IJsselmeerwerken

LANDSCAPE INTERVENTIONS TO RESTORE THE ESTUARINE GRADIENT IN THE WIERINGERHOEK

Master Thesis Landscape Architecture Wageningen UR

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COLOPHON

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ABSTRACT

The Dutch Delta is home to unique nature: The Delta Nature. The current biodiversity of the IJsselmeer-lake bottom has been described as a desert. The biodiversity crisis has been compared to be in the same degree as the climate crisis. Therefore, it requires urgent action in the IJsselmeer area. This thesis aims to improve the estuarine gradient in the Wieringerhoek and, by doing so, improve biodiversity, and water quality and create a resilient transition between fresh and salt ecotopes.

To reach the determined objective, the building with nature approach was integrated into the GeoDesign framework. In this research, three design models were made and presented to experts familiar with the topics and study area. Landscape design principles of freshwater and saltwater marshes and the stage in between were determined and integrated into the specified case study area: the Wieringerhoek. This led to a final design together with a set of design principles and rules for implementing the design principles in the IJsselmeer. These design principles were informed by expert judgment and the various design iterations. The final design does offer the conditions to maintain the freshwater and saltwater ecotopes. These ecotopes themselves have a positive impact on both biodiversity and water quality. Although to significantly impact the water quality, more similar projects need to be created in the whole IJsselmeer area. The design forms a solution to higher fluctuating salinity concentrations due to climate change.

The toolbox of design principles is suitable for other locations in the IJsselmeer and other river mounds with similar conditions. However, when designing in the IJsselmeer area, the transition between fresh- and saltwater must be created carefully and highly managed so the freshwater reservoir function of the IJsselmeer can be maintained. The restrictions posed by the water safety regulations make it impossible to create a literal estuarine gradient. The estuarine gradient is in this sense only a salinity gradient with corresponding ecotopes of an estuary. The design interventions presented in this will create a more biodiverse IJsselmeer with improved water quality. Ecotopes similar to an estuary will develop there but not create an estuarine gradient in the traditional sense but a controlled estuarine gradient.

Key-words: landscape design, IJsselmeer, biodiversity, water quality, estuarine gradient, freshwater marsh, saltwater marsh, building-with-nature, GeoDesign

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CHAPTER 1
Introduction

1.1. Introduction

The Dutch Delta is home to unique nature: *The Delta Nature*. This area stretches from the North Sea, the Wadden Sea and the IJsselmeer to the Southwest Delta and the major rivers. Since the Middle Ages, we have diked and reclaimed our Low Countries against flooding from the rivers and the sea, culminating in the major projects of the twentieth century: the Zuiderzee Works and the Delta Works. They have made the Netherlands safe and prosperous. However, they came with a large ecological downside: natural flows of water, sand, silt and nutrients have been altered and sometimes even blocked by dams (van Leijenhorst, 2018).

"The necessity of addaptive policy for the IJsselmeer."

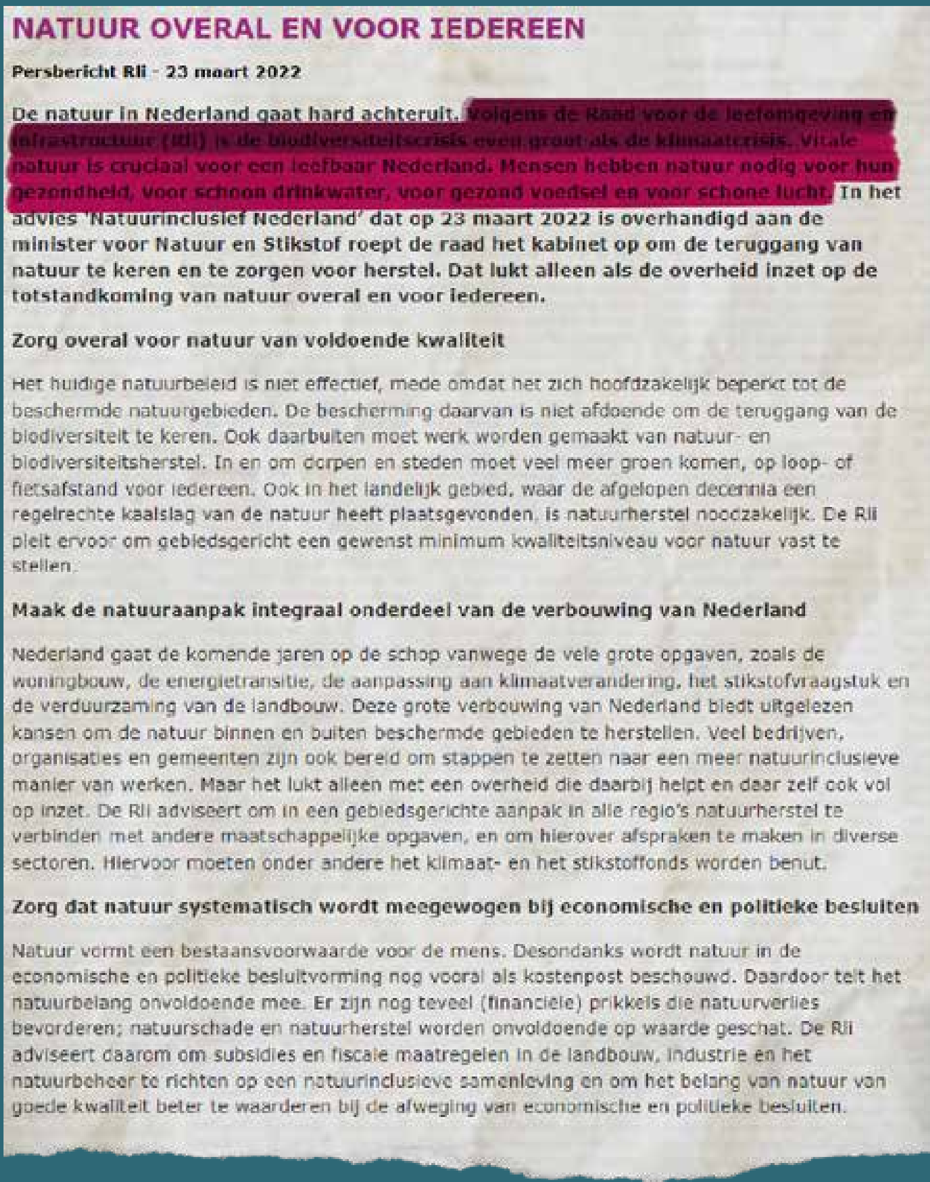
Stresstest van de IJsselmeerbuffer toont noodzaak voor adaptief beleid

Dit artikel laat zien hoe snel inzichten kunnen veranderen en toont daarmee de noodzaak voor nog meer flexibiliteit in analyse, beleid én uitvoering.

Het Deltaprogramma onderzoekt in een beleidscyclus van zes jaar of en wanneer maatregelen nodig zijn om Nederland voor te bereiden op klimaatverandering, waaronder de effecten van toenemende droogte.

om perioden van droogte te overbruggen en is daarmee een belangrijke bron van zoetwater voor allerlei gebruikers (landbouw, natuur, industrie, drinkwater, stedelijke infrastructuur) in Noord-Nederland.

Figure 1: News snippet (KNW, 2021)



NATUUR OVERAL EN VOOR IEDEREEN

Persbericht Rli - 23 maart 2022

De natuur in Nederland gaat hard achteruit. Volgens de Raad voor de leefomgeving en infrastructuur (Rli) is de biodiversiteitscrisis even groot als de klimaatcrisis. Vitale natuur is cruciaal voor een leefbaar Nederland. Mensen hebben natuur nodig voor hun gezondheid, voor schoon drinkwater, voor gezond voedsel en voor schone lucht. In het advies 'Natuurinclusief Nederland' dat op 23 maart 2022 is overhandigd aan de minister voor Natuur en Stikstof roept de raad het kabinet op om de teruggang van natuur te keren en te zorgen voor herstel. Dat lukt alleen als de overheid inzet op de totstandkoming van natuur overal en voor iedereen.

Zorg overal voor natuur van voldoende kwaliteit

Het huidige natuurbeleid is niet effectief, mede omdat het zich hoofdzakelijk beperkt tot de beschermde natuurgebieden. De bescherming daarvan is niet afdoende om de teruggang van de biodiversiteit te keren. Ook daarbuiten moet werk worden gemaakt van natuur- en biodiversiteitsherstel. In en om dorpen en steden moet veel meer groen komen, op loop- of fietsafstand voor iedereen. Ook in het landelijk gebied, waar de afgelopen decennia een regelrechte kaalslag van de natuur heeft plaatsgevonden, is natuurherstel noodzakelijk. De Rli pleit ervoor om gebiedsgericht een gewenst minimum kwaliteitsniveau voor natuur vast te stellen.

Maak de natuuraanpak integraal onderdeel van de verbouwing van Nederland

Nederland gaat de komende jaren op de schop vanwege de vele grote opgaven, zoals de woningbouw, de energietransitie, de aanpassing aan klimaatverandering, het stikstofvraagstuk en de verduurzaming van de landbouw. Deze grote verbouwing van Nederland biedt uitgelezen kansen om de natuur binnen en buiten beschermde gebieden te herstellen. Veel bedrijven, organisaties en gemeenten zijn ook bereid om stappen te zetten naar een meer natuurinclusieve manier van werken. Maar het lukt alleen met een overheid die daarbij helpt en daar zelf ook vol op inzet. De Rli adviseert om in een gebiedsgerichte aanpak in alle regio's natuurherstel te verbinden met andere maatschappelijke opgaven, en om hierover afspraken te maken in diverse sectoren. Hiervoor moeten onder andere het klimaat- en het stikstoffonds worden benut.

Zorg dat natuur systematisch wordt meegewogen bij economische en politieke besluiten

Natuur vormt een bestaansvoorwaarde voor de mens. Desondanks wordt natuur in de economische en politieke besluitvorming nog vooral als kostenpost beschouwd. Daardoor telt het natuurbelang onvoldoende mee. Er zijn nog teveel (financiële) prikkels die natuurverlies bevorderen; natuurschade en natuurherstel worden onvoldoende op waarde geschat. De Rli adviseert daarom om subsidies en fiscale maatregelen in de landbouw, industrie en het natuurbeheer te richten op een natuurinclusieve samenleving en om het belang van natuur van goede kwaliteit beter te waarderen bij de afweging van economische en politieke besluiten.

Figure 2: News snippet (Rli, 2022)

"The Biodiversity Crisis is as big as the Climate Crisis"

Migration routes of plants and animals also came to an halt (van Leijenhorst, 2018). The fish biomass decreased, as did the nutritional value of mussels. As a result, fish and macrofauna-eating birds decreased, while herbivores increased (Noordhuis *et al.*, 2014) As a result of these water projects, in many places the abiotic and biotic variation in the large bodies of water has been lost and many species lack suitable habitats (van Leijenhorst, 2018).

In the recent decades the biggest change in the *IJsselmeer* area in the most has been the decline in eutrophication, which decreased since the 1980s (Deltacommissie, 2021). This decrease has been accompanied by changes in the food web, for example in the species composition of the phytoplankton and the amount aquatic plants (Noordhuis *et al.*, 2019). The current biodiversity of the lake bottom has been described as a desert (Zijden, Mandemakers and Wildenburg, 2019). The biodiversity crisis has been compared to be in the same degree as the climate crisis (Raad voor leefomgeving en infrastructuur, 2022). This is why it requires urgent action, also in the *IJsselmeer* area.

"More room and dynamics, more ebb and flow, fresh and salt water transitions are necessary for a healthy delta nture"

Herstel van veerkracht van deltanatuur is nodig

17 februari 2022 • Achtergrondverhaal • Leestijd 4 minuten

Het gaat niet goed met de deltanatuur in Nederland. Meer ruimte en dynamiek, meer eb en vloed, meer zout en zoet overgangen zijn nodig om de deltanatuur gezonder te maken. Hiervoor ontwikkelde Staatsbosbeheer de Natuurwinststrategie deltanatuur. In de Grevelingen laat ecoloog Sander Terlouw zien waarom dat nodig is.

Figure 3 (right): News snippet (Staatsbosbeheer, 2022)

1.2. The Wieringerhoek

With the closure of the *Afsluitdijk* in 1932, the former *Zuiderzee* (= Southern Sea) estuary was transformed into the freshwater Lake *IJsselmeer*. The *Afsluitdijk* became a hard border between the IJsselmeer (fresh water) and the Waddenzee (salt water). This change in ecosystem provided safety, drinking water resources and also created agricultural land, with an accommodating decline in supply of nutrients (de Leeuw *et al.*, 2021). The estuarine gradient became an abrupt transition, which consequently lead to a loss of the characteristic habitats and their corresponding plant- and animal species (de Boer and Wolff, 1996).

At the key point of this transition zone is the *Wieringerhoek* (figure 5), which forms the area of interest of this study. In the *Wieringerhoek* there are many opportunities for improving the estuarine landscape for fishes and birds. There are multiple opportunities to connect surrounding landscapes such as the *Waddenzee* and natural landscapes in the *Wieringermeerpolder* with the *Wieringerhoek*. Another important function of the *Wieringerhoek* is recreation. The *IJsselmeer* is used for various forms of water recreation, including boating, sailing and kiting. In the *Wieringerhoek* there are ports for recreational boating in *Den Oever*, *Medemblik* and *Enkhuizen* (Mandemakers, van der Winden and Klinge, 2019).

Next to the lack of a fresh-salt water gradient there is only one habitat type that dominates the Wieringerhoek: deep open water. Damming and fixing the water table prevented the development of emergent vegetation and caused steep water-land gradients (Lammens *et al.*, 2008), lacking of any soft transition, which gives a low habitat diversity in the area, which is concerning for both fish and birds. The lack of a natural litoral zone results in a lack of breeding space for birds and little variation in food. (Mandemakers, van der Winden and Klinge, 2019).

The Ministry of Infrastructure and Water proposed a goal for the *IJsselmeer* for 2050 (Ministerie van Infrastructuur en Waterstaat, 2018): "*to make the area so resilient that the ecosystem is can withstand the effects of climate change and sustainable usage resiliently.*" The Wieringerhoek project contributes to the agenda 2050. Two complementary goals were stated at the starting point of the project (van Leijenhorst, 2019). First to strengthen the delta character of the IJsselmeer-Waddenzee connection by creating natural transitions. The secondary goal is to contribute to the protection of freshwater supplies in the IJsselmeer, by creating a more resilient system that can deal with salinity fluctuations.

"Recovery of Nature in the Delta helps the Netherlands protect to rising sea levels

NIEUWS

Herstel natuur in delta helpt Nederland beschermen tegen stijgende zeespiegel

Nederland heeft een unieke kans om de verloren deltanatuur in Zeeland en Zuid-Holland terug te brengen en tegelijkertijd het landschap te beschermen tegen de stijgende zeespiegel. Door natuur en water de ruimte te geven ontstaat een groene kustverdediging als alternatief voor hogere dijken, dammen en meer stortsteen. Een open verbinding tussen zee en rivier en herstel van zandplaten, kwelders en schelpdierbanken geeft ook trekvogels en -vissen een toekomst in de Nederlandse delta.

Dat staat in het Living Planet Report 'Zoute en Zilte Natuur in Nederland'. Het rapport is een samenwerking van het Wereld Natuur Fonds (WNF) met de soortenorganisaties, Sovon en Naturalis Biodiversity Center. Het tweede rapport over trends in dierpopulaties in Nederland concentreert zich dit keer op de Zuidwestelijke Delta, Waddenzee, Noordzee, kustzone en de duinen. Niet eerder werden voor deze gebieden zoveel data van onderzoeksinstellingen en de soortenorganisaties over diersoorten samengebracht en geanalyseerd.

Figure 4 (right): News snippet (DUIKEN, 2022)

1.3. Objective

This landscape design research aims to improve the estuarine gradient in the *Wieringerhoek* and, by doing so, improve biodiversity and water quality. This will be done with softer transitions between ecotopes, that form new habitats of themselves (ecotones). This results in an ecological transition between the freshwater ecotopes of the *IJsselmeer* and the saltwater ecotopes of the *Waddenzee*. The objective of this thesis will be:

"To improve the estuarine gradient in the Wieringerhoek and, by doing so, improve biodiversity, water quality and create a resilient transition between freshwater and saltwater ecotopes."

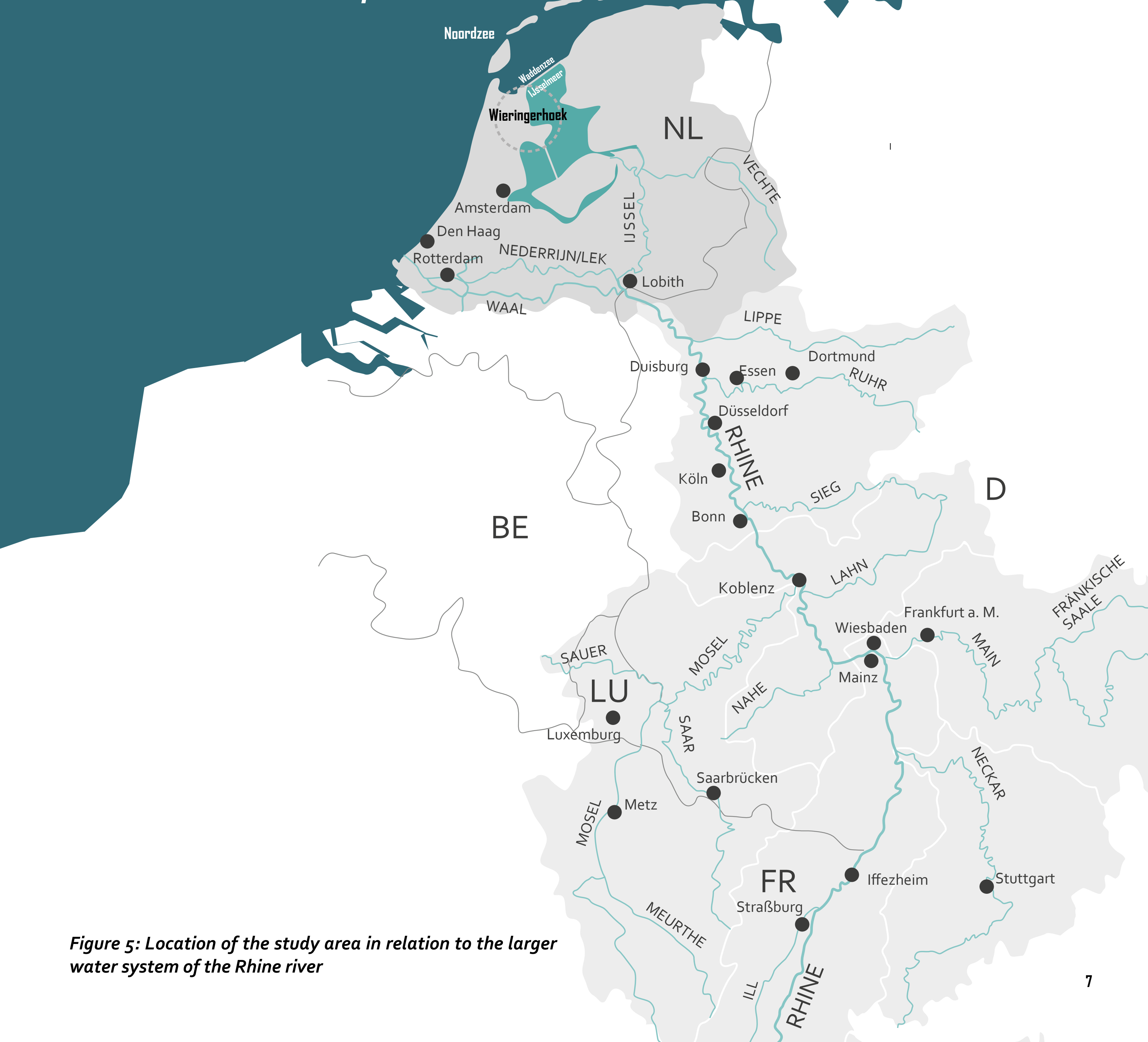


Figure 5: Location of the study area in relation to the larger water system of the Rhine river

1.4. Knowledge gap

The knowledge gap addressed in this thesis is the playing field of fresh- and saltwater. Studies and projects are done on the freshwater marshes in the *Markermeer* (adjacent to the *IJsselmeer*) area *Marker Wadden* project (De Rijk & Dulfer, 2020; IJff et al., 2021). In the Netherlands saltwater marsh projects were also realised by EcoShape in the *Proefkwelder Marconi* (Leuven et al., 2021). Other salt marshes were realised on a larger scale in *Grevelingen* (Terlouw & Lammerts, 2021). This thesis addresses both of these ecotopes and the in-between stage, which is the focus of this research (figure 6).

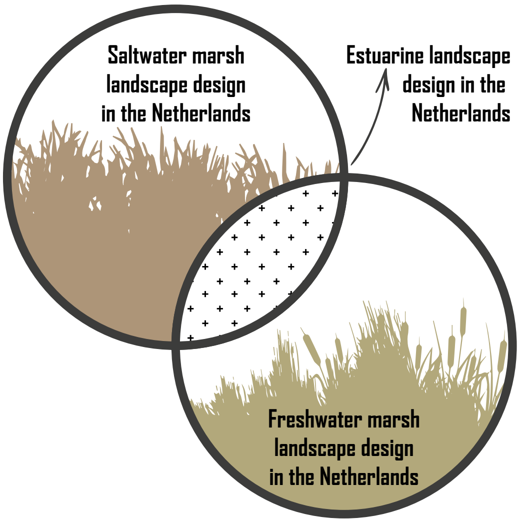


Figure 6: The knowledge gap

1.5. Research Questions

Landscape interventions will be researched through the *building-with-nature* approach (EcoShape and One Architecture, 2020). The balance between fresh and salt water also rises an opportunity for the unique habitats that are currently basically non-existent in the *Wieringerhoek* (Mandemakers, van der Winden and Klinge, 2019). To reach the determined objective, the building with nature approach will be integrated in the GeoDesign framework by Karl Steinitz will be used for its integration of expert involvement and iterative design process. The Steinitz framework is based on six questions and six corresponding models (Steinitz, 2012):

1. How should the study area be described in content, space, and time? (representative models)
2. How does the study area operate? (process models)
3. Is the current study area working well? (evaluation models)
4. How might the study area be altered? (change models)
5. What differences might the changes cause? (impact models)
6. How should the study area be changed? (decision models)

When the questions are rephrased for the Wieringerhoek, they give an overview of the research of this thesis.

Figure 7: Driving along the Wieringermeerdijk

1. How should the *Wieringerhoek* be described?
2. How does the *Wieringerhoek* operate?
3. Is the current *Wieringerhoek* working well?
4. How might the *Wieringerhoek* be altered?
5. What differences might the changes cause?
6. How should the *Wieringerhoek* be changed?

Allthough the six questions are a viable way of undertaking the research, the first three questions form part of the traditional landscape analysis of Wageningen University. The last question is used to come to the final design, and will be further informed by an external supervisor from *Witteveen+Bos* and relevant stakeholders that have expert knowledge on the *Wieringerhoek*. The fourth and fifth questions are used as specific research questions to answer the following design question.

Main Research/Design Question:

How can landscape design interventions improve the estuarine gradient in the Wieringerhoek and, by doing so, improve biodiversity?

Specific Research Question 1:

What landscape interventions can improve an estuarine gradient?

Specific Research Question 2:

What differences might the changes cause to the Wieringerhoek?

Figure 8: The way towards Den Oever

CHAPTER 2
Methodological and Theoretical Framework

2.1. Introduction

The first three questions from Steinitz framework will be answered in the traditional landscape analysis and form a part of the design process. The first question will be answered by creating **representation models** that will form the inventory of the current landscape. These representation models will be used to analyse how the landscape functions to get to **process models.** These processes will be evaluated based on the stated problems (lack of biodiversity and recreation) in **evaluation models.**

Specific Research Question 1: How might the Wieringerhoek be altered?

The first research question will be answered by research on the various ecotopes that are possible or already exist in the IJsselmeer. Various landscape interventions will be explored with the **change models.** These change models will be a set of design guidelines for to inform the second research question:

Specific Research Question 2: What differences might the changes cause?

The **impact models** will consist of various design models based on the proposed design guidelines of SPRQ1. Their impact will be modelled and assessed by an expert judgement.

Decision models will be the basis of the answer to the main research question ***"How can landscape design interventions improve the estuarine gradient in the Wieringerhoek and, by doing so, improve biodiversity?"***

These can be adjusted and go through the six steps (or some of the steps) again, or when a suitable model is selected it can be further developed in the final design. This will naturally flow in the **final design.**

The **final design** will be a more detailed version of the chosen decision model, with more emphasis on routing and potential landmarks. This will be created as a masterplan with corresponding cross sections and visualisations.

As discussed in Research Methods for Landscape Architecture Chapter 4 (Lenzholzer, Duchhart and Brink, 2016), Geodesign is not very intuitive. However, it does offer ways to analyse the landscape and use the analysis again when using modelling again during the design phase. Due to the scope of this thesis, simpler models are used to predict landscape change and ecosystem services.

2.2. Building-with-Nature

The Delta Committee presented an integral strategy for the long-term protection of the Dutch Rhine/Meuse delta and North Sea coast. Recommendations were made for the development of the coast and the Dutch hinterland: the delta program was born (Deltacommissie, 2010). The committee incorporated the two cornerstones of flood protection: '*building with nature*' and '*room for the river*'. The '*building with nature*' approach moves away from engineered coastal protection structures such as levees and surge barriers, relying instead on beach nourishment and growth (Kabat *et al.*, 2009).

'*Building with Nature*' is an approach that focuses on resilience and ecosystem services (Kamphuis, 2006; Kabat *et al.*, 2009; Aarninkhof, S G J, Dalfsen and Rijks, 2010; Waterman, 2010). *EcoShape* develops and shares knowledge about Building with Nature: a new approach to hydraulic engineering that harnesses the forces of nature to benefit environment, economy, and society. Many lessons learned from these projects have been collected by *EcoShape* after various projects were completed. These lessons were transferred in the five Building with Nature Design Guidelines, of which the first four will be used in this design research (De Vriend and Van Koningsveld, 2012):

Step 1: Understand the system (including ecosystem services, values and interests).

Step 2: Identify realistic alternatives that use and/or provide ecosystem services.

Step 3: Evaluate the qualities of each alternative and preselect an integral solution.

Step 4: Fine-tune the selected solution (practical restrictions and the governance context).

Step 5: Prepare the solution for implementation in the next project phase.

The realisation of freshwater marshes with the building with nature approach is shown in the Marker Wadden project. The wetland was constructed with sediment from the *IJsselmeer*. Sediment is dredged from the bed, and the resulting slurries are pumped into the project area (IJff *et al.*, 2021). Its large-scale development of new nature has been praised. Where in large parts of the world the emphasis is mainly on protecting nature, Marker Wadden shows building new nature is also a viable possibility (Xiong and Visser, 2018).

Saltwater marsh creation in the Netherlands has also been explored with the *building-with-nature* approach in the Netherlands (the Southern Delta in Zeeland). This approach has proved to restore the quality of the habitats and their closest surroundings to some extent. It influenced the availability of food and the time birds spend in these areas foraging for food (Granda, 2018). if future sea-level rise is on the higher side of the predictions, the initial investment becomes more cost-effective as less maintenance is necessary and a more robust system will develop which is in equilibrium with the dynamics (Wiersma *et al.*, 2014). Nature-Based Solutions offer potential to increase saltwater marshes in coastal wetland areas. Nature-based coastal defense is supporting nature and its biodiversity, and can secure ecosystem services for human wellbeing (Baptist *et al.*, 2021). Construction of salt marshes and the stimulation of salt marsh growth makes a positive contribution to the landscape value, recreational opportunities, coastal defenses and natural values. In addition, net CO2 and nitrogen are captured in salt marshes (Leuven *et al.*, 2021).

Building-with-Nature based wetland design and construction can contribute to sustainable water management, improve local ecosystems, and provide greater resilience for river deltas in storms and floods (Xiong and Visser, 2018). The strategy does not only create basic water safety: the integrated approach also includes provisions for freshwater supplies, the preservation of natural and recreational areas, and sustainable energy (Kabat *et al.*, 2009). However it must be noted that many costs and benefits of the *Building-with-Nature* approach remain elusive, which is true for both large-scale effects for which elaborate hydrodynamical modelling studies are necessary as small-scale effects of measures (Noordhuis *et al.*, 2019).

2.3. GeoDesign

The constant impact of water makes designing in this area challenging. This thesis will incorporate GeoDesign (Flaxman, 2010): "*GeoDesign is a design and planning method which tightly couples the creation of a design proposal with impact simulations informed by geographic context*." Geodesign as an idea has the potential to enable more effective and symbiotic collaboration between the geographically oriented sciences and the multiple design professions, such as landscape design research.

In his recent book *a Framework for Geodesign* (Steinitz, 2012), gives designing in research and in inter- and trans-disciplinary interactions a much more prominent role. The book presents the most recent and expanded iteration of the Geodesign framework. Although the framework itself was already presented in 1990 (Steinitz, 1990). The framework proposes six questions (figure 9) that must be addressed at least three times , first in forward order, then in backward order, and then one last time downward (Steinitz, 2012).

These six questions are specified for the study area, each question is associated with a modelling step, which will form the basis of this research (see figure 9 for the full flowchart of this design). The first three questions form the landscape analysis of the research, the fourth and fifth questions are specifically mentioned as research questions in this thesis. The final question is used to inform the decision to make a final design.

Landscape Analysis

Representation models, the data upon which the study relies. This will be presented similarly to the triplex model (Kerkstra et al., 1976). The first layer will be the hydromorphological model of the Wieringerhoek, the second layer will be the ecological model of the Wieringerhoek and the third layer the occupation of the Wieringerhoek.

Process models, look at how the layers of the representation models interact. Processes that drive the development of the study area are described.

Evaluation models, show the functioning of the study area with respect to the problems proposed in the *main research question* (salination, lack of biodiversity and pressure of the recreation) a multicriteria Analysis (MCE) is a powerful tool (Pietsch, 2012), that will be used to assess the functioning of the study area. This will inform the landscape design of the problem on a specific site.

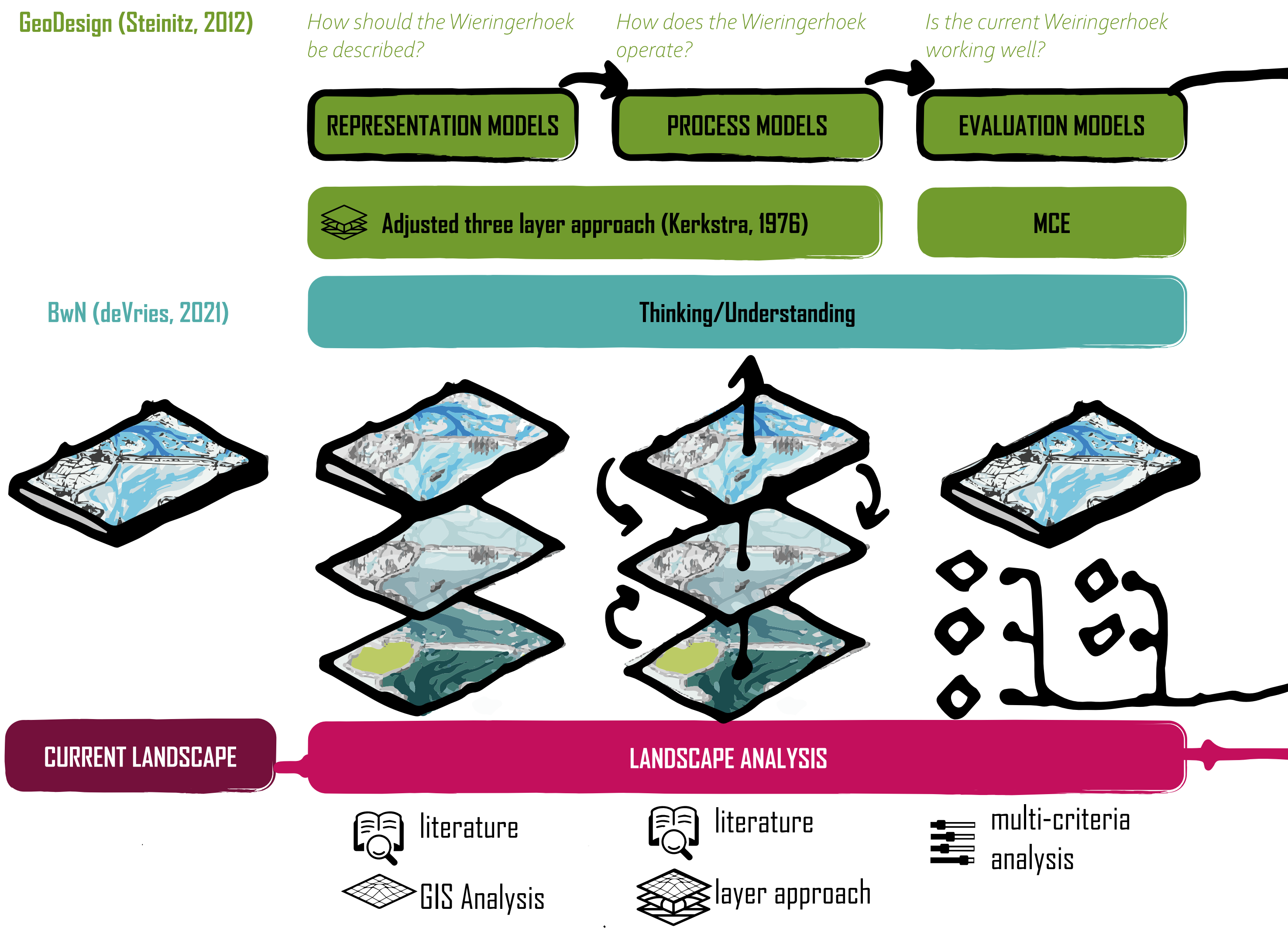


Figure 9: The methodological framework

Landscape Design

Change models (SPRQ1), change models are tools to change the landscape or how to improve or diversify ecotopes. These models will be based on literature research on the ecotopes in the IJsselmeer, but also on ecotopes that are not yet realised in the IJsselmeer. This will lead to a set of landscape design principles and guidelines for the development of estuarine ecotopes.

Impact models (SPQR2), these are directly related to the process models, and can be considered the process models of the future. Landscape design guidelines from the *change models* will be explored through sketching various conceptual designs. These will be assessed and if necessary, also adjust the change models. These models will be assessed during an expert judgement.

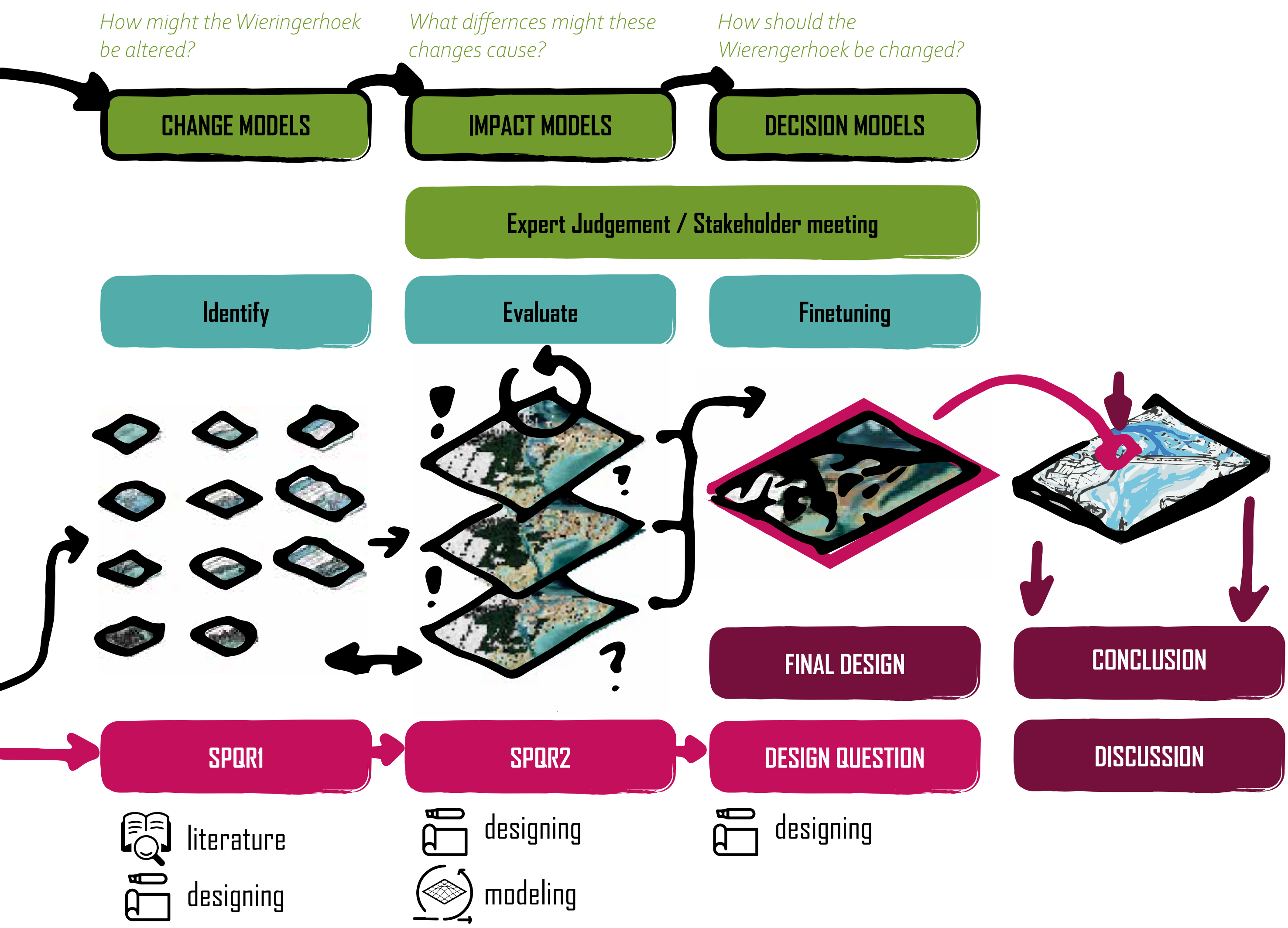
Decision models (DQ/MRQ), this will form the answer to the design question of this research. The design will be adjusted with the input from the change and impact models.

2.4. Expert Judgement

Experts are indispensable in modern organizations. They fill gaps in data and in the understanding of existing or missing data. They introduce, apply, and teach techniques and methods, some of which staff of the experts' principals - and ultimately others will continue to employ and disseminate. Technical experts reduce uncertainty by working out consensus opinions and probability ranges. Policy experts unravel the preferences and capacities of stakeholders; by doing so they dampen excessive certainty and may increase uncertainty in strategic ways that decision-makers and analysts find productive. When experts give their opinions in a context of decision-making, these become expert judgments.

Expert judgement plays an important role in forecasting and elsewhere, as it can be used to quantify models when no data are available and to improve predictions from models when combined with data. In order to provide defensible estimates of unknowns in an analysis, the judgements of multiple experts can be elicited (Wilson, 2017). For this research four experts were selected with a variety of expertise

- Perry Cornelisen – Ecologist at *Staatsbosbeheer*
- Marinus Bokhorst – Water specialist from *Rijkswaterstaat* involved in the *Wieringerhoek Project*
- Tom Wilms – Senior Nature-based Solutions in Integrated Coastal Zone Management at *Witteveen+Bos*
- Stijn Tijhuis – Landscape Architect at *Witteveen+Bos*



2.5. The Estuarine Gradient

An estuary is the transition area between the river(s) and the sea, the main characteristics of which are the influence of the tide and a gradient from freshwater to saltwater (de Leeuw and Backx, 2001). It consists of three zones (figure 10): a freshwater tidal area (1), a central area where fresh river water and salt seawater mix (2), and a coastal zone (3) (Day *et al.*, 1988). In the former Zuiderzee there was a gradual fresh-salt gradient from riverine waters from the Rhine in the south (mouth of the Rhine) to the Marine northern waters (The current *Waddenzee*) (Mandemakers, van der Winden and Klinge, 2019).

The necessity and duration of acclimation between fresh and salt habitats are unknown for many fish species. However, since small fish or fish larvae have a relatively large skin surface compared to their contents, it seems plausible that a more gradual adaptation to salt-sweet gradients for the small fish species and young life stages is most likely (Winter, Griffioen and van Keeken, 2014).

Salinity forms an essential determinant of species variety and species richness in estuaries and coastal areas (de Leeuw and Backx, 2001). Generally speaking, the salt water zone itself has a lower biodiversity (Whitfield *et al.*, 2011), this is because only specialised species can survive in this highly dynamic environment (Tangelder, Winter and Ysebaert, 2017). In estuarine environments, this effect is further strengthened by the higher dynamic of changing water levels and salinity, which makes the saltwater zone less biodiverse, then when there is a fresh salt water system present (Attrill, 2002). Traditionally, the various estuary habitats are defined based on salinity through the Venice System (figure 11); the classification shows 5 zones. However a more modern classification by Bulgers (figure 11) suggests by overlapping zones that factors other than salinity, such as substrate and turbidity, play a role in the distribution of species in an estuary (Bulger *et al.*, 1993).

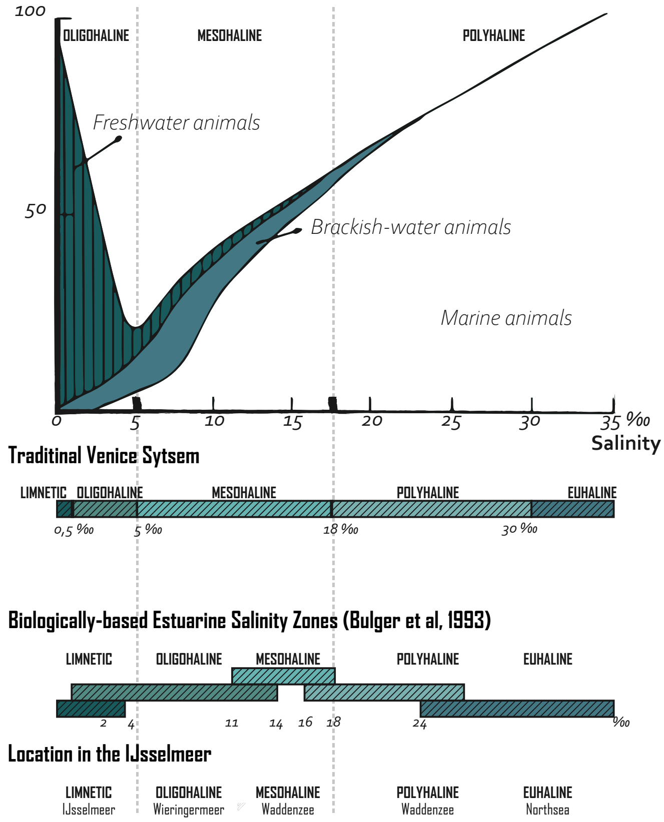


Figure 11: Salinity zoning in a natural estuary

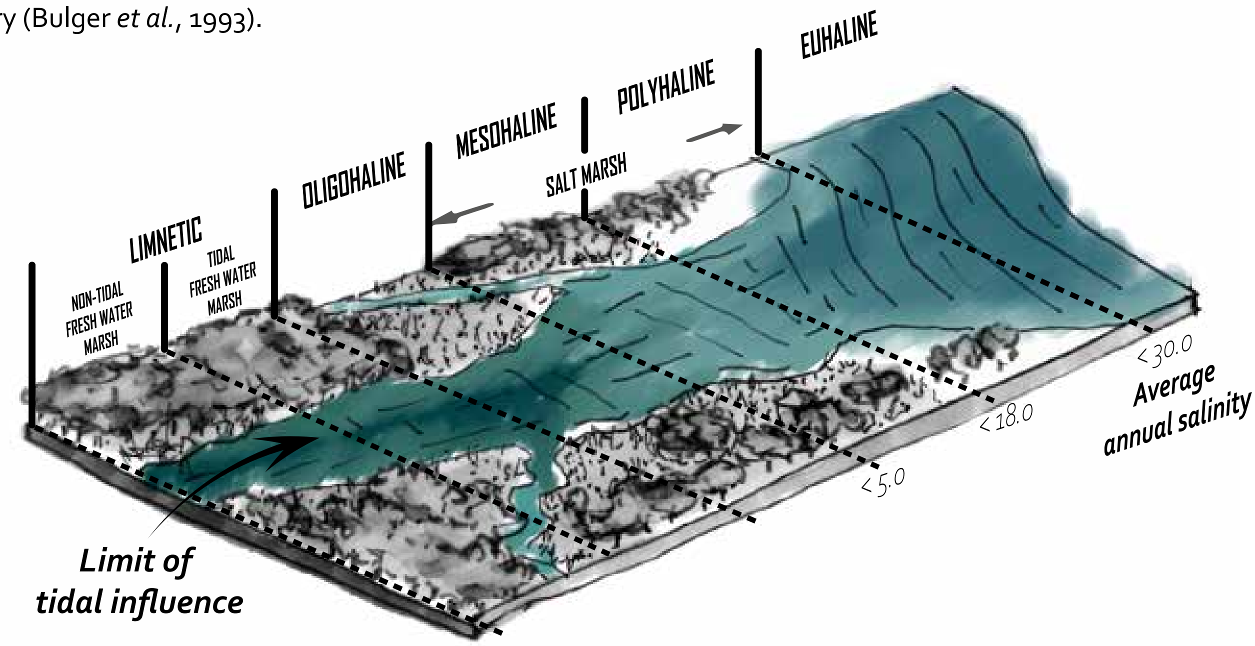


Figure 10: A natural estuarine gradient

2.6. Estuarine Ecotopes

Ecotopes are a classification system based on the smallest ecologically distinct landscape units with relatively homogeneous, spatially explicit abiotic landscape characteristics. Ecotopes have distinct characteristics and can therefore be considered representative of other functions and for the delivery of particular Ecosystem services (Ingegnoli, 2002). For environmental research, policy and conservation purposes, it is helpful to classify ecosystems or geographic areas into distinct spatial units based on geographical and ecological criteria (Frissell *et al.*, 1986; Dankers *et al.*, 2012).

The ecotopes between the marine saltwater and riverine freshwater habitats form a unique habitat due to the estuary's characteristics that form an unique combination of physical, chemical and biological features. They are distinguished by exceptionally high productivity (Alimov, 2007). These ecotopes function as natural evolutionary and biogeographic barriers (Khlebovich, 1974, 1990).

The functions of natural estuaries with various salinity zones are as the follows:

1. Estuaries serve as both pollution sources for the open sea and marginal filters for the polluted runoff from the river drainage basin (Lisitzin, 1999; Schiewer, 2002);
2. Ecologically diverse ecosystem, world's most productive natural habitats;
3. Estuarine habitats protect streams, river channels, and coastal shores from excessive erosion caused by wind, water, and ice.

The intensity of the functions of estuarine ecosystems mentioned above is greatly defined by the estuarine salinity gradient (Telesh and Khlebovich, 2010).

Because this thesis aims to restore the estuarine gradient between the *IJsselmeer* and the *Waddenzee*, both freshwater and saltwater ecotopes must be considered. In the "*Verkenning Wieringerhoek Basisstudie systeemfunctioneren"* six ecotopes have been appointed as particular of interest to create in the *Wieringerhoek*, for their attractiveness to certain bird species (Mandemakers, van der Winden and Klinge, 2019), these can be seen in table 1. Coastal habitats such as tidal areas and salt marshes are ranked among the most important habitats in the Netherlands regarding ecosystem services (Temmerman *et al.*, 2013).

Although this thesis aims to improve the estuarine gradient of the IJsselmeer, the focus area is the *Wieringerhoek* and freshwater ecotopes and transitional ecotopes will form the focus of this research. The *Waddenzee*, as the main salt water ecotope will have minimal or no design interventions. For the research the zes.1 system for the salty waters (Bouma *et al.*, 2005) and the rws system for the freshwater ecotopes (van der Meulen, 1997) will be used to identify the ecotopes and their characteristics. The current ecotope presence is shown in table 1.

In most of the Wadden Sea ports, the release of freshwater runoff from the hinterland within the ports contributes significantly to the maintenance dredging requirements by strengthening sediment import from the sea. The concept of creating estuarine gradients was developed to resolve this issue. It consists of creating bypasses around a port, creating more gradual salinity transitions and accompanying natural variations, whilst at the same time improving fish passage possibilities. These solutions form a win-win situation by reducing maintenance dredging and improving the natural quality (Dankers *et al.*, 2012).

Ecotope	*Example species*	*Presence Wieringerhoek*
Fresh shallow waters	grebe, common tern, little tern, avocet, spoonbill, giant tern, osprey, black-tailed godwit	Barely present
Fresh water depth/ channel	Greater Scaup, black tern, common tern, merganser, nun	Present
Fresh helophyte marsh	bittern, mustache, spoonbill, black-headed gull	Not present
Pioneer birds from open sandy islands	sand plover, common tern, little tern, avocet	Barely present
Brackish waters and shallow areas	grebe, common tern, little tern, avocet, spoonbill, black tern, Greater Scaup, split merganser, osprey, nun, bar-tailed godwit	Not present
Brackish helophyte marsh	bittern, spoonbill, shelduck, graylag goose, black-winged stilt	Not present

Table 1: Ecotope pressence in the Wieringerhoek

2.7. Estuarine Biodiversity

Being transitional areas, estuaries are rich in gradients of processes and environmental factors:

1. Between the hydromorphological dynamics of the river and the sea;
2. between fresh riverine fresh water and marine saltwater;
3. between river sediment and marine sediment.

A consequence of the *Afsluitdijk* (dam) is that it blocks the fish migration route from the river to the sea and vice versa. Furthermore, the regulated constant water level and steep dikes and dams prevent the development of littoral vegetation, as flood plains are absent (Lammens *et al.*, 2008). With the restoration of fresh-salt transitions biodiversity will be increased, and the number of characteristic flora and fauna species and biotic communities will increase (Raad voor de Wadden, 2008). These biodiversity improvements are to create the ecotopes in table 1, attract the related bird species, and accommodate fish migration from the *Waddenzee* and *IJsselmeer*.

Although the brackish and semi-brackish habitats themselves do not offer the highest biodiversity, they offer space for more rare species. The increased biodiversity in a natural estuary comes from the sum of the environments and the transition zones (de Leeuw and Backx, 2001). High biodiversity means higher genetic variation, a necessary condition for evolutionary adaptation to a changing environment and survivability (Begon, Howarth and Townsend, 2014). For migrating fishes between the two systems the salinity gradient is helpful for fish to orient themselves towards the sweet water (Jager, 1998).

Species richness is the simplest way to describe community and regional diversity (Magurran, 1988), which makes it a natural measure of biodiversity (May, 1988). Boundaries of ecotopes, characterized at the spatial scale of hectares (Forman, 1995), often correspond to species distributions (Reed, O'Connell, Michael and Murphy, 1997), different types of ecotopes would differ significantly from each other in their species composition and thus have a higher species richness. The landscape cohesion and variation of the ecotopes are an essential aspect of the structure and function of Estuarine Habitat, according to *the ministry of Agriculture Nature and Food Quality* (Netherlands). The quality of the habitat type is determined by this ecotope diversity and the associated biodiversity. Many species spend part of their life cycle in different areas within the habitat type. (Ministerie van Landbouw Natuur en Voedselkwaliteit, 2016). This makes number of hectares of different ecotopes an indicator to estimate biodiversity.

The sizes of the marshes are based on its impact on water quality. For this the research reports by Asjes (2000) and Pohnke et al. (2018) were used as a starting point for the saltwater and freshwater marshes respectively. A brackish zone can make a significant contribution to the recovery of natural processes that are characteristic of the fresh-salt transition in an estuary, which is based on a large area, of up to 5% (figures 12 an 13 for more subdivisions) of the *IJsselmeer* (Asjes, 2000). To have an effect on the water system level, the surface with freshwater helophyte swamp should amount to approximately 5 to 10% (figure 14; and figure 15 for more subdivisions) of the total lake surface (Pohnke et al., 2018).

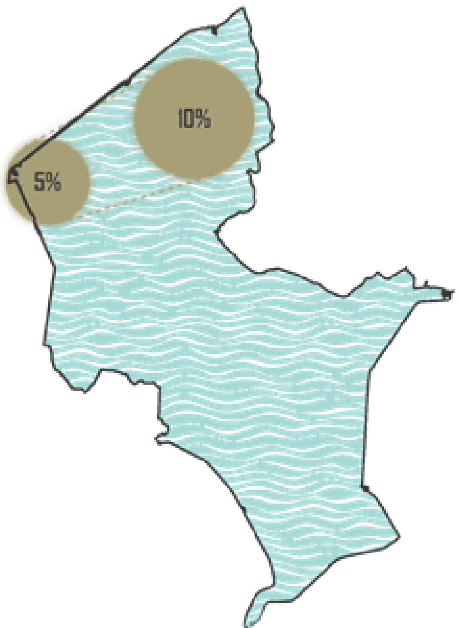


Figure 12: 5 - 10% of IJsselmeer as a freshmarsh

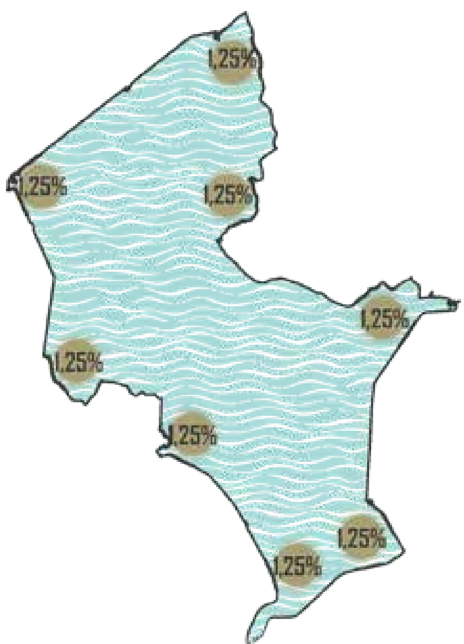


Figure 13: Multiple spots in IJsselmeer as a freshmarsh

2.8. Safety Regulations

The importance of the IJsselmeer for the freshwater supply for agriculture and nature of a large part of West, North and East Netherlands makes salination of the area a sensitive topic (HydroLogic, 2021). In addition to the freshwater function, the lake has a drinking water function. Because of the safety consideration of the freshwater demands, the IJsselmeer will not return to its original brackish status (Lammens *et al.*, 2008). The salinity concentration is defined as an indicator of the *Kaderrichtlijn Water* (*Water Framework Directive*) and should not exceed given norms (Twynstra Gudde and HydroLogic, 2019).

Salination is expected to increase by 2050 in the climate scenarios (especially the W+ scenario), due to rising drought problems (Bonte, 2009). Drought makes it easier for the salt water to seep in the *IJsselmeer* through the spuisluizen (= sea locks). This thesis seeks ways to incorporate the natural Estuarine gradient to get a more resilient system, while also keeping the *IJsselmeer's* freshwater reserve mainly intact. So designing in the area must be done in a smart way that makes sure the mixing of fresh and salt water does not become problematic for the drinking water and can be managed and regulated.

Hydromorphological alterations (the *Afsluitdijk* and *Wieringermeerdijk* for example) done to create a safe freshwater reserve of the IJsselmeer may be mitigated by various measures. For example these measures are fish passages, adapting shorelines, wind-sheltered areas and water level fluctuation (Lammens *et al.*, 2008). Currently the five main interventions to regulate water safety and quality in the *IJsselmeer* are (Lammens *et al.*, 2008):

1. The Afsluitdijk resulted in the change from estuary to freshwater lake;
2. The Wieringermeerdike forms a too steep gradient from land to water;
3. The Houtribdike the closure of the Houtribdijk (Fig. 1) prevented the distribution of the silt to IJsselmeer and changed the pattern of distribution in Markermeer as well;
4. Fixed Water level, seasonal water level fluctuation may be beneficial for the littoral vegetation. However, in the IJsselmeer area, natural water level fluctuation conflicts with safety and fresh water needs;

These measurements and regulations will be respectfully integrated in the design, and if possible be adjusted to suit the aim of this thesis.

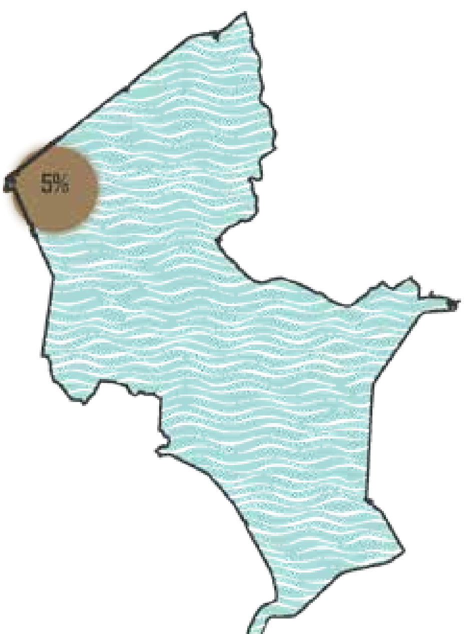


Figure 14: 5% of IJsselmeer as a saltmarsh

Figure 15: Twice 2.5% of IJsselmeer as a saltmarsh

Landsape
ANALYSIS

CHAPTER 3
Representation Models

3.1. Introduction

The Landscape Analysis has two aims in this study. First, put the study area in its relevant context. This context is the *IJsselmeer*. This because the whole lake influences the Wieringerhoek on various levels. It explains where certain landscape interventions are possible and not possible. The context of the study area provides reasons for the location of the potential of interventions. Secondly it provides the necessary foundation for the Landscape Design.

The first step, according to the Steinitz model, is the creation of representation models (Steinitz, 2012), these models form the data upon which the study relies. This is followed up by process models, they look at how the layers of the representation models interact. Processes that drive the development of the study area are described. Finally, the evaluation models, show the functioning of the study area with respect to the problems proposed in the *main research question*, that will be used to assess the functioning of the study area. This will inform the landscape design of the problem on a specific site.

3.2. Zuiderzee Origins

The origin of the IJsselmeer started in the Holocene (< 13 000 years ago, figure 16), which took place just after the last ice age. Landscape development is determined by a warmer climate and rising sea levels because of the melting of the land ice. In the Early Holocene, most of the *IJsselmeer* area was part of the deserted Pleistocene valley of the Rhine and Meuse. Sediment supply from the hinterland was lacking and the freshwater discharge was limited to the discharge of excess precipitation. In the low parts of this otherwise wooded cover sand landscape due to the lack of drainage with a continuous sea-level rise, peat swamps emerged.

(2) During the *Atlanticum* (around 7000 years ago, figure 17), the sea gradually intruded the estuary of *IJssel* and the (*Overijsselse*) *Vecht* and formed an important part of the current coastal plain. An inner delta formed in the current province of North Holland. East of this the now salty to brackish lagoon peat was covered with clayey deposits. With the rise of the sea level, the lagoon moved gradually eastwards, which drowned the present forests.

Due to further sludge covering in the coastal area and the formation of beach walls during the Early Subboreal (5660 to 2400 years ago), the area behind it gradually became isolated from the sea. It changed in an extensive peat bog. Initially, the *Overijsselse Vecht* and the *IJssel* (at this stage not connected to the Rhine) transverse through this peat swamp and independently of each other their water to the west through one of the last tidal inlets, the estuary of Bergen.

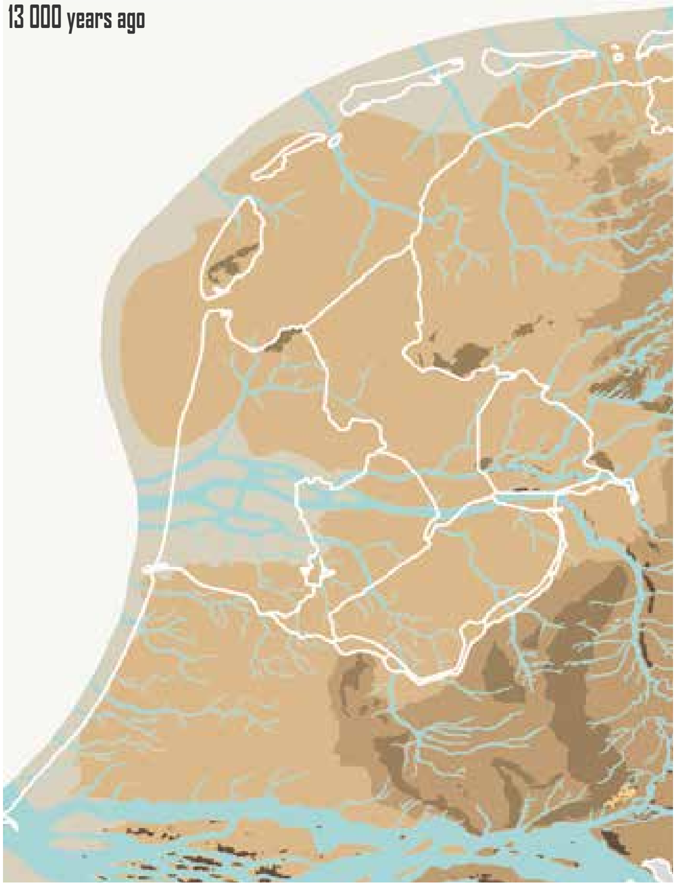


Figure 16: Pleistocene Rhine Delta

Figure 17: The Rhine Delta in the Atlanticum

Figure 18: The Rhine Delta in the Middle Subboreal

Figure 19: The Rhine Delta in and the Almere-Lagoon

The last series of intrusions from the sea into the *IJsselmeer* took place during the Middle Subboreal (figure 18). Because of the drainage problems, the freshwater lakes in the peat area became larger and became connected. Outside of here, the peat growth went unimpeded whereby a mosaic of low and high moors arose. These low and high moors were connected by narrow streams (Pons, 1992). Along the edges of the area, the peat expanded further.

The mouth of the *IJssel* has slibbed up gradually. The *IJssel* attempted to create a new way out to the sea, by bending at the height of eastern Flevoland southwards, where it emptied into a peat lake. This lake is considered one of the earliest stages of *Lake Flevo*. This lake enlarged due to the deteriorating drainage in the mouth area of the *IJssel* and it made contact with lakes in the *Eem* basin through narrow gullies.

The closure of this estuary marked an important turning point in the development of the *Zuiderzee* area. From the west, the sea had no more influence on the area behind and water drainage stagnated. Because the *IJssel* became connected to the Rhine they discharged more water (Zagwijn, 1971). The lakes enlarged at the expense of the surrounding peatland and grew together as a result. Roman writers called this lake complex, the Lake Flevo.

In the north Lake Flevo probably had a narrow connection with the sea through the *Vlie*. As soon as this connection became wider, the first marine clays intruded from the W*adden* region via the peatland in the southern lake area (figure 19). These clays became mixed with organic residues and became subsequently deposited in a fresh to brackish environment, the *Almere-Lagoon*. The emergence of new tidal channels increased the tidal influence in the IJsselmeer region (Sha, 1990). The tidal channels drained the surrounding peatlands, making these suitable for peat exploitation (Lenselink, 2001).

Peat formation came to an end in the precursor of the Zuiderzee, the Flevo lagoon, around AD 800 (Ente, Koning and Koopstra, 1986). In the 8th century, peat exploitations took place in the peat area between *Wieringen*, West-Friesland and *Caasterland*, just like in North Holland. This exploitation led to the settling and oxidation of the peat and thus to ground-level subsidence. As a result, the peatland got flooding problems and became vulnerable to sea influences. The narrow gullies became wider and wider, eroding peat and Pleistocene sands along the gullies. In the peat area, large parts of the peat complex were lost due to wind-wave erosion (Lenselink, 2001).

In the following centuries the connection between the sea and Lake Flevo improved (figure 20). The peat area in the mouth of the *IJssel*, located between *Wieringen*, West Friesland, and *Caasterland* largely disappeared. The narrow peat streams of the past turned into tidal channels. The decreasing organic matter content and the increasing sandy and/or clayey components in these deposits reflect the change from a freshwater swamp to a lagoon, the *Almere-lagoon* (Ente, 1971; Sha, 1990). In addition, a new peat exploitation wave between 1000 and 1600 resulted in a further land loss at the site of the current *Wieringermeer*. From the year 1200, the brackish to saline conditions were increasing.

Around 1340 the *Sudersee (former Zuiderzee)* was first mentioned. Around 1350 A.D., the dikes around the Zuiderzee largely had come into being. The North, West, and Southwest part of the Zuiderzee were already dominated then by strong marine influences. The eastern part of the Zuiderzee only became salinized in 1600, as a result of the strongly reduced discharge of the *IJssel*. By the mixing of fresh *IJssel*-water and seawater, there was a salt gradient of 2000 mg/l chloride in the south up to 15,000 mg/l chloride (brackish water) in the north at the tidal inlets.

Around 1600 A.D. the Zuiderzee got the size known to us (figure 21). Clearing the peat could increase the tidal volume in the northern inlet. A huge hunger for sand arose in the basin area: meters thick peat packages had been knocked away after all and the inland sea 'asked' for sediment supply. This sand hunger led to a further deepening of the tidal channels between *Wieringen* and *Friesland*. The erosion of the Pleistocene cover sand created sandbanks next to and at the ends of the channels. In the *Zuiderzee* and especially the southern part, there are clayey deposits with numerous marine shells.

In the *Zuiderzee* there was a large variation of tides, topography, and soil. At the tidal inlets, the mean tidal amplitude was 1.6 m, which decreased sharply in a southerly direction to a few decimetres in the extreme south. High water levels occurred during storm surges in the southern basin heights of 3.2 to 3.3 m -HNAP (Normal Amsterdams Peil). Brackish transition zones could be found at the mouths of the rivers and on places with sweet seepage (Lenselink, 2001).

The inhabitants of islands in the Zuiderzee area have a long tradition of living and struggling with the sea (Van Den Biggelaar *et al.*, 2014). Natural drainage induced by the degradation of the peat swamp initially created favourable conditions for habitation (van Balen, 2008). However these conditions decreased in due to salty inlets from the *Waddenzee* (van der Heide and Wiggers, 1954; Hogestijn *et al.*, 1994). Several floods from the *Zuiderzee* formed ultimately the reason for plans of the closure of the *Zuiderzee* (Lenselink, 2001).

Figure 20: Lake Flevo

Figure 21: The Zuiderzee

3.3. The change from Zuiderzee to IJsselmeer

(7,8) The Zuiderzee Works was a large-scale project that would change the topography, the environment, the associated processes, and the human use in the IJsselmeer area. In 1891 the plan was developed to create a dam in the neck of the Zuiderzee over a length of about 30 km. The closure decreased the risk of flooding, reduced the length of the coastline, and the water finally became possible to control. Due to the construction of the *Afsluitdijk* in 1932, the Zuiderzee was turned into the largest freshwater lake in Europe with an area of 350 000 ha (Lenselink, 2001). This also combated the previously mentioned degradation of the naturally drained peatlands (Wiggers, 1955). The construction of the Houtribdijk between *Lelystad* and Enkhuizen (1975) provided further compartmentalization where the *Markermeer* (69 293 ha) and the IJsselmeer (112 755 ha) were created.

Reclamation of these lands made an increase in agricultural land possible. The following polders were constructed in the *IJsselmeer* area: the *Noordoostpolder* (1942; 48 000 hectares). Eastern *Flevoland* (1957; 54 000 ha) and Southern *Flevoland* (1968; 43 000 ha). In 1918 the Closure Act made way for the partial reclamation of the Zuiderzee: the Zuiderzee Works (Lenselink, 2001). After the construction of the Afsluitdijk in 1932, the tidal basin area in the Western Dutch Waddenzee decreased from around 4000 Km^2 to 700 Km^2, and as it was predicted the tidal prism increased by 26% (Dastgheib and Roelvink, 2012).

The newly formed IJsselmeer sweetened due to the supply of water from the IJssel. The environment changed from brackish to sweet. In just 5 years , the chloride content decreased from 12 000 mg/l to 200 mg/l. Algae and zooplankton virtually adapted immediately. Saltwater fish as Herring and Anchovies disappeared within two years as a result of the reduced withdrawal options from the *Wadden*-Sea and the declining salinity. Eel, Spierings, and three-spined stickleback managed to maintain themselves and were even more numerous. Flounder and Sea trout also remained in the sweetening IJsselmeer. The sweet IJsselmeer offered options for water supply for drinking water and agriculture. Next to this, the IJsselmeer created favourable conditions for recreation shipping and sand extraction (Lenselink, 2001).

In addition to the decrease in salinity, the tide fell and was replaced by a more constant level which led to the

Figure 22: The Zuiderzee and water flow dynamics

diminishing of sediment supply. There was no longer a supply of clayey sediment to where the *Noordoostpolder* and the *Flevopolders* were constructed. The wind-driven current and the stirring of the water resulted in low cliffs or eroded banks. This steepness of the embankments hinders a gradual land-water transition. This effect is further enhanced by the fact that the water level is being held artificially high in summer. The riparian vegetation has little chance to expand during the growing season (and can therefore also not retain or capture sediment).

From 1939, seven years after its closure, the fish species in the *Zuiderzee* were changed to that of typical sweet, nutrient-rich open water. Perch, Zander, Bream, Roach and, Pos dominated the open water. The desalination of the riparian countries proceeded slower. Although most areas now are desalinated, along the Frisian IJsselmeer coast you can still encounter typical salty plant species.

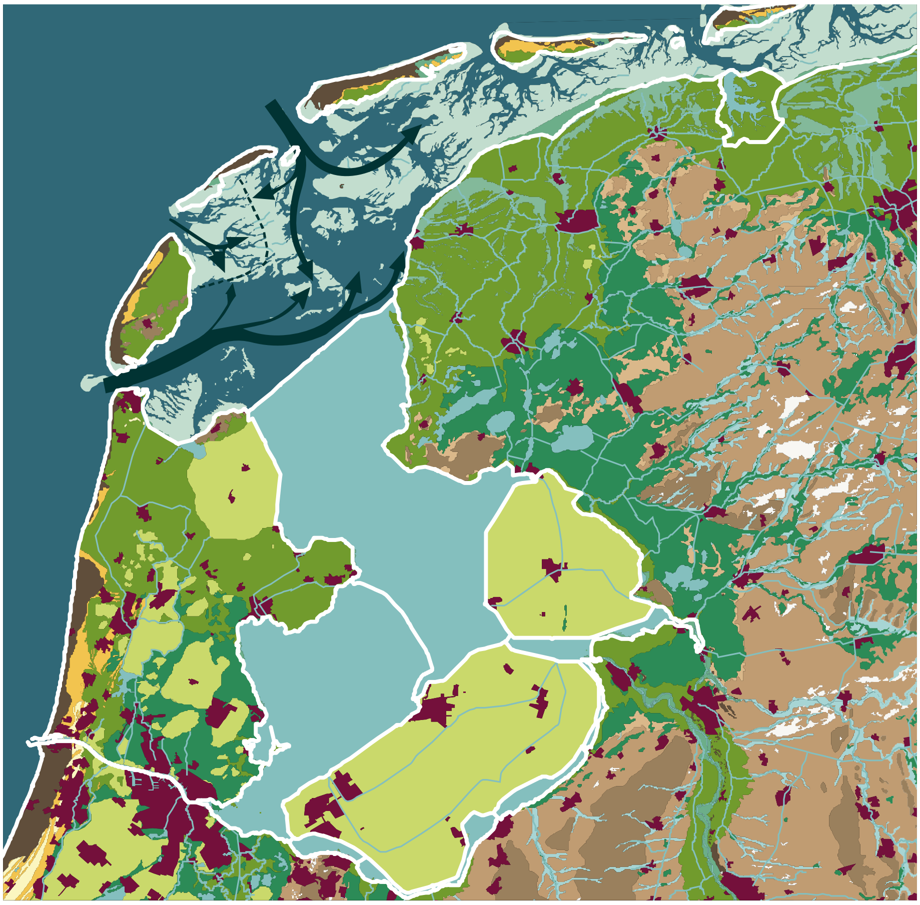


Figure 23: Changed water flows due to the Afsluitdijk

3.4. The Hydromorphological Layer

The hydromorphology of the study area is largely defined by human interventions such as the dikes and the dam: *The Afsluitdijk.* Closure dams such as *The Afsluitdijk* are traditionally used to protect tidal inlets, rivers and, estuaries from occasional storm surge events, and/or to provide possibilities to reclaim new land from the tidal basin area (Dastgheib and Roelvink, 2012). The *Afsluitdijk* is under the continuous influence of the sea, so just using sand to create the dike was not enough. This is why the dike mainly consists of boulder clays (Thijsse, 1972). The construction of the closure dam caused an instantaneous change in tidal wave dynamics which triggers extensive morphological changes on both sides of the dike (Dastgheib and Roelvink, 2012). This change in tidal dynamics is shown in figure 22 and 23 based on illustrations in the book *'Een halve Eeuw Zuiderzeewerken* (Thijsse, 1972).' This book gives an overview of the human interventions that led to the transition from the Zuiderzee to the IJsselmeer.

The closure distorted the autonomous behaviour of the inlet system drastically, large-scale effects in the hydrodynamics and consequently the morphodynamics were observed (Elias *et al.*, 2003). The current hydromorphology is the first layer of this research and can be seen in figure 25. The change caused by the creation of the *Afsluitdijk* may continue to cause morphological changes. Because of the grandiose of the interventions, they may continue for centuries before the whole system reaches a new 'equilibrium' state (Dastgheib and Roelvink, 2012). It can be concluded that human interventions on hydromorphology are thus substantial and defining for the area.

Water discharge in the direction of the IJsselmeer area mainly goes via the *IJssel*, the *Overijsselse Vecht*, the *Veluwe* brooks, and the *Eem*, but also via the *Vecht* and the pumping stations. The water system of the *IJsselmeer* is subdivided in 3 parts; the *IJsselmeer*, the *Markermeer* and the *Veluwe-Edge-lakes* (van Nieuwenhuijze *et al.*, 2011). A flexible water level management was introduced in 2018 (Rijkswaterstaat, 2018), which can be seen in figure 24. This is important to guarantee the freshwater supply for agriculture, drinking water, and industry but also to be able to respond well to climate changes.

The mainland surrounding the IJsselmeer is mainly divided into polders (Kosian, 2017) and peat reclamation fields (Bekius and Kooiman, 2016). The polders are areas of the *Zuiderzee* that were claimed for agriculture and the peat reclamation landscape originates from the reclamation from the 8th century. They are approximately at the same level as the shallow areas of the IJsselmeer bottom. The province of Friesland is mainly defined by the peat exclamation landscape and North Holland by the polder landscape. However both areas are expected to further subsidize (Van den Born *et al.*, 2016) with the peat areas as the most vulnerable part with an expected subsidence of 8 to 10 millimetres per year. Together with the rising sea level, this forms a toxic combination that requires resilient solutions both on land and in the water.

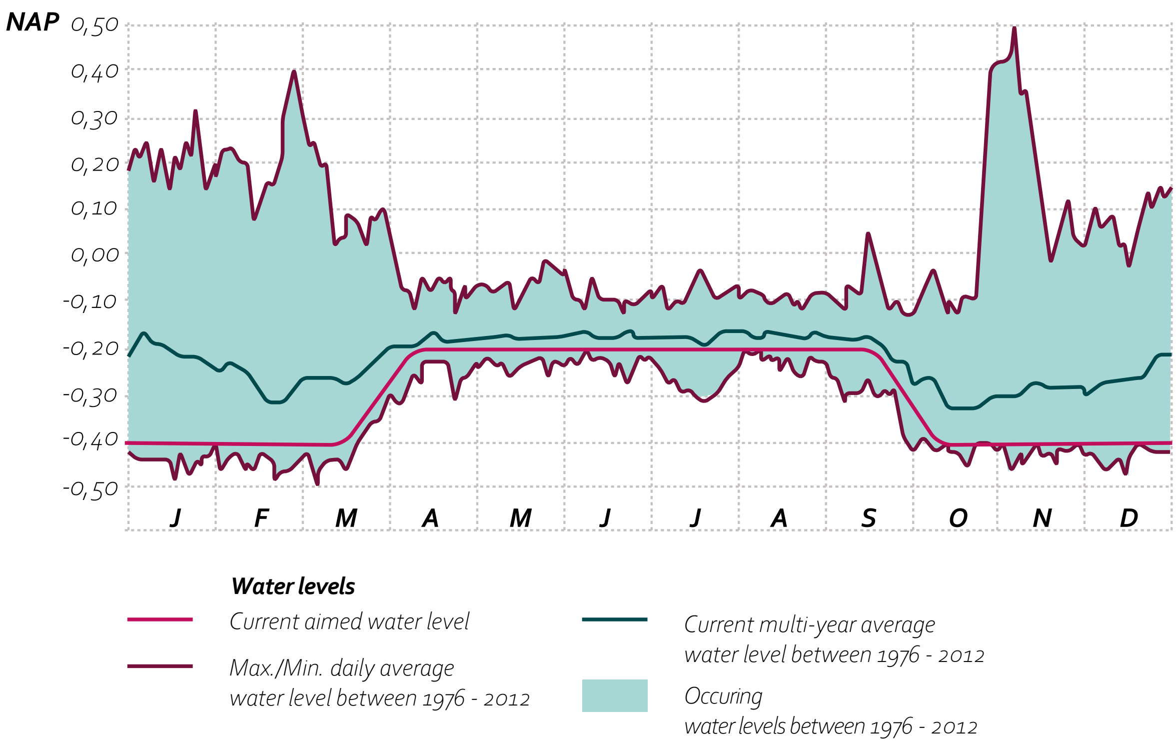


Figure 24: Water levels in the IJsselmeer according to Rijkswaterstaat (2018)

Legend

- The Peat Polders
- The Reclamation Polders
- Water flows

Figure 25: The Hydromorphological Layer

3.5. The Occupational Layer

Manmade structures (cities, dikes, etc) define the area as previously mentioned. The area is surrounded by dikes that define the water level in the area to protect the agricultural land lying beyond the dike. The location of these dikes is shown in figure 27. With the closure of the *Zuiderzee*, the *Zuiderzee* cities have lost their direct access to the North Sea. The IJsselmeer dikes along the older polders are developed over the centuries. These polders have a small-scale character, and contrast with the more tight coasts of the modern polders: the *Wieringermeer*, *Noordoostpolder*, and *Flevoland* with kilometres of straight coasts. The *Houtribdijk* cuts right through the former Zuiderzee as a symbol of a bygone ambition to acquire even more new agricultural land.

Recreation in the *Wieringerhoek* and the IJsselmeer area mainly consists of boating, sailing and kiting (Mandemakers, van der Winden and Klinge, 2019) but does not exclude walkers and especially cyclists (KAW architecten en adviseurs and Arcadis, 2006). However the recreation is mainly on the IJsselmeer itself, and together with commercial boating, they form the boat intensity (Eerden, Rijn and Roos, 2005), which is shown in figure 27. The fairways are there mainly to connect the various cities of the IJsselmeer and form a port to the North Sea.

Another big influence on the biodiversity of the study area comes in the form of windmills (figure 27). Close to the *Afsluitdijk*, there is a large windmill park. Although they do not have a direct influence on marine biodiversity once they are built, they do influence bird species. When talking about building windmills, the bird protection foundation of the Netherlands placed the whole *IJsselmeer* and *Waddenzee* area as a high-risk area for birds (Aarts and Bruinzeel, 2008). This means that they find the area too valuable for birds to add the stress of the windmills to the area. Currently, the windmills do not have a significant negative impact on the ecotopes near the windmills. This is due to the lack of other ecotopes than deep and very deep water (Heunks *et al.*, 2015). However, when looking at a potential design around this area, there could be significant negative aspects for especially bird species.

The Dutch Military also has a shooting field on the *Afsluitdijk*. They value an open water area to shoot, to make sure no boats or people are hit during their exercises. This is something to consider when designing the study area. There could be argued for removal or move of the shooting area in favour of the design.

The experience of the landscape also forms an essential part of decisions made for the *IJsselmeer* area. For example, rest and openness are valued and part of the agenda for 2017-2023 (Rijkswaterstaat, 2017). The integrated vision for the North Holland IJsselmeer coast in 2021of that was created by the municipalities of *Hollands Kroon*, *Medemblik* and *Enkhuizen* and the province of North Holland also takes openness as an important part of the area (Wing *et al.*, 2021). So this openness is an important attribute of the area that is highly valued (figure 26 shows the visual aspect of this openness).

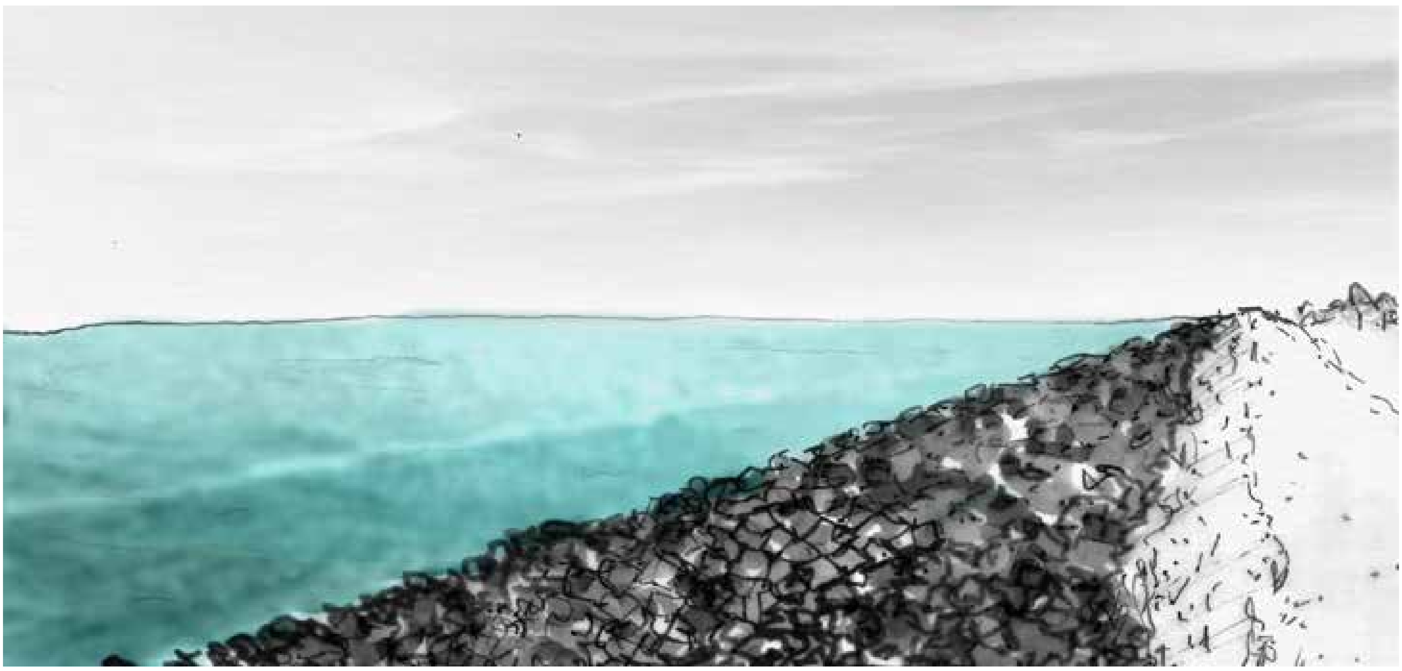
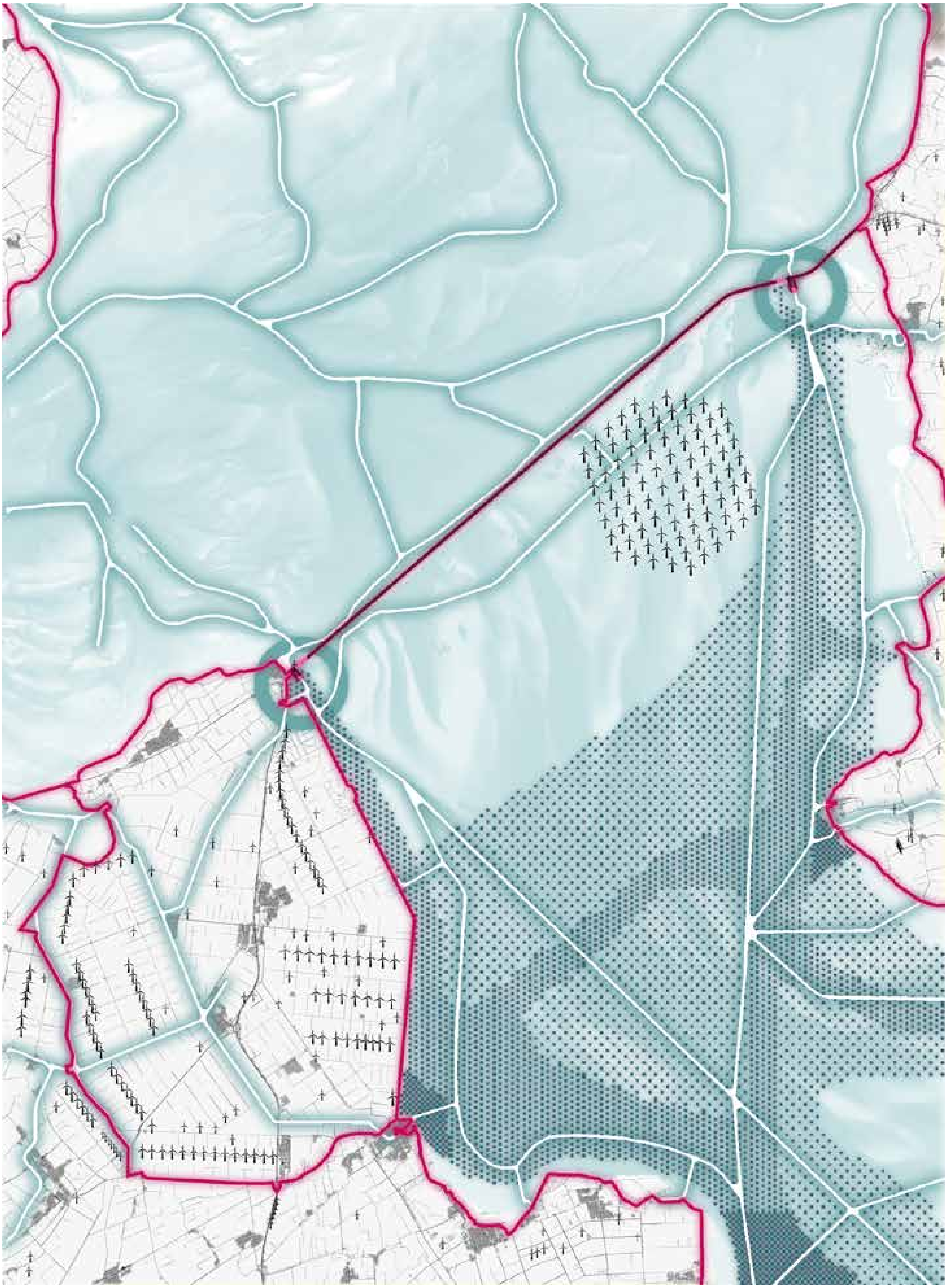


Figure 26: The openness of the IJsselmeer



Legend

- The Afsluitdijk
- Dikes
- Gulleys
- Windmills

Figure 27: The Hydromorphological Layer

3.6. The Ecological Layer

From an ecological point of view the IJsselmeer is not doing well. Numbers of birds (van Roomen *et al.*, 2012) and fish (de Leeuw, Dekker and Buijse, 2008) have decreased since the eighties. It seems that the IJsselmeer system is still looking for a new balance in species after the closure of the sea, in 1932. The water quality is also considered poor (Gaalen, Osté and Boekel, 2020) which can be seen in figure. The lake bottom itself can be categorized as a desert: flat sand, peat and/or silt soils, virtually without a 'third dimension'. While many dominant open water fish species (e.g. zander, perch, eel) do like some variation in height (Zijden et al., 2019).

Hard land-water transitions in addition to the homogeneity in, the abrupt transitions between different habitats also make it system vulnerable (Mandemakers, van der Winden and Klinge, 2019). Large parts of the IJsselmeer are bordered by basalt-clad dikes without natural shelter or foreshore. These areas are therefore unsuitable for flora and fauna that use a terrestrial and an aquatic habitat and thus need a gradual transition. Estuarine flora and fauna are currently not present in the *IJsselmeer*. It needs both a freshwater and saltwater habitat. The Afsluitdijk forms a hard barrier between these two habitats.

The water itself is relatively clear and rather nutrient-rich. Zebra mussels form the most important food source for water birds. The IJsselmeer also acts as an important stopping place for various traveling bird species. Although this is accompanied by a lack of breeding opportunities for bare ground brooders, such as terns, which depend on bare sandbanks for breeding (Directoraat-generaal Rijkswaterstaat, 2002).

The water ecotopes can be differentiated into four zones: the very deep water, the deep water, the moderately deep water, and the shallow water ecotopes (the full range of ecotopes can be seen in the map of the ecological layer in figure 33). The ***very deep water ecotope (figure 28)*** class includes all parts that are permanent, at an average summer level, deeper than 5 meters. In very deep water, because of stratification (summer stratification, or

Figure 28: The very deep water

Figure 29: The deep water

permanent stratification due to a deep salt tongue), prolonged oxygen deprivation can occur, making the environment unattractive for a large number of species. At great depths, there also takes no primary production place, due to lack of light. As a result, there is relatively little food present and that food is difficult to reach for diving ducks and fish-eating birds. Nevertheless, in the IJsselmeer, it are precisely the parts that are deeper than 5 meters that form the most attractive feeding areas for fish-eating birds in the winter months (van Eerden and Vaate, 1984; Platteeuw, 1985).

The ***deep water ecotope class (figure 29)*** has ecological description of deep water largely corresponds to that of the very deep water. It includes all parts that are permanent between 3 and 5 meters deep at an average summer level. The deep water is distinguished based on the absence of long-term stratification in combination with the absence of an extensive cover with vegetation. In this zone diving ducks can forage efficiently on zebra mussels (= driehoeksmossel) (de Leeuw, 1997).

The ***moderately deep water ecotope (figure 30)*** class includes all parts that are permanently between 1 and 3 meters deep at an average summer level. Then moderately deep water is limited by the depth to which vegetation can still occur extensively. Of course, this depth is also depending on the amount of light that can reach the bottom and thus of the dynamics, soil type and phytoplankton density because of the nutrient richness (de Leeuw, 1997).

The ***shallow water ecotope class (figure 31)*** includes all parts that are permanently shallower than 1 meter but deeper than 0.3 meters. The maximum depth at which these zones occur is usually below 1 meter (Coops, 1996). The riparian vegetation can play an important role if spawning and growing area for fish, but also forms the habitat for a wide range of swamp-bound birds (such as reed songbirds) and some characteristic species of mammals (for example the otter) and amphibians and reptiles (frogs and grass snakes).

Figure 30: The medium deep water

Figure 31: The shallow water

Various helophyte species can occur in the shallow water and on the swampy transition from water to land. A width of approximately 0.5 meters or more makes the zone ecologically relevant. The addition of vegetation in the ***shallow water ecotope (figure 31)*** thus creates a new ecotope: the ***swamp and helophyte zone (figure 32 and 33).*** When the width is limited the helophyte zone can serve as a breeding ground for undemanding waterfowl such as grebe, mallard, and reed warbler. The zone can be limited width act as breeding ground for undemanding waterfowl such as grebe, mallard and reed warbler. With a larger width are there options for demanding species such as mustache, bearded male, marsh harrier and bittern. The ecotope also has an important function as a spawning and growing area for all kinds of fish (including the pike) and as a biotope for a species-rich macrofauna community. Depending on the management (more or less intensive, exploitation of reed/ rushes) the helophyte vegetation is more or less species-rich. Rough rushes and sea rushes can be encountered at reeds. In wide wet strips (> 3 metres) a more species-rich helophyte belt can establish itself then in narrow wet strips (van der Meulen, 1997).

With a south-westerly wind, relatively soft air comes to the Netherlands in winter, which means that winter temperatures have been considerably higher than before since the late 1980s. This is a northwestern European effect that comes on top of global warming, which means that the increase in temperature in the Netherlands is stronger in winter than in summer, which has as a consequence that the water temperature also increases in the *IJsselmeer* area (Noordhuis, 2010).

Nature development in the *IJsselmeer* area has been increasing since 1990 (Noordhuis, 2010). To increase biodiversity further, the government made 110 million euros available to improve biodiversity in the lake for the coming years (Soenveld, 2020). This raises opportunities for further change of hydromorphology and its consequences for the ecology.

Figure 32: The freshwater marshes

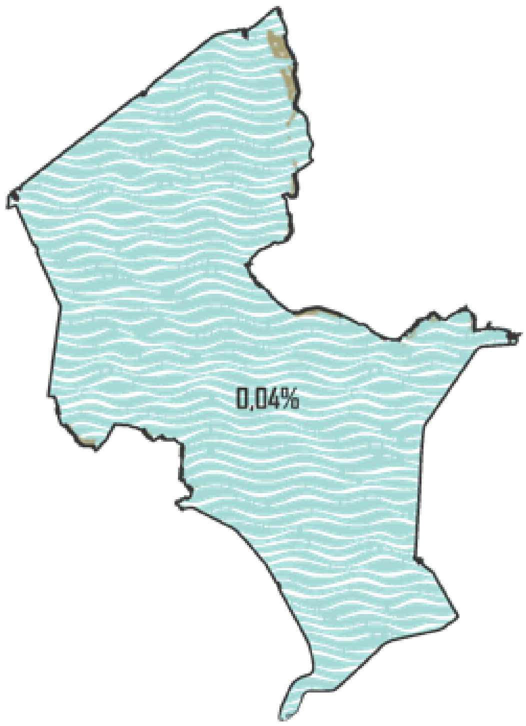


Figure 33: According to the research by Asjes (2000) there is 5 - 10% required in the IJsselmeer to have an impact the water quality the current to,04% shows the urgency of the problem

Freshwater Ecotopes

- Very Deep waters
- Deep waters
- Medium deep waters
- Shallow waters
- Swamp and helophyte zone
- Flood free plains
- Reed
- Shrubs
- Roughness

Saltwater Ecotopes

- High dynamic littoral
- High dynamic sub toral
- High Dynamic Supralitoral
- Salt marsh
- Low dynamic high littoral
- Low dynamic low littoral
- Low-dynamic medium littord
- Low Dynamic Sublittoral
- Low Dynamic Supralitoral

Figure 33: The Ecological Layer

CHAPTER 4
Process Models

The shaping and future shaping of the *Wieringerhoek* is mainly kept in place due to human interventions. The harsh boundaries of the dikes and dams define the ecotopes and ecotones of the study area. The construction of the *Afsluitdijk* stopped salt water from infiltrating the *IJsselmeer* and formed a strong border between freshwater and saltwater ecotopes. The change from Zuiderzee to the IJsselmeer still influences the area for the coming century (Dastgheib and Roelvink, 2012). Possible future interventions will sustain this unnatural equilibrium or move it in another direction.

Salination stays a problem in the area, a gradient between fresh and salt water could offer a more resilient solution to this problem. Although salination still forms a problem in the area, its benefits and potential for biodiversity is not achieved in current the state.

The *Afsluitdijk* cuts This also defines the strong border between freshwater and saltwater ecotopes. The area used to have a gradient between these ecotopes, the Afsluitdijk cuts this gradient in half. Current ecotopes are more diverse on the edges of the study area. However, the centre is very open and consists only of the deeper water ecotopes. Fairways form another strong border through the ecotopes in the IJsselmeer. The poldering of the areas surrounding the IJsselmeer also resulted in lower biodiversity. These deep gullies need to be constantly dredged. They are often traversed by large freighters another boat activity. These fairways are supposed to stay intact. This makes them difficult but defining elements. These boats have an impact on fish and bird species and they form a source of pollution for the area.

The lack of topography and change of topography gives another reason for the lack of biodiversity. This came due to the diking but also due to the removal of the tidal influence by the Afsluitdijk. These dikes are strong borders between water and land ecotopes. This led to a decrease in biodiversity. Recently there is a more flexible water level introduced in the IJsselmeer (Rijkswaterstaat, 2018), this already led to an increase in biodiversity after three summers (Klip, 2020). This does conflict with the value of openness that is associated with the IJsselmeer. More ecotopes are possible when there are softer transitions, especially in the shallow water areas and the foreshores of the dikes, where there are opportunities for sandbanks and marshes.

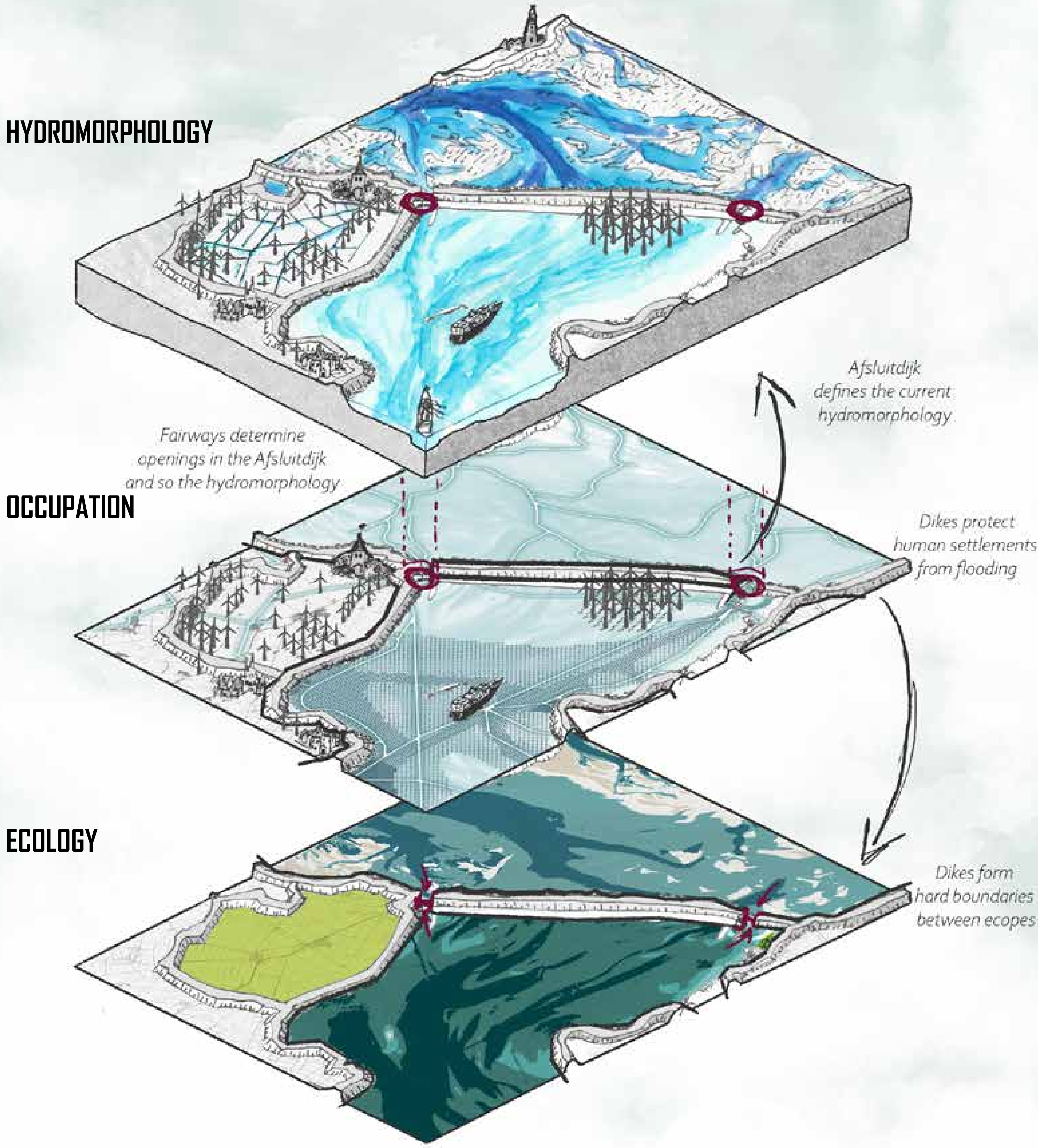


Figure 34: Interaction between the three layers

CHAPTER 5
Evaluation Models

5.1. Introdcution

The functioning of the study area with respect to the problems proposed in the *main research question* (no estuarine gradient and lacking biodiversity). The current landscape is evaluated in the following model of landscape units (figure 35). Each landscape unity is rated on its suitability to reach the project aims.

Suitability analysis in a geographical context is used to determine the appropriateness of a given area for a particular use (Ndubisi, 2002). In this case the suitability to realise more diverse ecotopes such as fresh and salt marshes. The basic premise a suitability analysis is that each aspect of the landscape has intrinsic characteristics that are to some degree either suitable or unsuitable for the activities being planned. Suitability is determined through systematic, multi-factor analysis of the different aspects of the terrain. Water depth will be the most defining factor in this case. The results are often displayed on a map that is used to highlight areas from high to low suitability. The three layers will be assessed in how they raise opportunities for change.

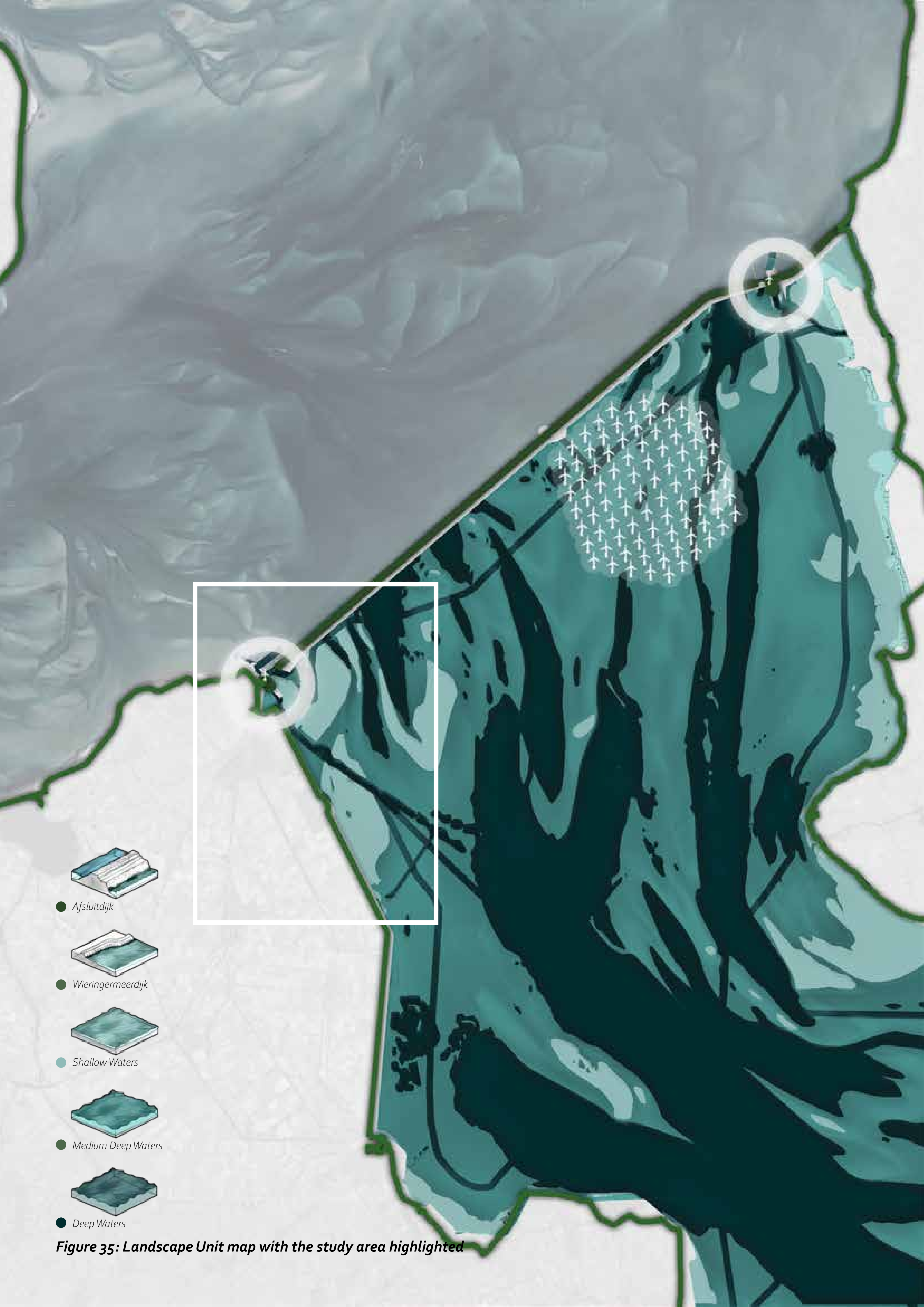


Figure 35: Landscape Unit map with the study area highlighted

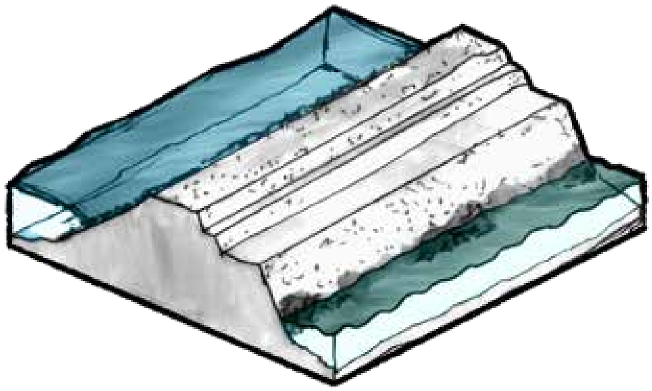


Figure 36: The Afsluitdijk

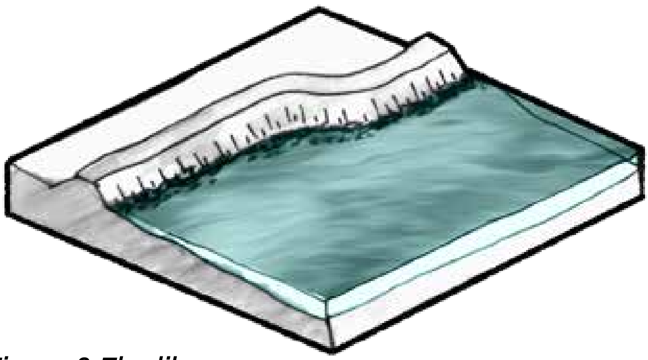


Figure 38: The dike

5.2. Landscape Units

The Afsluitdijk is the most defining factor of the area for it shaped its hydromorphology for the previous and coming centuries. It acts as the separating border between the fresh and saltwater habitats. It is also a defining factor in the connection between Friesland and North-Holland.

However, although it is such a separating factor it also raises a lot of opportunities for connecting the two habitats by controlled intrusions. Next to this the edges of this dam can also be used for creating a subtle land water transition with various new ecotopes. With this change safety regulations must be taken into consideration.

This landscape unit is quite like the Afsluitdijk. In these case it forms the protection for the polders from the water in the IJsselmeer. It also acts has a hard border between the polders and the water ecotopes of the IJsselmeer. Its edges on the IJsselmeer-side are covered by a strip of basalt rocks as an extra defence measurement.

It also lends itself as a potential subtle land water transition with various new ecotopes. Connections can also be made with the shallow waters in the foreshore. It stays important to keep its protective function intact.

Figure 37: Location of the Afsluitdijk

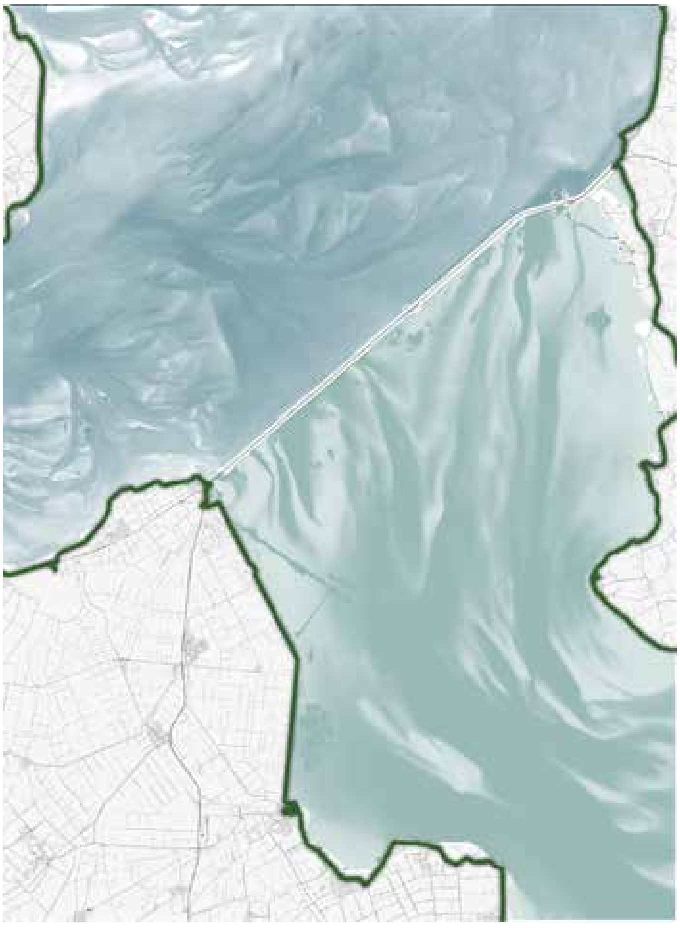


Figure 39: Location of the dikes

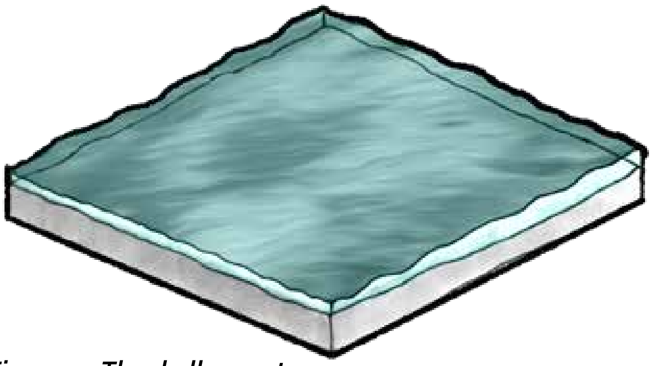


Figure 40: The shallow waters

Shallow water is the most interesting landscape unit with respect to this research, together with the dikes. It consists of all the water that is at least 0,30 meters deep and a maximum depth of 3 meter. Parts of the shallow waters are vegetated by marshes and helophyte swamps, these are mainly on the eastern site at the province of Friesland. They form the transition area between the land and the deeper waters.

Because of its limited depth this landscape unit offers the most opportunity for change. It is also widely spread and directly connected to the dikes, so connections with foreshores can be made possible.

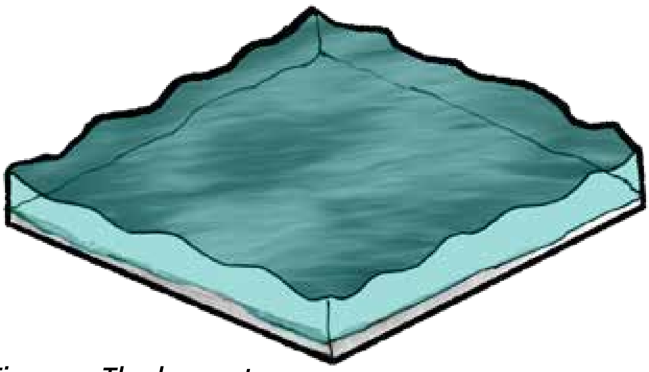


Figure 42: The deep waters

The medium deep waters include all parts that are permanent, that that is, at an average summer level, be between 3 and 5 meters deep. Moderately deep water is limited by the depth to which vegetation can still occur extensively.

It takes more effort to develop marshes here, for the sea floor must be raised a couple of meters. At the edges of this landscape unit, where it borders the shallow waters there are higher possibilities for change.

Figure 41: Location of the shallow waters

Figure 43: Location of the deep waters

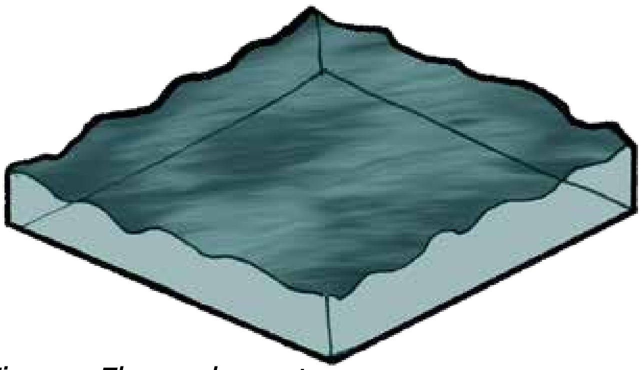


Figure 44: The very deep waters

The deep water includes all parts that are permanent, that is, at an average summer level, bellow 5 meters deep. It is a combination of the very deep water ecotope and the deep water ecotope due to their similarity in description. The fairways are also part of this landscape unit.

Because of their depth they are hard to transform in other ecotopes. The fairways themselves are also almost impossible to change due to their importance in the overall transportation network. So when change is made an alternative must be proposed. Allthough

Figure 45: The very deep waters

Landsape DESIGN

CHAPTER 6
Change Models

6.1 Introduction

The *Landscape Design* section built upon the *Landscape Analysis* section. It takes the evaluation model as a starting point for the design interventions. Additional research will be provided on the to-be-realised ecotopes. The next step will be the design sketches and modelling exercises. To keep an iteration going these design sketches will result in additional landscape design guidelines. The final iteration will be the final design, which will be judged by stakeholders and experts in the decision phase.

The landscape principles to improve biodiversity are based on *Building with Nature* guidelines from EcoShape, as was further elaborated in the second chapter (EcoShape & One Architecture, 2020). They informed the requirements of marshes, both the fresh- and saltwater marshes. Because of the strong influence of height and slope, the variation within the ecotopes is quite nuanced (Mandemakers et al., 2019). Those nuances will be expressed in ecotones for the gradual transition from land to water.

6.2. Create a Salinity Gradient

One of the most important aspects of the estuarine gradient is the creation of a salinity gradient (previously discussed in chapter 2.5.). The main inlet of water is through the current sluices, which will be opened more to create the necessary salinity concentrations for the growth of saltmarshes. Next to this, there will be an opening close to the sluices to have a constant opening for fishes to pass through, without interruption from boats and the working of the sluices. Another way to get saltwater in is through the creation of pipes which salt water can be pumped (see figure 46).

To regulate the salinity concentration further into the created estuarine gradient there will be underwater dikes (figure 46). These dikes respond to the different densities of fresh and saltwater. Saltwater has a higher density and thus will stay below the fresh water.

These interventions are to create a safe salinity gradient that does not influence the freshwater reservoir function of the *IJsselmeer*. It will also create the necessary conditions to create saltwater ecotopes. But they will maintain a lower salinity in the areas where freshwater ecotopes are to be created.

Principles to create a Salinity Gradient

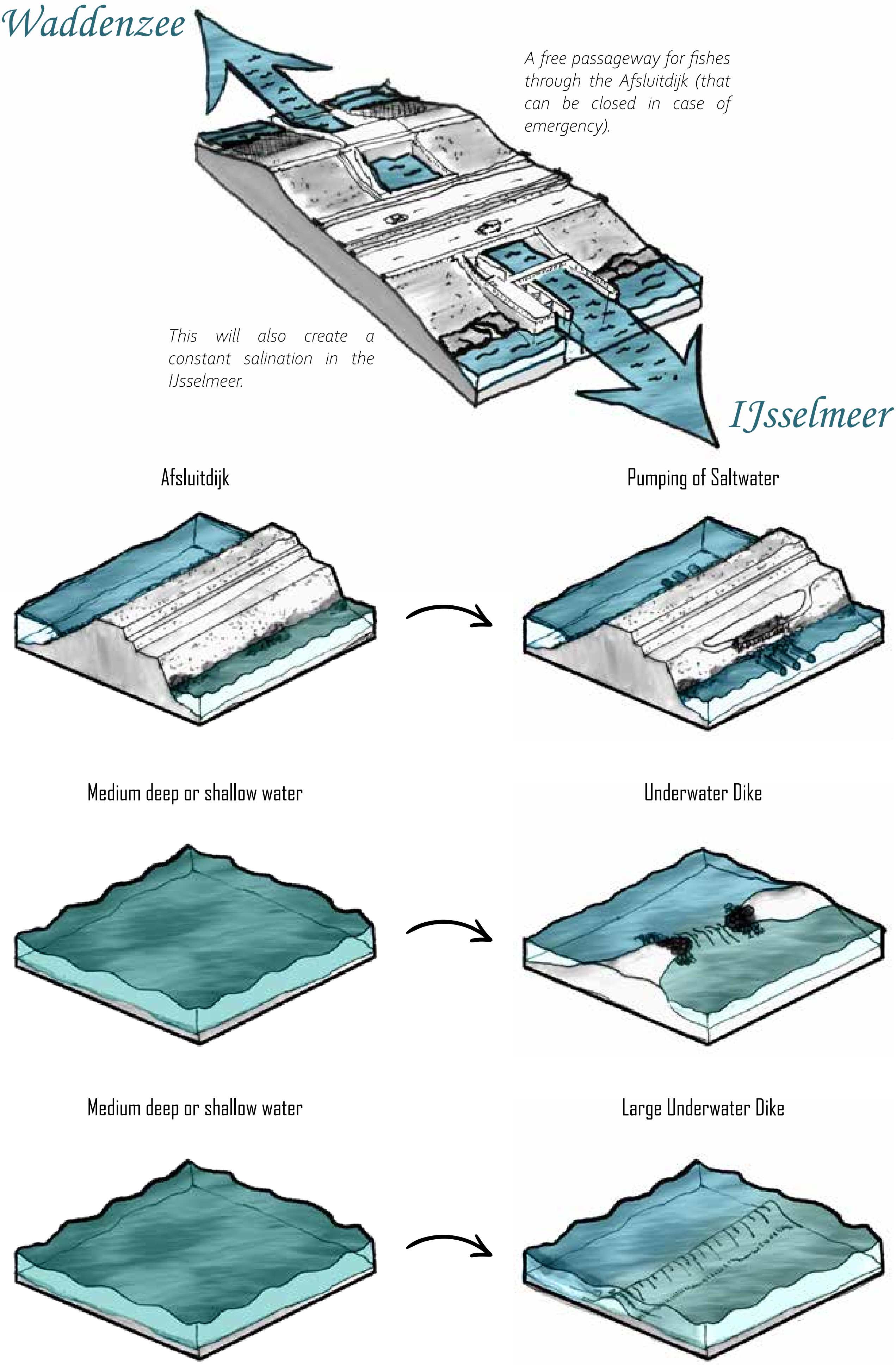


Figure 46: Landscape Design Toolbox for a controlled salinity gradient

6.3. Salt Water Marshes

Estuarine salt marshes are intertidal wetlands vegetated by salt tolerant, nonwoody, rooted, vascular plants (Hopkinson & Giblin, 2008). Coastal habitats such as tidal areas and salt marshes are ranked among the most important habitats in the Netherlands regarding ecosystem services (Stijn Temmerman et al., 2013). The marsh's plants take in CO2 from the atmosphere (rather than sea). Unlike terrestrial soils, the sediments in which healthy saltmarsh plants grow do not become saturated with carbon as the sediments accrete vertically with a rising sea level. This means that the rate and quantity of carbon sequestration can increase over time (Chmura et al., 2003). A brackish zone can make a major contribution to the recovery of natural processes that are characteristic of the fresh-salt transition in an estuary, which is based on a large area, of up to 5% of the *IJsselmeer* (Asjes, 2000).

Salt Marshes themselves are among the most productive ecosystems in the world even rivalling intensively cultivated agriculture (Odum, 1971). This high production is attributable to several factors, including nutrient enrichment from watershed runoff and tidal mixing (Day et al., 1988). These are important components of estuarine systems because they provide a food source to both estuarine and coastal ocean consumers, serve as habitat for numerous young and adult estuarine organisms, provide refuge for larval and juvenile organisms, and regulate important components

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Pioneer zone

The pioneer zone, which is dominated by pioneer species with cover >5%. One of such pioneer species is the common cord grass (Spartina anglica) (Van der Wal et al., 2008)

Pre-pioneer zone

Just beyond the pioneer zone lies the transition zone on the tidal flat, with only a few pioneer plants per m2 present, i.e. a cover <5%. (Baptist et al., 2016; Marion et al., 2009). Pioneer vegetation establishment on the bare intertidal flat preceding the marsh is essential for salt marsh development (van der Wal et al., 2008b).

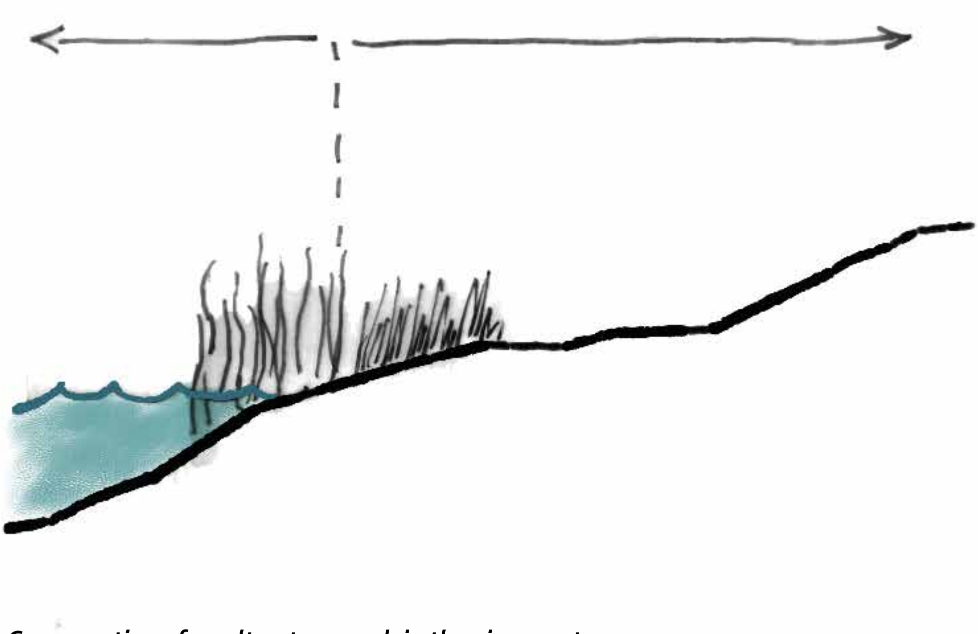


Figure 47: Cross-section of a saltwater marsh in the pioneer stage

Human impacts have reduced the extent of tidal marshes within coastal seascapes through replacement with unvegetated flats or hardened shorelines of lower habitat value (Bishop et al., 2017). However, tidal marshes are hotspots of nutrient sequestration and removal and so can buffer anthropogenic nutrient inputs to coastal systems (Gedan & Silliman, 2009; Piehler & Smyth, 2011). The fragmentation of tidal marshes causes reductions in patch sizes, increasing prevalence of edge effects, including higher exposure to coastal erosion from wind, waves and boat wakes, and poorer connectivity among tidal marsh patches (Gilby et al., 2021). This means that saltmarshes are best realised in a large unfragmented area.

The coastal saltwater habitats are mainly defined by the tidal dynamics that the sea offers. The tide fluctuation ant the depth are the main defining characteristic of these ecotopes. The tidal movement is already realised in the IJsselmeer (Rijkswaterstaat, 2018), although it is small for significant impact: NAP -0,10 and -0,30. According to Asjes (2000), a large and naturally functioning brackish water area provides a foraging area for birds, facilitates the migration of diadromous fish species, prevents freshwater fish from leaching into the Wadden Sea and provides habitat for benthic fauna that is bound to brackish water. Seagrass beds may develop in the brackish water area, and submerged aquatic plants such as fountain herbs, rush fields and brackish (reed) marshes.

The Saltmarsh can best be created in a location where saltmarshes were present before embankment (French, 2008), which is the case in the *Wieringerhoek*. Seeding with Salicornia plant fragments kick-starts colonisation (Baptist *et al.*, 2021). The average salinity must be greater than 0.5 g of solutes per kg of water (Odum, 1988) The slope of the area must be aligned gently towards the sea, which reduces flow velocity and enhances sedimentation (Burd, 1995). The soil must consist of sand with 25% mud boosts vegetation cover and species richness (Baptist *et al.*, 2021). To limit erosion is another requirement for a saltmarsh, so the place must be relatively sheltered (French, 2008). However some sediment suspension is required for survival (1-10 mg/l) and growth (1-100 mg/l) of the saltmarsh (Borsje et al., 2011; Li & Yang, 2009; S. Temmerman et al., 2004).

Salt marshes are exposed to a unique combination of environmental variables, including strong salinity gradients, fluctuating water levels and water tables, and anaerobic, waterlogged sediments. There are distinct patterns of species distribution and biogeochemical zonation in salt marshes that arise from gradients in elevation and porewater drainage (Haines & Dunn, 1976). Each molecule of CO_2 sequestered in tidal salt marsh soil (and also in mangrove, which replaces salt marsh in the subtropics) has a greater 'value' than any other ecosystem due to the lack of production of other greenhouse gases; this is because sulphates present in salt marshes reduce the activity of microbes that produce methane (Weston et al., 2014).

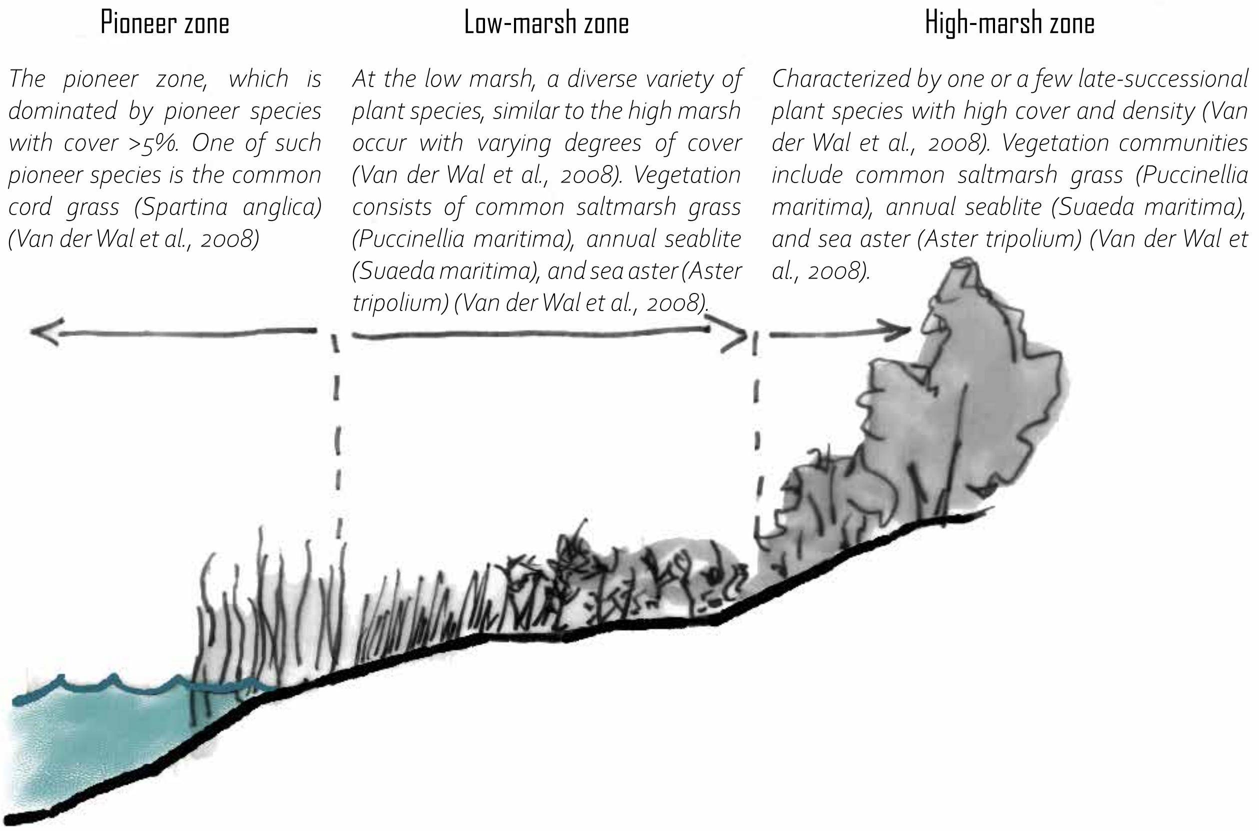
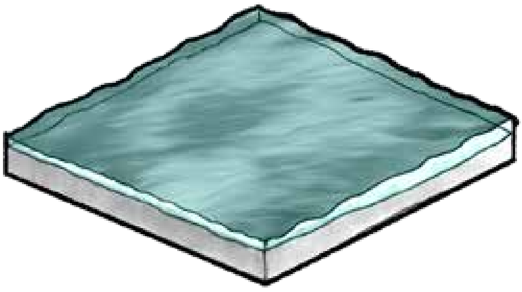


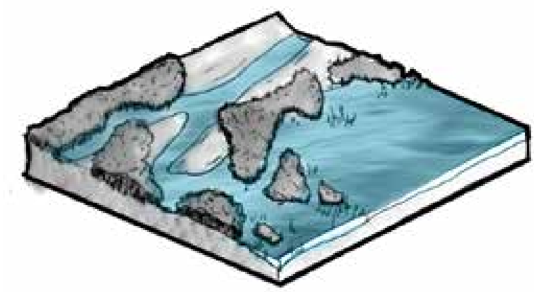
Figure 48: Cross-section of a saltwater marsh

Saltwater Marshes

Medium deep to shallow waters

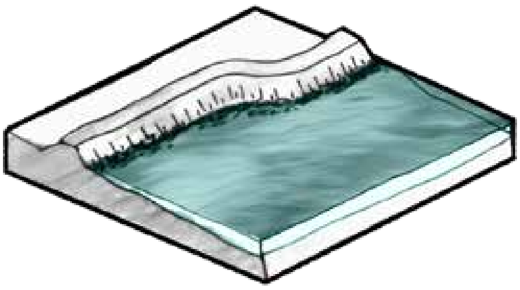


Saltwater marsh

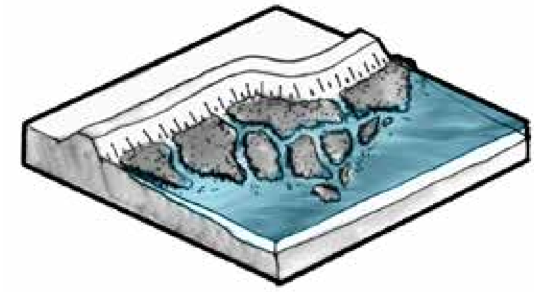


Must be created in locations where saltmarshes were present in the past or seeding of salicornia to kickstart colonisation (Baptist et al. 2021). The place were saltmarshes are to be realised must be relatively Sheltered.

Regular dikes

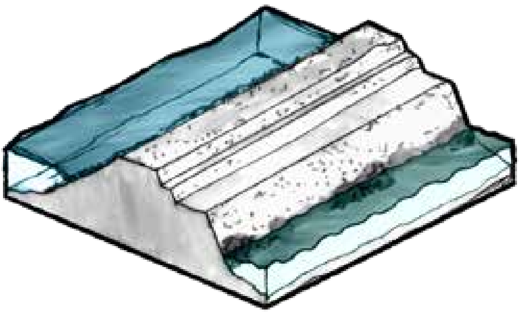


Saltwater marsh along dike



Mixing sand with 25% mud boosts vegetation cover and species richness (Baptist et al., 2021). The average salinity must be greater than 0.5 g of solutes per kg of water. The slope of the area must be aligned gently towards the sea (1:0-1:18 or 1:0-1:64), which reduces flow velocity and enhances sedimentation (Burd, 1995). sediment suspension is required for survival (1-10 mg/l) and growth (1-100 mg/l) (Borsje et al., 2011; Li & Yang, 2009; S. Temmerman et al., 2004).

The Afsluitdijk



Saltwater marsh along the Afsluitdijk

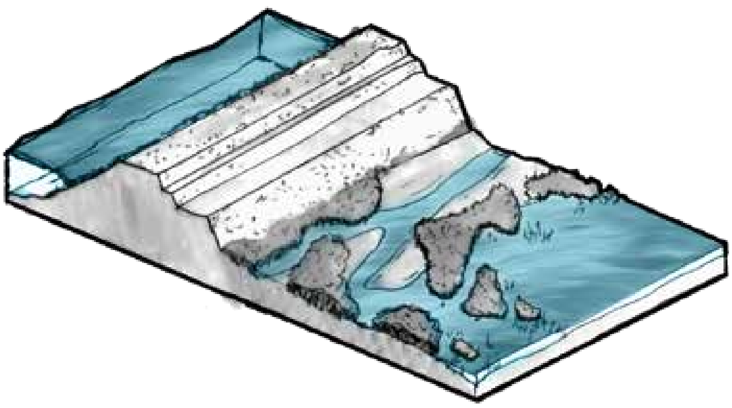


Figure 49: Landscape Design Toolbox for saltwater marshes

6.4. Fresh Water Marshes

Various helophyte species can occur in the shallow water and on the swampy transition from water to land. The zone becomes ecologically relevant a width of approximately 0.5 meters is achieved. However, even when the width is limited the helophyte zone can serve as a breeding ground for undemanding waterfowl such as grebe, mallard and reed warbler. When the 0,5 meters threshold is achieved a larger width are there options for more demanding species such as Savi's warbler, bearded male, marsh harrier and bittern.

The ecotope also has an important function as a spawning and growing area for all kinds of fish and as a biotope for a species-rich macrofauna community. Depending on the management (more or less intensive, exploitation of reed/ rushes) the helophyte vegetation is more or less species-rich (van der Meulen, 1997). Only the outermost meters of wide reed beds are used by fish, so a mosaic of reed beds and open water (1:2 ratio) is needed to be effective as a habitat; a large contiguous reed bed is therefore ineffective for fish (Mandemakers et al., 2019). Very dense reed beds (stem density >30 %), which often arise in very eutrophic water, are less accessible to fish and therefore less effective

While many dominant fish species in open water (for example, pike-perch, perch, eel) really like structures, for example as a foraging area or shelter/residence area. In for improving habitats for fish. This is especially a risk in the development of helophyte swamps in the polders (where the water system is highly eutrophic (Mandemakers et al., 2019). In freshwater marshes, the physicochemical properties of the water determine to a large extent the composition of fauna living therein. The nutrient richness is very decisive for diversity and is largely determined by the concentrations of phosphate and nitrate. Most animals are not directly influenced by these concentrations and can live in waters with deviating values. They are indirectly influenced, however, because the concentrations to a large extent the composition and structure of the determine vegetation. As with terrestrial ecosystems, waters that are moderately nutrient-rich have the greatest diversity (Kalkman et al., 2010).

A tidal forest, a forest that is flooded during the spring cannot be used for fishes, they prefer more open areas. However, they can be used to improve other aspects of the ecosystem. On the one hand, a tidal forest provides a habitat for certain organisms such as: amphibians, some specific fish species and for certain bird species (Mandemakers et al., 2019).

For birds, the forest can be used as breeding and serve as a foraging site, provided the forest is in the water. It then forms an interesting habitat for colony birds. On the other hand, if the forest is well connected to the aquatic ecosystem (the IJsselmeer), provide additional organic material. The input of organic matter is an important function of the riparian zone (see 'Functions of a gradual land-water transition' in section 2.2). In addition to the floodplain grasslands and helophyte swamps, a tidal forest may provide an important additional source of organic matter.

In areas with low to moderate wave action, such as the IJsselmeer, combining wetland forests with traditional earthen barriers can reduce wave heights while providing habitat value and supporting biodiversity. The design of dikes can integrate inundation-tolerant vegetation to maximize flood risk reduction (EcoShape & One Architecture, 2020).

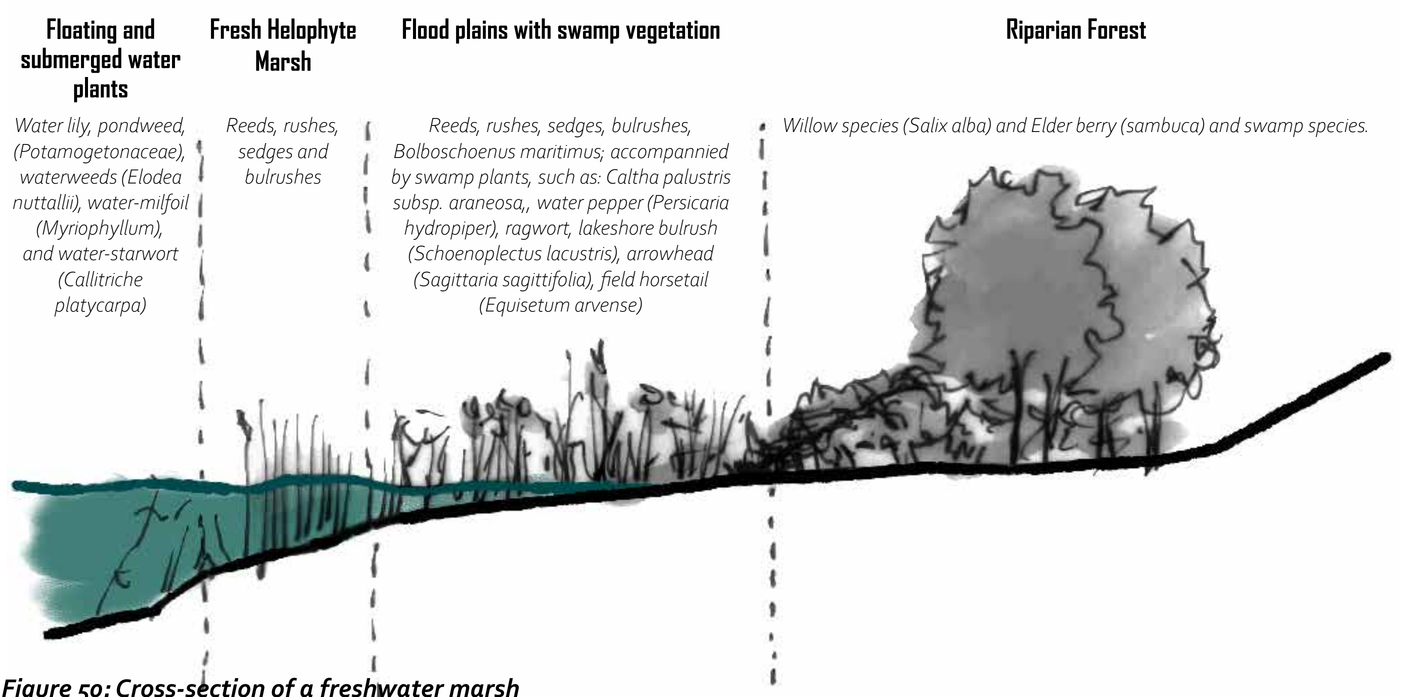
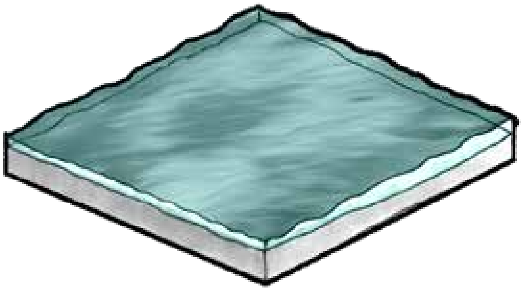


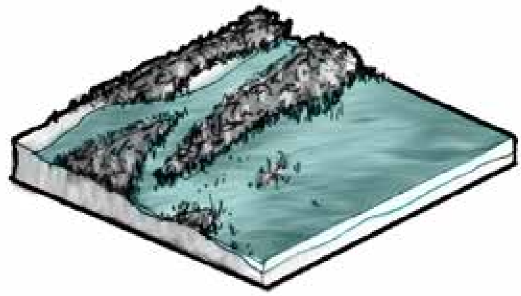
Figure 50: Cross-section of a freshwater marsh

Design principles for Fresh Water Marshes

Medium deep to shallow waters

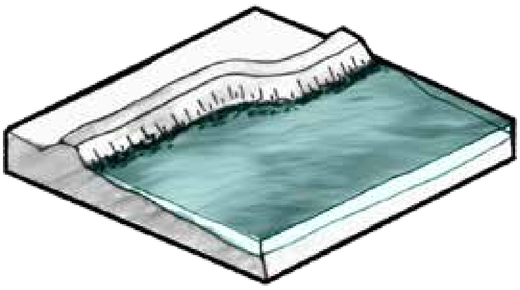


Freshwater marsh

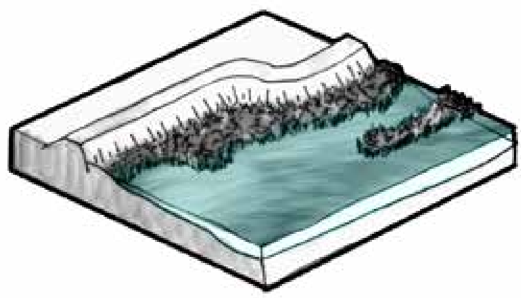


Foreshore environments improve dike resilience and enhance flood defenses by dampening wave forces with their shallow slopes. They stabilize the dike with additional mass and increasing seepage length (EcoShape & One Architecture, 2020).

Regular dikes

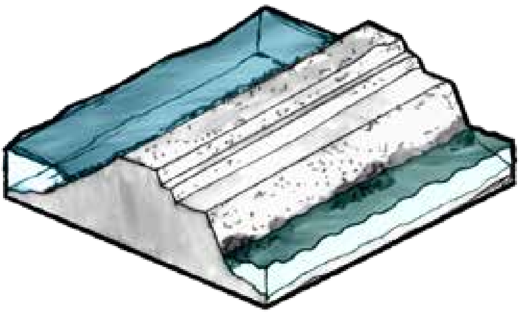


Freshwater marsh along dike



Width of at least 0.5 meters. A mosaic of reed beds and open water (1:2 ratio) is needed to be effective as a habitat for fisth.

The Afsluitdijk



Freshwater marsh along the Afsluitdijk

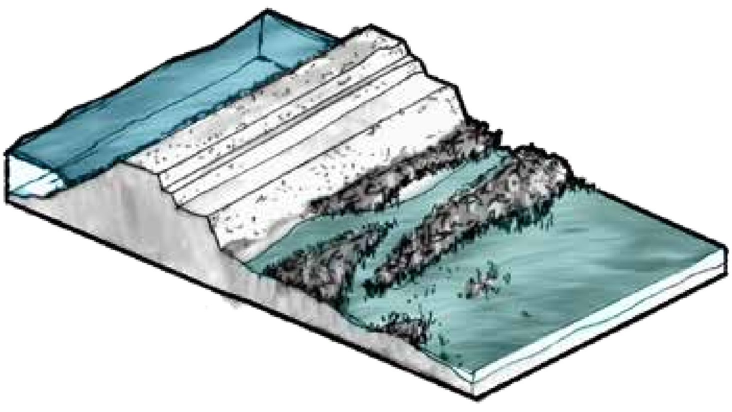
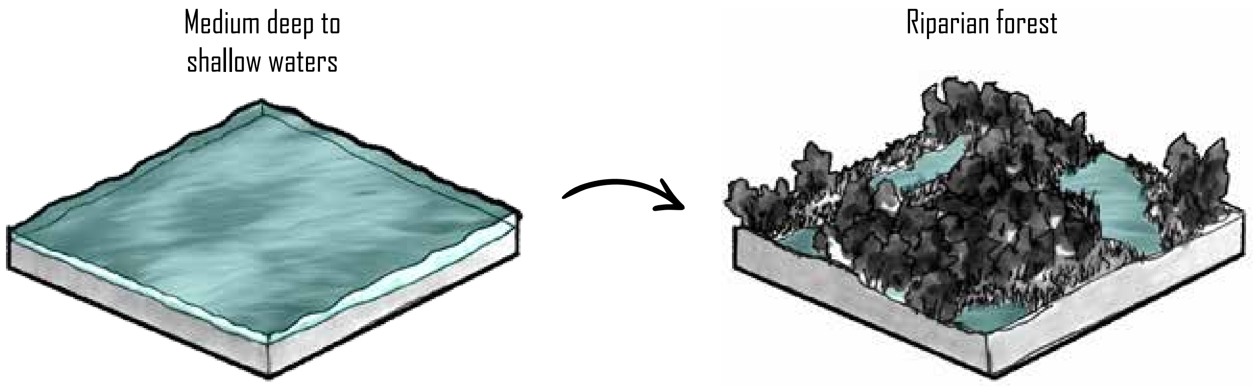


Figure 51: Landscape Design Toolbox for freshwater marshes

Design principles for Riparian Forests



A riparian forest provides an important additional source of organic matter. Dikes integrate inundation-tolerant vegetation to maximize flood risk reduction.

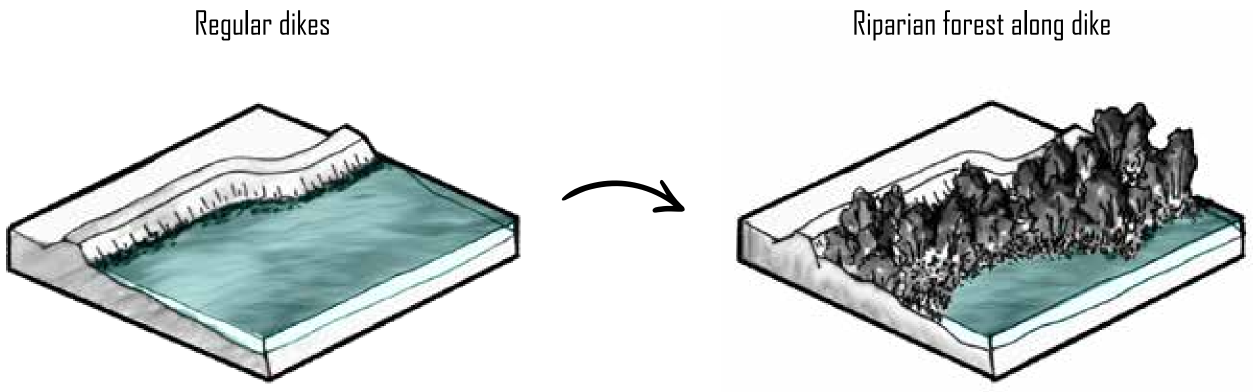


Figure 52: Landscape Design Toolbox for riparian forests

Design principles for traversing the landscape

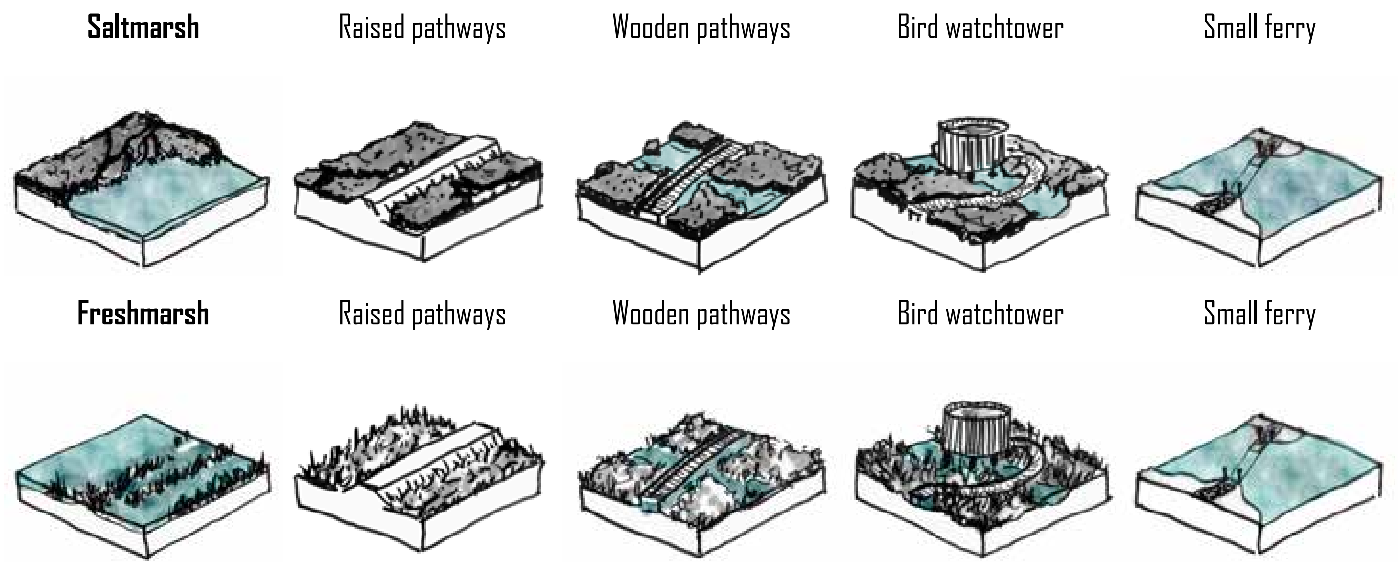


Figure 53: Landscape Design Toolbox for fresh- saltmarsh exploration

CHAPTER 7
Impact Models

7.1. Introduction

The impact models are created with the landscape design principles of the previous chapter. They are assessed by the expert panel mentioned in the methodology (chapter 2). In this chapter, the three preliminary designs created for this research are briefly discussed together with the feedback received during the expert judgement. The next chapter will explain how this shaped the final design.

7.2. Starting points

The landscape design goes out from free regional design principles in favour of ecology. The first principle is the creation of the salinity gradient (figure 54). This to facilitate the unique species that come with this gradient and to accompany fluctuations in salinity level along the *Afsluitdijk* to create a more resilient transition zone.

Secondly there will be a land water gradient along the dikes surrounding the *IJsselmeer* (figure 55). However, this gradient does not limit itself to the dikes and can also be created on the shallower parts of the *IJsselmeer* when new land is to be created.

Thirdly there will be connections between the *IJsselmeer* and the surrounding landscape (figure 56). The *Robbenoordbos* lends itself to realise connections with the freshwater habitats of the IJsselmeer.

Lastly the evaluation models provided from chapter 4 provide the basis for the following designs. A summary of the provided conclusions follows now. Shallow waters are mainly used for the creation of new marshes. These can be connected with the foreshores of the dikes, which also offers opportunities for ecotope development. The dikes themselves stay largely intact due to their safety function.

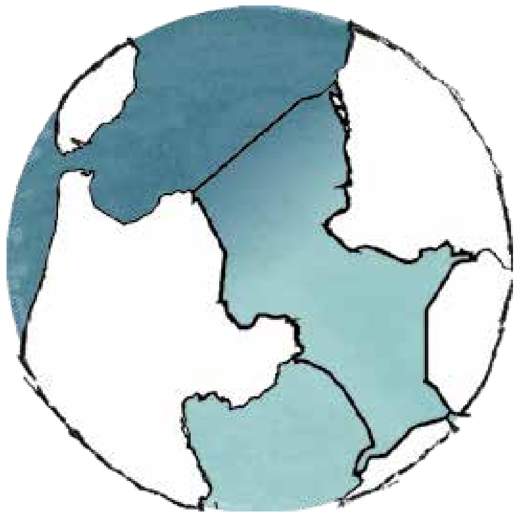


Figure 54: The Salinity Gradient

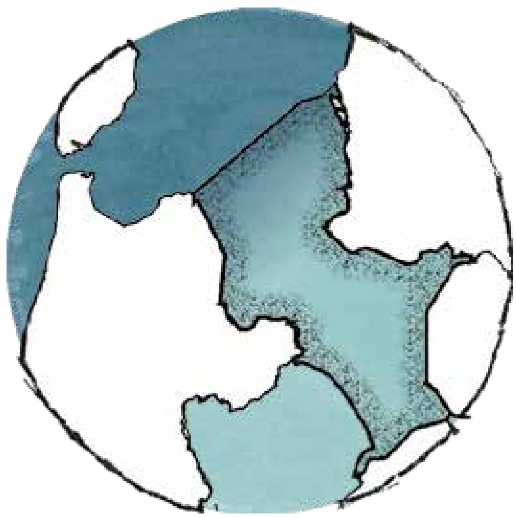


Figure 55: Land- water-gradient

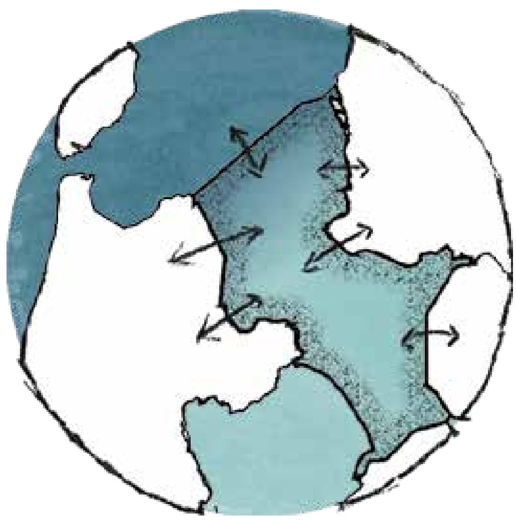


Figure 56: Ecotope Connections

0
0.5
1 km

7.3. First model

In this first model, three openings directly link the fresh and salt water. The first opening is broader and deeper to make traversal by boats possible. Riparian forests also strengthen the inlet to limit sludging of the gullies. The second and third water inlet on the east side of the design is not accessible by the larger boats, making it more suitable for ecotope development. Salt and fresh water can interact in this area and thus have a nutrient exchange. These are foreseen with underwater dikes to have greater control over the saltwater inlet.

The length of the waterways between fresh and saltwater aims to create a natural gradient between fresh and saltwater (chapter 2.5., figure 10). In addition, along the dikes, there are either marshes or flood forests (of at least 200 meters in width) to help with protection against high water levels.

The design follows the hydromorphology of the area (chapter 3.5, figure 24). Higher areas are used to create islands and shallow-water habitats so that marshes can develop. There is a variety between large and smaller fragmented ecotopes, which leads to the highest species richness.

The panel mentioned in the methodology has commented on this design, which is summarized in figure 58. The first thing that struck the design team was the islands in front of the sluices. They suggested that it was not recommended in this area because of how much water the sluices need to function. It was recommended to instead dig deeper into this area and use this material to raise the other islands.

The following criticism was mainly on the flood forests and mainly its location. In some places, they are not placed in a natural manner. Another suggestion was made on the forest that connects the dikes and the new nature area, where it would be more suitable to create an area that looks like the *Bieschbosch*, so with more smaller waterways.

The next problem they found was that the fresh and saltwater marshes are so close together. In high water scenarios, the saltwater could flood the islands and destroy the fresh marshes. So this will need some protection from this washing over.

Figure 58: Expert Judgement on the first Model

Figure 57 (left page): First preliminary design

Saltwater marsh

Freshwater marsh

Riparian Forest

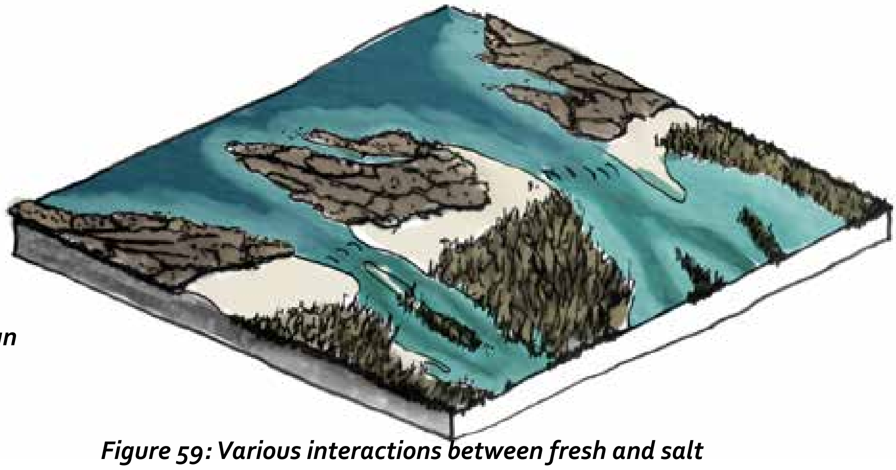


Figure 59: Various interactions between fresh and salt


0
0.5
1 km

7.4. Second model

In the second model (figure 60 and the summary of its judgement in figure 61), the saltmarshes are closed off by dikes (figure 62). This closing-off means there is less interaction between fresh and saltwater ecotopes, not so apparent anymore as in the previous model. As a result, the saltwater inlet is relatively controlled and limited when looking at water safety. Although a significant proportion of salt marshes are created, there is little gradient transition between fresh and saltwater habitats.

The diking in of the saltmarshes makes the introduction of the saltwater safer for the *IJsselmeer*. Because the saltwater inlet is easy to control in this way, with limited to no interaction between the salt and fresh water. This is due to the *IJsselmeer* being the most extensive freshwater reservoir in the Netherlands. This function gets threatened by the addition of saltwater habitats. Therefore, this design offers a safer solution for the implementation of saltmarshes in this area.

The dikes lend themselves to traverse the new system, either by bike or foot. The dikes raise recreation opportunities without people interfering with the ecotopes and their development. They also prevent the saltwater from washing over to the freshwater marshes.

The limited interaction between the ecotopes was immediately pointed out as the weakest aspect of this preliminary design. Because these nutrient interactions are essential for the development of saltmarshes. However, this separation was also considered a strength, due to the possibility of introducing a stronger tidal influence in the closed of saltwater marshes. As previously mentioned (chapter 3.6.), the current tidal influence is possibly unsuitable for the optimal development of saltmarshes. So, these dikes could offer an opportunity to create more tidal dynamics.

Figure 61: Expert Judgement on the first Model

The choice for making more smaller saltwater marsh pockets was made to create more variety. However, the expert judgement advised against this and suggested creating one larger saltwater pocket because a larger pocket would create the highest biodiversity.

The biggest lesson of this design is that the closing of the saltmarshes offers new opportunities at another tidal range, but this does not outweigh the benefits of a nutrient interaction. Next to this the dikes are useful to limiting washing over of saltwater directly in the salt marshes and the other way around.

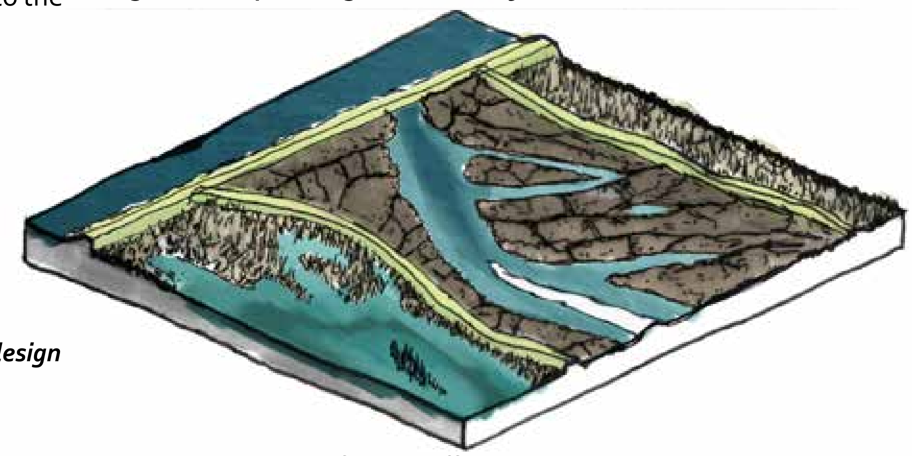


Figure 62: Pockets of closed off salt water ecotopes

Figure 60 (left page): Second preliminary design

- Saltwater marsh
- Freshwater marsh
- Riparian Forest


0
0.5
1 km

7.5. Third model

The most defining characteristic of the final preliminary design (figure 63) is that there is only one connection between the freshwater and the newly created freshwater habitats of the *IJsselmeer* and the saltwater ecotopes of the newly created design. The saltwater and freshwater meet only at this point. This makes the mixing of salt and fresh water easy to control. Riparian forests further strengthen this meeting point. Figure 65 shows this meeting point of the salt and fresh water.

The expert judgement (result in figure 64) again saw this as a solid and weak point. Because the saltwater inlet is limited, it is easier to control the mixing between the two water types. However, this does not offer enough nutrient exchange to create a functional ecosystem.

This design aims to create a continuing saltwater marsh along the Afsluitdijk combined with additional saltwater inlets. This gives both dikes a new identity and further strengthening, especially in the parts where marshes and riparian forests are created. It does have opportunities to continue the saltmarshes along the entire length of the *Afsluitdijk*.

The marshes on this site of the *Afsluitdijk* are protected from the waves of the *Waddenzee*. This protection makes this location ideal for the development of saltmarshes. The expert judgement mentioned this does require more interaction between the two water types because of the nutrient exchange.

The design also introduces a continuous freshwater marsh along the *Wieringermeer*-dike together with riparian forests(zachthoutooibos). This offers more stability and biodiversity to the dike than in its original form. In addition, the dikes already offer a land-water gradient, which can be enhanced to create a more biodiverse gradient. These continuing marshes along offer a new experience when traversing the *Afsluitdijk* and *Wieringermeer*-dike.

This model is another iteration of the first model, although it was less well-received than the first model. This was mainly due to the limited interaction between fresh and salt water. When looking at increasing biodiversity, this is the weakest point of the design, and this should be incorporated into the final design.

Figure 64: Expert Judgement on the first Model

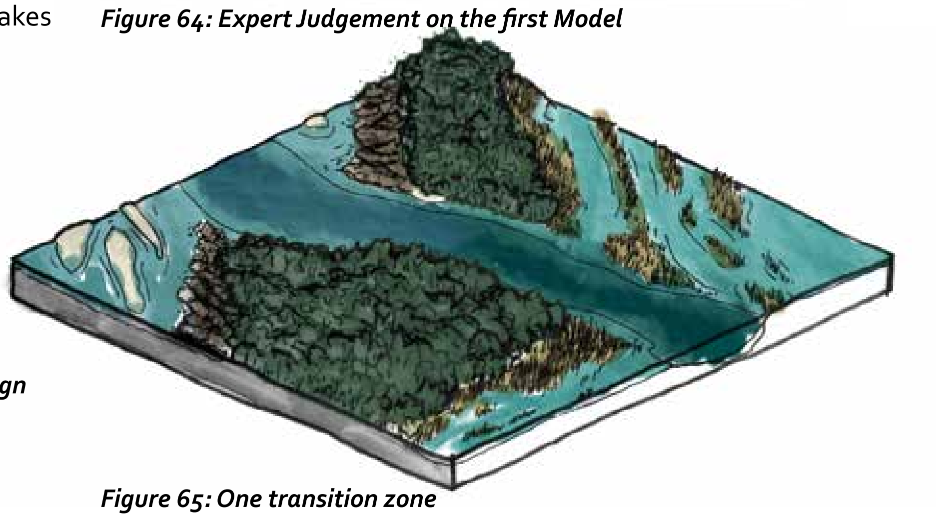


Figure 65: One transition zone

Figure 63 (left page): Third preliminary design

Saltwater marsh
Freshwater marsh
Riparian Forest

CHAPTER 8
Decision Model

As a final step of this design research, the feedback received on the three preliminary designs is used to create a synthesis. This synthesis is created by addressing the weaknesses of the three preliminary designs and keeping/enhancing the strengths.

One opening is created next to the current sluices, where fish can swim through all the time. However, the opening can be closed when there is an urgent scenario considering safety.

Between the fresh and saltwater habitats, multiple connections are chosen instead of just one.This is done to stimulate the previously mentioned interaction between nutrient flows. Multiple openinges is chosen over a safer singular opening because the saltwater inlet can already be controlled at the *Afsluitdijk*.

In the final design there is also a basin created behind the sluices. This is more deepened in comparison to the current situation. This deepening is done so the sluices can keep their original function. However, they require much water, so the sluices' working is improved, and the dug-up sand is used to create the islands shown in the design.

Figure 66: Final Landscape Design (right page)

- *Saltwater marsh*
- *Freshwater marsh*
- *Riparian Forest*
- *Mudflat*
- *Saltwater*
- *Freshwater*
- *Underwater plants*
- *Wooden walkways*
- *Raised walkways*
- *Separation dike*

Figure 70
Figure 74
Figure 72
0
500
1,000
1,500 m

Figure 67: Birds-eye view of the final design

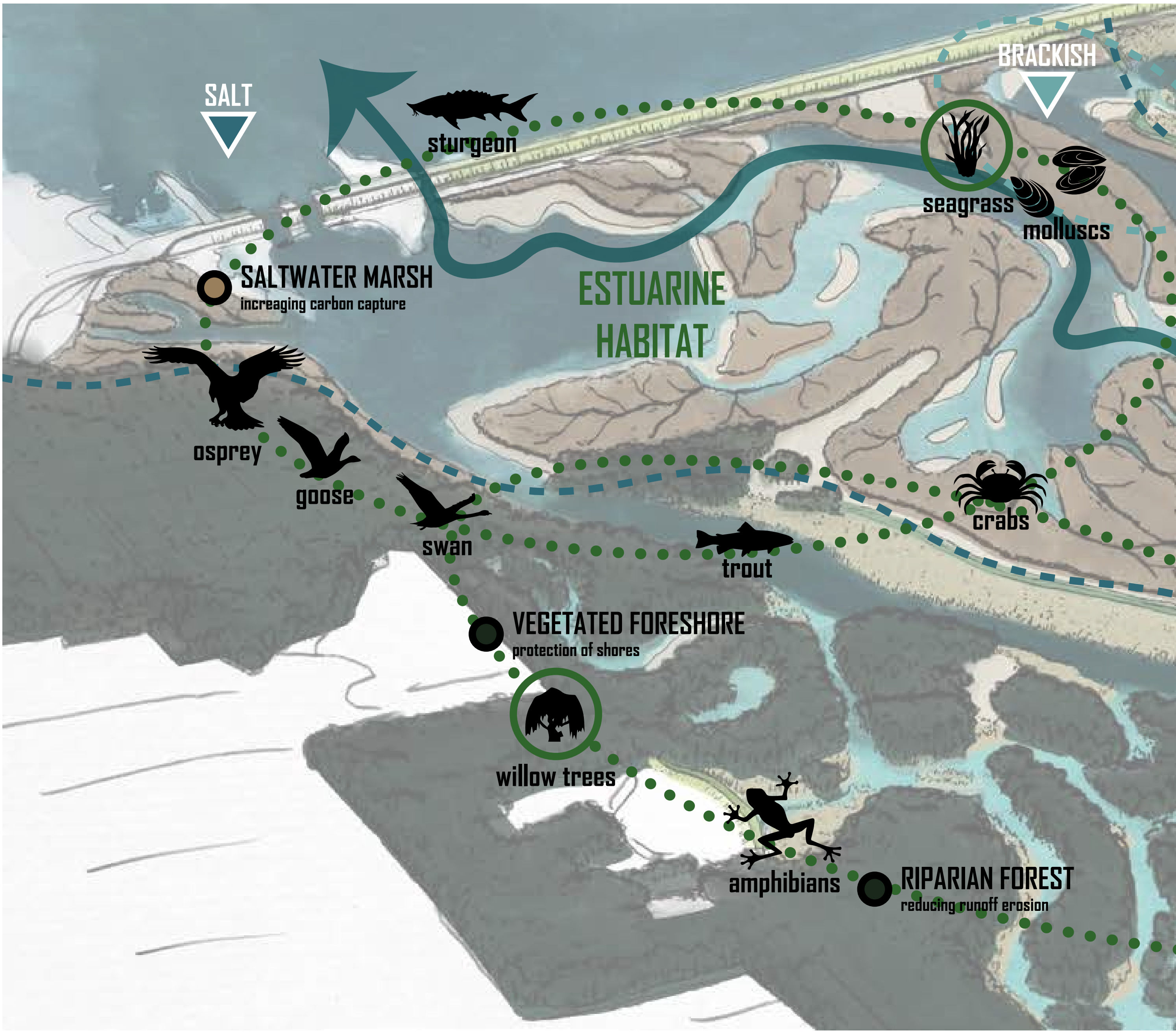
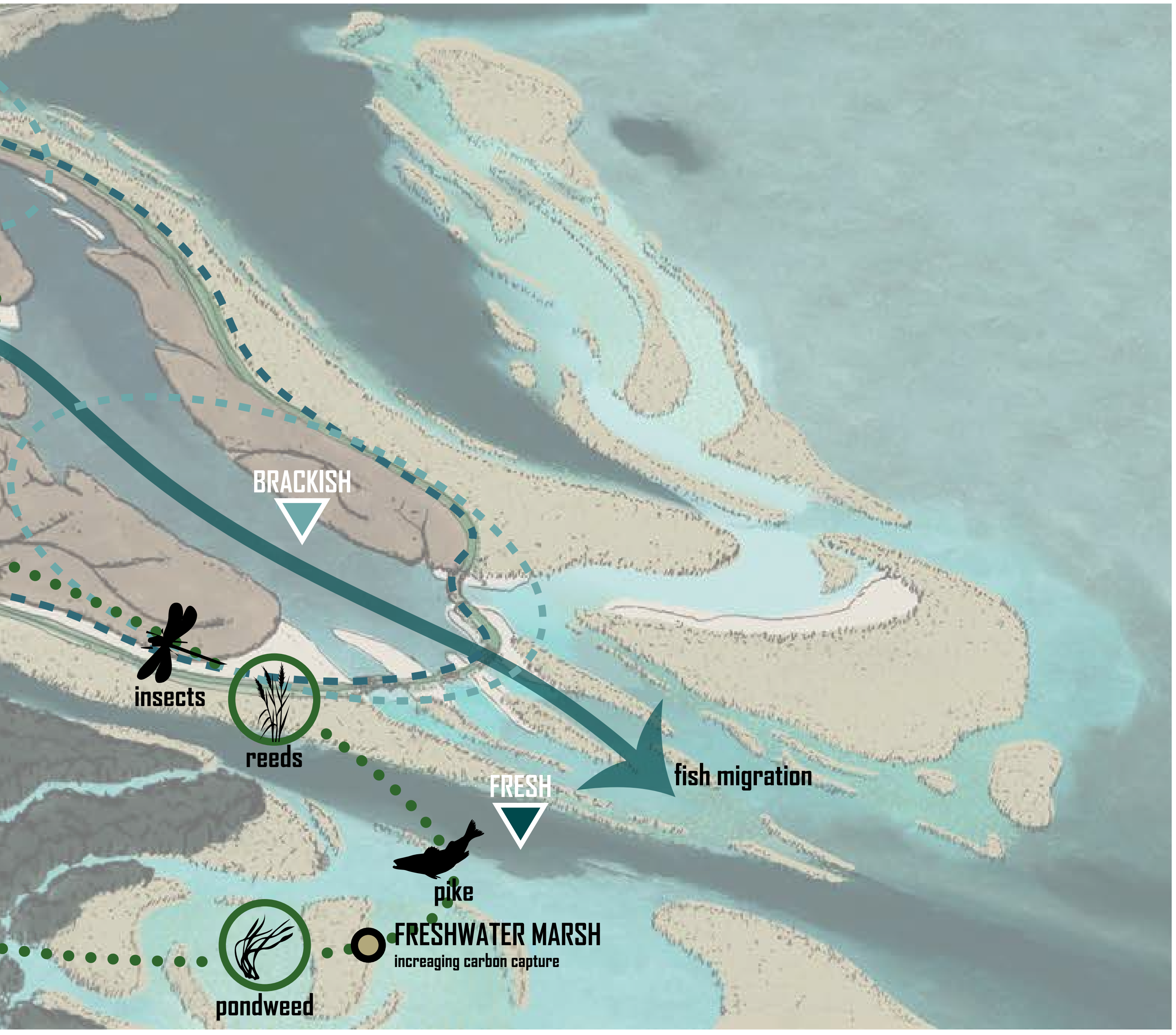


Figure 68: Food web of the final design


BRACKISH
insects
reeds
fish migration
FRESH
pike
FRESHWATER MARSH
increasing carbon capture
pondweed

Along the Wieringermeerdijk and the Afsluitdijk there is a continuous gradual land-water transition. These can be seen in figure 70 and figure 72 respectively. For both the variants for fresh and salt marshes are used.

Figure 69: View over the saltmarshes near Den Oever

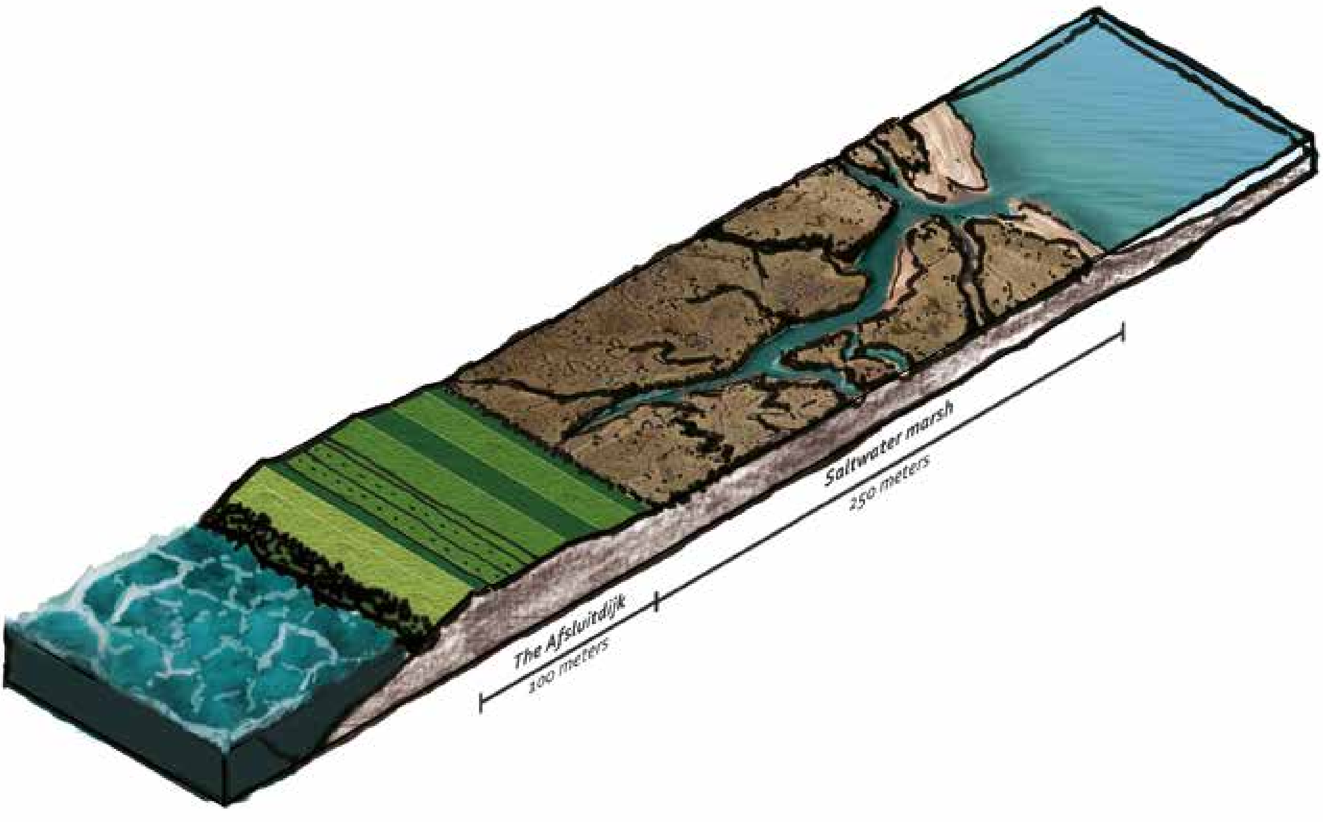


Figure 70: Saltwater marshes along the Afsluitdijk

Another addition is the smaller water ways in the forest, which opens the up for more water and amphibious animals. In the cross-section (figure 72), these interactions are further explained. The forest on the IJsselmeer side will be similar in character to the *Bieschbosch* in the Netherlands. The forest is connected with the Robbenoordbos, for ecology it would be beneficial to also make connections with the water system. But due to safety reasons the dikes need to stay in place.

Figure 71: Walkways through freshwater marshes and riparian forests

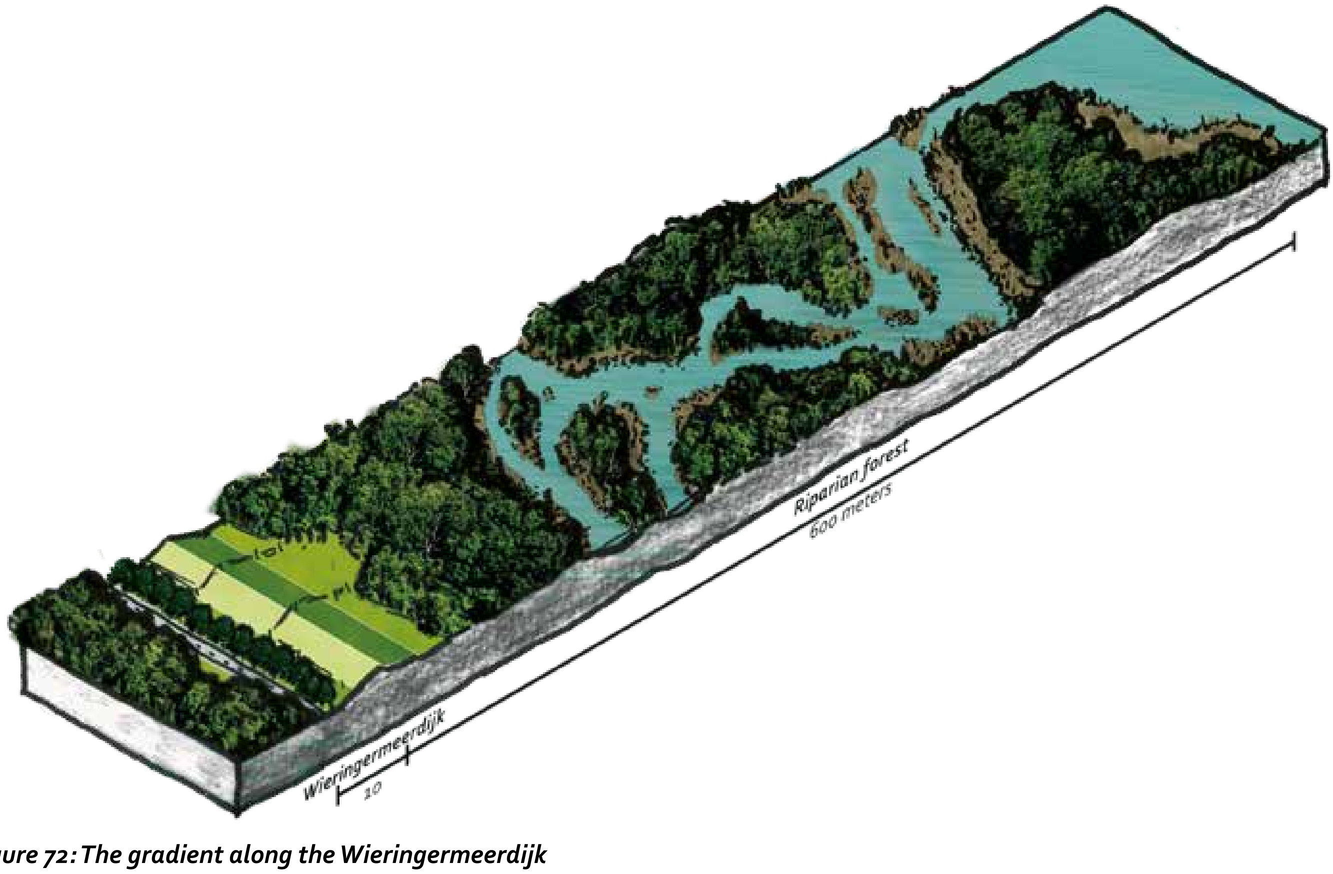


Figure 72: The gradient along the Wieringermeerdijk

The middle of the design is crossed by a raised dike to separate fresh and salt habitats. This limits wash over from salt water to the fresh water habitats, because direct contact with highly salinized waters kills the fresh water marshes. The dikes also offer opportunities for recreation. This can be seen in the cross-section of figure 74.

Figure 73: Recreation on the separating dike

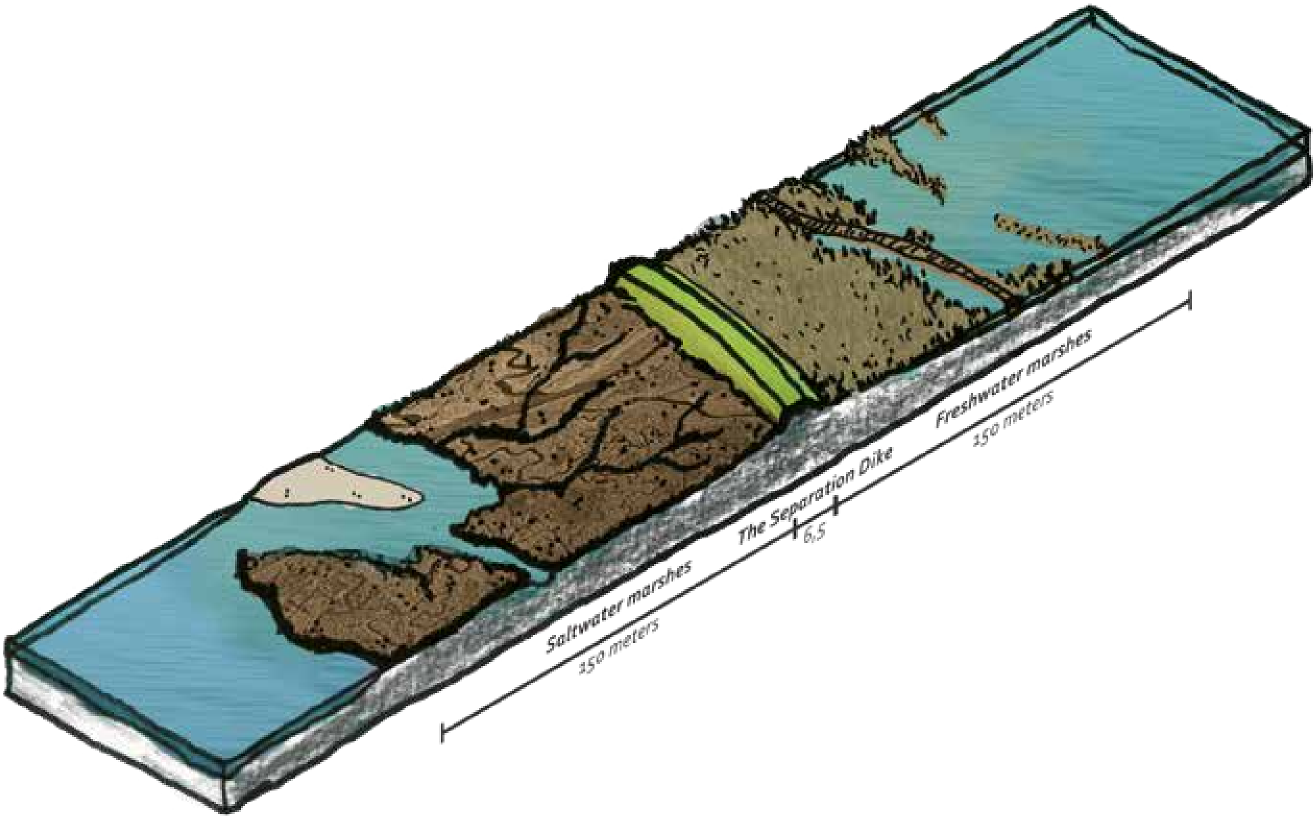


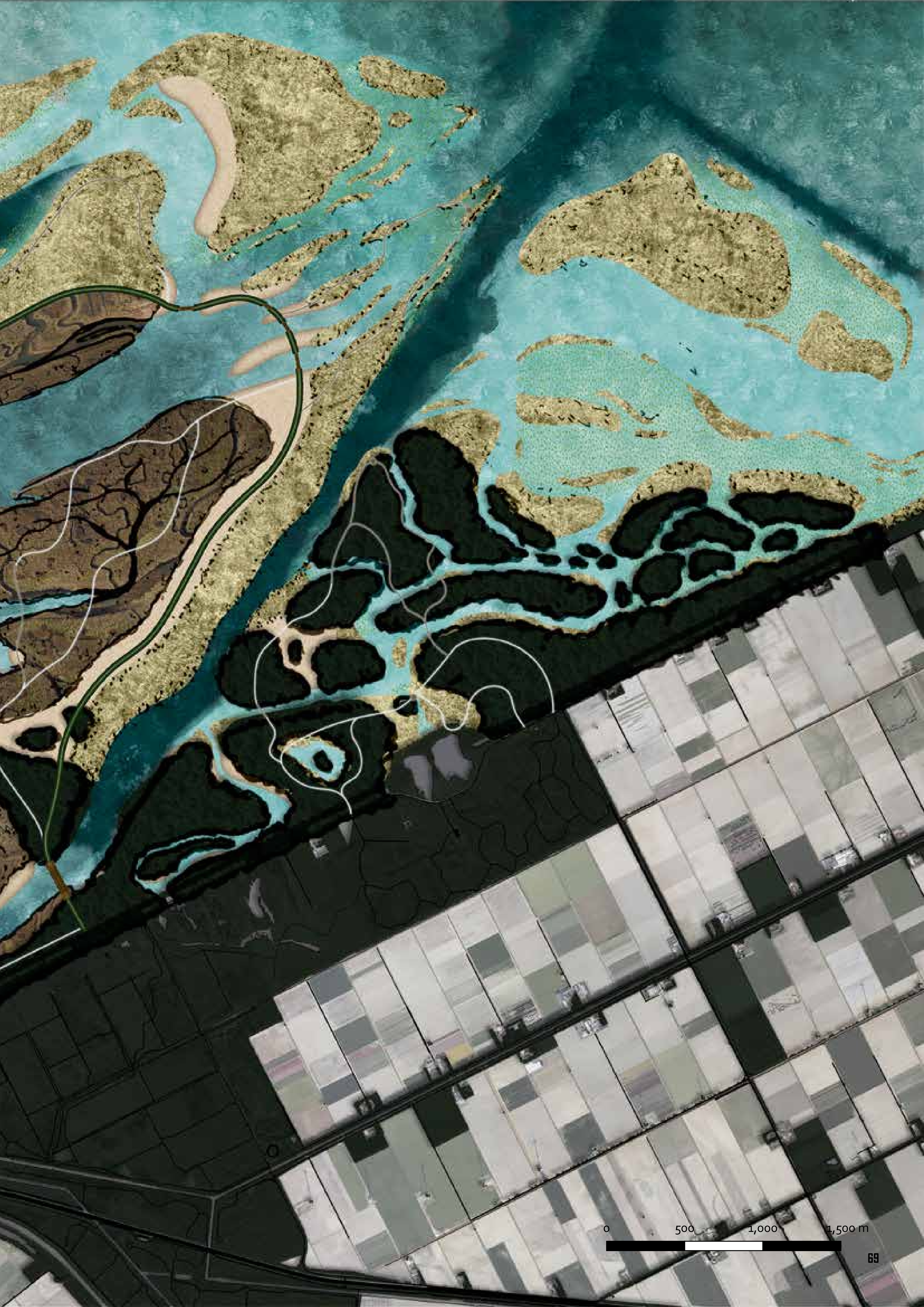
Figure 74: The separating dike between fresh and salt ecotopes

For the routing the dike is used as a backbone from which routes start. From there various wooden walkways depart. The dikes will also be accessible for bikes. This dike can be seen in the more detailed cross-section of figure 76 and its user experience in figure 75.

Figure 75: seperation dike close up

Figure 76: Detailed separating dike between fresh and salt ecotopes

Figure 78: Final design (large image)


0
500
1,000
1,500 m

CHAPTER 9
Discussion & Conclusion

9.1. Discussion

1. **Location of salinity gradient**

In the three proposed design models and the final design the location of the connection between fresh and saltwater is situated close to the location of the current waterways (figure 79). This decision was made due to the already present mixing of salt and fresh water, which offers opportunities for mixing these two types of water. However, there are more possibilities to create an estuarine gradient in this area. Two of them are briefly discussed below and why they have not been chosen.

An option considered for the estuarine gradient is through the *Wieringermeerpolder* (Witteveen+Bos, 2006). The biggest benefit of this solution is that water safety of the IJsselmeer stays completely intact. This plan has already been extensively explored as the project *Wieringerrandmeer (translate: Wieringen Edge Lake).* However, when it was presented it was not well received: about 30 agricultural companies were to be relocated on the current land area of *Wieringen* and *Wieringermeer*, which led to the ultimate demise of the plan (Sloot *et al.*, 2006).

It was estimated that the *Wieringerrandmeer* project would influence the surrounding area up to five kilometres surrounding the Wieringermeerpolder. This would lead to increased groundwater levels that would influence the agriculture in a negative way, what could be mitigated locally (Bonte, Witjes and Vergeer, 2007). Municipalities and the province stated that the future of agriculture in this region would be secure and offered a "stable future perspective", but those farmers had strong doubts about this. The changed water management in the area would also have a negative impact on other agricultural lands (Sloot *et al.*, 2006).

This proposed plan had mainly been about fresh water

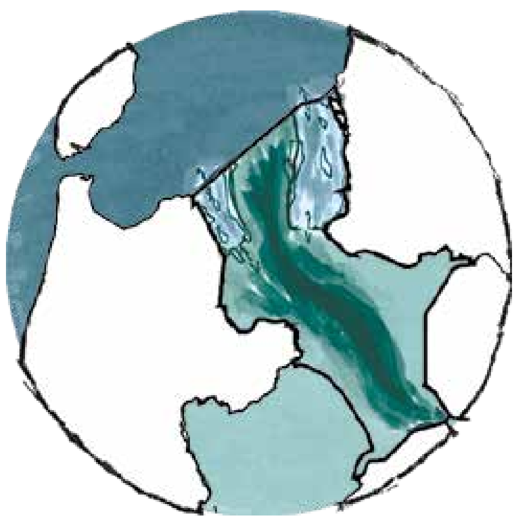


Figure 79: Design concept of this study

Figure 80: The Wieringerrandmeer by Palmboom & van den Bout Stedenbouw

habitats because salination would rise in the area and salt seepage would ruin the surrounding farms (Sloot *et al.*, 2006). This location was not chosen because of the huge amount of fresh and salt water ecotopes required to have a significant impact on water quality of the *IJsselmeer* (see figure 12, and figure 14 in section 2.4.). When created on this location, it would cause a large depoldering of the *Wieringermeerpolder*. This would also mean that much of the topsoil would have to be removed to be able to realise the required ecotopes. A location in the IJsselmeer would thus be easier to realise and get less resistance from the inhabitants of the area.

A second possibility is an inverse of the first option (figure 82). Instead of creating the estuarine gradient at the sluices, coupled to the current openings in the *IJsselmeer*, the opening is located in the middle of the *Afsluitdijk.* However, this option was also not chosen because of the missed opportunities when connecting the designs with the current sluices. Although this option could have provided a design solution in which nature could truly be separated from the ships. Furthermore, it would not influence the military field of fire. This option could be further explored in another iteration of this research.

2. Case study area

In this research, the area of the *Wieringerhoek* was chosen as a case study for testing the design of constructed marshes in the *IJsselmeer* instead of a case study area at the sluices in Friesland. This was chosen because there is a planned project for a salinity gradient in the *Wieringerhoek* (Mandemakers, van der Winden and Klinge, 2019). Additionally, there were experts on this area available through *Witteveen+Bos.* The area of the *Wieringerhoek* has a higher urgence for ecosystem development. The Frysian coast is currently further developed with freshwater marshes. This was another reason why the *Wieringerhoek* was chosen.

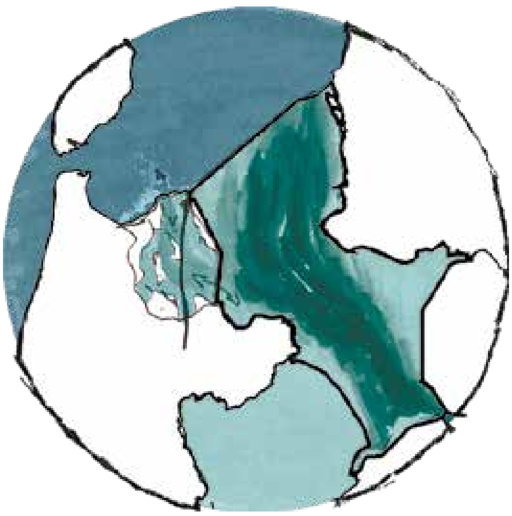


Figure 81: The Wieringerrandmeer

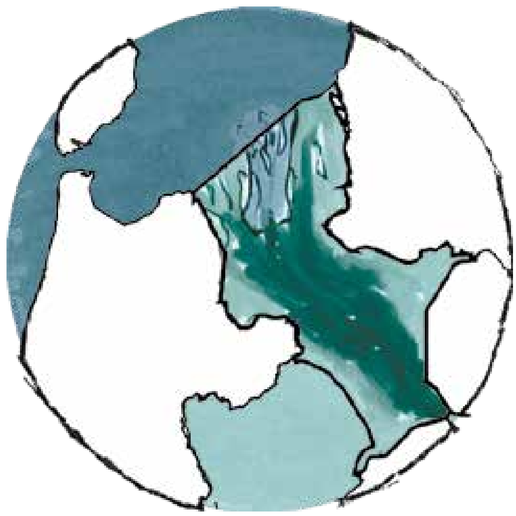


Figure 82: The salty inner-lake

3. Realisation of ecotopes

The creation of freshwater marshes has been researched on the *Marker Wadden* project and were taken as a large inspiration for the freshwater part of this design (De Rijk and Dulfer, 2020; IJff *et al.*, 2021). Because this is a project that has already been implemented, it is proven that freshwater marshes can be realised successfully in the *IJsselmeer.* The further shaping and realisation of the freshwater marshes in the *Wieringerhoek* should be realised according to the lessons learned from the *Marker Wadden* project.

The *Marker Wadden* are a series of manmade freshwater marsh islands created in the *Markermeer* (bordering the *IJsselmeer*). The *Marker Wadden* attracted a large number of birds already during its creation. According to the government, its positive impact on water quality and underwater ecology is not yet demonstrated (De Rijk and Dulfer, 2020). This is currently an ongoing research, but the positive interaction of constructed wetlands on water quality has been atoned, especially when the system promotes sedimentation (Johnston, 1993). Sedimentation is already happening in the *Wieringerhoek,* because of the low streaming speed of the *IJsselmeer* (van Dessel, 1988).

Reception of the introduction of riparian forests in the *IJsselmeer* might not result in the most positive response of the public. The openness of the lake is highly valued, so the perception of loss of openness in favour of these forests should be further researched. The social consensus of any project in the *IJsselmeer* requires further research, because currently there is

Saltwater marshes are most easily created on the areas where salt marshes were present in the past (French, 2008). This was pursued when designing the area. However, liberties were taken when this area was created. Additionaly, it is uncertain if the saltmarshes can naturally grow there when raising all the islands. Consequently, they might need to be planted.

Exploring the influence of the tides on the development of saltmarshes was outside the scope of this research. When the current tide of the IJsselmeer is kept, the tides will fluctuate approximatelly twenty centimetres (Rijkswaterstaat, 2018). This will place the design in a microtidal estuarine system, in which seasonal cycles and storms play a more important role in sea level changes than astronomical tides that are more dominant in classical estuaries.

Microtidal estuarine systems are associated with smaller marshes, more salt stress and more summer drought than classic tidal estuarine systems, due to irregular flooding of the marshes (Ibáñez *et al.*, 2012). The sea level changes regulate the primary productivity of salt marsh vegetation, and the vegetation, in turn, constantly modifies the elevation of its habitat toward an equilibrium with sea level (Morris *et al.*, 2002). Lateral marsh development may react very rapidly to decreasing flooding frequencies but more slowly to increasing flooding frequencies (Balke *et al.*, 2016). Follow up research can be done on either the influence of low tides on the realisation of saltmarshes or on the introduction of larger tides in the *IJsselmeer.*

Large tidal dynamics also can have a negative impact on the development of marshes. Dronkers emphasizes the important role of the period of slack water between flood and ebb phases and its importance for the deposition of fine sediments (Dronkers, 1986, 1998, 2016). But the lack of strong tidal dynamics is a weakness that this design does not address, and further research is proposed on the creation of higher tidal dynamics and its influence on

Figure 83: Current Markerwadden (image by Natuurmonumenten)

the *IJsselmeer* area.

The design, however, does offer potential for tidal dynamics. Because the created dike that separates the fresh marshes from the saltmarshes can also be used to create and maintain tides in the saltmarsh area of the design. However, this requires additional sluices to maintain safety regulations. In the final design, it is chosen not to introduce an increase of tidal dynamics in the *IJsselmeer.* It is both very expensive to realise this it blocks a direct connection between the fresh and salt water which was a major aim of this study. The impact of these tides on the system as a whole and the technical interventions required are suitable for follow up research.

Many assumptions are taken into account when creating the salinity gradient in the design. The underwater-dikes and their functioning need to be researched in more technical detail. This would require waterflow and salinity modelling for the design and could result in a necessary change in the design. Its safety on maintaining the freshwater bubble must also be further researched.

The size of the marshes needs to at least double even after the design is realised as will be further discussed in the conclusion, to have a significant impact on the water quality as can be seen in figure 12, and figure 14 in section 2.4. respectively. Further design studies can be done with the landscape design principles generated in chapter 6 to realise the desired impact on water quality as described in the studies by Asjes (Asjes, 2000).

4. Design decisions

The question that also arises is the societal significance of a design like this. It is located far away from bigger cities, which makes it harder to reach for casual tourism. It does offer recreational opportunities, there must be people to take these opportunities. Because a large amount of land is moved for this nature development, it becomes a very expensive project. The societal benefits of a large-scale design like this need to be further researched. The area itself is quite remote with no major city close by. This makes the area suitable for day trips and longer trips, but the demand for this must be further explored. However, areas like the *Bieschbosch* in the *Westerschelde* show that there is demand for wetland tourism to some degree. This area is swampier than the *Bieschbosch* which makes its visual characteristics quite different from that.

In this design research, the hydromorphological layer is used as the main input for design decisions. This is the best decision when talking about realisation of the design (less sand has to be moved). The bottom of the lake is defined by the old sea flows before the realisation of the *Afsluitdijk.* These shapes are not relevant anymore and they are still subject to change in the coming century (Dastgheib and Roelvink, 2012). In future research, design decisions can also be further investigated by the current streams of the IJsselmeer, although it is largely a quiet lake there is still some flow that keeps changing the terrain.

This research had a large ecological focus, which meant that the occupational layer and human experience of the landscape took a backseat during this research. It is suggested that, when realising or further exploring designs for the *Ijsselmeer*, that human experience is taken into consideration. In the '*nationaal waterplan of*

Figure 84: Saltmarshes of the Westerschelde (image by Paul Oostveen)

2016-2021', it is suggested that the Netherlands should search for smart combinations between water, living and infrastructure, sustainable energy and nature (Ministerie van Infrastructuur en Milieu, 2015). The project at the *Wieringerhoek* lends itself for these ambitions, but more integrative design solutions must be further explored.

One of these ambitions is housing combined with water. For example living on the water, which has been shown as a successful concept for the Netherlands (Fit, 2006; Schuwer, 2007). The demand for living on the water is also increasing (Fit, 2006). The design could offer opportunities for living on the water in this new nature area. As mentioned before, the area is quite remote so this might make it less attractive for people to live.

Another demand is recreation. The current final design is large in scale; further detail level must be developed before a possible construction. The design of educational centres and recreational hubs is merely a suggestion in this design and architects could further develop those.

Energy demand is expected to rise in the Netherlands and there are possibilities to produce energy from the difference between salt and fresh water. The company REDstack has built a pilot plant on the *Afsluitdijk.* The installation produces 50 kW (Klomp, 2012). It has already been suggested as a way to let salt water in the *IJsselmeer* as a design principle in chapter 6. It could be used together with the windmills and possible solar islands to generate more energy on the *IJsselmeer.* Its influence on ecotopes of the proposed design of this thesis must be further researched together with integrated design solutions.

5. Methodology

GeoDesign offers a framework with a large stakeholder involvement (Steinitz, 2012). Reliance on few expert opinions is not considered the most suitable way for landscape architecture to continue developing its body of knowledge. Landscape design researchers should conduct more empirical research that is based on observed and measured phenomena (Meijering *et al.*, 2016). An expert judgement is often considered the lowest form of research (Golubnitschaja *et al.*, 2012). Expert judgements are dependent on individual, subjective opinions, which is unavoidable, but underlines the importance of the verifiability of the assessment (Nillesen, 2019).The author would argue that it does have benefits in design projects. It is possible to gather many opinions and ideas on certain design concepts from various perspectives. Because there were multiple experts present during the session, there was some triangulation present when the experts could judge each other. The author did a landscape analysis (chapters 3, 4 and 5) that can also verify the judgement with further triangulation.

The experts were selected on their expertise on both the topic and the study area. All the experts have worked before on the *Wieringerhoek,* so they were very familiar with the area. This familiarity with the study area made the discussion easier. It also made the design more relevant. As mentioned in the introduction, this is a real project, and the selected experts were involved in the actual project, which gave them more knowledge on what was and was not possible to realise in this area. This made these experts more suitable than experts that were just familiar with, for example, the topics of ecology or water management.

The discussion with experts that were familiar with the area also influence their judgement of the study area based on preference of their respective organisation. As mentioned by Nillesen (2019), this is expected. But this could also enhance the research due to involvement of various stakeholders and weighing of their opinion.

In this research, three design options were presented in one meeting. In future research, it is recommended to have an expert judgement meeting after each iteration of the GeoDesign framework, which is also recommended by Steinitz (Steinitz, 1990, 2002, 2012). Only one meeting was held due to the time constraints of the research, and the difficulty of planning meetings where everyone was available.

The author made the final decisions based on the expert judgement on the three preliminary designs. Although he tried to be as objective as possible, there is some degree of bias due to preference and personal opinions on the design.

9.2. Conclusion

Specific Research Question 1

What landscape interventions can improve an estuarine gradient?

Creating an estuarine gradient largely depends on the realisation of a salinity gradient: the gradual transition from a salty environment to a fresh environment: the gradual transition from a salty environment to a fresh environment. This salinity gradient must have an interaction between the freshwater and saltwater to encourage nutrient exchanges. Both fresh and salt systems and corresponding ecotopes are further explained in the toolbox of figure 85. The most suitable habitats for change are the dikes and the dams, the dikes and the medium deep to shallow waters. The toolbox offer suggestions on how to change existing landscape units into new landscape design principles that create more biodiversity and an improved water quality.

For the saltwater ecotopes, this mainly consists of the creation of saltwater marshes along the saltwater inlet of the system. Currently the freshwater system of the *IJsselmeer* is closed of from the saltwater system of the *Waddenzee*. So, an opening in the *Afsluitdijk* is needed to facilitate this gradient. Saltwater inlet through the sluices is possible and a viable solution for the creation of salt water ecotopes. However, a new direct opening (that does not close) without boats and the sluice dynamics is necessary for fish species. This makes a direct opening a necessary requirement for the creation of an estuarine gradient. Another way to pump in water is through pipes under the *Afsluitdijk.* Therefore, it is necessary to have a possibility to close each direct connection between the *Waddenzee* and the *IJsselmeer.* Another way of managing the saltwater concentration is by implementing underwater dikes at various points in the design that work on the density difference of fresh and salt water. These interventions to manage the salinity concentration at various stages are there to safeguard the freshwater reservoir function of the *IJsselmeer* when there is a storm or another peak inlet of saltwater.

The saltwater marshes are created mainly on the locations where there were saltmarshes in the past. However, it is possible to seed with Salicornia plant fragments to kick-start the colonisation of the saltmarshes. It is also vital to create the required slope angle for saltmarshes. Saltmarshes transition from a floodplain to a saltmarsh. In the creation of the saltmarsh, it is enough to create the floodplain (with some additional seeding) to let the marshes grow themselves. It is also essential to fragment the marsh with streams to create the necessary nutrient dynamics for growth.

For the freshwater system, the landscape design principles consist of the ecotopes: freshwater marshes and riparian forests for the higher areas. These ecotopes can transition from one to the other. Even the saltmarsh can transition into a riparian forest when it is outside the influence of saltwater. Various helophyte species can occur in the shallow water and on the swampy transition from water to land. The zone becomes ecologically relevant when a width of approximately 0.5 meters is achieved. However, even when the width is limited, the helophyte zone can serve as a breeding ground for undemanding waterfowl. So a mix of both is recommended with a focus on larger marsh areas.

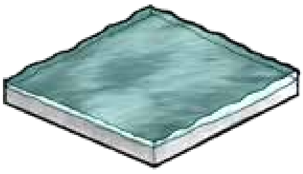
Most fish species cannot use a riparian forest; they prefer more open areas than the smaller waterways in these forests. However, they can be used to improve other aspects of the ecosystem. On the one hand, a tidal forest provides a habitat for certain organisms such as amphibians, some specific fish species, and certain bird species. On the other hand, when it connects to the aquatic ecosystem (the *IJsselmeer*), the riparian forest can provide additional organic material.

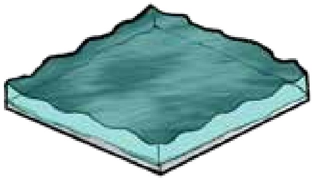
The toolbox can be viewed in its in entirety in figure 85.

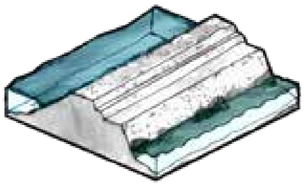
Landscape Design Toolbox for an Estuarine Gradient

	MEDIUM DEEP TO SHALLOW WATERS	MEDIUM DEEP OR SHALLOW WATERS	DAMS (THE AFSLUITDIJK)

CURRENT



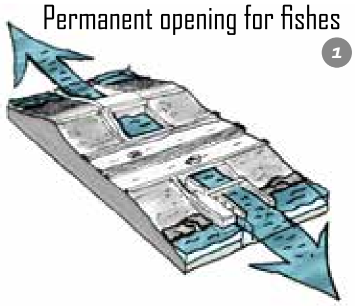




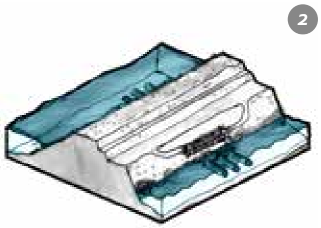
SALTWATER INLET

A free passageway for fishes through the Afsluitdijk (that can be closed in case of emergency). This will also create a constant salination in the IJsselmeer.

Permanent opening for fishes

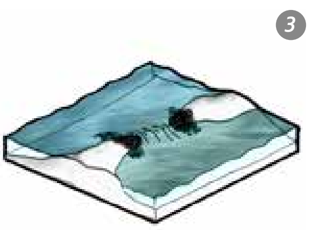


Pumping of Saltwater



SALTWATER REGULATION

Underwater Dike



Underwater Dike

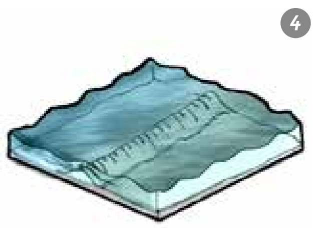
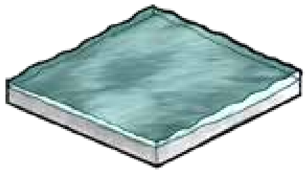
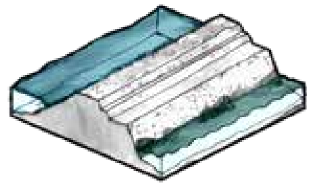


Figure 85: Landscape design toolbox for an estuarine gradient

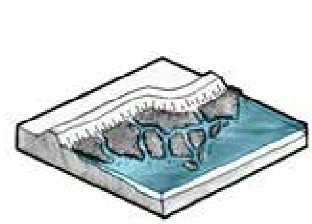
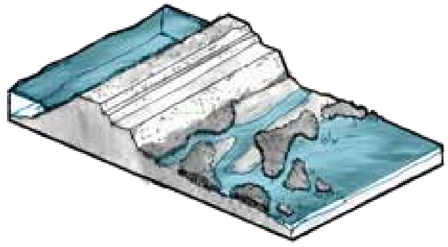
MEDIUM DEEP TO SHALLOW WATERS | **REGULAR DIKES** | **DAMS (THE AFSLUITDIJK)**

CURRENT



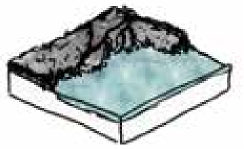


SALTWATER MARSH

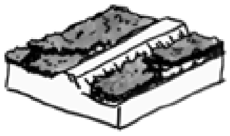




Mixing sand with 25% mud boosts vegetation cover and species richness (Baptist et al., 2021). Place must be relatively Sheltered.

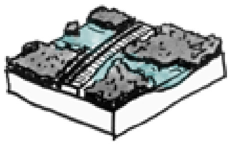
The slope of the area must be aligned gently towards the sea (1:0-1:18 or 1:0-1:64), which reduces flow velocity and enhances sedimentation (Burd, 1995). sediment suspension is required for survival (1-10 mg/l) and growth (1-100 mg/l) (Borsje et al., 2011; Li & Yang, 2009; S. Temmerman et al., 2004).



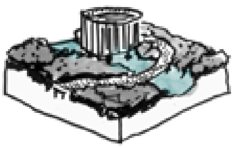
Raised pathways



Wooden pathways

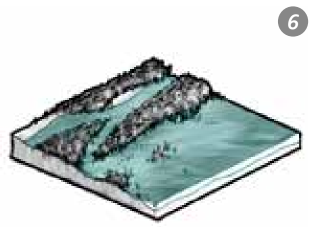
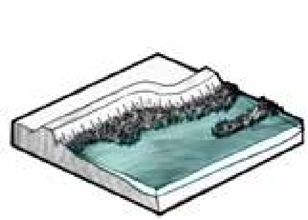
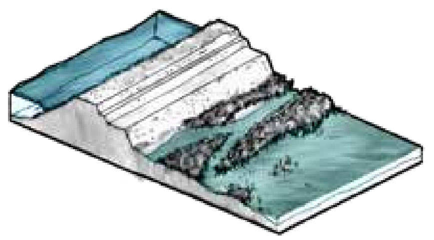


Bird watchtower



Small ferry

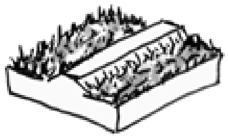
FRESHWATER MARSH

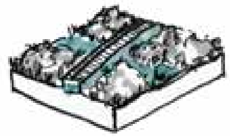
Width of at least 0.5 meters. A mosaic of reed beds and open water (1:2 ratio) is needed to be effective as a habitat for fisth.

Foreshore environments improve dike resilience and enhance flood defenses by dampening wave forces with their shallow slopes. They stabilize the dike with additional mass and increasing seepage length (EcoShape & One Architecture, 2020).

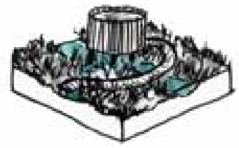
Raised pathways



Wooden pathways

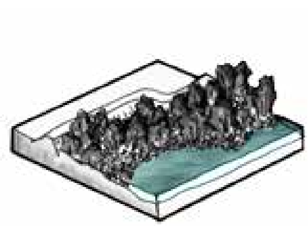


Bird watchtower



Small ferry

RIPARIAN FOREST

A riparian forest provides an important additional source of organic matter. Dikes integrate inundation-tolerant vegetation to maximize flood risk reduction.

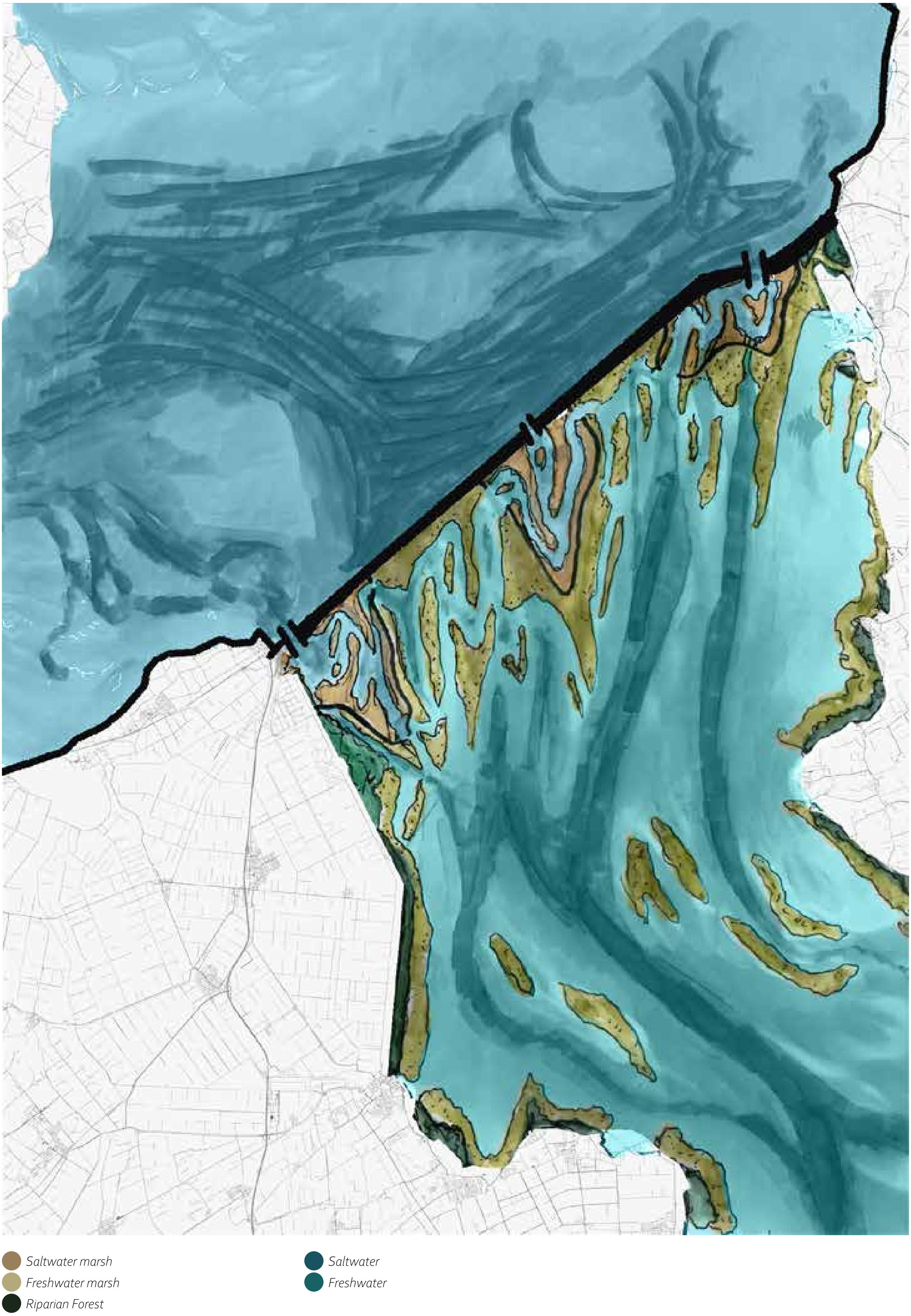


Figure 86: Implementation of the design toolbox (figure 85) in the whole IJsselmeer mouth area

Specific Research Question 2

What differences might the changes cause to the Wieringerhoek?

In this research, three design models were made and presented to experts familiar with the topics and study area. This method aimed to determine which landscape design principles were most suitability integrated into the specified case study area: the *Wieringerhoek*. This led to a set of rules for implementing the design principles in the *IJsselmeer*. These design principles were informed by expert judgement and the various design iterations.

Expert judgement

1. Create multiple openings between the fresh and salt ecotopes instead of just one to create enough nutrient interaction to make marsh growth possible;
2. Create a large body of water directly behind the sluices (because the sluice uses much water so this is why it is required to have a large body of water behind the sluices) and use this soil to raise the other islands and create an even deeper basin at this behind the sluices;
3. More extensive connected systems are favoured over smaller fragmented systems together with a large variety between small and large ecotope patches;
4. Separate forests and marsh ecotopes more to not attract predator species of the marsh animals;
5. Fragment the riparian forest with small gulleys to stimulate fish life.
6. Create another constant opening next to the sluices to have an open passageway for fishes.

Design iterations

1. Use the morphology created during the *Zuiderzee* era to create the marshes;
2. Create a salinity gradient both along the *Afsluitdijk* and the *Wieringermeerdijk;*
3. Create connections between the existing forest of the *Wieringermeerpolder* and new riparian forests in the lake (these were also highly favoured during the expert judgement);
4. Create a recreation line as the separation of freshwater and saltwater marshes, so both ecotopes can be viewed at the same time;
5. Create a raised surface between fresh and salt marshes to limit washover of saltwater in the freshwater marshes;
6. Dikes raise opportunities for changed tidal dynamics.

Main Research/Design Question:

How can landscape design interventions improve the estuarine gradient in the Wieringerhoek and, by doing so, improve biodiversity and water quality?

The two specific research questions helped inform the final design from figure 78. This toolbox of design principles forms a part of the answer to the main research question. These principles are suitable for other locations in the *IJsselmeer* and other river mounds with similar conditions (as can be seen in figure 86).

However, when designing in the *IJsselmeer* area, the transition between fresh- and saltwater must be created carefully and highly managed so the freshwater reservoir function of the *IJsselmeer* can be maintained. The restrictions posed by the water safety regulations make it impossible to create a literal estuarine gradient. With the created design, conditions of a natural estuary are simulated, but the system itself is to precarious for the creation of an estuarine gradient with tidal dynamics. The estuarine gradient is in this sense only an salinity gradient with corresponding ecotopes of an estuarine. The tidal interactions that are present make the design a micro-tidal estuarine system. The environment of an actual estuary is rougher than the simulated system of this design.

The design does offer the conditions to maintain the freshwater and saltwater ecotopes. These ecotopes themselves have a positive impact on both biodiversity and water quality. Although to significantly impact the water quality, more similar projects need to be created in the whole *IJsselmeer* area. A suggestion for this is shown in figure 86. The design forms a solution to higher fluctuating salinity concentrations due to climate change. The design interventions presented in this will create a more biodiverse *IJsselmeer* with improved water quality. Ecotopes similar to an estuary will develop there but not create an estuarine gradient in the traditional sense but a controlled estuarine gradient.

9.3. Bibliography

A

Aarninkhof, S G J, Dalfsen, J. a Van, & Rijks, D. (2010). Sustainable development of nourished shorelines. *PIANC MMX Congress Liverpool UK*, 1–12.

Aarts, B., & Bruinzeel, L. (2008). *De nationale windmolenrisicokaart voor vogels*. http://www.vogelbescherming.nl/index.cfm?act=files.download&ui=54AE8F76-E361-5CAF-A989E812B4AD6701

Alimov, A. F. (2007). Theory of ecosystem functioning: application to estuarine ecology. *Symposium ECSA42 "Estuarine Ecosystems: Structure, Function and Management*, 16–22.

Asjes, J. (2000). *Meerwaarde van een Brakke Zone bij de Afsluitdijk Een kwalitatieve beschouwing*.

Attrill, M. J. . (2002). A Testable Linear Model for Diversity Trends in Estuaries. *Journal of Animal Ecology*, *71*(2), 262–269. https://www.jstor.org/stable/pdf/2693444.pdf?refreqid=excelsior%3A1c8e57ab6fe6c0efcdf305c596b98eb6

B

Balke, T., Stock, M., Jensen, K., Bouma, T. J., & Kleyer, M. (2016). A global analysis of the seaward salt marsh extent: The importance of tidal range. *Water Resources Research*, *52*(5), 3775–3786. https://doi.org/10.1002/2015WR018318

Baptist, M. J., Dankers, P., Cleveringa, J., Sittoni, L., Willemsen, P. W. J. M., van Puijenbroek, M. E. B., de Vries, B. M. L., Leuven, J. R. F. W., Coumou, L., Kramer, H., & Elschot, K. (2021). Salt marsh construction as a nature-based solution in an estuarine social-ecological system. *Nature-Based Solutions*, *1*(August), 100005. https://doi.org/10.1016/j.nbsj.2021.100005

Begon, M., Howarth, R. W., & Townsend, C. R. (2014). Ecology's Evolutionary Backdrop. In N. Hoboken (Ed.), *Essentials of ecology* (4th ed., pp. 28–53). Hoboken, NJ : Wiley. https://wur.on.worldcat.org/v2/search/detail/1007051219?queryString=essentials of ecology

Bekius, D., & Kooiman, M. (2016). *Karakterisering Nederlandse veenontginningen Eindverslag en verantwoording* (Issue september). https://www.cultureelerfgoed.nl/binaries/cultureelerfgoed/documenten/publicaties/2019/01/01/bijlagen-bij-de-agrarische-landschappenkaart/VO+eindverslag+26092016.pdf

Bishop, M. J., Mayer-Pinto, M., Airoldi, L., Firth, L. B., Morris, R. L., Loke, L. H. L., Hawkins, S. J., Naylor, L. A., Coleman, R. A., Chee, S. Y., & Dafforn, K. A. (2017). Effects of ocean sprawl on ecological connectivity: impacts and solutions. *Journal of Experimental Marine Biology and Ecology*, *492*, 7–30. https://doi.org/10.1016/j.jembe.2017.01.021

Bonte, M, Witjes, T., & Vergeer, T. (2007). *Geohydrologisch onderzoek voor het Wieringermeer* (Vol. 40, Issue 23).

Bonte, Matthijs. (2009). Drinkwaterfunctie Markermeer en verzilting IJsselmeergebied. *Stromingen*, *16*(2&3), 49–60. https://www.researchgate.net/publication/45107361_Drinkwaterfunctie_Markermeer_en_verzilting_IJsselmeergebied

Borsje, B. W., van Wesenbeeck, B. K., Dekker, F., Paalvast, P., Bouma, T. J., van Katwijk, M. M., & de Vries, M. B. (2011). How ecological engineering can serve in coastal protection. *Ecological Engineering*, *37*(2), 113–122. https://doi.org/10.1016/j.ecoleng.2010.11.027

Bouma, H., de Jong, D. J., Twisk, F., & Wolfstein, K. (2005). A Dutch Ecotope System for Coastal Waters (ZES.1). *Middelburg, Report RIKZ/2005.024*, *2005*(July 2005), English version June 2006.

Bulger, A. J., Hayden, B. P., Monaco, M. E., Nelson, D. M., & McCormick-Ray, M. G. (1993). Biologically-based estuarine salinity zones derived from a multivariate analysis. *Estuaries*, *16*(2), 311–322. https://doi.org/10.2307/1352504

Burd, F. H. (1995). *Managed retreat: a practical guide*. English Nature.

C

Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., & Lynch, J. C. (2003). Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles*, *17*(4). https://doi.org/10.1029/2002gb001917

Coops, H. (1996). *Helophyte zonation: impact of water depth and wave exposure*. Katholieke Universiteit Nijmegen.

D

Dankers, N., van Duin, W., Baptist, M., Dijkman, E., & Cremer, J. (2012). The Wadden Sea in the Netherlands: Ecotopes in a World Heritage Barrier Island System. *Seafloor Geomorphology as Benthic Habitat*, *June 2009*, 213–226. https://doi.org/10.1016/B978-0-12-385140-6.00011-6

Dastgheib, A., & Roelvink, D. (2012). Zuiderzee is now called IJsselmeer*: Process-based Modeling. *NCK-Days 2012 : Crossing Borders in Coastal Research.* https://doi.org/10.3990/2.176

Day, J. W., Hall, C. A. S., Kemp, W. M., & Yanez-Arancibia, A. (1988). Estuarine ecology. In *Estuarine ecology*. https://doi.org/10.2307/2937399

de Boer, K., & Wolff, W. J. (1996). *Tussen zilt en zoet: voorstudie naar de betekenis van estuariene gradiënten in het Waddengebied*. http://library.wur.nl/WebQuery/clc/934509

de Leeuw, C. C., & Backx, J. J. G. M. (2001). *Naar een herstel van estuariene gradienten in Nederland*. file:///C:/Users/dbos/AppData/Local/Mendeley Ltd./Mendeley Desktop/Downloaded/Leeuw, Backx - 2001 - Naar een herstel van estuariene gradienten in Nederland.pdf

de Leeuw, J. (1997). Demanding divers : ecological energetics of food exploitation by diving ducks. *Van Zee Tot Land*, *61*, 178. https://puc.overheid.nl/rijkswaterstaat/doc/PUC_93866_31/

de Leeuw, J. J., Dekker, W., & Buijse, A. D. (2008). Aiming at a moving target, a slow hand fails! 75 years of fisheries management in Lake IJsselmeer (the Netherlands). *Journal of Sea Research*, *60*(1–2), 21–31. https://doi.org/10.1016/j.seares.2008.03.005

de Leeuw, J. J., Tien, N. S. H., van der Hammen, T., & Smith, S. R. (2021). Vissen binnen ecologische randvoorwaarden. *Landschap*, *1*, 35. https://www.landschap.nl/wp-content/uploads/2021_1_34-41DeLeeuw.pdf

De Rijk, S., & Dulfer, W. (2020). *Mid Term Review Kennis en Innovatieprogramma Marker Wadden (KIMA)*.

De Vriend, H. J., & Van Koningsveld, M. (2012). Building with Nature: Thinking, acting and interacting differently. In *Ecoshape* (1st ed., Issue June). Ecoshape, Building with Nature.

Deltacommissie. (2010). *Deltaprogramma 2011*.

Deltacommissie. (2021). *Deltaprogramma 2022*.

Directoraat-generaal Rijkswaterstaat. (2002). *Natuurontwikkeling IJsselmeergebied 2002-2010*. https://edepot.wur.nl/346280

Dronkers, J. (1986). Tidal asymmetry and estuarine morphology. *Netherlands Journal of Sea Research*, *20*(2–3), 117–131. https://doi.org/10.1016/0077-7579(86)90036-0

Dronkers, J. (1998). Morphodynamics of the Dutch Delta. In J. Dronkers & M. B. A. M. Scheffers (Eds.), *Physics of Estuaries and Coastal Seas* (pp. 297–304).

Dronkers, Job. (2016). Dynamics of coastal systems: Second edition. In *Dynamics of Coastal Systems: Second Edition* (2nd ed.). World Scientific Publishing Co. Pte. Ltd. https://doi.org/10.1142/9818/SUPPL_FILE/9818_CHAP01.PDF

DUIKEN. (2022). *Herstel natuur in delta helpt Nederland beschermen tegen stijgende zeespiegel - Duiken Magazine*. https://duiken.nl/herstel-natuur-in-delta-helpt-nederland-beschermen-tegen-stijgende-zeespiegel/

E

EcoShape, & One Architecture. (2020). *Building with Nature: Creating, implementing and upscaling Nature-Based Solutions* (E. van Ekelen & M. Bouw (eds.)). Nai010 Publishers.

Eerden, M. R. van, Rijn, S. H. M. van, & Roos, M. (2005). *Ecologie en Ruimte. gebruik door vogels en mensen in de SBZ's IJmeer, Markermeer en IJsselmeer*. Ministerie van Verkeer en Watterstaat & Directoraat-Generaal Rijkswaterstaat & Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling RIZA.

Elias, E., Stive, M., Bonekamp, H., & Cleveringa, J. (2003). Tidal inlet dynamics in response to human intervention. *Coastal Engineering Journal*, *45*(4), 629–658. https://doi.org/10.1142/S0578563403000932

Ente, P.J. (1971). Het ontstaan van Marsdiep en de Zuiderzee. In *Werkdocument 102 abw* (Vol. 20, Issue 8). https://puc.overheid.nl/rijkswaterstaat/doc/PUC_19092_31/

Ente, Pieter Jacob, Koning, J., & Koopstra, R. (1986). *De bodem van oostelijk Flevoland*. Rijksdienst voor de IJsselmeerpolders.

F

Fit, J. (2006). *Drijvende woningen, op weg naar een volwassen segment van de woningmarkt?* Amsterdam School of Real Estate.

Flaxman, M. (2010). Fundamentals of Geodesign. *Peer Reviewed Proceedings of Digital Landscape Architecture 2010 at Anhalt University of Applied Sciences*.

Forman, R. T. T. (1995). Land mosaics: the ecology of landscapes and regions. In F. O. Ndubisi (Ed.), *The Ecological Design and Planning Reader* (pp. 217–234). Island Press. https://doi.org/10.2307/2261341

French, J. R. (2008). Hydrodynamic modelling of estuarine flood defence realignment as an adaptive management response to sea-level rise. *Journal of Coastal Research*, *24*(2B), 1–12. https://doi.org/10.2112/05-0534.1

Frissell, C. A., Liss, W. J., Warren, C. E., & Hurley, M. D. (1986). A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. *Environmental Management*, *10*(2), 199–214. https://doi.org/10.1007/BF01867358

G

Gaalen, F. Van, Osté, L., & Boekel, E. Van. (2020). *Nationale Analyse Waterkwaliteit (PBL)* (Issue april). https://www.pbl.nl/nieuws/2020/nationale-analyse-waterkwaliteit-op-website-kennisimpuls-waterkwaliteit

Gedan, K. B., & Silliman, B. R. (2009). Patterns of salt marsh loss within coastal regions of North America. In B. R. Silliman, E. D. Grosholz, & M. D. Bertness (Eds.), *Human impacts on salt marshes: A global perspective* (pp. 253–265). University of California Press.

Gilby, B. L., Weinstein, M. P., Baker, R., Cebrian, J., Alford, S. B., Chelsky, A., Colombano, D., Connolly, R. M., Currin, C. A., Feller, I. C., Frank, A., Goeke, J. A., Goodridge Gaines, L. A., Hardcastle, F. E., Henderson, C. J., Martin, C. W., McDonald, A. E., Morrison, B. H., Olds, A. D., … Ziegler, S. L. (2021). Human Actions Alter Tidal Marsh Seascapes and the Provision of Ecosystem Services. *Estuaries and Coasts*, *44*(6), 1628–1636. https://doi.org/10.1007/s12237-020-00830-0

Golubnitschaja, O., Costigliola, V., Benini, A., Kastrup, J., Berliner, L., Boecker, H., Yeghiazaryan, K., Bowis, J., Bubnov, R., Butler, P., Roelandse, M., Cafiero, C., Chan, W. S. H., Characiejus, D., Coelho, J., Danesi, R., Rovigatti, U., De Meester, F., Desiderio, D. M., … Zhan, X. (2012). General Report & Recommendations in Predictive, Preventive and Personalised Medicine 2012: White Paper of the European Association for Predictive, Preventive and Personalised Medicine. *EPMA Journal*, *3*(1). https://doi.org/10.1186/1878-5085-3-14

Granda, M. S. (2018). *Achieving Natura 2000 by Building with Nature in the Eastern Scheldt*. University of Utrech.

H

Haines, B. L., & Dunn, E. L. (1976). Growth and Resource Allocation Responses of Spartina alterniflora Loisel to Three Levels of NH4-N , Fe , and NaCl in Solution Culture. *Botanical Gazette*, *137*(3), 224–230. https://www-jstor-org.ezproxy.library.wur.nl/stable/pdf/2473854.pdf?refreqid=excelsior%3A5a2346ed86ad1764f72177b17377635b

Heunks, C., Kleyheeg-Hartman, J. C., Boonman, M., & Verbeek, R. G. (2015). *Effecten van Windpark Fryslân op vogels , vleermuizen en overige beschermde natuurwaarden*. https://www.rvo.nl/sites/default/files/2016/02/Bijlage 3A bij PB Effecten en mitigatie WPF.pdf

Hogestijn, J. W. H., Bartels, M. H., Laarman, F. J., & Tiesinga, G. H. L. (1994). *Ruimte voor verandering, cultuur historisch Jaarboek voor Flevoland*.

Hopkinson, C. S., & Giblin, A. E. (2008). Nitrogen Dynamics of Coastal Salt Marshes. In D. G. Capone, D. A. Bronk, M. R. Mulholland, & E. J. Carpenter (Eds.), *Nitrogen in the Marine Environment* (2nd ed., pp. 991–1036). Elsevier. https://doi.org/10.1016/B978-0-12-372522-6.00022-0

HydroLogic. (2021). *IJsselmeer en Markermeer Beschrijving hoofdlijnen verziltingscasus onder aan de infographic*. https://www.helpdeskwater.nl/publish/pages/192772/p1231-teksten-infographic-ijm-20210531.pdf

I

Ibáñez, C., Morris, J. T., Mendelssohn, I. A., & Day, J. W. (2012). Coastal Marshes. In John W. Day, C. C. Byron, M. W. Kemp, & A. Yáñez-Arancibia (Eds.), *Estuarine Ecology* (2nd ed., pp. 129–163). Wiley-Blackwell. https://doi.org/10.1002/9781118412787.ch6

IJff, S., Veraart, J. A., Willems, J., Duijn, M., van den Berg, N., & Stouten, G. M. (2021). Innovatieve governance voor Building with Nature: Lessen uit het Marker Wadden-project. *Landschap: Tijdschrift Voor Landschapsecologie En Milieukunde*, *38*(1), 24–33.

Ingegnoli, V. (2002). Landscape Structure. In *Landscape Ecology: A Widening Foundation* (pp. 53–82). Springer Berlin Heidelberg.

Jager, Z. (1998). Accumulation of flounder larvae (Platichthys flesus L.) in the Dollard (Ems estuary, Wadden Sea). *Journal of Sea Research*, *40*(1–2), 43–57. https://doi.org/10.1016/S1385-1101(98)00010-0

J

Johnston, C. A. (1993). Mechanisms of Wetland-Water Quality Interaction. In *Constructed Wetlands for Water Quality Improvement* (1st ed., pp. 293–299). CRC Press. https://doi.org/10.1201/9781003069997-35

Kabat, P., Fresco, L. O., Stive, M. J. F., Veerman, C. P., Van Alphen, J. S. L. J., Parmet, B. W. A. H., Hazeleger, W., & Katsman, C. A. (2009). Dutch coasts in transition. *Nature Geoscience*, *2*(7), 450–452. https://doi.org/10.1038/ngeo572

K

Kalkman, V., Odé, B., & Gmelig Meyling, A. (2010). Patronen in de Nederlandse biodiversiteit. In J. Noordijk, R. M. J. C. Kleukers, E. J. van Nieukerken, & A. J. van Loon (Eds.), *De Nederlandse Biodiversiteit*. KNNV Uitgeverij.

Kamphuis, J. W. (2006). Coastal engineering - Quo vadis? *Coastal Engineering*, *53*(2–3), 133–140. https://doi.org/10.1016/j.coastaleng.2005.10.003

KAW architecten en adviseurs, & Arcadis. (2006). *Structuurplan Gemeente Wieringermeer*. http://docplayer.nl/31098097-Structuurplan-gemeente-wieringermeer.html

Kerkstra, K., Struik, J. B., & Vrijlandt, P. (1976). *Denkraam : instructie KB2-studio landschapsarchitectuur*. Wageningen L.H. https://library.wur.nl/WebQuery/groenekennis/169536

Khlebovich, V. V. (1974). Critical salinity of biological processes. *L.: Nauka*, *235*.

Khlebovich, V. V. (1990). Some physico-chemical and biological phenomena in the salinity gradient. *Limnologica LMNOA 8*, *20*(1).

Klip, H. (2020, July 22). *Na drie zomers heeft flexibel peil in IJsselmeer waarde al bewezen*. KNW. https://www.h2owaternetwerk.nl/h2o-actueel/flexibel-peil-in-ijsselmeer-heeft-waarde-al-bewezen

Klomp, H. (2012). Dialysis dike. Pilot plant for blue energy; . *Ingenieur (Utrecht)*, *124*(2), 30–31. https://www.osti.gov/etdeweb/biblio/21541955

KNW. (2021, July 12). *Stresstest van de IJsselmeerbuffer toont noodzaak voor adaptief beleid*. https://www.h2owaternetwerk.nl/vakartikelen/stresstest-van-de-ijsselmeerbuffer-toont-noodzaak-voor-adaptief-beleid

Kosian, M. (2017). *Droogmakerijen*. https://www.cultureelerfgoed.nl/binaries/cultureelerfgoed/documenten/publicaties/2019/01/01/bijlagen-bij-de-agrarische-landschappenkaart/104263_Droogmakerijen_PDFA.pdf

L

Lammens, E., Van Luijn, F., Wessels, Y., Bouwhuis, H., Noordhuis, R., Portielje, R., & Van Der Molen, D. (2008). Towards ecological goals for the heavily modified lakes in the IJsselmeer area, the Netherlands. *Hydrobiologia*, *599*(1), 239–247. https://doi.org/10.1007/s10750-007-9202-2

Lenselink, G. (2001). De ontwikkelingsgeschiedenis van het IJsselmeergebied. *De Levende Natuur*, *102*(6), 196–200. citeulike-article-id:10484219

Lenzholzer, S., Duchhart, I., & Brink, A. Vanden. (2016). The Relationship between Research and Design : Methods and Methodology. In A. Brink, D. Bruns, H. Tobi, & S. Bell (Eds.), *Research in Landscape Architecture: methods and methodology* (1st ed., Issue November, p. 13). Routledge. https://www.researchgate.net/publication/330432991 The

Leuven, J., de Vries, B., Dankers, P., van Puijenbroek, M., Willemsen, P., Coumou, L., Cleveringa, J., Baptist, M., & Elschot, K. (2021). *Kwelderontwikkeling als Nature-based Solution*.

Li, H., & Yang, S. L. (2009). Trapping effect of tidal marsh vegetation on suspended sediment, Yangtze Delta. *Journal of Coastal Research*, *25*(4), 915–936. https://doi.org/10.2112/08-1010.1

Lisitzin, A. P. (1999). The Continental-Ocean Boundary as a Marginal Filter in the World Oceans. In J. S. Gray, W. Ambrose, & A. Szaniawska (Eds.), *Biogeochemical Cycling and Sediment Ecology* (pp. 69–103). Springer Netherlands. https://doi.org/10.1007/978-94-011-4649-4_4

M

Magurran, A. (1988). *Ecological Diversity and Its Measurement*. Princeton University Press. http://link.springer.com/content/pdf/10.1007/978-94-015-7358-0.pdf

Mandemakers, J. J., van der Winden, J., & Klinge, M. (2019). *Verkenning Wieringerhoek*. https://www.helpdeskwater.nl/onderwerpen/water-ruimte/ecologie/programmatische-aanpak-grote-wateren-pagw/@236605/project-wieringerhoek/

May, R. M. (1988). How Many Species are There on Earth? *Science*, *241*(4872), 1441–1449. https://www-jstor-org.ezproxy.library.wur.nl/stable/pdf/1702670.pdf?refreqid=excelsior%3A903118caa05489d590a036a52625c21d

Meijering, J., Tobi, H., Brink, A. van den, & Bruns, D. (2016). Assessing research priorities and quality. In *Research in Landscape Architecture* (1st ed., pp. 85–102). Routledge. https://doi.org/10.4324/9781315396903-6

Ministerie van Infrastructuur en Milieu. (2015). *Ons Water in Nederland*. https://www.onswater.nl/

Ministerie van Infrastructuur en Waterstaat. (2018). *Agenda IJsselmeergebied 2050: Krachten bundelen voor het Blauwe Hart*.

Ministerie van Landbouw Natuur en Voedselkwaliteit. (2016). *Profieldocument Estuaria (H1130)* (Issue september 2014). https://www.natura2000.nl/sites/default/files/profielen/Habitattypen_profielen/Profiel_habitattype_1130_2016.pdf

Morris, J. T., Sundareshwar, P. V., Nietch, C. T., Kjerfve, B., & Cahoon, D. R. (2002). Responses of coastal wetlands to rising sea level. *Ecology*, *83*(10), 2869–2877. https://doi.org/10.1890/0012-9658(2002)083[2869:ROCWTR]2.0.CO;2

N

Ndubisi, F. (2002). Managing Change in the Landscape: A Synthesis of Approaches for Ecological Planning. *Landscape Journal*, *21*(1), 138–155. https://www.jstor.org/stable/pdf/43323576.pdf?refreqid=excelsior%3A6b36abe288135a413465e6393db45e02&ab_segments=&origin=

Nillesen, A. L. (2019). Discussion & Recommendations. In A. L. Nillesen (Ed.), *Spatial Quality as a decisive criterion in flood risk strategies* (1st ed., pp. 1–200). A+BE | Architecture and the Built Environment.

Noordhuis, R. (2010). *Ecosysteem IJsselmeergebied nog altijd in ontwikkeling: Trends en ontwikkelingen in water en natuur van het Natte Hart van Nederland* (Vol. 8002, Issue september).

Noordhuis, R., Groot, S., Dionisio Pires, M., & Maarse, M. (2014). Wetenschappelijk eindadvies ANT-IJsselmeergebied. In *Deltares*.

Noordhuis, R., Rijk, S. De, Geest, G. Van, Maarse, M., Vergouwen, S., & Boon, A. (2019). *Klimaat Scan*.

Odum, E. P. (1971). *Fundamentals of Ecology* (3rd ed.). Saunders.

P

Piehler, M. F., & Smyth, A. R. (2011). Habitat-specific distinctions in estuarine denitrification affect both ecosystem function and services. *Ecosphere*, *2*(1). https://doi.org/10.1890/ES10-00082.1

Pietsch, M. (2012). GIS in Landscape Planning. In M. Ozyavuz (Ed.), *Landscape Planning* (First, pp. 55–84). InTech. https://doi.org/10.5772/38996

Platteeuw, M. (1985). *Voedseloecologie van de grote (Mergus merganser) en de middelste zaagbek (Mergus serrator) in het IJsselmeergebied 1979/1980 en 1980/ 1981*. https://puc.overheid.nl/rijkswaterstaat/doc/PUC_109179_31/

Pohnke, C., Klinge, M., & Witteveen+Bos. (2018). *Bureaustudie Vis in het IJsselmeergebied* (Issue December).

Pons, L. J. (1992). Holocene peat formation in the lower parts of The Netherlands. In J. T. A. Verhoeven (Ed.), *Fens and bogs in The Netherlands: vegetation, history, nutrient dynamics and conservation* (pp. 7–79).

R

Raad voor de Wadden. (2008). *Zoet-zoutovergangen : advies over kansen voor herstel van zoet-zoutovergangen in het Waddengebied*. https://puc.overheid.nl/doc/PUC_130298_31/1

Raad voor leefomgeving en infrastructuur. (2022). *NATUURINCLUSIEF NEDERLAND: Natuur overal en voor iedereen*. www.rli.nl

Reed, N. F., O'Connell, Michael, A., & Murphy, D. D. (1997). *The science of conservation planning: habitat conservation under the Endangered Species Act*. Island Press. https://archive.org/details/scienceofconservoooonoss

Rijkswaterstaat. (2017). *Natura 2000 Beheerplan IJsselmeergebied 2017 - 2023 IJsselmeer*. https://library.wur.nl/WebQuery/hydrotheek/2290095

Rijkswaterstaat. (2018). *Peilbesluit IJsselmeergebied*. https://doi.org/RWS-2018/16279

Rli. (2022, March 23). *Natuur overal en voor iedereen | Raad voor de leefomgeving en infrastructuur*. https://www.rli.nl/pers/2022/natuur-overal-en-voor-iedereen

S

Schiewer, U. (2002). Recent Changes in Northern German Lagoons with Special Reference to Eutrophication. In G. Schernewski & U. Schiewer (Eds.), *Baltic Coastal Ecosystems: Structure, Function and Coastal Zone Management* (pp. 19–30). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-04769-9_2

Schuwer, D. (2007). *Wonen op het water: succes- en faalfactoren* (Issue November). Wageningen UR.

Sha, L. P. (1990). *Sedimentological studies of the ebb-tidal deltas along the West Frisian Islands, the Netherlands* (Vol. 64) [Utrecht University]. http://dspace.library.uu.nl/handle/1874/238556

Sloot, P., van Amersfoort, M., van Berkum, J., de Bonte, A., van Dijk, M., Mulder, P., & Verbeek, L. (2006). *Landbouw effect rapportage Wieringerrandmeer*.

Soenveld, J.-P. (2020, December 12). Het IJsselmeer wordt niet langer meer vergeten. *Friesch Dagblad*. https://frieschdagblad.nl/regio/Het-IJsselmeer-wordt-niet-langer-meer-vergeten-26803384.html

Staatsbosbeheer. (2022, February 17). *Herstel van veerkracht van deltanatuur is nodig*. https://www.staatsbosbeheer.nl/over-staatsbosbeheer/blijf-op-de-hoogte/natuurverhalen/natuurwinststrategie-deltanatuur

Steinitz, C. (1990). A Framework for Theory Applicable to the Education of Landscape Architects (and Other Environmental Design Professionals). *Landscape Journal*, *9*(2), 136–143. https://doi.org/10.3368/lj.9.2.136

Steinitz, C. (2002). On teaching Ecological Principles to designers. In *Ecology and Design: Frameworks for Learning* (pp. 390–395). https://doi.org/10.5822/978-1-61091-491-8_33

Steinitz, C. (2012). *A framework for geodesign : changing geography by design LK - https://wur.on.worldcat.org/oclc/1152964052* (First edit). Esri. http://books.google.com/books?id=aF-J7WujMxQC

T

Tangelder, M., Winter, E., & Ysebaert, T. (2017). Ecologie van zoet-zout overgangen in deltagebieden. In *Wageningen University*. https://doi.org/10.18174/436428

Telesh, I. V., & Khlebovich, V. V. (2010). Principal processes within the estuarine salinity gradient: A review. *Marine Pollution Bulletin*, *61*(4–6), 149–155. https://doi.org/10.1016/j.marpolbul.2010.02.008

Temmerman, S., Govers, G., Wartel, S., & Meire, P. (2004). Modelling estuarine variations in tidal marsh sedimentation: Response to changing sea level and suspended sediment concentrations. *Marine Geology*, *212*(1–4), 1–19. https://doi.org/10.1016/j.margeo.2004.10.021

Temmerman, Stijn, Meire, P., Bouma, T. J., Herman, P. M. J., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature*, *504*(7478), 79–83. https://doi.org/10.1038/nature12859

Terlouw, S., & Lammerts, C. (2021). *Natuurwinststrategie deltanatuur*.

Thijsse, J. T. (1972). *Een Halve Eeuw Zuiderzeewerken* (Dienst der Zuiderzeewerken (ed.)). H.D. Tjeenk Willink B.V.

Twynstra Gudde, & HydroLogic. (2019). *Handreiking Verzilting In opdracht van Rijkswaterstaat Inhoudsopgave*.

V

van Balen, R. (2008). De ondergrond van Schokland. *Grondboor & Hamer*, *62*(3/4), 77–81.

Van Den Biggelaar, D. F. A. M., Kluiving, S. J., Van Balen, R. T., Kasse, C., Troelstra, S. R., & Prins, M. A. (2014). Storms in a lagoon: Flooding history During the last 1200 years derived from geological and historical archives of Schokland (Noordoostpolder, the Netherlands). *Geologie En Mijnbouw/Netherlands Journal of Geosciences*, *93*(4), 175–196. https://doi.org/10.1017/njg.2014.14

Van den Born, G. J., Kragt, F., Henkens, D., Rijken, B., Van Bemmel, B., & Van der Sluis, S. (2016). Dalende bodems, stijgende kosten. In *Planbureau voor de Leefomgeving: Rapportnummer 1064*.

van der Heide, G. D., & Wiggers, A. J. (1954). Enkele resultaten van het geologische en archeologische onderzoek betreffende het eiland Schokland en zijn naaste omgeving. *Langs Gewonnen Velden. Facetten van Smedings Werk, Wageningen*, 96–113.

van der Meulen, Y. A. M. (1997). *Meren Ecotopen Stelsel - Een ecotopenstelsel voor de meren van het IJsselmeergebied en Volkerak-Zoommeer* (Ministerie van Verkeer en Waterstaat & Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling (eds.)).

Van der Wal, D., Wielemaker-Van den Dool, A., & Herman, P. M. J. (2008). Spatial patterns, rates and mechanisms of saltmarsh cycles (Westerschelde, The Netherlands). *Estuarine, Coastal and Shelf Science*, *76*(2), 357–368. https://doi.org/10.1016/j.ecss.2007.07.017

van Dessel, B. (1988). *Ecologische inventarisatie van het IJsselmeer*. https://edepot.wur.nl/378201

van Eerden, M. R., & Vaate, A. bij de. (1984). *Natuurwaarden van het Ijsselmeergebied*. https://doi.org/Flevobericht 242

van Leijenhorst, I. (2018). *Verzoek om advies CieMER over doelbereik bepalen in Colofon Aanleiding*.

van Leijenhorst, I. (2019). *Startbeslissing Wieringerhoek* (Issue november). https://www.commissiemer.nl/projectdocumenten/00006873.pdf

van Nieuwenhuijze, L., van der Salm, J., Schengenga, P., & Gronheid, T. (2011). *Handreiking ruimtelijke kwaliteit: buitendijks bouwen IJsselmeergebied*. H+N+S. https://books.google.nl/books?id=q2GFzQEACAAJ

van Roomen, M., Hornman, M., Flink, S., Langendoen, T., Winden, E. Van, Nagy, S., & Van Turnhout, C. (2012). *Flyway-trends for waterbird species important in lakes IJsselmeer and Markermeer*. https://europe.wetlands.org/publications/flyway-trends-waterbird-species-important-lakes-ijsselmeer-markermeer/

W

Waterman, R. E. (2010). *Integrated Coastal Policy via Building with Nature*. TU Delft.

Weston, N. B., Neubauer, S. C., Velinsky, D. J., & Vile, M. A. (2014). Net ecosystem carbon exchange and the greenhouse gas balance of tidal marshes along an estuarine salinity gradient. *Biogeochemistry*, *120*(1–3), 163–189. https://doi.org/10.1007/s10533-014-9989-7

Whitfield, A. K., Elliott, M., Basset, A., Blaber, S. J. M., & West, R. J. (2011). Paradigms in estuarine ecology - A review of the Remane diagram with a suggested revised model for estuaries. *Estuarine, Coastal and Shelf Science*, *97*, 78–90. https://doi.org/10.1016/j.ecss.2011.11.026

Wiersma, A., Tangelder, M., Brouwer, J., & Abma, R. (2014). *Sustainable scenarios for the Southwest Delta based on Building with Nature strategies*. https://library.wur.nl/WebQuery/wurpubs/fulltext/317873

Wiggers, A. J. (1955). Wording en opbouw van de Noordoostpolder : geschiedenis van de ontginning en eerste ontwikkeling (1940 - ca. 1960). In *Flevobericht* (Issue 269). Lelystad: RIJP.

Wilson, K. J. (2017). An investigation of dependence in expert judgement studies with multiple experts. *International Journal of Forecasting*, *33*(1), 325–336. https://doi.org/10.1016/j.ijforecast.2015.11.014

Wing, Witteveen+Bos, IMA, & Terwisscha & Wagenaar. (2021). *Kustvisie ijsselmeerkust*.

Winter, H. V., Griffioen, A. B., & van Keeken, O. A. (2014). *De Vismigratierivier: Bronnenonderzoek naar gedrag van vis rond zoet-zout overgangen* (Issue november). https://library.wur.nl/WebQuery/wurpubs/fulltext/300166

Witteveen+Bos. (2006). *Integraal Effectrapport Wieringerrandmeer*. www.commissiemer.nl/docs/mer/p16/p1619/1619-113integraaleffectrapport.pdf

Xiong, L., & Visser, R. De. (2018). Marker Wadden, The Netherlands: a building-with-nature exploration. *Landscape Architecture Frontiers*, *6*(3).

Z

Zagwijn, W. H. (1971). De ontwikkeling van het “Oer-IJ” estuarium en zijn omgeving. *Westerheem: Tijdschrift Voor de Nederlandse Archeologie*, *20*, 11–18. https://catalogus.cultureelerfgoed.nl/Details/articles/200093321

Zijden, N. C. van der, Mandemakers, J. J., & Wildenburg, M. C. E. (2019). *Verkenning Wieringerhoek*. *december*, 48.