

# Revelation of the blue energy landscape

The implementation of a blue energy plant as landscape machine at the Volkerakdam



Karlijn Looman  
Koen Verhoeven

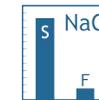
## Symbology



Fresh water: water with a low concentration of dissolved salts, mostly lakes, rivers or groundwater.



Salt water: water that contains a significant concentration of dissolved salts, mostly oceans and seas.



Salinity difference between fresh and salt water: blue energy requires the highest possible difference in salinity.



Amount of water: the amount of fresh and salt water determines the theoretical electricity production.



Physical edge: blue energy requires an edge between fresh, salt and brackish water to get a maximum difference in salinity.



Pumps: required to pump the water in and/or out the blue energy plant.



Membranes: the membranes are the main part of a blue energy plant where the electricity is produced.



Clean water: membranes require clean water since certain pollution causes a decrease in generated electricity.



Required space: mainly determined by the amount of membrane stacks, pumps and a installation for water filtration.



Energy: electricity is the main end-product of the blue energy plant.



Transport of electricity: the generated electricity needs a grid to transport it to locations where electricity is required.



Brackish water: main by-product of a blue energy plant. It is the sum of the amount of fresh and salt water.

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The implementation of a blue energy plant as landscape machine at the Volkerakdam

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## Preface

This thesis report contains the results of our research on the possibilities for the design of a blue energy plant as landscape machine at the Volkerakdam. We conducted this research as part of our Master study Landscape Architecture and Planning at the Wageningen University. The work described in this report was executed between September 2011 and May 2012.

Our interest for renewable energy sources started with the course Atelier 2011 '*Envisioning desired futures for two sustainable energy islands in the Dutch delta region*' at Wageningen University. The Atelier introduced us to renewable energy sources with blue energy as one of the possibilities. We saw the potential of blue energy in the Netherlands but we also felt the need for more research on blue energy in relation to the landscape. Working on this thesis has been challenging, but it was also satisfying to see that a natural landscape can contribute to a machine which generates renewable energy. The results of this thesis hopefully contribute to the discussion and implementation of a blue energy plant. We hope that this report reveals the possibilities of a blue energy plant in the landscape, and that it supports the discussion on designing with natural processes.

During the process of this thesis we have been supported by many people. We like to thank Renée de Waal and Sven Stremke for their critical and motivating supervision. Thanks also to Paul Roncken and Maurice Paulissen for their comments on our work. And thanks to the employees of REDstack, Rijkswaterstaat Zeeland and Zuid-Holland, Jan Post and Marieke de Lange for helping us in many different ways during our research. And last but not least we would like to thank our colleague students, friends, and family for their critical listening and positive support.

Wageningen, May 2012  
Karlijn Looman  
Koen Verhoeven

“The challenge to the Netherlands in the coming centuries is not primarily a threat; it also offers new prospects. Changing the way our country is managed creates new options; working with water may improve the quality of the environment and offers excellent opportunities for innovative ideas and applications. Where there is water, new forms of nature can arise. Water can be used to produce food and generate energy. Flood defences can be used for roads.”

*[Professor C.P. Veerman, Chairman of the Delta Committee, Deltacommissie 2008]*

“That includes our knowledge in the field of water, energy, and the high-quality food- and agricultural sector. We can therefore contribute to the solution of complex issues like climate change and resource scarcity, while strengthening our economy.”

*[Queen Beatrix in the speech from the throne 2011 about the society which stimulates people and companies]*

“Even if it takes many years before a commercial blue energy system can be realized, one should already reserve places where a future blue energy plant can be built.”

*[Deltares, 2010a, p.25]*

“If all the water of the Rhine would be used for blue energy(...), it would provide 70% of the Dutch electricity consumption”

*[J. Veerman at Clubgreen, n.d.]*

“For some years building with nature, also called eco-engineering, is a unmistakable trend.”

*[Technisch weekblad, vol. 10, 2012, p.7]*

“We changed all the estuaries into aquariums (...). With a salt or brackish environment the Volkerak-Zoommeer gets rid of the blue-green algae problem.”

*[A. van Hees, 2004]*

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## Summary

The climate is changing. It is necessary to switch to renewable energy sources to mitigate the effects of climate change. 'Blue energy' is one form of renewable energy. 'Blue energy' is energy that can be generated by mixing fresh and salt water. Through reversed electro dialysis (RED) an electric current is built up. This study describes how a blue energy plant can be placed into the landscape while using the concept of the landscape machine. The study starts with a description of twelve preconditions for the realisation of a blue energy plant: fresh water, salt water, salinity difference between fresh and salt water, amount of water, physical edge between fresh, salt and brackish water, pumps, membranes, clean water, required space, electricity, transport of energy and brackish water. There are sixteen locations in the Netherlands where fresh water meets salt water. Most of them are located where a river flows into the sea. On the basis of the technical preconditions it appears that one location is more suitable for a blue energy plant than the other. The influence of the blue energy plant on the landscape is also taken into account. From the possible locations the Volkerakdam is chosen for further research. This research consists of a landscape analysis, two concepts, and a design for a blue energy plant at the Volkerakdam.

The elaboration of the Volkerakdam is based on a theoretical framework and design principles. The theoretical framework contains two ways of looking to- and designing a landscape. The main approach is the concept of the landscape machine. In this concept the landscape is seen as a whole of natural processes with the characteristics of a machine with elements like predictability, input, fuel, and output. The second approach is the revelation of natural processes (eco-revelatory). The emphasis is on making the natural processes visible in the landscape. These two approaches form the basis of the design principles. The design principles are a collection of 40 possible solutions for the implementation of a blue energy plant. Each part of the blue energy plant, as described at the technical preconditions, contains three design principles with sub-design principles when necessary. All design principles contain a link with the theoretical framework. Using this list of design principles, the right choice can be made to design a blue energy plant for any location.

At the next step, two different concepts are developed for the Volkerakdam. Each concept has its own character, but both function as a landscape machine. One concept is developed as a combination of natural- and revealing processes. The other concept is a combination of mainly technical- and revealing processes. Both concepts contain a design, details, visualisations, and description. The most important aspect of both concepts is that the technical filtration of the water is replaced with natural filtration, using wetlands. Also multifunctional use of the landscape appears clearly in both concepts.

A combination of both concepts is developed into one design. The design shows how a blue energy plant can be placed in the landscape. A time line is used to create a design for 2020, 2030, and 2050. In 2020, the construction of a pilot plant is started to test if a wetland has sufficient capacities to filter the water. The pilot scale installation generates electricity for approx. 150 households and has a surface area of 120m<sup>2</sup>. A productive blue energy plant of 10MW can be realised around 2030 when the pilot is successful. 10MW is enough energy for 25,000 households. The required surface area of the blue energy plant is equal to three soccer fields. To generate this amount of energy, 10m<sup>3</sup> of fresh water and 10m<sup>3</sup> of salt water per second is required. Wetlands play an important role in this design. Both fresh and salt water wetlands require a wetland of 175 hectares. The wetlands contain mussels, algae's and vegetation which work together to ensure the water is filtered. Besides that, the mussels, algae's, and plants each have another function like food, biomass, and material for pharmaceuticals. The wetlands develop towards a regulated nature area with walking and cycling as most important recreational activities. The blue energy plant has the goal to generate energy, but besides that it functions as info centre, look-out and restaurant. The clean fresh and salt water leaves the blue energy plant as a stream of brackish water (20m<sup>3</sup>/s). The brackish water is discharged at the Volkerak sluices. The brackish water creates a gradual transition from brackish to salt water which results in a better operation of the sluices. There is also space for the development of brackish nature and a fishway through a small hole in a dike. The design shows that it is possible to generate electric-

ity in a sustainable way while at the same time the landscape serves other functions. This interaction between (natural) processes ensures that the landscape works as a machine: a landscape machine. The design is a revelation of the possibilities for a blue energy landscape.

The design concludes with a vision for the landscape of 2050. The blue energy plant and the surrounding landscape continue to expand. In 2050, the blue energy plant generates 60MW. The blue energy plant is developed to the most important energy supply of the region. Besides that, the surroundings of the Volkerak focused on the latest techniques for filtering of water through wetlands. The products that are harvested from the wetlands are used for numerous purposes. The wetlands and the brackish water ensure the development of special nature areas. The areas are interesting for walking, cycling, and several types of water sports

The main conclusion that can be drawn is that it is possible to design a blue energy plant in such way that it functions as a landscape machine. It is important for each location which design principles are most applicable. Blue energy as energy source still has to develop strongly but offers great potential for de development of the landscape.

## Samenvatting

Het klimaat is aan het veranderen. Het is nodig om over te stappen op duurzame energiebronnen om het effect van klimaatverandering te beperken. 'Blue energy' is één vorm van duurzame energie. 'Blue energy' is energie die kan worden opgewekt door het mengen van zoet en zout water. Door middel van omgekeerde elektrolyse (reverse electrodialysis, RED) wordt een elektrische spanning opgebouwd. Dit onderzoek beschrijft hoe een blue energy centrale kan worden ingepast in het landschap met behulp van het concept van de landschapsmachine. Het onderzoek start met een beschrijving van twaalf technische randvoorwaarden voor het realiseren van een blue energy centrale: zoet water, zout water, saliniteitsverschil tussen zoet en zout water, hoeveelheid water, fysieke grens tussen zoet, zout en brak water, pompen, membranen, schoon water, benodigde ruimte, energie, transport van elektriciteit en brak water. Er zijn zestien locaties in Nederland waar zoet en zout water bij elkaar komen. Over het algemeen zijn dit de plaatsen waar een rivier uitmondt in zee. Aan de hand van de technische randvoorwaarden blijkt dat de ene locatie beter geschikt is voor een blue energy centrale dan de andere. Hierbij is ook gekeken naar de invloed van een blue energy centrale op het landschap. Uit de mogelijke locaties is de Volkerakdam gekozen voor verdere uitwerking. Deze uitwerking bestaat uit een landschapsanalyse, twee concepten en een ontwerp voor een blue energy centrale bij de Volkerakdam.

De uitwerking van de Volkerakdam is gebaseerd op een theoretisch kader en ontwerpprincipes. Het theoretisch kader bevat twee invalshoeken voor het kijken naar- en het ontwerpen van een landschap. De voornaamste invalshoek is het concept van de landschapsmachine. Bij dit concept wordt het landschap gezien als een geheel van natuurlijke processen die karakteristiek vertonen van een machine met elementen zoals voorspelbaarheid, input, brandstof en output. De tweede invalshoek is het onthullen van natuurlijke processen (eco-revelatory). De nadruk hierbij ligt op het zichtbaar maken van de natuurlijke processen in het landschap. Deze twee invalshoeken vormen de basis voor de ontwerpprincipes. De ontwerpprincipes zijn een verzameling van 40 mogelijke oplossingen voor het implementeren van een blue energy centrale. Per onderdeel van de blue en-

ergy centrale, zoals deze bij de technische randvoorwaarden zijn besproken, zijn drie ontwerpprincipes gecreëerd met waar nodig sub-ontwerpprincipes. Hierbij is voortdurend de link gelegd met het theoretische kader. Aan de hand van deze lijst van ontwerpprincipes kan voor iedere willekeurige locatie de juiste keuze worden gemaakt voor het ontwerp van een blue energy centrale.

Vervolgens zijn twee verschillende concepten uitgewerkt voor de Volkerakdam. De concepten hebben ieder een verschillend karakter, maar beiden functioneren als een landschapsmachine. Eén concept is uitgewerkt als een combinatie van natuurlijke- en onthullende processen. Het andere concept is een combinatie van voornamelijk technische- en onthullende processen. Beide concepten bevatten een ontwerp, details, visualisaties en een toelichting. Het meest belangrijke aspect van beide concepten is dat de technische filtering van het water is vervangen door natuurlijke waterfiltering aan de hand van wetlands. Multifunctioneel gebruik van het landschap komt in beide concepten ook duidelijk naar voren.

Een combinatie van beide concepten is uitgewerkt in één ontwerp. Het ontwerp laat zien hoe een blue energy centrale kan worden ingepast in het landschap. Hierbij is gebruik gemaakt van een tijdlijn met een ontwerp voor 2020, 2030 en 2050. In 2020 start men met de aanleg van een proefcentrale waarbij wordt getest of een wetland voldoende capaciteiten heeft om het water te filteren. De proefcentrale genereert elektriciteit voor 150 huishoudens en heeft een oppervlakte van 120m<sup>2</sup>. Indien dit succesvol is, kan rond 2030 een productieve blue energy centrale van 10MW worden gerealiseerd. 10MW is genoeg energie voor 25.000 huishoudens. De benodigde oppervlakte van de centrale is gelijk aan drie voetbalvelden. Om deze hoeveelheid energie te genereren, is 10m<sup>3</sup> zoet water en 10m<sup>3</sup> zout water per seconde nodig. Bij dit ontwerp spelen de wetlands een belangrijke rol. Zowel voor het zoete water als het zoute water is een wetland nodig van 175 hectare. De wetlands bestaan uit mosselen, algen en planten die samen zorgen dat het water wordt gefilterd. Daarnaast hebben de mosselen, algen en planten ieder nog andere functies zoals voedsel, biomassa en grondstof voor

de farmacie. De wetlands ontwikkelen zich tot een gereguleerd natuurgebied met wandelen en fietsen als belangrijkste recreatieve functies. De blue energy centrale heeft het genereren van energie als doel, maar wordt daarnaast gebruikt als informatie centrum, uitkijkpunt en restaurant. Het schone zoete en zoute water verlaat de blue energy centrale als een stroom brak water (20m<sup>3</sup>/s). Het brakke water wordt geloosd bij de Volkeraksluizen. Het brakke water creëert een geleidelijke overgang van brak naar zout water wat zorgt voor een betere werking van de sluisen. Door een kleine opening in een dijk is daarnaast ruimte gecreëerd voor de ontwikkeling van brakke natuur en een vistrap. Het ontwerp laat zien dat het mogelijk is om op een duurzame manier elektriciteit te produceren terwijl tegelijkertijd het landschap verschillende andere functies dient. Dit samenspel van (natuurlijke) processen zorgt ervoor dat het landschap werkt als een machine: een landschapsmachine. Het ontwerp vormt een onthulling van de mogelijkheden voor een blue energy landschap.

Het ontwerp wordt afgesloten met een visie voor het landschap van 2050. De blue energy centrale en het omliggende landschap blijven zich uitbreiden. In 2050 genereert de centrale 60MW. De centrale is ontwikkeld tot belangrijkste energievoorziening van de regio. Daarnaast heeft de omgeving van het Volkerak zich toegelegd op de nieuwste technieken voor het filteren van water met behulp van wetlands. De producten die worden geoogst van de wetlands worden voor talloze doeleinden gebruikt. De wetlands en het brakke water zorgen voor de ontwikkeling van bijzondere natuurgebieden. De gebieden zijn erg interessant voor wandelen, fietsen en verschillende vormen van watersport.

De belangrijkste conclusie die kan worden getrokken, is dat het mogelijk is om een blue energy plant dusdanig te ontwerpen dat het functioneert als een landschapsmachine. Hierbij is het van belang dat voor iedere locatie wordt gekeken welke ontwerp-principes het meest van toepassing zijn. 'Blue energy' als energiebron moet zich nog sterk ontwikkelen maar het biedt grote mogelijkheden voor de ontwikkeling van het landschap.



*Cloudy sky at the Volkerak*

# 1

## INTRODUCTION

## 1.1 General introduction

Demand for energy services for the improvement of human welfare, economy and health are increasing. All societies require energy to serve productive processes. Since 1850 the global use of fossil fuels (coal, oil and gas) has increased to dominate energy supply, leading to a rapid growth in carbon dioxide emissions. There are several options for lowering CO<sub>2</sub> emissions from the energy system while at the same time the global energy demand can be satisfied [IPCC, 2011a]. The most important options are switching from fossil fuel to renewable energy sources (energy transition), saving energy, more efficient use of fossil fuels [Brouwers and Entrop, 2005] and reducing the energy demand [KNAW, 2007].

As well as having a large potential to mitigate to climate change, renewable energy can provide wider benefits. Renewable energy may, if implemented properly, contribute to social and economic development, energy access, a secure energy supply, and reduce negative impacts on the environment and health [IPCC, 2011a].

According to IPCC, among other organizations, sustainable energy sources become more and more important. Blue energy is one of the possible promising solutions.

Blue energy is the energy generated by mixing fresh and salt water through membranes. Or according to Post [2009, p.205] it is *'a popular term for salinity-gradient energy, indicating the theoretical non-expansion work that can be produced from mixing two salt solutions with different concentrations'*. The term blue energy is confusing for many people since it is often used as all renewable energy sources related to water. In this thesis the definition of Post is used.

There are two methods to generate blue energy: the Pressure Retarded Osmosis technique (PRO) and the Reversed Electro Dialysis technique (RED). The RED technology seems to be the most promising when used for power generation from sea water and river water [Post et al., 2007]. This technology uses membranes along which fresh water on one side, and salt water on the other side flows. The difference in the concentration of ions between salt and fresh water

produces electricity when passing through those membranes. Generating blue energy is possible in laboratory practice but the implementation of a commercial RED blue energy plant in the landscape is not realised yet. But *"even if it takes many years before a commercial blue energy system can be realized, one should already reserve places where a future blue energy plant can be built"* [Deltares, 2010a, p.25].

Worldwide blue energy has a theoretical potential of 1600 TWh, equal to the Chinese energy production in 2002 [Sandvik and Skilhagen, 2008]. In fact, all estuaries in the world where fresh water meets salt water have potential for blue energy generation. Taking into account that 22 of the 32 largest cities in the world are situated around an estuary [Ross, 1995] it provides opportunities to combine this with blue energy. In this way energy sinks (cities) and energy source (blue energy) are next to each other.

According to the First law of thermodynamics energy cannot be produced but is always conserved [Clausius, 1850] When one normally talks about 'producing energy' this often refers to the second law of thermodynamics; destroying exergy and creating entropy. Mixing of salt ions (from salt and fresh water) reduces exergy and increases entropy. In the situation of blue energy on the left-hand side (figure 1.1), the salt water is still separated from the fresh water and exergy is relatively high. On the right-hand side, the salt- and fresh water are mixed and entropy is relatively high.

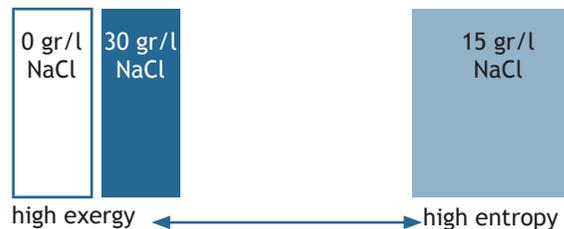


Figure 1.1: Destroying exergy and creating entropy [based on: Stremke et al., 2011]

## 1.2 Knowledge gap

The topic of blue energy still faces a big knowledge gap. A lot of research has been done on blue energy, but all this research is based on the technological side of it [see for instance: Pattle, 1954; Isaacs & Seymour, 1973; Loeb, 1975; Jagur-Grodzinski & Kramer, 1986; Veerman, 2008; Lako, 2009; Post, 2009; Deltares, 2010a; Ecofys, 2010]. There has not been any research yet about the landscape design, impact and implementation of a blue energy plant. Acquiring and using this knowledge will be the main topic of the thesis.

A quick-scan from Deltares [2010a] showed all knowledge gaps concerning blue energy. The following knowledge gaps were stated concerning the surroundings of a blue energy plant:

- Effects on the natural environment
- Effects on infrastructure, water works and delta works
- Effects on people living in the surrounding area and other stakeholders
- Possible locations and availability of fresh and salt water

## 1.3 Problem, purpose and significance

This research uses a problem as starting point. The research problem in this master thesis is the unknown effect of a blue energy plant to its surrounding landscape and how to implement such plant at a certain location. While the focus of the research on blue energy until now was on the technological side, this thesis focuses on the implementation of a blue energy plant in the landscape.

The purpose of this master thesis is to create a design and design principles which are an inspiration for the implementation of a blue energy plant in order to find an answer to the stated problem. Besides that the design should deliver a multifunctional landscape with the elements of a landscape machine. The concept of the landscape machine is part of the theoretical framework. The 'landscape machine' is a combination of continuously interfering natural processes which together function like a machine with a certain input, fuel and output.

Since blue energy will be commercially interesting in a few years time, the results of the thesis can provide a framework for the design and implementation of a blue energy plant. The results of this thesis show how to deal with the processes of a blue energy plant in the landscape. The results can be used by landscape architects, but are also useful for nature organizations, engineers, municipalities and promoters of sustainable energy sources. Looking at the pragmatic worldview (chapter 2), the results are real-world oriented and therefore usable for those organisations. These organisations, as well as the people living in the area are the target group for this thesis. The thesis also gains more insights about landscape machines; how they could work, what a landscape machine exactly could be and how it could be implemented in the landscape.

## 1.4 Research questions

The following research questions are derived from the knowledge gap, problem and purpose statement.

### Main research question

*What are the technical preconditions for a blue energy plant and how can a design using the concept of 'the landscape machine' help to implement a blue energy plant within the surroundings of the Volkerakdam?*

### Sub questions:

- What are the technical preconditions for a blue energy plant?
- What are possible locations for a blue energy plant in the Netherlands?
- What are the effects of a blue energy plant on the landscape near the Volkerakdam?
- What are the requirements for creating a blue energy plant as landscape machine?

### Design question

*How can the landscape for a blue energy plant be designed in such way that it fulfils its function as energy generator while applying the concept of a landscape machine?*

### Sub questions:

- Which design principles for a blue energy plant can be derived from the technical preconditions in relation to the landscape machine?
- What are the possibilities for the implementation of a blue energy plant within the range of the landscape machine?

## 1.5 Delineation and assumptions

The thesis had to be finished within a time span of 6 months for two people. This section describes the delineation of the thesis and which assumptions are made to get an answer to the research questions within this time span.

The research does not focus on the technical matter of the blue energy installation. Since this thesis is conducted as part of the study 'Landscape architecture' the focus is on the landscape around a blue energy plant. This angle of incidence is new within the field of blue energy. Choices on the technical level are based on existing literature and interviews. Only information required for a decent design will be used. Research of inter alia Post [2009], Veerman [2009] and Deltares [2010a] are used to make a design for a blue energy plant.

Blue energy is still in an experimental phase. It is expected to be feasible within a few years [Veerman, 2009], but at the moment the technology is too expensive to implement it on a large scale. The thesis is based on the assumption that blue energy becomes economically feasible within a few years.

The thesis report describes 16 possible locations for blue energy. The concepts and design for a blue energy plant focus on only one location; the Volkerakdam.

At the moment the Volkerak-Zoommeer contains fresh water. There are plans to make to turn it into a salt water lake. This research is based on the assumption that the Volkerak-Zoommeer will become salt enough to generate blue energy.

Wetlands with certain plants have the ability to filter water. Based on interviews [Paulissen, 2012, de Lange, 2012] and existing literature it is assumed that a wetland filters the water enough to create fresh water for a blue energy plant.

## 1.6 Structure of the report

This report consists of 11 chapters. Chapter 1 contains the subject description, knowledge gaps, research questions, project delineation and assumptions. In chapter 2 the research design is described. The chapter describes the way the research is executed and which research techniques are used. The worldview in the same chapter explains the personal and disciplinary background of the authors on the subject. The further chapters can be divided into four phases.

The first phase is the orientation phase. Chapter 3 describes the climate change and the consequences of climate change on the blue energy plant and surroundings. In chapter 4 the technology of blue energy is described. Out of this description technical preconditions are determined and are presented in a list which is also visible at the fold-out part of the report cover. This list is used in chapter 5 'Possible locations'. The chapter describes the possible locations for blue energy in the Netherlands. These locations are selected based on the technical preconditions. Out of the possible locations one of the locations is chosen; the Volkerak. Chapter 6 tells the history, present and future of the Volkerak (Zuid-Holland and West-Brabant) and surroundings.

The second phase focuses on the framework of the thesis. Chapter 7 describes the theoretical framework. Several design theories, based upon the concept of the landscape machine and eco-revelatory design, are used to create a theoretical framework for the design. The knowledge of the theoretical framework and technical preconditions led to design principles which are presented in chapter 8.

The third phase is the design phase. Chapter 9 presents two concepts and the evaluation of those concepts. Using the evaluation in chapter 9 the final design is presented in chapter 10. The design consists of a master plan, details, visualizations, cross sections and a description.

The last phase contains the evaluation of process and design. Chapter 11 describes the conclusion, discussion about the design, theories and way of working.

|    |   |             |
|----|---|-------------|
| 1  | <b>Introduction</b>   |             |
| 2  | <b>Research design</b>  |             |
| 3  | <b>Climate change</b><br>Consequences of climate change on the blue energy plant and his surroundings                         | Phase one   |
| 4  | <b>Technical preconditions</b><br>Description technical preconditions for a blue energy plant in the landscape                |             |
| 5  | <b>Possible locations</b><br>The possible locations for blue energy in the Netherlands  |             |
| 6  | <b>Volkerak</b><br>Description of the history, present and future of Volkerak and his surroundings                            |             |
| 7  | <b>Theoretical framework</b><br>A theoretical framework for the design  | Phase two   |
| 8  | <b>Design principles</b><br>Principles for the design for a blue energy plant   |             |
| 9  | <b>Concepts</b><br>Two concepts made by the authors, evaluated by using the technical preconditions and the design principles | Phase three |
| 10 | <b>Design</b><br>The final design   |             |
| 11 | <b>Discussion</b><br>About design, process, methods, way of working   | Phase four  |

A blue heron is perched on top of a white rectangular sign. The sign is mounted on a dark metal post that is partially submerged in a canal. The water is dark and reflects the surrounding environment. The heron has a long, sharp beak and is looking towards the left. The sign has black text on it.

VERBODEN TE VISSSEN  
VISWATER  
H.S.V DE VESTE

*Blue heron sitting on a sign (prohibited to fish) at the canal around Willemstad*

# 2

## RESEARCH DESIGN

This chapter describes the research design of the thesis which gives direction to the process of a design. The design process does not follow a linear procedure, but is a continuous shift between design and research.

The first section gives insight on the worldview and background of the authors. This helps to understand the choices which are made throughout the thesis.

The chapter continues with the research approach which combines research and design. It describes how the research is conducted. This is followed by a list of techniques used to arrive at the design for a blue energy plant. The techniques are described per part of the report. The fourth section of the chapter describes the research process. The last section gives a short definition of the most important terms in the report.

## 2.1 Worldview

The term worldview stands for a “*basic set of beliefs that guide action*” [Guba, 1990, p.17]. The worldview influences the practice of research and should therefore be identified [Creswell, 2009]. This thesis is influenced by the personal and disciplinary background of the authors.

Our background is based on the practical context of the previous study at a university of applied sciences combined with several years of education at Wageningen University with a certain system approach as guideline. The combination of the two different types of education leads to different insights and views on the topic. The theoretical- and research based background of Wageningen University helps to make design principles based on different theories. The previous bachelor education places the gained knowledge in a practical context which enables us to realize a usable and understandable design.

The world view is also dependent on the subject, and therefore not static. For this thesis the worldview is mainly ‘pragmatic’ and ‘constructivist’. This briefly means problem centred, real-world practice, and oriented research. Instead of focusing on methods, researchers emphasize the research problem and use all approaches available to understand the problem [Rossman & Wilson, 1985].

We share the idea that a landscape should be experienceable and (multi)functional. Besides that the landscape keeps evolving which is a continuous process. Gary Strang [1996] wrote an interesting text ‘Infrastructure as landscape’ which is relevant for the thesis topic; it mentions the influence of the human being in the landscape and looking at the landscape as a system; a landscape machine. It is important to take these processes into account, together with the history and abiotic processes to find solutions for occurring problems. The landscape has to serve multiple functions and it should provide possibilities to do something in the landscape and with the landscape.

## 2.2 Research approach

The research approach of this thesis can be seen as a way to combine research and design. Combining research and design in a proper way is important for the thesis. The research is focussed on designing.

This design study uses an adapted version of the method of Ledewitz [1985] (figure 2.1). The model presents designing as a complex intellectual activity. This model describes the design process as the examination of the design problem through the assessment of a series of complex and interrelated components. The problem is solved as a result of the analysis of information provided through research and scientific activities, thereby producing a design. The model focuses on interaction: both in terms of the components of the design problem, and in terms of the relationship between research and design [Milburn & Brown, 2003]. Different from the original model is the construction phase which is only imagined as such.

In this study researching and designing was an interactive process. The process started with gaining insights on blue energy and the concept of the landscape machine. This led to new knowledge and design principles which were used as material for two concepts. Based on the insights gained from the concepts and advanced research on the location it was possible to create a design. These steps represent an interaction of research and design which led to an answer to the research questions (figure 2.2).

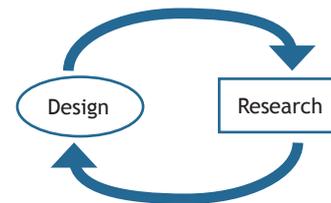


Figure 2.2: Continuous process of design and research

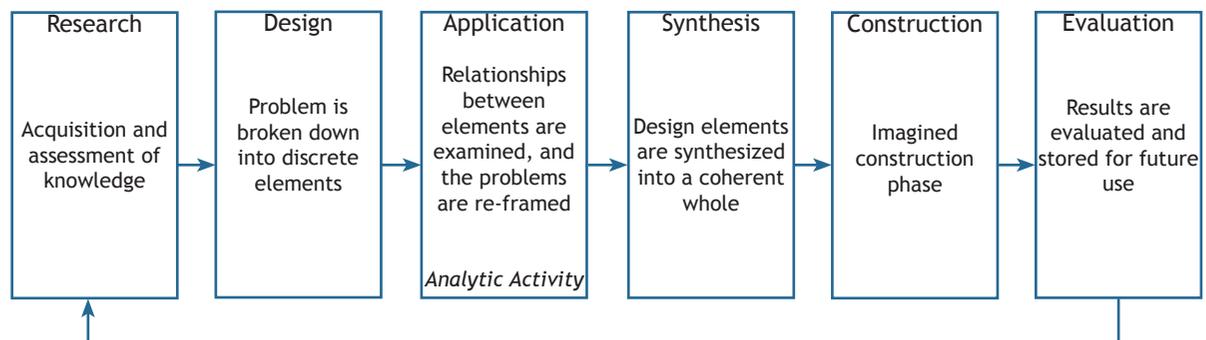


Figure 2.1: Relationship between research and design as identified by the complex intellectual activity model [based on: Ledewitz, 1985]

## 2.3 Research techniques

The list below describes the techniques used to carry out the research. This is followed by a description of the research techniques used for each part of the report.

- Interviews: face-to-face with open end questions and taking notes while recording [Creswell, 2009, p. 182]. To trigger discussions sketches are presented during the interview. In this way the expert is able to explain if something is possible or not. Experts are useful to gain inside information.
- Literature study: There is much information available on all different topics which are used in the design (e.g. blue energy, brackish water). It is important to use all this information and combine it with the design principles and design.
- Sketches and visualizations: Sketches are used throughout the whole thesis to start discussions, test design principles, and to draw the final design.
- Design principle testing: During the project design principles are made for blue energy plants in a certain environment. These are tested by two concepts to confirm them.

### Climate change

The information on climate change in chapter 3 is collected by a literature study. The information is needed to create a design for a safe blue energy plant which can deal with the changes in the weather patterns in the future.

### Technical preconditions

To identify the possible locations for blue energy in the Netherlands, a full understanding is necessary of the requirements for blue energy. These requirements for blue energy are described as technical preconditions in chapter 4. The technical preconditions are mainly based on the reports of Veerman [2008], Post [2009], Quak [2009], Smalbrugge [2009], Deltares [2010], Ecofys [2010] and interviews with J. Veerman and J.W. Post [2011]. Out of those studies twelve technical preconditions are defined. For these preconditions symbols were created. These symbols are explained on the fold-out part of the report cover.

### Possible locations

The next step after gathering the preconditions of a blue energy plant was to create a list of all possible locations for blue energy in the Netherlands.

A map of the Netherlands combined with literature of Rijkswaterstaat [2006, 2008-2011], Witteveen & Bos [2006], Deltares [2008-2010], Veerman [2008], Smalbrugge [2009], Quak [2009] and Alterra [2011] are used to select the possible locations. All places where fresh- and salt water meet give theoretical opportunities for a blue energy plant. The locations with an average discharge of minimal 200 m<sup>3</sup> of fresh- or salt water per minute are selected as possible location. This amount of water is chosen since only a large scale blue energy plant will influence the landscape which is challenging for the thesis and interesting concerning the worldview.

The selection criteria resulted in 16 possible locations. For every location the technical potential is described using the technical preconditions. The outcomes of the feasibility of a location are presented with a description and a concluding table. The chapter itself only contains the finally chosen location. The descriptions of all 16 locations are added as appendix 1. More information on the used research techniques can be found in the introduction of the chapter.

### Volkerak

The landscape analysis in chapter 6 describes the history, present, and future situation of the location chosen for the blue energy plant: the Volkerak. Maps and literature are used to create an overview of the lake, Volkerakdam, and surroundings. The systematic layer-approach is used to describe the landscape. The information in this chapter is required to be able to create a reliable design (chapter 9 and 10).

### Theoretical framework

The theoretical framework in chapter 7 describes the concept of the landscape machine. This concept is chosen out of a several theories on landscape ecology and other metaphors of describing a landscape. At first the theoretical framework was described as an essay. Later on this is adapted to the story as visible in this report.

### Design principles

The design principles in chapter 8 are the fusion of the technical preconditions and theoretical framework. Each part of the blue energy plant is evaluated on the possibilities for a design principle. This included interviews with two ecologists (M. Paulissen and M. de Lange) in order to include natural processes. This finally resulted in 40 design principles.

### Concepts

Chapter 9 contains two concepts for the design of a blue energy plant at the Volkerakdam. The concepts are used to test and confirm the design principles. Each author created one concept with sketches, a design, and visualisations.

### Design

The final design in chapter 10 is created with a combination of many research techniques. The chapter contains drawings, visualisations, cross-sections, maps, and a text. The information in the text is a combination of the gathered information in previous chapters. Besides that it contains new knowledge on for example fishways. This knowledge was collected with interviews and literature research.

### Discussion and conclusion

This chapter does not contain any of the research techniques mentioned in the introduction of this section. It contains an evaluation and conclusion on the design, process, and theories.

## 2.4 Process

The process of this research can be explained with the process flowchart (figure 2.3). This section describes the flowchart.

The first step was to define the topic of the study: blue energy. After some exploratory research on the topic it was possible to select the knowledge gaps concerning blue energy in relation to the landscape. These knowledge gaps resulted in research questions. The next step was to describe the technical preconditions for blue energy and the theoretical framework of the landscape machine and eco-revelatory design.

With the technical preconditions as basis the following step was to find the possible locations for blue energy in the Netherlands. From these possible locations one location was chosen for further research and a analysis: The Volkerak.

The next step was to define the design principles for the design of a blue energy plant. These design principles are based on the technical preconditions and theoretical framework. Thereafter two concepts for the design of a blue energy plant at the Volkerakdam were created; one by each author. The concepts combine the different parts of the research: the technical preconditions, theoretical framework, design principles, and landscape analysis. The concepts were used to test the design principles. The next step was to discuss the created concepts and discuss which elements of each concepts could be used for the final design. After a more detailed analysis and research it was possible to create the final design for a blue energy plant at the Volkerakdam. This research included the potential to create a landscape machine from a blue energy plant. Finally the outcomes of the design were discussed and evaluated.

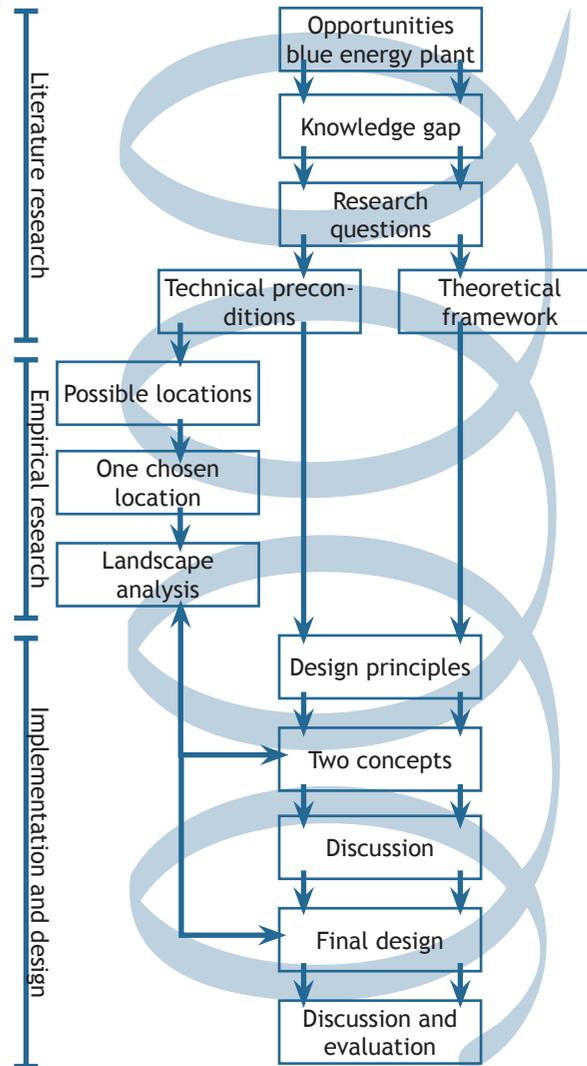


Figure 2.3: Research process

## 2.5 Definition of terms

- Blue energy*: Salinity-gradient energy, indicating the theoretical non-expansion work that can be produced from mixing two salt solutions with different concentrations. [Post, 2009, p.205]
- Climate Change*: A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. [IPCC, 2011a]
- Design*: Organize parts into a coherent whole at all scales and for many purpose assigns, from tool to landscape. [Vroom, 2005, p.251]
- Energy sink*: Areas where energy demand exceeds supply
- Energy source*: Areas where supply exceeds demand [Stremke, 2010, p.86]
- Energy transition*: Changing the energy system that uses fossil fuels into an efficient system that is based on renewable energy sources. [Energi-transitie, 2011]
- Environment*: The natural world, as a whole or in a particular geographical area, especially as affected by human activity. [Oxford University Press, 1989]
- Landscape*: The combination of land and scape indicates an area, an expanse, a space, that has been created or shaped, is visible as such, and therefore can be represented. [Vroom, 2006, p.177]
- Landscape architecture*: The art of planning and designing the open-air environment. Especially with reference to the harmonious fitting of building, roads, etc. into the landscape. [Oxford University Press, 2002, p.1536]
- Landscape machine*: Hopeful and curious products of a type of design research where landscape processes show the characters of a machine with elements like predictability, production, input and (unintended) output. [Roncken, Stremke and Paulissen, 2011]
- Sustainability*: Sustainable development meets the needs of the present generation without compromising future generations hence the opportunities to meet their needs. [Vroom, 2005, p.107]



*Harbour and industry area Moerdijk, looking from Willemstad*

# 3

## CLIMATE CHANGE

Climate change is a world-wide problem which also influences the design for the blue energy plant and surroundings. The design for a blue energy plant faces climate change in two ways; it has to deal with the changing circumstances of the climate while on the other hand blue energy is one out of many renewable energy sources to mitigate to climate change. By creating a design which makes blue energy visible,

people probably will get more aware of the possible alternatives for fossil fuels.

The consequences of climate change are described in this chapter with a focus on the Dutch South-Western Delta. The two figures at the end of this chapter (page 28) provide an overview of the effects of climate change on the Netherlands.

### 3.1 Climate change scenarios

According to the KNMI (The Royal Netherlands Meteorological Institute), among other organisations, the climate will change. Probable effects of climate change in the Netherlands are a rise of sea level, drier summers and an increase of the mean temperature. The KNMI uses four scenarios (figure 3.1) for probable effects of climate change [KNMI, 2006]. The KNMI based these scenarios on information of the Intergovernmental Panel on Climate Change (IPCC). The scenarios are divided in changes in the air flow patterns and changes in temperature. IPCC [2011b] concluded that it is almost certain that more extreme weather conditions will occur. To make sure the design for the blue energy plant succeeds concerning safety issues, the worst case scenario (W+) is chosen for this thesis. The W+ scenario means briefly that the worldwide temperature will increase with two degrees until 2050 and that the air flow patterns will change. This will result in milder, wetter winters, and warmer, drier summers. Periods of drought will become a bigger problem since evaporation will increase and the pattern of precipitation will change. Exact numbers for the expected climate change are described in table 3.1. What this means for the Netherlands is summarized at figure 3.3 and 3.4.

Table 3.1. Climate change in the Netherlands around 2050 compared to 1990 for the W+ scenario [based on: KNMI, 2006]

|        |  |         |
|--------|--|---------|
| Winter | Average temperature                                | +2.3 °C |
|        | Coldest winter day per year                        | +2.9 °C |
|        | Average precipitation amount                       | +14%    |
|        | Number of wet days ( $\geq 0.1$ mm)                | +2%     |
|        | 10-day precipitation sum exceeded once in 10 years | +12%    |
|        | Maximum average daily wind speed per year          | +4%     |
| Summer | Average temperature                                | +2.8 °C |
|        | Warmest summer day per year                        | +3.8 °C |
|        | Average precipitation amount                       | -19%    |
|        | Number of wet days ( $\geq 0.1$ mm)                | -19%    |
|        | Daily precipitation sum exceeded once in 10 years  | +10%    |
|        | Potential evaporation                              | +15%    |

### 3.2 Changes in discharge of rivers

The current calculated maximum discharge of the Rijn (in English: Rhine) and Maas (in English: Meuse) are respectively 16000 m<sup>3</sup>/s and 3800 m<sup>3</sup>/s (Table 3.2). For the future the rivers must be prepared to accommodate 18000 m<sup>3</sup>/s for the Rijn and 4600 m<sup>3</sup>/s for the Maas every 1250 years. However, the mean discharge of the river Rijn will probably decrease from 1700 m<sup>3</sup>/s to 700 m<sup>3</sup>/s during the summer [Deltacommissie, 2008].

The Deltacommissie recommends to use the Kramer, Volkerak-Zoommeer, the Grevelingen and possible also the Oosterschelde (in English: Eastern Scheldt) as storage area for excess water from the rivers Rijn and Maas when discharge to the sea is blocked by closed storm surge barriers. This also means that the lakes become fresh for a short period [Deltacommissie, 2008, p.26].

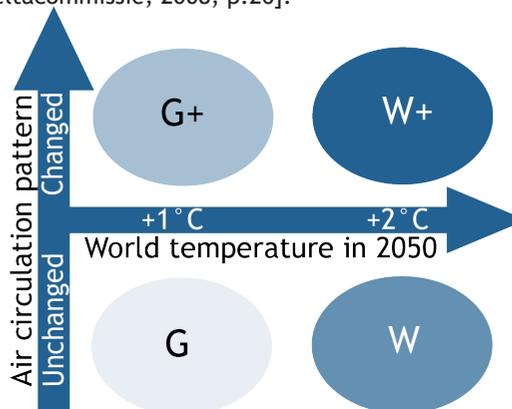


Figure 3.1: KNMI Climate scenarios [based on: KNMI, 2006]

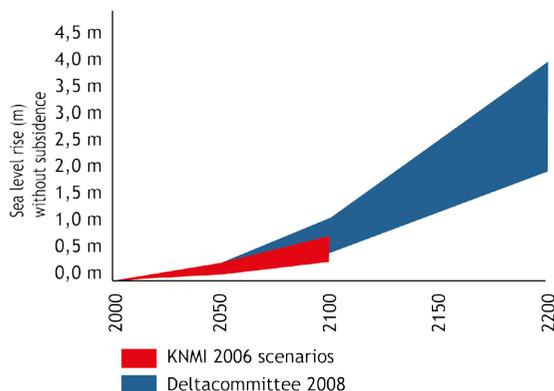


Figure 3.2: Expected Sea level rise in meters [based on: Deltacommissie, 2008, p.24]

### 3.3 Sea level rise

The Dutch Government asked the Deltacommittee for recommendations for the protection of the Dutch coast and low-lying hinterland against the consequences of climate change. These recommendations are based on reports of the IPCC and the KNMI'06 scenarios. The Deltacommittee focussed on sea level rise and the consequences of it. Figure 3.2 shows the sea level rise without subsidence of the Netherlands. Due to glacial isostasy and subsoil compaction due subsidence along the Dutch coast is expected to be over 10 centimetre in 2100. Taking both processes of sea level rise and subsidence into account the relative sea level rise will be 40 centimetres in 2050 and 65-130 centimetres in 2100. The main risk concerning the rise of the sea level is flooding [Deltacommissie, 2008]. Sea level rise also influences the generation of blue energy. To generate blue energy a constant output of brackish water is required. When dams have to close more often because of high water, draining brackish water can become a problem.

“Being able to live in our delta has never been something we can take for granted. Its maintenance and development demand continuous efforts; the work is never done. Fulfilling this task offers great opportunities for creating additional environmental (spatial) quality.”

[Deltacommissie, 2008, p.21]

### 3.4 Fresh water shortage

Sea level rise effects the fresh water supply as the salt water will penetrate further inland through rivers and subsoil. This decreases the potential of blue energy since it will influence the salinity of fresh water (see chapter 4).

Drier summers will decrease the amount of fresh water, while salt water seepage makes the available fresh water saltier. This will damage agriculture, ecology, and shipping [Rijkswaterstaat and Deltares, 2008]. Other possible effects are water quality problems and shortage of cooling water for power stations [Deltacommissie, 2008, p.27].

In case of water shortage four categories are defined to give priorities to the use of water (table 3.3) [Landelijke Commissie Waterverdeling, 2004]. These categories are based on safety issues (category 1), public facilities like energy supply (category 2), and economical, and natural issues (category 3 and 4). The blue energy plant will be in category 2. In theory this means that the energy supply of a blue energy is more important than the economical issues. But when shortage of water occurs the safety and irreversible damage is more important than energy supply. This means that the blue energy generation will come to a hold.

Table 3.2. Current discharge of the Rijn compared to the scenarios [based on: Deltacommissie, 2008]

| Mean Rijn discharge                       | 1968-1998  | 2050          | 2100          |
|---|--|---------------|---------------|
| Mean summer discharge (m <sup>3</sup> /s) | 1700   | 1100 - 1700   | 700 - 1700    |
| Change in mean summer discharge (%)       |  | -35 - 0       | -60 - 0       |
| Mean winter discharge (m <sup>3</sup> /s) | 2750   | 2950 - 3200   | 3100 - 3600   |
| Change in mean winter discharge (%)       |  | +5 - +15      | +15 - +30     |
| <b>Peak Rijn discharge*</b>               | <b>Reference discharge</b>                                     | <b>2050</b>   | <b>2100</b>   |
| Peak Rijn discharge (m <sup>3</sup> /s)   | 16000  | 15500 - 17000 | 16000 - 17500 |
|   | *Taking the assumed state of German dikes in 2020 into account |               |               |

Table 3.3. Priorities of water use in case of shortage in the Netherlands [based on: Landelijke Commissie Waterverdeling, 2004]

| Category 1  | Category 2               | Category 3                                      | Category 4  |
|---|--------------------------|---|---|
| <i>Safety and avoiding of irreversible damage</i> | <i>Public utilities</i>  | <i>Small-scale top quality usage</i>            | <i>Other interests (economical, including nature)</i> |
| 1. Stability of water barriers                    | 1. Drinking water supply | Temporary irrigation of capital-intensive crops | Shipping  |
| 2. Subsidence of peat                             | 2. Energy supply         |   | Agriculture   |
| 3. Nature (related to soil)                       |                          | Process water                                   | Industry  |
| priority above-->                                 |                          |   | Water recreation                                      |
|   |                          |   | Fishery   |
| priority above-->                                 |                          |   | Nature (as long as no irreversible damage appears)    |
| priority above-->                                 |                          |   |   |

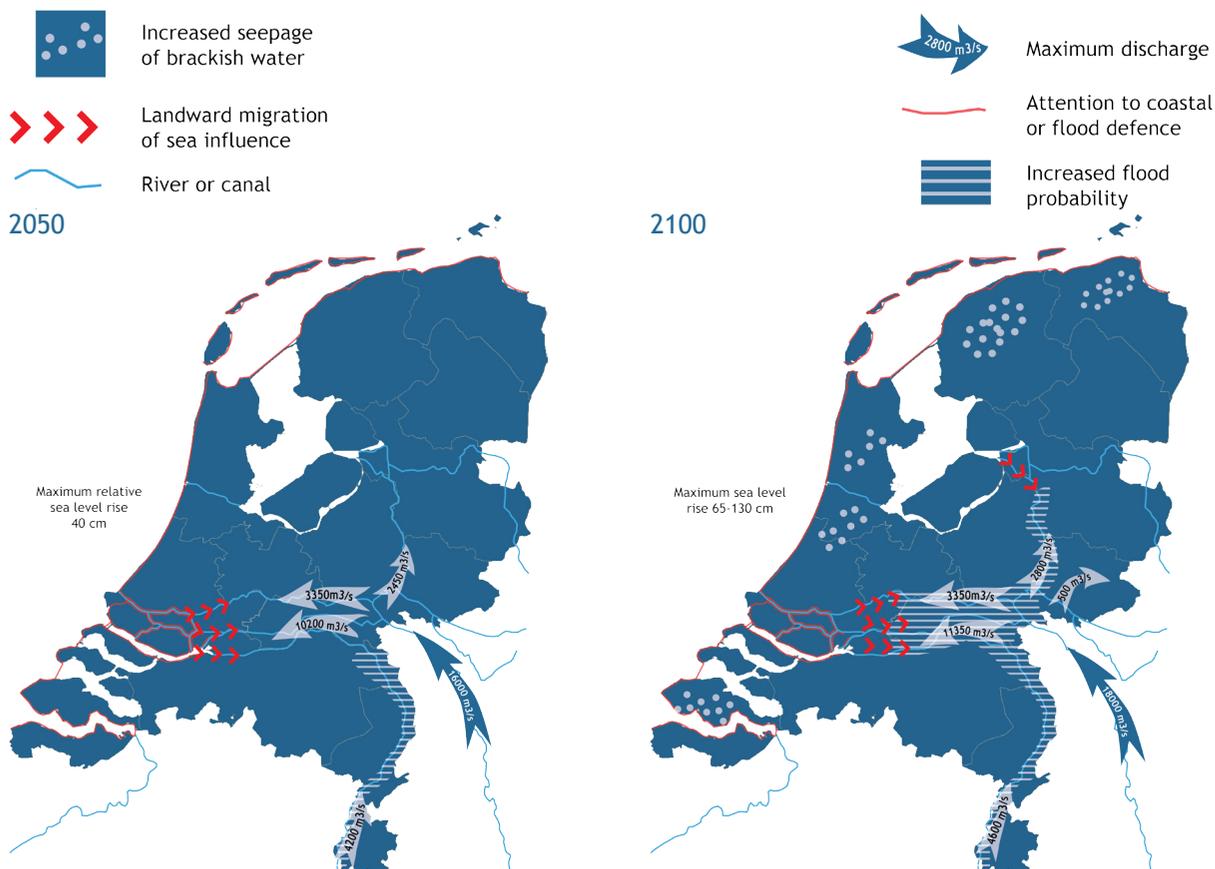


Figure 3.3: Overview effects of climate change 2050 [based on: Deltacommissie, 2008, p.28]

Figure 3.4: Overview effects of climate change 2100 [based on: Deltacommissie, 2008, p.30]





*Bench-scale demonstration of blue energy using RED-technology, at Wetsus, Leeuwarden*

# 4

## TECHNICAL PRECONDITIONS FOR BLUE ENERGY PLANTS

Post [2009, p.205] describes blue energy as: *'a popular term for salinity-gradient energy, indicating the theoretical non-expansion work that can be produced from mixing two salt solutions with different concentrations'*. This means in practice, the energy produced by mixing fresh- and salt water through membranes. For many people the term 'blue energy' means all energy sources related to water. For this thesis the definition of Post as stated above is used.

There are two methods to generate blue energy; the Pressure Retarded Osmosis technique (PRO) and the Reversed Electro Dialysis technique (RED). The RED technology seems to be the most promising since it has more opportunities for river mouths regarding power density, energy recovery, fouling behaviour and, process economy [Post, 2009, p.5]. Therefore

employing the RED technology is chosen to research further in this master thesis.

This chapter gives an answer to the following research question: *What are the technical preconditions for a blue energy plant?*

Besides that it partly addresses the effects of a blue energy plant on the surroundings.

The chapter starts with a description of the energy potential of blue energy, followed by the technical preconditions. These technical preconditions are used to select possible locations for a blue energy plant in the Netherlands (chapter 5) and to create a realistic design(chapter 10). The last section of this chapter describes the link between the technical preconditions and the influence on the landscape.

## 4.1 Energy potential

Worldwide blue energy plants have the potential to generate 1 TW of electricity from water, which is 8600 TWh per year. To compare, worldwide 20,000 TWh [IEA, 2011] is generated from different sources in 2009, which means that blue energy can fulfil over 40% of the current electricity demand. The energy potential depends on the definition. The mentioned number is called the technical potential. Other definitions are the theoretical, economic and exploitable potential [Post, 2009, p.194].

**Theoretical potential (1724 GW):** Energy that is potentially available if all energy being discharged at the river mouths was harvested without any energy losses (figure 4.1).

**Technical potential (983 GW):** Share of the theoretical energy that can be recovered with current technology, regardless other restrictions.

**Economic potential (590 GW) :** Part of the technical potential that can be developed at costs competitive with other energy sources.

**Exploitable potential (?):** Fraction of economic potential that can be used if the environmental, political and other unique constraints are accounted for.

“In order to find out the exploitable potential, for each site an entire study should be made to the impact of the environment and ecological system (e.g., flora and fauna, water quality, bank morphology) due to changing nutrient flows and sediment transport, changing local salinities and gradients, building infrastructural works for the plant, etc.”

[Post, 2009, p.200]

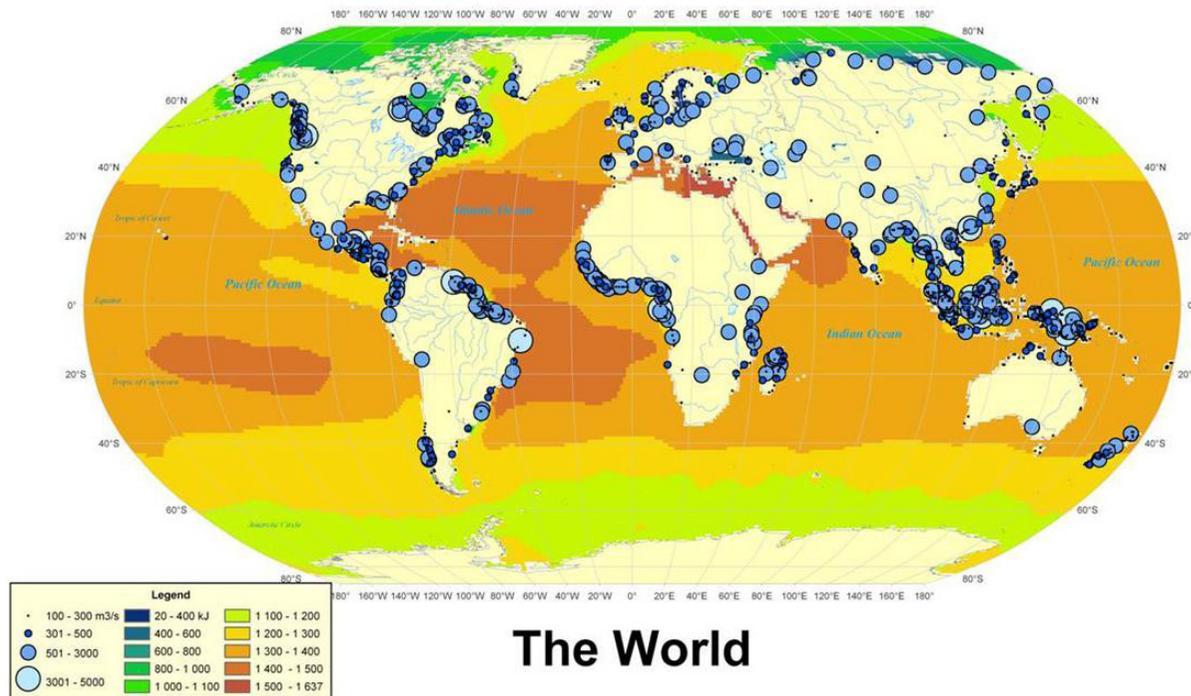


Figure 4.1: Theoretical worldwide potential for blue energy [Veerman, 2009]

## 4.2 Technical preconditions

The RED technology uses membranes along which fresh water on one site, and salt water on the other side flows. The difference in the concentration of ions between salt- and fresh water creates electricity when ions pass through ion-selective membranes. When  $\text{Na}^+$  and  $\text{Cl}^-$  ions (salt) pass through an ion-selective membrane, a difference in the potential is created [Veerman, 2008]. This potential-difference creates electricity when connected to an energy cell (figure 4.2). When many of these membranes are packed together, this is called a stack. It can be compared with a stack of batteries.

The technical preconditions determine the technical potential. The preconditions are divided in twelve subjects: fresh water, salt water, salinity difference between fresh- and salt water, amount of water, physical edge, pumps, membranes, clean water, required space, energy, transport of electricity, and brackish water.

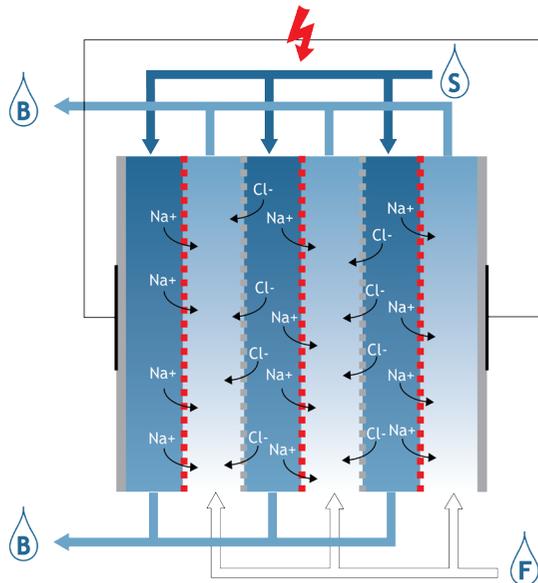


Figure 4.2: Blue energy RED-technology [based on: Post, 2009, p.21]



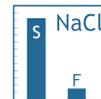
### Fresh water

Fresh water can occur on the earth's surface as ice, lakes, and rivers or underground as groundwater, or aquifer. Fresh water has a low concentration of dissolved salts. The definition of fresh water (to exclude it from salt water) according to the Venice System is that it contains less than 500 mg (0.5 gram) of salt per litre of water [Paulissen, Veraart and Massop, 2011]. A river normally contains between 0.3 and 0.5 gr/l NaCl [Quak, 2009].



### Salt water

Salt water is defined as water which contains a significant concentration of dissolved salts, mostly oceans. Salt (or saline) water contains at least 30 gr/l NaCl (table 4.1). The North Sea between contains 34-35 grams of NaCl per litre [Deltares, 2010a]. Further inland the salinity decreases. For example, the Oosterschelde has a salt concentration of approximately 28 gr/l NaCl [Rijkswaterstaat, 2008, p. 11].



### Salinity difference between fresh and salt water

Blue energy requires the highest possible difference in salinity between fresh- and salt water. Current insights into the effects on the efficiency of membranes show a strong decrease of the generated electricity by reducing salt gradient [Deltares, 2010a]. Though it is still unclear what the minimum amount of salt should be to generate electricity and still be commercially attractive. Smalbrugge [2009, p.12] uses 20 gram NaCl per litre of water as minimum.

Table 4.1: Salinity of water compared with concentrations chloride and sodium chloride

| Type     | Salinity (‰) | Concentr. Cl (mg/l) | Concentr. NaCl (gr/l) |
|----------|--------------|---------------------|-----------------------|
| Fresh    | 0 - 0.5      | 0 - 300             | 0 - 0.5               |
| Brackish | 0.5 - 30     | 300 - 17,000        | 0.5 - 28              |
| Salt     | >30          | >17,000             | >28                   |

Ecologist M. Paulissen [interview, 2012] gave the following explanation about salinity differences under natural circumstances.

When fresh and salt water abruptly meet this gives a reaction. In a blue energy plant this reaction is used to generate electricity. When such reaction occurs in a natural setting it has consequences for the organisms in fresh or salt water. It creates an enormous shock environment where not many animals or plants can live in. Plants or animals are physiological and morphologically set to fresh- or salt water and when they come into the wrong circumstances they dry out or burst apart. In an estuary is no abrupt transition but gradual. In case of a gradual transition the potential generated energy is spread out over a bigger area.



#### Amount of water

The amounts of available fresh- and salt water determines the theoretical electricity production. Enormous amounts of water are available for blue energy, which can be used to a certain extend (see section 4.1). Climate change is important to take into account concerning the available amounts of fresh water. During dry weather periods, which are expected to occur more often [IPCC, 2011a], water from the rivers in the Netherlands is primarily needed for the Nieuwe Waterweg at Rotterdam [Quak, 2009]. This means that it is not possible to take away enormous amounts of water for blue energy at other locations. The available amount of water should be continuous to be able to fulfil the ongoing electricity demand.



#### Physical edge

Suitable locations for blue energy plants are those locations which are characterized by large salinity gradients. The most obvious location is the mouth of a river in a sea or ocean. Unfortunately, through currents, tidal effects and fluctuating river discharge the water from sea or ocean interferes with the river and is therefore decreasing the difference in salinity. Therefore locations with a physical separation be-

tween fresh- and salt water, such as a dike, sluice, or dam, are mainly interesting for the realization of a blue energy plant. The physical separation prevents mixing of the fresh- and salt water [Deltares, 2010a].



#### Pumps

Pumps are required to pump the fresh- and salt water into the blue energy plant, and/or pump the brackish out of the blue energy plant. The amount of pumps should be reduced to a minimum to avoid energy losses. It depends on the location how many pumps are required and where the pumps should be situated. The plant can be located above and beneath the water surface. The costs for a plant above the surface are lower, and maintenance is easier [Ecofys, 2010].



#### Membranes

The membrane stacks are the main element of the installation. Much research is done on this subject [see e.g. Weinstein and Leitz, 1977; Lacey, 1980; Jagur-Grodzinski and Kramer, 1986]. One stack of membranes has the size of 0.5\*0.5\*1.5 meter. 1m<sup>3</sup> of stacks generates 5kW. In the future this is expected to be at least twice as much [Veerman, 2011].



#### Clean water

One of the current issues concerning blue energy are the high costs of the filtration of the water. Blue energy membranes require clean water without nutrients with multivalent ions. Multivalent ions, such as Calcium and Magnesium ions, have a lowering effect on the stack voltage. Monovalent selective membranes can prevent this. "*Fouling of ion exchange membranes is considered to be one of the most important limitations for practical use of electro-dialysis processes.*" [Post, 2009, p.27]. Biofouling is primarily causing clogging of the flow channels and spacers between membranes which results in an increase of the energy losses for pumping. The RED technique is less sensible for nutrients in the water than the PRO technique.

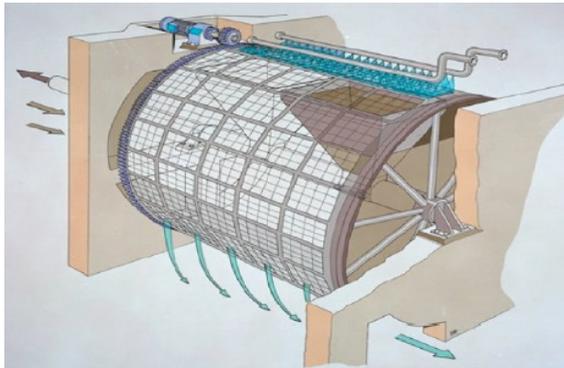


Figure 4.3: Example of a wire mesh to clean the water [Mollenbroek, 2007, p.37]

All parts in the water with a size bigger than 50 micron have to be filtered out. Smaller parts can pass through the membranes. A wire mesh is used to filtrate the water (figure 4.3). The water flows through the mesh while the drum is turning around slowly. High pressure jets clean the mesh. The dirt particles are collected at the upper part of the drum. The filtration of water is the most energy consuming part of the installation [Quak, 2009]. According to Post [2009, p.117] a combination of measures will be the best solution to restrict biofouling at minimum costs.



#### Required space for energy plant

The required space of a blue energy plant is mainly determined by the amount of membrane stacks needed for a certain amount of water and the installation to clean the water (figure 4.4). REDstack uses the following dimensions for a blue energy plant:

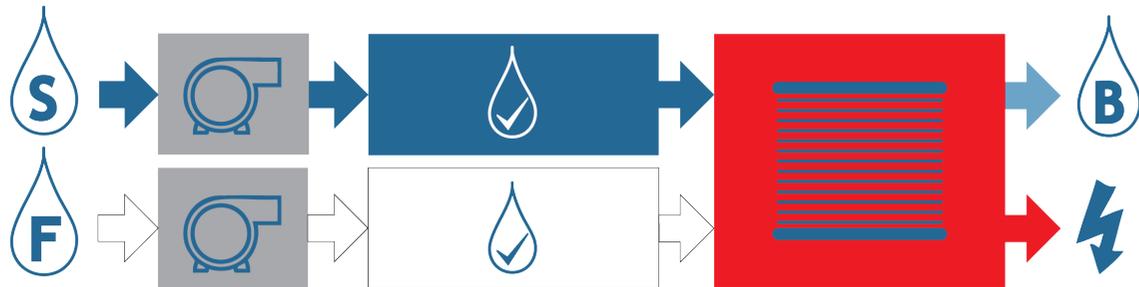


Figure 4.4: Schematic overview of a blue energy plant with the right proportions of pumps, filtration area and stacks [based on: Quak, 2009]

When 180m<sup>3</sup> of fresh water is mixed with 180m<sup>3</sup> of salt water per minute, the blue energy plant has to process 360m<sup>3</sup> of water each minute. This means 9 Olympic swimming pools filled with water every hour. This produces 4MW of electricity, comparable with a normal size wind turbine [Winvast, 2011]. The required space is 7,200 m<sup>2</sup>, which is approx. 1 soccer field.

- 1m<sup>3</sup> meter of stacks requires 6m<sup>2</sup> of space including the required space filtration of water. A stack has the height of 1.5 meter.
- 1m<sup>3</sup> of fresh water per second requires an installation of 2,400m<sup>2</sup>. When higher amounts of water are used, the installation can be relatively more compact.
- The pre-filtration area needs approximately the same amount of space as the stacks [Quak, 2009, p.36]
- The pumping installation is assumed to require around 50% of the size of the stacks [Quak, 2009, p.36]
- The total size of the blue energy plant is approximately 9 times the size of the stacks. When the amount of processed water increases, this factor can be lower [Grasman, 2011].

The complete blue energy plant can be built as a combination of several sea containers. In this way the plant is modular, easy to ship and many parts can be assembled in the factory which reduces the costs [Post, 2011].



## Energy

Electricity is the product of the blue energy plant.  $1\text{m}^3$  of river water has the theoretical potential to generate 2.5MJ when mixed with a surplus of sea water, or 1.5MJ when mixed with  $1\text{m}^3$  of sea water. In practice, 1MJ can be generated when  $1\text{m}^3$  of fresh water is mixed with  $1\text{m}^3$  of sea water from the North Sea [Veerman, 2010]. Compared to hydropower this is equivalent to a water power dam of 200 meter high [Quak, 2009].

When other factors such as pumping of water, cleaning and other electricity consuming issues are taken into account, the numbers are different. REDstack provided numbers based on their experience. Exact numbers on these issues are not described in this report due to confidentiality issues. Only the end results of those calculations are mentioned in this thesis.



## Transport of electricity to sinks

The generated electricity needs a grid to transport the energy to locations where energy is used (energy sinks). The costs of a high voltage power line are high. It depends on the size of the blue energy plant if a new power line has to be added to the Dutch grid, or that the current grid is sufficient. High voltage power lines underground are more expensive than above the ground [TenneT, 2011a]. Deltares [2010a] mentions the maximum capacity of the Dutch energy grid as one of the constraints for a blue energy plant. Figure 4.5 shows a map of the current high voltage electricity network in the Netherlands. Site specific research is needed for conclusions on this issue.



## Brackish water

The main by-product of a blue energy plant is brackish water.  $1\text{m}^3$  meter of fresh water mixed with  $1\text{m}^3$  of salt water results in  $2\text{m}^3$  of brackish water. Brackish water is water with a salinity gradient between fresh and salt water. It contains 0.5 - 30 gr/l of dis-



Figure 4.5: High voltage power network in the Netherlands. The red lines show the existing network. [based on: TenneT, 2011]

solved salts (table 4.1). Naturally, most brackish water can be found at estuaries of rivers where fresh water meets salt water. In the case of a blue energy plant, the brackish water outlet should be placed in such a way that short circuits currents between the brackish and the fresh- or salt water inlets cannot occur since this will influence the salinity gradient, and by that the potential-difference of the water [Deltares, 2010a]. The effect of cleaned brackish water on the environment is expected to be minimal, especially for the RED technique [Ecofys, 2010]. Higher amounts of water can cause erosion around the outlet of the plant. The exact influence of the brackish water requires site specific research and design.

### 4.3 Influence on landscape design

The technical preconditions will determine the design of the blue energy plant and surroundings to a certain degree. This section describes these influences.

The streams of fresh water, salt and brackish water require enough space. The amount of water determines if the streams of water will look like a small ditch or a big canal/lake. The higher the amount of water, the bigger the influence on the landscape.

The amount of water will also influence the size of the blue energy plant itself and therefore the landscape. The higher the amount of water the bigger the plant itself will be. The size of the pumps will also increase with a higher amount of water. The plant can be located above and beneath the water surface. It depends on the surrounding landscape what the influence of the blue energy plant will be. For example, in an urban area, like the harbour of Rotterdam, a blue energy plant will have another influence on the landscape as in an open rural landscape.

The brackish water what remains as output of the blue energy plant should be directed in such way that short circuit currents between the brackish and the fresh or salt water inlets cannot occur since this will influence the salinity gradient [Deltares, 2010a]. A high amount of brackish water will effect the landscape because of the required space. Besides the amount of water the salinity of brackish water will influence the flora and fauna in and near the water. The exact influence of the brackish water on the landscape asks for site specific research and design.

The required physical edge between fresh, salt and brackish water strongly influences the possibilities for a design. The physical edge will be visible in the landscape.

The last technical precondition which will influence the landscape design is the network required to transport the generated electricity. The cables for the transport can be put underground or above the ground to connect it to a high voltage network. When placed above the ground it will influence the visible landscape.

### 4.4 Conclusion

The twelve technical preconditions for a blue energy plant, using the RED technology, are:

- Amount of fresh water (river water).
- Amount of salt water (sea water).
- The highest possible difference in salinity between fresh and salt water.
- The available amount of water. The higher the amount of water, the more energy can be generated.
- Physical edge between fresh, salt and brackish water to get a maximum difference between fresh and salt water.
- Pumps to get the water into the blue energy plant, or to pump it out of it.
- Membranes to generate the electricity.
- Clean fresh and salt water.
- Enough space for siting the blue energy plant.
- Electricity as product of the blue energy plant.
- Network to transport of electricity to sinks.
- Space for brackish water

The required space is the main element what influences the landscape. Space is needed for the blue energy plant, the amount of fresh- and salt water, and the discharged brackish water.



*Example of a physical edge between fresh and salt water at the Krammersluizen, Zeeland*

# 5

## POSSIBLE LOCATIONS FOR BLUE ENERGY IN THE NETHERLANDS

Worldwide there is an enormous potential for blue energy. The potential is described in the previous chapter. This chapter describes the possible locations for blue energy in more detail and gives answer to the research question *“What are possible locations for a blue energy plant in the Netherlands?”*

The chapter starts with an introduction on the used methods and continues with one of the selected locations. The other 15 locations are added as appendix I. This location study resulted in the choice of one location for a blue energy plant. This choice is described in the section thereafter. This section also contains a table with a short overview of all locations. The chapter finishes with a conclusion.

## 5.1 Introduction

The locations for blue energy are a selection based on the technical preconditions of the previous chapter and the following criteria. Only places where water physically meet are taken into account. Locations with a small amount of available fresh or salt water (less than 200 m<sup>3</sup> per minute, or 3 1/3 m<sup>3</sup>/s) are not mentioned in this overview. It is also possible to use other sources like the discharge water of a power station, waste water treatment plant near the sea or the discharge water of a salt factory. These locations are not taken into account in this overview because the research is limited to locations with bigger landscape interventions. They are beyond the scope of this thesis.

For analysing each of the in total 16 locations the same criteria are used. Figure 5.1 shows an overview of the possible locations. Each description of a location contains calculations on size and energy. All locations contain a map of the Netherlands and a more detailed map with the theoretical size of the blue energy plant as a blue square. The detailed map also shows the arrows with fresh (white), salt (blue) and brackish water (red). All these maps are on the same scale (1:25,000). In this way it is possible to visually compare the locations. For each location the influence on the landscape is described.

The calculations are based on the following numbers and facts:

- 1m<sup>3</sup> of water per second is equal to 1MW of electric energy [Veerman, 2009]
- A Dutch household uses 3,500 kWh of electricity per year [Milieucentraal, 2011].
- A soccer field is 7,350 m<sup>2</sup>
- The output of brackish water is the sum of fresh and salt water which entered the blue energy plant
- For all locations the maximum capacity of the water is used to compare the potential. In practice the usable capacity of the water will be less because of dry periods or other functions which require water.

One of the technical preconditions mentioned in chapter 4 is 'clean water'. Since Post [2009, p.119] concludes that a combination of different cleaning solutions can avoid biofouling, it is assumed that this is the case for every location. The second precondition not taken into account are the amount of pumps since this totally depends on the design. In general the amount of pumps should be reduced to a minimum to avoid energy losses. The third precondition not mentioned in this part are the membranes since this does not influence the choice of the location.

Table 5.1 at the end of the chapter provides an overview of all locations. Based on the gathered data, the conclusion describes the choice for one of the locations as basis for the design.



Figure 5.1: Overview of possible locations for blue energy in the Netherlands

## 5.2 Volkerakdam



The Volkerak-Zoommeer is a lake which contains fresh water. The lake is on the border of three provinces. Since several years there are problems with the quality of the water. This led to plans to change the fresh water lake into a salt water lake [Planstudie waterkwaliteit Volkerak-Zoommeer, 2011]. These plans also influence the possibilities for blue energy. The plans are not certain yet and it will take several years before the plans will be realized. That is why two scenarios are described with each two possible locations; at the Philipsdam and Oesterdam when the Volkerak-Zoommeer stays fresh, and at the Volkerakdam and Dintel when the plans of a salt water lake are realized. Only the Volkerakdam is described in this chapter. The other locations are added as appendix I. This scenario describes the situation of a salt Volkerak-Zoommeer.

The Hollandsch Diep and Haringvliet provide fresh water. Salt water can be obtained from the Oosterschelde. Like the possible locations at the Haringvlietdam and Philipsdam this location also uses the water which is not directly needed for the Nieuwe Waterweg. The required space is 144,000m<sup>2</sup> (almost 20 soccer fields). The blue energy plant can be located at the Volkerakdam. The generated energy can be used for the nearby Volkerak sluices.

In the nearby surroundings is no separate lake where the brackish water can be drained. A solution for this is to locate the inlet of salt water at the west side of Volkerak near de dam, and discharge the brackish water at the Volkerak near the Volkerak sluices. A small dam south of the sluices separate the sluices from the lake for more than a kilometre. Most likely this will be enough to avoid recirculation of the water, but more calculations are needed.

### Technical preconditions



The fresh water is provided by the Hollandsch Diep and Haringvliet. It contains approx. 0.5 gr/l NaCl [Deltares, 2011].



The Volkerak-Zoommeer has a connection with the salt Oosterschelde. The salinity will be approx. 16-23 gr/l NaCl [Rijkswaterstaat, 2008]



The difference between fresh and salt water is suitable to generate blue energy.



The discharge of the Nieuwe Waterweg which can be used is 60 m<sup>3</sup>/s for 90% of the year [Rijkswaterstaat, 2011].



The Volkerakdam is a dam with sluices and provides a physical edge between fresh and salt water.



The required space is available. An installation of 60 m<sup>3</sup>/s requires 144,000 m<sup>2</sup> of space.



The installation can generate 60 MW. This is enough electricity for approx. 150,000 households.



The produced electricity can be transported using the present high voltage power line at the dam.



120m<sup>3</sup>/s. The location offers possibilities for the discharge of the brackish water but recirculation might occur.

### **Influence on the landscape**

The surrounding landscape of the Volkerakdam exists of polders with an agricultural function, natural areas existing of unembanked areas, and large scale open water. The scale of the natural areas offers space for a blue energy plant (figure 5.2 and 5.3). The landscape in the surroundings of the Volkerak is open. A big building of 144,000 m<sup>2</sup> will influence the open landscape and horizon. The blue energy plant can be placed at the Volkerakdam when the lake becomes salt again. This will influence the landscape ecology. The brackish water has to be separated from the salt water which can be realised with a barrier. The current fresh water environment of the Volkerak will change due to the influence of brackish and salt water. More research is needed to determine what the exact influences are.

### **Conclusion**

The Volkerakdam is an interesting location for blue energy. It has some uncertainties like the exact salinity of the water and possible recirculation of the brackish water. Besides that it is not yet certain if the Volkerak-Zoommeer will become salt. If these uncertainties can be solved the location offers good opportunities for a blue energy plant.



*Figure 5.2: Open landscape near the Volkerakdam, looking from a bird hide to the Volkerakdam*

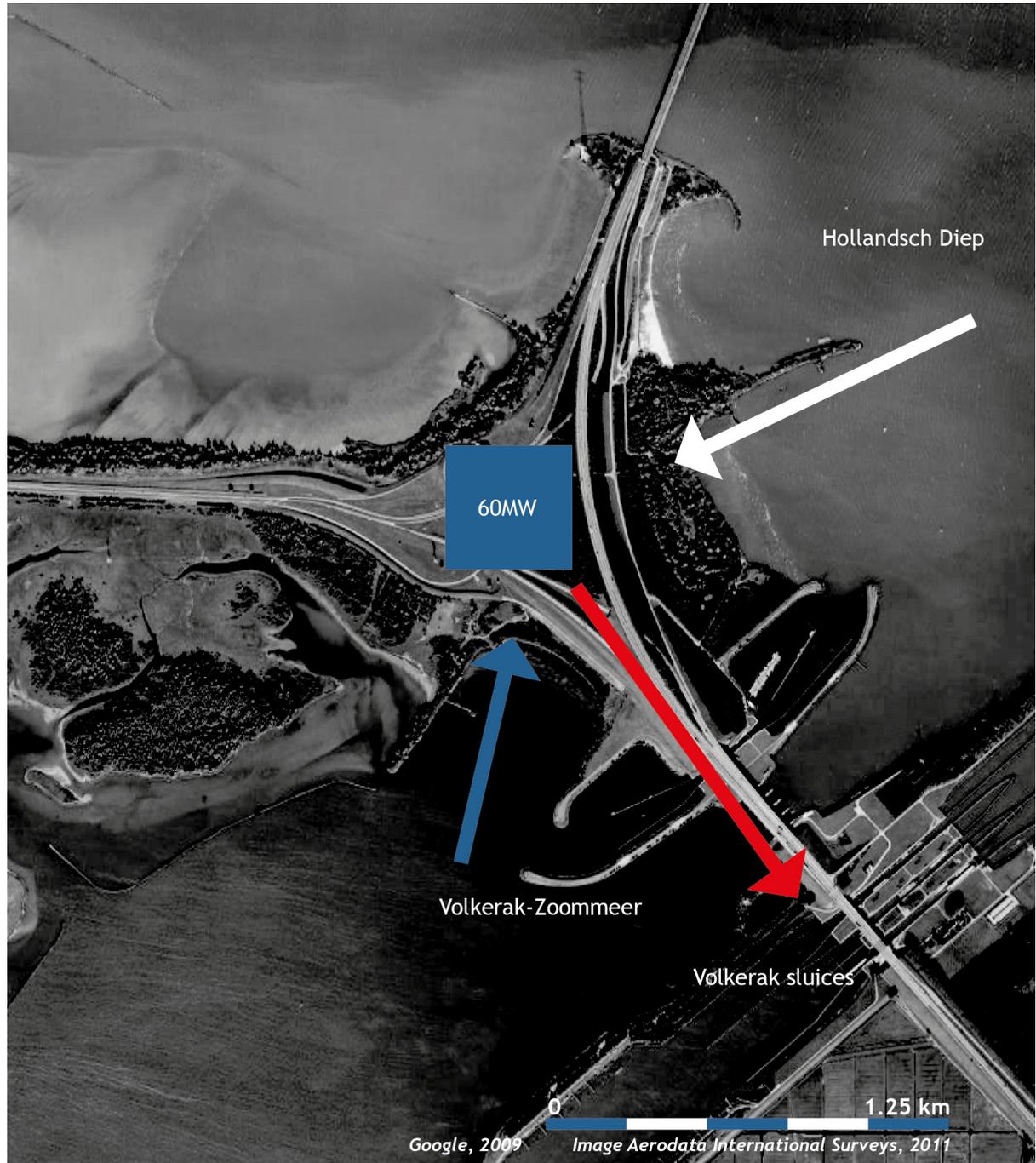


Figure 5.3: Theoretical size and power of blue energy plant with fresh (white), salt (blue) and brackish (red) water streams

### 5.3 Siting of blue energy plant

All described locations have some advantages and disadvantages. Table 5.1 shows an overview of all locations. This overview only shows the numbers of the locations. Most numbers are based on sources of that certain location. Although for some locations it was not possible to find all the required data. In those cases assumptions have been made which are mentioned in the text. Especially energy transport is difficult to calculate. More research is needed for each location to come up with reliable numbers on this issue and therefore this feature is not mentioned in the overview of locations (table 5.1).

Out of all the described locations the locations which provide the best opportunities are: The Afsluitdijk, Katwijk, Rotterdam Botlek, Haringvlietdam, Philipsdam and the Volkerakdam.

The Afsluitdijk was not chosen because other designs are already created for this location and the authors want to create a new design for a blue energy plant

on a new location. For the same reason the Haringvlietdam was not chosen since one of us already made a design for a blue energy plant for this location.

When looking at table 5.1 the location Rotterdam Botlek looks like a location which provides opportunities, but looking from a landscape architectonic view there is not enough available place for the blue energy plant itself.

Out of all the described locations there are three locations which provide the best opportunities. The Philipsdam is the most interesting location since all required technical preconditions are available, besides a nearby power line. This was also the conclusion of Quak [2009, p.56] on the locations of that research. But where Quak looked to the possible locations for a blue energy plant with a hydrologic view this thesis focuses on a landscape architecture view to the possible locations. This view consists of the technical preconditions as described in the pre-

Table 5.1: Overview of possible locations for blue energy in the Netherlands

|                           | Salinity fresh water (gr/l NaCl) | Salinity salt water (gr/l NaCl) | Amount of water (m <sup>3</sup> /s) | Required Space (m <sup>2</sup> ) | Potential power (MW) | Brackish water (m <sup>3</sup> /s) |
|---------------------------|----------------------------------|---------------------------------|-------------------------------------|----------------------------------|----------------------|------------------------------------|
| The Dollard               | 0.3                              | 20                              | 80                                  | 192000                           | 80                   | 160                                |
| Eemskanaal                | 0.3                              | 22                              | 11                                  | 26400                            | 11                   | 22                                 |
| Lauwersmeer               | 2                                | 18                              | 44                                  | 105600                           | 44                   | 88                                 |
| Harlingen                 | 0.5                              | 29                              | 6                                   | 14400                            | 6                    | 12                                 |
| Afsluitdijk               | 0.3                              | 29                              | 450                                 | 1080000                          | 450                  | 900                                |
| Balgzandkanaal            | 0.8                              | 23                              | 3.5                                 | 8400                             | 3.5                  | 7                                  |
| Noordzeekanaal            | see text                         | 25 - 27                         | 40                                  | 96000                            | 8                    | 80                                 |
| Pump station Katwijk      | 0.5                              | 30                              | 18                                  | 43200                            | 18                   | 36                                 |
| Rotterdam Botlek          | 0.3                              | 30                              | 500                                 | 1200000                          | 500                  | 1000                               |
| Rotterdam Nieuwe Waterweg | unknown                          | 30                              | 1000                                | 2400000                          | 1000                 | 2000                               |
| Rotterdam Maasvlakte      | 15                               | 30                              | 500                                 | 1200000                          | 500                  | 1000                               |
| Haringvlietdam            | 0.2                              | 30                              | 60                                  | 144000                           | 60                   | 120                                |
| Philipsdam                | 0.5                              | 27                              | 60                                  | 144000                           | 60                   | 120                                |
| Oesterdam                 | 0.5                              | 20                              | 60                                  | 144000                           | 60                   | 120                                |
| Volkerakdam               | 0.5                              | 20                              | 60                                  | 144000                           | 60                   | 120                                |
| Dintel                    | 0.5                              | 20                              | 11                                  | 26400                            | 11                   | 22                                 |

vious chapter and the influence on the landscape. Disadvantage of the Philipsdam is the plan to make the Volkerak-Zoommeer salt. Since it seems to be a matter of time before this happens [Rijkswaterstaat, 2011b], this location has to be rejected.

The remaining locations are pump station Katwijk and the Volkerakdam. Both locations have their advantages and disadvantages. The decision to choose for the Volkerakdam is made based on the field of study of the authors. The Volkerakdam seems to offer more opportunities to make the blue energy plant which functions like a landscape machine (see chapter 7). The design for a blue energy plant can be part of several other changes which will occur when the Volkerak-Zoommeer becomes salt, like an expected increase of recreation at and around the lake.

## 5.4 Conclusion

The answer to the research question “*What are possible locations for a blue energy plant in the Netherlands?*” is answered in this chapter. Attachment I describes 16 locations in the Netherlands that provide opportunities for blue energy in the Netherlands. All locations have one or more disadvantages. The main differences between the locations are the required space for a blue energy plant, the amount of water and the salinity difference between the fresh- and salt water.

For this thesis the best suitable location for a blue energy plant is the Volkerakdam. The main advantage is the available space and available physical edge. Besides that the lake becomes salt again what is beneficial for the water quality of the lake. This will give some uncertainties like the exact salinity of the lake and possible recirculation of the brackish water. A big advantage of this location is that the Volkerakdam and surroundings offers opportunities to make the blue energy plant functioning like a landscape machine.



*Nature area Hellegatsplaten looking from the Hellegatsdam towards Dinteloord*

# 6

## VOLKERAK

This chapter describes the history, the present, and also partly the future situation of the lake Volkerak and surrounding area. This area will be the location for the blue energy plant. The area is selected in the previous chapter.

The information in this chapter is required to create a design in this area. In this way, the chapter supports the next part of this report in order to get an answer to the research questions. The Volkerak-Zoommeer consists of two parts; the Volkerak and the Zoom-

meer. For the thesis the focus is on the Volkerak, and especially the surroundings of the Volkerakdam.

The chapter starts with the history of the South-Western Delta and contains figures with the history since 5500 before present (BP) until now, and a timeline. This is followed by the present conditions, including a figure with the layer-approach. Because the selection of this location for this thesis is based on the fact that the Volkerak-Zoommeer becomes salt, the chapter also describes the future of the area.

## 6.1 History of the South-Western Delta

The Volkerak-Zoommeer is part of the Dutch delta works which are well known all over the world [Deltares, 2009]. Where it used to be part of the brackish estuary South-Western Delta of the Netherlands, nowadays it contains fresh water which causes new problems.

During the subboreal (5560-2400 years BP) the shallow bottom of the North Sea caused that sand was transported to the Dutch coast (figure 6.2). The west coast closed what resulted in a fresh water lagoon behind the dunes. This lagoon changed through the time in peat land. Around 500 BP the South-Western Delta was one big peat area crossed by only a few rivers (e.g. fore-Schelde, fore-Maas and fore-Rijn). Later, during the subatlanticum (2400-0 years BP), the coast started to run down. The estuaries of the rivers got wider and as result the sea was able to intrude further inland [Zagwijn, 1986]. Several floods by the sea beat off the peat until only small areas of peat were left [Lidth de Jeude et al., n.d.].

The Volkerak lake is approximately 600 years old. It probably arose after the Elisabeth flooding in 1421 [Bureau Stroming, 2007]. The whole area between Dordrecht, Gorcum and Roosendaal changed into an inland sea. The current Biesbosch is a result of that flooding [Stichting Deltawerken Online, 2011]. From that moment on the tide from the sea streamed into the inland sea. See time line on the next pages.

The Volkerak contained salt meadows and looked like the current Waddenzee. Around 1550 the inhabitants of the surrounding area started to impolder the Volkerak. In the 16<sup>th</sup> and 17<sup>th</sup> century agriculture, fishery, and trade between the Netherlands and Belgium created welfare. The crops which were produced were mainly potatoes, grain, and beets. The villages around the Volkerak developed into cities with prosperity [Bureau Stroming, 2007]. A few of these cities are Middelburg, Veere, Zierikzee, and Goedereede [Lidth de Jeude et al., n.d.]. During the Eighty Years' War the economic activity slowly got less. Sea Beggars (Geuzen) threw down dikes during the conflict with Spain. Many villages suffered from the conflict and some cities, like Brielle, never recovered from its seizure [Lambert, 1985].

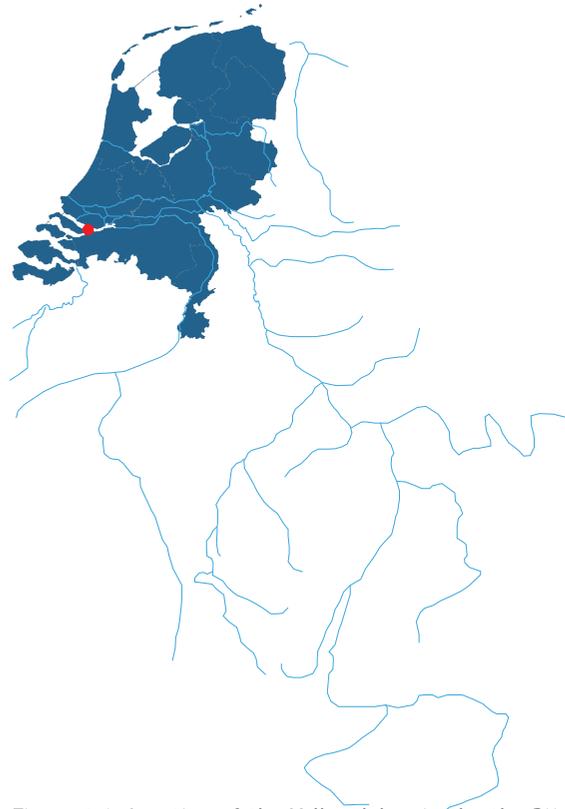


Figure 6.1: Location of the Volkerakdam in the the Rijn-Maas Delta

The storm tide of 1953 had a big influence for the lake. An important part of the Netherlands were not protected against the sea. The flood inundated 160,000 ha (figure 6.2, 1953) [Lambert, 1985]. Everybody agreed: this cannot ever happen again [Deltares, 2009]. A Delta plan was developed to prevent flooding in the future. The current Volkerak was part of this plan (see time line, figure 6.9). The Deltaplan shortened the sea coast from hundreds kilometres of dikes to 30 kilometres. The Volkerak is circumscribed by three dams.

One part of the plan was a dam at the north side of the Volkerak. The dam was intended to be a barrier between fresh in the south (Volkerak) and salt water north of the dam (Haringvliet). Environmental societies and shell fisheries has caused the plan to change dramatically. It happened in such way that the Har-

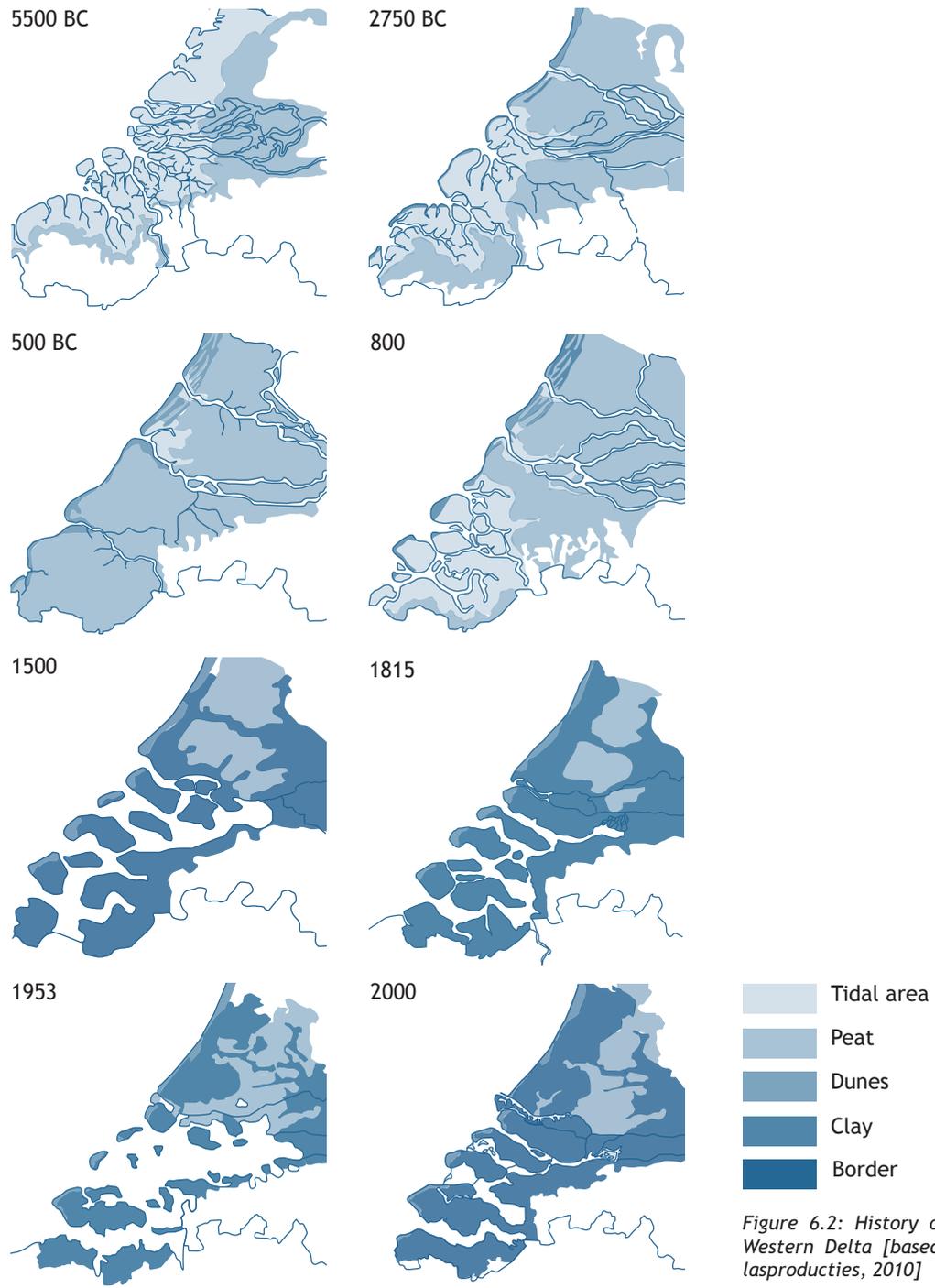


Figure 6.2: History of the Dutch South-Western Delta [based on: Noordhoff Atlasproducties, 2010]

## Time line



Figure 6.3: The South-Western Delta, around 1613 [Edward-Wells, 2012]



Figure 6.4: Allerheiligenflood, 1570 [Leslink, 2012]

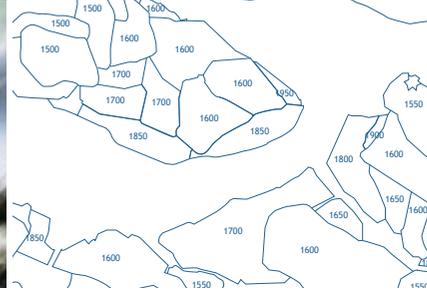


Figure 6.5: The impoldering of the Volkerak



Figure 6.6: Watersnoodramp, 1953 [ANP, 2012]

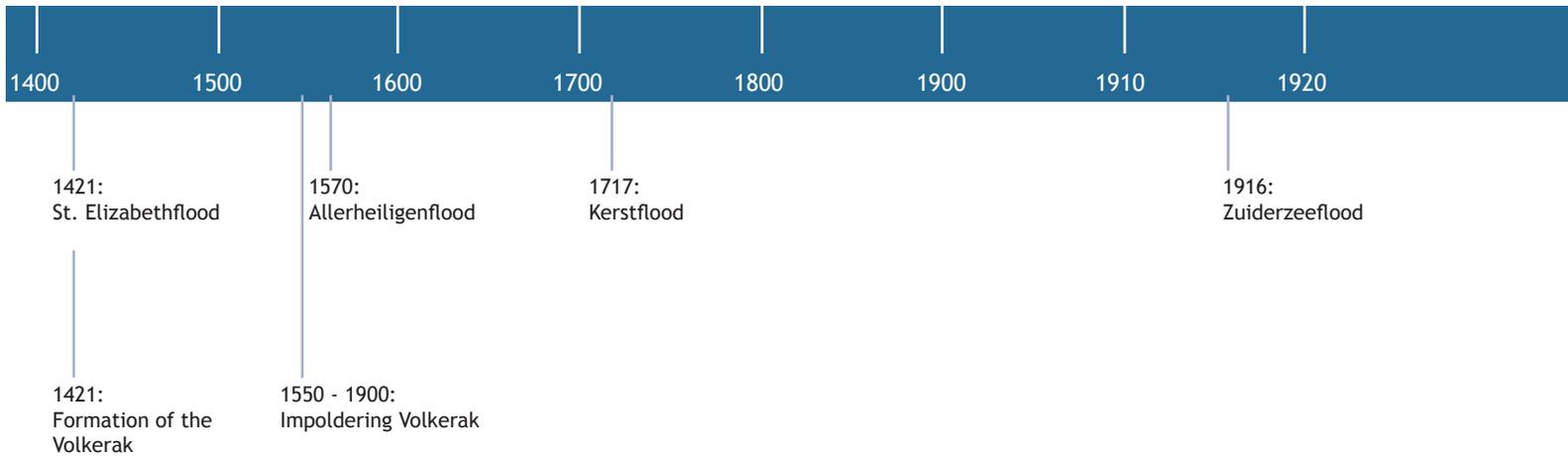




Figure 6.7: The Deltacommittee, 1954 [Safecoast, 2012]



Figure 6.8: Construction of the Volkerak-dam, 1957-1969 [ANP archief, 1965]

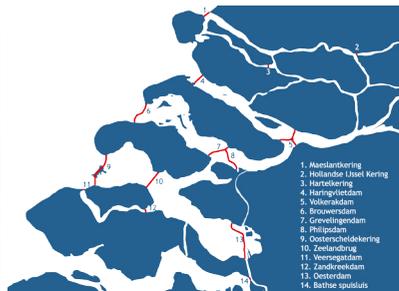
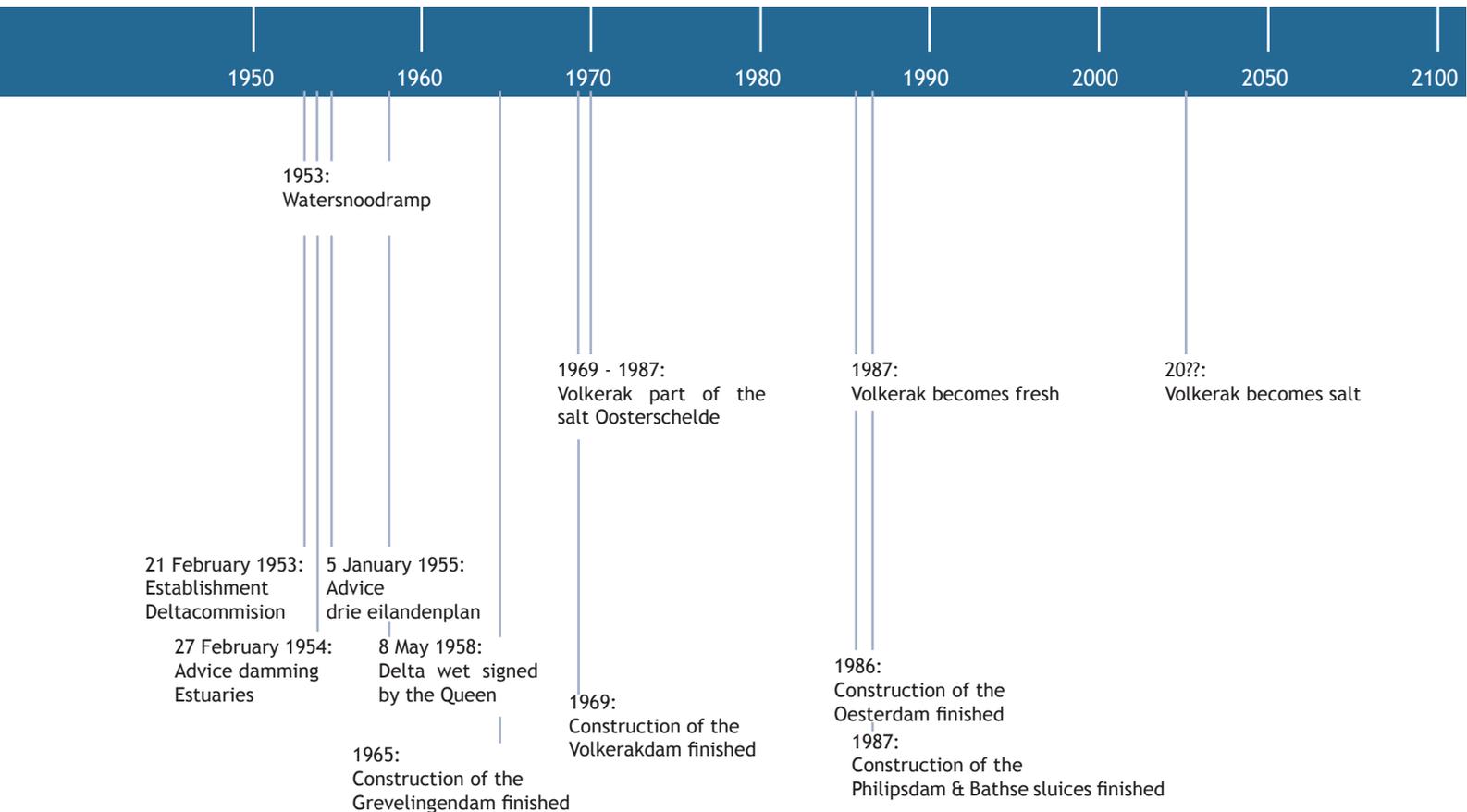


Figure 6.9: The Deltaworks [based on: Stichting Deltawerken online, 2011]



Figure 6.10: The Volkerakdam [Stichting Deltawerken online, 2011]



ingvliet now became a fresh water body and an extra dam was placed at the Grevelingen to create a new barrier between fresh and salt water [Lambert, 1985]. The construction of the Volkerak dam started in 1957. This dam has two functions. The first one was to make the construction of other barriers like the Brouwersdam possible. Without the dam the islands were difficult to reach. Nowadays the dam still has a connecting function. The other function is to separate three waters: The Haringvliet, the Hollandsch Diepm, and the Volkerak [Stichting Deltawerken Online, 2011]. It is a secondary dam, which mean there are other dams in front of it which prevent flooding [Rijkswaterstaat, Volkerak sluices movie 3m.35].

The second dam is Grevelingen dam which provides a barrier between the salt Grevelingen lake and the Volkerak. The construction started in 1958. The Grevelingen dam had to facilitate the construction of other dams [Stichting Deltawerken Online, 2011].

The Philipsdam is the third dam. It separates the Volkerak from the salt Oosterschelde. The construction started in 1977 with an artificial island to make the construction of the dam possible. The dam itself was finished in 1987 [Stichting Deltawerken Online, 2011]. Between 1969 and 1987 the Volkerak was part

of the salt Oosterschelde. After the closure of the Philipsdam the Volkerak became a fresh water lake. The original salt meadows became permanently dry. This area of approximately 1600 hectare developed into nature [Bureau Strooming, 2007].

The surroundings of the Volkerak have a long history concerning fortresses. Many fortresses are built, destroyed and surrounding areas were inundated throughout the last centuries. The area east of the Volkerak was part of the 'Zuiderlijke Waterlinie'; a defence line of fortresses and inundation zones from Bergen op Zoom (Noord-Brabant) to Nijmegen (Gelderland). The defence line was originally set up by Willem van Oranje to protect the Netherlands from Spanish domination, among others during the Eighty Years' War [Zuiderwaterlinie, 2012]. Figure 6.11 shows an overview of the fortresses in the surroundings of the Volkerak. Most interesting fortresses are Fort Sabina (number 2), Fort Prins Frederik (number 4) and Fort de Hel (number 3) because they are still present in the landscape and used for cultural and recreational purposes. The nearest city which was part of the defence line is Willemstad (number 1).

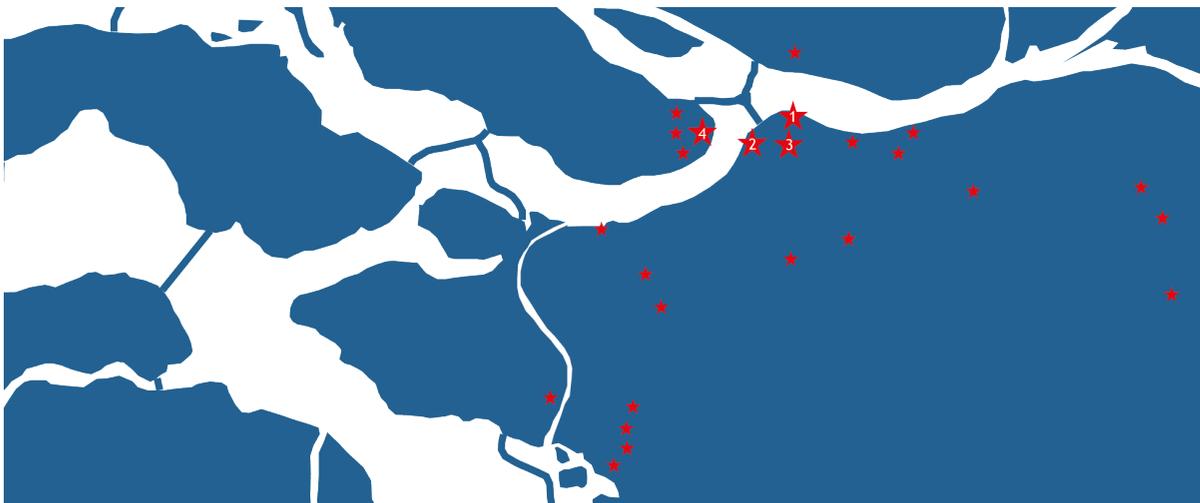


Figure 6.11: Fortresses in the area [Zuiderwaterlinie, 2012]

## 6.2 Present conditions of the Volkerak

There is still a strict edge between inside and outside the dikes in the surroundings of the Volkerak. Inside the dikes is mainly agricultural land, outside the dikes is water and nature. The Volkerak is important for ships. Together with the Eendracht (Schelde-Rijn canal) it connects the harbour of Antwerpen with the important rivers of the Netherlands. All these ships pass the Volkerak sluices [Bureau Strooming, 2007]. This section introduces the current conditions of the Volkerak and the surrounding area; Oostflakkee and West- Brabant.

### Volkerak

The Volkerak and Zoommeer were created by the construction of the Oesterdam (1986) and the Philipsdam (1987) in the eastern part of the Oosterschelde. The dams were made to reduce the basin of the Oosterschelde. Because of the construction of the Oosterschelde barrier the tidal range was reduced. The construction of the dams limited this decrease to an acceptable level. [Rijkswaterstaat, 2011b].

The Volkerak sluices (figure 6.13 and 6.18) are the biggest inland shipping sluices complex in the world. To imagine, in 2009 230 million tons of load passed the sluices which is equal to a row of trucks of 3,5 times around the world. [Rijkswaterstaat, Volkerak sluices movie 7m.30 - 7m.50]. The Volkerak sluices have the possibility to drain 80-100 m<sup>3</sup>/s of water from the Hollandsch Diep to the Volkerak [Deltares, 2011]. The Volkerak sluices use 1.273.813 Kwh per year. This energy comes from the nearby energy network. Electricity pylons create a line from Goeree-Overflakkee over Haringvliet to South Holland. The current surface of the Volkerak is 6,450 hectares. A quarter of that exists of former marshes and plates



Figure 6.12: Blue-green algae at the Volkerak

which became permanent dry after the closure. The average water depth is 5.2 meters, with a maximum depth of 24 meter [Rijkswaterstaat, 2011b].

Since the summer of 1994 too much blue-green algae grows in the Volkerak-Zoommeer (figure 6.12). This is caused by the supply of the nutrients from the rivers of Brabant and Hollandsch Diep, in combination with the limited circulation of the water in Volkerak-Zoommeer [Rijkswaterstaat, 2011b]. Blue-green algae causes a lot of toxins in the water. The water is no longer suitable for swimming water, drinking water and for irrigation of agricultural land [Bureau Strooming, 2007]. In late summer the blue-green algae dies away which causes an enormous smell [Rijkswaterstaat, 2011b]. Since that time, there is a search for solutions to solve the problem of blue-green algae.

There are several harbours, see figure 6.14, despite that water recreation is limited on the Volkerak. Most users of the harbours look for fun outside the water of Volkerak. The most formal reason for that is the blue-green algae. Thereby the Volkerak is a busy shipping route. The Volkerak is mostly a transit route between the rivers and the delta. Each year approx. 50,000 recreation boats pass the Volkerak sluices [Bureau Strooming, 2007].

### Nature

Until the closure of the Volkerakdam in 1969, the Volkerak was a brackish large intertidal area with high difference between high tide and low tide what resulted in sand plates, mudflats and salt marshes. Volkerak was a connection between the fresh Hollandsh Diep and the salt Grevelingen and the Ooster-



Figure 6.13: The Volkerak sluices

schelde. Between 1969 and 1987 Volkerak was part of the salt Oosterschelde and became a salt lake. After the closure of the Philipsdam in 1987, the connection with the salt Oosterschelde was closed. The lake became fresh and the tide disappeared [Bureau Stroming, 2007]. Mudflats and marshes became permanently dry and desalinated (fresh rain water washed the salt from the soil). Most of this 'new land' turned into natural areas. The natural areas are managed by several nature organizations, like Natuurmonumenten, Staatsbosbeheer, and the Zeeuwse landschap.

The area is still developing. The existing nature area is a landscape where forest and open parts alternate (figure 6.15). The variation is encouraged by grazing of Shetland ponies, Scottish Highlanders and other bovines. In the nature areas are many breeding birds, less common species like marsh harries, stonechat, whinchat, owl and the great spotted woodpecker. The nature areas have several observation huts which can be reached by footpaths.



Figure 6.14: Marina, Willemstad



Figure 6.15: The nature area Hellegatsplaten

### Surroundings of Volkerak

The Volkerak is enclosed by the island Goeree-Overflakkee, the Philipsdam, West-Brabant and the Volkerak sluices, see figure 6.16. The layer approach, see figure 6.17, with the occupation-, network-, and underground layer were used as a basis for the following section.

### Landscape

Overflakkee is created by concretion of several small islands, which in turn were created by draining marshes and mudflats in the 15th and 16th centuries. Around these oldest parts new polders were created constantly. Around 1800 it became one island, the island of Goeree-Overflakkee. The old dikes of those polders can still be found in the landscape. The old creeks remember to the origin of this dynamic landscape on various places [Oostflakkee, 2011]. The underground of Volkerak consists of young sea clay ground. The characteristics of Oostflakkee are the large-scale polders with agriculture (figure 6.20) and a clear landscape structure because of the dikes. The structure of these polders is mainly straight and does not follow the structure of the underground. This can be seen at the creeks that lie in the polders and are in contrast with the straight lines of the ditches and dikes. The inland and outland areas form a contrast with each other. Where the inland farmland is open and structured, the outland shows a more natural, not structured area.

The young sea clay landscape of West-Brabant has a rich history, what is not always visible in the landscape. The Brabantse rivers the Dintel and the Steenbergse Vliet are rivers with meadows and connect the landscape of West-Brabant with the Zeeuwse and South-Holland delta. The creek landscape of West-Brabant is characterized by polders, dykes, linear development on and alongside the dykes, straight polder roads and meandering creek remnants [HNS, 2010]. The creeks are recognizable, natural elements in a cultural landscape. The dykes in the landscape are just a few meters high but form an important structural element in the mostly flat landscape. They make rooms in the landscape and give the landscape size and scale. Other characterizing elements in the landscape are the many present fortifications [HNS, 2010] (see section 6.1).

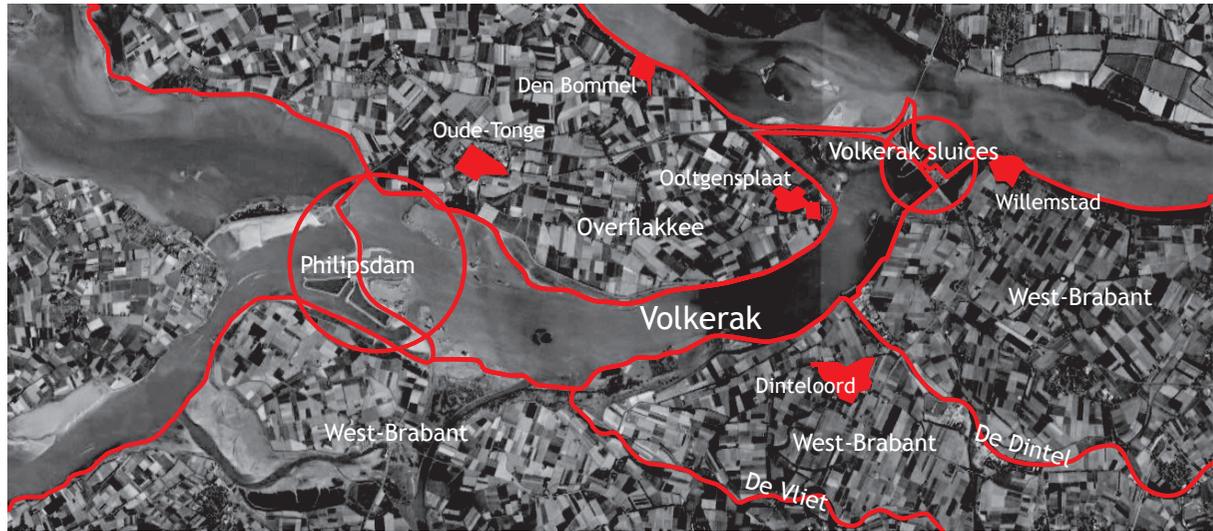


Figure 6.16: Current situation of the Volkerak

The villages of Goeree-Overflakkee and West-Brabant lie on creek ridges or along the dike. Near the (formal) open water are old harbour villages. The old farms are situated at the edge of the polder. The new farms lie more in the middle of the polder. The main roads in the area form a new network which has no relation with the polders or underground. The older small roads follow the dikes of the polder. The large waterways are mainly used for water transport and the small waterways are mainly used for water recreation. In the eastern part of the area a relationship between the underground, the network and occupation layer is visible in the small rivers of Brabant. The dikes of the polders around the rivers follow the forms of the river and villages are situated near the river (see figure 6.17).

Both landscapes of Goeree-Overflakkee and West-Brabant are sea clay landscapes with a wide and open character. Water is nearby everywhere. The sky is bright, the wind is (always) blowing and the landscape colours are green, grey and blue [Lidth de Jeude et al., n.d.].

### Nature

Where outside the dikes nature dominates, inside the dikes there are not many nature areas and the

landscape is determined by agriculture. There are a few nature enclaves in the form of creek remnants and embankments.

### Agriculture

The agricultural area lies inland and safe behind the dikes (figure 6.19). The sea clay is fruitful ground for agriculture what makes a connection between the underground and the occupation layer. The area of Overflakkee and West-Brabant has grown through trade, agriculture and the sugar industry. Along the Dintel there are still traces of the beet culture for the sugar industry, for centuries the engine of the economy in the region. The agriculture was and is an important economical factor in this area, but this function alone does not give sufficient opportunities for a healthy economic growth. By intensification of the agriculture, improvement of the quality of the product and glasshouse horticulture, the agriculture will maintain on an economically acceptable level [Oostflakkee, 2011].

### Recreation

There is not much recreation on the land around the Volkerak, but despite that the recreational sector is the most important economical factor after agriculture. The region is not very attractive for recrea-

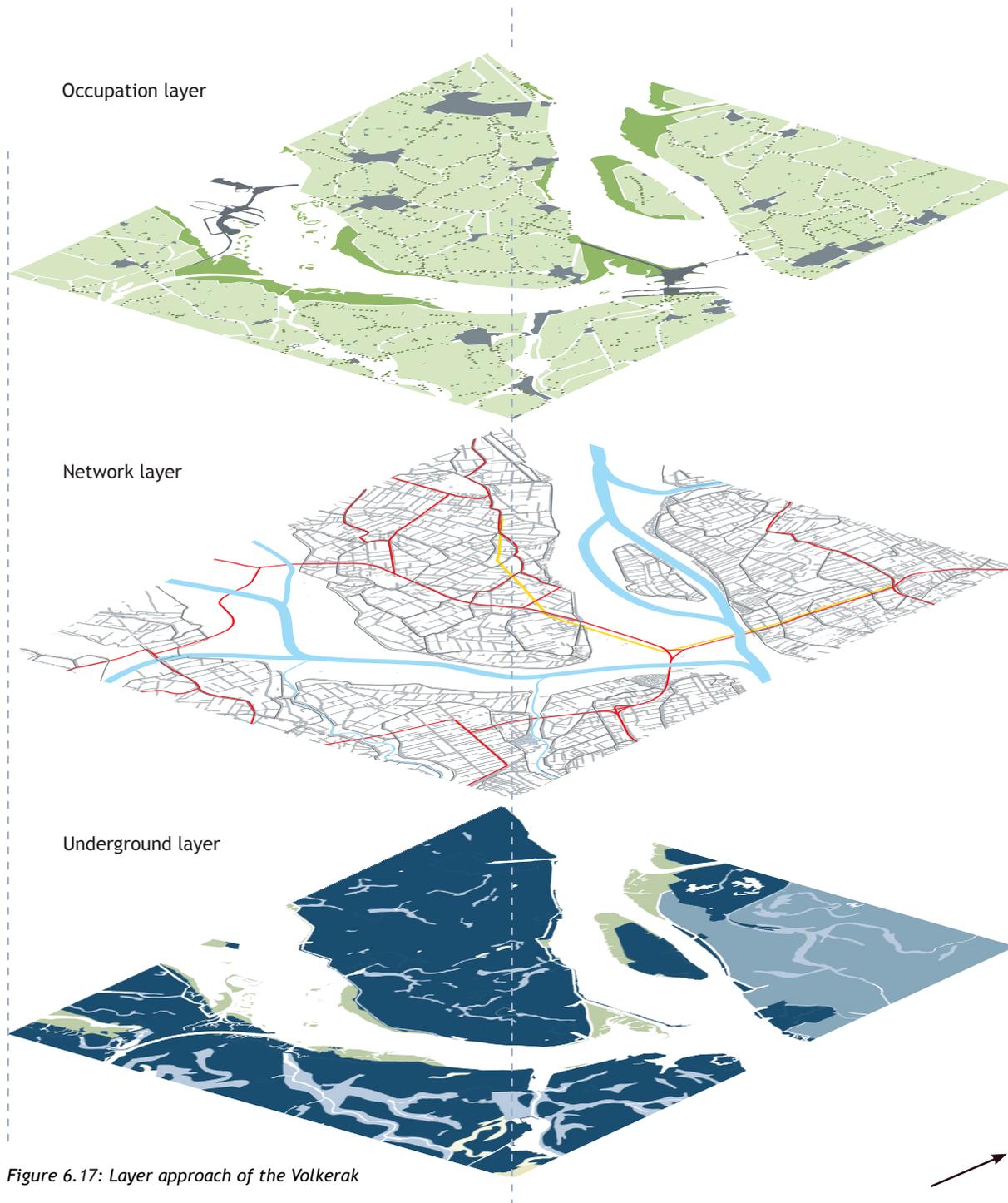


Figure 6.17: Layer approach of the Volkerak

tion; there are hardly any recreational routes, accommodation or attractions and the nature areas around the Volkerak are not accessible most of the time [Bureau Strooming, 2007]. The water of Volkerak offers opportunities for water recreation. As said before there are several harbours at the Volkerak. On Overflakkee are two holiday parks and several camp sites owned by farmers. The government of Oostflakkee believes that developing new recreation in the area is important for preservation of the landscape. A problem for the water recreation on the Volkerak is the blue-green algae in the lake. The blue-green algae has caused that economic developments are reduced. Restaurants are closed, houses are for sale, it causes deterioration and the quality of the villages becomes lower. On this moment there is not much recreational development in the area to coop with these problems [HNS, 2010]. In the future recreation on- and around the Volkerak has great potential, and can be seen as the blue-green hart of the region. When the water quality will be improved and the identity of the lake and the region is strengthened, the recreation can benefit from this. It is therefore important to improve the recreational infrastructure [Bureau Strooming, 2007].

- trees
- development
- marshes and mud flats
- delta works
- agriculture
- roads
- electricity overhead lines
- polder ditches
- dikes
- waterways
- cover sand
- tidal plain
- inversion ridge
- creek
- peat
- plain

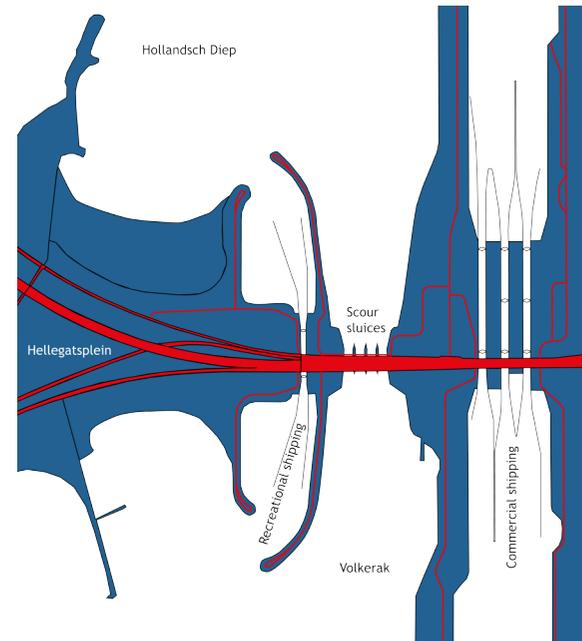


Figure 6.18: Structure of Volkerak sluices from west to east



Figure 6.19: Agriculture area, West-Brabant



Figure 6.20: Agriculture area, Overflakkee

## 6.3 Future of the South-Western Delta

The Delta works brought safety and made the South-Western Delta accessible. Tide was reduced and basins with stagnant fresh- and salt water were created. Especially agriculture benefited from the large fresh water basins in the area. Decrease of tide, several separate inland waterways and the increase of freshwater in the Delta however has a downside: the poor water quality of the Volkerak-Zoommeer. The blue-green algae causes smell and green poison water, by high temperatures. [Programmabureau Zuidwestelijke Delta, 2010].

Research has showed that salinization of the Volkerak-Zoommeer and tidal dynamics are the only practical solution. The water quality will improve, blue-green algae will disappear, the natural values will increase, and there will be new ecological chances [HNS, 2010]. That the lake will become salt is almost certain but in which period of time depends on the government [interview with Rijkswaterstaat, 2011b]. A disadvantage of a salt Volkerak is that it is possible that salt water enters the Hollandsch Diep through the Volkerak sluices. This is not allowed because fresh water is required for agriculture, industry and drink water supply. The problem can be solved in three ways. The first option is a separation system where the sluices are completely filled with fresh water or salt water (depending on the direction of the ship). This is expensive since it requires major changes to the current sluices and it takes longer for a ship to pass the sluices. The second option is a screen of bubbles that prevents mixing of fresh- and salt water. This is a new technique that seems to be

cheaper and faster than the first option [DHV, 2011]. The third option (in combination with the second option) is to lower the salinity of the salt water near the sluices to a brackish environment. In this way the difference in salinity is lower, what also decreases the salinity at the Hollandsch Diep. This option requires a continuous stream of fresh or brackish water to create a brackish water environment.

According to Programmabureau Zuidwestelijke Delta [2010] it is important that the dynamic character will come back in the South-Western Delta to solve today's problems. The connection between land and water offers many opportunities for recreation. Also the connection over land and water between the blue-green hart and the surrounding cities of the Delta is essential for shipping, commuting and tourism.

Another problem is the changing climate. Sea level rises. Irregular and intense rainfall occurs. Peak discharges of the rivers are therefore higher and in the summer drought will occur. These climate changes have consequences for the water management of the South-Western Delta [Programmabureau Zuidwestelijke Delta, 2010]. According to Programmabureau Zuidwestelijke Delta there are three options to ensure safety in the coming century. To ensure safety in the future, provides the transformation of the delta to an open (figure 6.21) system where river water flows freely into the sea a possible solution. A delta that moves with the changes. Another option is to offer resistance. Strengthen the dikes, make more space for storage of river water and retaining salt

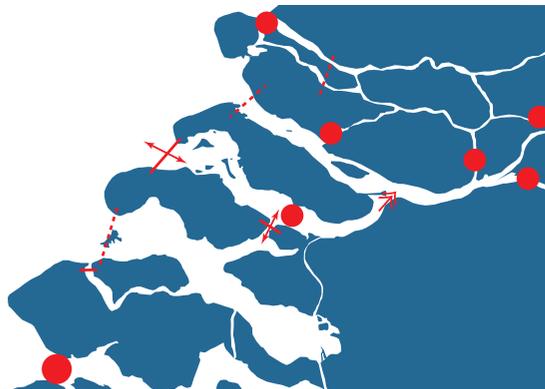


Figure 6.21: Scenario 2100 "Open" [based on: Programmabureau Zuidwestelijke Delta, 2010]

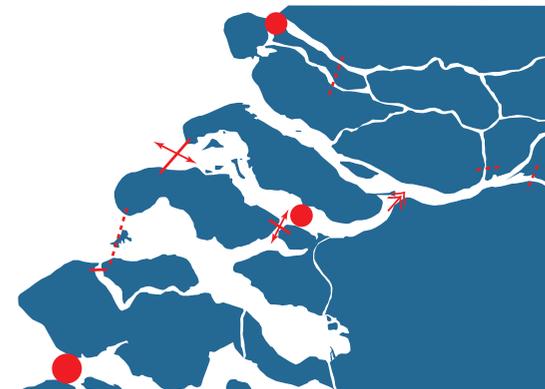


Figure 6.22: Scenario 2100 "Closable Open" [based on: Programmabureau Zuidwestelijke Delta, 2010]

- Fully open
- ⊕ Closed with pass option or drainage sluice
- Closed with lock
- Fully closed
- ⋯ Closable open

water. A middle path is: closable-open (figure 6.22). Open when possible, closed when is needed. An open system (figure 6.23 and 6.24), as proposed by the Programmabureau Zuidwestelijke Delta, offers the most potential for a blue energy plant sited by the Volkerak sluices. In this system dynamics in the Delta are gradually restored while maintaining safety. This offers opportunities for the future. The Volkerak and the salt Oosterschelde can be connected again.

Therefore the water quality in the Volkerak will improve and salinity will be increased in the Volkerak. This is a positive aspect for the blue energy plant.

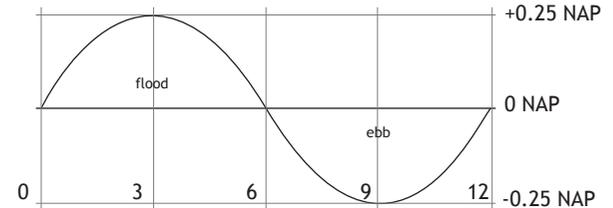


Figure 6.23: Cycle of tides at the Volkerak (12h 25 min) [Rijkswaterstaat, 2012]

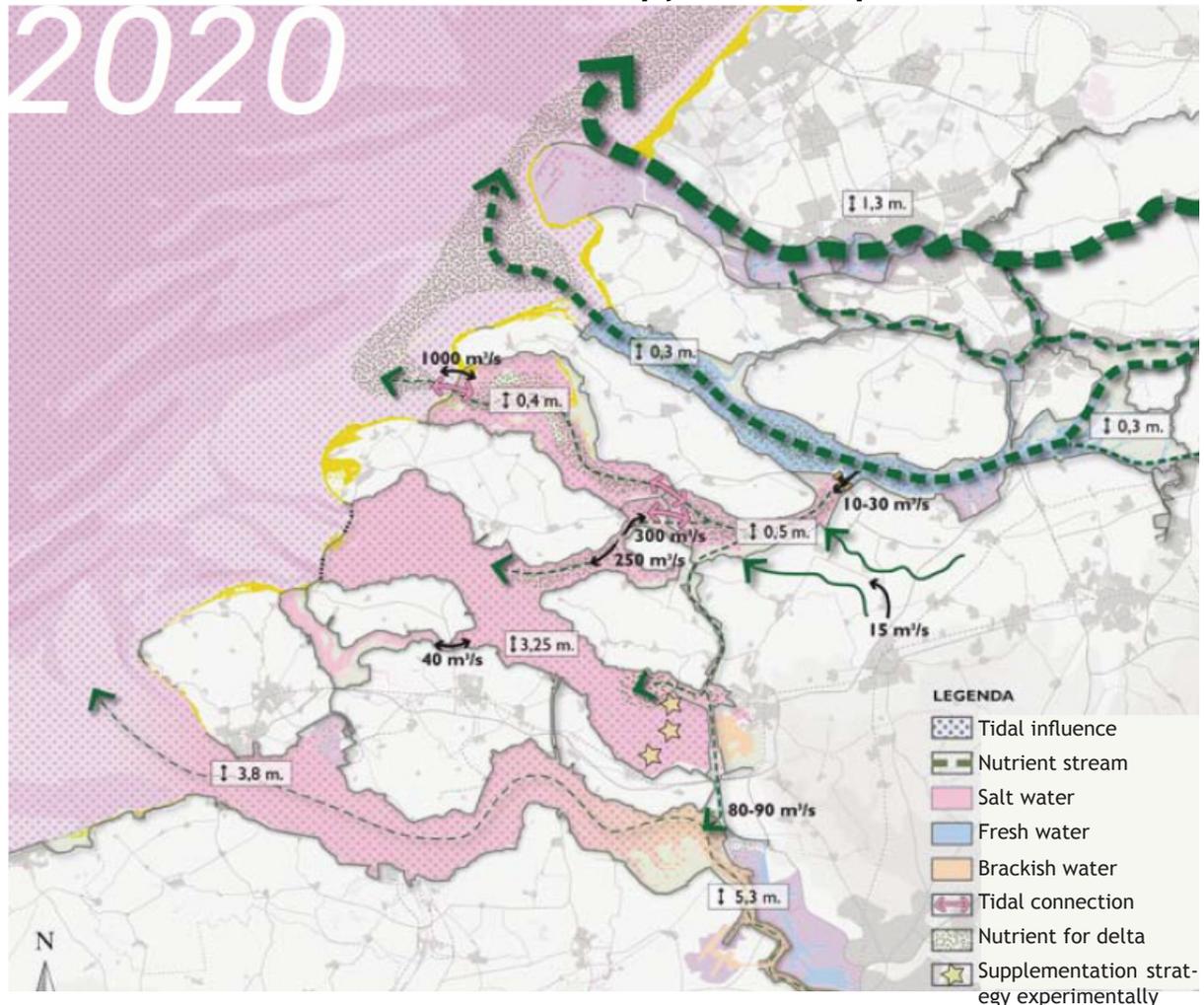


Figure 6.24: Vision 2020 of gradually restoring of the dynamics (tidal, fresh-salt transition, nutrient flow) [based on: Programmabureau Zuidwestelijke Delta, 2010]



*Maintenance path for the Volkerak sluices, looking towards the sluices*

# 7

## THEORETICAL FRAMEWORK

The design further on in this thesis is based on a theoretical framework. This framework determines the way the authors design and look at the landscape with a blue energy plant. The chapter starts with an overview of several theories applicable for landscape architects. Further on a selection of these theories is

chosen as framework for the design. The chapter finishes with an section on how to apply this framework on the design. This will help to answer the main- and design research question, with a focus on the question: *What are the requirements for creating a blue energy plant as landscape machine?*

## 7.1 Ecological processes in the landscape

The landscape can be seen as a combination of natural processes. Making use of natural or ecological processes to come to a (sustainable) design is described in mutual articles. Because of the worldview and theoretical lens the authors became attracted by these processes.

The theories of (landscape) ecological design and eco-revelatory design are two theories which also see the processes of the landscape as important guideline for landscape design. Since the publication of Ian Mcharg's 'Design with nature' [1969] landscape ecology is an applied analyse model for studying the past, current, and future structures of the landscape, including ecological, hydrological, and other impacts. The need for ecological knowledge in planning and design is still valid according to many designers [Lovell and Johnston, 2009; Forman, 2002; Spirn, 1985]. Using the concept of an ecosystem as a basis for landscape design will provide a greater understanding of the landscape at multiple scales, while incorporating the needs of society and interactions between human activities and the environment [Spirn, 1985]. Landscape ecology includes the ecological processes, patterns and change of land mosaics. Large area and long-term focus provide a foundation for how to design and plan the land for a more sustainable future [Forman, 2002]. Forman also suggests that the successful synthesis of ecology and design may offer the greatest opportunity to curtail the degradation of our remaining resources, by combining nature and culture within landscapes.

To work with natural processes, it is important to be familiar with them. The hard part is to define them, to make use of it and to work with those processes so that the natural processes will create multiple benefits. Working with natural processes as natural technologies can create a cultivated ecological landscape that provides a high-quality human habitat while minimizing impact on the natural systems [Wenk, 2002].

Another theory that is based upon ecological processes which inspires landscape designers is the theory of "eco-revelatory design". Eco-revelatory design is about revealing and interpreting ecological phenomena, processes and relationships, based on

the assumptions that landscapes can reflect cultural values of nature and have the power to communicate those values [Brown, Harkness and Johnston, 1998]. Eco-revelatory design highlights aspects that are overlooked by designers and public in the hope that it will enliven the site, make people more aware of its complexities, and promote ecological awareness [Liverman, 2007]. Eco-revelatory design can create a connection between people and "*stormwater flows, food production, restoration, waste processing, and other environmental processes, including the negative consequences of human actions that often remain hidden and unknown in anthropogenic landscapes*" [Lovell and Johnston, 2009].

An important aspect that Koh [1988] describes in "An Ecological Aesthetic" is the self-organizing (developmental and evolutionary) of a creative system (biological and psychological). When this element of a self-organizing system is missing this can be expressed in lower levels of stability of the biological system [Koh, 1988].

The essence of the theories described above is that the ecosystem functions as a basis for a landscape design. This basis of natural processes will help to produce a sustainable design. The concept of the landscape machine also uses natural processes as guideline, but in this case from a different angle. This concept is described in the next sections.

## 7.2 The Landscape Machine

Roncken et al. [2011] have been tracing a type of landscape architecture which inspires them to believe in new resilient landscapes and their value to landscape services. They have labelled these landscapes by addressing an inherent paradox: landscape machines. These landscapes make use of elements that a machine also has (the predictability, production orientation, fuel, efficiencies of the input, and output), and a natural ecosystem what connects the machine to the landscape [Roncken et al., 2011]. This inspired the authors of this thesis to make a sustainable landscape design with the use of the concept of the landscape machine. This section describes the concept of the landscape machine and the relation to the other theories. The section thereafter explains why the concept of the landscape machine is fruitful for this thesis and how it will be applied in the design. This section is based on the paper of Roncken, Stremke and Paulissen, published in the Journal of Landscape architecture in 2011. The authors of this thesis consider the landscape machine as a theoretical concept which is open for development instead of a set theory. It is a concept that may change the way one looks at the landscape and perceives changes in the landscape.

A landscape machine is no machine for landscaping but it is a machine made out of landscape features and driven by natural processes in the landscape to produce a multitude of food products, natural biotopes, clean air, sustainable energy, and so on. The landscape machine can be defined by two main aspects. For one it has a certain input and output of certain materials. It is driven by the amount of energy of the input. Second, the natural processes within the landscape machine are continuously interfering with each other and therefore will affect the landscape. The input does not change, but the landscape and machine can change. The landscape machine makes use of the natural processes within the landscape to come to a 'clean' productive landscape. The machine should be mainly self-organizing. When no self-organizing system is present in the landscape, the machine will stop working because the mechanical components of the machine are based on natural processes or the specific behaviour of flocks of animals that themselves are affected by on-going events.

The landscape machine is a quite new concept. Students of Wageningen University designed with the concept of a landscape machine what has resulted in price winning designs. These examples are also described in the paper of Roncken et al. The design "Dredge landscape Park - the story is in the soil" [de Vries & Herrebout, 2007] makes use of the landscape machine to clean an amount of polluted dredge in the water system. Another example of a landscape machine is the design "Saline landscapes [Molpheta & van Wonderen, 2009]". The assignment was to implement a newly developed fish farming pond, in a closed cycle of food, nutrients and by-products, in the landscape. The designers were challenged to upscale this small industrial scale of one test farm, to the scale of a landscape machine. The location is the island Noord-Beveland, in the province of Zeeland. The main characteristics of Noord-Beveland are agricultural land and the relationship with the sea. The crop farming (dependent on fresh water) and the tourism on the western coastlines form the economical basis of the island. The future scenario would be to adapt to the increasing intrusion of salt water while maintaining the production of crops and an expansion of the recreational interest to the whole area while embracing historical features. There seems a tendency towards nature development in combination with other functions of recreation. The first up scaling of the design consisted of aquaculture farms that are part of bigger closed system, related to the nearby sea and the fresh water catchment areas. The designers introduce a triple dyke system with two rows of 'inlagen' that both protect the land from the sea and provide an essential component within the new production system. This landscape can thus be more than an agrarian landscape. It will have the functions of food production with a minimum of input, like fish, algae, cockles, rag worms and mussels, protecting the land from water threats, adapting to historic features in the landscape, and enriching the local biodiversity. This design of a landscape machine, both the nature values and the agricultural demands can be met, a landscape that will be accessible for people who wants to experience the delta landscapes. In the "Saline landscapes" design the input of the landscape machine is the salt water into the polders. The output consists of biodiversity, delta landscape, food production, recrea-

tion and coastal defence. The machine itself are the polders with the double dyke system with the natural process of the tides. The design shows that the implementation of a small scale test farm can lead to a sustainable design which has more functions than the production of foods.

The landscape machine is an example of a landscape design where several functions are presented in one design. Multifunctionality in landscapes is a topic that is presented by several authors [Wiggering, 2003; de Groot, 2006; Lovell and Johnston, 2009]. A multifunctional landscape is more than a multifunctional ecosystem. It is about ecology, production and cultural functions all in the same site. The goal of such multifunctional design is to do more than just providing the standard design; it is about providing food, energy, water quality, treating waste, increasing biodiversity, visual quality, and providing recreational opportunities [Lovell and Johnston, 2009].

Also the aesthetic experience can be experienced in the landscape machine but Roncken et al. see that designed landscapes commune well with the beautiful and the picturesque but somehow miss the point of a raw authentic landscape mechanism that simply cannot be restrained: the sublime. The sublime is not a picture of a beautiful landscape what expresses eternal time frame of awareness. It is the experience of the sublime, as defined by its most extensive examinations reveals an interpretation on aesthetics. *“The sublime is not maximised drama in overromantic depictions as is generally understood but rather the cultural project of sublimation, which offers possibilities for the continuation of a project of artistic and intellectual modernity”* [Roncken et al., 2011, p.70]. Designing of new living landscapes, for designers it is essential to imagine, to deal with unresolved complexity. To come to a sublime design, the design process will lead to an experiential research to find the balance between processes of nature and living landscapes and the benefits that the landscape can give us. The sublime is still in an experimental learning phase. It is not another learning theory for stylish or artistic form principle. The aesthetics within landscape architecture is been limited to architectural compositions. The future of sublime can bring an active theory on experiential

learning that can enhance design research of living landscapes.

## 7.3 Designing the machine

The essence of the landscape machine is to make use of the natural processes within the landscape. These processes are continuously interfering with each other and therefore resulting in landscape components. The mechanical components of the landscape machine are natural processes that are affected by themselves. The landscape machine mainly uses natural processes. Within the case of a blue energy plant this is only one part of the system. The blue energy plant makes use of the natural process of mixing fresh- and salt water what results in brackish water. With a technical addition (membranes) on the natural process it will result in brackish water and energy. Roncken et al. acknowledge the downside of a combination of machines and landscapes. They describe a hard cast machine which is placed in its surroundings, but without looking to his surrounding environment. Therefore it will be experienced as a parasite in the landscape that produces waste [Marx, 2000]. Landscape machines are also considered as machines because of their productivity. *“These machines are made of landscape features and are driven by landscape processes; they will produce a multitude of products such as natural biotopes, clean air, energy and so on”* [Roncken et al., 2011, p.72]. In the case of the blue energy plant membranes make use of the natural processes of mixing fresh and salt water without influencing the mixing process itself; the output of water does not change. The hard cast machine, in this case the membranes, are used to do more with the natural processes. The membranes create an output to the machine; electricity. This output is created because of the fuel, which is the salinity difference between fresh and salt water. Creative solutions in architecture and landscape architecture usually work with nature rather than against it, letting nature and landscape complement humans and building [Koh, 1988]. When using natural materials for the hard cast machine it will give more than ecological and economical means for material and energy savings, it will create richness and expressiveness of natural form [Koh, 1983].

The input of the blue energy plant (fresh- and salt water) has to have a certain quality to be able to harvest the energy. When a blue energy plant would be developed as a normal hard cast machine, the quality of the water will be improved using a wa-

ter treatment plant. This hard cast machine can be changed into a landscape machine when natural processes would take over the water treatment function. This is possible when a combination of bacteria, plants, oxygen and soil is used to clean the water [de Vries & Herrebout, 2007]. The theory of revelatory design as described in the first section of this chapter, makes natural processes visible. In other words it reveals processes in the landscape in a creative way. The landscape machine extends this by using a fixed input, the machine and the output to reveal and make the processes of the landscape understandable. In terms of a blue energy plant there is the predictable year round input of salt- and fresh water with the production of electricity and brackish water as output. In this way the machine is a landscape which improves the quality of the fresh- and salt water. With the addition of membranes sustainable energy can be produced. When the landscape machine is evaluated, both intended and unintended output should be taken into account. While the intended output consists of energy and brackish water, the exact influence of the blue energy plant on the landscape is unknown and therefore might result in unintended, yet unknown, output.

One of the most important things for this thesis is the use of ecological processes to come to a sustainable design for now and in the future. To come to a good sustainable design it is necessary to focus on spatial and temporal scales, create a balance between use of resources, be place specific and focus on more than one problem to avoid side effects [Karr, 2002]. Multifunctionality in a landscape has been recognized as a condition for sustainability [Lovell and Johnston, 2009]. Multifunctionality in a sustainable landscape design is a plurality of production (food and electricity), natural, economic and social functions.

The sublime, as mentioned in the second section of this chapter, cannot yet be experienced in designed landscapes, for as far as known. But the sublime can play an important role in the landscape machine. The landscape machine is based on natural processes and those processes play an important role in living landscapes. The landscape machine seeks for natural processes that can replace mechanical processes, the search for this asks for fantasy and imagination.

## 7.4 Conclusion

This fantasy and imagination is also required in the search for the sublime. The living landscapes asks for an active theory on experiential design process what can brings new forms and new landscapes to the design of a sublime landscape machine.

To come to a sustainable design for a specific region it is necessary to study the region. Also Ian Mcharg's Design with nature [1969] described this. Look at the past, current and future structure of the landscape, including ecological, hydrological and other impacts on the surrounding environment. An important aspect is that every region should display the beauty of its local landscape [Spirn, 2002].

For this thesis it is important to create a sustainable design. To reach this target it is important to realize that changes in the landscape have impact on the surroundings and ecological systems. It does not mean that doing nothing or making only small gestures is the solution. It means asking questions to people who have the greatest knowledge, weighing and judging answers and monitoring the effects of design and being prepared to respond to surprising consequences [Nassauer, 2002]. Therefore contact with experts on ecological systems are required. *"No singular expert will understand the whole process or can fully predict what will happen in newly initiated landscapes"*. [Roncken et al., 2011. p.73].

The example of a landscape machine, as described in the second section of this chapter, shape the concept of the landscape machine. The value of the landscape machine for the design is that the ecological processes that keep the machine going have a certain size and form that will have influence on the design. Those natural processes of the landscape machine will provide certain design principles and will help to come to the form of the final design of a blue energy plant.

The landscape machine is a combination of continuously interfering natural processes which together function like a machine with a certain input, fuel and output. The landscape and machine can change, but the input and fuel do not change.

Using the concept of the landscape machine will influence the design for a blue energy plant. The theoretical framework described in this chapter forms the basis for a design for implementing a blue energy plant in the form of a landscape machine. It will give focus to do more with ecological processes in the landscape to come to a design what will provide more than just a design for implementing an object in the landscape. Especially in relation to eco-revelatory design in order to reveal ecological phenomena the ecological processes become visible in the design.

Instead of creating a hard-cast machine for generating energy, the blue energy plant and surroundings have to function as a machine of natural processes. The landscape should not be static but should have the possibilities to evolve. This does not mean it has to change continuously; the machine can also be fairly stable as long as it is self organizing. The design should address the elements of a machine: predictability, a fuel, production orientation and efficiency in input and output (figure 7.1). To improve the relation with natural processes all mechanical parts of the blue energy plant have to be replaced by a natural comparable element as far as possible. Important for the landscape machine is that it is multifunctional in producing food, electricity, increasing biodiversity and that it should have ecological but also economical meaning. It should be possible to do something in and with the landscape.

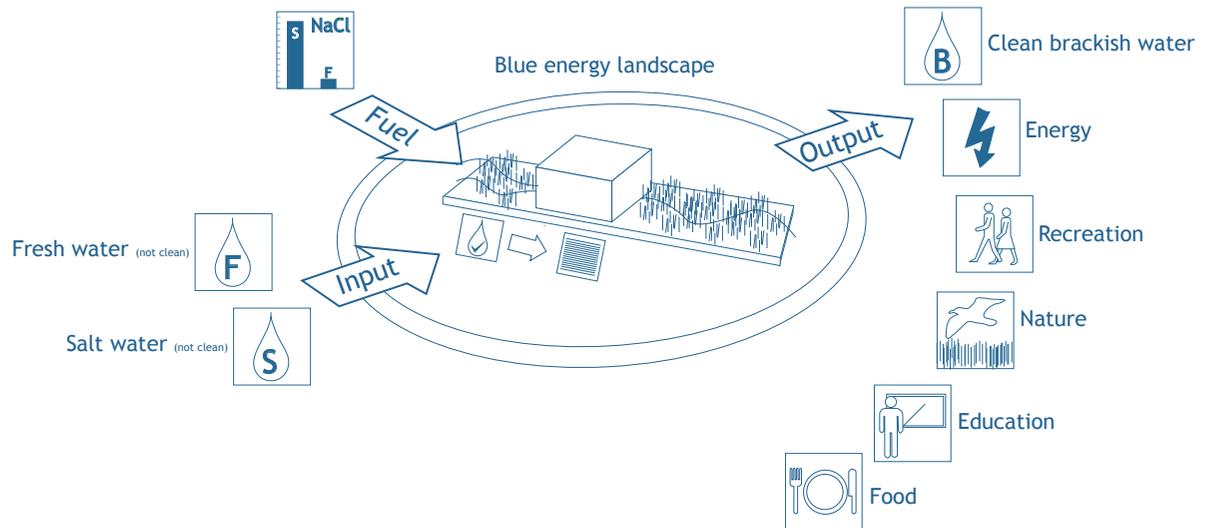
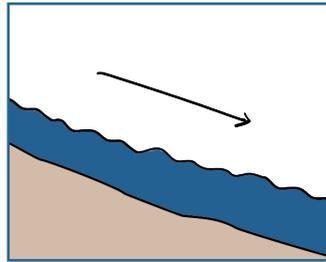
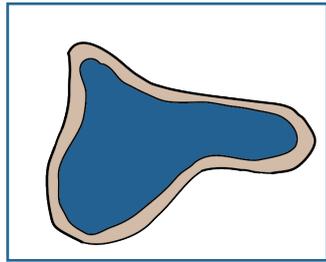
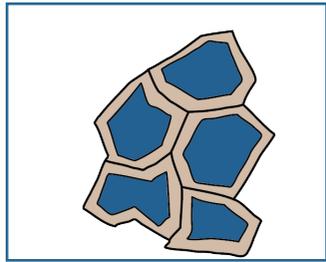
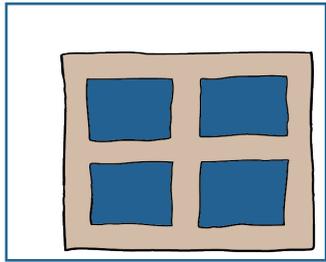
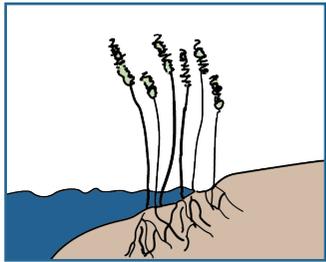
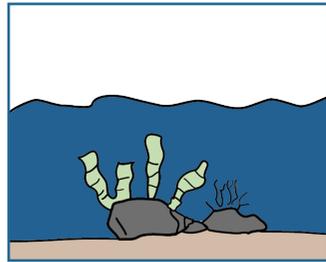
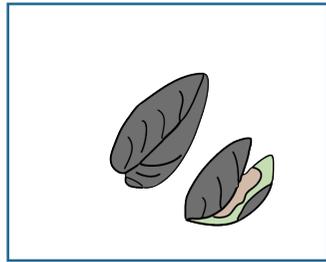
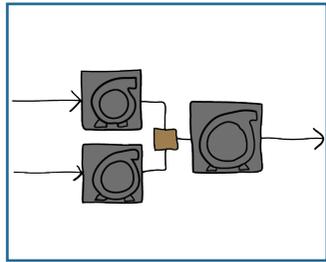
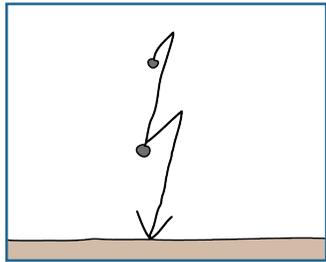
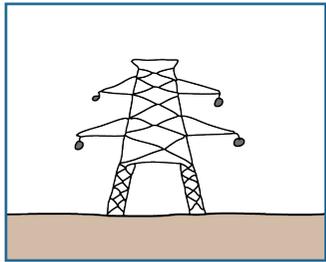
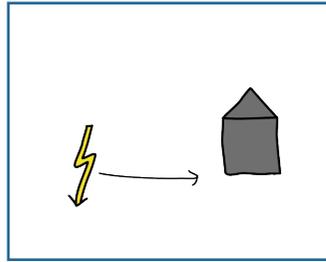
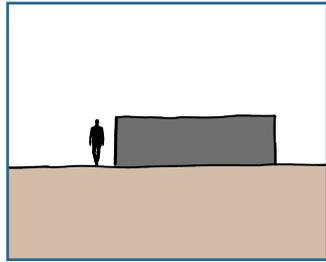
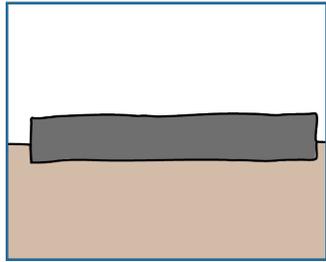
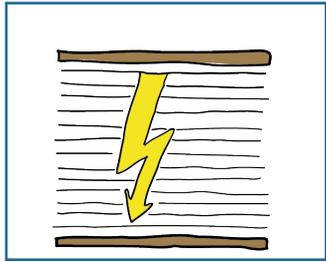
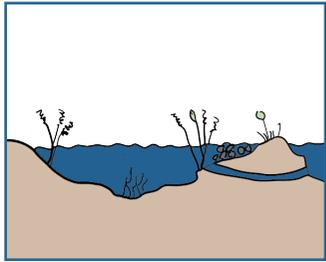
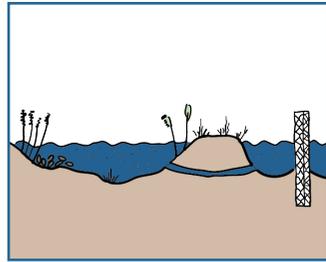
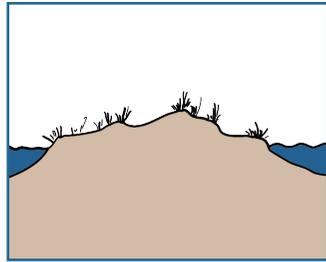
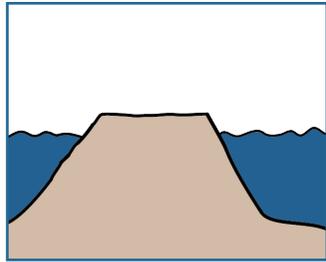
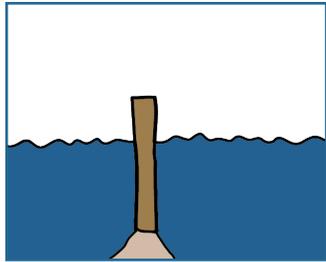
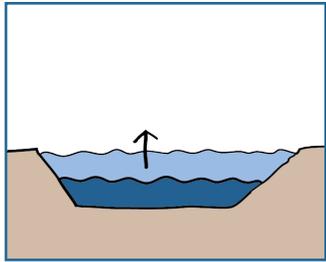
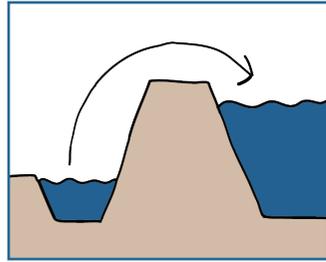
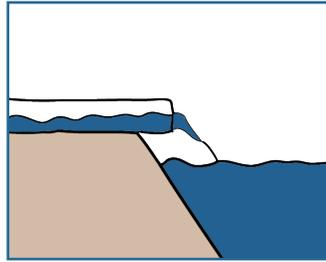
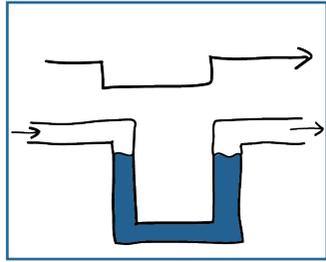
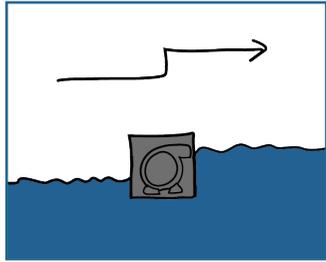
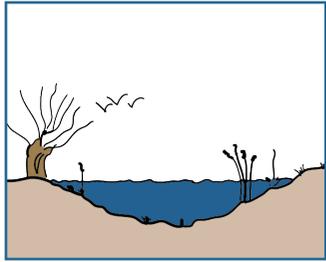
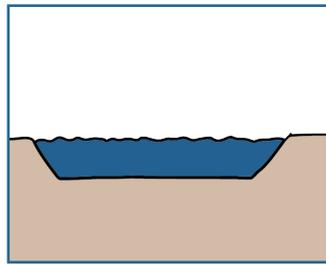
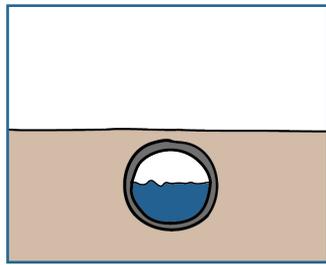
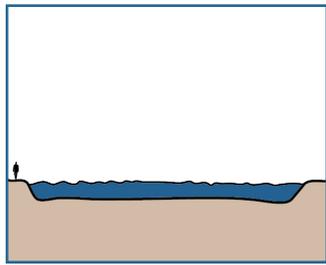
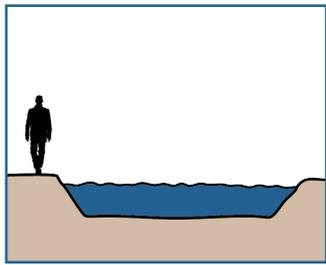
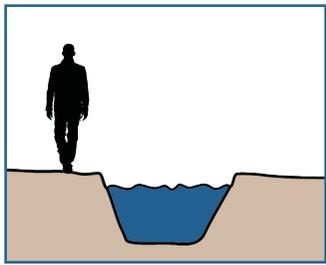


Figure 7.1: Blue energy plant as landscape machine [based on: Roncken et al., 2011]



# 8

## DESIGN PRINCIPLES

The design principles in this chapter visualize the preconditions for a blue energy plant (chapter 4) in relation to the theoretical framework (chapter 7). The design principles show how the information of the technical preconditions and the theoretical

framework can be translated in a design. This chapter gives answer to the following research question: *“Which design principles for a blue energy plant can be derived from the technical preconditions in relation to the landscape machine?”*

## 8.1 Introduction

The design principles are divided in the three main parts of a landscape machine: input, machine and output. These parts are further divided in the required elements for a blue energy plant. Each element contains three design principles. All design principles are placed in a matrix (figure 8.12). This matrix contains two axes which are explained in the following paragraphs. Both axes are based on the theoretical framework of the previous chapter.

The horizontal axis shows the possibilities between technosphere and biosphere. The technosphere contains elements of a hard-cast machine. It is predictable and product oriented with input- and output efficiencies. The biosphere contains elements of a natural ecosystem [Ronken et al., 2011]. Both of them are present in the concept of the landscape machine although a design can be developed more in the technical (technosphere) or natural (biosphere) direction. A complete system of a blue energy plant can function as a landscape machine. Each design principle on its own is a choice to create such a machine. The choice for a more technical or natural design depends on stakeholders, architect, and surrounding landscape.

The vertical axis shows the possibilities between concealed and revealed design. This is based on the theory of eco-revelatory design. The word 'eco-revelatory' contains two parts: ecology and revealed. The 'ecological' part of this theory is part of the horizontal axis (biosphere) since both describe ecological- and natural processes. The 'revelatory' part determines the vertical axis of the matrix. It depends on stakeholders, the purpose of the architect, or the surrounding landscape if a certain element of the blue energy plant should be concealed or revealed.

The design principles in the matrix can show the difference between a concealed and technical element of the landscape versus an revealed and natural element, and everything in between. The design principles together form the possibilities to create a design which fits best in the landscape (which is different for any location).

All design principles are provided with a description. The description contains the meaning of a design

principle and if the principle meets the requirements to create a sustainable energy landscape. A design for an energy landscape like one for a blue energy plant should be sustainable to increase the credibility and realizability. The requirements for a sustainable energy landscape are biodiversity, safety, competition with other land use functions, social cohesion and solidarity, aesthetics and identity. Biodiversity is required to have a well-functioning ecosystem. Without enough biodiversity an ecosystem cannot maintain itself and will eventually be a threat for the environment [Planbureau voor de Leefomgeving, 2012]. The design interventions should pose no threat to the biodiversity. Safety is important since interventions should pose no physical harm. Climate change is one safety factor. The dikes, blue energy plant itself and other parts like pumps should be prepared for the changing climate (chapter 3). The Dutch landscape is already used intensively. Each intervention will compete with other land use functions. It is important that energy provisions should not compromise provision of the basic needs like food and water. Social cohesion and solidarity is another factor of a sustainable energy landscape. The design (principles) should not compromise existing local value systems, social integration, and community. People are familiar with the area they live in. The people feel connected with the area and are therefore sensitive for changes in their landscape [Vries, 2007]. This is also related to the identity of an area. It is important that changes in the landscape are well planned to create social integration and contribute to the identity or strengthen the identity. Aesthetical values can be applied to all design principles. The aesthetical values are not described in this chapter since they strongly depend on the location. Energy-conscious interventions should not harm landscape quality. Energy transition is actually a chance for improving landscape quality.

Only the requirements of a sustainable energy landscape which apply to a certain design principle are described. Some design principles also contain sub-principles. These sub-principles can only be applied in a design when the main principle is chosen.

## 8.2 Input

### Amount of water

Figure 8.1a, 8.1b and 8.1c

The amount of water determines the size of the channels for the input of fresh- and salt water. This influences the impact on the landscape. A ditch can be enough for a small blue energy plant, but it is also possible to use a river as input of fresh water. A blue energy plant is considered as small when it generates more than 100 kW which is equal to 100 litres per second. A medium size blue energy plant gener-

ates between 100 kW and 10MW (or 100-10,000 litres per second). A big scale blue energy plant generates more than 10MW [based on: Molenbroek, 2007, p.46].

A small stream is relatively concealed and easier to integrate in the landscape. It competes less with other land use functions compared to a river. The competition of land use functions can be either beneficial or harmful for the area, depending on the particular location which is different for each design.

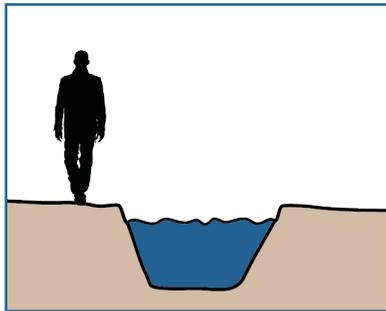


Figure 8.1a: Ditch

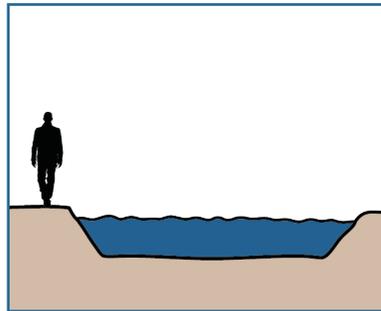


Figure 8.1b: Canal

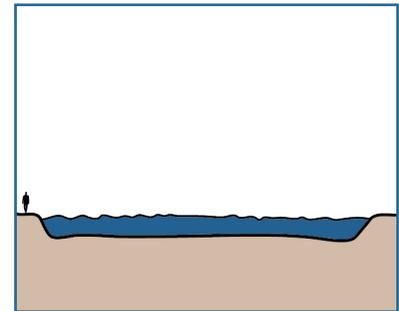


Figure 8.1c: River

### Design canal

Figure 8.2a, 8.2b and 8.2c

The streams for the input of water can be designed in many ways between a purely technical pipeline and a natural brook with flora and fauna. The main restriction for all principles is that it should at least transport the required amount of water for the blue energy plant. A natural brook will have more biodiversity compared to a pipeline. The design principle

of de natural water stream is placed at the right side of the matrix since it contains natural processes. It offers a place for flora and fauna and depending on the plants it will also clean the water (see design principle 8.6). The design of the water stream creates possibilities to improve the landscape quality. It depends on the surrounding area if a pipeline or a natural stream will fit better in the landscape. The pipeline is situated at the lower left corner of the matrix since it is technical and concealed.

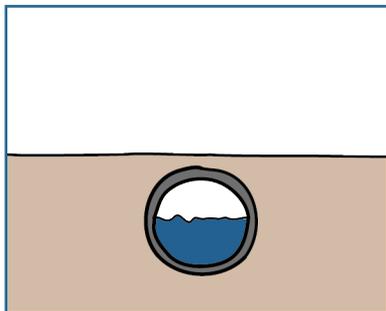


Figure 8.2a: Pipe

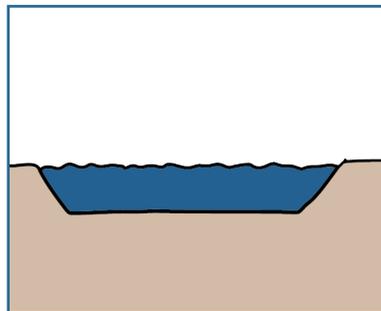


Figure 8.2b: Canal

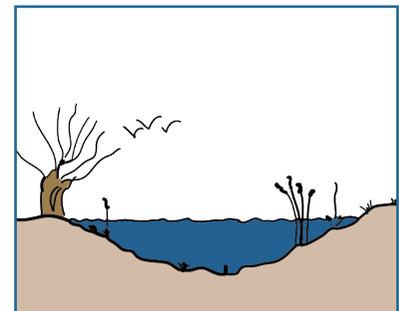


Figure 8.2c: Brook

## Water pumping

Figure 8.3a, 8.3b and 8.3c

Figure 8.3.1a, 8.3.1b and 8.3.1c

In an ideal situation the blue energy plant does not require any pumps since they use electricity. Often it is not possible to have no pumps because of too less difference in height between fresh, salt, and/

or brackish water levels. Besides that pumps might be required to get around an existing object in the landscape which should be maintained. One option is to use a pipe with the principle of interconnected vessels. In this way it is possible to get around an object without using pumps. One major requirement for this method is that it is possible to install a pipe under (and around) the object.

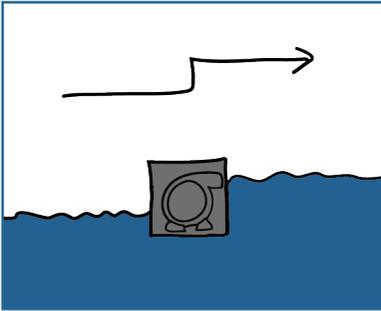


Figure 8.3a: Mechanical pump

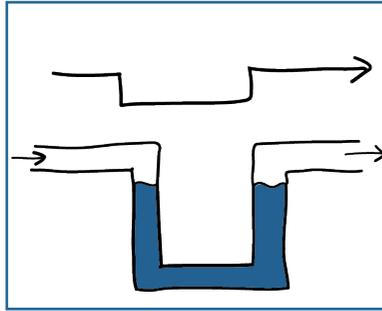


Figure 8.3b: Interconnected vessels

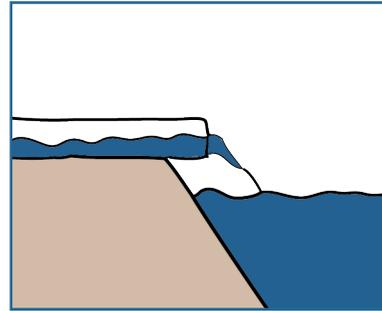


Figure 8.3c: No pump required

Depending on the situation the amount of pumps can vary between zero and three pumps (for each stream one), where zero fits best in the concept of the land-

scape machine. Nevertheless pumps are technical and therefore placed at the left side of the matrix.

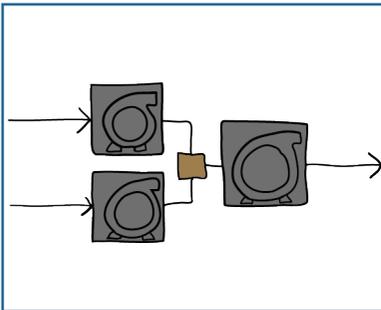


Figure 8.3.1a: Pumps required for input and output

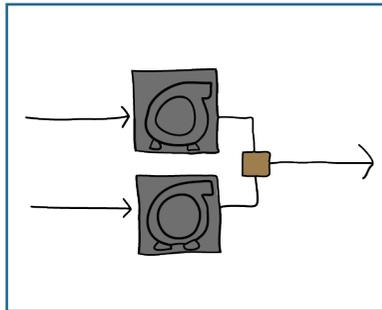


Figure 8.3.1b: Pumps required for input

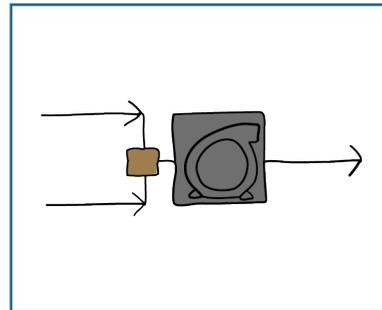


Figure 8.3.1c: Pump required for output

### Water retention

Figure 8.4a, 8.4b and 8.4c

It is possible, but not essential to store the water before it enters the blue energy plant. This can serve two goals. The first one is that the water can be stored until it is required in periods there is not enough input of water. The second goal is that a lake filled with water can generate extra energy when a turbine is placed at the output location of the stor-

age lake. This improves the multifunctionality and it combines natural processes of the landscape. Therefore it fits within the concept of the landscape machine. The design principles show three possibilities: water retention by pumping the water to an enclosed retention area, water retention by increasing the water level, or no water retention. An enclosed retention area is more revealed, but also more technical to realize.

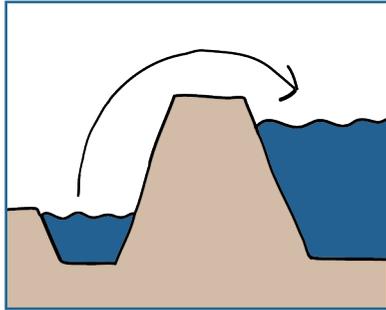


Figure 8.4a: Storage in separate area

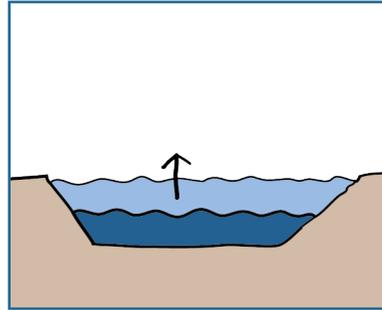


Figure 8.4b: Increase of water level

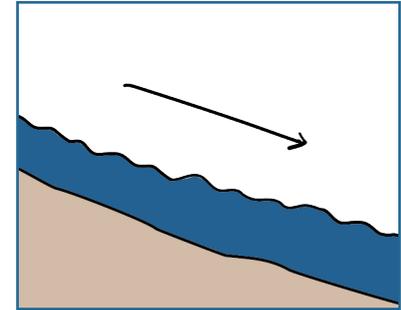


Figure 8.4c: No water retention

### Physical edge

Figure 8.5a, 8.5b and 8.5c

A physical edge between fresh, salt, and brackish water is required for a maximum difference in salt concentrations. This edge can be anything between a technical sheet pile and a natural dune landscape. A sheet pile is more concealed and requires less space

than a natural dune but it does not address to the concept of the landscape machine. A dune is more natural and therefore placed at the right side of the matrix. It increases biodiversity, but it might compete more with other land use functions because of the required space. It is therefore more revealed compared to a sheet pile.

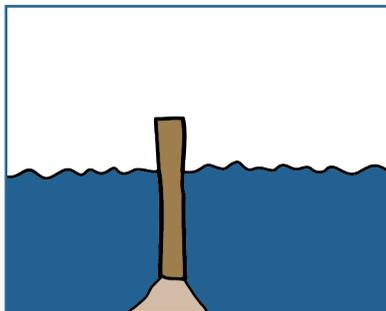


Figure 8.5a: Sheet pile

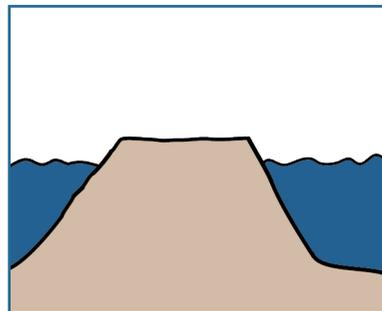


Figure 8.5b: Dike

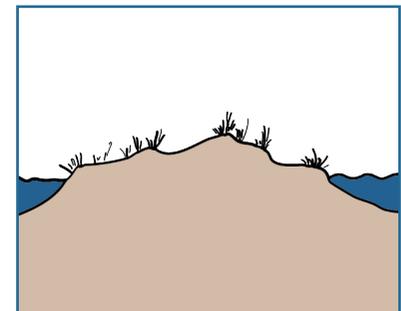


Figure 8.5c: Dune

## 8.3 Machine

### Water filter

Figure 8.6a, 8.6b and 8.6c

Figure 8.6.1a, 8.6.1b and 8.6.1c

Figure 8.6.2a, 8.6.2b and 8.6.2c

As described in the technical preconditions (chapter 4) the water for the blue energy plant needs to be filtered to avoid biofouling. This filtering can be done by a technical installation (design principle A), a natural filter (design principle C), or a combination of both (design principle B). A natural filter fits better in the concept of the landscape machine and is placed on the right side of the matrix.

Natural filters are called helophyte-, or halophyte filter, or wetland. Helophyte filters are used for cleaning of fresh water, halophyte filters for the cleaning of salt water. The term helophyte refers to peren-

nial plants whose buds overwinter under water (typically found in marshy ground). Halophytes are plants adapted to saline conditions. An extended description of natural filters can be found in chapter 9.

A technical filter has many differences compared to a natural filter concerning the criteria for a sustainable energy landscape. Where a technical filter will harm the biodiversity in the water, a natural system of filtering will result in the opposite: an increase of biodiversity.

A technical filter installation does not have a big influence on the landscape compared to wetland filtration. A wetland requires much space and might compete with other land use functions. However, a wetland offers new opportunities for production of food, biomass, and recreation.

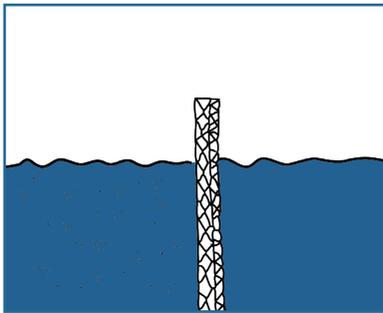


Figure 8.6a: Technical water filter

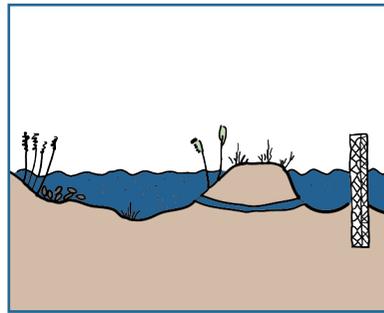


Figure 8.6b: Combination of technical and natural filtering

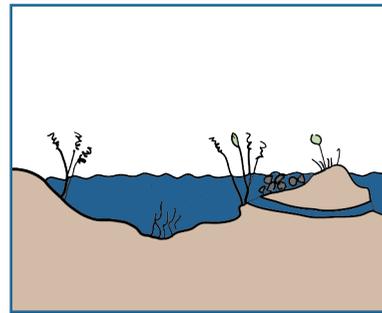


Figure 8.6c: Natural water filter

When design principle B or C are selected there are two sub-principles applicable. The first sub-principle (8.6.1) gives the possibilities for natural water filtration, a combination of all of them provides the best cleaning results. The second sub-principle shows the

difference between natural water filtration with a technical look (design principle 8.6.2a) and a complete natural look (design principle 8.6.2c). The first one increases the controllability of water quality, while the last one creates a more natural wetland.

For both fresh- and salt water conditions there are plants which can clean the water. Also some algae's and bivalves are able to clean water. A combination of different species can filter many elements in the

water like particular matter and solutions. Eventually a natural filter can take out most of the elements that can cause biofouling in a blue energy plant.



Figure 8.6.1a: Bivalves

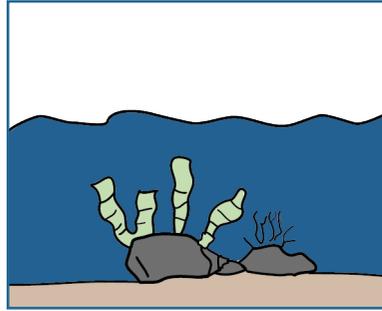


Figure 8.6.1b: Algae

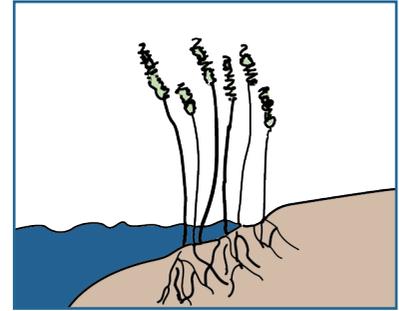


Figure 8.6.1c: Plants

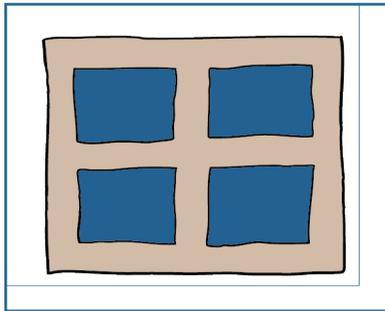


Figure 8.6.2a: Technical shaped wetland

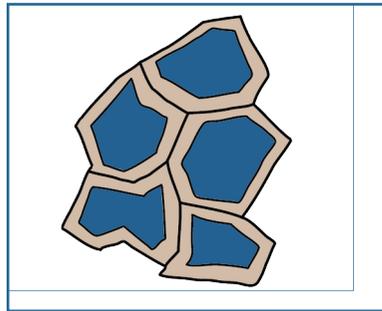


Figure 8.6.2b: Half-natural shaped wetland

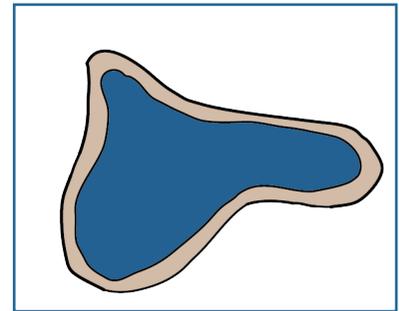


Figure 8.6.2c: Natural shaped wetland

## Membranes

Figure 8.7

The main elements of a blue energy plant are the

membrane stacks. The blue energy plant would not function without membranes and cannot be replaced by natural processes. That is why this design principle only offers one possibility.

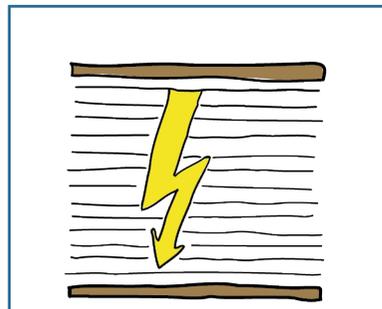


Figure 8.7: Membranes

### Siting of blue energy plant

Figure 8.8a, 8.8b and 8.8c

The blue energy plant can have many forms and still fulfil its function as ‘energy generator’. Depending on the location it can be better to place the blue energy plant under the surface or above the surface. One consideration is the input- and output water level. The blue energy plant should be placed in such way that it reduces pumping to a minimum to avoid un-

necessary use of electricity. Another consideration is how the blue energy plant fits within the landscape. The required space, aesthetics, social cohesion and identity determine if a blue energy plant fits within the landscape. When the blue energy plant is placed at the surface (principle 8a) it is more revealed than under the ground (principle 8c), but all three principles are mainly technical and therefore placed at the left side in the matrix.

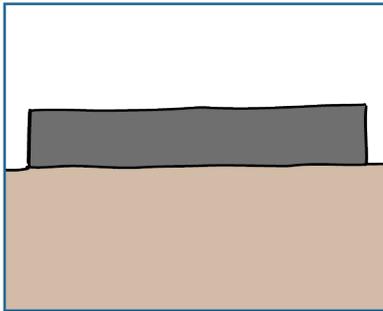


Figure 8.8a: Above the surface

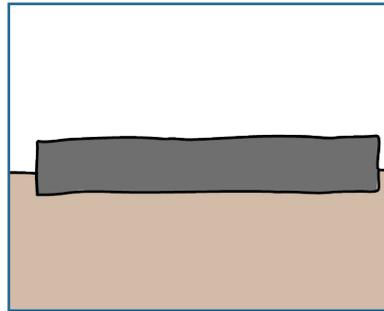


Figure 8.8b: Half in the ground

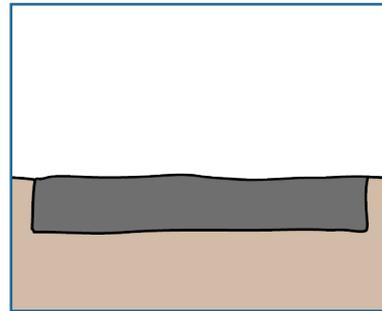


Figure 8.8c: Under the surface

### Size of blue energy plant

Figure 8.9a, 8.9b and 8.9c

The size of the blue energy plant is determined by the amount of energy which will be generated. The division of a small, medium, or large scale blue energy plant is the same as at the division for the amount of water (first element at input). The functional part of the blue energy plant itself can be only a few meters high because the water should be pumped as less as possible. A lower blue energy plant requires

less water pumping. The standard size is the height of a container which is approx. 2.5m [Quak, 2009, p.27]. When the planned amount of generated electricity increases, the required space of a blue energy plant increases in surface area instead of the height of the blue energy plant. This influences other land use functions. However, when looking at aesthetics and multifunctionality it is possible to vary with the height and combine it for example with an information centre.

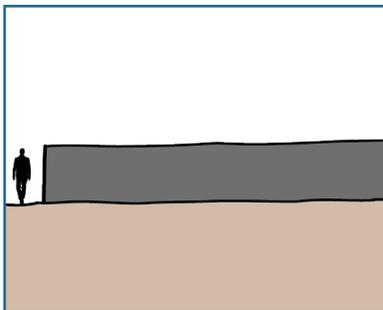


Figure 8.9a: Large installation

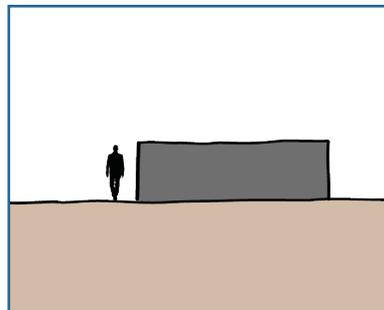


Figure 8.9b: Medium installation

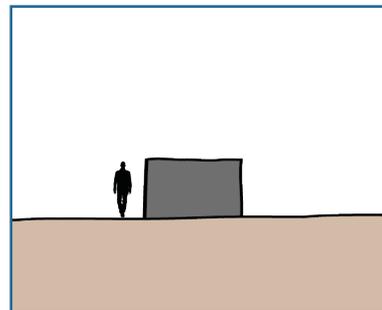


Figure 8.9c: Small installation

## 8.4 Output

### Connection to grid

Figure 8.10a, 8.10b and 8.10c

The electricity needs to be transported from energy source (blue energy plant) to energy sink, no matter what length. This requires cables which can be hidden in the ground or be visible as conventional electricity pylons. It is also possible to use new, notable and revealed pylons with additional aesthetical values. An underground cable is concealed and does not visually compete with other land use functions, but underground it might interfere with for example

trees. Conventional and new electricity pylons are visible in the landscape from a distance and require free space at the ground.

All three options have to be safe. An underground cable as well as a conventional electricity pylon are considered as safe. When a new electricity pylon is designed the safety should be taken into consideration. For all three principles one should create a safety zone around the cables to reduce the electrocution hazard and health issues [Gemeente Oisterwijk, 2010].

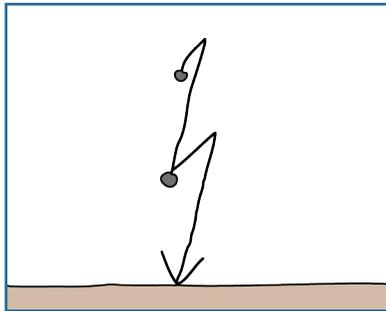


Figure 8.10a: Revealing pylon

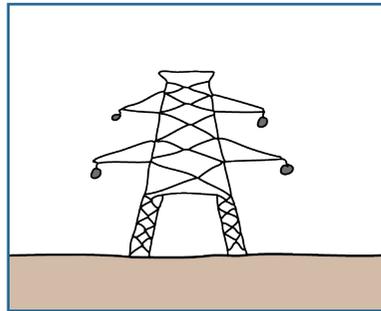


Figure 8.10b: Standard pylon

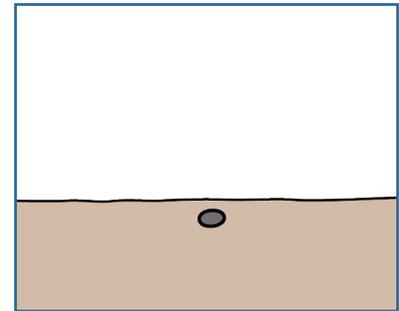


Figure 8.10c: Hidden cable

### Distance to sinks

Figure 8.11a, 8.11b and 8.11c

The distance between energy sinks and sources should be kept to a minimum to increase sustainability. The shorter the distance the less costs and energy degradation during transport [Ehrenfeld and Gertler,

1997]. A shorter distance also decreases the competition with other land use functions. The distance between sinks and sources does not say anything about the technosphere/biosphere and revealed/concealed axes in the matrix. That is why they are placed as group near the centre of the matrix.

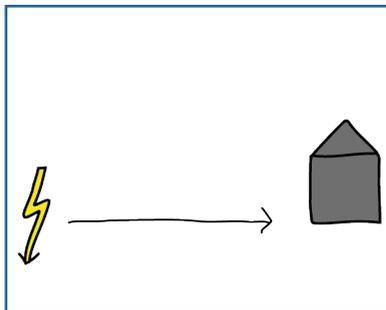


Figure 8.11a: Big distance

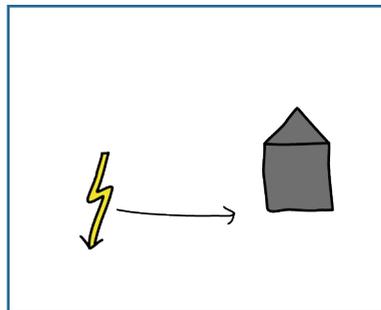


Figure 8.11b: Medium distance

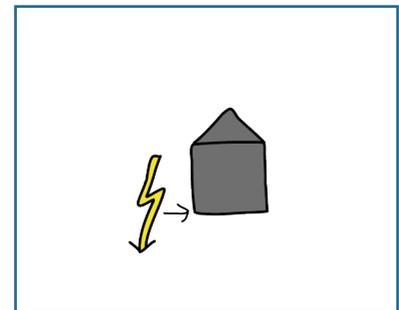
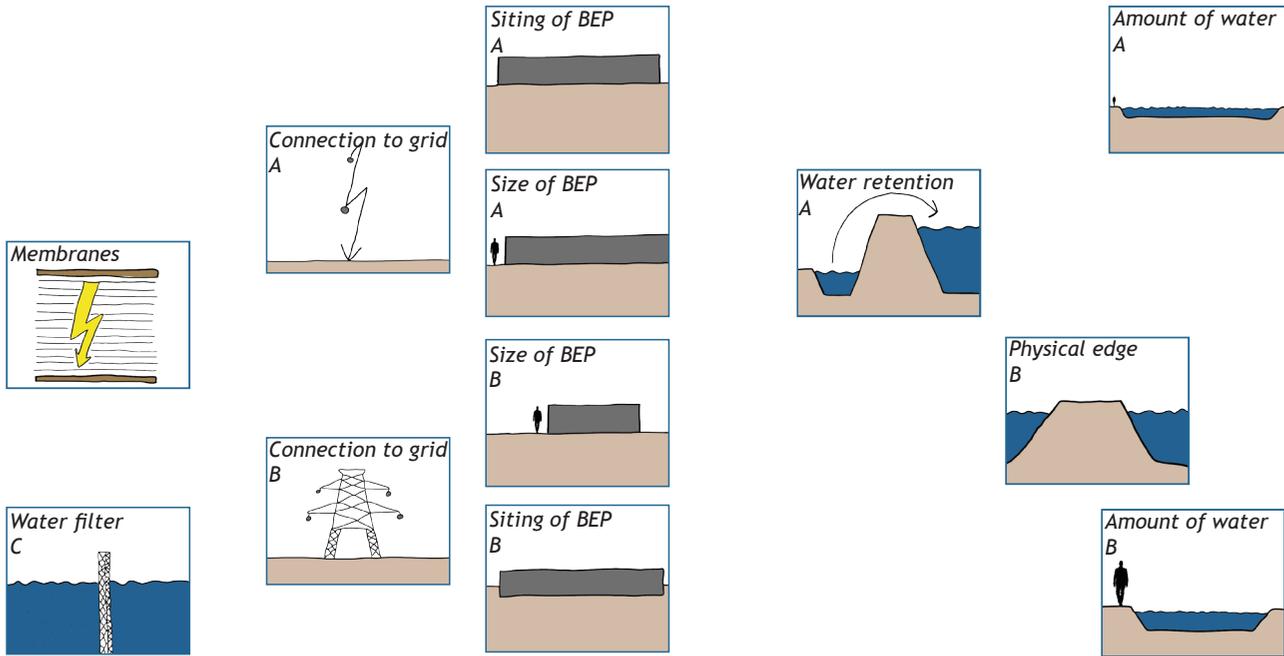
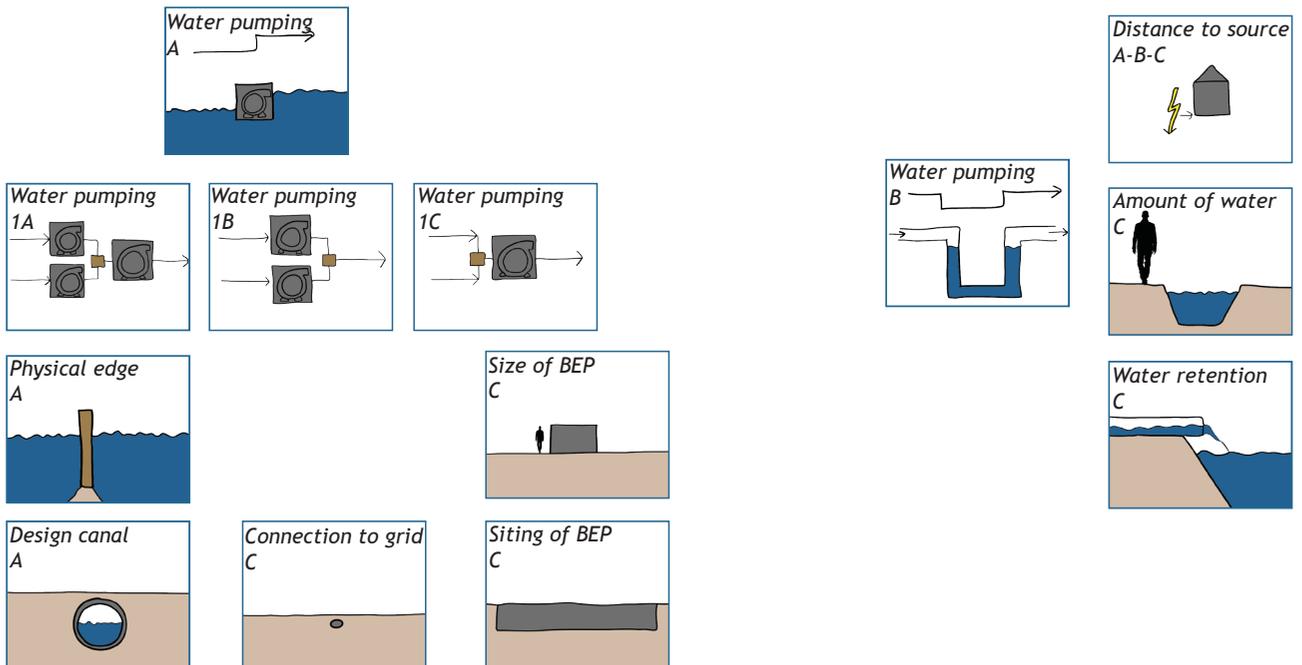


Figure 8.11c: Short distance

Revealed



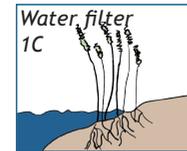
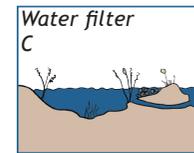
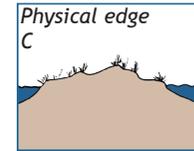
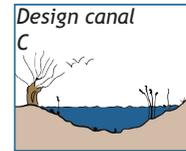
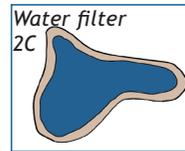
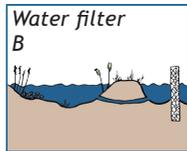
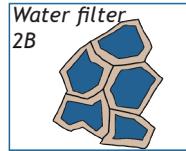
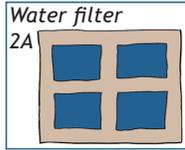
Technosphere



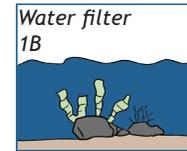
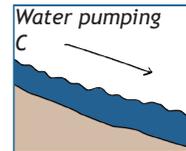
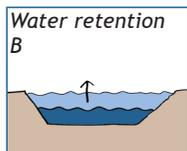
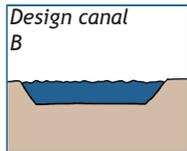
Concealed

Figure 8.12: Matrix with design principles

Revealed



Biosphere



Concealed

### Brackish water

Brackish water is the main visible output of the blue energy plant. The output of brackish water is comparable to the input of fresh and salt water apart from the salt concentration. The design principles at the input are also applicable for the brackish water and are therefore not described again.

## 8.5 Conclusion

The design principles show several possibilities for the design of a blue energy plant. The choices made for a design depend on the location and the preconditions of the stakeholders. These choices also determine if the design will become a landscape machine. Often it will not be possible to choose from all three options. For example, it is possible to use wetlands for the filtration of water. If the location does not provide enough space for a wetland, the technical solution has to be chosen. The design principles help to make the right choices in the design process of a blue energy plant.

The research question *“Which design principles for a blue energy plant can be derived from the technical preconditions in relation to the landscape machine?”* can be answered with the list of 40 design principles described in this chapter. In short the list contains design principles for: the amount of water, design of the canal, water pumping, water retention, physical edge, water filter, membranes, siting of blue energy plant, size of blue energy plant, connection to the grid and distance to energy sinks.





# 9

## CONCEPTS

The concepts in this chapter are the next step in the design process. In the context of this chapter the term 'concept' is defined as the creative and structuring moment at which the first image of the final design arises [Steiner, 2000, p.296]. In this stage the distinction between the intuitive and rational becomes blurred [Baljon, 1992, p.105]. The chapter contains two concepts; one of each author. The concepts make use of the information of all previous chapters. Especially the design principles form

an important structure for the concepts. The chapter gives an answer to the question: "*What are the possibilities for the implementation of a blue energy plant within the range of the landscape machine?*" Both concepts are developed for the Volkerakdam and surroundings. The chapter starts with an introduction about the starting points of both concepts. This is followed by the concepts itself. Thereafter the concepts are discussed. The discussion is the basis for the design that is explained in chapter 10.

## 9.1 Starting points

The concepts are developed in two directions. The directions are based on the matrix with the design principles of the previous chapter. The concept of Karlijn is focussed on the natural right side of the matrix. The concept functions like a landscape machine of natural processes. The concept of Koen is focussed on the technical left side of the matrix. Also this concept functions like a landscape machine, but contains more elements of a machine in the landscape (figure 9.1).

Some elements are similar in both concepts. These elements are the wetlands, the blue energy membranes, the (functional) size of the blue energy plant and therefore also the amount of water which enters the blue energy plant. We have chosen to use 10 m<sup>3</sup>/s of fresh water as starting point. There are three main reasons to select this amount of water. The first reason is that 10 m<sup>3</sup>/s is continuously available throughout the year [Deltares, 2011]. The second reason is that the blue energy technique is still in development. At this moment REDstack is building a pilot-scale demonstration plant at the Afsluitdijk which generates 50 kW [De Ingenieur, 2011]. A blue energy plant of 10 m<sup>3</sup>/s multiplies the amount of generated energy and will be the first full scale commercial blue energy plant [Molenbroek, 2007, p.46]. It is not (yet) realistic to design a blue energy plant with the size of the Afsluitdijk (attachment I, location afsluitdijk). The third reason is that 10 m<sup>3</sup>/s is enough to see the influence of a blue energy plant in the landscape which is interesting for the aim of this thesis. 10m<sup>3</sup>/s of fresh water can generate 10MW when mixed with 10m<sup>3</sup>/s of salt water. It requires a membrane stack volume of 4,000m<sup>3</sup> and a total of 24,000m<sup>2</sup> of space. This is comparable with 3.3 soccer fields. It will generate enough electricity for more than 25,000 households. Besides that 10 m<sup>3</sup>/s of fresh water and 10m<sup>3</sup>/s of salt water results in 20m<sup>3</sup>/s of brackish water. The numbers above are based on mixing fresh and salt water with a ratio of 1:1.

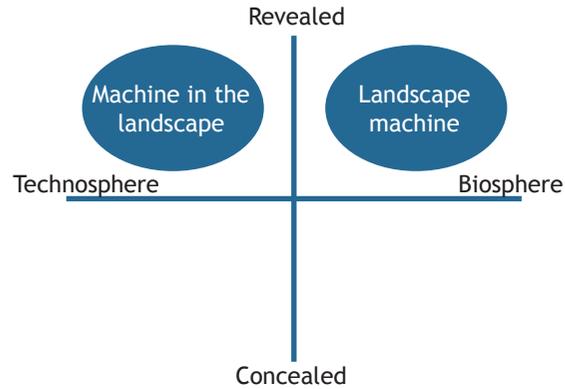


Figure 9.1: Focus of both concepts placed in the matrix

### Wetlands

An important part of both concepts are the wetlands. This section explains why both concepts make use of a wetland and how wetlands work. Wetlands have the ability to filter water. The blue energy plant requires clean water. By using a wetland instead of a technical filter it is possible to replace a part of the technical blue energy plant by natural processes. Replacing technical elements for natural processes is required to create a landscape machine.

The blue energy plant requires clean water to avoid biofouling at the membrane stacks. Biofouling causes clogging of the flow channels and spaces between membranes which results in an increase of the energy losses for pumping [Post, 2009]. The water needs to be filtered from particles larger than 50 micron, nutrients with multivalent ions (magnesium, sulphate, phosphate and calcium), bacteria's and micro-algae. A combination of several plants, bivalves and algae's are able to clean the water [Lange, 2012]. A blue energy plant requires a continuous stream of clean water. Since natural processes are difficult to predict and calculate it is advised to include a technical filter next to the wetlands to remove the last unwanted elements out of the water.

Filtration of water by a wetland requires more time than technical filtration. The more time it takes for the water to pass the wetland, the better the water will be filtered. According to M. de Lange [2012] the minimal required time to filter the water sufficient is approx. 12 hours.

A wetland can have many shapes. The design principles (chapter 8 ) show three possibilities. There are major differences between those possibilities. For an optimal filtration it is important to include several steps of filtration. In this way it is possible to control the amounts of water, the time the water spends in an area and the kind of filtering elements (e.g. vegetation, bivalves and algae's). When the wetland is divided in one or more sectors there are still many possible solutions for the shape of the wetland. Kadlec and Wallace [2009, p.659] describe five ways for the design of a wetland. They differ in the amount of inlets and outlets and ways to redistribute the water (figure 9.2).

A blue energy plant requires two different wetlands; one for fresh water, and one for salt water. These are respectively called helophyte filter and halophyte filter. Both filters have to clean the water from bacteria's [Post, 2011], small particles [Quak, 2009], multivalent ions [Post ea., 2009] and micro algae's. Each filter requires other elements to filter the water. For example, reed is able to filter the fresh water, but is not able to grow in salt water.

A helophyte filter for filtering fresh water can contain the following elements:

- Vegetation: Reed and bacteria's surrounding the reed to filter small particles and certain nutrients [Lange, 2012; Kadlec and Wallace, 2009]
- Bivalves: Fresh water mussel (*Dreissena polymorpha*) to filter plankton [Lange, 2012]

A halophyte filter for filtering salt water can contain the following elements:

- Vegetation: English Cordgrass to filter small particles [NC State university, 2012]
- Bivalves: Blue mussel (*Mytilus edulis*) to filter plankton [Lange, 2012; Koidream, 2012]
- Macro-algae: Sea lettuce (*Ulva lactuca*) to filter nutrients [Resource, 2012; Koidream, 2012]

The advantage of the selected natural elements to filter the water is that most of them can be used for another purpose. Reed can be used for roofing of houses and biomass. Mussels can be eaten and Sea lettuce can be used as biomass, pharmaceutical purposes, food or paper.

The measures of the wetlands depend on the amount of water, the time the water spends in the wetland and the depth of the water in the wetland. Based on the interview with M. de Lange [2012] and Kadlec and Wallace [2009] the following numbers are chosen. The depth of the water can be approx. 25cm. The water needs to be in the wetland for at least 12 hours. For  $1\text{m}^3/\text{s}$  this results in a wetland of approx. 17.5 hectares ( $1\text{m}^3/\text{s} * 60\text{sec} * 60\text{min} * 12\text{hours} / 0.25\text{m} / 10000\text{m}^2 = 17.28\text{ha}$ ). In the concepts  $10\text{m}^3/\text{s}$  of water is used. This means that the fresh and salt water wetland each have to be approx. 175 hectares.

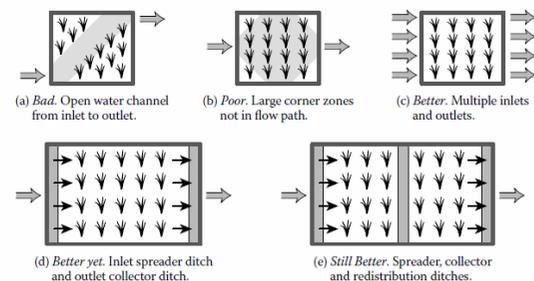


Figure 9.2: Possible wetland designs [Kadlec and Knight, 1996]

## 9.2 Concept 'What you see is what you get!'

A blue energy plant in a wide and open landscape what is surrounded by water. The area breathes calmness. This character of the landscape will be preserved in the concept

Traditionally the inland is cultural land. A static open agricultural land crossed by dikes. Where the outside area is dynamic, influenced by the natural forces of the water and has a natural atmosphere (see chapter 6). That contrast is an important element what will be used as a basic principle for this concept.

The blue energy plant gives the area literally power and gives this area a new dimension where the rest of the Netherlands can learn from. This area shows that nature can be more than just nature. In this concept nature brings us food, electricity, clean water, recreation, and information. The vision is to make the blue energy plant in the form of a landscape machine. A machine that uses natural processes to come to products that serves the human society and will do no harm to the natural areas. The natural processes that can serve, as parts of the landscape machine, are tides, and natural filtering through flora and fauna in the Volkerak.

### The services of nature

Outside the dike nature in the South-Western delta

exist of mudflats and salt marshes. Mudflats and salt marshes are very useful. They form a natural buffer against flooding and protect the inland. They catch sand and silt, so that less needs to be dredged. They purify the water and bring out the natural food chain in balance again. Nature also offers relaxation: we can walk, cycle and have endless fun. That's good for the hospitality and tourism sector. These natural services are necessary for the functioning of our society. This gives them an economic value [Waterwegen en Zeekanaal NV, 2011]. The services that nature can bring will be used in the design for the blue energy landscape.

### Blue energy landscape

The blue energy plant needs the input of fresh- and salt water. The amount of water what is used for the blue energy plant is  $10 \text{ m}^3/\text{s}$  fresh and  $10 \text{ m}^3/\text{s}$  salt water. In this area the salt water comes from the Volkerak where the fresh water comes from Hollands Diep and Haringvliet. The design has the atmosphere of an outland area, as originally occur in the South-Western Delta. A salt natural environment, and a fresh natural environment with a strict and physical edge, the Volkerakdam, between them (figure 9.3). Before the fresh- and salt water goes through the membranes of the blue energy plant it needs to be filtered, as described in section 9.1. Normally a tech-

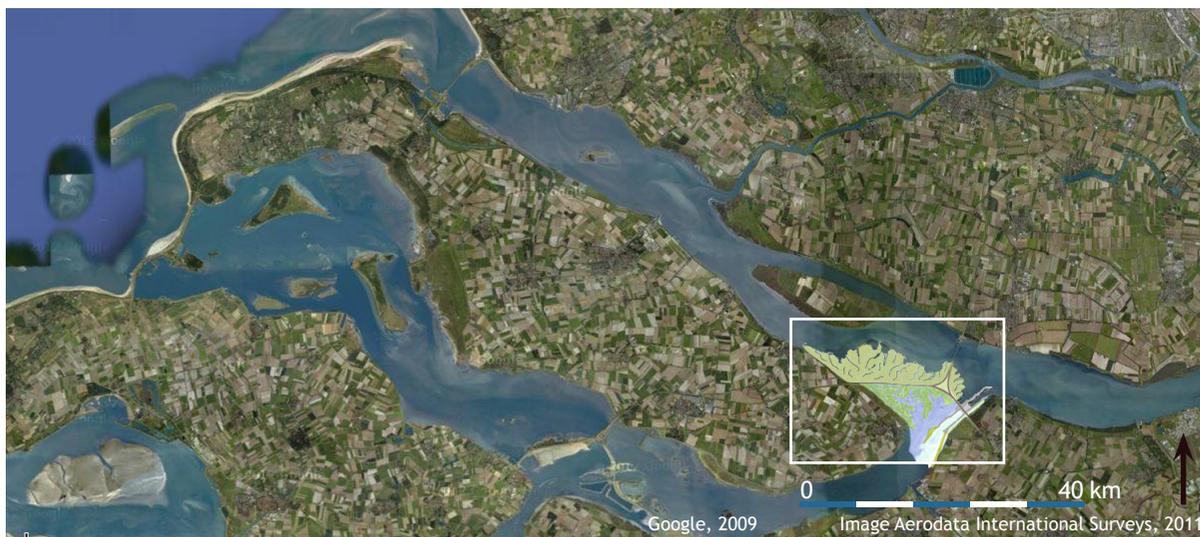


Figure 9.3: Overview of the concept implemented in the landscape of Volkerak

nical process is used for the filtration of water but wetlands have the ability to filter water. The water will be filtered in the outland, which has from origin and still has a natural atmosphere. To stay in that atmosphere the input of the water will have a natural appearance. (figure 9.8) This means that filtration of the water and the streams to the blue energy plant will use natural processes to clean the water. The natural appearance will be inspired on the development of streams in a natural way. Following the original heights and current lines the pattern of the fresh- and salt natural water filter is formed (figure 9.4 and 9.5). The inspiration of the natural appearance for the halofyten filter is het Verdrongen land van Saefthinge (figure 9.6) and the helofyten filter is inspired by the Biesbos (figure 9.6).

The salt water comes with high tide over the small natural dike, with a height of 0.25m above NAP, into the natural filter. The filter stands in the first area of bouchots (mussels on poles) (figure 9.8, 9.9 and 9.10.). These mussels filter the water on algae, bacteria's and multivalent ions. The water follow the water streams and goes through a natural filter with several halophytes (figure 9.11, and 9.12). The wa-



Figure 9.5: Biesbos [Google Earth, 2009]



Figure 9.6: Het Verdrongen Land van Saefthinge [Google Earth, 2009]

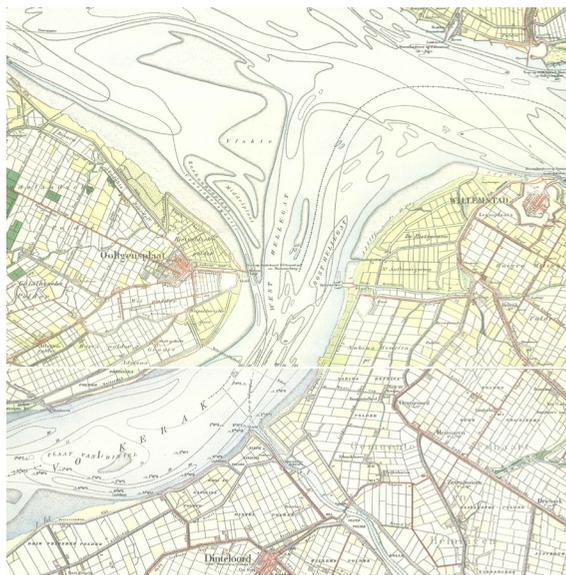


Figure 9.4: Historical map 1920. [C. Jacobusse, H. Stam, 2006]

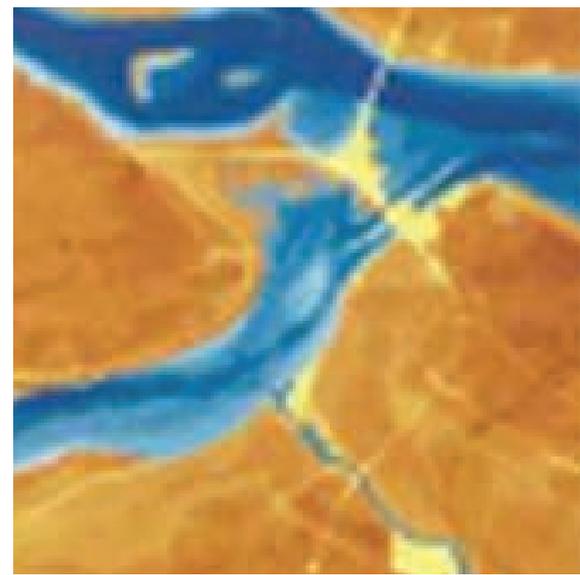


Figure 9.7: Height map 2000. [Zuidwestelijke delta, 2009]



Figure 9.8: Design blue energy landscape

0 3 km

ter will come eventually out in a stream. The stream will bring the filtered water to the blue energy plant. This will be done through heights in the area to avoid the needs of technical pumps (figure 9.14).

The fresh water will come over a small dike into the natural filter. The filter consists in the first area of bouchots (figure 9.16). These mussels filter the water on algae, bacteria's and ions. The water follows the water streams and goes through a helophyte filter filled with reed (figure 9.12). The water will come eventually out in a canal. The canal will bring the filtered water to the blue energy plant (figure 9.8) .

The poles give the design an extra dimension to experience the natural flows of the Volkerak. When it is high-tide the poles are under water when it is low-tide the poles are visible (figure 9.9, and 9.10). When the wind, which is always around in the Volkerak, blows through the poles the sound of the wind is being strengthened by the shells of the mussels. The poles are being placed on the sightlines from a recreational point in the area.

The blue energy plant will be placed underneath the surface. This way the open character of the area is maintained. The bleu energy plant and the working

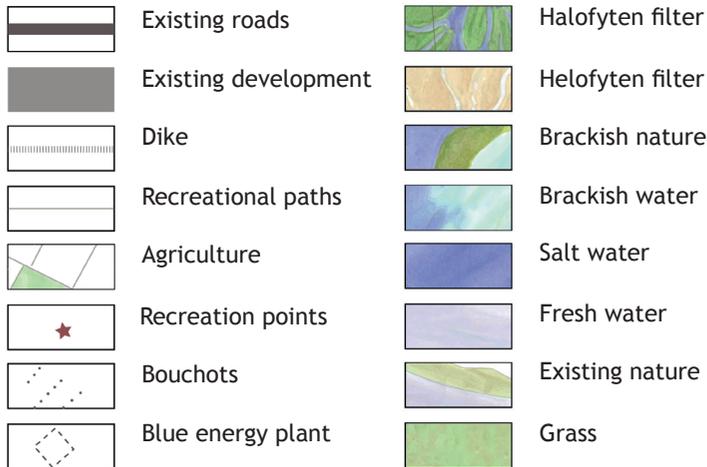


Figure 9.9: Bouchots by ebb [www.jdgbill.com]



Figure 9.10: Bouchots by flood [G. Le Guyader, K.E. Epik]



Figure 9.11: English cord grass (*Spartina anglica*) [www.nature-diary.co.uk]



Figure 9.12: Reed (*Phragmites communis*) [www.agroatlas.ru]



Figure 9.13: The landscape works like a natural machine

of it, is still visible. With a glass plate over a small piece of the blue energy plant the membranes will be experienced from above (figure 9.17). The blue energy plant will be visible through a light bowl, which stands above the blue energy plant. The light bowl will burn when electricity is being produced. In this way I want to show, that in this natural area energy is being generated (figure 9.17).

Another advantage to place the blue energy plant underneath the surface is that the water can make use of the natural height difference between the

blue energy plant and the water. The natural height prevents that an extra pump is needed.

The output stands out of brackish water and electricity. The electricity will be used for a small percentage for the blue energy plant itself and for the Volkerak sluices. Sinks and sources are next to each other what makes the design sustainable. The rest of the energy will be transported by the electricity lines that are already there, see section 4.2.

The brackish water will be transported, with the help



Figure 9.14: Cross section A-A' Through heights in the landscape the water will be transported through the wetlands

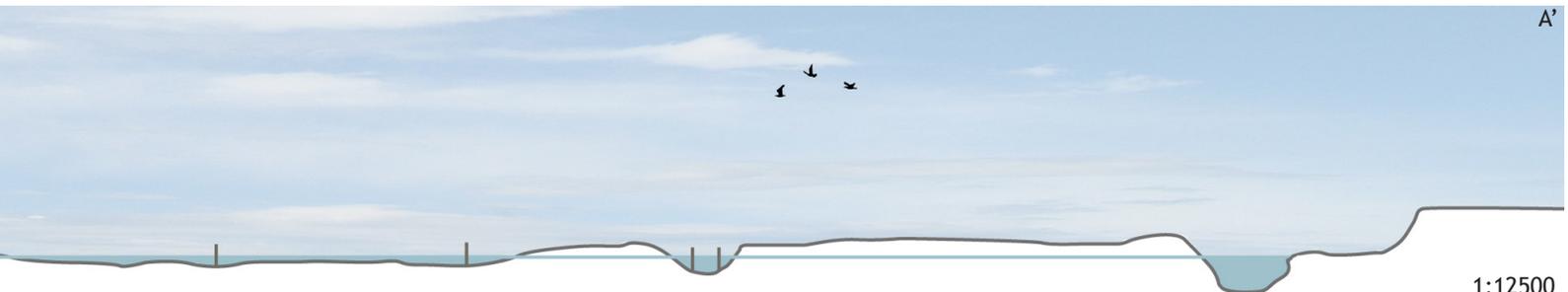


Figure 9.15: Atmospheric image of the information centre [based on: Alluminum centre, Houten NL]

of a pipeline and a pump, to the sluices of the volkerakdam. To prevent that the brackish water will come to fast by the salt water a dike will be created (figure 9.8). In this brackish stream, with no help of human hands, a new brackish environment will evolve. The brackish water will make an estuary between the fresh water and salt water. This will bring the brackish environment back into the Volkerak. This brackish environment has a positive influence on the flora and fauna especially on migrating fish. A fishway (vis-trap) will help the migrating fish.

The bleu energy landscape is open for public. The public are hikers from Goeree-Overflakkee, tourists, nature seekers or engineers who wants to learn from the landscape and the blue energy plant. Small education boards in the area itself will give interesting facts about it.

As shown in chapter 6 there is a lack of recreational infrastructure. By joining the existing recreational route, the recreation network is extended and creates a shorter route to the mainland. The area is accessible through a path for cycling and walking.



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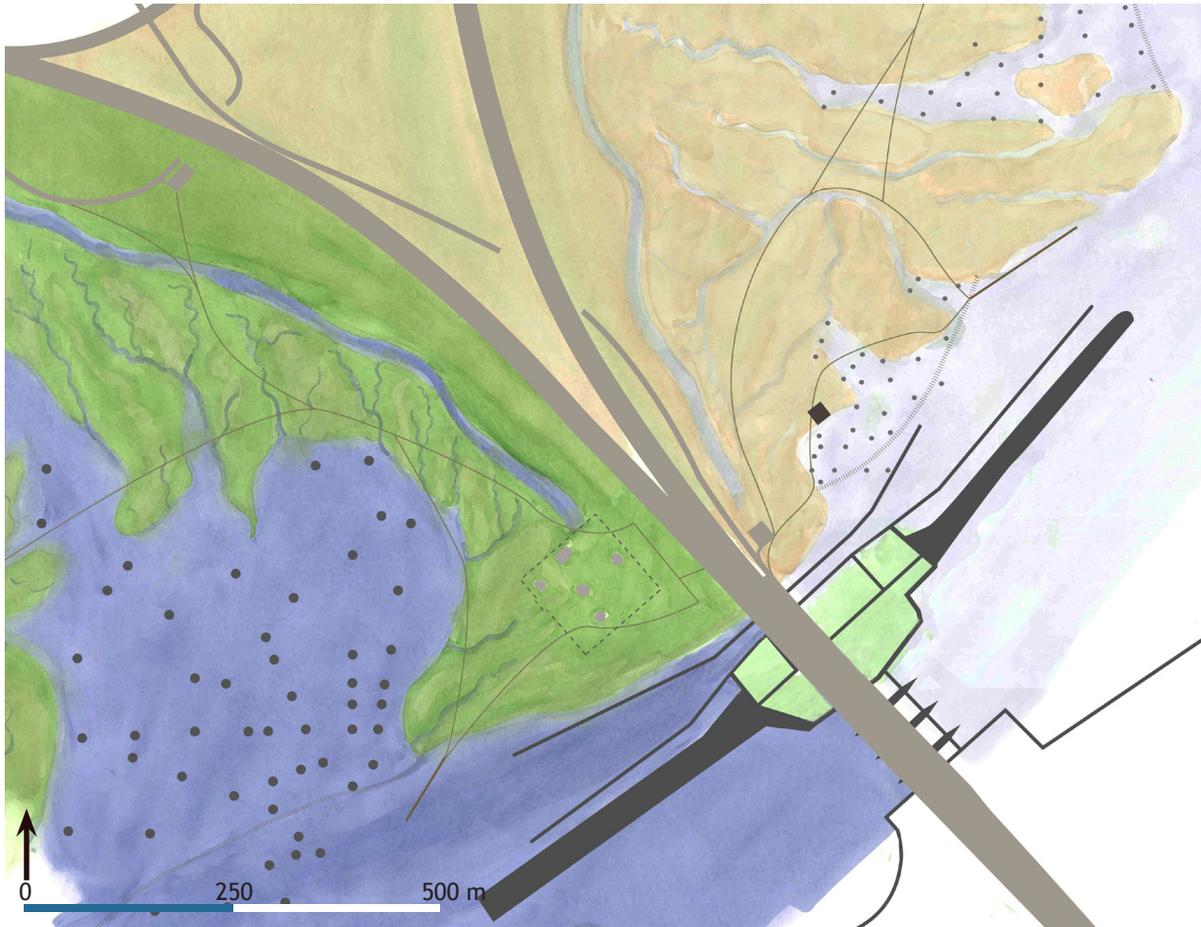


Figure 9.16: Detail design blue energy landscape

The path is made by wood that comes from the area. The wooden path follows the natural lines of the area and will bring visitors to the recreational points where the natural filter can be experienced in an interesting way (figure 9.16).

To gather information over the natural processes and the blue energy plant an information centre is built. This information centre is being placed in the fresh area (figure 9.16). The information centre is designed in such a way that it looks that it rises from out of the reed beds (figure 9.15). In this information centre there is also the possibility to taste the area. The mussels that are produced and used in the filter can be eaten in the restaurant of the information centre.

The blue energy landscape is a natural landscape that produces energy like a machine. The nature is more than nature it acts like a filter, food production, park for natural pleasure, generating of sustainable energy, and a place for fauna. By this landscape the Volkerak will get a strong identity of a sustainable delta landscape.



Figure 9.17: Atmospheric image of the blue energy plant placed underneath the surface

### 9.3 Concept 'Blue water world'

Recreation, education, energy generation, and innovation. Four subjects which are dealing with extensively in this concept. Multifunctionality is important in this concept. The landscape functions as a machine and the landscape contains a machine. The two main parts of this concept are the blue energy building and the wetlands. A building in the centre of the concept combines a blue energy plant with a centre for information, research, sports, a restaurant, and a panorama roof. The wetlands provide clean water for the blue energy plant, research possibilities, recreation, and food. The description of the concept starts with a general introduction about the machine and the used shapes. This is followed by an explanation of the different layers in the building and the landscape. The concept contains a masterplan (figure 9.20) and how this plan is situated in the Delta (figure 9.18). Figure 9.24 shows the processes. Figure 9.19 and 9.27 give an impression of the blue energy plant with the wetlands, together with two principle sketches (figure 9.21 and 9.23). Figure 9.29 at the end of this section shows a more detailed version of a part of the masterplan.

#### The machine in the landscape and the landscape machine

The main element is the blue energy plant. All other

functions are a result of the presence of a blue energy plant. These functions are combined in one building. This building contains a machine, a blue energy plant, but the whole building also functions as a machine. Energy is generated, researchers develop new techniques, recreationists are attracted by the building and spend time and money in the info centre, sports centre, and restaurant. The combination of all these functions in one building is unique. The functions enhance each other. In the next decennia the building will become an icon of sustainability and will be known like the Deltaworks and Neeltje Jans are known at the moment.

The multifunctional building is placed at the Volkerakdam. The designed area around the Volkerakdam as a whole functions as a landscape machine, guided by natural, technical as well as human processes. The wetlands at both sides of the Volkerakdam filter the water to get clean water for the blue energy plant. At the same time the wetlands provide green, biomass and food. Besides that the wetlands are constructed in such way that they also can be used for research and innovation purposes. For example, the vegetation of the wetland can be partly replaced by another crop to test new filter capacities. Figure 9.19 and 9.23 show the design of the wetlands. Every



Figure 9.18: Overview of concept in the landscape

circle repeats this system. Only the vegetation and bivalves used for the filtering will vary between fresh and salt (see section 9.1 about wetlands).

Fresh and salt water enters the wetlands, gets filtered, enters the blue energy plant, generates energy, brackish water discharges at the Volkeraksluices, and becomes salt again in the Volkerak (figure 9.24). To make sure that the wetlands are continuously provided with water, the wetland at the side of the Volkerak is provided with small wind turbines at the centres of the four circles. In this way it is possible to get water into the wetlands during high tide and low tide. Like every machine the wetlands require maintenance. Without maintenance the wetlands will silt up which in the end results in less power for the blue energy plant. Besides that the vegetation, algae's, and mussels needs maintenance to preserve the system. The vegetation and mussels can be used for other purposes like roofing material, biomass, and food.

### Shape of wetlands

The round shapes of the wetlands are revealing. Besides the aesthetical aspect, the round shape also has a practical function. The wetland starts with one central point divides a few times in more but smaller streams. The water enters at one spot and divides equally over the area. The wetland is divided in several layers. Each area lies almost 10 centimetres lower than the previous area. Each section of this shape has another filtration function. In this way the filtering is optimized (see option 'e' in figure 9.2).

The areas which will become wetland are currently part of the Volkerak and Hollandsch Diep. This means there is no present shape which can be used as guideline, apart from a minor height difference of the surface under the water. This offers opportunities for new, revealing shapes. Because of the size of the round shapes they will be visible from a big distance. It will make people wonder what is happening. Together with a multifunctional building this results in an attractive, revealing new landscape.

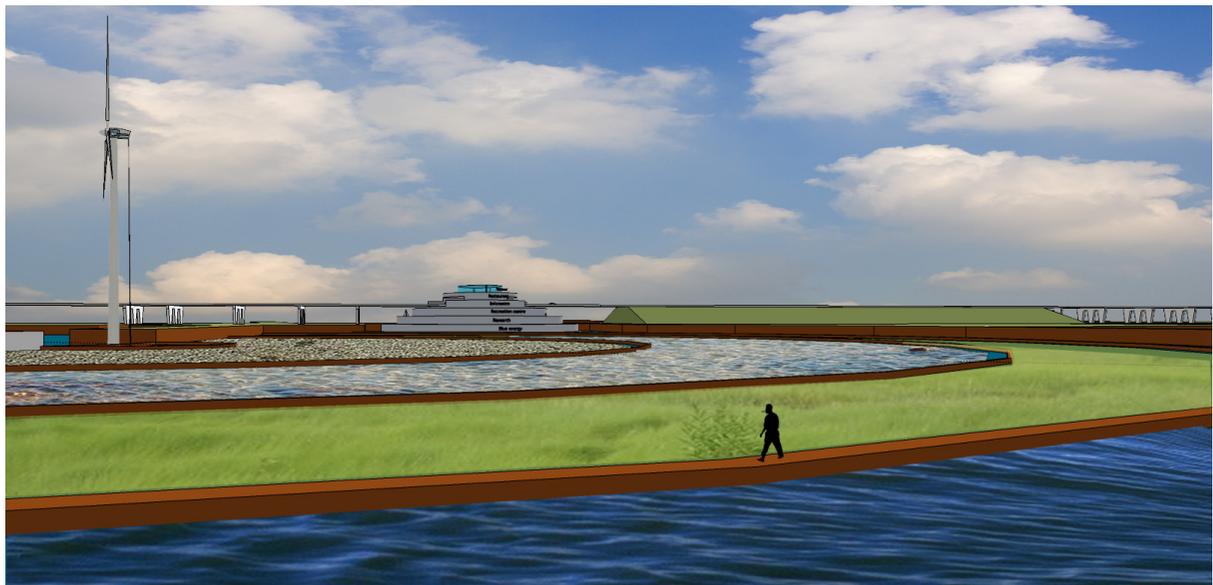


Figure 9.19: Impression of blue energy plant with wetlands in the background



Figure 9.20: Masterplan



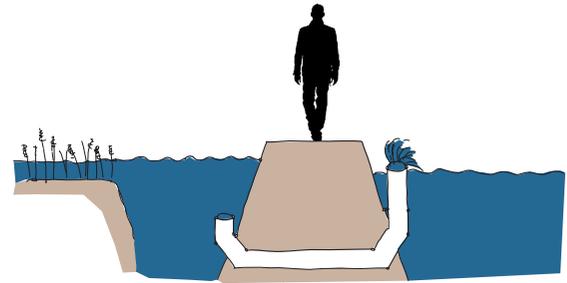
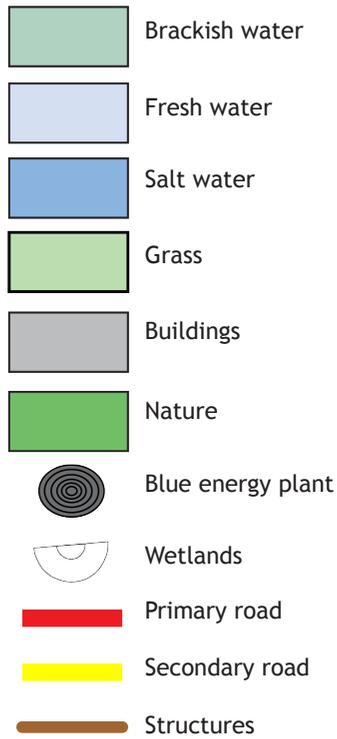


Figure 9.21: Principle of edge between two parts of the wetland



Blue energy plant  
Figure 9.22: Sea lettuce to clean the water [De digitale school, 2012]

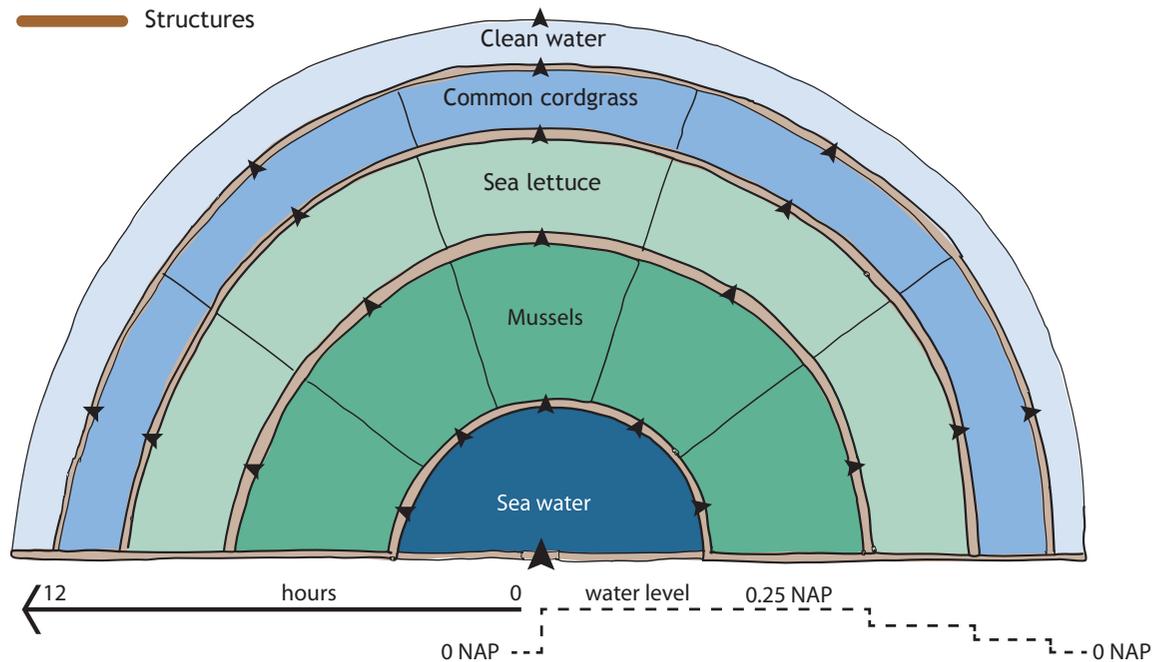


Figure 9.23: Principle of circle-shaped wetland with several steps of filtration

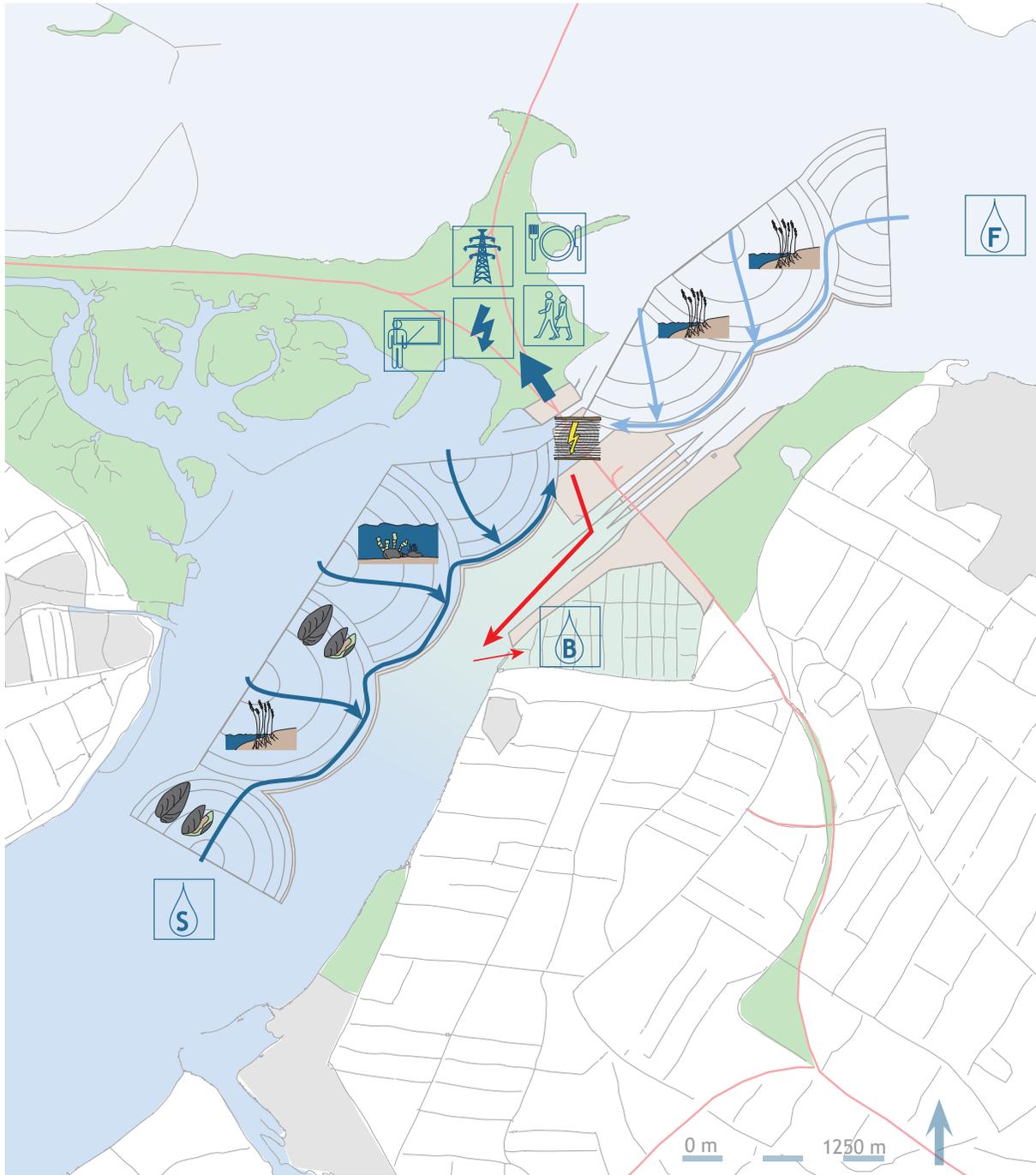


Figure 9.24: Processes of landscape machine

### The multifunctional building

The building for the blue energy plant also contains a restaurant, info centre, sports centre, and research centre.

The restaurant has a ground surface of approx. 2,000m<sup>2</sup>. It also contains a panorama roof to overlook the surrounding area with the wetlands. The restaurant serves locally produced products like mussels, and sea lettuce from the wetlands. When researchers discover new crops which filter the water this also can be used in the restaurant. The restaurant also offers space for people who want to rent a part of the building for conferences or party's.

The info centre (1600 m<sup>2</sup>) can be reached by bike immediately from the bridge, or by car via the new exit of the road parallel to the highway nearby. The info centre offers information about the blue energy plant, the Volkerakdam and other deltaworks, the sluices and the surrounding area. It is also possible to use this part for educational purposes. This can be combined with the research and blue energy plant.

The concept provides many possibilities for sports. Like many designs the concept contains possibilities for walking and cycling in the area, but besides that it also offers possibilities for rafting, canoeing, can-



Figure 9.25: Flow-rider as one of the sports in the multifunctional building [Ambieer Zoetermeer, 2012]



Figure 9.26: Rafting on brackish water discharged from the blue energy plant [Vakantiepark Vlugtenburg, 2012]

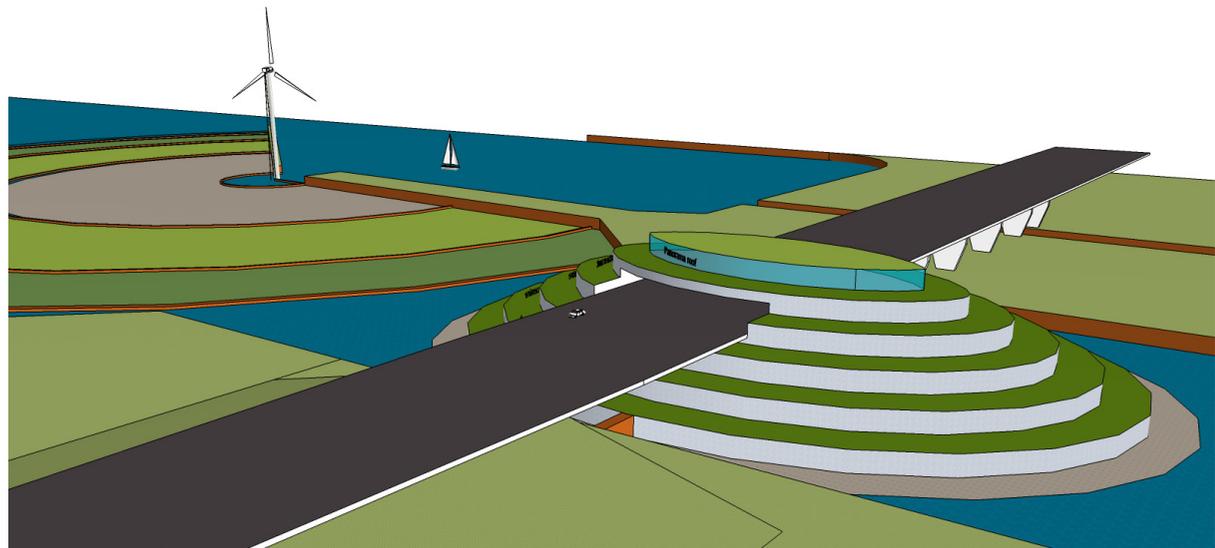


Figure 9.27: Multifunctional building at the Volkerakdam with one of the wetlands on the background

ycling, climbing, sailing, surfing, and many more adventure sports. The sports centre is mainly situated in the central building. Some of the sports can be performed inside, in the surroundings of the Volkerakdam. The goal is to create a well-known sports centre like Papendal in Arnhem, only in this case mainly for adventure sports. The sports centre has a ground surface of approx. 7,500m<sup>2</sup>, which is comparable to one soccer field. Also grass surface around the building which is currently part of the Volkerak sluices can be used for additional sports. This can develop over time when the main sports centre turns out to be successful.

The main part of the building is used for the blue energy plant and the research related to that. The research centre focusses on research on blue energy, wetlands and algae, but offers enough space

for much more water-related research. The total surface area from the two lowest layers above the water surface is approx. 28,000m<sup>2</sup>. The blue energy plant itself, which is located under the water surface has a surface of approx. 22,000m<sup>2</sup>.



Figure 9.28: Algae research in multifunctional building [New Mexico State University, 2012]

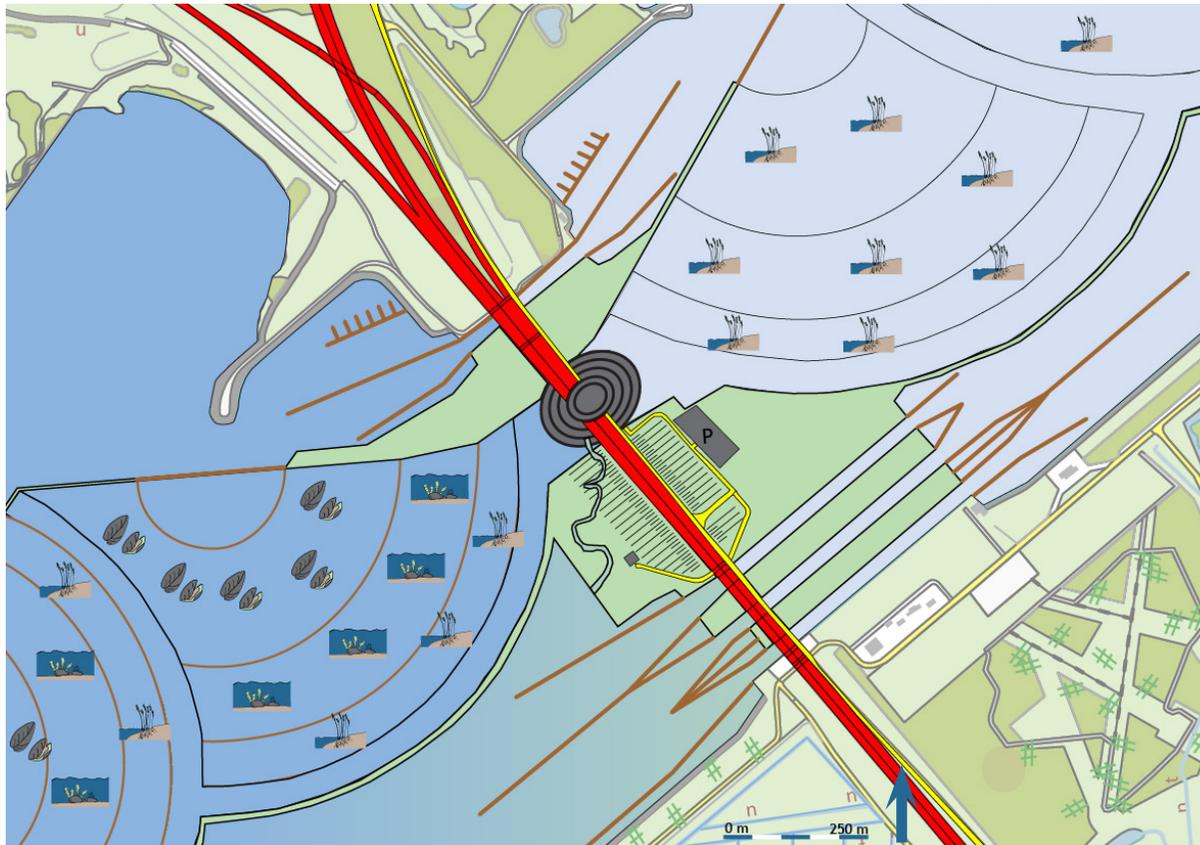


Figure 9.29: Detail of blue energy plant

## 9.4 Discussion and conclusion

This section describes the discussion about the two concepts and how this can be used to create a design which combines certain elements of both concepts. The concept of Karlijn ‘What you see is what you get’ mainly focusses on natural elements. The blue energy plant and surroundings function as a landscape machine. The concept of Koen ‘Blue water world’ mainly focusses on technical processes in a natural landscape. The blue energy plant functions as a machine in the landscape.

### Landscape machine

The processes of both concepts are shown on the masterplan of each concept (figure 9.8 and 9.20). The wetlands are the main elements that distinguish the concepts from a ‘normal’ technical blue energy plant. The concept of Karlijn mainly focusses on a natural appearance of the ongoing processes, while the concept of Koen also uses the same natural processes but with a more technical approach.

### Design principles

All mandatory design principles (wetlands, membranes, size of the blue energy plant, amount of water) for a blue energy plant are present in both concepts. The differences between the concepts are mainly based on the choice between natural- and technical principles. Figure 9.30 shows how the used design principles for each concept are situated in the matrix.

The amount of water is determined in the introduction. Both concepts use 10 m<sup>3</sup>/s as starting point. There is no big difference between the used methods to deal with the water.

The design of the water streams is different between the two concepts. The concept of Karlijn contains natural water streams which are adapted to the landscape. The concept of Koen uses constructed water streams. The natural stream is focussed on encourage natural processes, the constructed stream is designed in such way that it optimises the flow of water.

Both concepts use pumps and other techniques to overcome height differences. In both concepts one pump is required to pump the brackish water back to the surface. In the concept of Koen four pumps

are used to continuously pump the water from the Volkerak into the filtration wetlands. These pumps are powered by small wind turbines.

One of the proposed design principles is ‘water retention’. None of the concepts contain water retention because it did not fit into the design at this location. As a result the water is drained into the Volkerak immediately after the blue energy plant.

The physical edge in both concepts is created by the Volkerakdam and keeps its function to separate fresh- and salt water. Also the physical edge between brackish- and salt water is the same in both concepts, although the edge itself has a more natural look in the concept of Karlijn compared to the concept of Koen.

The main difference between the two concepts is the water filtration. Where the concept of Koen contains a wetland with a technical appearance, the concept of Karlijn is based on a natural wetland which fits in the current landscape. The difference in filtration determines an important part of both concepts.

The blue energy plant itself has the same size in both concepts. Both concepts place the blue energy plant under the surface. Main difference between the concepts is that in the concept of Koen there is a large revealing building on top of it. In the concept of Karlijn the blue energy plant is hidden; only attentive pedestrians will notice the presence of the plant in the landscape.

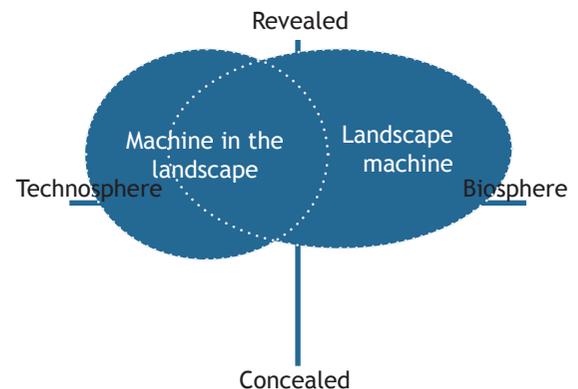


Figure 9.30: Use of design principles in practice

Both concepts use more or less the same method for the transport of energy. The electricity is partly used for the Volkerak sluices and the remainder is transported to the nearby grid. Another conclusion is that both concepts do not exclude which design principle is used for the transport of energy.

The amount of discharged brackish water in both concepts is 20 m<sup>3</sup>/s. In the concept of Karlijn the water is transported with a pipeline towards the Volkerak sluices. In the concept of Koen the discharged water is used for a wild water river which ends near the Volkerak sluices.

### Conclusion

Both concepts make use of the concept of the landscape machine, but in two different ways. In this way the concepts show the possibilities for the implementation of a blue energy plant within the range of the landscape machine.

The concept of Karlijn expands an existing natural area while the concept of Koen makes use of new, circle shaped, elements on the landscape. The wetlands look natural (Karlijn) versus constructed (Koen). This influences the predictability of the wetlands. The constructed wetlands of Koen make sure that the water is always filtered before it enters the blue energy plant. The natural wetlands of Karlijn cannot guarantee the same; it depends on the way the nature develops how efficient the wetland will work. On the other hand the concept of Koen requires major adjustments in the current landscape, while the concept of Karlijn fits within the current structures. Both concepts create a multifunctional landscape with recreation, education and blue energy. The concept of Koen contains more possibilities for recreation. The concept of Karlijn contains more nature.

The design (see next chapter) is a combination of both concepts. The blue energy plant will be situated under the surface because this was used in both concepts. On top of it will a multifunctional building including an info centre and restaurant (like the concept of Koen). The blue energy plant will be located at the spot that Karlijn has chosen because it is more realistic to build an installation in an open area instead of under a bridge. The wetlands will be a com-

ination of both concepts. It will contain the looks of a natural wetland. To ensure the predictability there will be a physical edge in the wetland to create more steps of filtration. The brackish water will be drained at the Volkerak sluices with a pipeline from the blue energy plant to the sluices.

This chapter gives answer to the research question “What are the possibilities for the implementation of a blue energy plant within the range of the landscape machine?”. The answer can be seen in the design of both concepts. The blue energy plant within the range of the landscape machine can be developed in many ways between ‘the machine in the landscape’ and ‘the landscape machine’. Where the ‘landscape machine’ more focus on the implementation of natural processes with blue energy as end result. The ‘machine in the landscape’ looks like a real machine and focus on the product of blue energy, it still contains natural processes like wetland. The following design in the next chapter will show another possibility for a blue energy plant within the range of the landscape machine.





*Impression of the blue energy landscape*

# 10

## DESIGN

The discussion of the previous chapter 'concepts' is the basis for the design described in this chapter. The design makes use of the information of all previous chapters. This chapter gives answer to the questions: *“What are the effects of a blue energy plant on the landscape near the Volkerakdam?”*, *“How can the landscape for a blue energy plant be designed in such way that it fulfils its function as energy generator while applying the concept of a landscape machine?”*, and *“What are the possibilities for the implementation of a blue energy plant within the range of the landscape machine?”*. This last question is already been answered in the previous chapter but this chapter provides another possibility.

The design is problem oriented. The problems described at the analysis of the Volkerak (chapter 6) are solved within this design over a time path of 40 years. A pilot scale installation for 2020, a medium size blue energy plant in 2030 and a full scale blue energy plant in 2050. The chapter starts with an introduction, followed by a short description for a pilot installation in 2020. Next is the main design for a blue energy plant in 2030, with an explanation of the working of the design, several visualisations, and details. After that the design for 2050 shows how a blue energy plant can evolve as a landscape machine. The chapter ends with conclusions and answers to the research questions.

## 10.1 Introduction

The Volkerak knows several problems. The main problem is the blue-green algae. The algae's have negative effect on the recreation, drinking water, and for irrigation of agricultural land (chapter 6). Besides the negative effects of blue-green algae on the recreation, there are hardly any recreational routes and attractions in and around the Volkerak. As said in chapter 6 the recreation in the area has great potential. The blue - green heart as the Volkerak is called, is surrounded by large cities like, Rotterdam, Breda, and Bergen op Zoom. These cities offers future visitors. When the recreational infrastructure and the identity of the lake improves, the recreation can benefit from this. In this design the problem of the blue-green algae will be solved by salinization of the Volkerak-Zoommeer. The open connection with the salt Oosterschelde will be restored and tides will come back in the Volkerak. In this system dynamics in the Delta are gradually restored while maintaining safety [Programmabureau Zuidwestelijke Delta, 2010]. The open connection with the Oosterschelde will improve water quality and salinity will be increased in the Volkerak.

The main problem of a blue energy plant at the Volkerakdam is the recirculation of the brackish water. The brackish water will be discharged in the salt Volkerak. When no measures are taken the brackish water will go straight to the salt water, what has a negative effect on the salinity of the water. A physical edge between salt- and brackish water offers a solution.

The fresh- and salt water has to be transported from the inlet to the blue energy plant. Because there are minimal height differences in the area pumps are needed. The use of technical solutions instead of natural processes is in contrast with our approach to the design as a landscape machine. Where it is possible a solution has to be found.

### Concepts as basis for the design

The design is based on the discussion of the two concepts (section 9.4). Both concepts use the same design principles; natural water filtration, membranes, size of blue energy plant, amount of water, siting of blue energy plant underneath the surface, use of revealing canals or brooks, and a physical edge in the form of a dike between fresh, salt and brackish wa-

ter. These design principles will be used in the design that is presented in this chapter. Next to the used design principles several points of the discussion form a basis for the design of a blue energy plant. One of those points is the predictability of the wetlands. The more the wetlands have a constructed form, the better it can ensure that the water is being filtered before the water enters the blue energy plant.

## 10.2 Time line

The technique of blue energy is in a laboratorial stage but it will become economically feasible within a few years [Veerman, 2009]. The technique of the blue energy will become more developed over a longer time. Therefore, the design for implementing the blue energy plant is divided into phases (see figure 10.1). Also the changes in the landscape take time. Especially taking the natural processes of the landscape machine into account the design for the blue energy plant is divided in three steps to see the changing landscape. In 2020 a pilot scale installation of the blue energy plant will be built. 2030 the blue energy plant will expand to an installation of 10 MW. This blue energy plant functions as a light variant of the landscape machine. In 2050 the blue energy plant will be expanded to the maximum of 60MW. The maximum is the amount of fresh water that can be used of the Hollandsch Diep without limiting the water supply for the harbour of Rotterdam.

An important component of the time line is that the landscape develops as a landscape machine. The landscape machine in this design works with ecological processes for the filtration of water. The streams of the water will change the landscape of the wetlands over time. The energy potential of the water can be seen through the constant change of natural areas which are under constant influence of tides. An example of this landscape is “Het verdronken land van Saeftinge” at the border with Belgium. The water constantly creates new land but also takes land away.

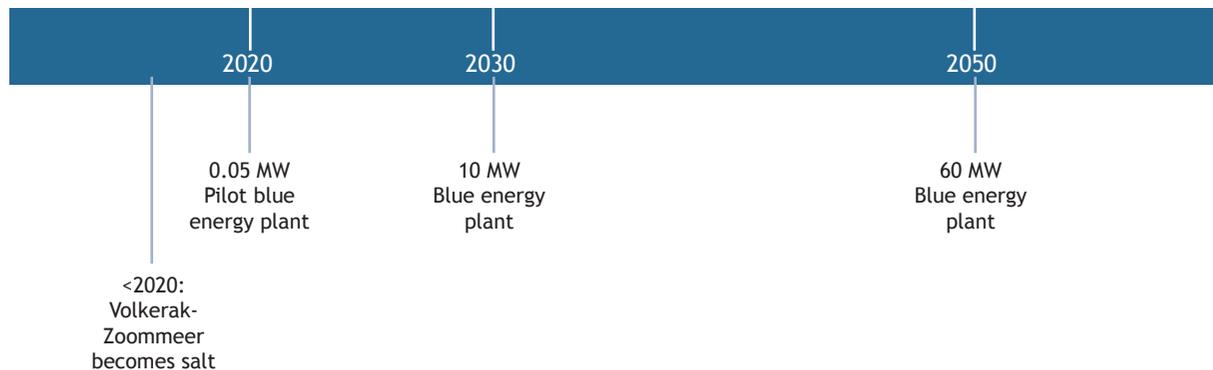


Figure 10.1 Time line of the development of the blue energy plant

## 10.3 Pilot scale blue energy plant 2020

In 2020 a pilot scale installation of a blue energy plant will be built near the Volkerakdam (figure 10.3). The purpose of this blue energy plant is to test if the system works in practice, especially with a wetland for filtration of water. There are currently no known other projects where a wetlands filters the water to the degree required for blue energy. The blue energy plant will generate approx. 50 kW (0.05 MW), which is 50 litres of water per second. The installation requires 120 m<sup>2</sup> of space. 50 kW is enough power to provide electricity for approximately 125 households. The electricity can be used for the recreational sluices.

The pilot scale blue energy plant has a small influence on the landscape. The blue energy plant will be built as a temporary installation. This means that approximately 16 containers are used to house the blue energy plant (figure 10.2). The water enters the blue energy plant through a small scale fresh- and salt water wetland. The brackish water is discharged at the entrance of the recreational sluices. In this way only one pump is required to pump the water from the blue energy plant towards the Volkerak. Because of the small amount of brackish water it will mixed with the salt water from the Volkerak before it re-enters the halophyte wetland. This will have no influence on the salinity of the salt water.

The pilot scale blue energy plant does not function as a landscape machine. The amounts of mussels and other vegetation from the wetlands are not enough for a farmer to harvest. The blue energy plant includes natural processes, but does not add significant functions to the landscape.



Figure 10.2: Container with a blue energy pilot installation

|  |  |
|--|--|
|  | Pilot scale installation blue energy plant |
|  | Existing electricity lines                 |
|  | Existing pylons                            |
|  | Fresh nature area with helofyten           |
|  | Salt nature area with halofyten            |
|  | Fresh water                                |
|  | Salt water                                 |
|  | Brackish water                             |
|  | Existing sea dike                          |
|  | Existing polder dike                       |
|  | Bouchots                                   |
|  | Existing roads                             |
|  | Existing Volkerak sluices                  |
|  | Agriculture                                |
|  | Existing development                       |
|  | Existing fortresses                        |
|  | Existing camping sites                     |



Figure 10.3 Implementation of the blue energy plant of 0.05 MW near the Volkerakdam

## 10.4 Blue energy landscape 2030

We expect that in 2030 the blue energy technique is further developed and the pilot scale installation can be replaced for a blue energy plant of 10 MW. For this installation an amount of 10 m<sup>3</sup>/s fresh water and an amount of 10 m<sup>3</sup>/s salt water is needed. The installation requires 24,000 m<sup>2</sup> of space. 10 MW is enough power to provide electricity for approximately 25,000 households. The blue energy plant discharges 20 m<sup>3</sup>/s of brackish water. Where the pilot scale installation does not yet function as a landscape machine, the 10 MW installation will. The landscape will evolve, and besides electricity, many more products will be produced in the blue energy landscape.

### Wetlands

Before the water enters the blue energy plant it needs to be filtered to avoid biofouling (chapter 4). The fresh- and salt water wetlands of 2020 are going to be extended to filter an amount of 10 m<sup>3</sup>/s. These natural filters are one of the options in the design principles (chapter 8). The blue energy plant needs supply of fresh- and salt water. This can be realised by using a technical- or natural solution. The connection with the salt Oosterschelde will be restored and tides will come back. Tides can be used for natural water supply and will be used for getting the water into the natural filter.

### Fresh water wetland

10 m<sup>3</sup>/s of fresh water for the blue energy plant comes from Hollandsch Diep. The height difference between the Hollandsch Diep and the blue energy landscape is used to get the water into the natural filter. The filter consists of reed (*Phragmites communis*). Reed has the ability to filter fresh water. To filter one cubic meter fresh water 17.5 hectare of filter is required (chapter 9). To filter 10 m<sup>3</sup>/s fresh water a filter of minimum 175 hectare is needed.

The stream of the Hollandsch Diep goes from east to west. It is therefore logical to go with the stream and “to catch” and filter the water on the east side

of the blue energy plant (figure 10.8). The filter will be split in two parts and has a total size of approximately 240 ha. The wetland is split in two parts because the recreational sluices need to be accessible. Part one lies between the recreational sluices and the shipping sluices, and part two between the bridge and the recreational sluices. The shape of the filter follows the straight and hard lines of the dam. The natural forms within the wetland create a contrast with the straight lines of the dam (figure 10.8). The water will flow over a small dike into part one, where the water will be filtered through the reed banks. With streams, with a natural appearance, the water will be transported to the second part of the wetland with the pipes using the law of interconnected vessels (chapter 8). The water will come into part two where it will be further filtered by reed (figure 10.5).

The landscape of the filter exists of large reed banks that are being crossed by several small water streams (figure 10.8). The filtered water will come into the canal, which follows the line of the existing road. The canal will bring the filtered water to the blue energy plant (figure 10.8 and figure 10.26).

### Salt water wetland

The salt water enters the salt water wetland with high tide. The tide varies between -0.25m NAP at low tide and +0.25m at high tide. With high tide the water will come over a dike with a height of 0m NAP into the natural filter. This dike prevents that water will flow away with low tide (see figure 10.4). The tidal dike follows the straight lines of the Volkerak-dam and is only visible with low tide.

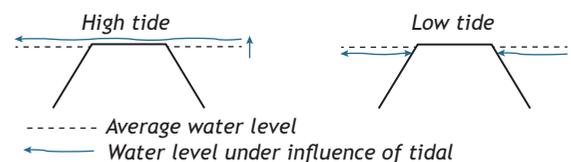


Figure 10.4: Principle of the tidal dike



Figure 10.5: Cross-section A - A' Fresh water wetland. Transportation of the water through using the law of interconnected vessels



Figure 10.6: Design 2030 situated in the South-Western Delta

The salt water filter exists out of two parts (figure 10.8); The mussel field and the natural filter. Mussels have the character to filter salt water. In this filter the salt water mussel *Mytilus edulis* is being used. Each individual mussel filters about 2 to 3 litres of sea water per hour [Molluscs, 2012]. Each hour 36,000 m<sup>3</sup> of salt water flows into the filter. On every square meter can be approximately 400 mussels. To filter 36,000 m<sup>3</sup> of salt water 18,000 (36,000 m<sup>3</sup>/2l) mussels are needed. A minimum of 45 m<sup>2</sup> (18,000/400) is needed to filter the salt water. The field with the mussels is bigger (80 hectares) to filter the water as far as possible and because the mussels only grow on the poles and therefore do not cover the whole area. The mussel field is surrounded by dikes what gives the filter a cultural dimension of a new polder (figure 10.7). Goeree-Overflakkee was expanded over time

by several polders with an agricultural function. This filter can be seen as the newest polder for the island with a new way of agriculture (aquaculture). For that reason we followed the line of the island to come to the shape of the dike between the mussel field and the natural filter. The second dike of the mussel field provides a shorter connection for cyclists between Goeree-Overflakkee and West-Brabant (figure 10.8). The dike will improve the recreational infrastructure in the green-blue hart.

To make a statement with the blue energy landscape we want to make a architectural point in the dynamic landscape. The mussels will grow on bouchots. Bouchots are poles wrapped in a net that is overgrown with mussels. The bouchots are placed in a static grid. The grid is based on the size of the boat



Figure 10.7: Cross-section B - B' Salt water wetland with the mussel field and halophyte filter



Figure 10.8: Design blue energy landscape 2030



(15 by 4m) which will harvest the mussels. The grid is placed in a contrasting angle with the second dike of the mussel field. The bouchots are a static element. The water which enters the mussel field every flood will form a dynamic play with the bouchots (figure 10.10). Natural process will be revealed in this way.

When the water is filtered by the mussels the water will go through the dike into the natural filter (see figure 10.7). The total size of the salt water filter is around 540 ha (including mussels). The form of the filter is based on the existing heights in the landscape (figure 9.7).



Figure 10.9: Atmospheric image of the fresh water filter

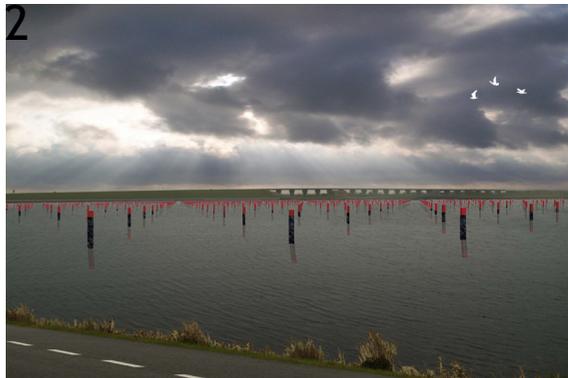
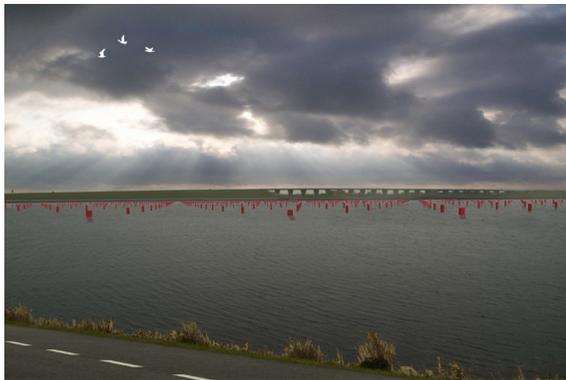
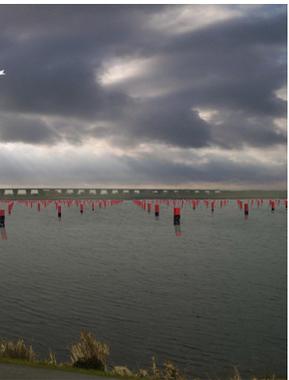


Figure 10.10: Atmospheric image of the static grid of bouchots with the dynamic movement of the salt water



Figure 10.11: Atmospheric image of the salt water wetland



The landscape of the filter consists of large areas with English cord grass (*Spartina anglica*) and Sea lettuce (*Ulva lactuca*) which are crossed by streams with a natural appearance (figure 10.11). The filtered water comes into a canal, which follows the line of the existing road. The static canal will bring the filtered water to the blue energy plant (figure 10.8 and 10.26).

### Blue energy plant

An amount of  $10 \text{ m}^3/\text{s}$  asks for  $24,000 \text{ m}^2$  (3 soccer fields) of space for the blue energy plant (chapter 4). The blue energy plant of approximately 150 by 150 m will be placed underneath the surface to make optimal use of natural heights and to avoid the need of an extra pump. To guarantee the water quality the blue energy plant also contains an additional technical water filter. The blue energy plant will be made visible by several look throughs in the ground in the

same way as introduced in the concepts (chapter 9). These look throughs reveal the underlying membranes of the blue energy plant (figure 10.12). Above the membranes of the blue energy plant there will be around 20 cm soil. This soil will therefore be different from the abiotic layer of the salt wetland. Vegetation between the salt wetland and above the membranes will therefore be different. The concealed membranes will be revealed by a difference in the vegetation (figure 10.13).

To reveal that the blue energy landscape is dedicated to generate renewable energy the existing pylons in the landscape will get a new appearance. People who pass by can experience the meaning of the blue energy landscape (figure 10.15). The main pylon above the blue energy plant also contains a building besides its function to transport the generated energy (figure 10.14). This building provides an amazing



Figure 10.12: Atmospheric image of the membranes placed underneath the surface

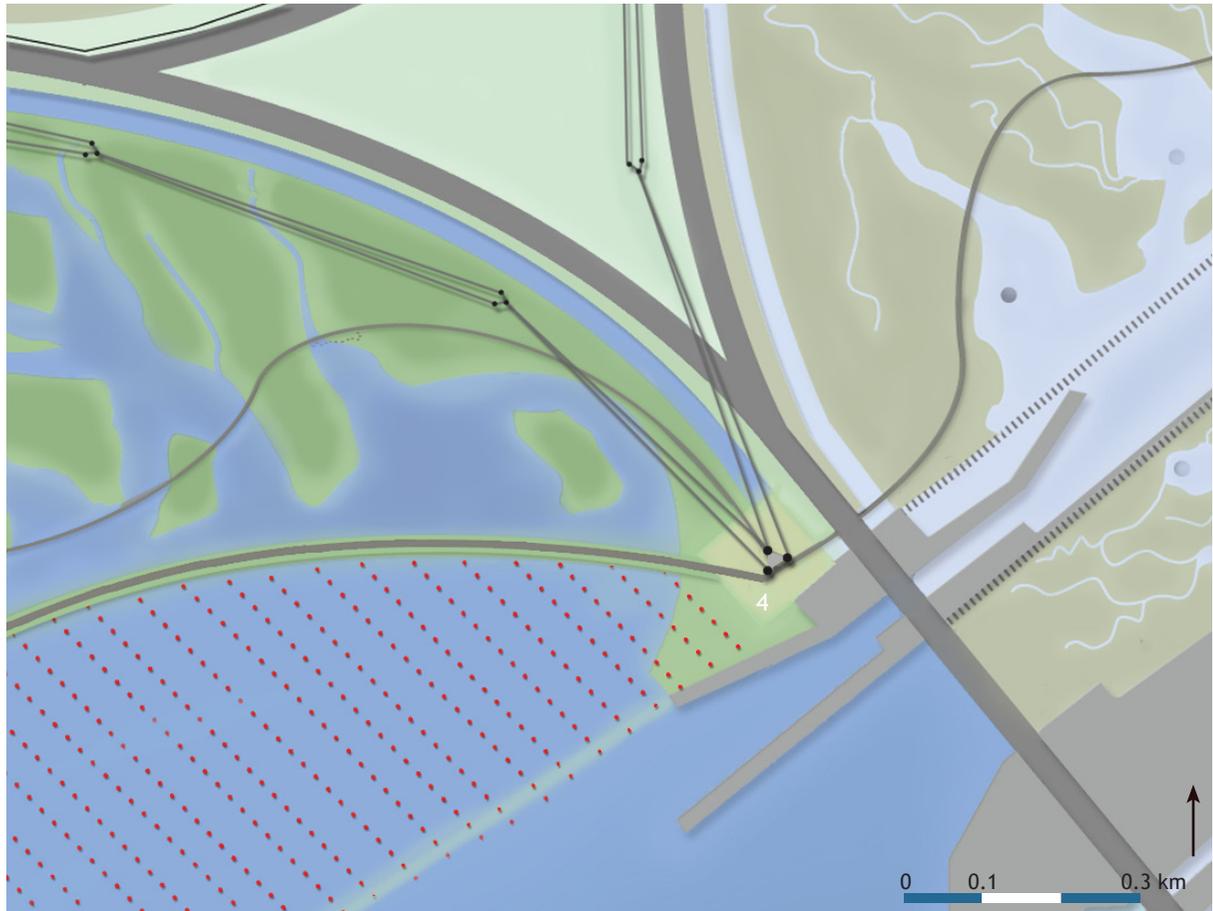
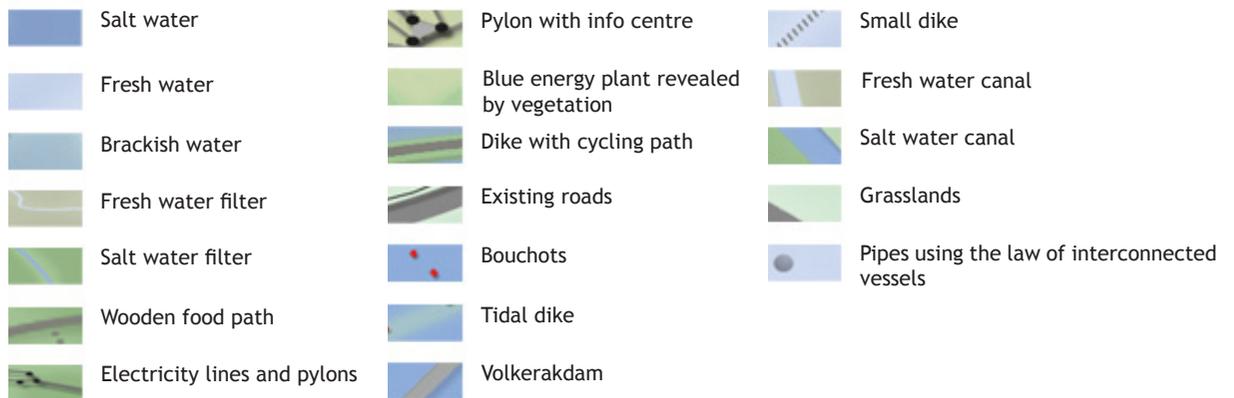


Figure 10.13: Detail of the blue energy plant and surrounding area



view, an information centre, and a restaurant where the mussels of the mussel filter can be eaten. The building will be high enough (approx. 80m) to overlook the blue energy landscape and to see how all natural and technological processes come together.

The design for the pylons is based on the shape of the plants in the wetlands. It looks like if the pylons arise from the underlying wetland. The new pylons will replace the existing pylons and will follow the hard line of the main road (figure 10.8). The new pylons will be placed at the moment the existing pylons need to be renewed.

### Energy

The blue energy plant will generate 10 MW. A part of the electricity will be used by the Volkerakdam (energy sink). The Volkerakdam uses 1.273.813 Kwh per year (chapter 6). The remaining electricity will be transported over the existing energy grid with new pylons, see previous section.

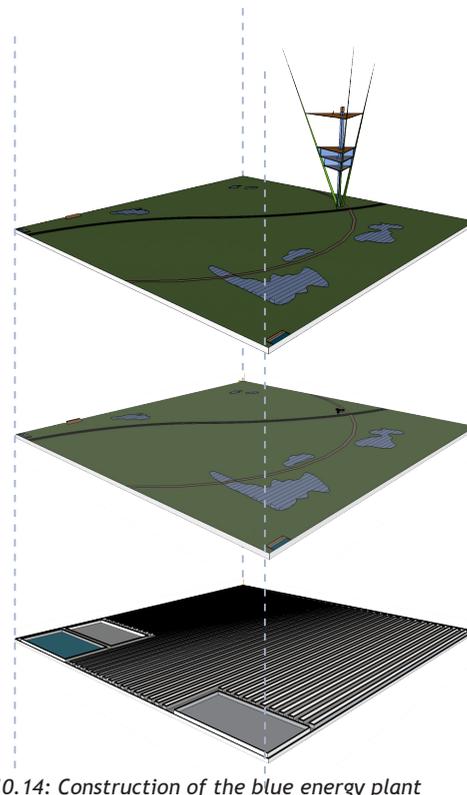


Figure 10.14: Construction of the blue energy plant



Figure 10.15: Atmospheric image of the blue energy plant

### Brackish water

The amount of discharged brackish water is 20 m<sup>3</sup>/s. The brackish water has to be drained in such a way that it does not affect the salt water. The brackish water will be transported by a pump and pipes underneath the surface, into the Volkerak near the shipping sluices. The stream of the brackish water is in this way concealed, but it has a practical function for the sluices. The Hollandsch Diep needs to stay fresh. The brackish water is used to avoid intrusion of salt water into the Hollandsch Diep, together with other measures (section 6.3).

To avoid recirculation of brackish water a physical edge has to be built between the brackish and the salt water. This physical edge is partly provided by a present dam south of the sluices but has to be extended. The straight lines of the Volkerak dam will be continued in the physical edge between the salt

and brackish water (figure 10.8). With the extended dike recirculation will be avoided. The brackish water will be used for a natural transition between fresh- and salt water.

The polder in West-Brabant behind the Volkerakdam will be used for a fishway and a brackish nature area. This polder, De st. Anthoniegorzen, has the function of nature and is a breeding place for several birds. A open connection between the polder and the Volkerak is being made to evolve the fresh polder to a brackish polder filled with nature. Without human hands, this area will evolve into a brackish nature area (figure 10.16). The South-Western Delta has known many brackish nature areas because of the Deltaworks many disappeared. This blue energy landscape, with an output of brackish water, gives a brackish nature area back to the South-Western Delta.

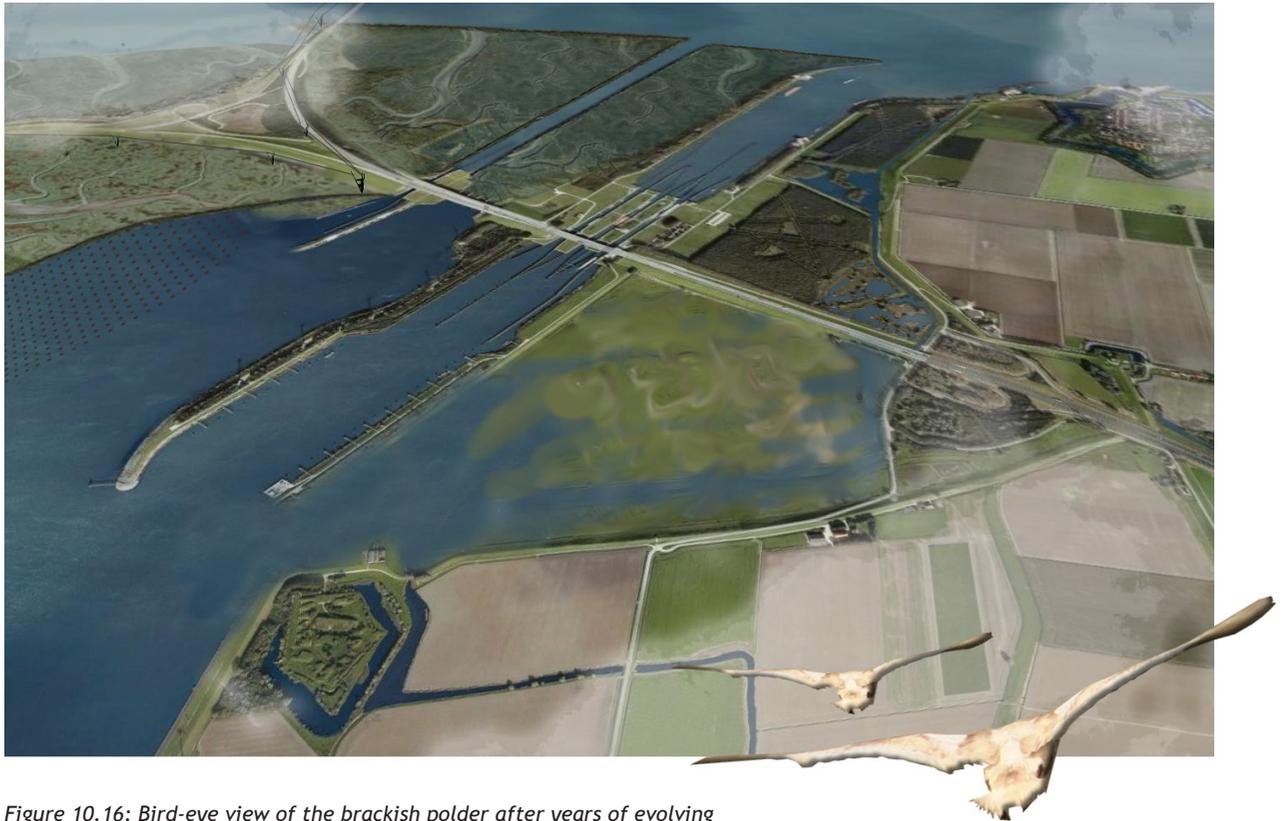


Figure 10.16: Bird-eye view of the brackish polder after years of evolving



+0,5m NAP

2

1

-0,25m NAP

+0,25m NAP

- Forest
- Lake
- Water with tidal influences
- Footpaths
- Ditches

0 0.2 0.6 km

Figure 10.17: Design detail of the fish way

0.4

## Fishway

One of the additional elements in the design is the fishway (figure 10.17). Fishways are needed because fish migrate between fresh- and salt water for spawning, resting and feeding. The fishway is required at the Volkerakdam because fish need a gradual transition from fresh- to salt water and vice versa. This is exactly what the principle of blue energy plant discourages since blue energy requires a maximum difference between fresh- and salt water. The fishway is placed at the east side of the Volkerak to avoid a reduction of the salinity gradient between fresh- and salt water at the blue energy plant. A long dam between the commercial shipping sluices and the filtration area avoids recirculation.

The fishway has a length of 3900m with a total decay of 25-75cm (depends on tide). The fishway starts in the North at the fresh Hollandsch Diep. The water streams southwards and passes a nature area with two lakes. The northern lake is called 'Zwanen Meer'. Further South the fishway passes the highway A59. This passage requires a tube. A small tube is already present but needs to be upgraded. South of the A59 the stream enters the brackish nature area 'St. Antoniegorzen'. This area is already a nature area but in the design it will change from fresh to brackish. The nature area will be partly flooded during high tide. At the end of the nature area the fishway enters the salt Volkerak. The further the fishes continue towards the sea, the bigger the salt concentration will be.

The fishway is designed for a discharge of 3.5 m<sup>3</sup> fresh water per second. The design of the fishway and amount of water are based on an already existing design at 's-Hertogenbosch [Tauw, 2011]. The fishway requires discharge of water because fish need a certain attraction flow to enter [Winter, 2007]. The fishway is designed in such way that the fish can enter during low- and high tide. As a result, the fishway will partly overflow at the side of the Volkerak during high tide, as well as a part of the nature area 'St. Antoniegorzen'.

Figure 10.20 gives an impression of the design for the stream near the highway A59. Figure 10.19 gives an impression of the fishway in the natural parts. The

bottom of the fishway is covered with stones to make a passage for crawling invertebrates possible.

The fishway provides migration possibilities for many fish species. Some examples are Salmon, Stickleback and Seatrout (figure 10.18) [Natuurinformatie, 2012]. There are also some other species which (almost) disappeared because there are not enough open connections between fresh and salt water. One of them is the Sturgeon. The fishway provides opportunities for these fish to recover.

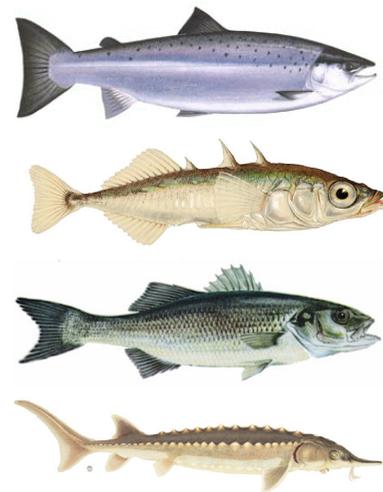


Figure 10.18: Migrating fish. From top to bottom: Salmon, Stickleback, Seatrout, Sturgeon [Natuurinformatie, 2012].

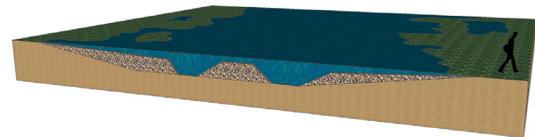


Figure 10.19: Natural design of fishway in nature areas (number 2 in detail of fishway)

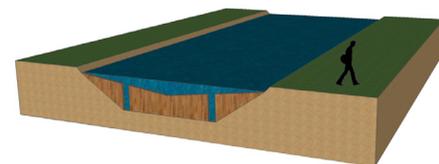


Figure 10.20: Regulated design of fishway near A59 (number 1 in detail of fishway)

## Nature

The natural filters form a large natural area. A fresh water habitat filled with reed and a salt water habitat filled with mussels, Cord grass and Sea lettuce. The main function of these areas is filtration of the water before it enters the blue energy plant. For the fresh water filter the best helophyte is reed (*Phragmites communis*) [interview with M. de Lange, 2012]. Therefore the fresh water filter is filled with reed. This natural filtration can be compared with the nature of the Biesbosch. A young sea clay landscape which develops into a freshwater clay marsh filled with reed. Because of the fluctuation in the water the marsh will inhibit the silt-up (in Dutch: *verlandig*). The wetlands stay open and the swamp can be maintained [Bal e.a., 2001]. The lowest part of the filter exists of open water. The water is surrounded by several pioneers at the temporarily dry areas and reed beds on the highest part of the filter. The fresh water filter is particularly relevant for water- and marsh birds. Remarkable species are the bluethroat (*Luscinia svecica*), Greylag Goose (*Anser anser*), Little Egret (*Egretta garzetta*), Bearded tit (*Panurus biarmicus*) and Small bean goose (*Anser brachyrhynchus*) [Bal e.a., 2001].

For the salt water the best halophytes are Cord grass (*Spartina anglica*) and Sea lettuce (*Ulva lactuca*) [M. Paulissen, P. Slim, 2009], as far as known. There is not much literature and experience about the use of halophyte filters. This natural filtration can be compared with the nature of the Land van Seaftinge but with difference in the salinity of the water and a higher difference between high and low tide. The salt water filter contains an abiotic layer which consists of young sea clay, sedimentation of soil material and salt water. The lowest part of the filter consists of open water with tidal marsh zones around it with Cord grass on the highest parts [Bal e.a., 2001]. The salt water filter is particularly relevant for (tidal) birds. Remarkable species are Black-necked grebe (*Podiceps nigricollis*), Little Egret (*Egretta garzetta*), Brant goose (*Branta bernicla*), and Bar-tailed godwit (*Limosa lapponica*).



Figure 10.21: Bluethroat [IBC, 2011]



Figure 10.22: Small bean goose [Luontoportti, 2012]



Figure 10.23: Little Egret [Azahari Reyes, 2012]



Figure 10.24: Black-necked grebe [Stuartelsom, 2012]

## Recreation

As described in chapter 6 there is great potential for recreation in the area. A lack of recreational infrastructure prevents that the potential is being used. In this design we want to reveal the blue energy landscape. The most simple way to do that is to make the landscape accessible for visitors. The recreational paths are connected to the existing recreational route of the ANWB and starts at several recreational areas, like the camping site near Ooltgensplaat. The path is accessible for cycling and hiking and should therefore be a safe path. The minimum size of a cycling path where users can safely pass each other is 2 meter [Zeegers, 2012].

The recreational paths exists of one large wooden path. This 2 meter path is curved and follows the organic forms of the natural filters. Because the path has many organic bends you see the landscape from different angles which gives the walk a more exciting effect. The curved path is also accessible in the evening and is be lightened by several lights which are working on sun energy (figure 10.25). The main path is accessible from different points through small straight paths (figure 10.8). Visitors can therefore decide for themselves to make a large walk of a few hours or a small one of 30 minutes. The main path leads visitors to the blue energy plant, where the working of the installation can be experienced.

The Volkerak offers great potential for water recreation. By salinization of the Volkerak the problem of blue-green algae disappears. In the summer the smell is away and the water is clean enough to swim in it. When the Volkerak is attractive again, the surrounding recreational points on Goeree-Overflakkee and West-Brabant will develop again and make more and attractive recreational points. The blue energy landscape can give a new dimension to the arising recreation in the surroundings of Volkerak.

## Adaption to climate change

In 2030 the sea level will rise with 0.3 m and the peak river discharge of the Rhine will increase with 1,000 m<sup>3</sup>/s (chapter 3). As said in chapter 6 the open water system in the South-Western delta will be restored. For the Volkerak this means an open connection with the Oosterschelde. In this system dynamics in the Delta are gradually restored while maintaining safety [Programmabureau Zuidwestelijke Delta, 2010]. The safety is very important. The wetlands will form a natural buffer against flooding and maintain safety in this way. [Waterwegen en Zeekanaal NV, 2011].



Figure 10.25: Atmospheric image of recreational path by day and night

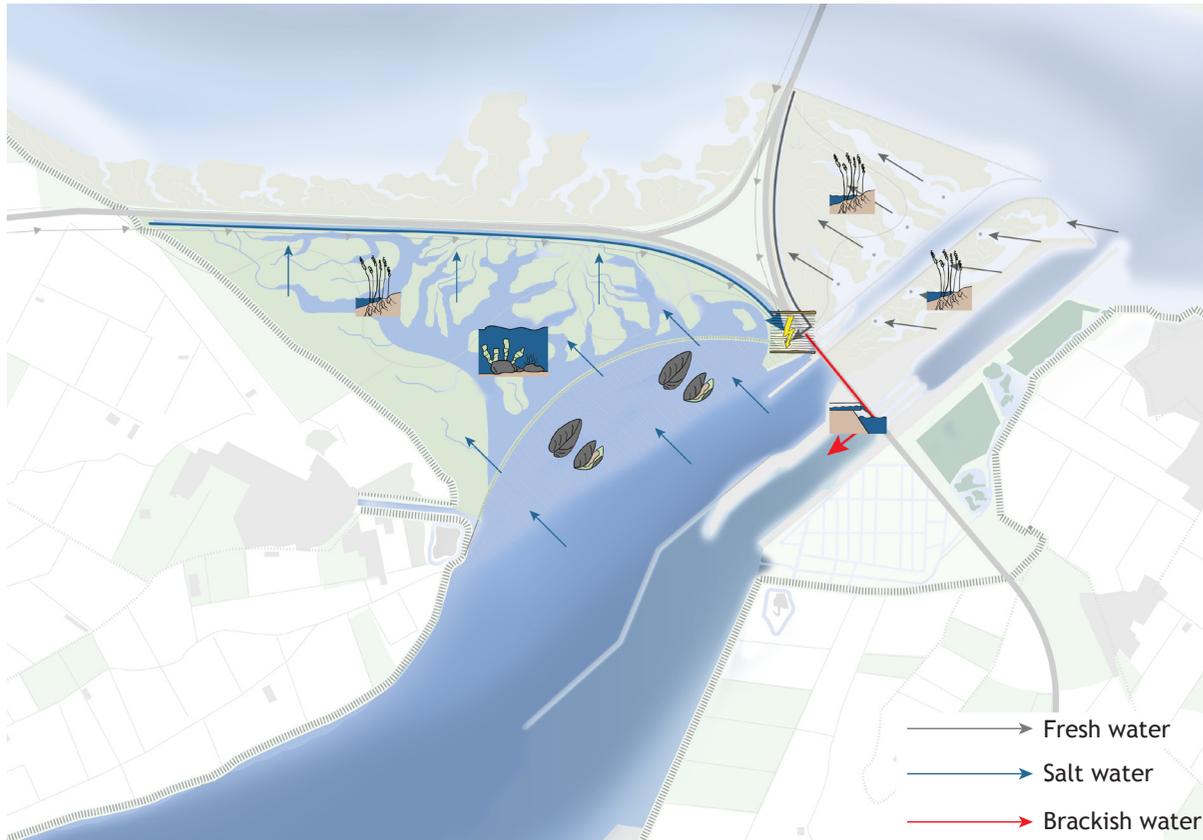


Figure 10.26: The landscape works like a landscape machine

### Landscape machine

In the design for a blue energy plant in 2030 the landscape works as a landscape machine. By making use of natural processes of natural filtration, and tidal in combination with technical processes of the blue energy plant itself the landscape delivers several products like electricity, biomass (reed), food (mussels and sea lettuce) and offers potential to recreation and research to the work of natural filtration.

The first natural process that is being used is the tide. The tide works as a natural motor that brings the salt water into the natural filter. Helophyten and Halofyten are used as natural water filtration systems and replaces the technical filtration (see figure 10.26). The membranes are technical and cannot be replaced by a natural process. The discharged brack-

ish water is used as natural transition between the fresh- and salt water. This natural transition is used for a fishway and as natural edge to avoid intrusion of salt water into the fresh Hollandsch Diep by the commercial shipping sluices of the Volkerakdam. The generated electricity will be transported over the a technical electricity grid. This cannot be replaced by a natural solution.

The landscape machine provides opportunities to the landscape to evolve. Water with his tidal energy can take land but also can make new land. Those natural forces evolve the landscape and changes the landscape over time. This evolving landscape gives a dynamic character to the landscape of the Volkerakdam.

## 10.5 Blue energy landscape 2050

In 2050 the blue energy plant will be expanded to the maximum capacity. The maximum capacity is based on the amount of fresh water that can be used of the Hollandsch Diep (chapter 5). The blue energy plant will generate approximately 60 MW, which is 60 m<sup>3</sup>/s of water per second. The installation requires 144,000 m<sup>2</sup> of space, or almost 20 soccer fields. 60 MW is enough power to provide electricity for 150,000 households and is equal to 20 medium size wind turbines of 3MW. The blue energy plant discharges 120 m<sup>3</sup>/s of brackish water, what means 800 bath tubs per second. The total size of the wetlands will be approximately 2100 ha fresh water wetland and 1750 ha salt water wetland.

Not only the blue energy plant will be brought to its maximum capacity. Also the landscape machine, with the blue energy plant as main function, will be maximized (figure 10.29). The salt natural filter will not only function as a filter it will also be used for salt water agriculture in the polders of Goeree-Overflakkee. Two polders of Goeree-Overflakkee will be in use for water filtration of the blue energy plant. Salt agriculture will take place in those two polders and will produce new trades. Farmers can choose what kind of salt crops they want to produce as long they have the ability to filter the water. Research on

helophytes and halophytes between now and 2050 will result in now crops for water filtration. Before the water enters the polders it will cross a field of bouchots filled with mussels (figure 10.27). The fresh water filter will be expanded to an even larger area of reed beds. Also the island Tiengemeten will be used as a natural filter (figure 10.28 and 10.29). In 2015 the island turns into a nature area and will get an extra dimension between 2030 and 2050; an natural island that filters fresh water for the blue energy plant. These natural filters form also natural barrier against extreme weather conditions.

The brackish water will be discharged at the same location as in 2030. The discharged 120 m<sup>3</sup>/s of brackish water reintroduces the problem of recirculation. To solve this problem the existing physi-

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Figure 10.27: Cross-section C - C' Salt water filtration in the form of aquaculture



Figure 10.28: Cross-section D - D' The island Tiengemeten as fresh water wetland

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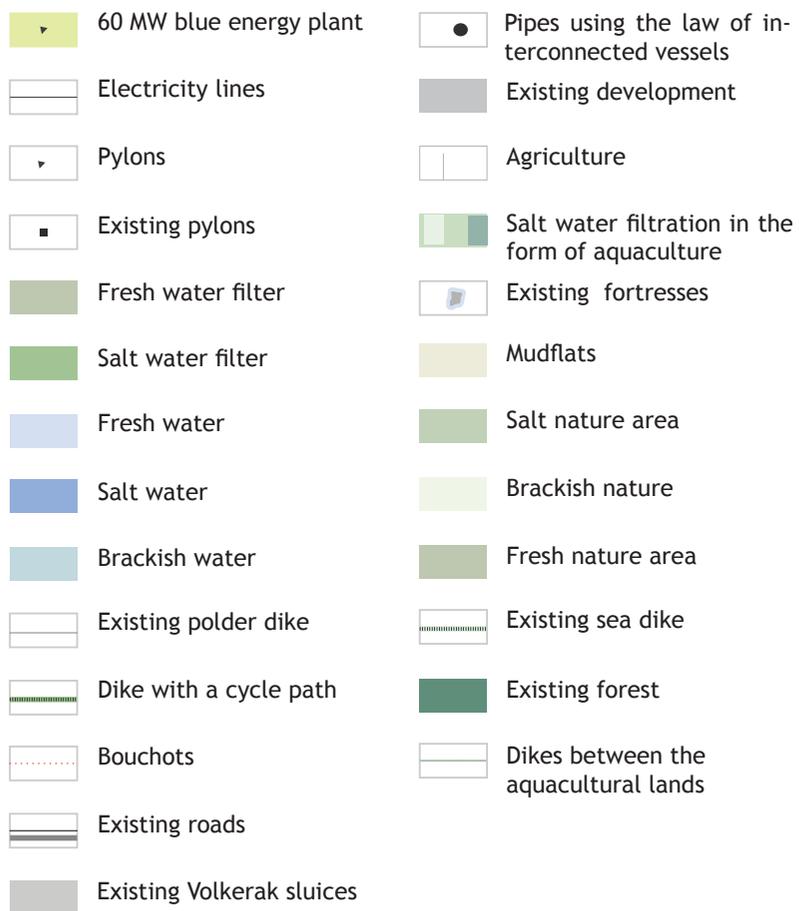
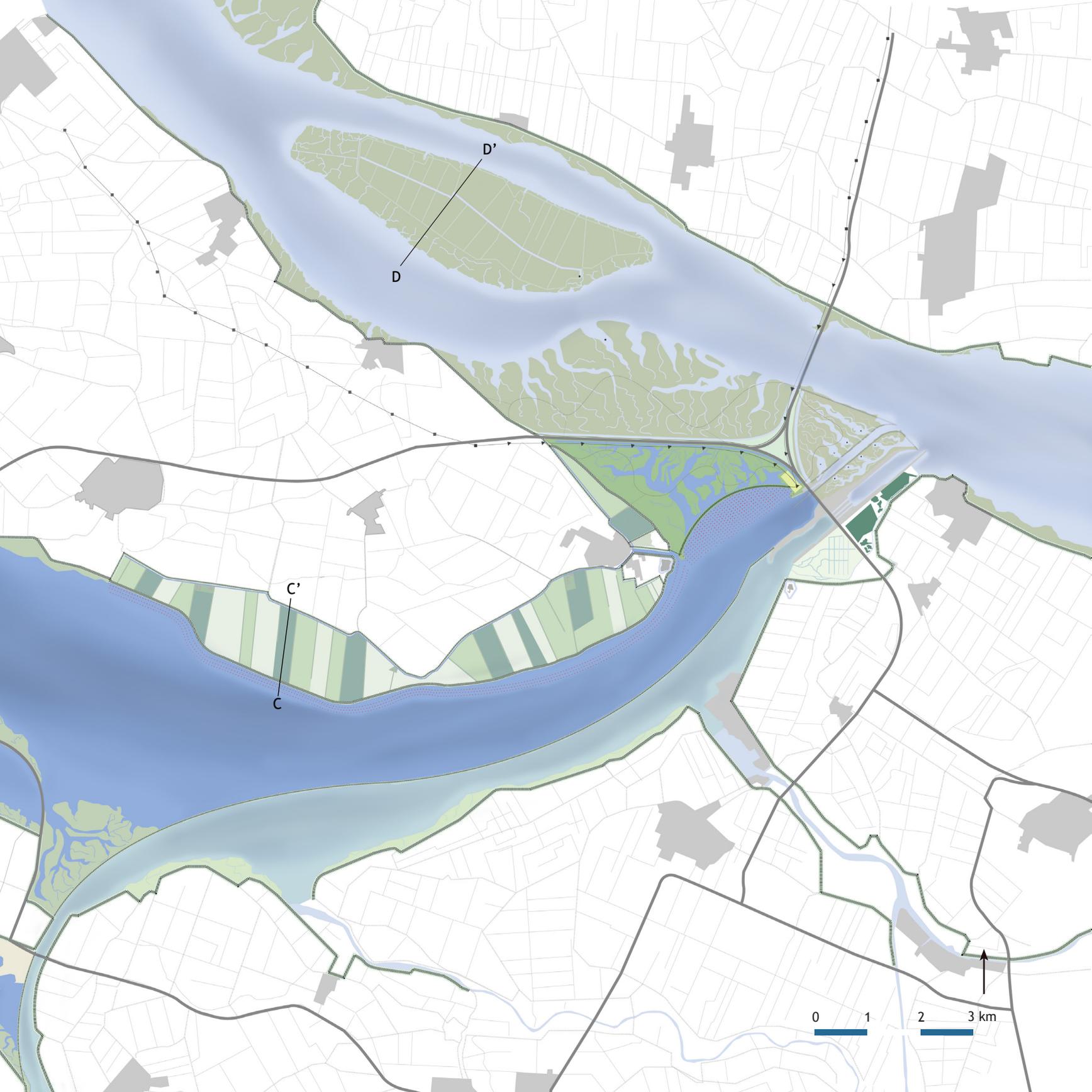


Figure 10.29: Design blue energy landscape 2050





cal edge has to be extended. The new physical edge will split the Volkerak in two parts (figure 10.29). The physical edge makes sure that the brackish water is discharged in the direction of the Zoommeer and further towards the Westerschelde through the Eendracht canal (figure 10.30). In this way the west side of the physical edge stays salt. The barrier influences the infrastructure at the Volkerak. The west side can be used for recreational shipping while the east side is mostly used for commercial shipping. The Krammer sluices lose their function at the moment the Volkerak becomes salt. A new recreational sluice provides a connection between the Oosterschelde and the Eendracht canal. In this way it is possible for recreational ships to reach Dinteloord and other places at the east side of the Volkerak.

The blue energy landscape is brought to the maximum capacity of the blue energy plant but also of the landscape machine. The landscape works for the blue energy plant but gives also place to nature, new ways of agriculture (aquaculture), an adaption to the changing climate and opportunities for recreation. The total size of the wetlands (3850 ha) is bigger than the required area for water filtration (2100 ha). This leads to an increased filtration of the water which can be enough to completely avoid additional technical filtration. The overcapacity of the fresh water wetlands also can be used for the pre-filtration of the water for drink water supply. In this way the landscape machine creates extra forms of output while the input stays the same.

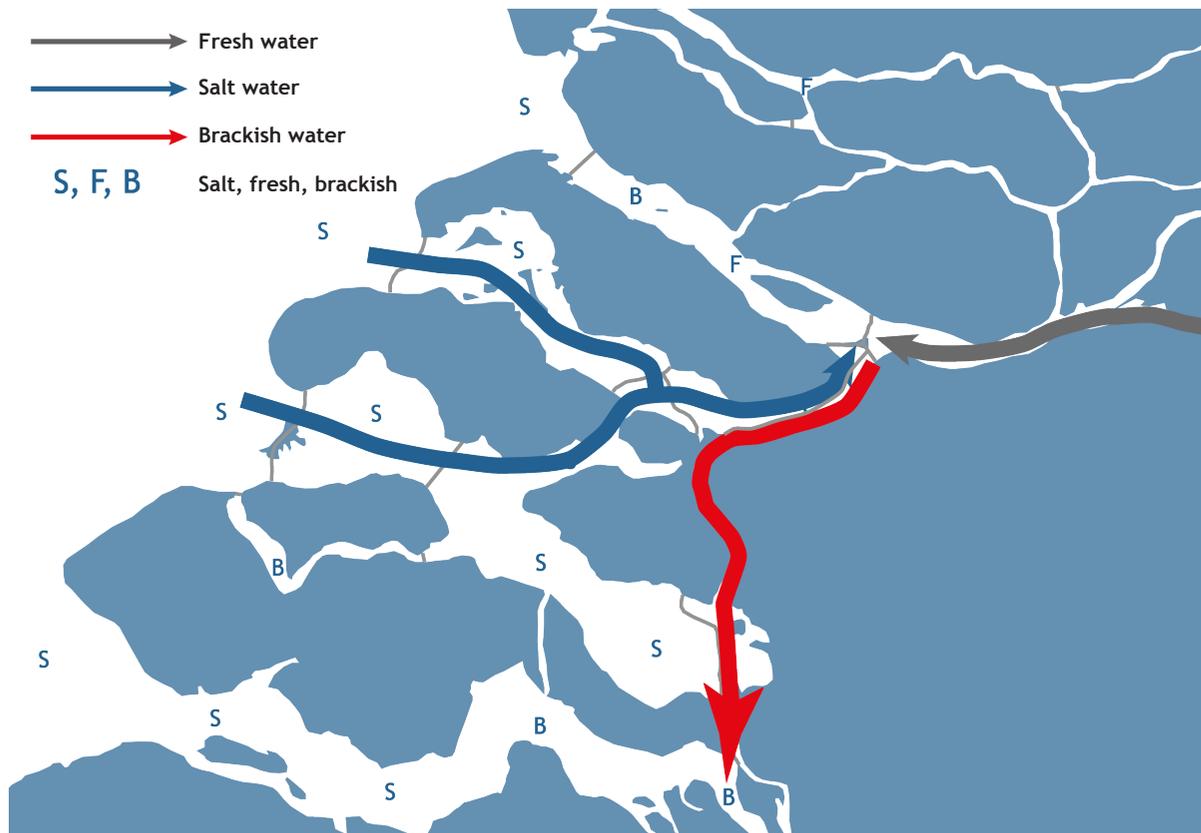


Figure 10.30: Flows of the water in 2050



Figure 10.31: Bird-eye view of the blue energy landscape in 2050

## 10.6 Conclusion

One of the phases in the research design (chapter 2) is the phase of construction. In this thesis the construction phase is replaced by an imagined construction phase. After this imagined construction phase a conclusion with answers to the research question follows.

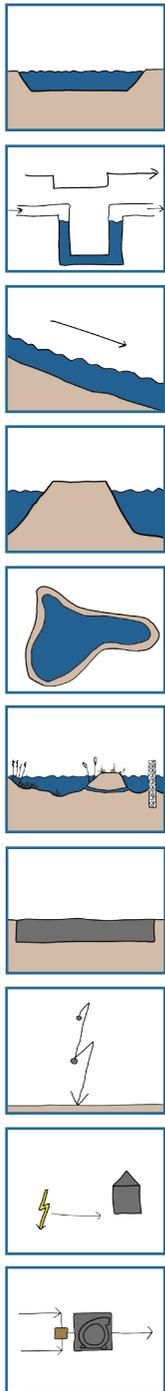
### Imagined construction phase

An open connection with the salt Oosterschelde is restored before 2020. The Volkerak turns salt and the blue-green algae disappears. The residence time of the water in the Volkerak changes from 14 to 4 weeks [Planstudie waterkwaliteit, 2009, p.16]. This reduction increases the water quality and resiliency of the lake. The realisation of the blue energy plant can start. The construction of the pilot scale installation is finished around 2020. The first few years requires a lot of testing with optimization of the membranes and wetlands. The wetlands need time to develop. Between 2020 and 2030 the wetlands slowly expand to the size required for a 10MW installation. In the first few years the wetlands require a lot of maintenance. In the beginning unwanted plants settle in the area and need to be removed. When the natural processes start to work the wetlands maintain itself better. When the plants, mussels and algae's are fully grown they can be harvested. For example, to use the reed of the fresh water wetlands for roofing, the reed has to be cut each year [Van der Linde Rietdekkers, 2012]. Another example; mussels need to be harvested every two years to be used as food [Schmidt Zeevis, 2012]. Eventually the wetlands evolve to a nature area with an extensive amount of flora and fauna. The required amount of maintenance decreases, but what remains is that the area would silt up without intervention. The extracted sand can be used for the 'Zandmotor' [Zandmotor, 2012]. This is another project based on the principle of building with natural processes. Besides that the sand can be used to continuously develop and expand the wetlands.

While the wetlands develop the recreation also increases. The wetlands are expanded with bicycle paths and foot paths. Part of these bicycle paths form a new connection between Goeree-Overflakkee, Rotterdam, and West-Brabant to improve the Dutch 'Knooppunten-netwerk' (in English: Node-network). Also water recreation will improve. In the

current situation there is no water recreation possible in the summer because of the blue-green algae problem. A salt lake makes water recreation possible again. The salt water also has another effect; people value salt water better than fresh water because it is more exiting and creates a holiday feeling [Planstudie waterkwaliteit, 2009, p.22]. An information centre will be built on top of the blue energy plant. This centre provides information about renewable energy sources, the Volkerakdam, and wetlands. The information centre also contains a restaurant which uses locally grown products like mussels and sea lettuce. The area becomes more interesting for living. People want to live close the area because of the nature areas, water and possibilities for recreation.

Between 2030 and 2050 the region develops into a full scale landscape machine. The blue energy plant generates 60MW around 2050, but the wetlands have an overcapacity. The overcapacity is created by a group of farmers at Oostflakkee which are interested in salt crops at their own land. Because of the intrusion of salt water from the Volkerak-Zoommeer in their irrigation system the yields and income of fresh water crops decreases. The farmers have to look for alternatives; wetlands with salt water crops. The overcapacity of the wetlands is used to improve the filtration even further. The stakeholders like farmers, Rijkswaterstaat, and Natuurmonumenten are working together to maintain the wetlands while preserving the filtration capacities. The blue energy plant provides energy for the whole region. Only in periods with extreme weather conditions the blue energy plant cannot fulfil its function. The Volkerak is designated as storage area for water of the rivers when the storm barriers at the coast are closed [Planstudie waterkwaliteit, 2009, p.19]. This reduces the possibilities to generate energy for a few days, but increases the safety of the system.



### Design principles

The design for the blue energy plant is based on the design principles (figure 10.32). For the input of fresh- and salt water a canal is used. These canals use hard lines and create a contrast with the natural wetlands. For the pumping of water two design principles are used: the interconnected vessels and a mechanical pump. Only the output of brackish water requires a pump. We do not use one of the principles to store water. The streams of fresh, salt, and brackish water are separated by (partly present) dikes. The water is cleaned with wetlands, but an additional technical filter is used to guarantee the required quality of the water. It is possible that the design for 2050 does not require a technical filter. The natural shaped wetlands for water filtration consists of mussels, algae's and plants. The blue energy plant is sited under the ground to optimise the streams of water. On top of the blue energy plant itself is a revealing building to show the presence of the plant. The generated electricity leaves the blue energy plant with revealing pylons. One energy sink is nearby; the Volkerak sluices. The rest of the electricity is transported to nearby villages and cities like Rotterdam. The brackish water is discharged through a pipe line.

### Conclusion

In the introduction of this chapter contains three questions: “What are the effects of a blue energy plant on the landscape near the Volkerakdam?”, “How can the landscape for a blue energy plant be designed in such way that it fulfils its function as energy generator while applying the concept of a landscape machine?”, and “What are the possibilities for the implementation of a blue energy plant within the range of the landscape machine?”. The three designs for 2020, 2030, and 2050 in this chapter gives answer to those questions.

There are many possibilities for the implementation of a blue energy plant within the range of the landscape machine. It can be developed as ‘the machine in the landscape’ and ‘the landscape machine’ (chapter 9). The design in this chapter shows ‘the landscape machine’ and is therefore more focused on the imple-

mentation of natural processes with blue energy as end result. The shape and the natural processes of the landscape are used as a basis for the implementation of the blue energy plant.

The most important effect of a blue energy plant on the landscape near the Volkerak is the required surface of the wetlands. The wetlands have the ability to filter the water before it enters the blue energy plant and gives the Volkerak a more natural appearance. This makes the area not only more attractive to several birds but also to nature seekers, and tourists. The canals, pipes, transportation of several water streams, and the pylons for transportation of the electricity also influence the landscape. Those features will have an influence on the landscape, but when it is placed in the area it gives the Volkerak more identity. It can be seen in the landscape what the meaning of this particular landscape is. The physical edge between fresh, salt, and brackish water are already mostly present in the landscape and have therefore no particular effect on the landscape near the Volkerakdam. This will change with the design of 2050. The physical edge will be extended between the salt- and brackish water. The Volkerak will be split in two lakes what will have effect on the water traffic. Commercial ships will use the brackish water lake and the water recreation will use the salt water lake. The blue energy landscape will bring recreation in the form of a bicycle- and footpath, and an information centre with restaurant. It will have a positive effect on the recreational infrastructure and will bring more tourists to the lake what will have a positive effect on the surrounding area of the lake Volkerak.

The design shows how a landscape for the energy plant can be designed in such a way that fulfils its function as a energy generator while functioning like a landscape machine. In the design can be seen that technical solutions can be replaced by natural solutions and still function as required. For example in the case of the natural filtration. Technical filtration is being replaced by wetlands filled with helophytes and halophytes which have the character to filter the water. The design offers possibilities for the landscape to evolve and still fulfil its function of generator of electricity.

Figure 10.32: Used design principles



*The sky at the Volkerak is brightening up*

# 11

## DISCUSSION

This chapter contains the discussion and conclusion of this thesis. The chapter starts with a reflection on the content and theory. After that all the research

questions are being answered in the conclusion. The chapter finishes with recommendations for further research.

## 11.1 Reflection on content

The technical preconditions in relation to the landscape are researched extensively. All relevant information on the topic of blue energy is collected by literature research and interviews. It was important to get a reliable technical basis for the design principles, concepts and design. The technical preconditions gained insights in the possibilities for the design and how to change them in natural processes. Nevertheless an expert on the technique of blue energy most likely will question some of the conclusions. For example, the salinity difference between fresh and salt water needs to be as high as possible. The exact minimal salinity difference between fresh and salt water to create a working blue energy plant is unknown, and therefore it is difficult to draw conclusions on this aspect of the technical preconditions. This influences the chance of the realisation of a blue energy plant until the exact salinity is known.

We found 16 possible locations for blue energy in the Netherlands. The description of each location is one page, but gathering the required information for each location cost much effort. At first we tried to get an overview of each possible location without a minimum amount of water as restriction, but this turned out to be beyond the scope of the thesis. That is why the research is limited to locations where fresh water meets salt water with an input bigger than 200m<sup>3</sup> of water per minute. Smaller blue energy plants can also be feasible, but for the sake of this thesis they were not interesting for us as landscape architects. Another aspect for the possible locations is that for each location more research is needed to know the exact influences of for example the building or effect of brackish water on the environment and surroundings. Although the 16 locations provide possibilities for blue energy, we want to emphasize that we do not think that a blue energy plant should be built at each location. Depending on the location it can be more logical to implement wind turbines or other renewable energy sources instead of a blue energy plant. Blue energy is not the only possible solution to mitigate to climate change, but it is one out of many possibilities.

The report contains a list of 40 design principles. The principles are based on the technical preconditions in relation to the concept of the landscape machine.

The design principles are placed in a matrix with the axis revealed versus concealed and technosphere versus biosphere. The matrix gives an impression of how the design principles are related to each other, but not how they exactly will function in a certain design. It depends on the execution of the design principle where it should be placed in the matrix. For example, a pump is highly technical (technosphere), but when this pump is powered by a wind turbine, it makes use of natural processes and therefore the design principles moves in the direction of the biosphere. The list of design principles is limited to the elementary elements which are directly related to the (design of a) blue energy plant. Many more design principles are possible when for example also aesthetical values play a role. It was hard to make a good distinction between the primary, required elements and secondary, optional elements. The list of design principles we finally created can be seen as a step by step guide of primary elements of a blue energy plant. For each part of the blue energy plant at least one of the possibilities should be chosen.

We both created a concept based on a different part of the matrix with design principles. This limited the freedom in design possibilities, but it also shows clearly how the choice for certain design principles lead to a totally different end-result. It was difficult to create two designs which only focus at one part of the matrix with design principles. When looking at the elements present in both concepts: a wetland, a blue energy plant, an info centre and the discharge of brackish water at the Volkerak sluices, they both look very familiar. But the detailing in shapes and purpose was totally different. This shows that there are many possibilities for the design of a blue energy plant. This research provides the preconditions, but the end-results can be totally different. This leads to the conclusion that it is useful to have a list of design principles as guideline for the design of a blue energy plant, but also that it is important to adapt the design principles for each specific location. In this way the design principles allow freedom in the design while still applying all required elements for a blue energy plant.

Based on the discussion about the concepts we created a final design for the blue energy plant. Where

## 11.2 Reflection on theory

the concepts showed the possibilities within the range of the landscape machine, the design is a combination of a natural landscape with more technical interventions to control the processes. We think that the final design shows how a blue energy plant can be implemented, but we also realise that it requires major interventions in the current landscape. At the moment is a discussion going on about the Hedwige polder near the border with Belgium. The discussion is about changing the current farmland into a nature reserve. While the Hedwige polder covers an area of 300 hectares, the design for 2030 covers an area of in total 800 hectares. Major difference between the Hedwige polder and our design is that our design does not influence current agriculture areas. Instead it changes a current nature area into a wetland (what it was before the realisation of the Deltaworks). The design covers a major area around the Volkerakdam, but the influence on the current structure is kept to a minimum.

The design contains a time-line with the landscape as we think it (should) look(s) like in 2020, 2030 and 2050. Logically it is easier to say something realistic about 2020 compared to 2050. We consider a pilot installation in 2020 feasible. The design for 2030 already shows major changes in the landscape. We think that the design for 2030 is possible when the pilot installation works properly. This depends on the exact salinity of the water and the development of new membranes for blue energy. The design for 2050 is mostly a vision. If the wetlands develop as a landscape machine as planned it can be profitable for farmers to switch to salt-crop wetlands. The concept of the landscape machine implies that the landscape is dynamic and cannot be static. For sure the landscape of 2050 will not be exactly the same as the design shows, but we hope it is an revelation of the possibilities for a blue energy landscape.

The design principles, concepts, and design are mainly based on the concept of the landscape machine and the theory of eco-revelatory design. The theoretical framework is not applied to the technical preconditions for blue energy and landscape analysis. That is why we decided to add the theoretical framework in a later stage of the report; before the design principles and after the landscape analysis. The main reason for this decision is that we decided to base the possible locations on technical preconditions. These preconditions contain numbers upon which it is possible to decide if a location is suitable for a blue energy plant or not. The concept of the landscape machine can be applied at most of the locations to a certain extent. This would not have influenced the choice for the location.

The concept of the landscape machine is called a 'concept' because it is not yet an established and confirmed theory. It is a relatively new way of thinking in the field of landscape architecture. We hope that with this thesis the concept of the landscape machine develops gradually into a settled theory. Until now the concept of the landscape machine mostly focussed on landscapes which from a theoretical angle function as a landscape machine. With the design we created for 2030 we show how the concept of the landscape machine fits within a more practical context. For us the landscape machine was a helpful way of thinking to develop a design based on natural processes. Instead of creating a design with functions like nature, agriculture, recreation and infrastructure, the concept of the landscape machine helps to do more with these functions and let them interact with each other. This results in a self-developing machine with a certain input, fuel and output.

Within the scope of this thesis the final design does not contain the most extreme solutions for the creation of a landscape machine. There are several reasons for that. We wanted to create a revealing and innovative design, but we also want to show that it is really possible to implement the design. Besides that Rijkswaterstaat asked us to create a design which can be implemented and the supervisors of our thesis are both working in the field of energy landscapes. The combination of these factors has resulted in a

sustainable blue energy landscape in a practical context with the concept of the landscape machine as inspiration for the design. In this context the design for 2030 can be seen as a 'light' version of a landscape machine. The visionary design for 2050 shows how the landscape machine can develop. The design has a big impact on the landscape, but still practical limitations (like the available amount of water) are used as guideline. From this point of view and with the scope of our thesis in mind we did not create a landscape machine 'to the max'.

The landscape machine works with natural processes. In the last few years more designs are created which work with natural processes, but not all of them are called 'landscape machines'. Other used names are 'building with nature' and 'eco-engineering'. Main difference with the concept of the landscape machine is that they do not explicitly mention the landscape as a machine. One example is the 'Zandmotor'. In this project the sand is brought up at one location at the coast. Streams of sea water transport the sand along the whole Dutch coast in order to strengthen the coast. The Zandmotor contains a certain input (water), fuel (streams in water), machine (sea) and output (stronger coast). In many of the projects working with natural processes is a role for climate change. The example of the Zandmotor is one of them. The saline landscapes of Molpheta and van Wonderen [2009] and our design for a blue energy plant also use climate change as reason for the project.

A remark on the concept on the landscape machine is that until now many 'landscape machines' contain elements of a wetland. The article of Ronken et al. [2011] contains two designs with wetlands [Molpheta and van Wonderen, 2009 and de Vries & Herrebout, 2007]. Now our design can be added to that list. We wonder if this means that the concept of the landscape machine unconsciously sends you in the direction of using wetlands, or that it is a coincidence.

The concept of the landscape machine also describes 'the sublime'. We discussed several times if 'the sublime' should be integrated in our design. Our conclusion was that 'the sublime' is still a vague term on which it is difficult to answer precisely what it

means. Of course we tried to design a beautiful and interesting landscape, but we did not strive to create a sublime landscape.

Besides the concept of the landscape machine we used the theory of eco-revelatory design. An important similarity is that they both make use of natural processes. But they differ in the way those processes are used. While the concept of the landscape machine uses the natural processes for creating a machine, the theory of eco-revelatory design is about showing those processes. We used the theory of eco-revelatory for dividing the design principles in revealing and concealing. This was useful for us because we wanted to look at the effect of a blue energy plant on the landscape. The division revealing and concealing helped us easily to make decisions on the impact on the landscape.

Concerning the design for a blue energy plant we can conclude that it was useful to use the concept of the landscape machine and theory of eco-revelatory design as theoretical framework. We found out that it is often possible to use natural processes instead of technical elements in a design. However, we also found out that it is impossible to replace all elements of a blue energy plant for natural processes. We hoped to find a natural equivalent for all technical elements, but this is impossible. The design for a blue energy plant will therefor always be a combination of both concepts: 'the machine in the landscape' and 'the landscape machine'.

## 11.3 Conclusion

The first chapter of this report describes the purpose and related research questions of this master thesis. This section gives an answer to the research questions and concludes with the achievement of the purpose: create a design and design principles which are an inspiration for the implementation of a blue energy plant.

### Research questions

**Main research question:** *What are the technical preconditions for a blue energy plant and how can a design using the concept of ‘the landscape machine’ help to implement a blue energy plant within the surroundings of the Volkerakdam?*

Chapter: 4, 6, 7, 8, 9, 10

There are twelve technical preconditions for a blue energy plant. The concept of the landscape machine forced us to think about natural processes in the landscape of Volkerak and how to use those processes instead of technical solutions. Using the twelve technical preconditions in relation to the landscape machine resulted in forty design principles that can be used for the sixteen locations that are suitable for blue energy in the Netherlands.

*What are the technical preconditions for a blue energy plant?*

Chapter: 4

There are twelve technical preconditions for a blue energy plant: fresh water, salt water, salinity difference between fresh and salt water, amount of water, physical edge between fresh, salt and brackish water, pumps, membranes, clean water, required space, electricity, transport of energy and brackish water.

*What are possible locations for a blue energy plant in the Netherlands?*

Chapter: 5 and attachment 1

There are many possible locations for a blue energy plant where fresh water meets salt water. There are in total sixteen locations where fresh water meets salt water with a minimal amount of 200 m<sup>3</sup> of water per minute. These possible locations are: the Dollard, Eemskanaal, Lauwersmeer, Harlingen, Afsluitdijk, Balgzandkanaal, Noordzeekanaal, pump station Katwijk, Rotterdam Botlek, Rotterdam Nieuwe waterweg, Rotterdam Maasvlakte, Haringvlietdam, Philipsdam, Oesterdam, Volkerakdam, Dintel. Not all

locations are equally suitable for blue energy. Main differences between locations are the salinity difference between fresh and salt water, the amount of water and the required space for the blue energy plant.

*What are the effects of a blue energy plant on the landscape near the Volkerakdam?*

Chapter: 9, 10

Concerning the required surface area the wetlands have the biggest effect on the landscape. The wetlands have the ability to filter the water before it enters the blue energy plant. Other effects of the blue energy plant are the required space for the blue energy plant itself, the canals and pipes to transport the water and the pylons to transport the electricity. The physical edges between fresh, salt, and brackish water are already mostly present in the landscape and have therefore no effect sorted by the blue energy plant. Other minor effects as a result of the blue energy plant are the info centre, bicycle- and footpaths.

*What are the requirements for creating a blue energy plant as landscape machine?*

Chapter: 4, 7

In general a landscape machine is seen as a whole of natural processes with the characteristics of a machine with the elements predictability, product orientation, input, fuel and output. In the case of a blue energy plant the input consists of fresh- and salt water. The fuel is the difference in salinity between fresh- and salt water. The machine consists of a wetland to filter the water and membranes to generate energy from the salinity difference between fresh- and salt water. Because of the use of the landscape as part of the blue energy plant extra outputs are created. The output of the ‘blue energy landscape machine’ is clean brackish water, energy, recreation, nature, education and food.

### Design questions

The following design questions are focused on the design itself. Therefore it is not possible to give a complete answer to these questions as text. The relevant chapters which give answers to the questions are mentioned for each question.

**Main design question:** *How can the landscape for*

*a blue energy plant be designed in such way that it fulfils its function as energy generator while applying the concept of a landscape machine?*

Chapter: 6, 8, 9, 10

The blue energy plant can be designed as landscape machine by replacing the technical elements as much as possible for natural processes. The design in chapter 10 shows the result of the search for an answer to this question. The most important addition to a technical blue energy plant is to replace technical filtration for natural filtration with wetlands. In this way it is possible to keep the function of a blue energy plant as energy generator while adding natural processes in order to create a landscape machine.

*Which design principles for a blue energy plant can be derived from the technical preconditions in relation to the landscape machine?*

Chapter: 4, 7, 8

In total 40 design principles can be derived from the technical preconditions in relation to the landscape machine. They are grouped as: the amount of water, design of the canal, water pumping, water retention, physical edge, water filter, membranes, siting of blue energy plant, size of blue energy plant, connection to the existing grid, and distance to energy sinks. The complete list can be found in chapter 8.

*What are the possibilities for the implementation of a blue energy plant within the range of the landscape machine?*

Chapter: 7, 8, 9, 10

The design for a blue energy plant within the range of the landscape machine can be developed in many ways between 'the machine in the landscape' and 'the landscape machine'. The 'machine in the landscape' looks like a real machine and is focused on the product of blue energy but still contains natural processes like wetlands. The 'landscape machine' is focused on the implementation of natural processes with blue energy as end result. It contains more natural elements.

## Purpose achievement

The purpose of this thesis was to create a design and design principles which are an inspiration for the implementation of a blue energy plant.

We created a design and two concepts for a blue energy plant using the concept of the landscape machine. The design and concepts are based on design principles. If the design is an inspiration for the implementation of a blue energy plant remains to be seen. We believe that the design is a revelation of the blue energy landscape of the future.

## 11.4 Recommendations for further research

The time span of 6 months for this thesis caused that some elements are not researched as extensively as they should. The purpose of the thesis was to create a design and design principles which are an inspiration for the implementation of a blue energy plant. During the thesis we dealt with some aspects of blue energy and the theoretical framework, but can be extended in other research. That is why this section gives recommendations for further research.

The research contains a design for a landscape machine at the Volkerakdam. This design does not test the most extreme possibilities for such landscape machine. In further research should be attention for testing the concept of the landscape machine to its maximum capacities. This can result in a better understanding of the possibilities of a landscape machine. The landscape machines described by Roncken et al. [2011] and this thesis report all contain (elements of) wetlands. The landscape machine should be applied in a totally new environment like mountainous areas to further test the possibilities.

The search for possible locations for blue energy in the Netherlands is now mainly based on the technical preconditions. The influence on the landscape needs to be furthered research for each location. This is only possible with an extensive landscape analysis and site visit. Besides that only locations where fresh water meets salt water are researched. Further research is needed on the possibilities of effluent water of for example sewerage water treatment plants and salt factories. Also small locations (<200 m<sup>3</sup> water per minute) require further research.

The wetlands in the concepts and design are based on several sources, but salt water wetlands (halophyte filters) need further research. From several plant, bivalves, it is known that they have the ability to filter water, but there is not much information on how the wetlands should be situated and designed. Further research can help to create a more optimal water filter for blue energy plants.

A blue energy plant can have many shapes. The concepts and design show some possibilities. As long as no large-scale blue energy plant has been realised it is difficult to conclude if a certain shape is better

than another. The same problem also applies to the best location for a blue energy plant. Is it better to situate it under the ground or above the ground? Is it better to have more smaller installations, or one big installation? The blue energy technique needs to be developed further to get an answer to these questions.

The design for the blue energy plant shows the effect of a blue energy plant in the landscape, but it does not give an answer to one of the knowledge gaps stated by Deltares [2010a]: the effect on people living in the surroundings and other stakeholders. Further research is required to get an answer to this knowledge gap.



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# LIST OF FIGURES

*All figures, symbols and pictures are made by the authors, unless otherwise indicated.*

*Cover illustration: Atmospheric image of poles with mussels (bouchots) during low-tide and high-tide*

## 1. Introduction

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## 2. Research design

- 2.0 Blue heron sitting on a sign (prohibited to fish) at the canal around Willemstad
- 2.1 Relationship between research and design as identified by the complex intellectual activity model [based on: Ledewitz, 1985]
- 2.2 Continuous process of design and research
- 2.3 Research process

## 3. Climate change

- 3.0 Harbour and industry area Moerdijk, looking from Willemstad
- 3.1 KNMI Climate scenarios [based on: KNMI, 2006]
- 3.2 Expected Sea level rise in meters [based on: Deltacommissie, 2008, p.24]
- 3.3 Overview effects of climate change 2050 [based on: Deltacommissie, 2008, p.28]
- 3.4 Overview effects of climate change 2100 [based on: Deltacommissie, 2008, p.30]

## 4. Technical preconditions

- 4.0 Bench-scale demonstration of blue energy using RED-technology, at Wetsus, Leeuwarden
- 4.1 Theoretical worldwide potential for blue energy [Veerman, 2009]
- 4.2 Blue energy RED-technology [based on: Post, 2009, p.21]
- 4.3 Example of a wire mesh to clean the water [Molenbroek, 2007, p.37]
- 4.4 Schematic overview of a blue energy plant with the right proportions of pumps, filtration area and stacks [based on: Quak, 2009]
- 4.5 High voltage power network in the Netherlands [based on: TenneT, 2011]

## 5. Possible locations

- 5.0 Example of a physical edge between fresh and salt water at the Krammersluizen, Zeeland
- 5.1 Overview of possible locations for blue energy in the Netherlands
- 5.2 Open landscape near the Volkerakdam look-

ing from a bird hide to the Volkerakdam

- 5.3 Theoretical size and power of blue energy plant with fresh (white), salt (blue) and brackish (red) water streams [underlying map based on: Google Earth, 2009]

## 6. Volkerak

- 6.0 Nature area Hellegatsplaten looking from the Hellegatsdam towards Dinteloord
- 6.1 Location of the Volkerakdam in the Netherlands
- 6.2 History of the Dutch South-Western Delta [based on: Noordhoff Atlasproducties, 2010]
- 6.3 The South-Western Delta, around 1613 [Edward-Wells, 2012. Available at: [http://www.grondbezit.nl/tl\\_files/zpg\\_sitepix/1613\\_Zelandia\\_Comitatus\\_Mercator%5B1%5D.jpg](http://www.grondbezit.nl/tl_files/zpg_sitepix/1613_Zelandia_Comitatus_Mercator%5B1%5D.jpg). Accessed 24 April 2012]
- 6.4 Allerheiligenflood, 1570 [Leslink, 2012. Available at: [http://lacomunidad.elpais.com/blogfiles/sibyllanetcom/0082-0123\\_seesturm\\_mit\\_schiffbruch.jpg](http://lacomunidad.elpais.com/blogfiles/sibyllanetcom/0082-0123_seesturm_mit_schiffbruch.jpg). Accessed 16 Feb. 2012]
- 6.5 The impoldering of the Volkerak [based on: Atlas van de Zuid-Westelijke delta, 2009]
- 6.6 Watersnoodramp, 1953 [ANP, 2012. Available at: <http://www.anp-archief.nl/page/243292/nl>. Accessed on: 24 April 2012]
- 6.7 The Deltacommittee, 1954 [Safecoast, 2012. Available at: <http://www.safecoast.org/canon/beschrijving.php?b=82>. Accessed 24 April 2012]
- 6.8 Construction of the Volkerakdam, 1957-1969 [ANP archief, 1965. Available at: <http://fast.mediamatic.nl/f/tqgr/image/549/6320-620-410.jpg>. Accessed 24 April 2012]
- 6.9 The Deltaworks [based on: Stichting Deltawerken online, 2011]
- 6.10 The Volkerakdam [Stichting Deltawerken online, 2011. Available at: [http://www.deltawerken.com/modules/mediagallery/popup.php?id=929&style\\_root=/home/deltawer/public\\_html/styles/blauw&style\\_root\\_http=http://www.deltawerken.com/styles/blauw&language=en](http://www.deltawerken.com/modules/mediagallery/popup.php?id=929&style_root=/home/deltawer/public_html/styles/blauw&style_root_http=http://www.deltawerken.com/styles/blauw&language=en). Accessed 24 April 2012]
- 6.11 Fortresses in the area [based on: Zuiderwaterlinie, 2012. Available at: <http://www>

zuiderwaterlinie.nl/kaart.aspx. Accessed 2 February 2012]

- 6.12 Blue-green algae at the Volkerak
- 6.13 The Volkerak sluices
- 6.14 Marina, Willemstad
- 6.15 The nature area Hellegatsplaten
- 6.16 Current situation of the Volkerak [underlying map based on: Google Earth, 2009]
- 6.17 Layer approach of the Volkerak
- 6.18 Structure of Volkerak sluices
- 6.19 Agriculture area, West-Brabant
- 6.20 Agriculture area, Overflakkee
- 6.21 Scenario 2100 “Open” [based on: Programmabureau Zuidwestelijke Delta, 2010]
- 6.22 Scenario 2100 “Closable Open” [based on: Programmabureau Zuidwestelijke Delta, 2010]
- 6.23 Figure 6.23: Cycle of tides at the Volkerak (12h 25 min) [Rijkswaterstaat, 2012]
- 6.24 Vision 2020 of gradually restoring of the dynamics [Programmabureau Zuidwestelijke Delta, 2010]

## 7. Theoretical framework

- 7.0 Maintenance path for the Volkerak sluices, looking towards the sluices
- 7.1 Blue energy plant as landscape machine [based on: Roncken et al., 2011]

## 8. Design principles

- 8.0 Selection of 30 out of 40 design principles described in the chapter
- 8.1 Amount of water
  - 8.1a Amount of water: ditch
  - 8.1b Amount of water: canal
  - 8.1c Amount of water: river
- 8.2 Design canal
- 8.3 Water pumping
- 8.4 Water retention
- 8.5 Physical edge
- 8.6 Water filter
- 8.7 Membranes
- 8.8 Siting of blue energy plant
- 8.9 Size of blue energy plant
- 8.10 Connection to grid
- 8.11 Distance to source
- 8.12 Matrix with design principles

## 9. Concepts

- 9.0 Two concepts: one of each author.
- 9.1 Focus of both concepts placed in the matrix
- 9.2 Possible wetland designs [Kadlec and Knight, 1996]
- 9.3 Overview of the concept implemented in the landscape of Volkerak [underlying map: Google Earth, 2009]
- 9.4 Historical map 1920. [Jacobusse C., H. Stam, 2006. *Grote historische topografische atlas / Zeeland*. Nieuwland Uitgeverij]
- 9.5 Biesbos [Google Earth, 2009]
- 9.6 Het Verdrongen Land van Saeftinghe [Google Earth, 2009]
- 9.7 Height map 2000. [Programmabureau Zuidwestelijke Delta, 2009. Atlas van de Zuidwestelijke Delta. [PDF] Middelburg. Available at: [http://www.zwdelta.nl/dynamisch/bibliotheek/217\\_0\\_NL\\_120213\\_PO-SAD\\_8.15\\_Atlas\\_Light.pdf](http://www.zwdelta.nl/dynamisch/bibliotheek/217_0_NL_120213_PO-SAD_8.15_Atlas_Light.pdf). Accessed 21 Maart 2012]
- 9.8 Design blue energy landscape
- 9.9 Bouchots by ebb [<http://www.jdgbill.com/images/bouchots.jpg>. Accessed 26 April 2012]
- 9.10 Bouchots by flood [<http://img.teva.fr/01A4000002298696-photo-le-mont-saint-michel-au-fond-veille-sur-les-ranges-de-moules-sur-bouchot.jpg>. Accessed 26 April 2012]
- 9.11 English cord grass (*Spartina anglica*) [[www.nature-diary.co.uk](http://www.nature-diary.co.uk). Accessed 7 April 2012]
- 9.12 Reed (*Phragmites communis*) [[http://www.agroatlas.ru/content/weeds/Phragmites\\_australis/Phragmites\\_australis.jpg](http://www.agroatlas.ru/content/weeds/Phragmites_australis/Phragmites_australis.jpg). Accessed 26 April 2012]
- 9.13 The landscape works like a natural machine
- 9.14 Cross section A-A' Through heights in the landscape the water will be transported through the wetlands
- 9.15 Atmospheric image of the information centre [based on: Alluminum centre, Houten, Netherlands, designed by M.J. de Haas]
- 9.16 Detail design blue energy landscape
- 9.17 Atmospheric image of the blue energy plant placed underneath the surface

## 10. Design

- 10.0 Impression of the blue energy landscape
- 10.1 Time line of the development of the blue energy plant
- 10.2 Container with a blue energy pilot installation
- 10.3 Implementation of the blue energy plant of 0.05 MW near the Volkerakdam
- 10.4 Principle of the tidal dike
- 10.5 Cross-section A - A' Fresh water wetland. Transportation of the water through using the law of interconnected vessels
- 10.6 Design 2030 situated in the South-Western Delta
- 10.7 Cross-section B - B' Salt water wetland with the mussel field and halophyte filter
- 10.8 Design blue energy landscape 2030
- 10.9 Atmospheric image of the fresh water filter
- 10.10 Atmospheric image of the static grid of bouchots with the dynamic movement of the salt water
- 10.11 Atmospheric image of the salt water wetland
- 10.12 Atmospheric image of the membranes placed underneath the surface
- 10.13 Detail of the blue energy plant and surrounding area
- 10.14 Construction of the blue energy plant
- 10.15 Atmospheric image of the blue energy plant
- 10.16 Bird-eye view of the brackish polder after years of evolving
- 10.17 Design detail of the fish way
- 10.18 Migrating fishes. From top to bottom: Salmon [<http://www.mrfish.nl/Modules/Divlmg/zalm.gif>, Accessed 25 April 2012], Stickelback [<http://www.dieren-info.nl/wp-content/uploads/2012/02/Driedoornige-stekelbaars.jpg>, Accessed 25 April 2012], Seatrout [<http://vissoorten.kustvissenineuropa.nl/zeeviseuropa/zeebaars.jpg>, Accessed 25 April 2012], Sturgeon [[http://fish.dnr.cornell.edu/nyfish/Acipenseridae/atlantic\\_sturgeon.jpg](http://fish.dnr.cornell.edu/nyfish/Acipenseridae/atlantic_sturgeon.jpg), Accessed 25 April 2012].
- 10.19 Natural design of fishway in nature areas (number 2 in detail of fishway)
- 10.20 Regulated design of fishway near A59 (number 1 in detail of fishway)
- 10.21 Bluethroat [IBC, 2011. Available at: <http://ibc.lynxeds.com/photo/bluethroat-luscinia-svecica/male-luscinia-svecica-cyanecula-phragmites-australis>. Accessed 8 May 2012]
- 10.22 Small bean goose [Luontoportti, 2012. <http://www.luontoportti.com/suomi/images/1833.jpg>. Accessed 8 May 2012]
- 10.23 Little Egret [Azahari Reyes, 2012. Available at: [http://1.bp.blogspot.com/\\_lFELKwm4ZV8/T5-fUvwdXpl/AAAAAAAAAEbE/eAo-9BKDC200/JAY\\_8336%2BLittle%2BEgret.jpg](http://1.bp.blogspot.com/_lFELKwm4ZV8/T5-fUvwdXpl/AAAAAAAAAEbE/eAo-9BKDC200/JAY_8336%2BLittle%2BEgret.jpg). Accessed 8 May 2012]
- 10.24 Black-necked grebe [Stuartelsom, 2012. Available at: <http://www.stuartelsom.co.uk/copyrightphotos/UK10-BNG01-05-10.JPG>. Accessed 8 May 2012]
- 10.25 Atmospheric image of recreational path by day and night
- 10.26 The landscape works like a landscape machine
- 10.27 Cross-section C - C' Salt water filtration in the form of aquaculture
- 10.28 Cross-section D - D' The island Tiengemeten as fresh water wetland
- 10.29 Design blue energy landscape 2050
- 10.30 Flows of the water in 2050
- 10.31 Bird-eye view of the blue energy landscape in 2050
- 10.32 Used design principles

## 11. Discussion

- 11.0 The sky at the Volkerak is brightening up





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