig. Er zijn natuurlijk nog meer gewassen, waterdrieblad en alles wat onder waterige omstandigheden kan groeien kan wel ergens voor gebruikt worden. Prima als je daar een hectare van hebt liggen, maar we hebben ons vooral gericht op waar heb je meerdere hectares voor nodig? Nou dan heb je Lisdodde, de grote en de kleine, en voor dat laatste is waarschijnlijk wel markt om isolatiemateriaal van te maken. En op dit moment is er weinig aanbod van kleine Lisdodde, dus de fabriek kan zeggen 'ja we kunnen het niet maken want er is geen aanvoer', maar degene die kleine Lisdodde telen die kunnen zeggen van 'we doen het niet, want het wordt niet verwerkt'. Dus het klopt inderdaad dat we dat daar graag zouden willen doen, maar het kan ook ergens anders. Ik zou het eigenlijk liever in de andere polder doen. Maargoed, daar gaan wij niet over. Op het moment is het ook zo dat ze zeggen dat er politiek geen enkele bul is om dat te doen en de wens, dus es gibt mich vragen. Maar de wereld kan snel veranderen, dus.."
R: "De meesten soorten voor paludicultuur zijn vaartplanten, dus die hebben verdamping in de zomer, betekent dat dat je meer water moet bufferen om de grond nat te houden in de zomer, omdat je natuurlijk die extra verdamping hebt van die planten?"
GJ: "ja, opzich is dat zo, maar goed omdat ze ook wortels hebben, kunnen ze water ook uit de diepere bodem opzuigen. Wat veenmossen natuurlijk niet kunnen. Veenmossen hebben natuurlijk een pakket nodig en een stabiele waterstand en moet dichtbij maaiveld zijn, maar bijvoorbeeld Lisdodde en riet kunnen van dieper water aan en meer voedselrijk, gebufferd water. En als het een keer droog valt, is het ook geen ramp, terwijl veenmossen natuurlijk veel gevoeliger zijn. Op dit moment zie ik hier niet echt perspectieven voor veenmos op grote schaal op gang te krijgen. Dat kan natuurlijk op de waard wel, wat je zei, eerst een veenpakketje opbouwen in de situatie met Lisdodde en riet en dan misschien op termijn naar veenmos gaan, dat zou kunnen."
R: "Maar stel voor als jij een paar cruciale punten gaat vernatten en je pakt een gradiënt mee naar het Schoonebeekerdiep. Wordt de kans op hoogveen herstel dan beter?"
GJ: "Ja, hoe natter de omgeving, hoe beter. Nu is één van de grote knelpunten de stabiliteit van de waterstand. Met alle ingrijpende maatregelen die genomen zijn, zie je met name dat daar een mooie ontwikkeling op gang is gekomen. Dat je ook stukjes actief hoogveen ertussen hebt. Dat wil je verder uitbreiden en daar is de stabiliteit van de waterstand een belangrijke factor in."
R: "En met de groei van veenmos sla je dus eigenlijk ook CO_2 op, want veenproductie is eigenlijk CO_2 opslag, als ik dat goed begrijp. Dat is ook één van de kaders waarin ik mijn thesis plaats. In plaats van een landschap wat CO_2 uitstoot, wat eigenlijk een doodlopende weg is, kan je een landschap maken wat CO_2 opneemt en wat kan leiden tot een groeiend landschap, een groeiend hoogveen gebied."
GJ: "Nu is het inderdaad zo dat in al die gedraineerde percelen waar akkerbouw plaatsvindt en hoogveen zit, dat je daar een remissie hebt van 25-40 dot. Dat kan natuurlijk naar bijna 0 of zelfs netto iets opslag."
R: "Dat is ook de reden waarom ik bijvoorbeeld dit heb uitgekozen, omdat hier heb je die bovenveencultuur, dus de heterogeniteit is vrij hoog, qua veen dikte, want je hebt die veendikte van 1 meter 20 maar ook van 20 centimeter, terwijl dit gebied is allemaal dalgrond, dus dan heb je alleen een moerige bovenlaag. Dat is niet zo heel boeiend voor CO_2 uitstoot."
GJ: "Moerige gronden kan ook nog heel veel CO_2 in, die het nog steeds aantrekt. Dus ook een moerige grond kan net zo goed een bron van CO_2 zijn als een veenpakket."
R: "Maar hoe ik het zie is dat het veen oxideert, dus het veen co2 gaat de lucht in, maar blijven die moerige gronden dan co2 uitstoten?"
GJ: "Zolang het moerig is wel ja."
R: "Maar op een gegeven moment wordt het zand."
GJ: "Ja, klopt"
R: "Zie je ook bijvoorbeeld kansen om het Bargerveen aan die kant uit te breiden? Hier heb je nog die Hondsruggen gedeelte, want hier heb je zo'n zandwinning en hier heb je een gedeelte dat tussen de hondsrug in ligt, dus dit is iets lager. Zie je kansen om in de loop van de tijd het veen te laten groeien die kant op, of denk je van we mogen blij zijn als het hier blijft?"
GJ: "Nou het is natuurlijk eerste prioriteit dat je het hier op orde krijgt en dan zou ik in eerste instantie zeggen van we gaan tot daar. Hier zou je het nog kunnen uitbreiden omdat je hier een gradiënt hebt naar een iets hogere rug en dan zou je het ook via paludicultuur kunnen uitmijnen. Maar dat is ook een kwestie van decennia. Maar als je het hier voldoende nat kunt krijgen, dan is dat opzich wel mogelijk, ja. Maargoed, dat voldoende nathouden van een sterk gedraineerde omgeving met landbouw enzo, is natuurlijk heel lastig. Daar droom ik zelfs niet van. Maar van dit wel."
R: "Ik had nog een vraagje over de hoogte van het veen, want hier ligt natuurlijk een dik veenpakket, kan dat pakket nog groeien? Of wat is eigenlijk de bepalende factor voor de dikte van het veenpakket?"
GJ: "In Nederland is het dikste veenpakket tot een meter of 8 geweest. Dus dat is zo'n beetje de max., en uiteindelijk is het nat-

uurlijk een balans tussen afbraak en opbouw van het veen. In het veenpakket treedt natuurlijk ook nog afbraak op en ook setting, dus op een gegeven moment wordt het ook niet dikker. Het groet aan de bovenkant nog wel aan, maar het zakt ook in, het wordt compacter door de druk. “

R: “Maar neemt het dan wel co2 op?”

GJ: “Ja, want het blijft aan de bovenkant groeien.”

R: “Dus het wordt niet dikker, maar het wordt samengeperst.”

GJ: “Ja, maar goed zo ver zijn we natuurlijk nog lang niet want het is 4 meter geloof ik in het Bargerveen, dus dat kan nog verdubbelen. Maar het hangt natuurlijk ook heel sterk af van de omvang van de veenkern he, de randen van het veen zijn natuurlijk niet kaarsrecht dus het is een koepel zegmaar en het zijn natuurlijk allemaal processen van het vasthouden van water enzo, werkt het allemaal meganisch enzovoort.”

R:”dus eigenlijk zit je midden in die veenkoepel toch?”

GJ: “Het zijn eigenlijk meerdere koepels die aan elkaar gegroeid zijn. Dus dat ..moor wat hier lag was eigenlijk een aaneenschakeling van allemaal veenkoepels. Het zijn natuurlijk ook depressies geweest, zoals hier begint het als depressie en dan begint er een koepeltje en hier ook nog één en het groeit weer aan elkaar vast, of het dijt zijwaarts uit naar bijvoorbeeld de hondsrug toe.”

R: “En omdat het zuurgronden zijn, zijn het goede condities voor verhoging.

GJ: “Waarschijnlijk is het Bargerveen ook het restant van meerdere koepels.”

R: “oke, dus zelfs binnen het Bargerveen? “

GJ: “Als je kijkt naar de ondergrond, zitten daar natuurlijk meerdere depressies in. En dan heb je ook weer een uitbraak gehad, waardoor het .. meer is ontstaan en ook de Runde. Eén zo’n koepel, op een gegeven moment zit daar zoveel water in dat er ook een moorausbruch, een veenbraak kan plaatsvinden, waar het ook weer in delen van die koepel optreedt en er dus een soort van geul ontstaat waardoor het water wegstroomt. Zo krijg je zegmaar een koepel met een hap er uit.”

R: “Dat snap ik nog echt, dat concept. Hoe dat dan die meerstal zo vol raakt dat het uit zijn voegen barst.”

GJ: “Ja, dat kan ook, als je een plas hebt tussen verschillende veenkoepels in, en nou weet ik zelf niet hoe dat precies in het Zwarte Meer was, maar ik heb begrepen dat dat ooit is ontstaan door een veenuitbraak. Maar het kan natuurlijk ook dat er tussen verschillende koepels zo’n plas ontstaat. En dat die op een gegeven moment hoger en hoger wordt, waardoor die niet meer kan afvoeren. En als dat het veen zelf niet krachtig genoeg is om die hele druk van dat water tegen te houden. Het is natuurlijk geen beton. “

R: “Ja, wat ik nou niet snapte is dat er binnenkort een natuurbouwleiding en een landbouwleiding wordt aangelegd, weet jij daar misschien iets vanaf? Wat ze daar precies mee bedoelen?”

GJ: “Nee dat weet ik niet precies. ik weet wel dat ze nu bezig zijn om het water wat in het Bargerveen valt en aan die kant wordt afgevoerd, dat ze dat zo leiden in principe in de toekomst ook naar die bufferzones toe, zodat het voor het Bargerveen behouden wordt. Dus in die laars van (..?) hier is een slenk aangelegd.”

R: “Dat is toch ook best goed dat ze hier die schapen laten lopen, want dan halen ze hier de voedingsstoffen weg?”

GJ: “Ja dat is één van de factoren geweest waardoor in dit gebied een pijpstrooi vegetatie is opengebroken, waardoor het kan doordringen en veenmossen daar ook weer een plek hebben gekregen. Dus die schapen is een van de factoren dat de vegetatie wat opener blijft en veenmossen dus kunnen groeien of ook dat je open plekken krijgt waar bijvoorbeeld … (53:30) kunnen groeien. En dat die schapen ’s nachts in de stal zijn en daar hun mest kwijt raken, zodat er een afvoer van nutriënten is.”

R: “Dus dat is gunstig voor de ontwikkeling van hoogveen.”

… (afronden)

GJ: “Hier hebben wij een proeftuintje ingericht, maar daar zie je ook al dat de bovengrond eigenlijk te voedselarm is, om daar nog een flinke biomassa te krijgen. We hebben daar ook Lisdodde ingepland, hij groeit wel maar.. en de waterstand is nog wel te veel fluctuerend, in de zomer is het te droog – wat dus niet gunstig is voor de Lisdodde – plus dat het ook nog vrij voedselarm is.”

… (dingen bekijken op de kaart)

GJ: “Ook daar zijn natuurlijk de problemen met de waterstand constant te krijgen. Dus er is een reservoir waar water wordt ingelaten en als er dan tekort is aan water, wordt het naar het proefvlak geleid. Maargoed er zit natuurlijk een fabriek die substraat maakt, dusja als je met Lisdodde en eventueel houtsnippers – dat wordt op dit moment ook toegevoegd aan turf om een goed substraat te maken – als alternatief voor veenmos, of in ieder geval als bijproduct/bijmengsel. En we hebben in ons rapport – het ligt nu nog bij de opdrachtgever en die moet zijn goedkeuring geven – een aantal percelen rondom de veenrestanten die hier nog liggen ook op snipppers met een natuurbestemming, in een van de rapporten die daarover zijn geschreven, wordt ook gezegd van ‘eigenlijk halen we onze doelstelling niet, want het veen breekt af want eigenlijk is het allemaal te droog’. Je kunt ook zeggen als je aangrenzend aan die snippers zorgt voor natter maken, eventueel paludicultuur, of ook als soort verbinding tussen die verschillende snippers – eventueel ook naar het Bargerveen toe – dat je wat kerngebieden linkt, soort van ecologische verbinding/netwerk zegmaar ontwikkelt, van natte zones wat ook als verbinding functionerend kan zijn. En nu is het zo dat vooral vanaf de Duitse kant vanuit de … commissie wordt aangegeven van politiek is dit geen doel, dus dat gebeurt allemaal niet. Maar je kan ook een keer omschakelen van ‘waarom moeten we blijven voortboeren op onze gangbare manier van maïs enzo ook met zware subsidies, waarom koppel je de subsidies niet aan andere dingen, die wel duurzaam zijn? Dan kun je een heel ander landschap ontwikkelen wat ook voor toerisme interessant is. Je hoeft niet je inkomsten uit landbouw te halen, dat hoeft je focus niet te blijven, want daar word je niet rijk van. Op een andere manier kan het ook en als je het voor toeristen aantrekkelijk kunt maken, gewoon een mooi landschap ontwikkelen en met producten. Bijvoorbeeld de Lisdodde voor isolatiemateriaal, heb je maar een paar honderd hectare voor nodig.. nou, leg maar aan.”

R: “Dat is ook één van de dingen waar ik tegenaan loop, want de huidige landbouw hier is eigenlijk niet duurzaam want het stoot heel veel co2 uit en de gronden worden steeds slechter omdat er steeds minder veen is..”

GJ: “Maar ze worden wel steeds duurder omdat de druk om mest uit te rijden is heel groot en je moet steeds minder mes uitrijden per hectare, maar we hebben nog steeds onze varkens en koeien waarvan we de mest kwijt moeten, dus de grondprijzen zijn daar ontzettend hoog.”

R: “Puur voor de mest? Oké, dat wist ik niet”

GJ: “Ik snap wel dat dat nu zo is, en dat je dat niet 123 kunt omschakelen, maar het is voor iedereen duidelijk dat dat geen duurzame situatie is.. dat moet anders.”

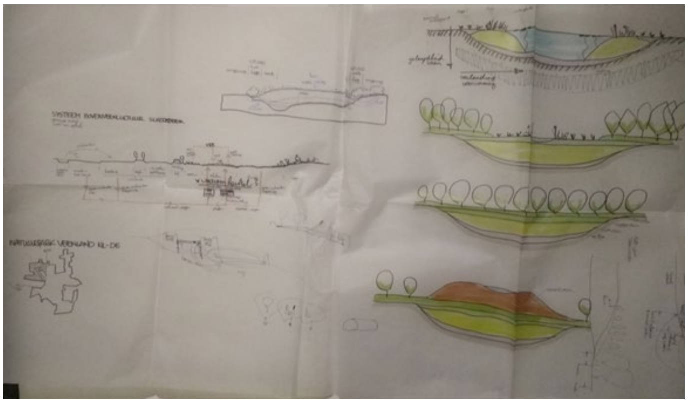
R: “Maar wat mij vooral opviel is zoals die natte landbouw, krijg je geen subsidie vanuit de EU, de huidige landbouw wel, terwijl dat eigenlijk een doodlopende weg is. En dan zoals een landbouw die goed is voor het landschap en heel veel ecosystemen heeft – wat niet in geld valt uit te drukken, maar dat zo’n type landbouw dan geen geld krijgt van de EU. Dat is een beetje krom.”

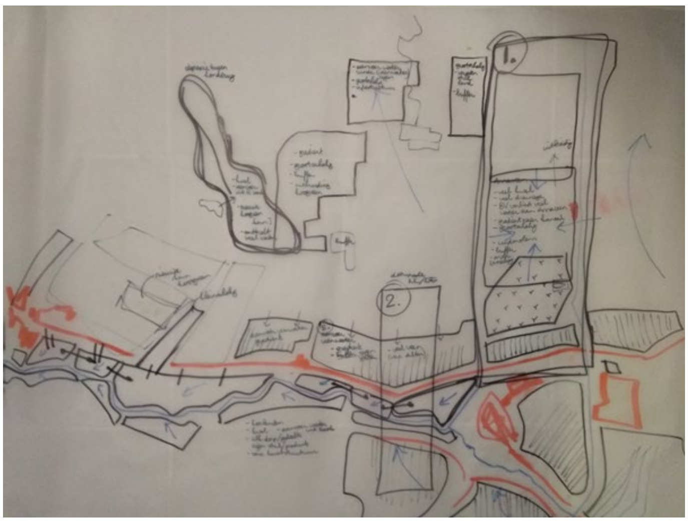
GJ: “Maargoed ik denk dat dat een kwestie van tijd is. En het is natuurlijk allemaal vies water wat je hier vanuit de landbouw met al die meststoffen afvoert, ja dat kan anders.“

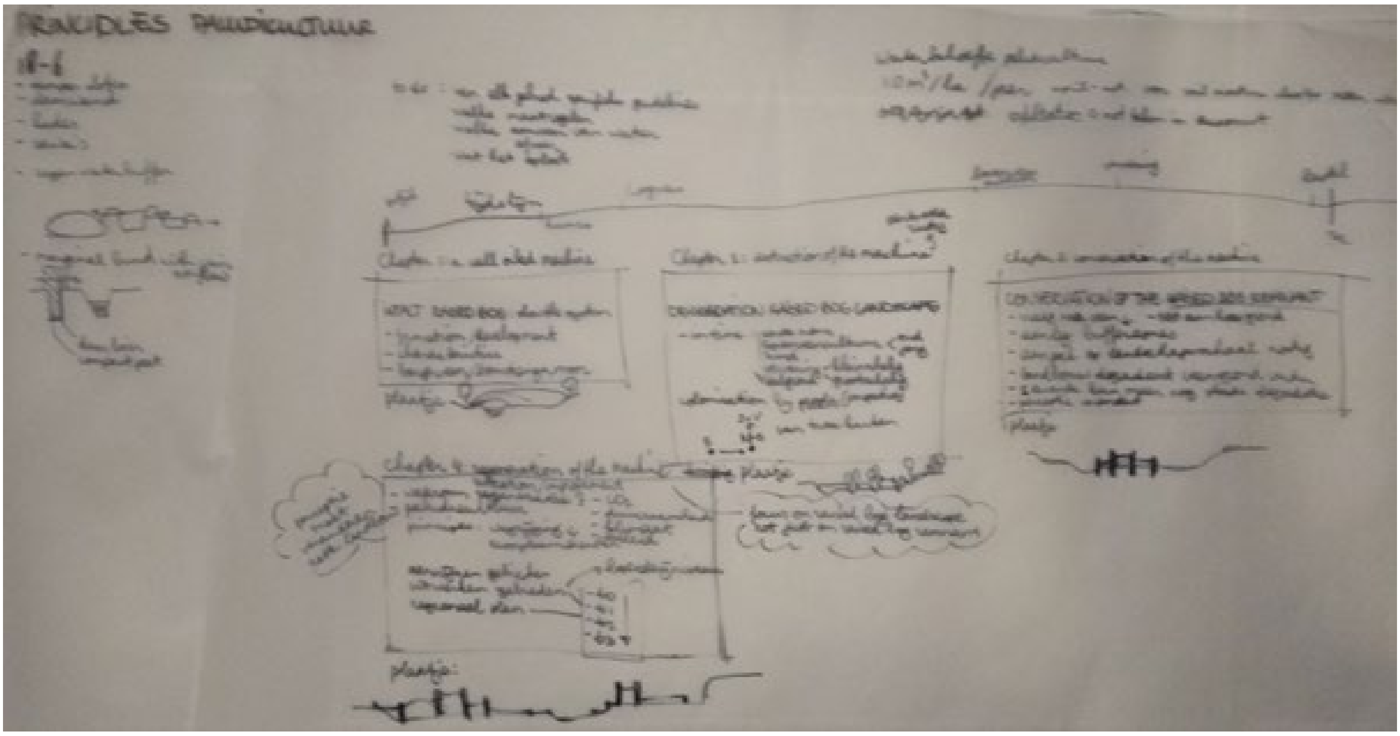
R: “Heeft het kanaal trouwens nog een functie? Is dat nog voor scheepvaart toegankelijk?”
GJ: “Nee ik denk niet echt dat dat daar voor gebruikt wordt. Nee, het is vooral afvoer van water.”

Appendix 8: Sketches

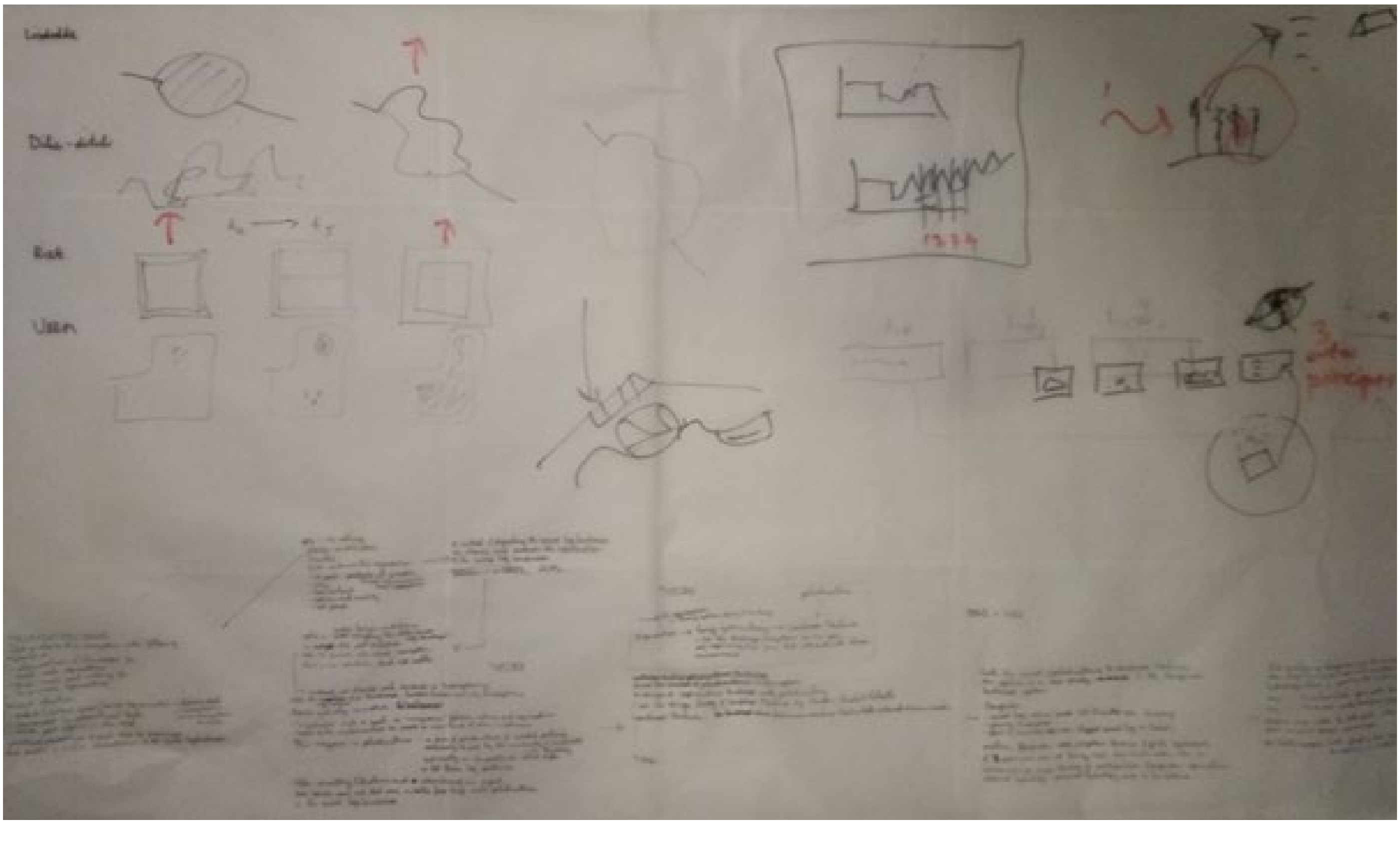
Analysis

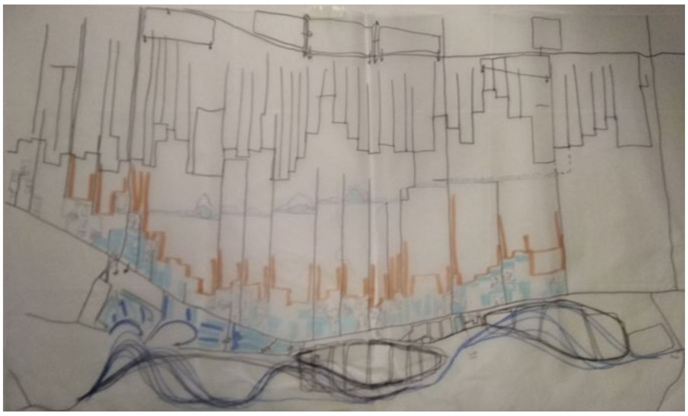


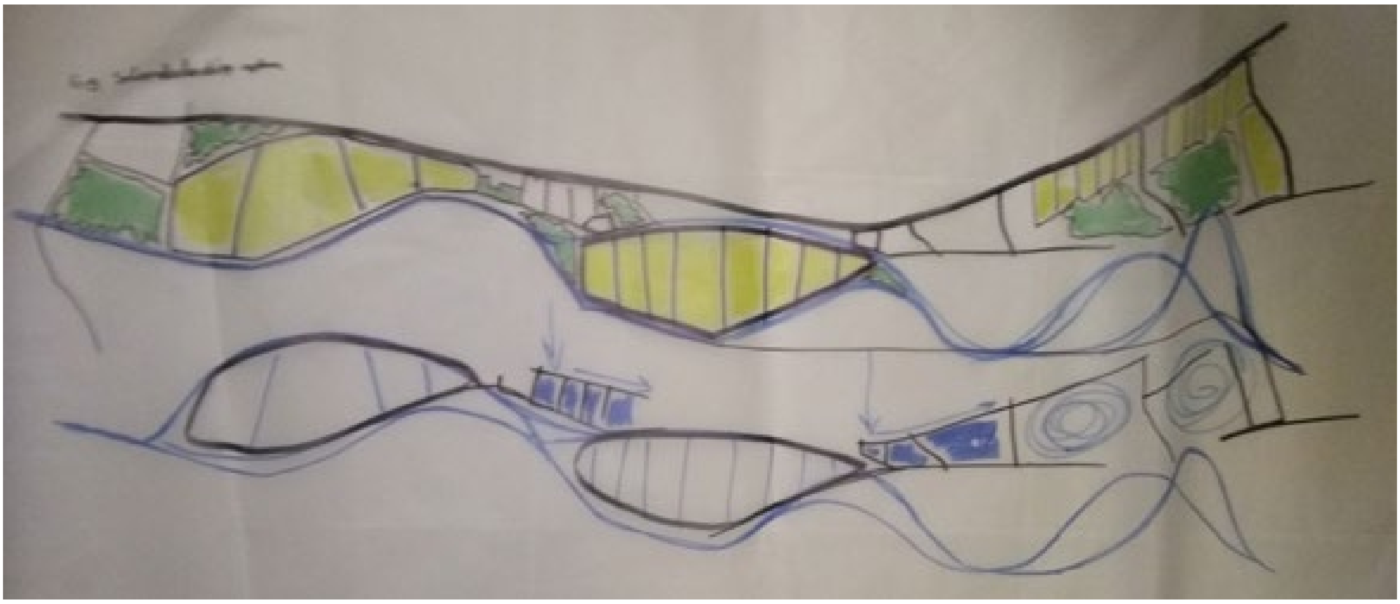


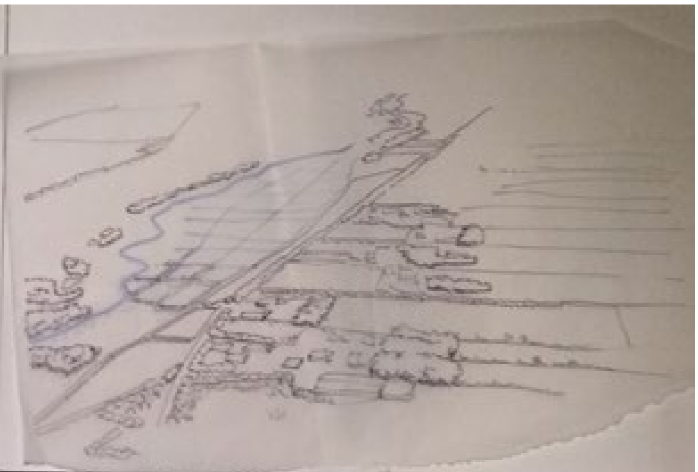

PRINCIPLES PALUDICULTUUR
Chapter 1: a well oiled machine
Chapter 2: destruction of the machine
Chapter 3: conservation of the machine
CONSERVATION OF THE RAISED BOG REMNANT
plaatje:

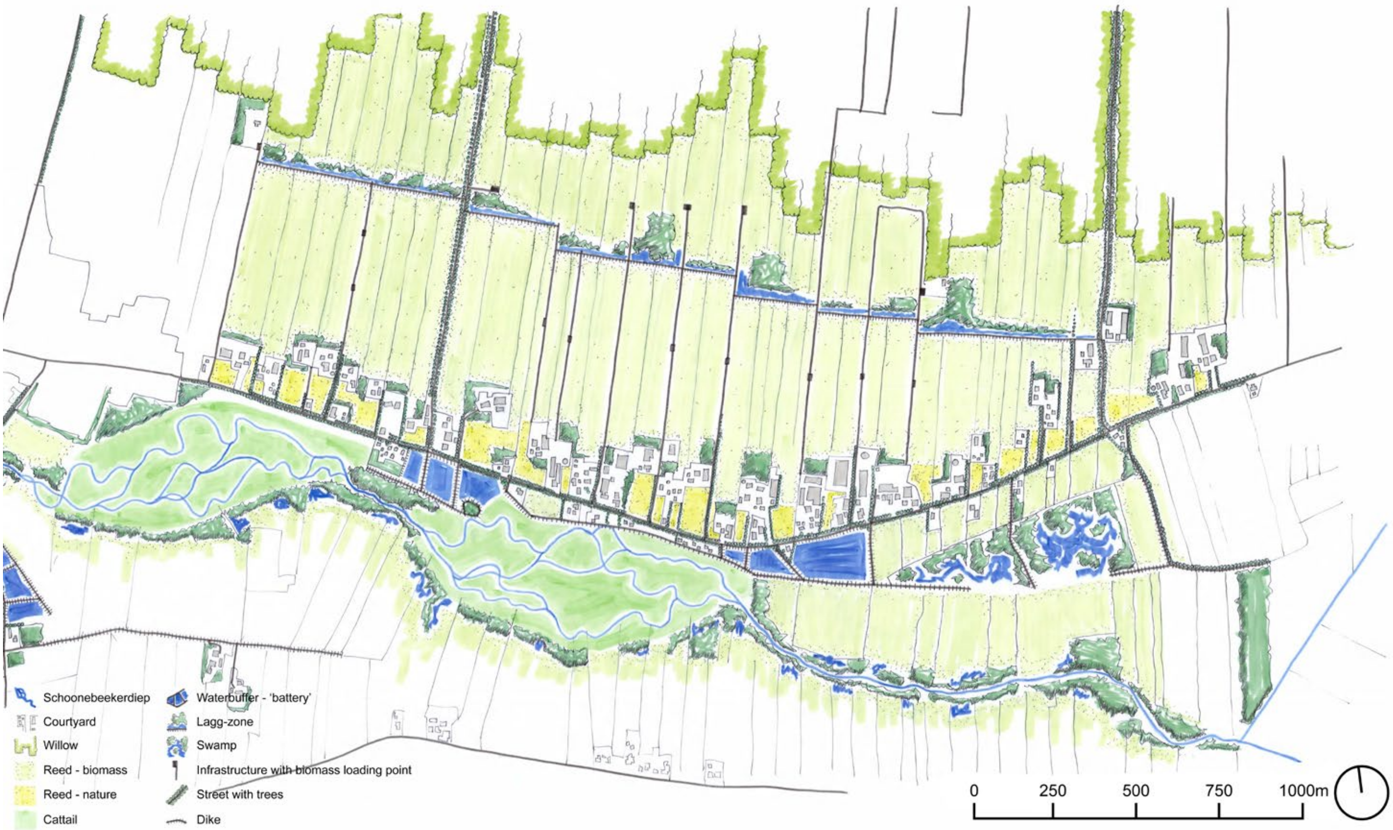

REGIONAAL
20-6


Risk
Veen
3
principes

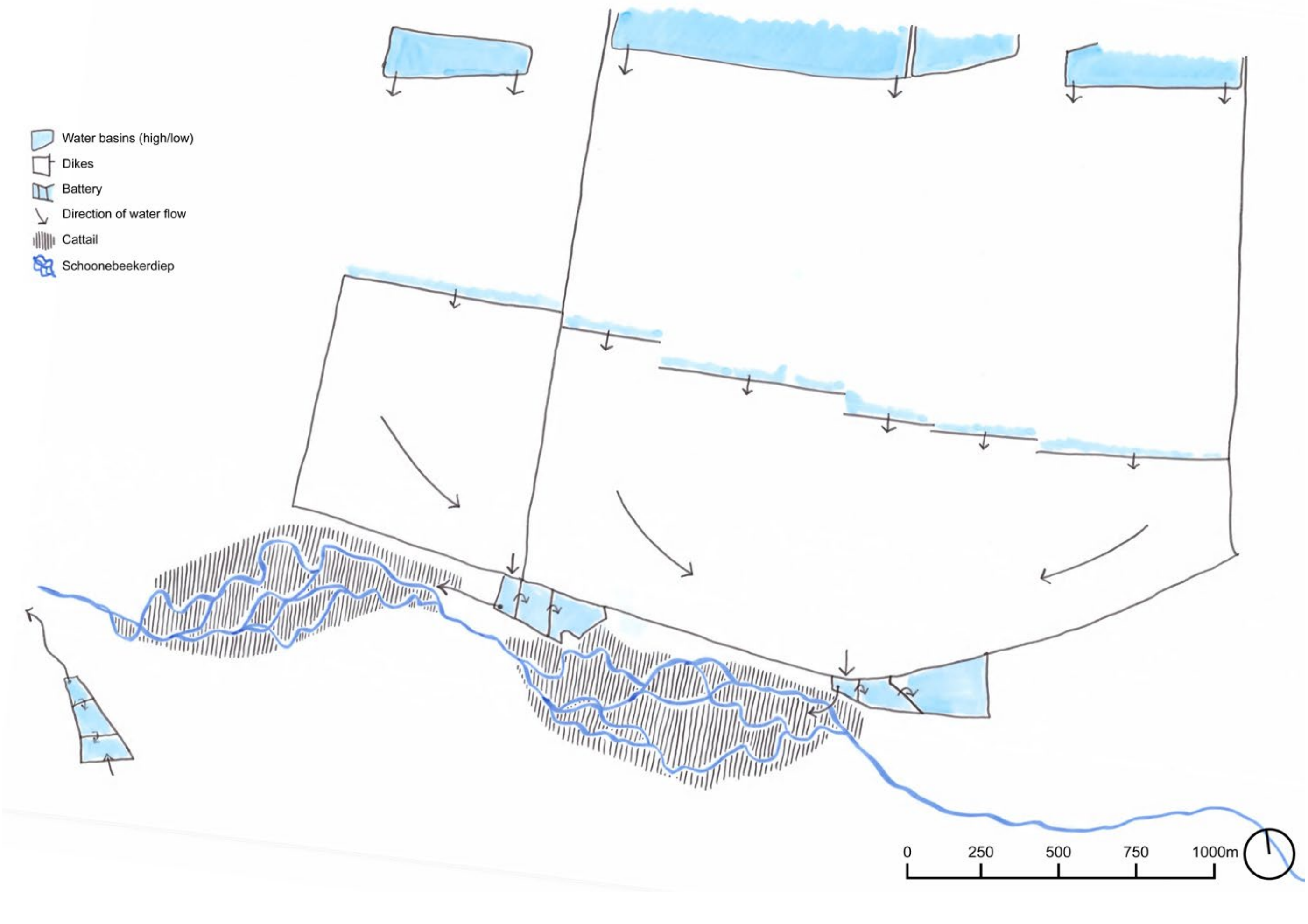






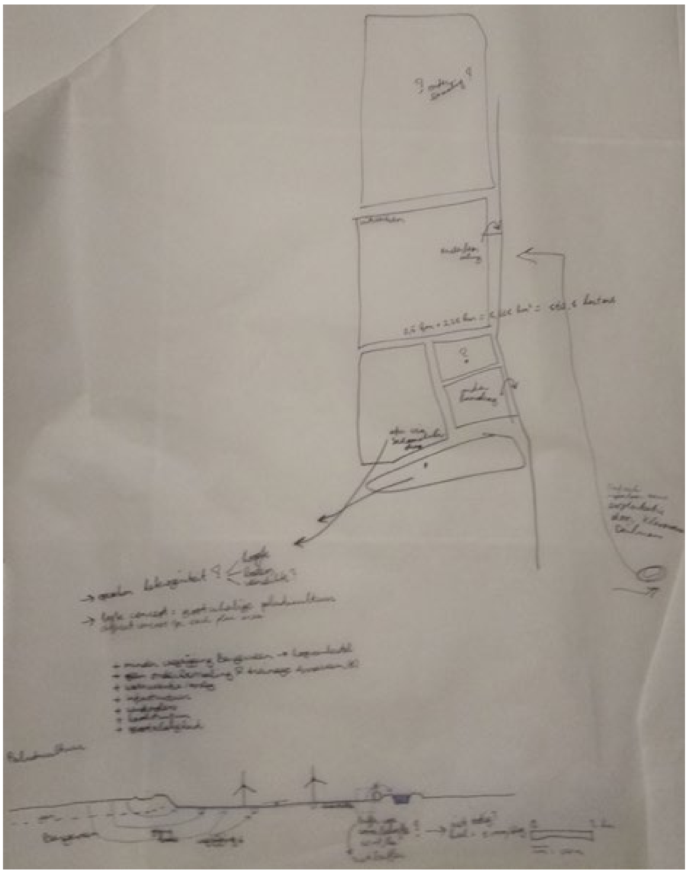


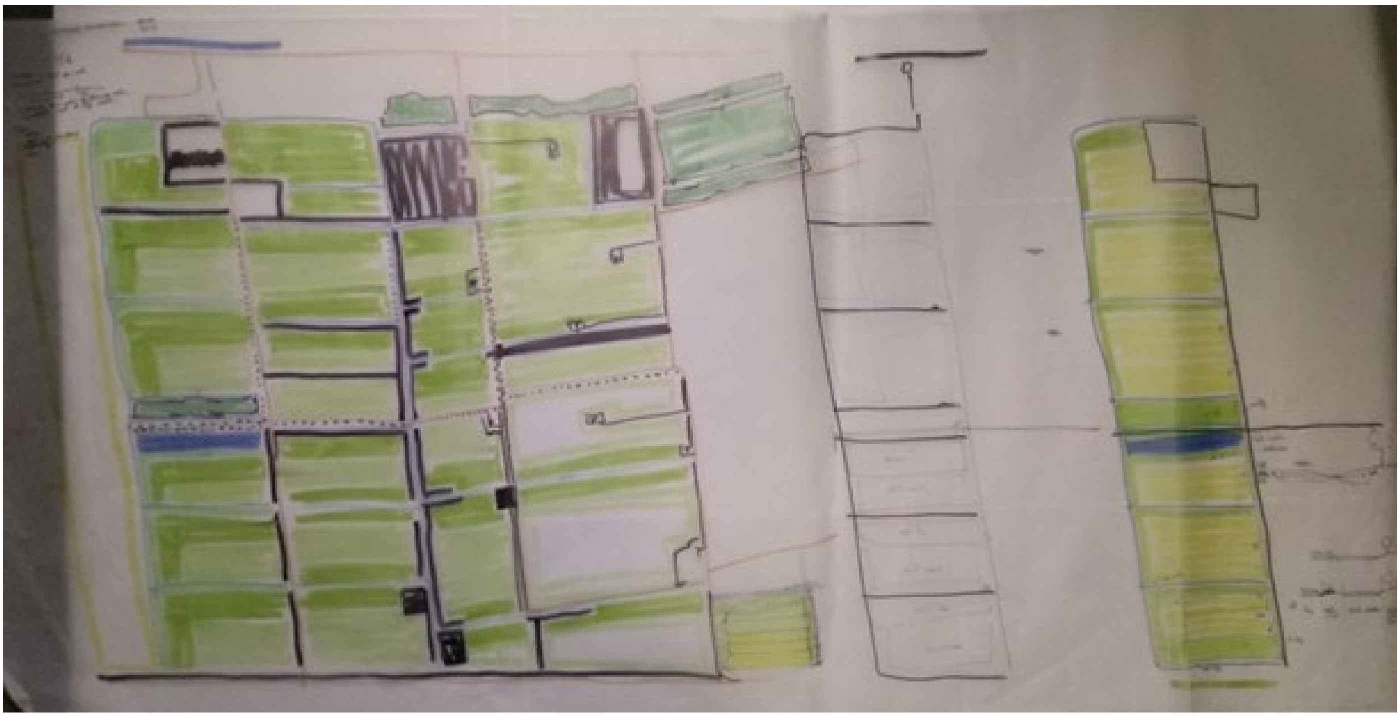
Schoonebeekerdiep
Courtyard
Willow
Reed - biomass
Reed - nature
Cattail
Waterbuffer - 'battery'
Lagg-zone
Swamp
Infrastructure with biomass loading point
Street with trees
Dike
0
250
500
750
1000m

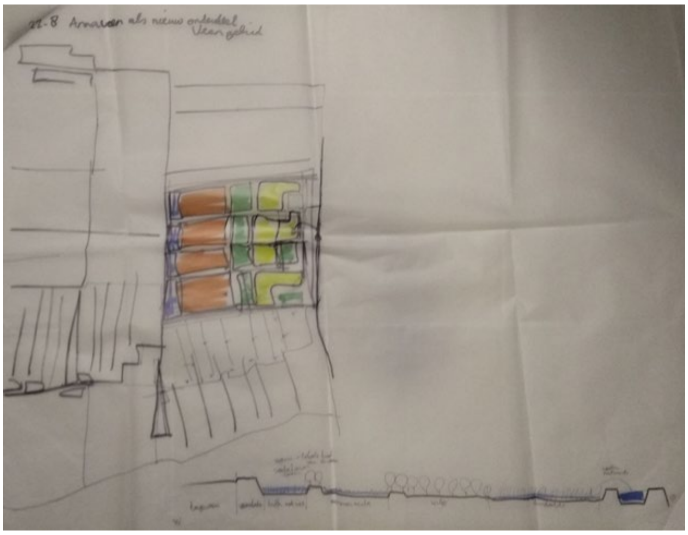


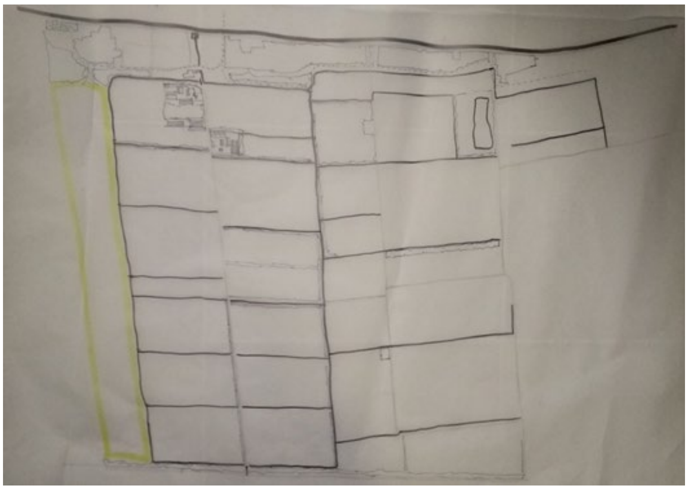
Water basins (high/low)
Dikes
Battery
Direction of water flow
Cattail
Schoonebeekerdiep
0
250
500
750
1000m

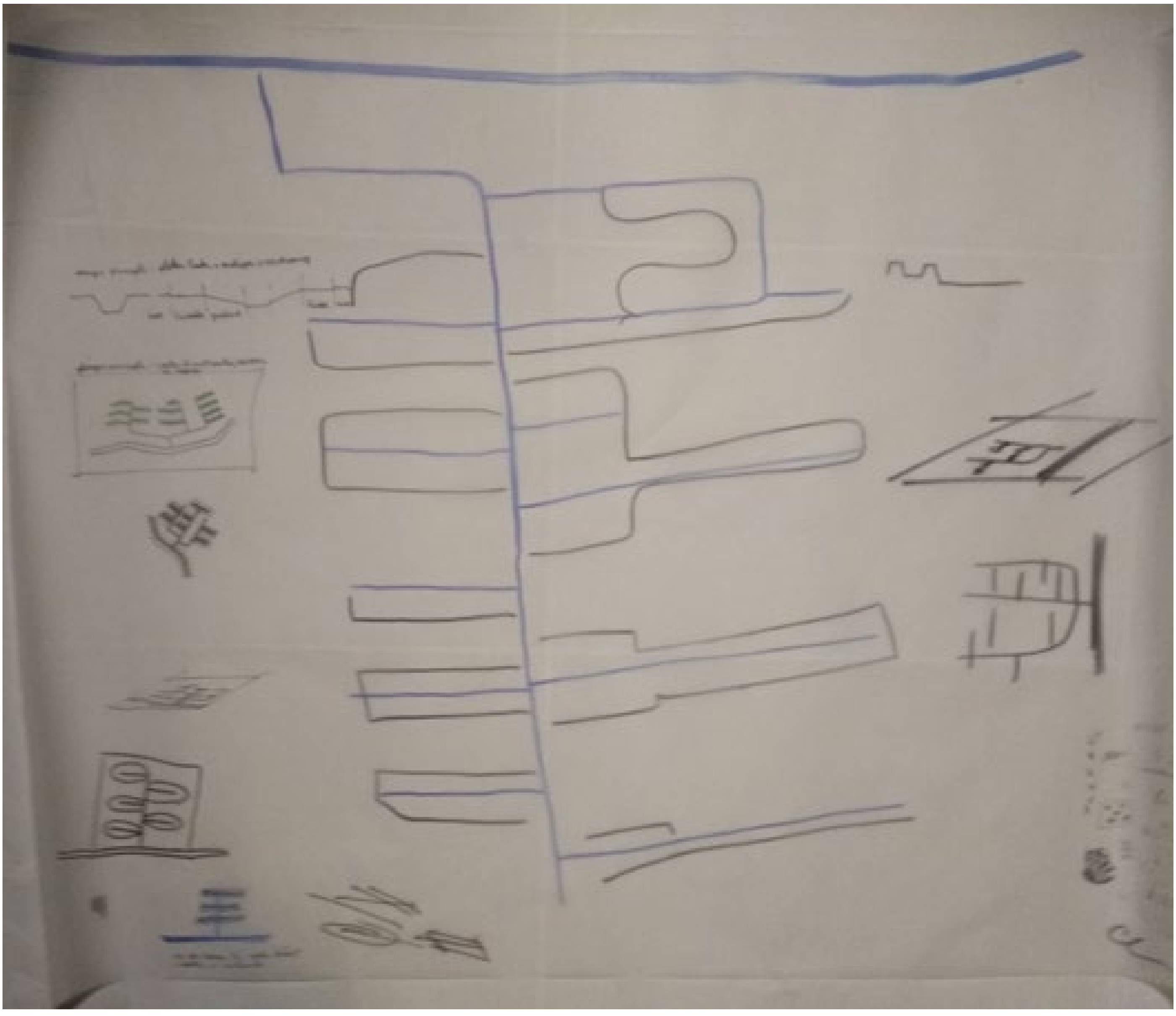
Annaveen



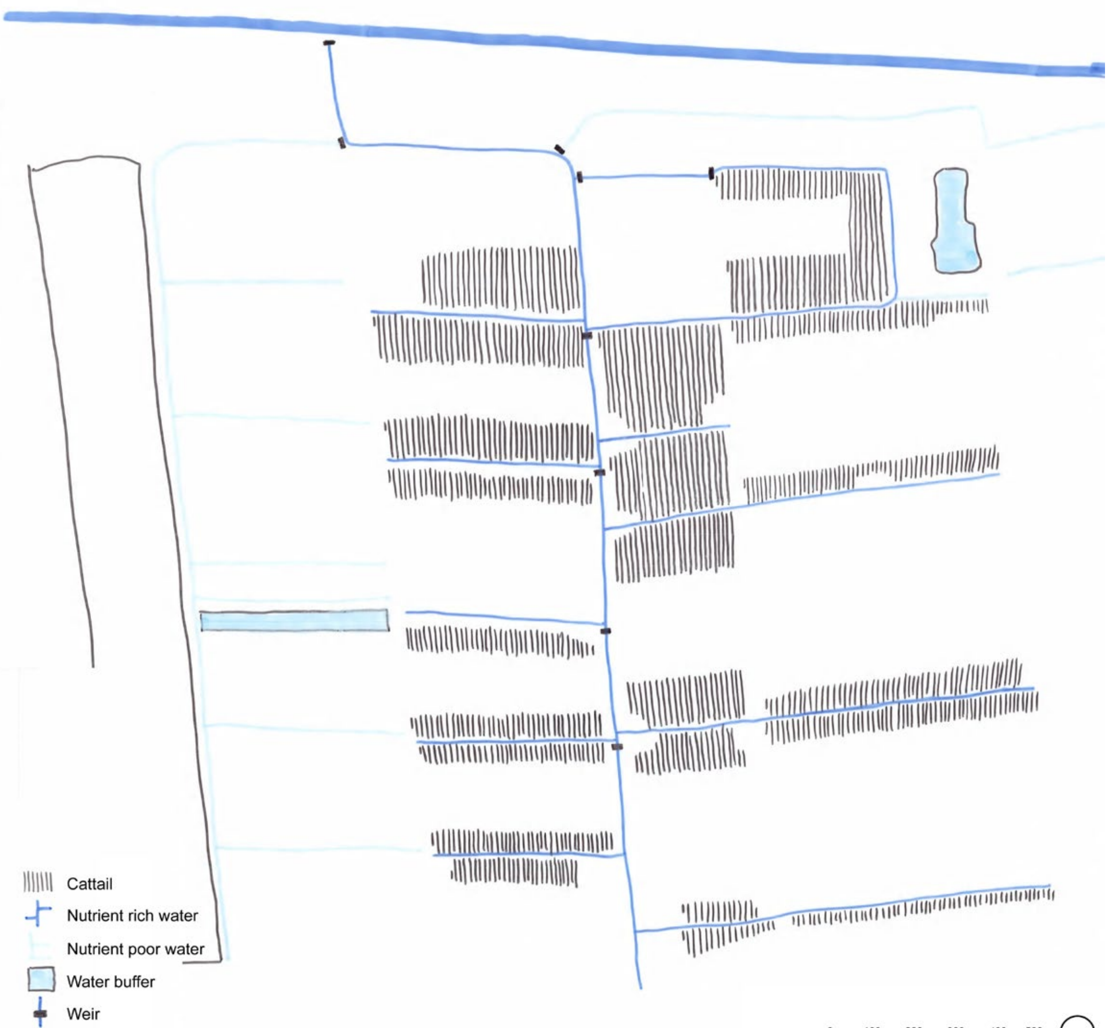


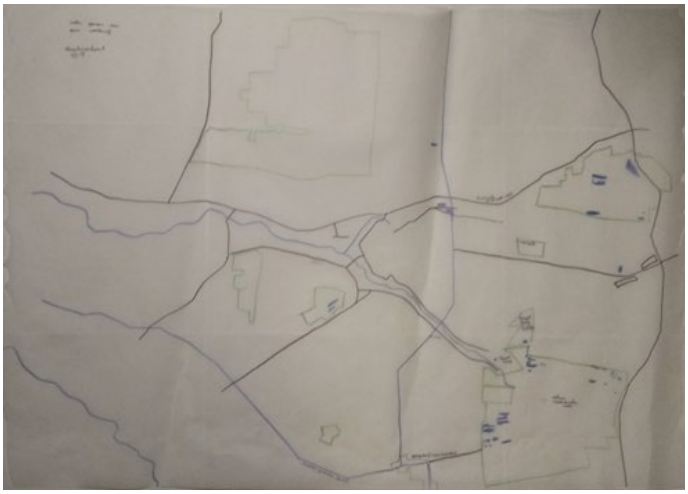

als nieuw onderdeel
Veengebied





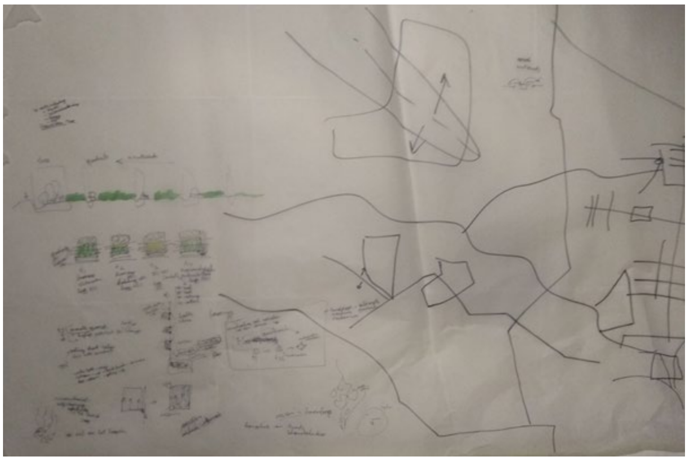

Cattail
Reed - biomass
Reed - nature
Willow
Street with trees
Forest
Windmill
Industrial railway
Ditches
Süd-Nord-Kanal
Former peat digging site - renaturated
0 100 200 300 400 500 m

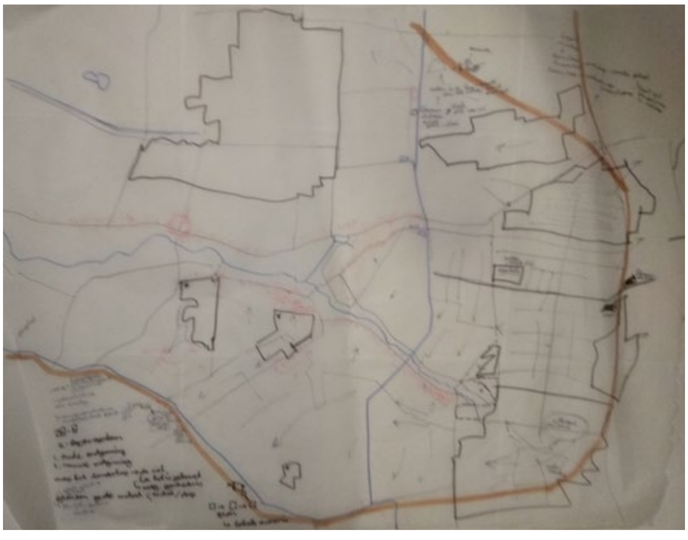

Cattail
Nutrient rich water
Nutrient poor water
Water buffer
Weir
0 100 200 300 400 500 m

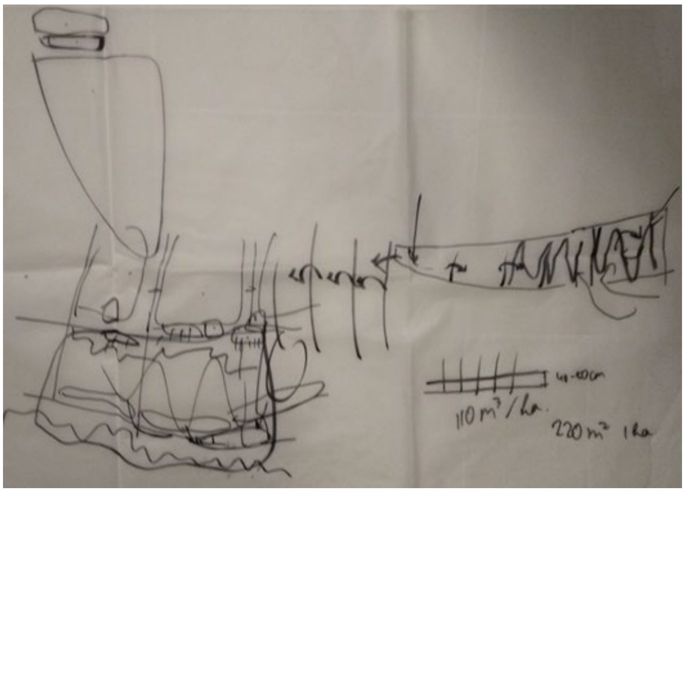



LANDSCAPE STRUCTURE MAP
1:25.000

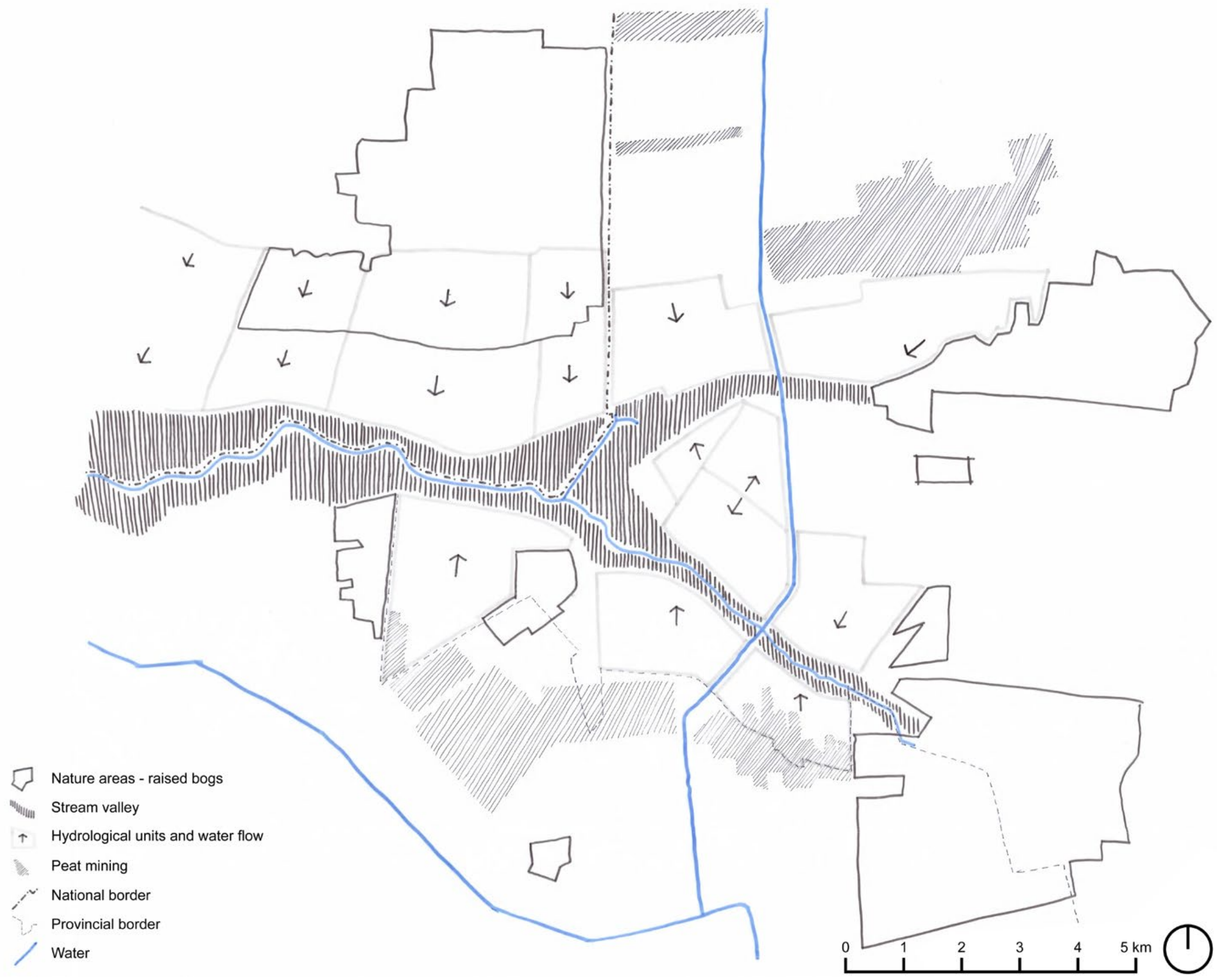

River system






110 m³/ha.
220 m³ / ha


Nature areas - raised bogs
Reed
Cattail
Peat moss
Willow
Forest
Tree lane
Water basins
Buidlings
0 1 2 3 4 5 km


Nature areas - raised bogs
Stream valley
Hydrological units and water flow
Peat mining
National border
Provincial border
Water
0 1 2 3 4 5 km