Designing a water-resilient landscape

Integrating nature-based solutions for a sustainable water system in Flevoland

Metropolitan Ecology of Places Series

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Designing a water-resilient landscape
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Integrating nature-based solutions for a sustainable water system in Flevoland

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Preface

This report is the outcome of my master's graduation project in the studio Metropolitan Ecologies of Places. So far, this has been my biggest project in my life as an urbanism student.

My interest in water systems and climate adaptation in combination with urbanism has grown during my master's. Especially during the second half of the first year, I found out that I am very interested in water systems. First, I did a group project about the Eem river in the Netherlands, and in the other quarter, I did a group project about river soundscapes based in Morocco. These projects inspired me to focus on water during my master's thesis.

Throughout the research, I encountered challenges and moments of inspiration. I am grateful for the possibility to do an internship at the waterboard Zuiderzeeland, because this made the choice to zoom in on a specific location easier. In the first half of the year, the project was focused on the entire IJsselmeer region, but this area was too large to design in a year. Therefore, after the second presentation, I zoomed in on Flevoland, personally, this province is closest to me because I grew up here.

During this project, I would like to thank my first mentor, Kristel Aalbers, who helped me define my project, encouraged me and gave me in-depth guidance. Also, I am thankful for my second mentor, Remon Rooij, who supported me and gave critical comments when necessary. Lastly, I would like to thank Michiel Heuser, my internship mentor, who motivated and encouraged me and helped me a lot to understand the different water problems in the province. Other colleagues at the waterboard helped a lot as well.

Furthermore, I would like to thank my parents and my brother who supported me throughout the year and Lotte, Annika, Esmee, Eva, Elena and Brenda who supported me at my presentations and helped me when I needed them.

Abstract

The province of Flevoland faces increasing pressure from climate-related water challenges, including water nuisance, drought, soil subsidence, salinisation and potential flooding. This thesis explores how nature-based solutions could be utilised to enhance the existing water system and improve the climate resilience of Flevoland. Through spatial analysis, it becomes evident that rural areas, particularly agricultural lands, will be affected by these climate-related water problems.

The research presents a future scenario where nature-based solutions are integrated into the polder. These solutions not only mitigate the effects of water problems but also contribute to the ecology. An important insight is the multifunctionality of nature-based solutions, addressing multiple problems at once and offering benefits for biodiversity.

The thesis concludes the future scenario with a governance chapter to focus on the involvement of stakeholders in Flevoland.

Keywords: nature-based solutions, Flevoland, water resilience, climate-adaptive, water quantity, water safety, soil health

Glossary

NbS: Nature-based solutions

NOVEX: Nationale OmgevingsVisie EXecutiekracht (national environmental vision executive power).

MRA: Metrpolitan Region of Amsterdam

NNN: Nature Network Netherlands

NAP: Normaal Amsterdams Peil.

Scales: from an urbanism perspective, the word scales means the different scale levels of neighbourhood, city, landscape and regional.

Kreekruggen: creek ridges

Hoge Vaart: Large waterway in Flevoland that has a higher water level than the Lage Vaart.

Lage Vaart: large waterway in Flevoland that has a lower water level than the Hoge Vaart.

Tochten: smaller waterways connected to the vaarten.

Peilvakken: Flevoland is split up into multiple peilvakken. Each peilvak has a different water level.

Content

context and theory

Introduction

Introduction

In this chapter, the main research question and the research subject will be explained.
This will be done by my motivation for the subject and by the current developments, such as climate change, urban growth and nature-based solutions. These developments will be concluded with the problem statement and the main research question.

Motivation

In recent years, it has become clear that the Netherlands will face increasing water problems due to climate change. The weather will become more extreme, resulting in dry summers and wet winters. Heavy rainfall and water nuisance have occurred more frequently, causing flooded streets and putting pressure on our water system (Bergeijk, 2024).

More projects like 'Room for the River' are needed in the Netherlands to respond to these challenges. Nature-based solutions are used more often, particularly around the large rivers, but the emphasis remains on technical solutions. Could these solutions also be used in the IJsselmeer region, specifically in Flevoland?

As a citizen of Almere, I live four meters below sea level, and this area, like other parts of Flevoland, will become even lower due to soil subsidence. What is the effect of this challenge on Flevoland's liveability? If the soil subsides, the sea level rises, and heavy rainfall occurs more often, will the IJsselmeer region, especially Flevoland, still be safe to live in? Or do we need to accept that these areas are becoming wetter, saltier and lower while we live here? Could nature-based solutions make Flevoland more resilient to water problems?

Threats and opportunities in the Netherlands

Climate change

Due to climate change, the Netherlands will face more challenges. The temperature throughout the year will be higher. The winters will become wetter and the summers will be drier. Furthermore, we will get heavier rain and the sea level will rise. The KNMI (2023) made four scenarios to show the changes in the future depending on the amount of greenhouse emissions (high and low), and on the change of climate (wetter or drier). These scenarios are visible in the different graphs (figures 1 and 2) on the right page.

Sea level rise:

Figure 1 shows two scenarios of sea level rise in the Netherlands, the lowest being a sea level rise of 44 centimetres and the highest 82 centimetres (KNMI, n.d.). The sea level has been rising since 1990, and will have consequences for the safety of the Netherlands. Both scenarios intensify pressure on the Dutch water systems, particularly along their borders with the North Sea and the Wadden Sea. Therefore, elements such as dikes, storm surge barriers and dunes have to become stronger in the future to cope with the higher water level (Postma, de Wit, 2023). Furthermore, there will be more salinisation along the coastal areas, damaging the freshwater supply (Rijksoverheid, n.d.).

Higher temperatures:

The expectation is that the temperatures will rise further, leading to more and longer heat waves in summer (The KNMI, 2023). In summer, there will be less rainfall, causing drought, and in combination with the heat, it could lead to water shortage. There will be more heavy rain in a short time, causing a higher chance of water nuisance and flooding of water bodies. Flevoland will be affected by these problems as well. The drought will put pressure on the water system. Twenty centimetres of the surface water of the IJsselmeer is used for water supply in the IJsselmeer region (Harbers and Heijnen, 2022). In summer, it is possible that this will not be enough water anymore, leading to the decision of who receives water.

The yearly temperature shows that the trendline is already rising, meaning that the temperature has risen in the last few decades. It also shows the expectation of four scenarios in the future. The low CO_2 scenarios show that the average temperature will be around 11,3 degrees while the high CO_2 scenarios show that it will be around 14,7 degrees and probably will be even higher after 2100.
The Hd-scenario means high CO_2 emissions, drier scenario.
Hn-scenario means high CO_2 emissions, wetter scenario.
Ld-scenario means low CO_2 emissions, drier scenario.
Ln-scenario means low CO_2 emissions, wetter scenario.

The high scenario indicates a CO_2 emissions increase until 2080 and then this levels off. In 2100, the temperature will have risen by 4,9 °C.
The low CO_2 emissions scenario indicates that the emissions are rapidly reduced and global warming will be around 1,7°C.

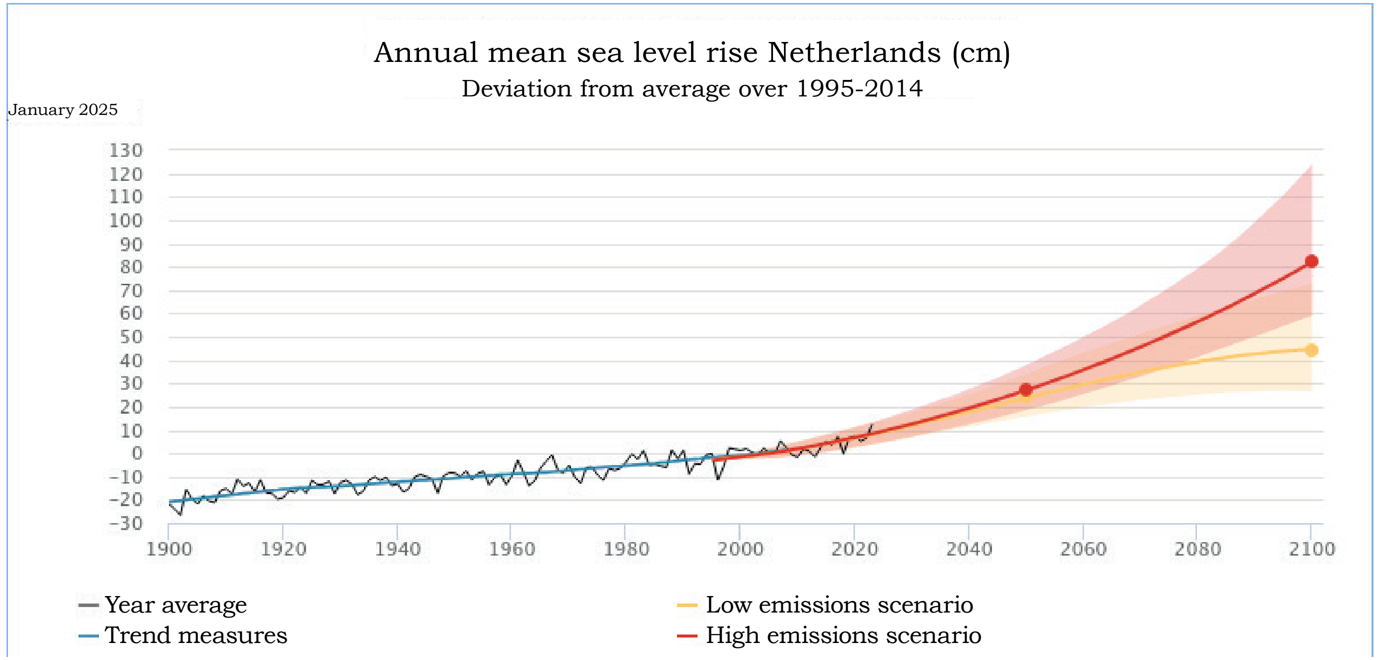


Fig. 1: Annual mean sea level rise Netherlands (KNMI, n.d.) (translated)

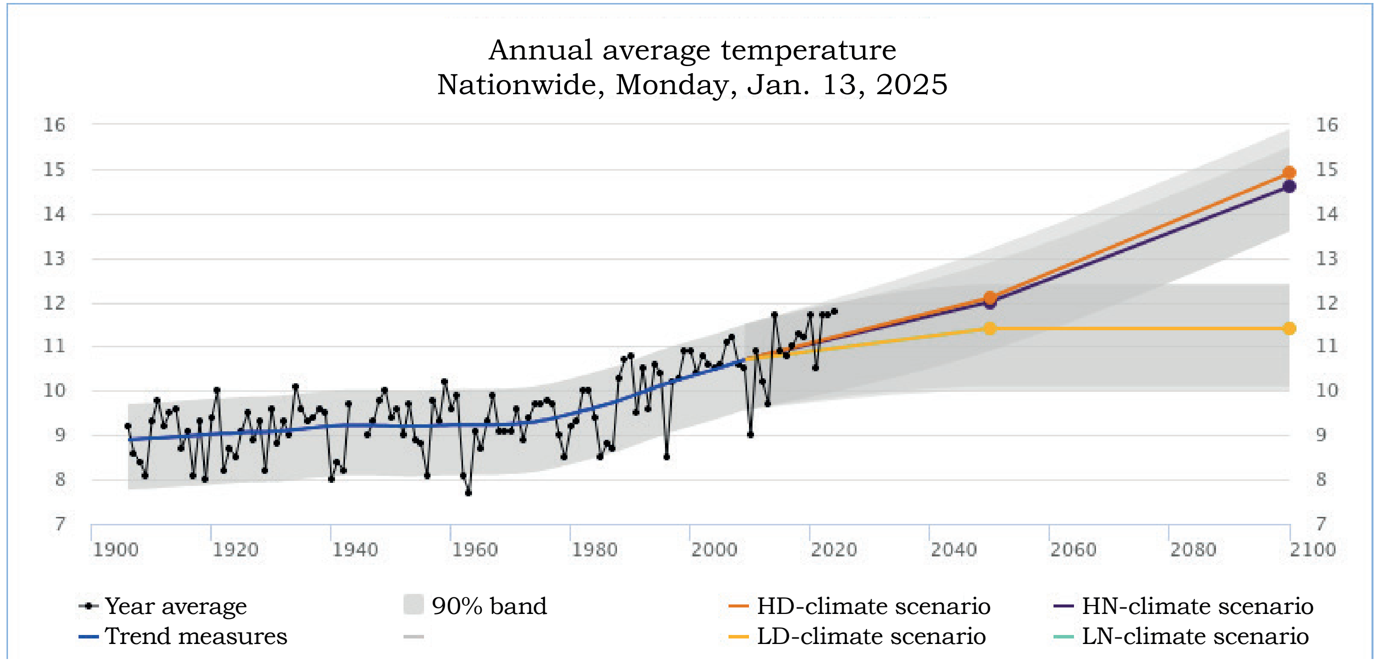


Fig. 2: Annual average temperature (KNMI, n.d.) (translated)

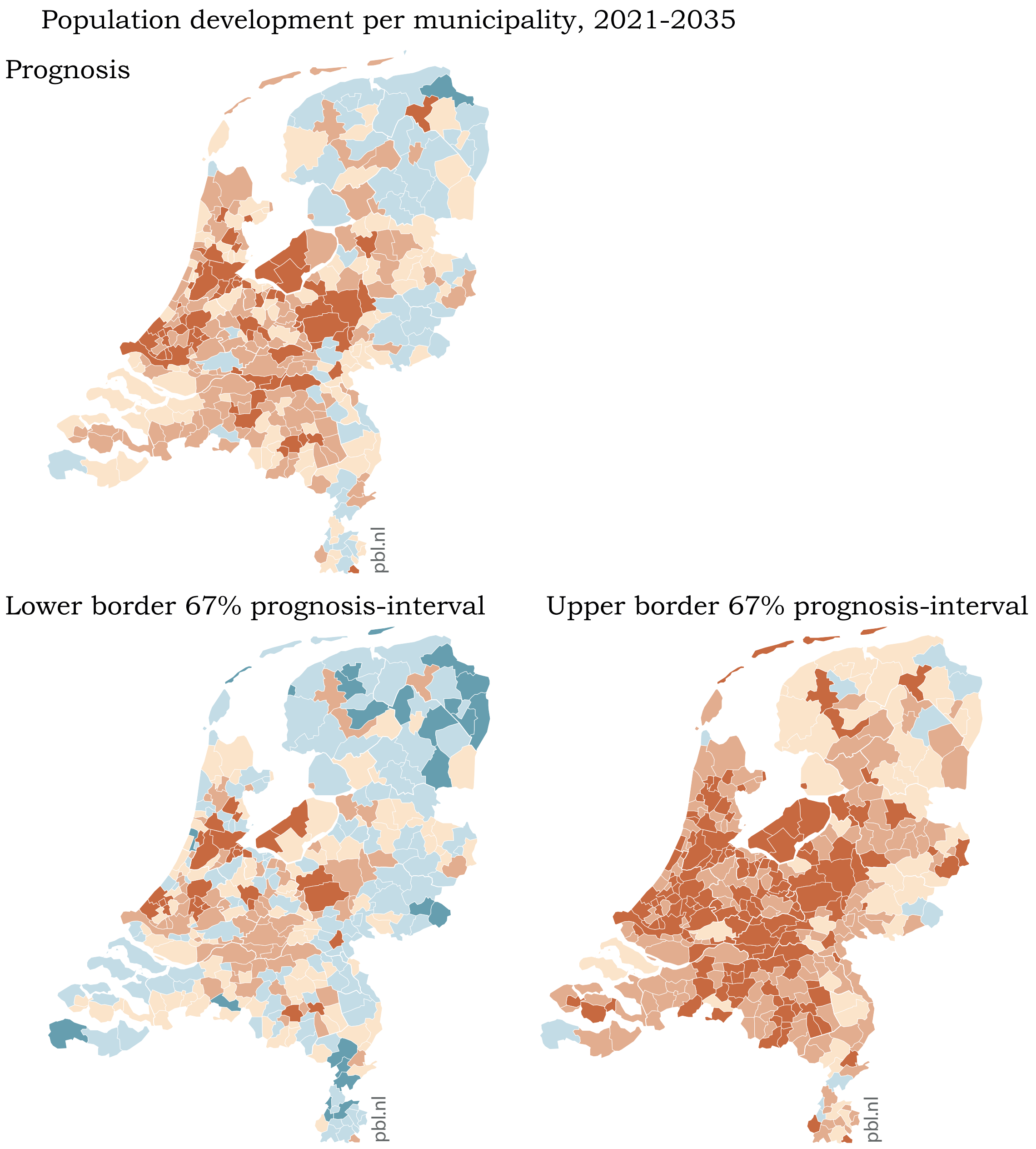
Urban growth

The population has increased significantly in the Netherlands in the last decades, and will continue to rise in the coming years. PBL (2022) expects that the country will have 18,9 million inhabitants by 2035, and Randstad is one of the strongest growing regions of the country, as seen in fig. 3. In the prognosis of CBS (n.d.) it is expected that there will be around 18,9 to 22,3 million people in the Netherlands in 2070. This depends on the life expectancy, the number of migrants and the birth rate in the future.

The lower maps of figure 3 show the two extremes for the growth of every municipality in 2035. In both maps, it is visible that the Randstad will grow and that the northern and southern parts of the Netherlands will either stay stable or will experience population decline.

Flevoland will grow strongly, especially in the Flevopolder, meaning that there will be less space in the future for other spatial interventions in this area. The two fastest-growing municipalities are Almere and Lelystad.

The Noordoostpolder will probably decline when you take the prognosis and lower border prognosis into account, as visible in fig. 3. This means that there could be more space for other interventions in the future.



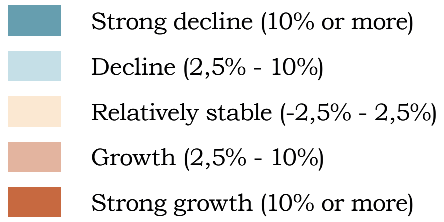


Fig. 3: Population development per municipality 2021-2035 (based on PBL & CBS, 2022) (translated)

Nature-based solutions

Even though there is more pressure on the Dutch environment from both urban growth and climate change, there are also new possibilities for development. An important example of these possibilities is the use of nature-based solutions to prevent problems of climate change. This shift is slowly in development; technical solutions are combined with nature-based solutions.

Nature-based solutions could be implemented in different regions and have different functions. Figure 4 shows the possibilities for nature-based solutions in the Netherlands and is designed to inspire policymakers and planners. The map visualises the opportunities to implement nature-based solutions in water management, climate mitigation and other challenges. The regions with the most detailed solutions are mostly in the peat areas, river landscapes and urban areas.

The regions of the map should be expanded and show possibilities for nature-based solutions in the rest of the Netherlands as well, especially in the low-lying peat areas.

Projects that focus on climate change need to be context-sensitive, based on location-specific features and processes (Kennisportaal Klimaatadaptatie, 2021).

- Randstad - chance of water storage in urban areas
- Coast - conservation of salt marshes for coastal sedimentation and CO2-storage
- Coast - coastal defence with double dikes
- River - oppertunities for a living river
- River - water storage in low-dynamic marshes
- High NL - highly promising, low groundwater recharge
- High NL - promising, low groundwater recharge
- High NL - somewhat promising, moderate groundwater recharge
- Peat - water and CO2 retention in historic peat
- Peat - retaining water and sequestering CO2 in growing peat

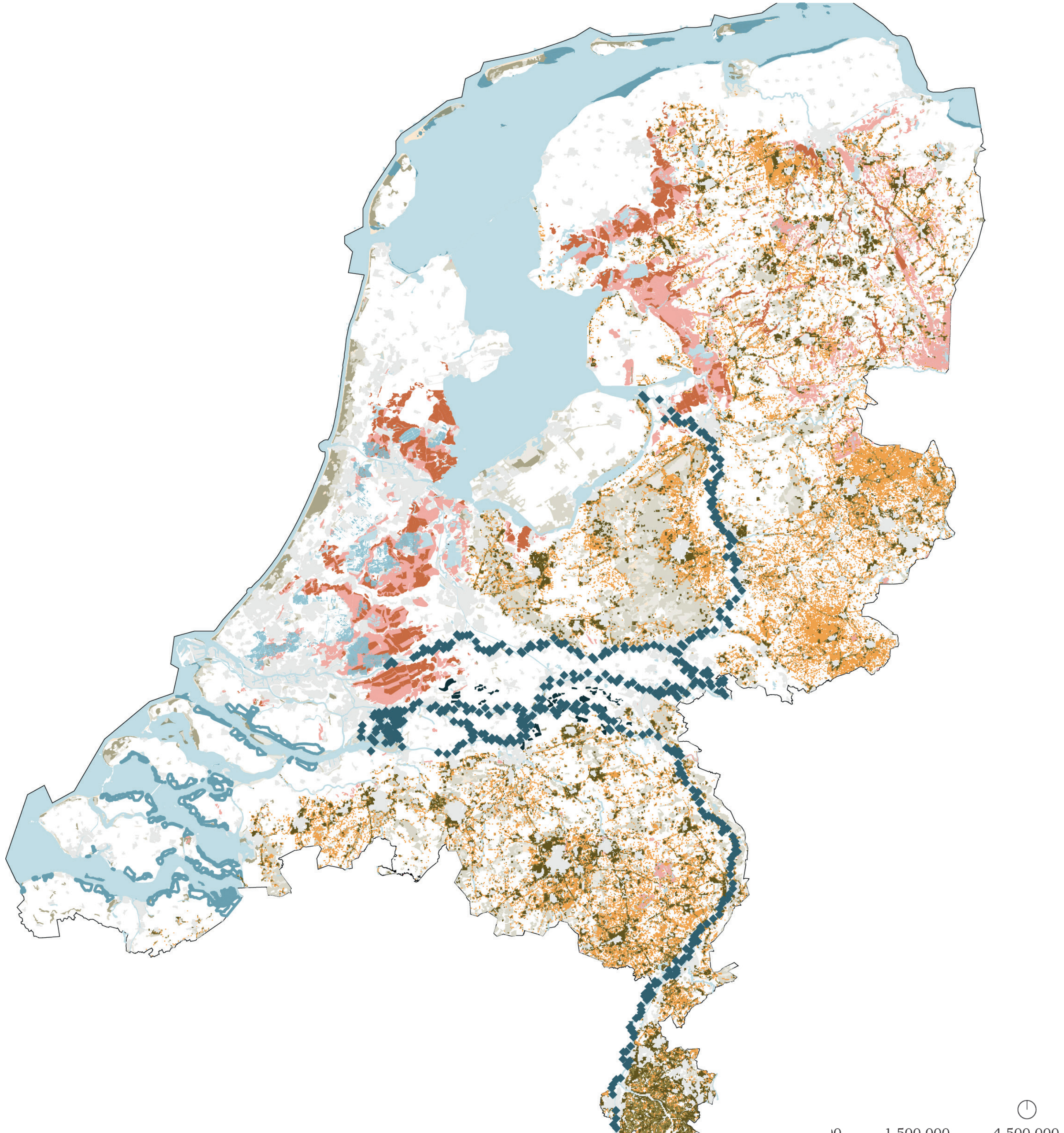


Fig. 4: Nature-based solutions (based on Stichting Climate Adaptation Services, 2025b)

Problem statement

Flevoland, as part of the IJsselmeer region and with the IJsselmeer as its largest freshwater supply, faces increasing challenges due to climate change. Extreme weather events will result in excess water and prolonged droughts, threatening the balance of the province's water infrastructure.

Despite maintenance and investments in technical solutions, the existing water management systems are reaching their capacity. The loss of ability to deal with these extreme weather events and other related water problems poses a risk to the liveability of the region (Ministerie van Infrastructuur en Waterstaat, 2025).

These issues will be compounded due to soil subsidence in clay and peat areas, which is driven by prolonged drainage to maintain dry soil for better land use. This not only stimulates the sinking of land but also accelerates the impacts of climate change and could reach a tipping point where adaptation is not possible anymore. The rising sea levels put more pressure on the IJsselmeer and Markermeer. If these lakes have higher water levels, they will increase the water pressure, intensifying seepage and salinisation, impacting different areas in Flevoland and are predicted to reach further inland, threatening the agricultural lands and the freshwater supply (Verzilting door zeespiegelstijging – Klimaateffectatlas, n.d.).

Without integrating interventions, Flevoland risks environmental and social consequences as these challenges intensify in combination with urban growth in the coming decades.

The different water problems are visible in the section below (fig. 5). The salinisation comes from the pressure of the IJsselmeer and Markermeer. The soil subsidence is happening because of the drying out of peat and clay areas. Lastly, water nuisance and drought are happening more often because of climate change. They are combined in figure 5 and cause problems for both urban and rural areas.

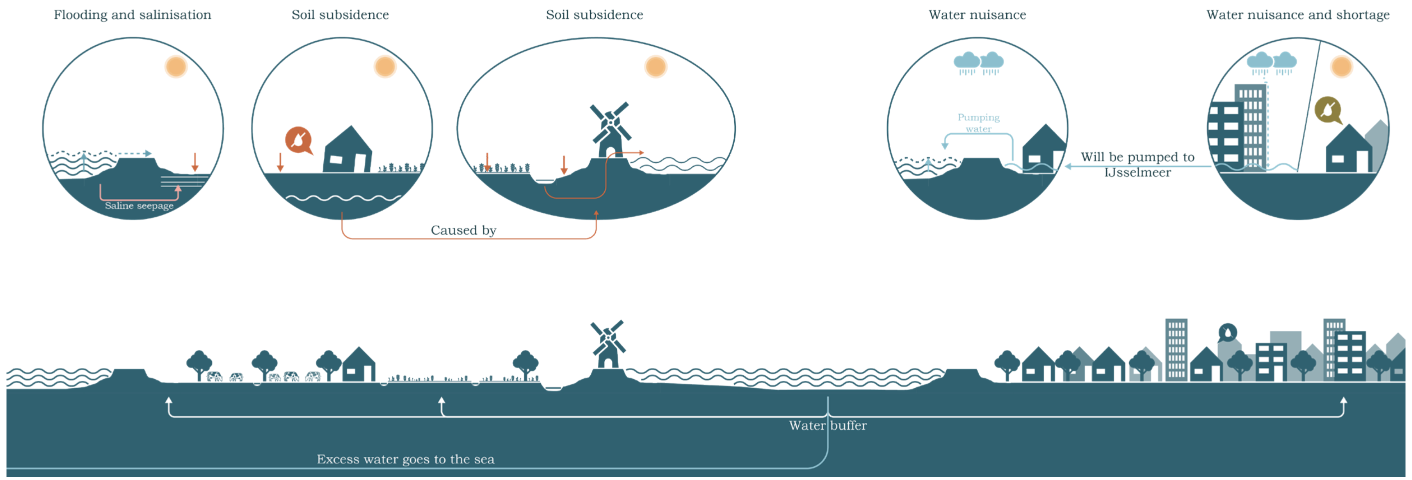


Fig. 5: schematic section five water problems in the IJsselmeer region

Research aim and main research question

In this graduation project, the implementation of nature-based solutions (NbS) for enhancing the resilience of Flevoland is explored with a focus on water problems. The aim is to develop a systemic approach for the use of NbS in a way that improves water problems by 2050 compared to the current situation, while stimulating biodiversity, agriculture, and a safe urban environment.

The desired outcome of this research will be a pattern language that shows the relations between the patterns and Flevoland. The patterns fit Flevoland and show an overall vision for the whole area.

The vision for 2050 is based on the maximisation method and is made for the whole province and a location in the South of Flevoland, between Almere and Zeewolde. The patterns and maximisation therefore work on different scales.

This leads to the following research question: How could nature-based solutions be utilised to enhance the water system in order to improve the resilience of Flevoland?

context and theory

Research approach

Introduction

In this chapter, the theoretical background, methodological framework and conceptual framework are discussed.
The theoretical background already answers the sub-research question: 'What are nature-based solutions?'. Furthermore, the definition of resilience is explained in the context of this project.
The methodological framework outlines the various sub-questions and the corresponding methodologies applied in this research.
Lastly, the conceptual framework explains in one image the context of this project.

Theoretical background

Resilience:

Resilience thinking is a way to address the development of complex social-ecological systems. There are three main aspects to this way of thinking: persistence, adaptability and transformability. In this context, resilience means:
"The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity." (Folke et al., 2010)

De Bruijne et al. (2010) explain that ecologists have already used resilience to explain the dynamics and complexity of biological environments. Their definition is similar to the description by Folke et al. (2010), but it has one major difference: the identity of the structure. Resilience in ecosystem management means the continuous ability to manage change and surprises. Ecological resilience refers to the amount of disruption required to change a system from being maintained by one set of processes to another set of processes. In ecology, there is no stable state, and the structure will change over time.

In this research, resilience does not encompass keeping the province as it is now. Rather, to develop it into a stronger system that could deal with disturbances in 2050 and further on. The system can then develop and reorganise itself to create a natural and strong environment.

These two definitions are used for the definition of resilience in this research: "The capacity of a system to deal with disturbance and reorganise while changing".

Nature-based solutions

Nature-based solutions (NbS) are a fairly new and broad umbrella concept that focuses on ecosystem services and aims to address societal challenges. The overarching goal of NbS is to support society's development goals, to safeguard human well-being that reflects cultural and societal values and enhance the resilience of ecosystems (Cohen-Shacham et al., 2016). Nature-based solutions are designed to address societal challenges such as food security, climate change, water security and disaster risk management.

The IUCN (International Union for Conservation of Nature) puts more emphasis on the need for well-managed and restored ecosystems, while the European Commission focuses more on a broader meaning and puts emphasis on applying solutions that not only use nature but are also inspired by nature (Cohen-Shacham et al., 2016).

The IUCN (Cohen-Shacham et al., 2016) came up with eight principles for NbS to further explain the definition:
First, they embrace the conservation norms of nature, and could be used alone or integrated into (technical) solutions. Second, they are determined by the site-specific context, both natural and cultural. Furthermore, nature-based solutions produce societal benefits, such as tourism and meeting places, and promote transparency and participation while focusing on maintaining biological and cultural diversity. Nature-based solutions are applied on a landscape scale. It recognises and addresses trade-offs between production and future options. Lastly, they are an integral part of the overall design of policies and actions to address a challenge.

This research focuses on the site-specific context, biological, and cultural biodiversity as a starting point for nature-based solutions. The NbS are applied at multiple scales and are an integral part of the overall design of policies and actions. Therefore, it becomes important to look through the scales and see how different interventions work together.

The nature-based solutions could be categorised into five categories. The different categories could help sort the approaches to NbS (Cohen-Shacham et al., 2016). These are:

1. Ecosystem restoration: restoration, engineering
2. Issue-specific ecosystem-related: adaptation, mitigation, services and disaster risk reduction
3. Infrastructure related: natural and green infrastructure
4. Ecosystem-based management: integrated coastal zone management and water resources management
5. Ecosystem protection: area-based conservation

The categories used in this research are mostly issue-specific and ecosystem-based management. These two elements are important for the different water problems addressed in this research. Infrastructure-related approaches are also considered in the pattern language, such as blue-green networks.

Berkhof et al., (2024) designed a catalogue with ten types of nature-based solutions where both humans and nature benefit from. These NbS are applicable in the Netherlands at different scales and are used as inspiration for the pattern development for this research.

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The following fit this research, and the locations of the solutions are visible in figure 6:

1. Dynamic nature management: By restoring the dynamics of nature, it is possible to create nature that shifts with natural processes, even if they change because of climate change. Nature will become more resilient and stronger against different types of threats. It is mostly applicable at a landscape scale in river areas, coasts or in forests.
2. Nature-friendly agriculture: Agriculture that uses natural processes for pest control and pollination, but improved biodiversity in and on land is needed. It will improve the resilience of the soil and therefore will create a soil that is better suited to extreme weather conditions. Nature-friendly agriculture could be used on one parcel and could be implemented on a higher scale. The transformation of the farm towards nature-friendly agriculture is a large investment, but it will pay for itself back through the services of biodiversity and nature.
3. Green-blue network: By improving green-blue networks, water and air quality will improve, just like the cooling effect and water storage. It could be used to connect natural elements from farms to urban areas. Furthermore, it is a basic quality for biodiversity and ecology in rural areas. It could be implemented in every ecosystem and is an important connector. In urban areas, it is more difficult to implement the network due to limited space and pressure

from other functions.

4. Natural coastal protection: Technical coastal protection cannot grow with climate change, eventually reaching its boundaries. However, natural coastal protection could grow with climate change and develop through time. Furthermore, it provides the possibility for regenerating ecosystems such as dunes. It is applicable in coastal areas of lakes and seas. Large investments are needed for the realisation of the projects, but the maintenance costs should be lower than technical solutions.
5. Rewetting the landscape: By rewetting peat areas, you create a natural force against salinisation, peat oxidation and soil subsidence. This can be achieved on a small scale and a larger scale. However, calculations show that rewetting the landscape on a larger scale could cause water shortages during dry periods.
6. Freshwater storage: In winter months, there is a precipitation surplus of 300 mm per year. In summer and spring, this surplus changes into a shortage. If the precipitation surplus is stored, it becomes possible to use this water in the dry months, reducing the shortage. To store more water in the soil, you need more organic material in the soil. This will improve the sponge effect of the soil and enhance the storage capacities. Almost all landscape types have the chance to have freshwater storage. It needs to be implemented on the landscape scale to guarantee effectiveness/ the costs of realising this depend on the scale and different opportunities in an area.

These definitions and goals are used in the report as a starting point for the pattern language and are used for the definition of nature-based solutions in Flevoland for this research.

Fig. 6: Locations of NbS in the Netherlands (own work)

1. Dynamic nature management
2. Nature-friendly agriculture
3. Green-blue network
4. Natural coastal protection
5. Rewetting the landscape
6. Freshwater storage

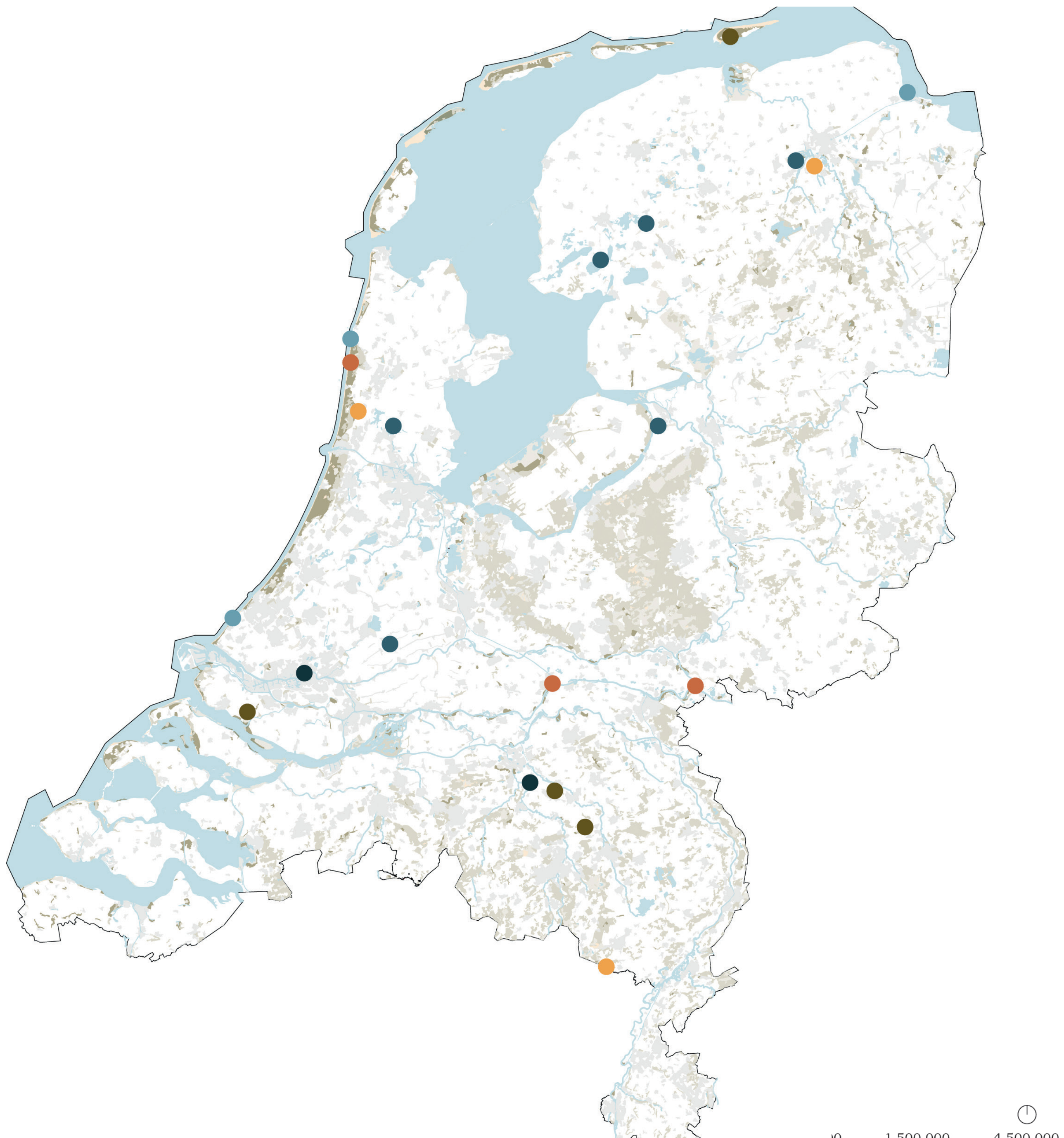


Fig. 6: Nature-based solutions (based on Klimaateffectatlas, 2025)

2.2 Methodological framework

To answer the main research question: 'How could nature-based solutions be utilised to enhance the water system and improve the resilience of Flevoland?', the research focuses on three parts of the question. These are the nature-based solutions, Flevoland and its water system.
The research approach is based on a systemic design, with a constant switch from theory to design. The research consists of three stages, as visible in the diagram (fig. 7). The first stage is the basis for the other two. To answer the last stage of the research question, the second stage needs to be answered as well.

The first stage: literature review and mapping
The first stage of the research is focused on understanding the main topics of the research question. These topics form the basis of the research and explain the definition of each element. The literature review consists of four topics, being:
1. The meaning of nature-based solutions
2. The definition of the water problems with an explanation related to the water system
3. The characteristics of Flevoland
4. The stakeholders

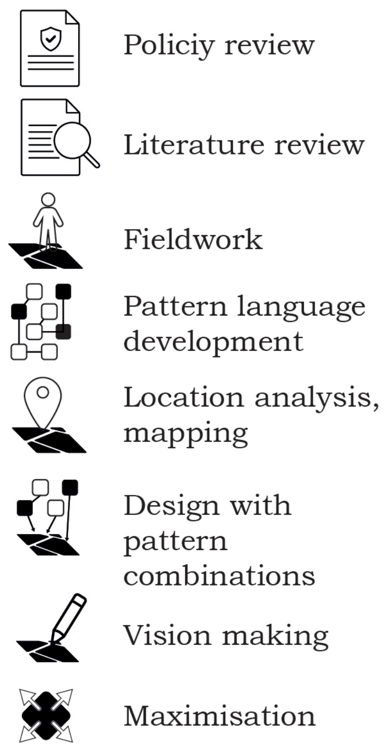
These four topics have specific sub-questions and are shown in the blue boxes in fig. 7:
The first being nature-based solutions:
- What are nature-based solutions?

The definition of nature-based solutions is based on research papers. This question is answered in the theoretical background and is a starting point for the development of the pattern language.

Water system:
The water system has three sub-categories: water quantity, soil health and safety. These problems need to be defined in the location of Flevoland to understand the context of these problems immediately. The water problems are explained through maps, policies, research papers, and knowledge from the waterboard Zuiderzeeland.

Water quantity focuses on the questions:
- What is water shortage?
- What is water nuisance?
- What are the consequences of these problems for Flevoland?

Soil health focuses on the following questions:
- What is salinisation?
- What is soil subsidence?



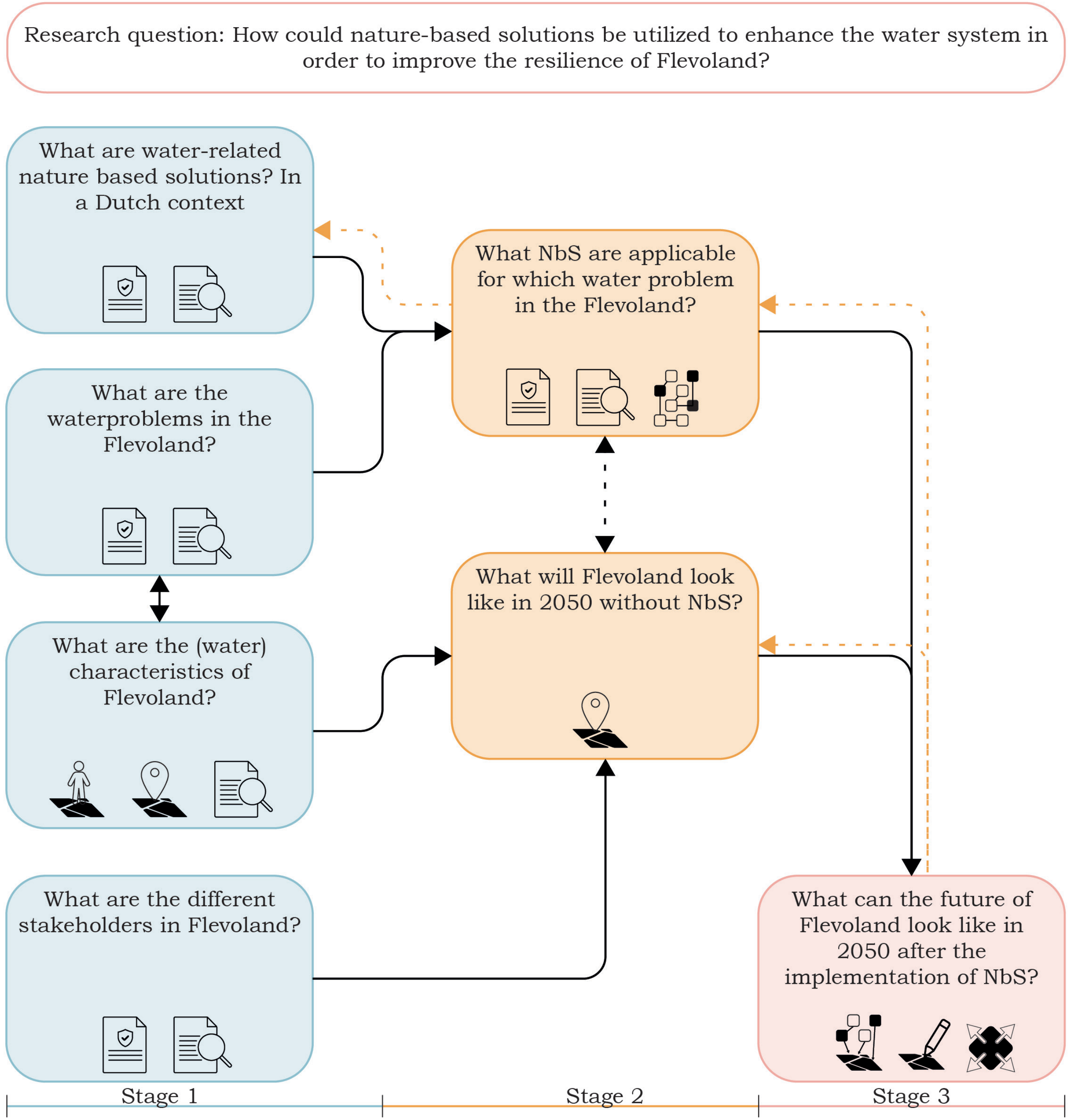


Fig. 7: Methodological framework

- What are the consequences of these problems for Flevoland?

Water safety focuses on the following question:
- What is flooding?
- What are the consequences of this problem for Flevoland?

Flevoland:
The last part of the first stage is the definition of Flevoland.
- What are the characteristics and historical background of Flevoland?
- How is the water managed in Flevoland?

Stakeholders:
- What are the different stakeholders in Flevoland?

These questions are answered with policy documents and with an analysis of the region. The questions are split up into two chapters and combined at the end of the chapters into one map.

The second stage (the yellow boxes):
The second stage of the research consists of the conclusion of the problem analysis and the start of the design of patterns for NbS. There are two questions related to this part of the research, the first question being:
- Which nature-based solutions could be used for which specific water problem?

The patterns are shown in the pattern book. The pattern book visualises the relations between patterns and Flevoland.
The goal of the patterns is that they could solve multiple problems, even though it may be possible that some patterns could only solve one problem. The patterns will follow from the definition, policy documents and literature review. The patterns also indicate possible difficulties, such as problems with stakeholders, costs or other problems.

The other half of this stage is based on the conclusion from Flevoland:
- What will Flevoland look like in 2050 if there are no new interventions?

In this question, the focus will be on the scenario without interventions. It will show the synthesis of the analysis of the water problems and Flevoland, combined with the effects for stakeholders.

The third stage (the pink box):
The third stage is the combination of the patterns (solution), maximisation and the tasks for the province. The patterns explain the options for the nature-based solutions, while the maximisation combines the different patterns in a specific location. This is then combined with the different challenges, such as ecology and urban expansion. The design goes back and forth between study and design. It focuses on the following question:
- What will the future of Flevoland look like in 2050 after the implementation of nature-based solutions for water problems?

This question is answered in the design and strategy chapter, and shows the integration of the maximisation strategy. This is combined with a governance chapter to show the different phases of the project. It will also explain how different stakeholders have different needs or certain roles in the future to reach the goal of a resilient Flevoland.

Pattern language:
The pattern language is used to show the different options of nature-based solutions with an explanation of how they work, on what scale they are applicable and for which problem they could be used. Each single pattern will have a hypothesis, a theoretical background and practical implications. These three components show how and where a pattern works. It will also indicate specific problems, such as stakeholders or other difficulties. Furthermore, each pattern shows the relation between other patterns and problems.

By structuring these in a pattern field, it becomes visible which solutions could work together and which do not. At the beginning of the pattern book, there will be an overview of all patterns, and it will show the relationship between patterns.

After categorising the patterns, they are used in the maximisation and the vision making of Flevoland for the scenarios of 2050.

Maximisation
The maximisation method includes two stages: maximisation and integration.
In the first stage, the maximisation proposal is built on the most desirable result for the five different water problems. The integration combines nature-based solutions for the water problems and introduces ecology, agriculture and urban expansion as other external topics. The integration will be combined with a governance page to explain the different stakeholders related to the interventions. The governance part will also explain the phasing of the nature-based solutions in combination with the policies that are needed to achieve the implementation of NbS.

Conceptual framework

The conceptual framework (fig. 8) visualises the necessity to deal with the consequences of climate change, aiming for a resilient Flevoland by using NbS (and policies) whilst urban growth, nature development, and a shift towards sustainable agriculture are realised.

The conceptual framework has two parts: the upper part visualises the challenges, and the lower part of the circle visualises the nature-based solutions from a water perspective.

The upper part of the circle showcases Flevoland's problems and challenges. The outer circle is climate change, which will impact the whole region and is an external factor that needs to be considered. The box in the middle shows the different land uses that put pressure on each other and the water system.

The bottom part of the circle consists of nature-based solutions for water safety, soil health and water quantity. The water elements are specific to Flevoland and will be influenced by the nature-based solutions. Furthermore, the water elements overlap, because some solutions could help solve multiple problems.

The arrows between the two boxes indicate the influence between the land-use and water elements. The urban areas, nature and agriculture influence the water system, but the water system influences the spatial elements as well. The arrows are the same size, because they could balance each other out. The dotted line around the arrow indicates that sometimes the influence is not the same from both sides, therefore leading to an imbalance. After the implementation, the land use will have less of a negative effect on the water safety, water quantity and soil health.

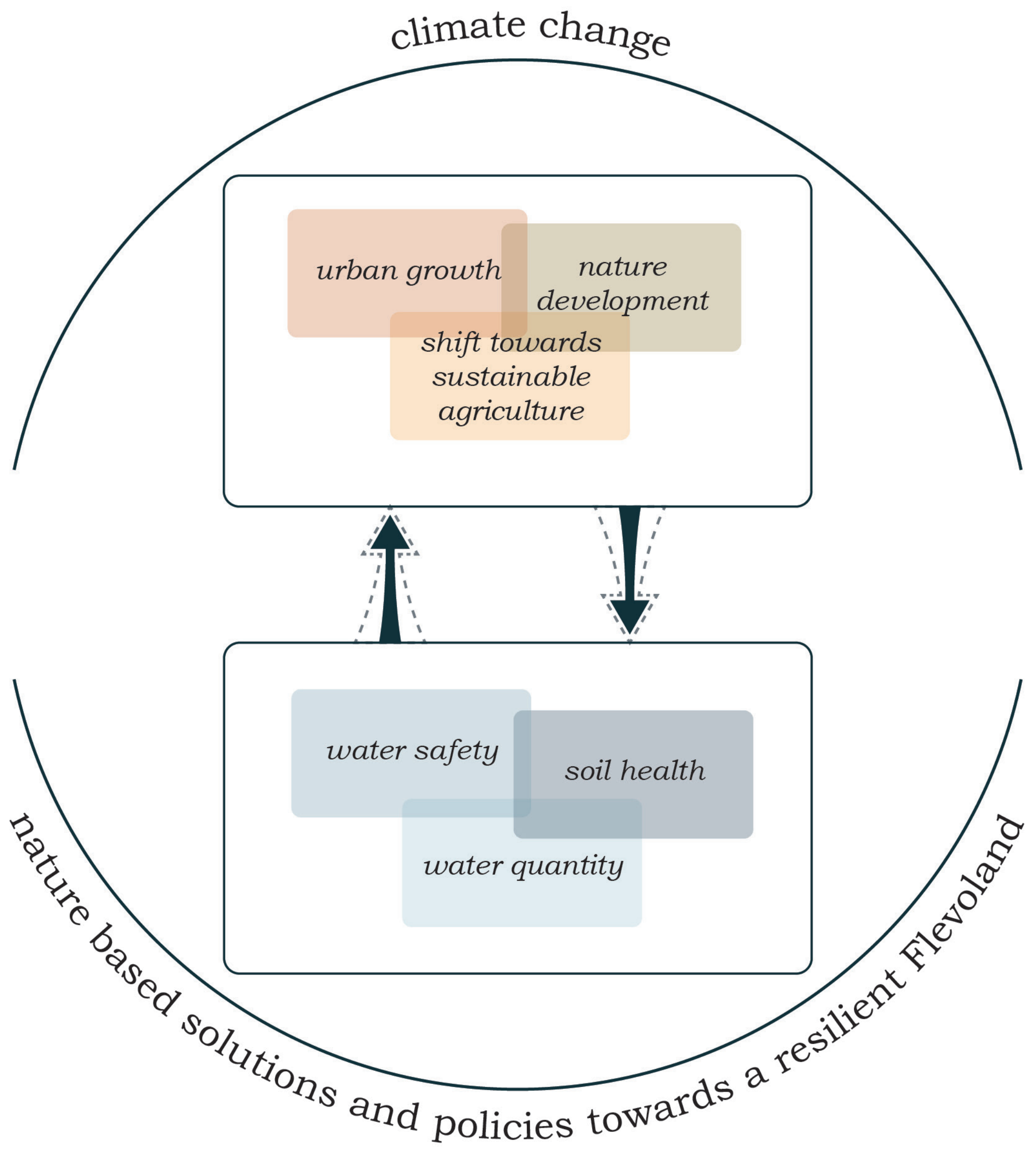


Fig. 8: Conceptual framework

Analysis

Flevoland

Characteristics and historical background
Urban areas
Rural areas
    Agriculture
    Nature
Water system
Conclusion
    Current situation
    Future situation

Introduction

This chapter answers the sub-question:

- What are the characteristics and historical background of Flevoland?
- How is the water managed in Flevoland?

These questions are answered in four different parts of this chapter. First, there is general information about Flevoland with a brief historical background on agriculture, nature and the urban areas.
Then, each of these spatial elements is further explained in the chapter, such as the urban areas, agriculture, rural areas and the water system.
Lastly, the maps are combined in two conclusion maps: one for the current situation and one for the future (2050).

Characteristics and historical background

Flevoland is the newest province of the Netherlands, situated in the former Zuiderzee. The waterboard Zuiderzeeland is responsible for the water management in the province.

The province consists of two polders (fig. 9): the northern one is the Noordoostpolder, and the southern part is the Flevopolder. The Flevopolder consists of two parts as well: Oostelijk Flevoland and Zuidelijk Flevoland; the border between these two polders is the Knardijk. This translates to Eastern Flevoland and Southern Flevoland, and the Knardike.

The Noordoostpolder consists of two municipalities: Urk and Noordoostpolder. The Flevopolder consists of four municipalities: Almere, Dronten, Lelystad, and Zeewolde.

Agriculture:
Flevoland consists mostly of agricultural land in all three polders. Because the polders were not built at the same time, the technical development evolved, leading to different plot sizes in the polder. The first developed polder was the Noordoostpolder; the parcel sizes are therefore the smallest. The main size was 800 by 300 metres. In Oostelijk Flevoland, the plot sizes are mostly 1000 by 300 metres, but around the edges of the Veluwerandmeer, a smaller ditch pattern was needed, and therefore the parcel size is 600 by 200 metres. Further technical development for drainage systems led to even larger parcels in Zuidelijk Flevoland. These parcels have a size of 1200 by 500 metres or 1800 by 500 metres. Because these sizes did not connect to the practices, the parcels were split up into smaller parcels with the use of access roads (van Duin, 1987).

Urban:
Lelystad is located at the most central location of the polders and next to the Oostvaardersdiep, near the crossing of multiple main roads. Lelystad was supposed to be the centre of the polders, but this is not visible anymore, because the Markerwaard is not realised (van Duin, 1987).

Almere was designed as the overflow area of the Randstad, Amsterdam and Het Gooi. Almere is designed with multiple cores to avoid massiveness. The blue-green structure lies between these cores (Directoraat-Generaal Rijkswaterstaat and Directie IJsselmeergebied, 1996).

Nature:
The province is designed with a focus on agriculture and the segregation of functions. The agricultural lands lie in the centre of the province, and natural areas are more located on the edges. If you zoom in, this function segregation is still visible, but between the edges of the lakes, the urban areas and larger nature sites, this segregation is less visible. (Directoraat-Generaal Rijkswaterstaat and Directie IJsselmeergebied, 1996).

Cicle around Lelystad
Polder names
Urban areas
Nature
Wetland
Water
Border provinces
Border municipalities
Knardijk (border between Zuidelijk and Oostelijk Flevoland

Fig. 9: Flevoland, municipalities and borders

3.3.1 Urban areas

Flevoland wants to create vital cities, villages and a future-proof regional economy. The goal is to create lively and healthy urban areas with a diverse housing market, facilities and places where people can meet. The accessibility should be improved as well, creating a strong knowledge and energy infrastructure with enough workplaces to create a basis for a thriving economy.

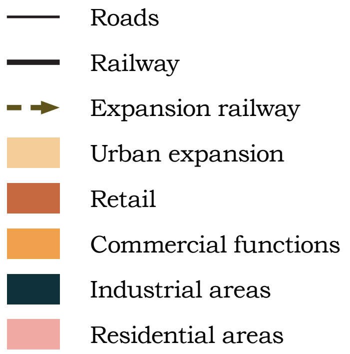
Furthermore, the province is an important region to build new houses, and the expectation is that it will grow from 435.000 inhabitants to 652.000 inhabitants in 2051. In 2022, Flevoland had 178.000 households, 50% located in Almere and 20% located in Lelystad. There was already a housing shortage of 4,9% in 2022.

The goal is to build 90.000 to 115.000 houses by 2050, 29.193 of this amount has to be built by 2030. The housing options should fit the demographics and development of the region. Additionally, the housing sites should be close to (new) public transport and cycling junctions, facilities and employment areas. New neighbourhoods must be energy-positive, water-positive, climate-adaptive, circular and nature-inclusive (Strategische Agenda Flevoland Deel II, 2022).

There are two NOVEX areas in Flevoland, one of the NOVEX locations is the MRA (Metropolitan Region Amsterdam) and the cities connected to this area are Lelystad en Almere. The expectation is that Lelystad will grow a minimum of 100.000 inhabitants and Almere will grow further as well (Strategische Agenda Flevoland Deel II, 2022). Figure 10 shows the expected urban expansions in Flevoland.

The other NOVEX area is Zwolle, and the municipalities of Urk, de Noordoostpolder and Dronten are part of this region. This NOVEX-location focuses on combining housing, employment, accessibility and sustainability, creating a future-proof region. The goal is to realise 50.000 houses in this region, while being climate adaptive and preserving the quality of the living environment (De Zwarte Hond, n.d.).

The bottlenecks of the transportation system should be improved, with a focus on sustainable mobility such as public transportation and cycling (Strategische Agenda Flevoland Deel II, 2022). Furthermore, Flevoland is also part of the NOVEX area of the Lelylijn. The Lelylijn is a new railway that should connect Lelystad with the northern parts of the Netherlands via Emmeloord. This railway should improve the economic strength of the North and the transportation from the new neighbourhoods.



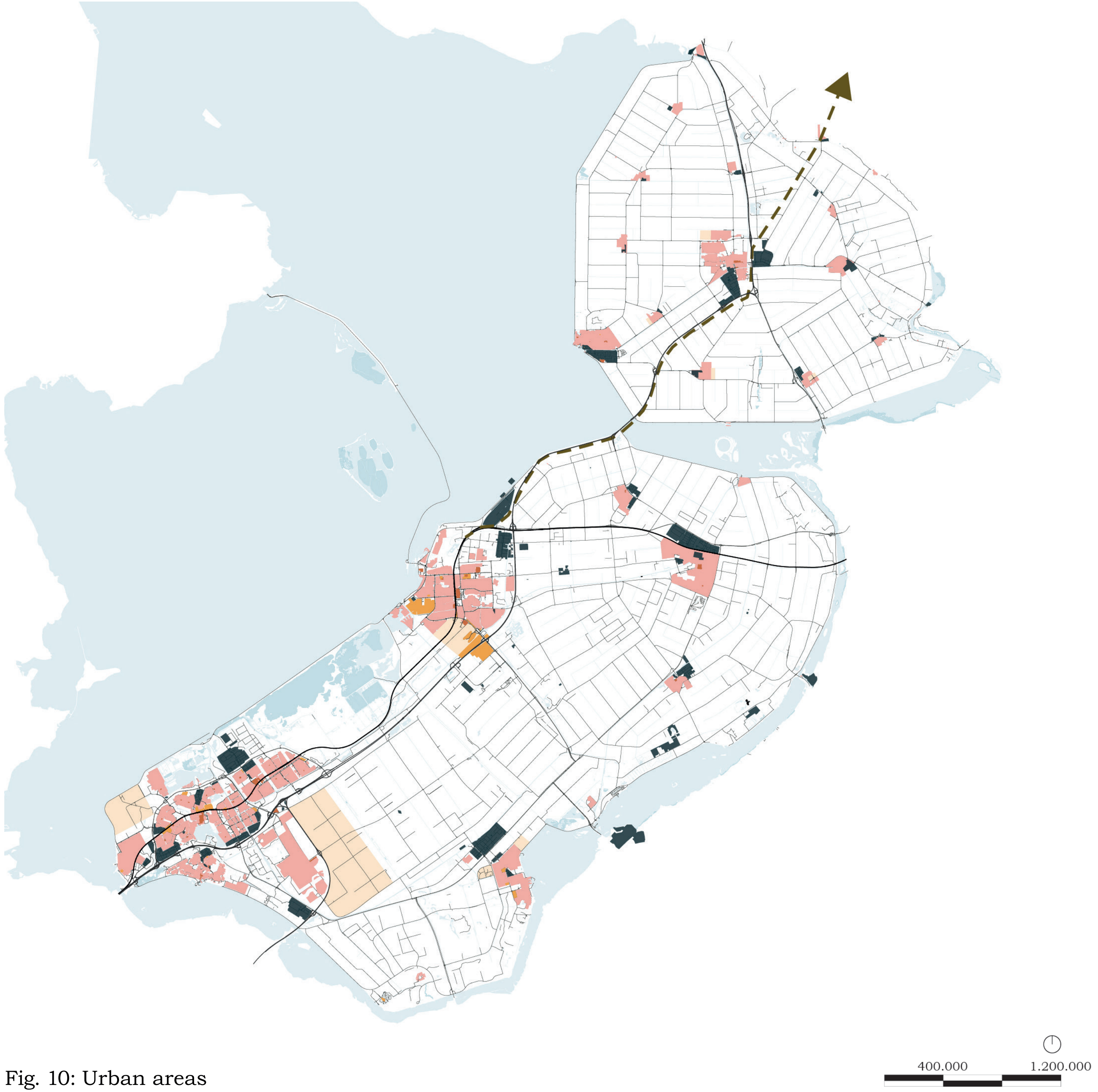


Fig. 10: Urban areas

3.3.2. Rural areas

Agriculture

Flevoland has an agricultural area of 88.000 hectares, which is 4.8% of the total area of the Netherlands. Approximately 70% of this area is used for arable farming, with the average in the Netherlands being 28% (Strategische Agenda Flevoland Deel II, 2022). The other 30% of the land is used for grasslands and horticulture. The agriculture in the province is large-scale and highly productive at the world level. This is due to the high quality of the soil. The production is based on a four- to five-year crop rotation (Randstedelijke rekenkamer, 2022).

Furthermore, the province had 1.654 agricultural companies in 2020, 14,1% of which were biological. These agricultural companies had a combined turnover of €1.1 billion in 2020.

The province wants to stay an agricultural province and is designed for optimal land use for agriculture. This is visible in the parcelling and water management.

Even though the province has this ambition, there is more pressure on the agricultural sector from new developments and climate change. Therefore, Flevoland is already researching different paths for an agricultural transition, such as nature-inclusive agriculture and agroforestry, but these plans are still very abstract, as Randstedelijke rekenkamer (2022) explained.

One of the developments is the search for new barracks for the defence. The search areas are in the south of Zeewolde on biological agricultural land, the Spiekweg and in Oosterwold (fig. 11). Furthermore, Flevoland is a search area for the development of a new blasting site for training with explosives, but it is not clear yet where this area will be located (Omroep Flevoland, 2024).

Search areas for defence
Orchard
Farmland

400.000
1.200.000

Fig. 11: Agricultural areas

Nature
In Flevoland, there are 19.221 hectares of nature, which is 13,6% of the total land surface area. The goal is to further develop the amount of nature with 1700 extra hectares of forest by 2050. For this goal, there is a forest strategy, and the search areas for the strategy are visualised in figure 12. (Strategische Agenda Flevoland Deel II, 2022)
Flevoland has multiple natural types, such as marsh landscapes, forests on clay soils and islands in the surrounding lakes. 50% of the total hectares of nature consists of forests, and 30% is large, dynamic nature: Oostvaardersplassen.

90% is part of the Nature Network Netherlands. This network emphasises that natural areas should be better connected with each other and with the surrounding agricultural lands.
In the future, the nature network should be combined with the natural areas of other European countries under the name Pan-European Ecological Network (Ministerie van Landbouw, Visserij, Voedselzekerheid en Natuur, 2025).

Two nature parks are also part of the Natura2000: the Oostvaardersplassen and the islands in the lakes surrounding the polder. Natura2000 is the European network of protected nature. In these locations, certain animals, plants and their natural living area are protected to keep the biodiversity intact (Ministerie van Landbouw, Visserij, Voedselzekerheid en Natuur, n.d.).
The Oostvaardersplassen is a marsh landscape between Almere and Lelystad, and in the area are a lot of geese and waterbirds, konik horses, cattle, red deer and foxes (Nationaal Park Nieuw Land, 2025). The nature was wet, unused land, and the nature started to develop into marshes, reed lands, and willow forests. These landscapes, especially the reed lands, are an important habitat for rare birds.

Natura2000 areas
Search areas forests
Nature Network Netherlands
Nature
Park

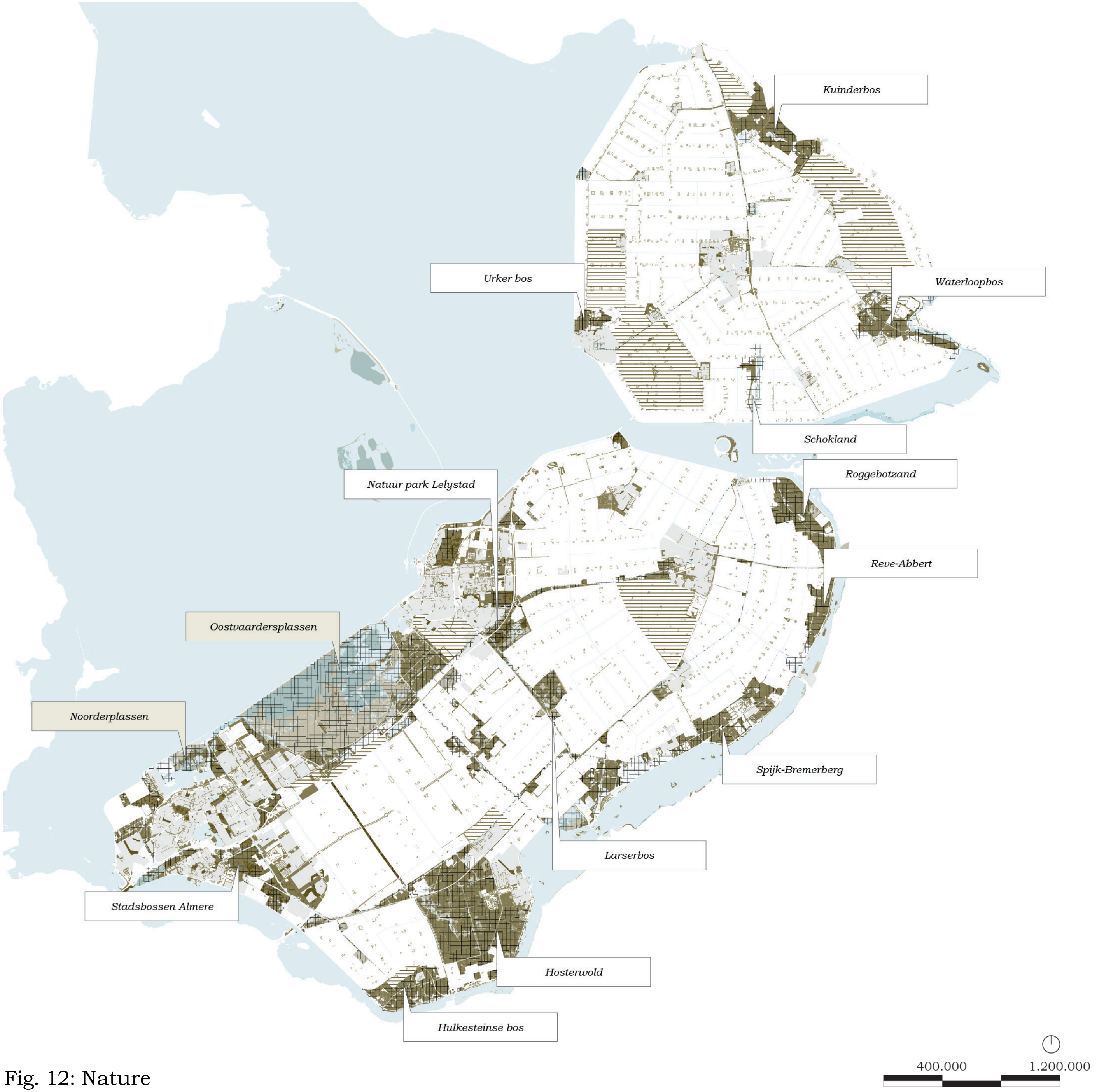


Fig. 12: Nature

Water system

Flevoland is on average 5 metres below sea level and has 251 kilometres of dikes. (Strategische Agenda Flevoland Deel II, 2022).

Flevoland is designed with large regions with the same water level target (peilvakken). When there is locally heavy rainfall, the water could easily access other areas with less rainfall due to the large water level areas. This helps with the reduction of water nuisance. In the Flevopolder, there are two main water level target areas, and in the Noordoostpolder, there are three peilvakken. In the urban areas and natural sites, there are multiple small peilvlakken. One large water system in the province regulates the water flows in the polder. The water flows from the ditches to the tochten and then from the tochten to the vaarten (fig. 13). These canals are connected to several pumping stations. The water level in the canals corresponds to the water level in the surrounding areas.

There are two areas in the Flevopolder with different target water levels. Each target area is connected to a vaart. This vaart is further connected to several pumping stations. These pumping stations regulate the water level by pumping water out of the polder.

The two vaarten are the Hoge and the Lage Vaart. The Lage Vaart is one meter lower than the Hoge Vaart and is connected to three pumping stations: Colijn, Wortman and the Blocq van Kuffeler. The Hoge Vaart is connected to the pumping stations Blocq van Kuffeler, Lovink and Colijn.
The Noordoostpolder has three vaarten, Lemstervaart, Urkervaart and Zwolse Vaart, connected to the three pumping stations: Vissering, Smeenge and Buma as visualised in figure 14.

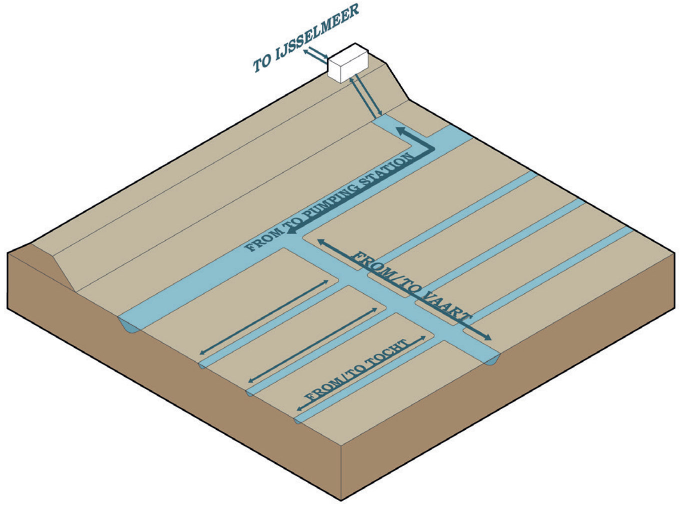


Fig. 13: water system Flevoland

- Wetlands
- Pumping stations
- Hoge and Lage Vaart
- Surfacewater
- Lower water level than department
- Higher water level than department
- Hoge department Flevopolders
- Lage department Flevopolders
- High department Noordoostpolder
- Intermediate department Noordoostpolder
- Low department Noordoostpolder

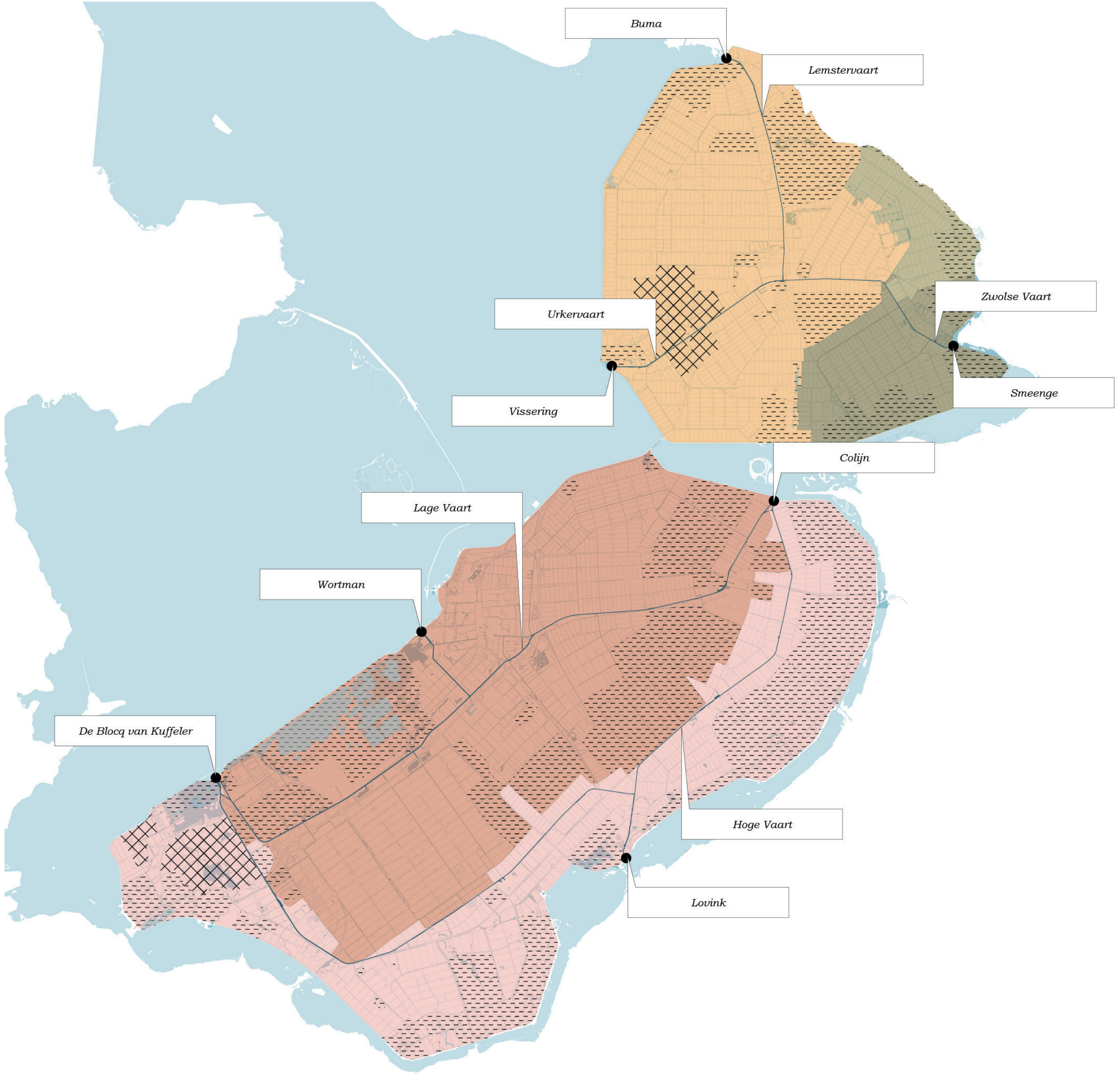


Fig 14: Target areas for water level

400.000 1.200.000

Conclusion of spatial analysis

Current situation

If the different maps are overlapped with each other, it becomes visible that the larger urban areas are in the Flevopolder, just like the nature areas. The agricultural lands are located mostly in the eastern part of the Flevopolder and the whole of the Noordoostpolder. The waterways are the border of the two largest nature areas: Horsterwold and Noorderplassen. The waterways are the borders because of the practical limitations of the water system and the maintenance of these natural areas.

In the Noordoostpolder, the largest urban area is placed in the middle of the area with small surrounding villages, but the natural areas are more located on the edges of the polder. The agricultural areas surround the urban and natural areas.

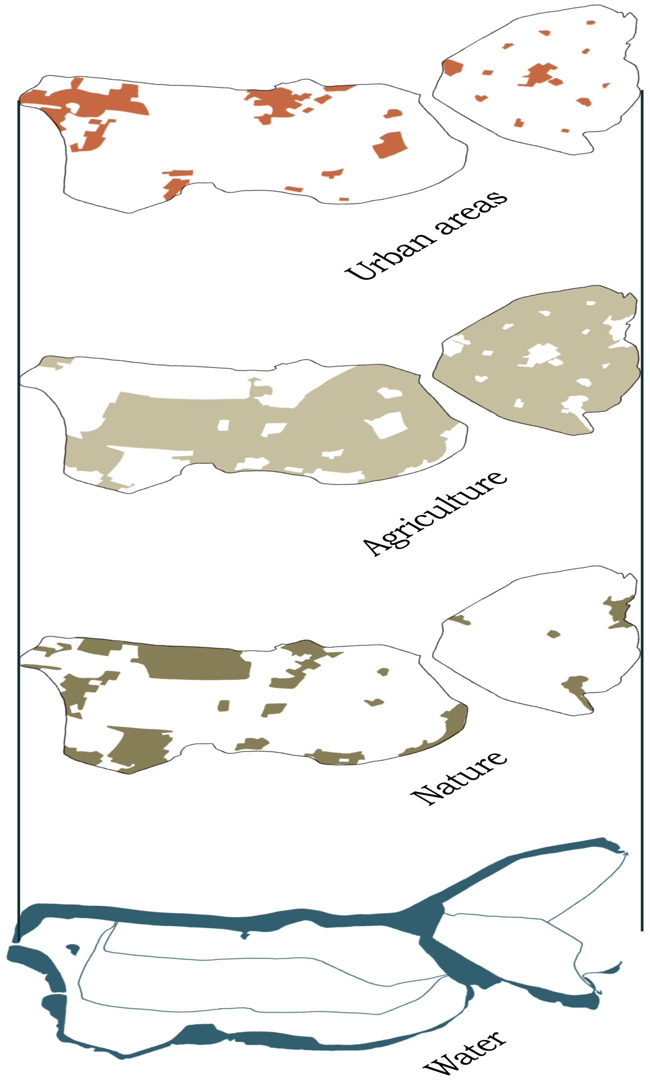


Fig. 15: Conclusion stacked

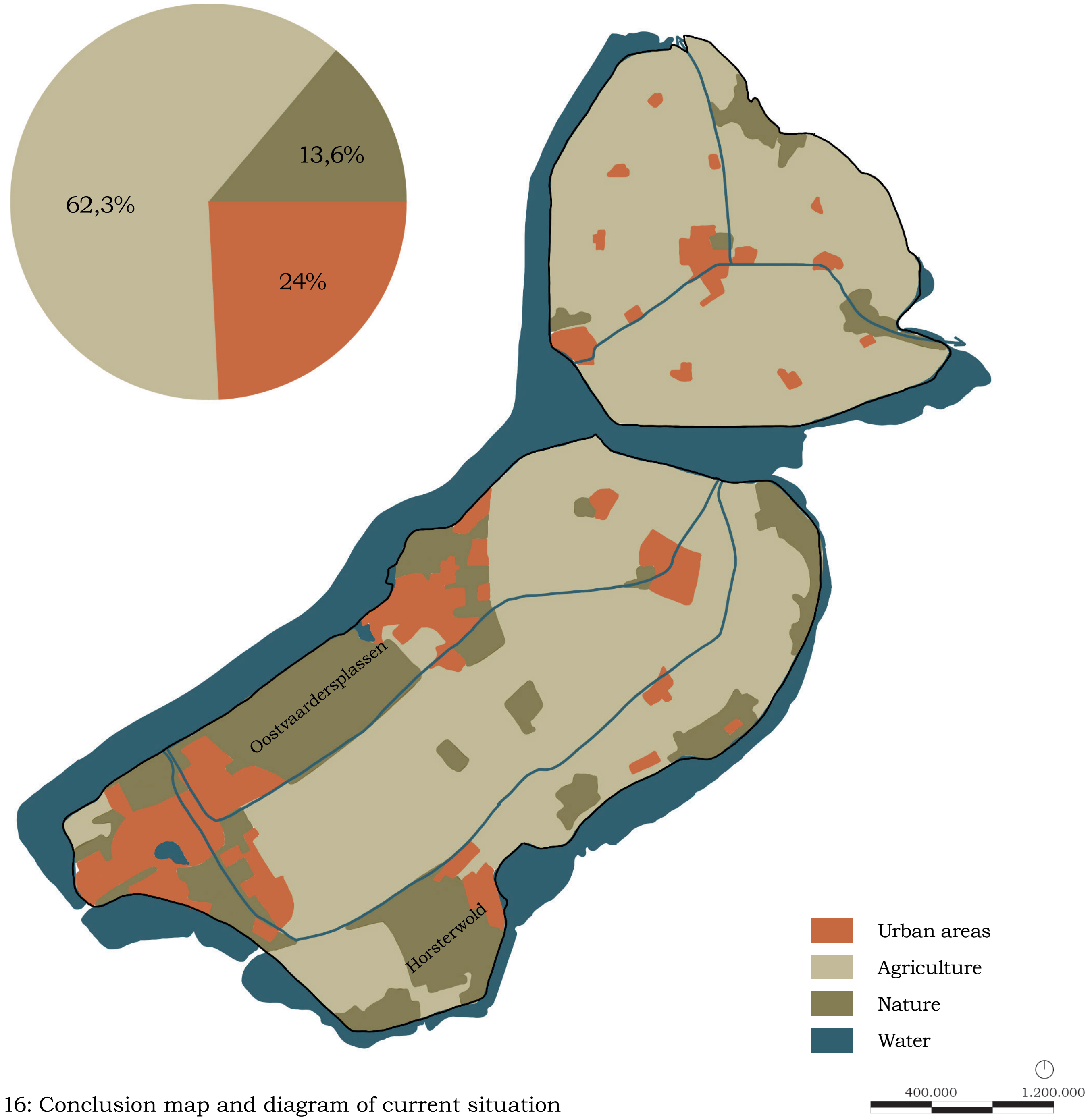


Fig. 16: Conclusion map and diagram of current situation

Future situation
For the future scenario of 2050, urban areas will grow. Especially around Lelystad en Almere/ Zeewolde. The expansions of these cities will move towards the agricultural land, causing the agricultural areas to shrink. Furthermore, there will be more pressure on the agricultural sector due to climate change and the expansion of natural areas in the province. The water system will be a constant factor, but the water levels may change over time.

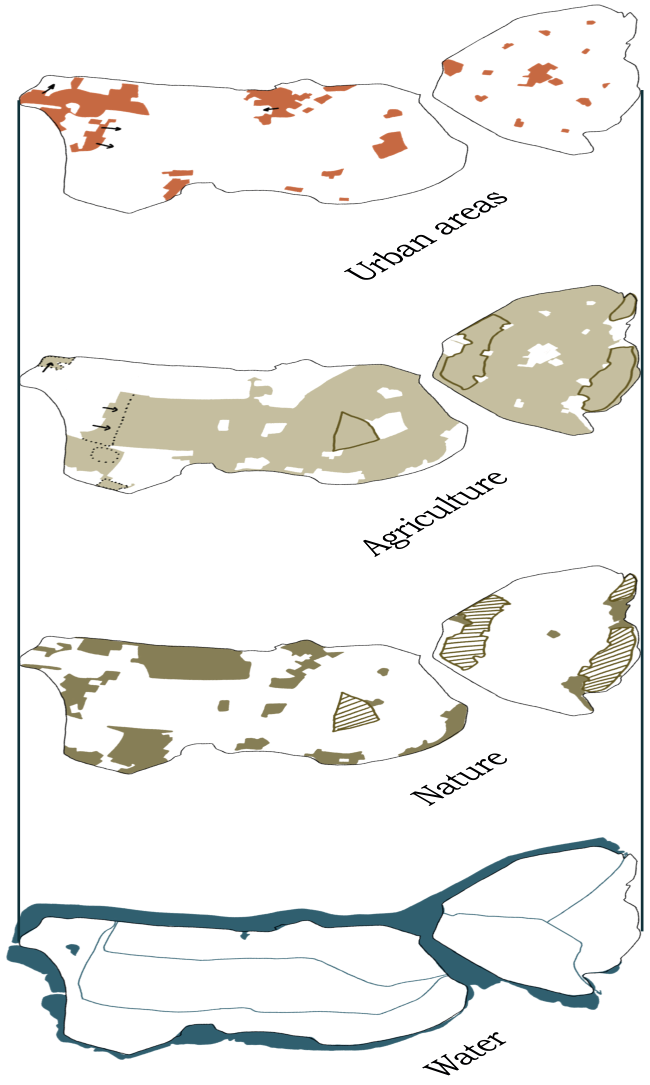


Fig. 17: Conclusion stacked

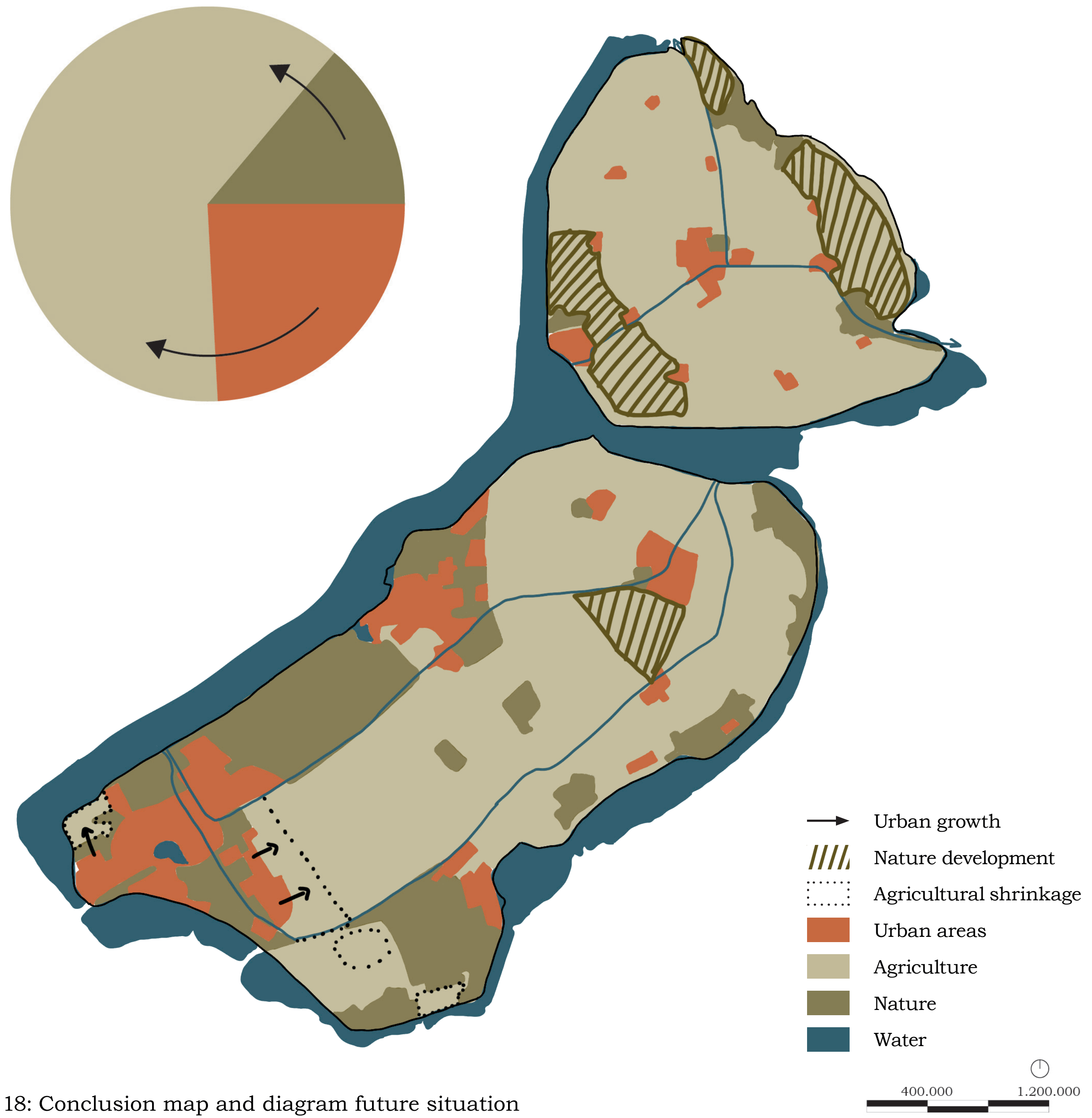


Fig. 18: Conclusion map and diagram future situation

Analysis

Water

Introduction

The chapter will be used to explain the different water problems related to Flevoland.
These problems are categorised into three sub-categories:

- Water quantity
- Soil Health
- Water Safety

At the end of the chapter, these problems will be combined in two maps: one for the current situation and the other for the future situation.

Water quantity

Because of climate change, the weather will shift towards more extremes. This means that dry periods will be longer and warmer, and wet periods will be more extreme. This could cause more problems for the province for agriculture, nature and the urban areas as well.

Water nuisance

Water nuisance (nuisance flooding) refers to inundation levels that do not cause significant threats to public safety or major property damage, but could disrupt daily activities. We can speak of water nuisance when the water has a depth between three and ten centimetres on the surface (AghaKouchak et al., 2018). Water nuisance in Flevoland is caused by heavy rainfall.

Heavy rainfall could locally cause water nuisance for a short time. In Flevoland, this could cause flooding in and outside buildings, and health risks due to polluted water on the street, because of mixed sewage systems. 10% of the buildings in the Netherlands have a chance of water nuisance with heavy rainfall every 1000 years. Especially low-lying paved areas are sensitive to water nuisance.

The maps show an indication of the maximal water depth as a result of heavy rainfall. In fig. 19, this is a rainfall of 70 mm in two hours, and in fig. 20, a rainfall of 140 mm in two hours. Right now, the expectation is that these rainfalls happen once every 100 years and every 1000 years, but at the end of the century, this could happen twice as often.

The maps are based on the Klimaeteffectatlas (2025), where the extreme rainfall will happen after four hours of dry weather.

Fig. 19: Water nuisance, once every 100 years (based on Stichting Climate Adaptation Services, 2025a)

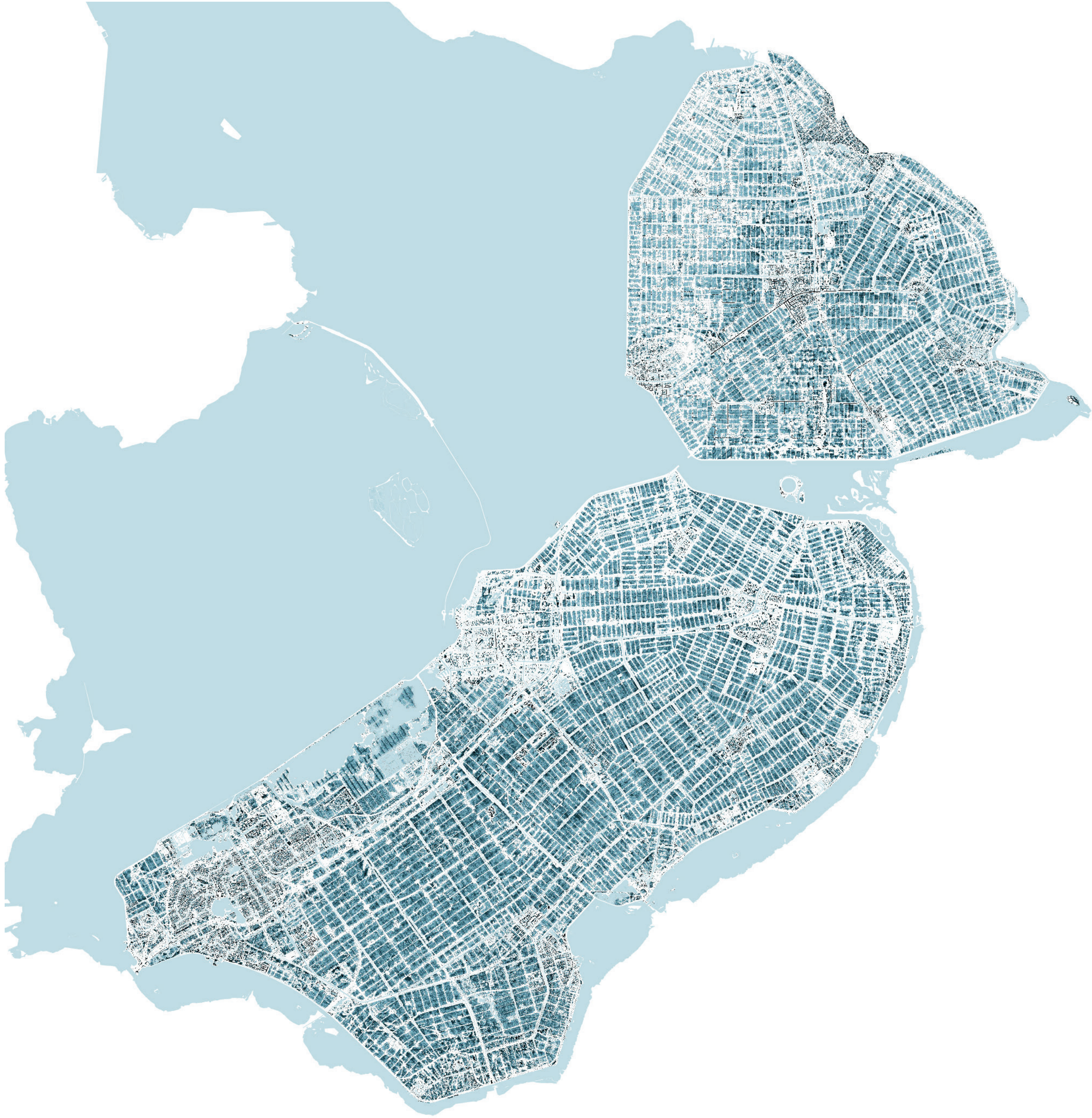


Fig. 20: Water nuisance, once every 1000 years (based on Stichting Climate Adaptation Services, 2025a)

The map on the right (fig. 21) shows the water levels on the surface level after heavy rainfall based on the heavy rainfall in Limburg from 2021. The problem in Flevoland is not the height of the water levels but the number of days or weeks that the groundwater level will be higher than normal. Because of the flatness of the polder, the water will take a couple of days or weeks before the groundwater level is back to its regular depth. This could result in crop damage on agricultural land. The amount of water nuisance on the surface level depends on the height difference of the land. The rainwater will be collected at the lowest point, and this water cannot flow out of this area. Therefore, the water could only disappear from the location by infiltration. This means that the groundwater level will take a longer time to return to its regular depth.

7,8 cm
15,6 cm
23,4 cm
31,2 cm
39 cm
46,8 cm
54 cm
60 cm

Fig. 21: Water nuisance, Limburg rainfall 2021 (Waterboard Zuiderzeeland, 2021)

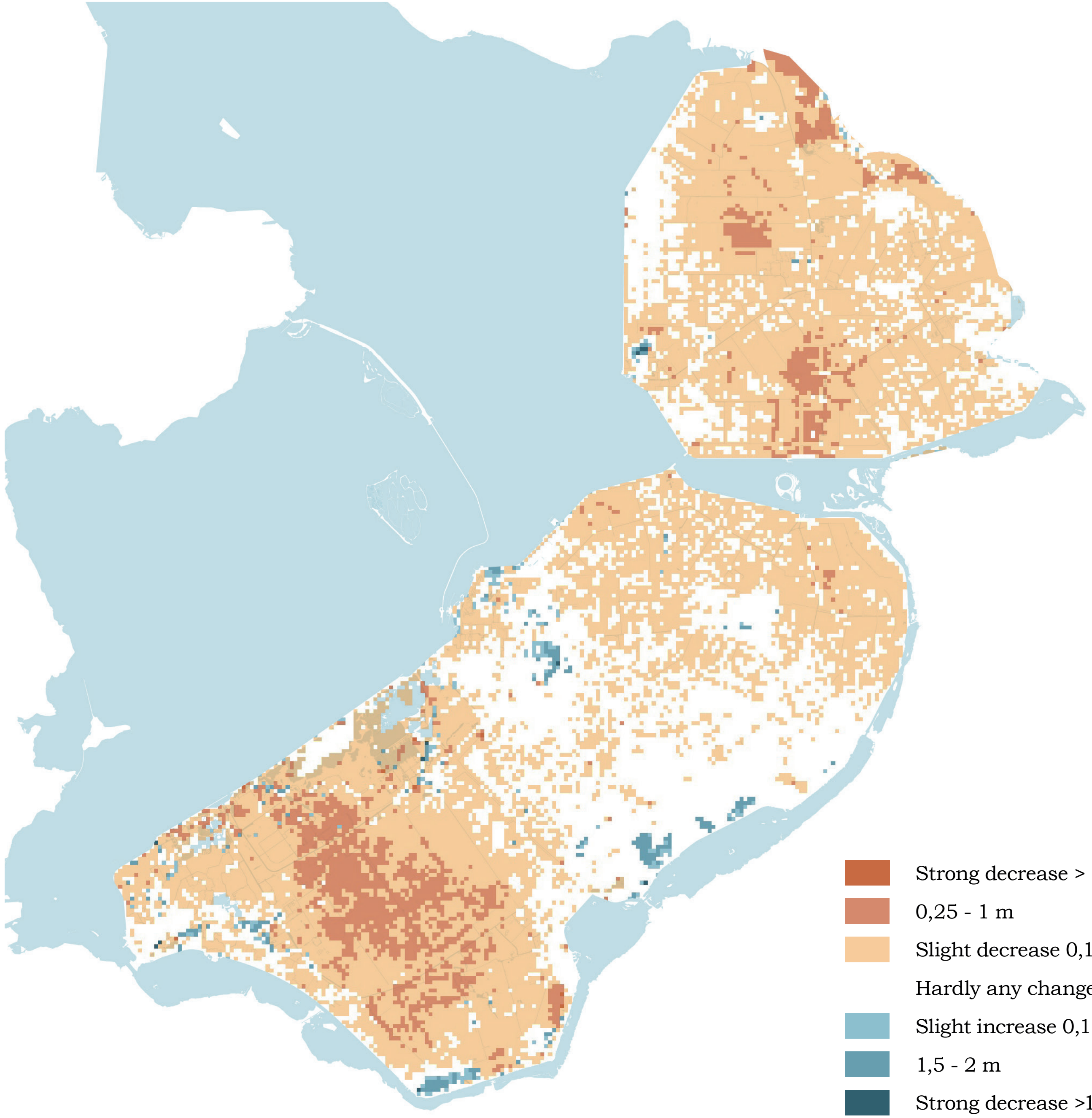
400.000
1.200.000

Drought
Drought is a worldwide phenomenon and is known as the 'creeping disaster', because it slowly develops and often goes unnoticed, even though the consequences could last for months. Drought could have consequences for agricultural practices, drinking water supply, recreation, and electricity production. Furthermore, it could lead to ecosystem problems as well, such as wildfires or the reduction of species in aquatic ecosystems (Van Loon, 2015).
Drought has four different categories:
The first is meteorological drought, which refers to a lack of precipitation. Secondly, soil moisture drought refers to the water shortage in the ground. This could lead to crop failure or dry natural areas. Hydrological drought is the lack of water in hydrological systems. The last type of drought could refer to the failure of water resources systems to meet water demands and to ecological or health-related impacts. This type of drought is called socio-economic drought (Van Loon, 2015).

In Flevoland, the average lowest groundwater levels vary. This is evident in figure 22. The map illustrates the lowest groundwater levels during an extremely dry year, such as 1976. In that year, the water shortage was greater than in 2018. The expectation is that the average groundwater level will continue to decrease in some areas, leading to increased drought.
The other map (fig. 23) shows the expected change of the groundwater level in 2050.

Fig. 22: average lowest groundwater level current situation (based on Stichting Climate Adaptation Services, 2025a)

< 0,2 m
0,2 - 0,4 m
0,4 - 0,6 m
0,6 - 0,8 m
0,8 - 1 m
1 - 1,5 m
1,5 - 2 m
> 2 m



Strong decrease > 1 m
0,25 - 1 m
Slight decrease 0,1 - 0,25 m
Hardly any change
Slight increase 0,1 - 0,25 m
1,5 - 2 m
Strong decrease >1 m

400.000 1.200.000

Fig. 23: Drought 2050 expectations (based on Stichting Climate Adaptation Services, 2025a)

During dry seasons, the soil can dry out, preventing plants from evaporating optimally. This process is known as drought stress, as plants close their stomata to reduce water loss through evaporation. This may lead to the (partial) death of the plant.

Drought stress primarily occurs in soils with a deep groundwater level and coarse texture, such as sand, but it could also happen in heavy clay soils.

In agriculture, drought stress results in reduced crop yields. Farmers, particularly those growing potatoes, beets, and other vegetables, will face these challenges due to the low drought tolerance of these plants. As a result, farmers will attempt to mitigate yield loss by watering the crops (Stichting Climate Adaptation Services, 2025b).

In nature, vegetation will adapt over time: species of moist and wet environments disappear and make way for drought-resistant species.

The locations where drought stress is happening now and where it is expected in 2050 are shown in fig. 24 and 25.

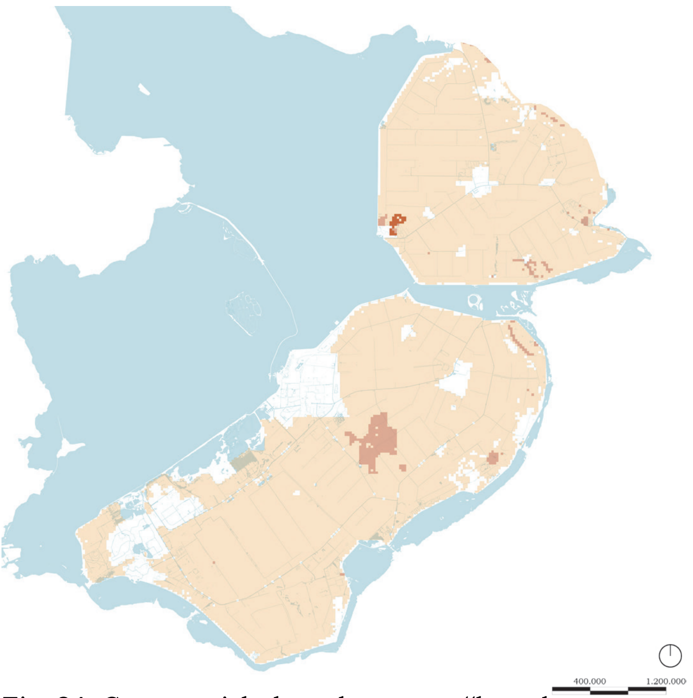


Fig. 24: Current risk drought stress ((based on Stichting Climate Adaptation Services, 2025a)

Annual yield loss

- Low < 10% with grass lands
- Middle 10 - 20% with grass lands
- High > 20% with grass lands

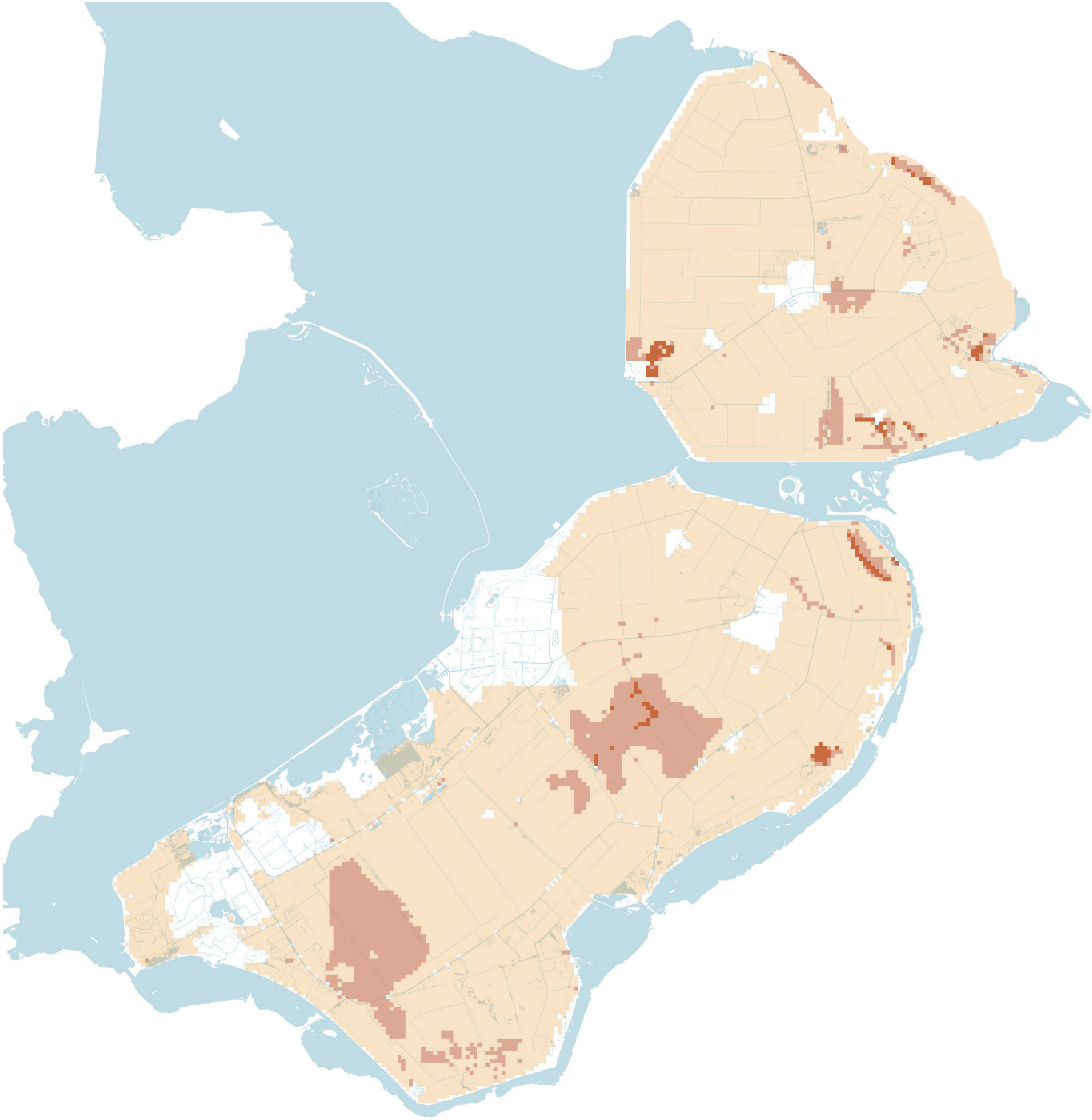


Fig. 25: Risk drought stress 2050 expectations (based on Stichting Climate Adaptation Services, 2025a)

400.000 1.200.000

Soil health

Flevoland has changed a lot through time, as is shown in the soil maps (fig. 26 to 29). 9.000 years B.C. Flevoland consisted mostly of sandy terrain with a few river areas and marshes during the last major ice age. This shift in 5.000 years B.C. was due to climate change. The sea rose, and the first peat areas were found around the coastline of the IJsselmeer region. The peat spread more between 5.000 years B.C. and 2.750 years B.C. Due to this, the coast changed a lot. This process went on towards 500 B.C. (Rijkswaterstaat et al., 2021).

From 1.250 until 1.500 A.C., the landscape changed again, this time due to human hands. The inhabitants of the Netherlands built dikes to protect the country, and the mills were used to pump water out of the polders. Woods were removed to make space for agriculture. Therefore, there was a lack of burning materials, and people started using peat as fuel. The winning of peat caused a typical type of landscape, long parallel strokes that are still visible in the Dutch landscape. From 1500 until now, people have won more land along the coast, Flevoland being one of the latest and largest.

Two major storms in 1916 and 1953 caused the development of the Zuiderzeewerken, creating the IJsselmeer and the design of the Deltaplan. These two projects caused a lot of changes for the flora and fauna, because the IJsselmeer and the Biesbosch changed from salt water to freshwater. Right now, the IJsselmeer is the largest freshwater lake in the Netherlands.

All these changes not only affected the surface but also changed the subsurface. By changing the groundwater level, agriculture improved. The tidal landscape changed into the Randstad, the most dense area of the Netherlands (Rijkswaterstaat et al., 2021). Because of these changes, the subsurface has a lot of different layers. Some of these layers have more salt because they were the seabed at some point. The peat remnants are still visible in the soil, and the process of changing soil types has been going on for many years before 9.000 B.C.. For Flevoland, there were a lot of changes through time, the land shifting transforming into sea, a lake and then back to land. Once, there was a river in Flevoland; this river was the Eem, still existing in the province of Utrecht. This river is also visible in the sections of the soil.

Stream valley
Water
Top sand Holocene
Top sand Pleistocene
Donk
Dunes
Tidal zone
Gully
Glacial
High dunes
Reclaimed
Salt marshes
Salt marshes ridge
Low dunes
Low Holocene
Loss
Older
City contour
Embankment
Peat

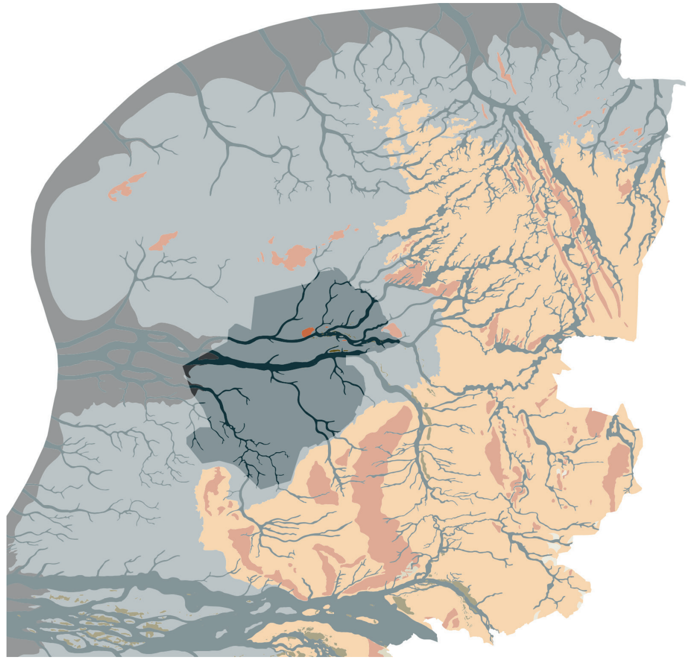


Fig. 26: 9000 B.C. (based on Rijksdienst voor het Cultureel Erfgoed, 2020)

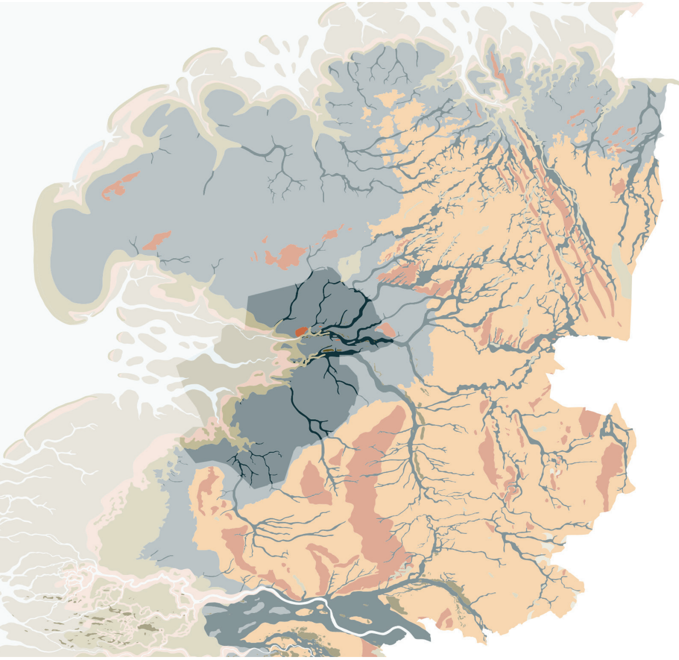


Fig. 27: 5000 B.C. (based on Rijksdienst voor het Cultureel Erfgoed, 2020)

Fig. 28: 1850 A.C. (based on Rijksdienst voor het Cultureel Erfgoed, 2020)

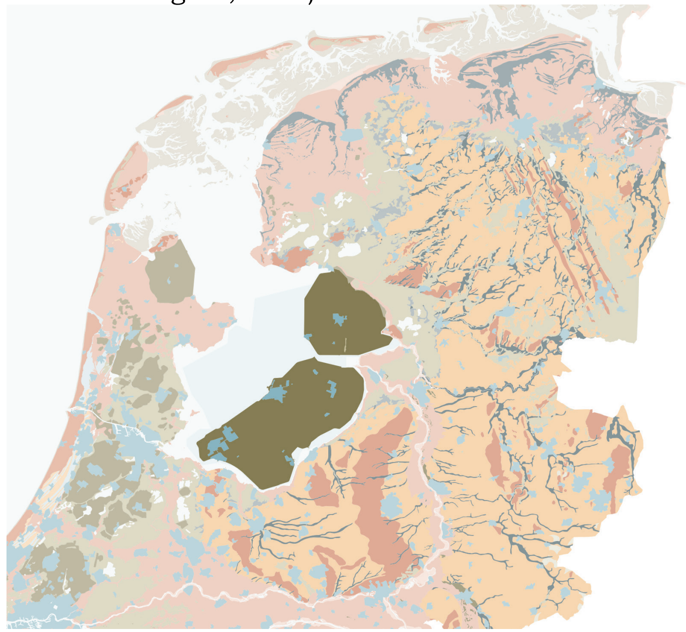


Fig. 29: 2000 A.C. (based on Rijksdienst voor het Cultureel Erfgoed, 2020)

Soil health

The maps (fig. 27 to 30) show the development of the soil through time, but this has consequences in the soil layers as well. Therefore, the sections showcase how the soil layers developed over time. The sections are 150 metres deep.

The first cross-section (fig. 31) is made in Almere and Zeewolde. This location is selected to visualise the river Eem. It is visible that the Eem formation was part of a transition. The older formations are mostly fluvial, while the Eem, Drente and Kreftenheye are fluvioglacial. The last soil layer is the Holocene. This is the current layer, and in the section, it is visible that the left side of the Holocene is a thicker part than on the Zeewolde side.

Fig. 30: Section marking

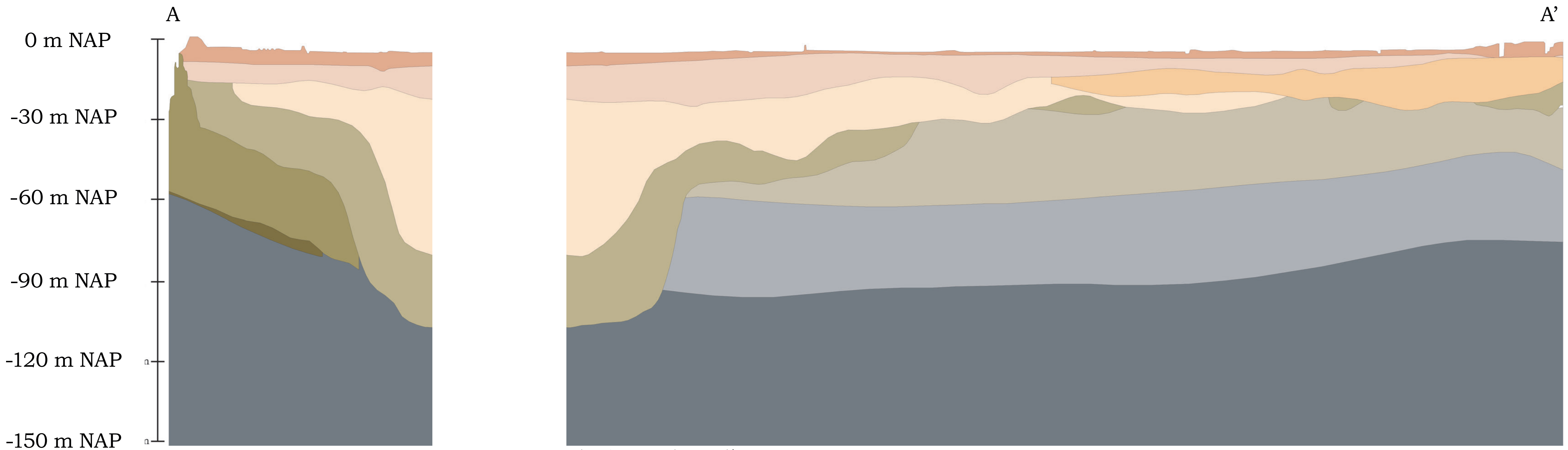


Fig. 31: section soil types

This section (fig. 33) shows how the Flevopolder is built up. By comparing the sections, it shows that one (fig. 33) is more even through the polder, except for the part in Almere, where the Kreekrug is still visible from earlier times. It is also visible that the Holocene layer is again bigger in Almere than in the rest of the polder. This means that the topsoil with clay and peat is thicker than in other locations.

Holocene layer
Formation of Boxtel (eolic)
Formation of Kreftenheye (fluvi-glacial)
Formation of Woudenberg (oligotrophic to eutrophic)
Eem formation (fluvi-glacial
Formation of Drente (glacial and fluvi-glacial)
Impounded deposits
Formation of Urk (fluvial)
Formation of Sterksel (fluvial)
Formation of Appelscha (fluvial)
Formation of Peize and Waalre (fluvial)

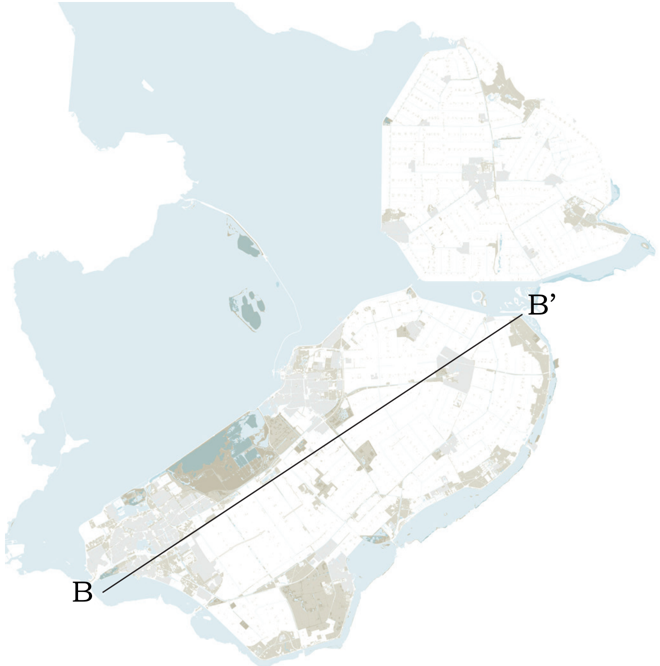


Fig. 32: Section marking

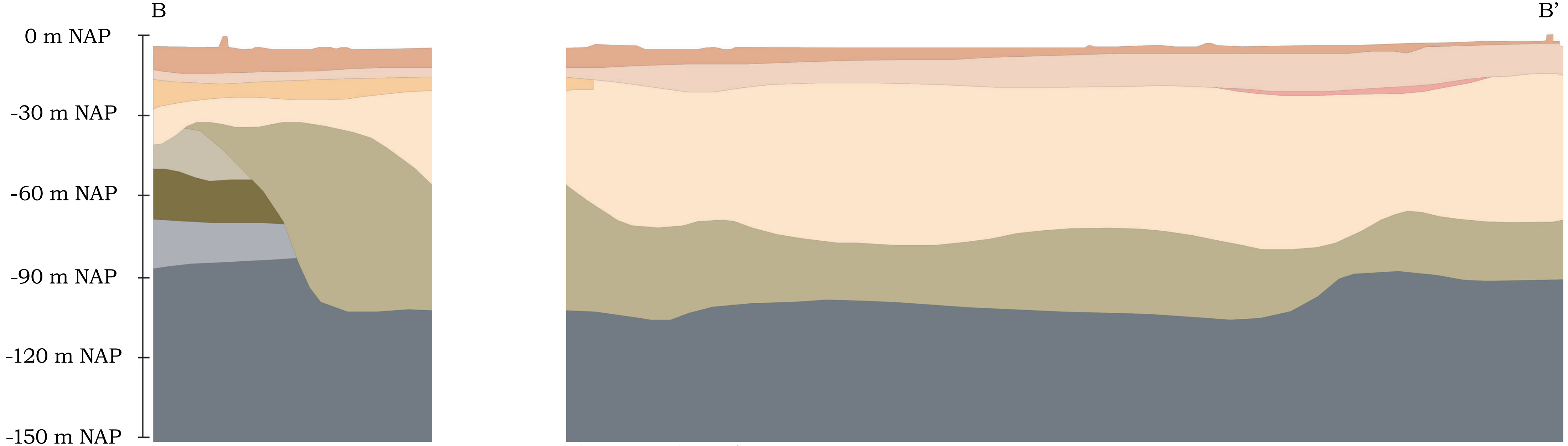


Fig. 33: Section soil types

Salinisation
Salinisation is the process of freshwater becoming saltier. The deeper groundwater layers are mostly saltwater. The upper water layers are freshwater, and the transition between these layers is called the fresh-salt interface. The depths of this interface are visible in figure 34.

Salinisation could happen due to six factors. The first is the atomisation of sea salt, meaning seawater dries out, and the salt that stays on the land will be blown inland. This only happens in a small stroke along the coastline.

Salinisation could also happen because of agricultural activities leading to the evaporation of water, and by the administration of salts in manure. High evaporation could be caused by crop irrigation or because of a higher groundwater level that helps with the capillary water supply.

Thirdly, in the IJsselmeer region, there is a large amount of historical deposition of marine sediments. The salt water in these layers is mostly in the deep clay layers (100 to 200 metres deep), but could locally be shallower in the ground. If this water goes up, it could lead to salinisation (De Boer & Radersma, 2011).

Furthermore, flooding from the sea and the lock-in of this seawater could lead to salinisation. This only happens in coastal areas and does not happen in Flevoland. The same applies to seawater intrusion along the coast and in estuaries. The intrusion front will move further inland in the future, which could cause more problems.

Lastly, the mixing of fresh and saltwater causes

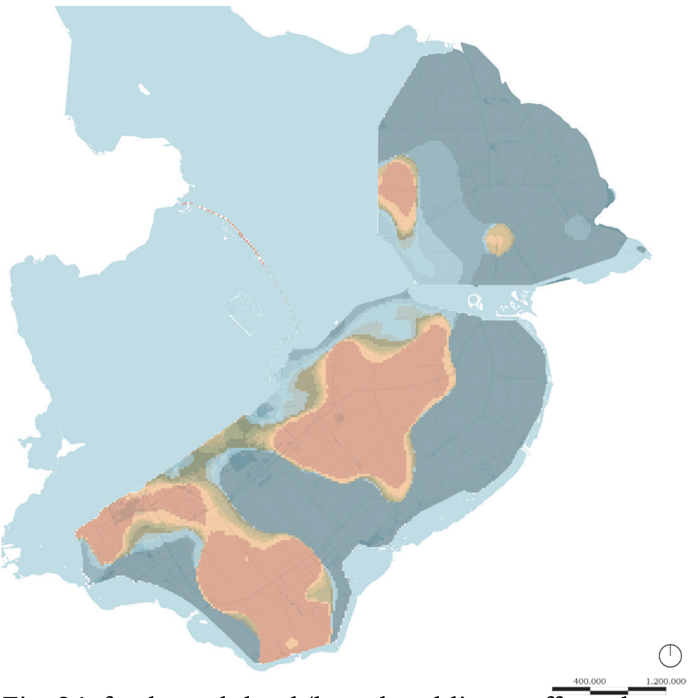


Fig. 34: fresh - salt level (based on klimaateffectatlas, 2025)

- <= -111 m
- -111 - -89 m
- -89 - -67 m
- -67 - -58 m
- -58 - -49 m
- -49 - -40 m
- -40 - -31 m
- -31 - -27 m
- -27 - -20 m
- > -20 m

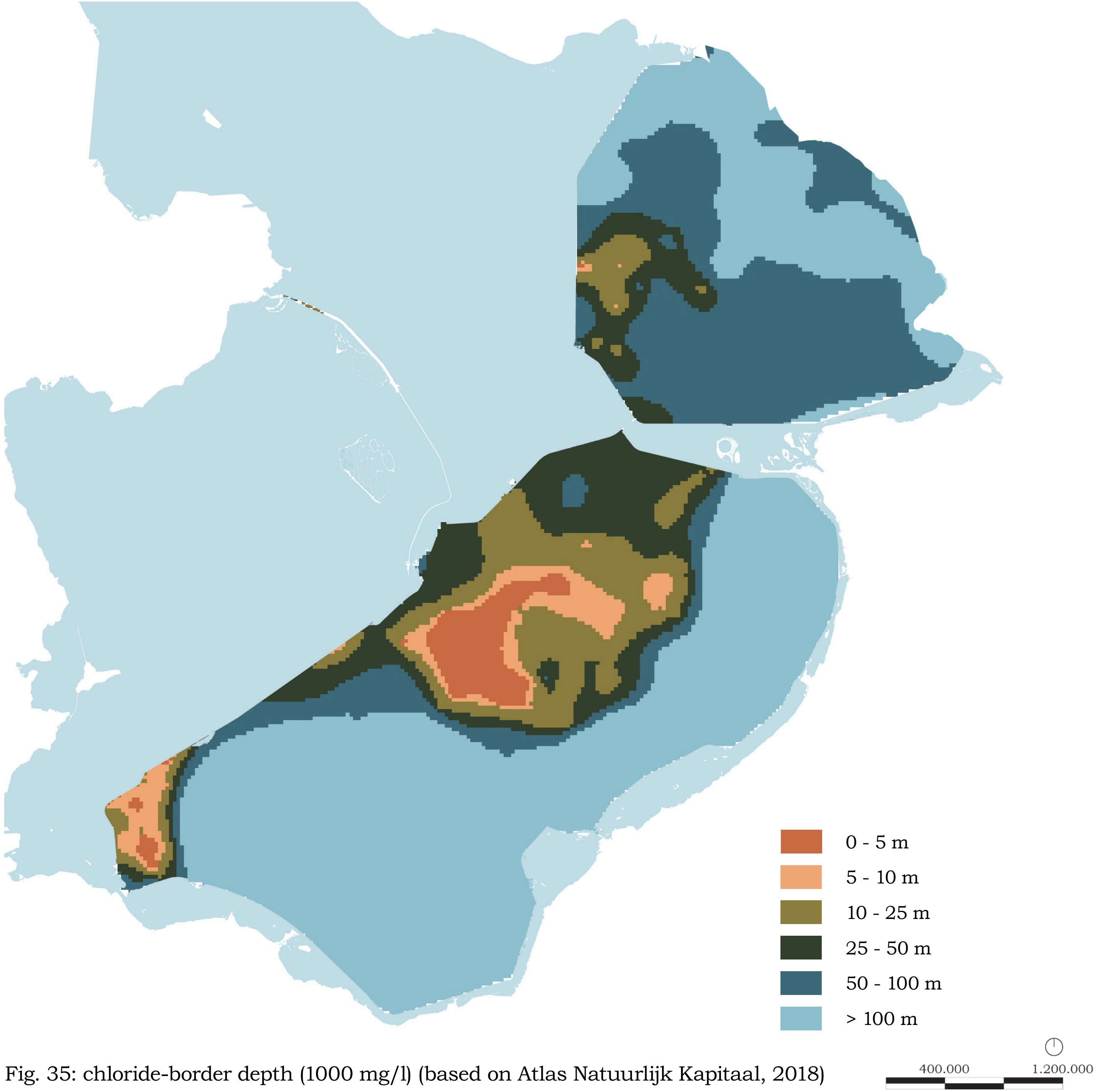


Fig. 35: chloride-border depth (1000 mg/l) (based on Atlas Natuurlijk Kapitaal, 2018)

brackish water. This process happens in great depths and regions with a lot of shallow clay layers, such as in the IJsselmeer region. This leads to problems for the growing of bulbs, horticulture, trees and fruit (De Boer & Radersma, 2011).

Salt groundwater could cause salinisation if the groundwater comes up. It could lead to the salinisation of ditches in polders and could lead to damage to the roots of a plant. Right now, the salinisation is managed because of the freshwater from rivers.

Fig. 36 and fig. 37 show the amount of salt in the surface water, and these amounts will change very slowly in the future. The surface water in the Noordoostpolder and the borders of the Flevopolder that are connected to the IJsselmeer and Markermeer will become saltier. The other areas in the province will change more towards freshwater. This has consequences for the surface water as well. The surface water quality will improve if the groundwater becomes fresher, and the surface water quality will be lower if there is more salinisation (Waterschap Zuiderzeeland, 2023).

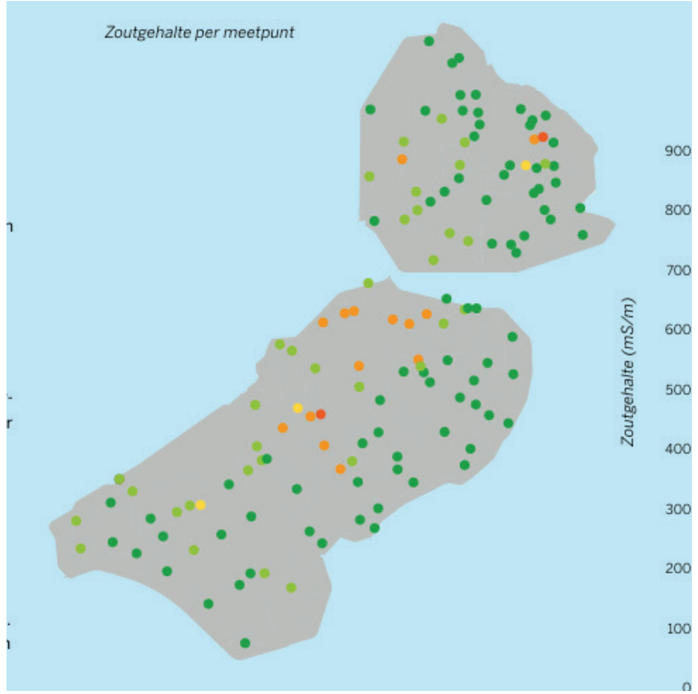


Fig. 36: Salt measures right now (Waterschap Zuiderzeeland, 2023a)

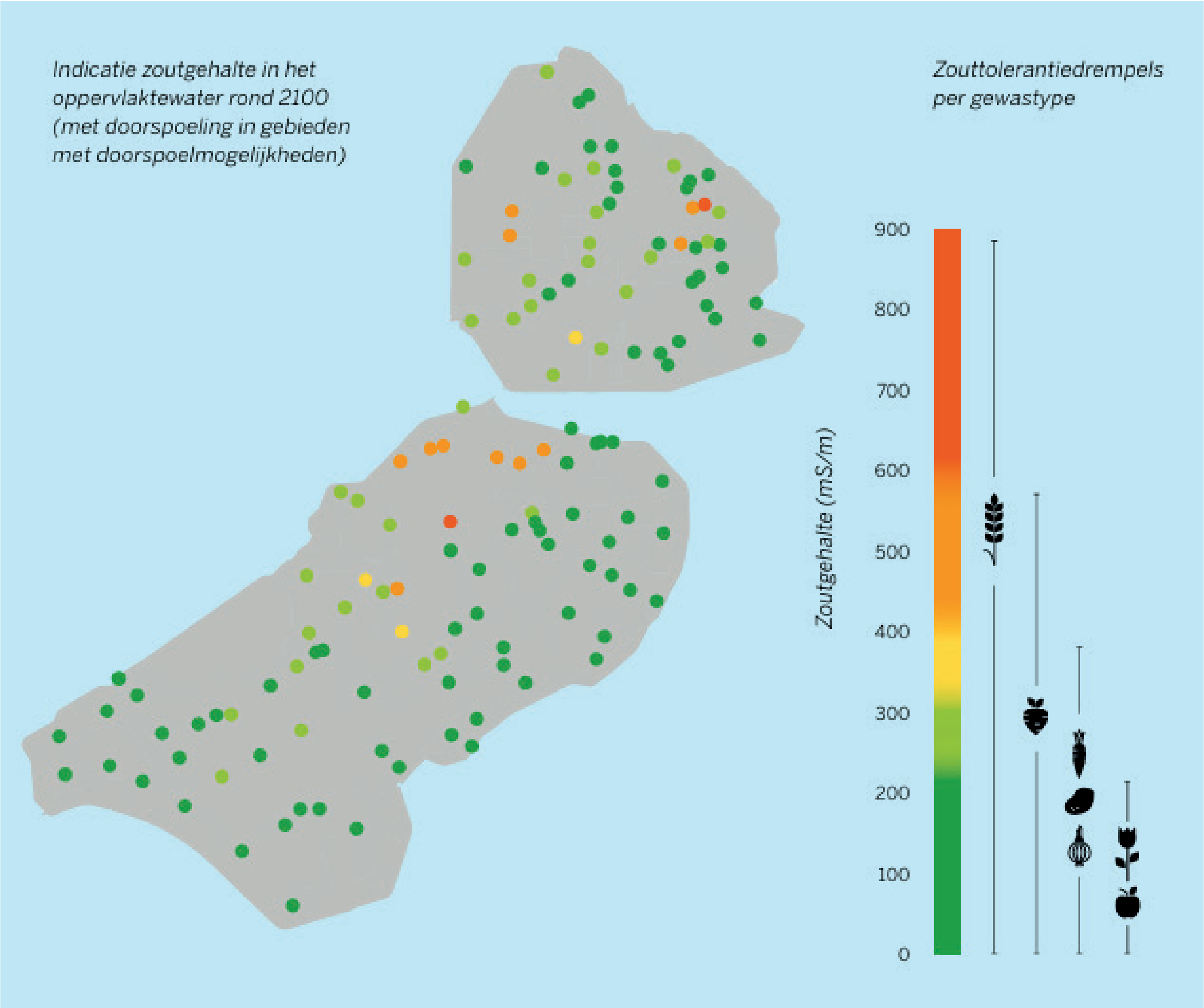


Fig. 37: Salt measures future (Waterschap Zuiderzeeland, 2023b)

Soil subsidence

In the future, the soil will subside more in the clay and peat areas in comparison to sandy soils. The processes of these two differ, but they both cause damage to buildings and agriculture. Soil subsidence occurs when sea or lake floors are no longer submerged, for example, in polder areas. It can be enhanced by lowering groundwater levels. Lowering the groundwater level is important to keep dry feet and is an important factor for the 'traditional' crops, where too wet conditions are threatening agricultural yields. The effects of soil subsidence are sinking roads, dikes and buildings and the risk of water nuisance in low-lying areas. Soil subsidence is an irreversible process (Bronswijk & Evers-Vermeer, 1990). Soil subsidence is the process of the sinking of the surface level due to the soil becoming drier. The process of soil subsidence depends on the soil type and has two different processes.

Clay soil:

Clay minerals are plate-shaped crystals that consist of platelets. Due to this structure, platelets are surrounded by water in a wet state. When the clay becomes drier, the platelets approach each other, leading to soil subsidence. There are three different stages of soil subsidence in clay soil. In the first stage, the normal shrinkage, the volume decrease of clay aggregates is equal to the loss of water volume. The aggregates remain fully saturated. In the second stage, the drying volume of aggregates still shrinks, but the water loss is higher than the volume decrease. This will lead to the entry of air into the pores. The last stage is zero shrinkage; the volume of the aggregates stays constant, and the water loss is equal to the increase of air volume in the clay.

In many cases, soil shrinkage has positive effects as well. The drainage of heavy clay soils improves through the cracking of the clay soil. Also, swelling and shrinkage are a natural process to restore soil compaction and improve the soil structure (Bronswijk & Evers-Vermeer, 1990).

Peat soils:

The drainage and peat cutting in the Netherlands have resulted in a major loss of peat soils. Peatlands covered approximately 40% of the Dutch surface, but this area has now declined to less than 10%. By draining the peatlands, leading to a more optimised oxygen and nutrient availability, it has become possible to use the land for agricultural practices and has allowed the use of heavy machinery. However, to facilitate intensive agriculture, deep drainage is needed, which causes rapid soil subsidence. This causes water level adjustments, which lead to more soil subsidence.

The soil subsidence is caused by three processes: shrinkage, compression and oxidation. Shrinkage is the loss of volume caused by the withdrawal of water from the upper soil layer. Also, the loss of the buoyant force of water in the upper layers leads to the compression of deeper layers. Furthermore, the oxidation of organic matter leads to a major peat loss after drainage. Up to 85% of subsidence could be attributed to oxidation.

Peat areas that are covered by clay have a lower subsidence because oxygen intrusion in the peat soil is limited below the clay layer, and there is less organic material that could decompose. (Brouns, Eikelboom, Jansen. 2015)

Soil subsidence in Flevoland occurs both because of peat and clay. In most locations, peat is beneath the clay, but the thickness of the clay differs strongly in the province. Especially, Schokland and Zeewolde have a lot of problems with soil subsidence as seen in fig. 38.

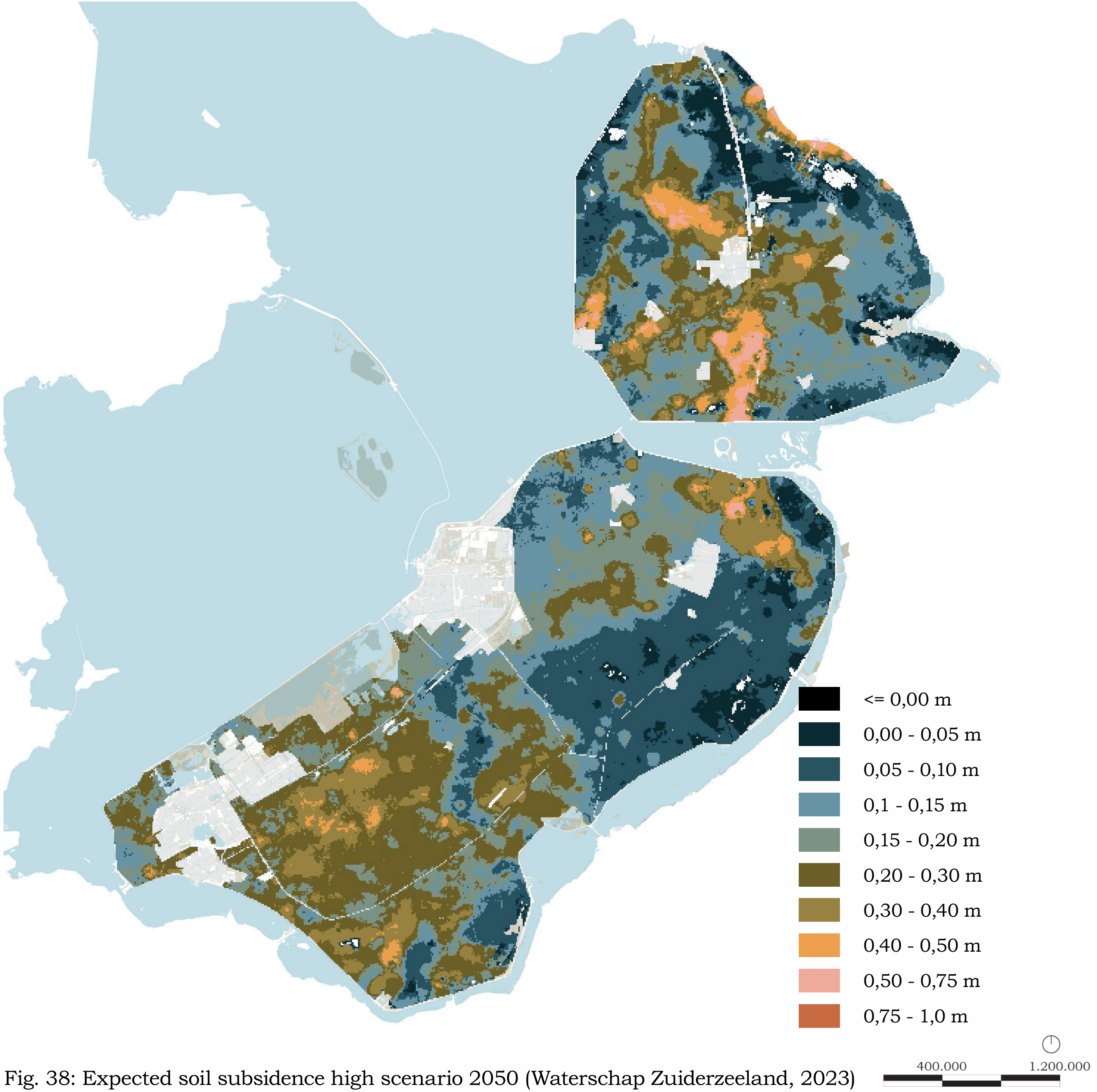


Fig. 38: Expected soil subsidence high scenario 2050 (Waterschap Zuiderzeeland, 2023)

Water safety

Flooding

The Netherlands focuses primarily on multilevel safety (meerlaags veiligheid) for flood protection. This approach combines the reduction of the impact of flooding and crisis management, should hazards occur. This risk approach (meerlaags veiligheid) combines water safety and spatial investments, allowing for the decision to build only on higher locations instead of in more flood-prone areas, thereby reducing flood risks (van den Hurk et al., 2014).

The multilevel safety has low chances of swift adaptation in the Netherlands. Therefore, it is becoming more important that water management should not only focus on the reduction of flood probability but also on building restrictions or flood-proofing houses. Because of all the technical interventions against the water and draining the land, the country and especially Flevoland, has gradually manoeuvred itself into a technical lock-in. Every time the regions subside more, the dikes have been raised and improved in the last decades. The chances of failure of the dikes are in the best case scenario once every 10.000 years and in the worst case scenario once every 1.000 years. In Flevoland, the chances of flooding are low, but the amount of damage to the area is high. Either nothing happens, or everything floods, because there is only one dike system that protects the entire polder. One breaking point in the dike, especially on the IJsselmeer/Markermeer border, could cause a lot of damage.

Figure 39 shows the water depth of a flood in the polder, and it shows that there is an all-or-nothing scenario in Flevoland. Around the border in some places, the water will be lower due to the height differences in the polder. This map is right now for a flooding once every 10.000 years, but it would look the same as a flooding every 1.000 years.

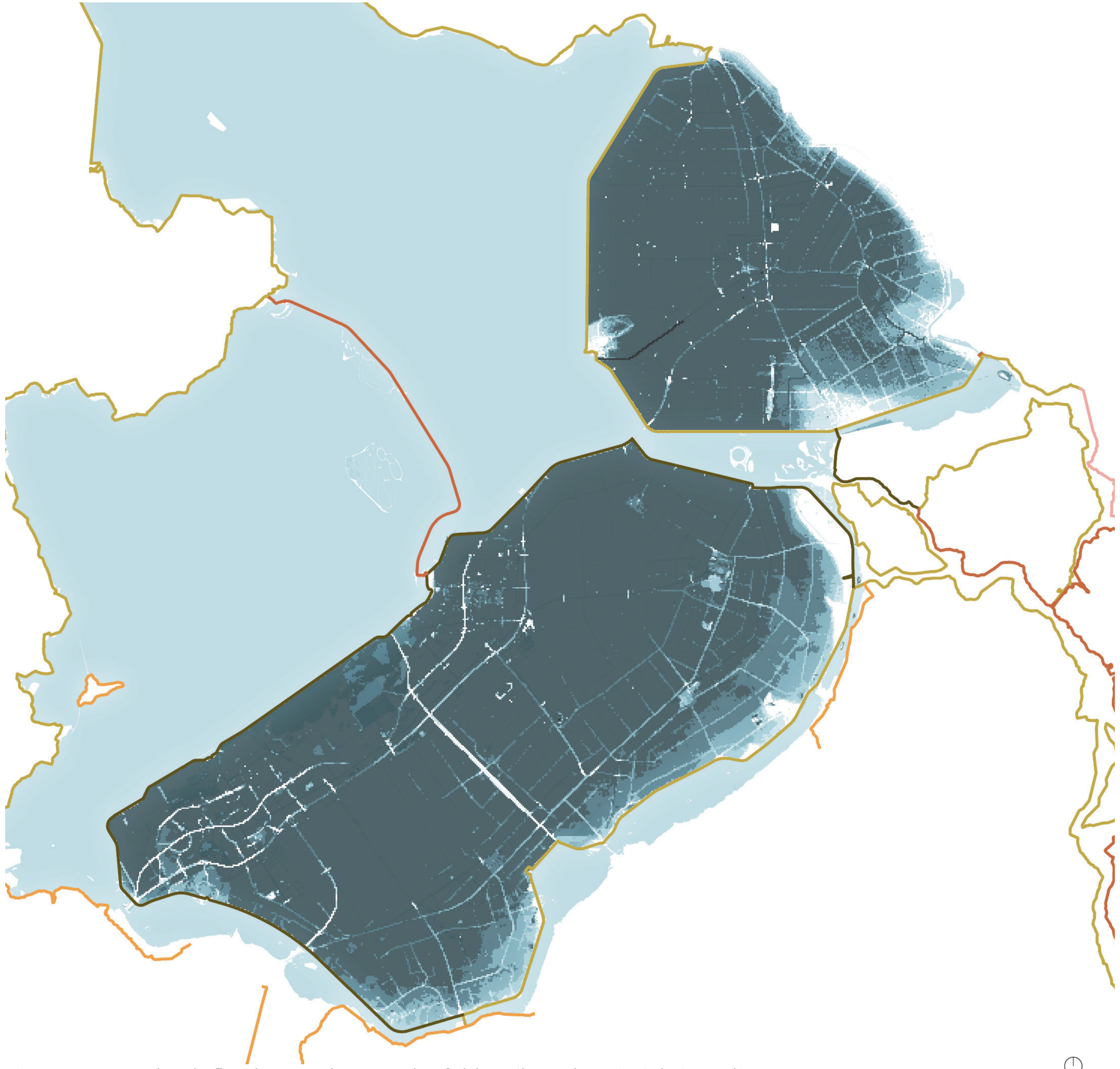


Fig. 39: Water depth flooding and strength of dikes (based on (Stichting Climate Adaptation Services, 2025b)

Combination map of problems

When all water problems are combined, it becomes visible that some overlap while others are right next to each other. For example, drought is in multiple spots combined with soil subsidence. This is logical because drought will dry out clay and peat, which will lead to soil subsidence. If the soil subsides, this could also be the space where there is more water nuisance. This is visible in the northwestern part of the Noordoostpolder.
The flooding map shows the deepest parts of the polder. The western part of the polder is higher, so the water will be lower.

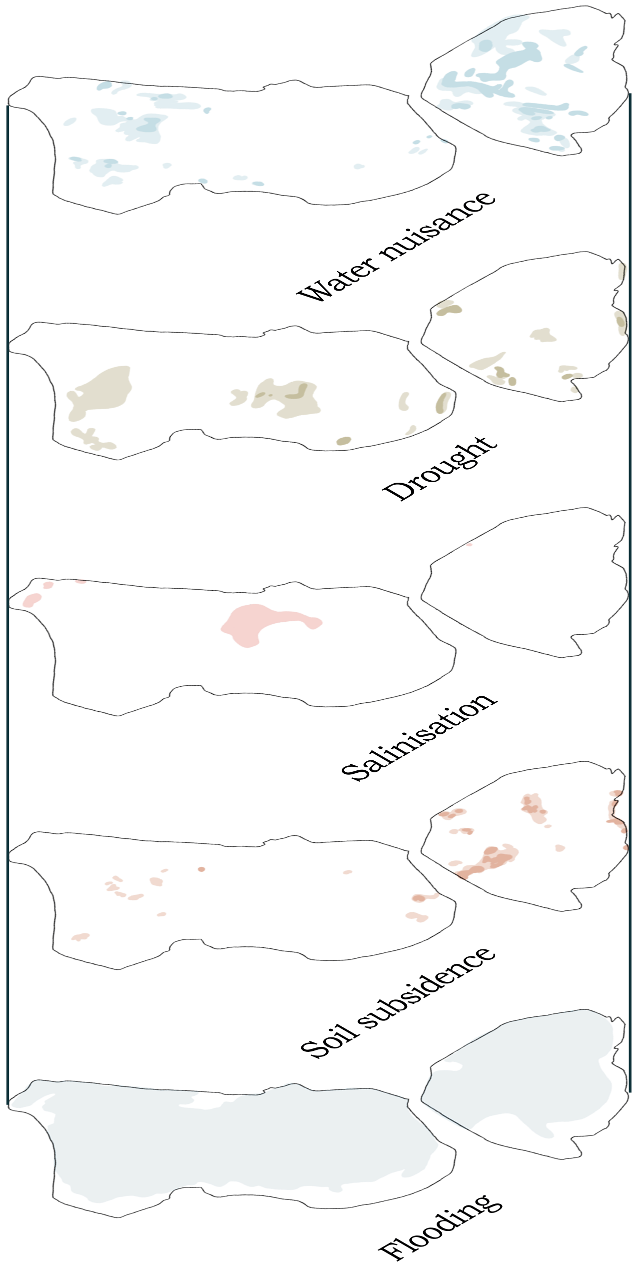


Fig. 40: Conclusion stacked

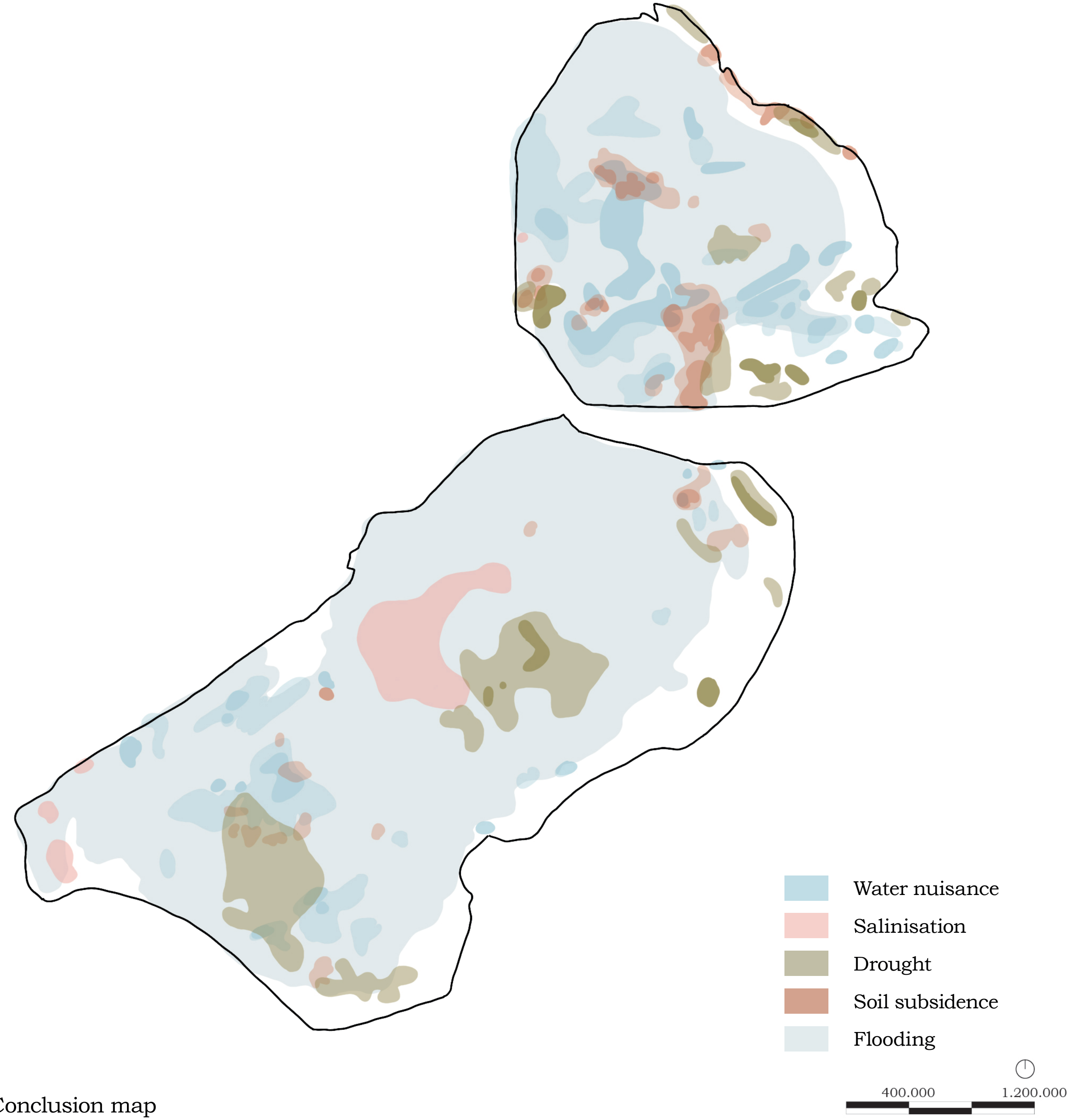


Fig. 41: Conclusion map

Combination map of problems future scenario

In the future scenario, after 2050, the expectation is that the soil will subside even further, and dry areas will expand as well. Because these spots will expand, they will be more often combined with water nuisance as well. This means that there will be more extremes in some areas, making it more difficult to find solutions for both problems. For salinisation, there is no clear expectation of what will happen in the future, which is visualised in fig. 43 with the question mark. The chance of flooding could become higher in the future; however, the water depth will stay around the same height if a flood occurs.

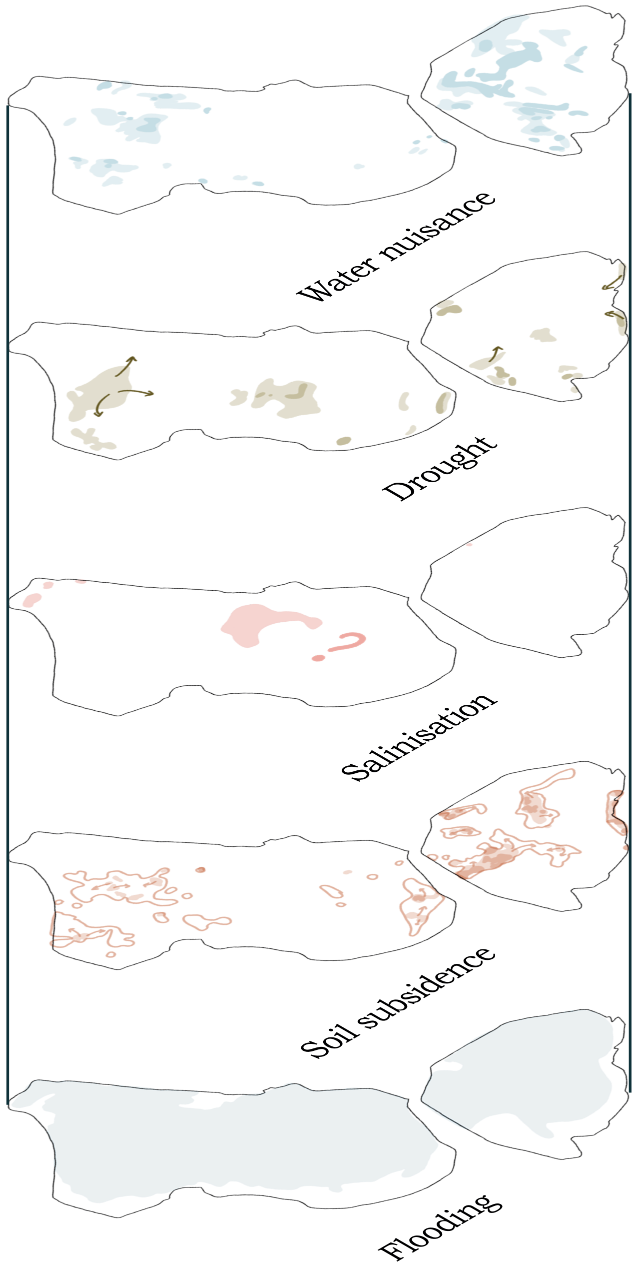


Fig. 42: Conclusion stacked future scenario

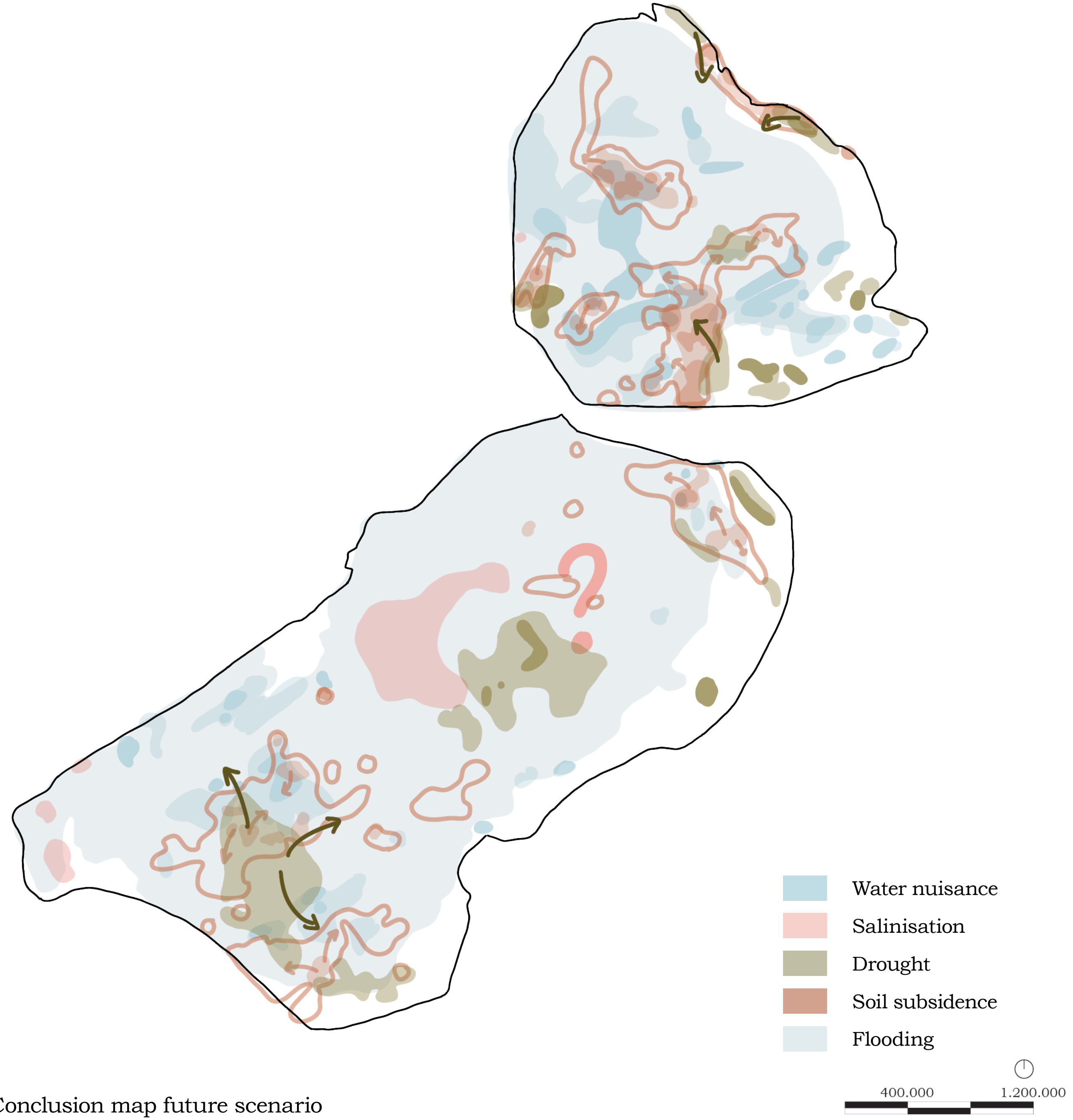


Fig. 43: Conclusion map future scenario

Analysis

Stakeholders

Introduction

The stakeholders are discussed in this chapter. The different interests and power of stakeholders will be visualised in a power-interest matrix and the information of the stakeholders will be later used in the maximisation strategy.

Stakeholder overview

Stakeholder	Problem perception	Overall goal	Resources	Power	Interest
Ministry of Infrastructure and Water	Dike improvement, transportation network such as the Lelylijn, nitrogen pollution	Connectivity, strong dikes, clean air, soil and water	Control, Finance control	High	Low
Ministry of Agriculture, Fisheries, Food Security and Nature	Sustainable agriculture, improved nature connections and nitrogen pollution	Sustainable, sufficient and safe food. Healthy nature in all areas	Control, Finance control	High	Low
Province of Flevoland	Flooding, low water quality, drought, soil subsidence	Pleasant working and living envi-ronment	Expertise, Control funding	High	High
Waterboard Zuiderzeeland	Flooding, water nuisance and drought, soil subsidence, water quality	Safety, enough and clean water	Expertise	High	High
Rijkswaterstaat	Flooding, water nuisance, drought, soil subsidence, water quality	Safety, liveable and accessible environment	Expertise, Funding	High	Middle
Municipality of Almere	Flooding, water nuisance and drought, soil subsidence, water quality	Vital, attractive, green and sustainable city Acceleration of housing constructions (Gemeente Almere, n.d.)	Control	Middle	High
Municipality of Zeewolde	Flooding, water nuisance and drought, soil subsidence, water quality	Inclusive society, preserve the character of the village, transition sustainable housing, shorten the food chains, preserve the openness of the landscape (Gemeente Zeewolde, 2022)	Control	Middle	High
Municipality of Lelystad	Flooding, water nuisance and drought, water quality	Acceleration of the city growth combined with facilities and implementation of the social task. Improving the green network in the city. Tackling the city centre and Lelystad Oost (Gemeente Lelystad, n.d.)	Control	Middle	High
Municipality of Dronten	Flooding, water nuisance and drought, soil subsidence, water quality	Housing development, invest in sustainable energy, improved biodiversity, farmers are important economic carriers, (Gemeente Dronten, 2020)	Control	Middle	High
Municipality of Urk	Flooding, water nuisance and drought, water quality	A diverse and qualitative housing supply, investing in a business environment, (Gemeente Urk, 2022)	Control	Middle	High
Municipality of de Noordoostpolder	Flooding, water nuisance and drought, soil subsidence, water quality	Sustainable housing in a green and climate-adaptive living environment. Growth of businesses (Gemeente Noordoostpolder, n.d.)	Control	Middle	High
Staatsbosbeheer	Low water quality, low biodiversity	A qualitative natural environment where people live healthy and safely	Expertise	Middle	Middle
Landowners	Land that becomes less usable for their function	Liveable land, make profit	Control	Low	High
Farmers	Soil subsidence, drought, water nuisance	Production of agricultural products, making a profit	Expertise	Low	High
Farmel Emmeloord, Vecozuivel and Farmdairy	Nitrogen pollution	The supply of milk and the production of dairy products (Farmel, 2021)	Expertise	Low	High
McCain	High costs from energy consumption	Production of agricultural products and the reduction of CO_2 emissions (Gemeente Lelystad, 2024)	Control	Low	Middle
FlevoLandschap	Low biodiversity, low water quality	Protect, develop, conserve and manage natural areas (5100 ha) and make recreation possible (Het Flevolandschap, n.d.)	Expertise Control	Middle	High

Stakeholder	Problem perception	Overall goal	Resources	Power	Interest
BoerenNatuur Flevoland	Low biodiversity, low water quality	Sustainable agriculture in Flevoland (BoerenNatuur Flevoland, n.d.)	Expertise	Middle	High
Het Blauwe Hart	Climate change, biodiversity loss and spatial pressure on nature (Het Blauwe Hart, n.d.)	Create more dynamic nature, restore natural sites for birds and fish, maintain landscape qualities (Het Blauwe Hart, n.d.-a)	Expertise	Middle	High
Mooi Flevoland	Biodiversity loss and spatial pressure on nature	Show the possibilities and qualities of the nature of Flevoland (MooiFlevoland, n.d.)	Expertise	Middle	Low
Natuurmomenten	Climate change, nitrogen pollution, water quality	More nature in the Netherlands, Restoration of nature, robust ecosystem	Expertise, Control	Middle	Middle
Aeres Hogeschool	Soil subsidence, drought, water nuisance, nitrogen pollution	Research and production of agricultural products (Aeres Farms, n.d.)	Expertise	Low	Middle
Wageningen University and Research	Climate change-related topics	Research topics related to food production, nature and healthy environments	Expertise	Middle	Low
Residents	Water nuisance, water shortage	Liveable and safe cities/ neighbourhoods		Low	Middle
Recreationists	Changes causing problems for recreational activities	Safe and high-quality recreation		Low	Middle

Public

Private

Civic

Explanation

Stakeholders are an important factor for the implementation of nature-based solutions. Without the participation of stakeholders, the implementation and realisation of a resilient space will become more difficult. The stakeholders are categorised into three categories: public, private and civic.

The public stakeholders are government-related parties such as municipalities, the province of Flevoland, waterboard Zuiderzeeland and multiple ministries. These stakeholders have the most power through policies, funding and expertise. For instance, waterboard Zuiderzeeland has a lot of expertise about the water system of Flevoland.

The ministries provide policies for the Netherlands, but don't make decisions specifically for Flevoland. However, the Ministry of Infrastructure and Water is connected to the improvement of the dikes and focuses on the design of the Lelylijn as well. Because the ministries are not directly linked to the implementation of nature-based solutions, they have low interest but have high power.

The province focuses more on the liveability of Flevoland and the preservation of agricultural activities. To reach this goal, an improved water system is necessary. Furthermore, the province has an important factor in decision-making and vision-making. Therefore, they have high power and a high interest.

The municipalities have control over the decision-making on a smaller scale. Therefore, they still have a lot of power, but have less power than the province. The province could make decisions against the wishes of the municipalities. The interest of the municipalities will be slightly less because certain interventions will not be realised in some municipalities. Therefore, they are not affected by these changes.

Agricultural parties:
The largest area of the province is used for agricultural land. Therefore, they are an important stakeholder with low power. Because of the amount of agricultural land (Flevoland being the largest agricultural province of the Netherlands), the farmers are well represented on the board of the waterboard Zuiderzeeland and Province Flevoland. The BBB (BoerenBurgerBeweging) has 10 of the 41 state seats on the board of the Province (Omroep Flevoland, 2023) and has 6 of the 25 seats at the Waterboard Zuiderzeeland (Waterschap Zuiderzeeland, n.d.). This means that indirectly, the interests of the farmer are included in the decision-making regarding the future of the province.

Related to the farmers are companies such as McCain, Farmel Emmeloord and Vecozuivel. These companies all work together with farmers for agriculture-related products, and are large companies that transport to the rest of the Netherlands as well. Therefore, these companies could have more power than farmers.

Another party that is related to the agricultural sector is the BoerenNatuurFlevoland. This is an institute that focuses on sustainable agriculture and the integration of nature and agriculture. Therefore, they have a high interest in the changes in the polder, with a slightly more positive attitude than other farmers.

Nature-related stakeholders:
Staatsbosbeheer is an important national stakeholder that maintains multiple natural areas in the province. Staatsbosbeheer is a public stakeholder and focuses on a healthy living environment and biodiversity. They have power through expertise, have middle power and high interest. FlevoLandschap has a large nature area as well (5100 ha). Therefore, the power and interest will be similar to Staatsbosbeheer.

Other nature parties, such as Natuurmonumenten and Het Blauwe Hart, focus on the development and improvement of natural areas.

MooiFlevoland focuses more on showing possibilities and qualities of the natural sites to other parties, such as residents and recreationists.
Residents and recreationists:

Because the research mainly focuses on the agricultural landscape, the residents will have a lower interest in future projects with nature-based solutions. Their power is lower as well because they could often only speak through participation.

Universities:
Aeres Hogeschool will have a high interest in nature-based solutions and has a lot of expertise related to agriculture. The high interest of the school is because it owns a farm as well. Therefore, new policies and nature-based solutions will affect them similarly to farmers.

Wageningen University Research has a lot of power through knowledge. The university does a lot of research on subjects like nature-based solutions, agriculture and a sustainable landscape. Therefore, it is an important stakeholder to consider when there is more research needed for the transformation of the already existing agriculture.

U1	Ministry of Infrastructure and Water
U2	Ministry of Agriculture, Fisheries, Food Security and Nature
U3	Rijkswaterstaat
U4	Province of Flevoland
U5	Waterboard Zuiderzeeland
U6	Municipalities
U7	Staatsbosbeheer
R1	Landowners
R2	Farmers
R3	Farmel Emmeloord, Vecozuivel, Farmdairy, McCain
C1	Citizens
C2	Nature and environmental organisations
C3	Knowledge institutes
C4	Citizens
C5	Nature and environmental organisations
C6	Knowledge institutes
C7	Nature and environmental organisations
C8	Knowledge institutes

Power interest matrix

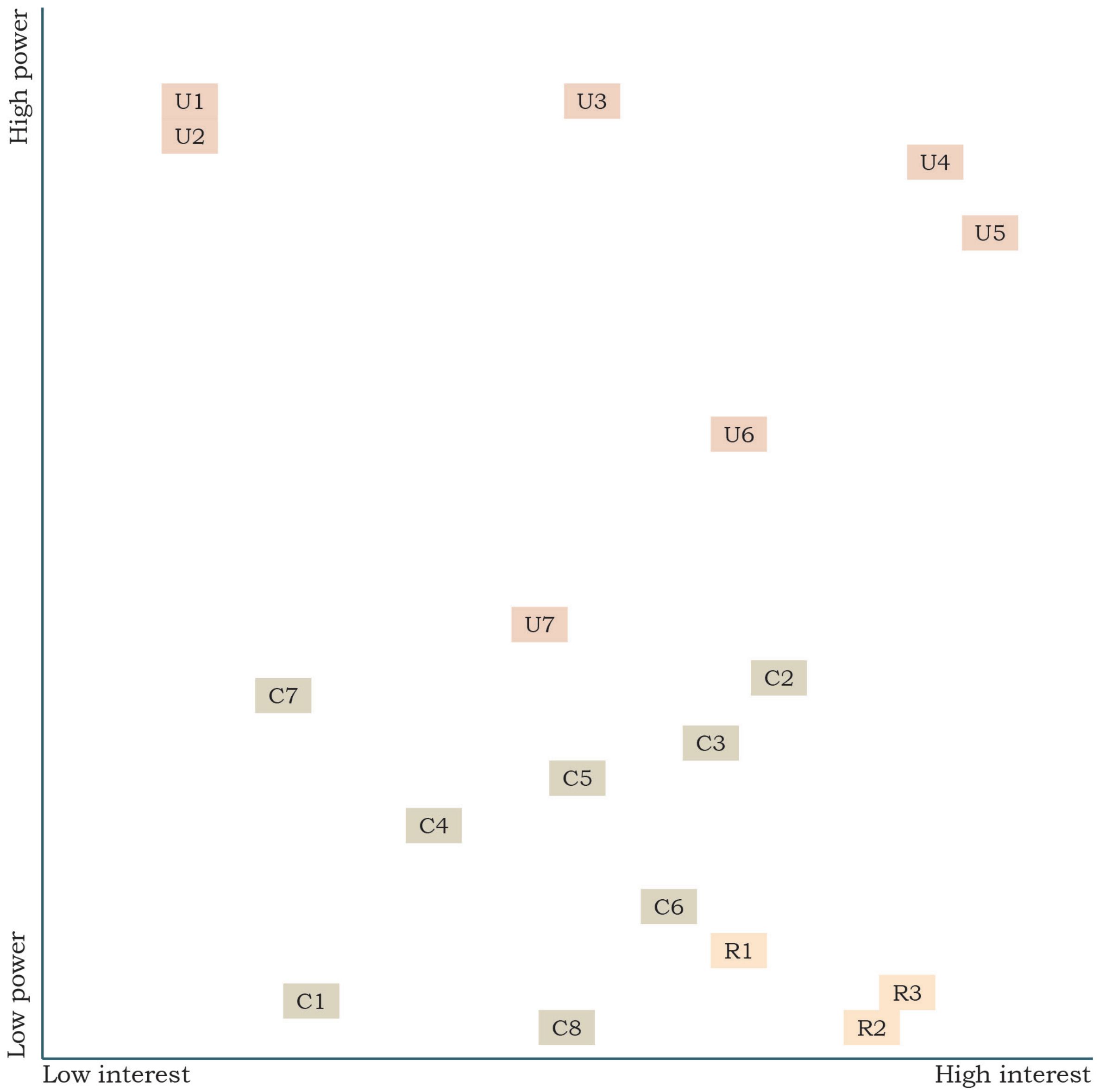


Fig. 44: Power interest matrix

Analysis

Conclusion

Current perspective
Future perspective

Current perspective

Right now, there is already pressure on agriculture due to soil subsidence, water nuisance and drought. These problems are partially connected to climate change, but also depend on the groundwater level. For farmers, it is important to keep the groundwater level lower, but this results in more soil subsidence and could cause more drought stress in warmer periods.
Nature and the urban areas are less affected by these problems.
Furthermore, the Noordoostpolder is more affected by the different problems in the polder. This is because of the old kreekruggen that went through the area. The problems overlap especially around Schokland, except for salinisation.

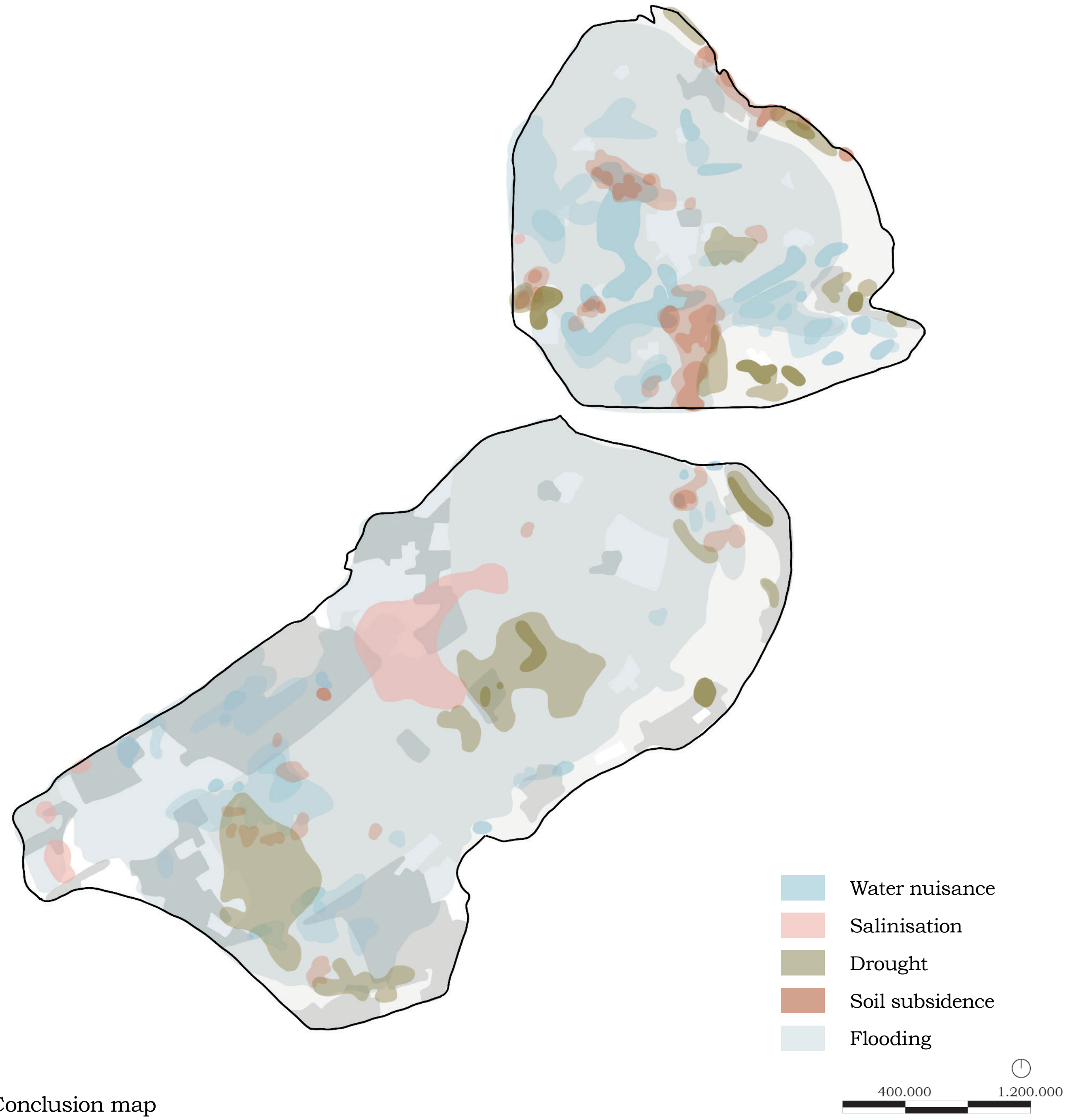


Fig. 45: Conclusion map

Future perspective

The future scenario shows that the urban areas will grow, as well as the natural areas. This will impact farmers and will lead to less agricultural land in the province. Furthermore, it will put additional pressure on agricultural land, alongside the pressure from various water problems. These water problems will expand as well throughout the region.

The soil subsidence will expand as well and could cause problems for urban development.
Schokland will become even drier through time. This could mean that these lands are no longer suitable for agriculture but need a new land use in the future.

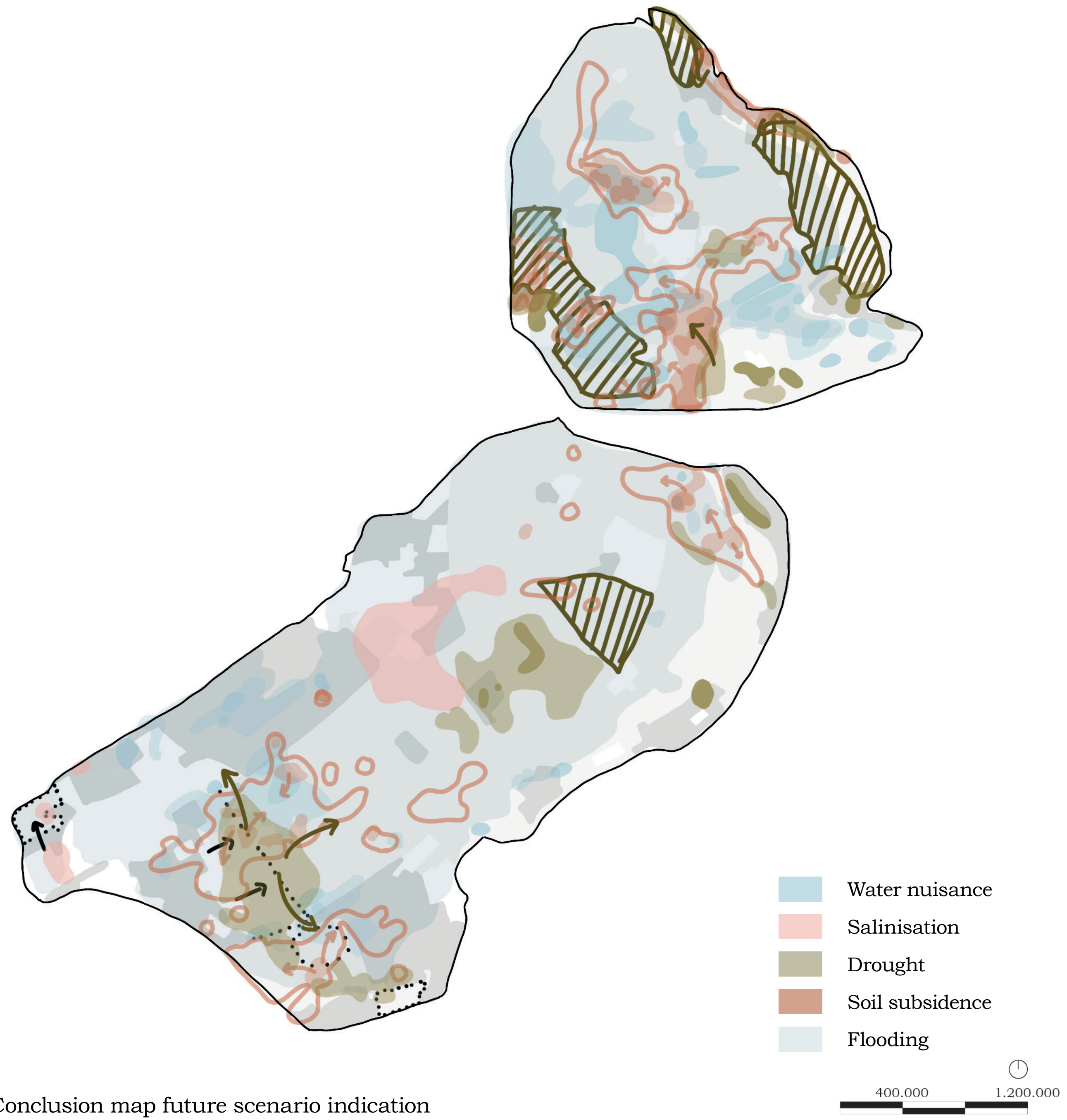


Fig. 46: Conclusion map future scenario indication

Design and strategy

Pattern language

Pattern list
Pattern fields

Intro

The pattern language is used for the research of nature-based solutions for the different water problems in Flevoland. Each nature-based solution could be used in and outside Flevoland. The NbS are solutions for flooding, drought, water nuisance, salinisation and soil subsidence. The last patterns are policies that are connected to the nature-based solutions.
Together, the pattern book answers the sub-question: Which nature-based solutions could be used for which specific water problem?

4.2 *Patterns language*

Scale
The scale of the patterns is visible through the circles. The scale goes from neighbourhood scale towards national scale. If a pattern is possible on multiple scales, there will be multiple circles coloured.

neighbourhood --> National

Related to
Sometimes the patterns are related to different subjects. The colour of the main subject shows which topics the patterns are connected to. For instance, the circle on the right shows that it is connected with salinisation.

Related to

Specific location
The specific location is used to see instantly if a pattern in a certain area is possible. The practical implementation will explain more in-depth about the requirements.

Related to patterns
Some patterns are related to other patterns. The letter and colour show the subject related to the pattern, and the number shows which specific pattern it is related to.

Related to patterns

Number of pattern
Each pattern has a specific number and colour/letter. The letter and colour show the main subject of the pattern, for instance, water nuisance. The number is used as a reference to the specific pattern. This is helpful to see the relations of patterns.

Example water nuisance

Hypothesis
The hypothesis explains in one sentence the goal of the pattern.

Theoretical background
The theoretical background explains why a pattern is needed and what the background is for the pattern.

Practical implementation
The practical implementation explains how a pattern fits in the environment. Some interventions/patterns can be implemented in many different locations, like blue-green networks. Others are more specific and cannot be implemented everywhere.

Pattern field

The pattern field (fig. 47) shows at what scales the different patterns are applicable and how technical each solution is. The pattern field shows that most patterns are applicable on multiple scales. However, due to certain types of interventions, most patterns fit the small scale the best. For instance, there are numerous solutions similar to creating wetlands and designing parks. These patterns are all on the smaller scale and related to each other. The patterns that are the most technical are dike restoration and aquifer storage.

A1 Living shorelines
A2 Restoration and improvement dynamic nature of the dunes
A3 Restoration salt marshes
A4 Dike restoration

B1Blue-green network improvement
B2 Water storage for heavy rainfall
B3 Water retention basin
B4 Crops resistant for water nuisance
B5 Stormwater parks
B6 Sponge city concept
B7 Room for the river

C1 Circular and nature-friendly agriculture
C2 Rewetting the clay-peat lands
C3 Subsidence-proof urban design

D1 Creating more freshwater storage
D2 Wetland restoration and creation
D3 Drought resistant plants and crops
D4 Rainwater harvesting system
D5 Aquifer storage

E1 Freshwater buffer zone
E2 Salt tolerant crops

P1 Water level fluctuations
P2 Multilayer safety
P3 Reduction of soil-sealing
P4 Transition fund
P5 Smart water management

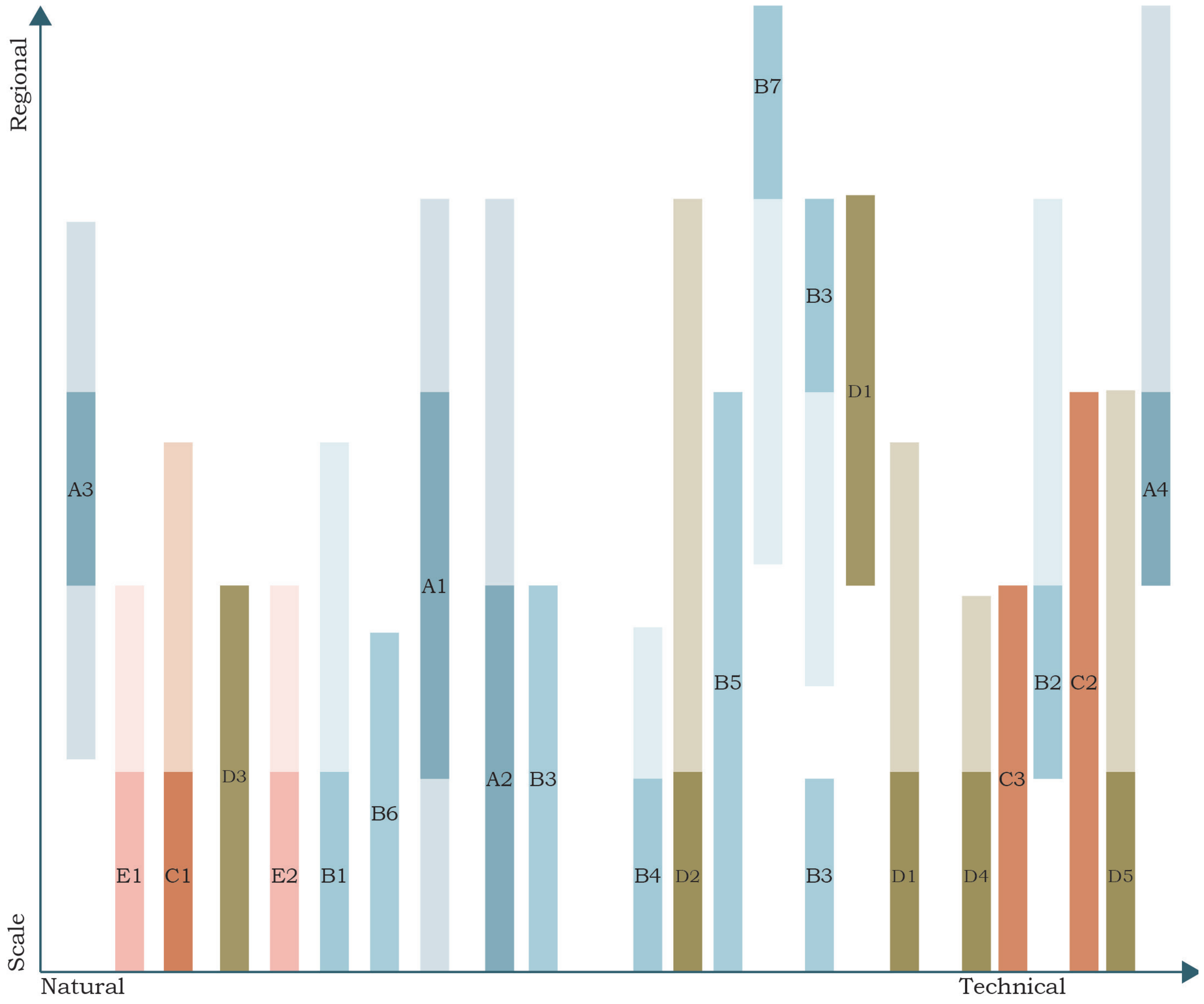


Fig. 47: Pattern field

Design and strategy

Implementation

Introduction

The maximisation strategy is based on the different water problems from the analysis chapter and shows the implementation of nature-based solutions. The maximisation strategy is made on two scales: the first is the entire province, and the other is zoomed in on a part of the province: a part of the northern rural area of Zeewolde. This location is underneath the Oostvaardersplassen and right next to the border of Almere.
What will the future of Flevoland look like in 2050 after the implementation of nature-based solutions for water problems?

5.1.1 Water nuisance

Water nuisance is especially prevalent on agricultural lands. Therefore, farmers should consider changing their agricultural practices.

Furthermore, the province needs to implement strategies and design places to deal with heavy rainfall. Heavy rainfall will cause more problems in the future because the rain could become more or more often. Therefore, more water storage locations could help with the catchment of the rain.

There are already two stormwater parks (fig. 48) designed in the low and high peilvakken in the Flevopolder. However, it becomes more important that the Noordoostpolder also becomes more resilient against water nuisance.

For urban areas, this translates to more design with sponge city concepts and in rural areas, the interventions should focus more on the water catchment. For farmers, it becomes necessary to research crops that are more floodproof.

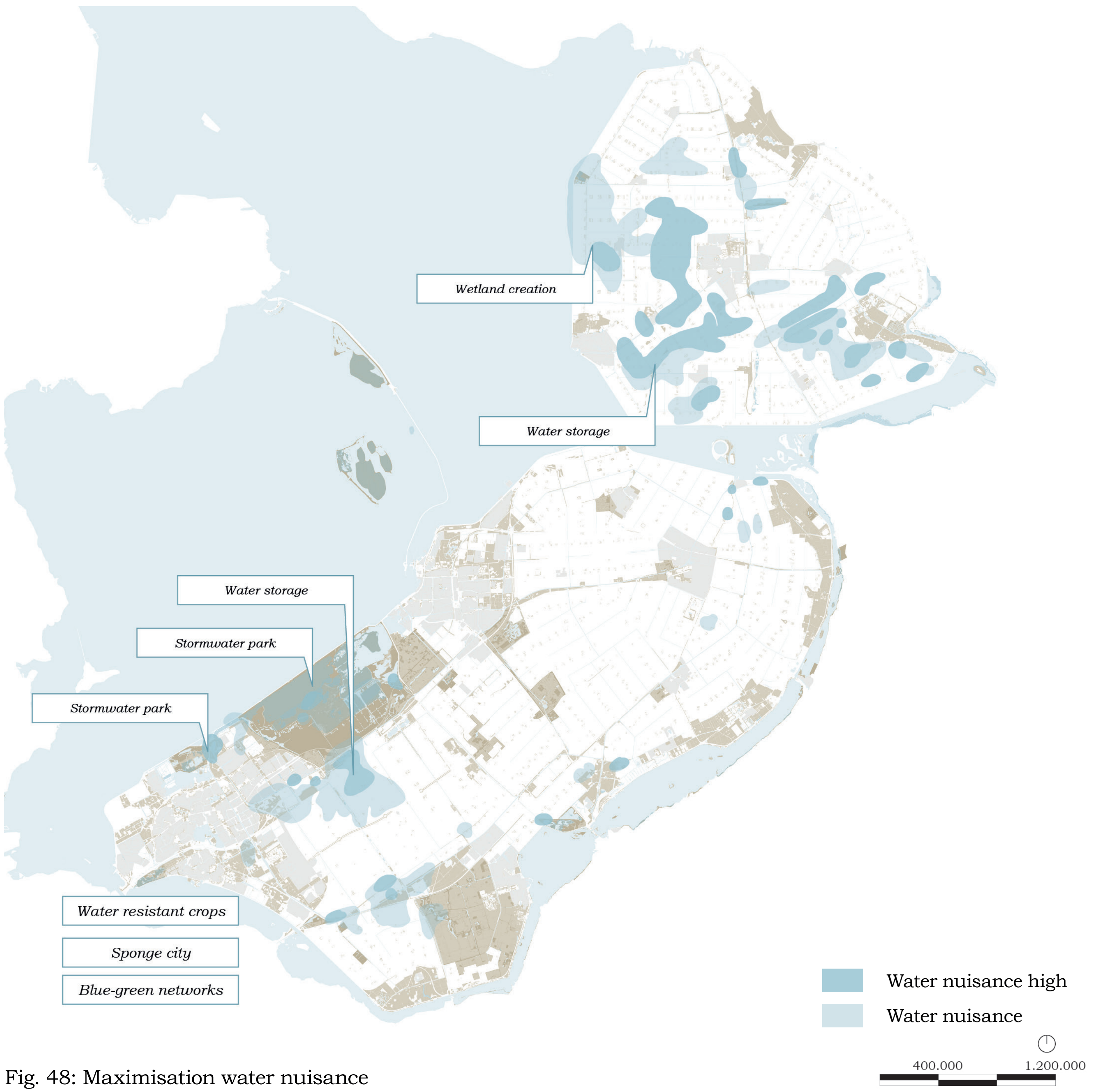


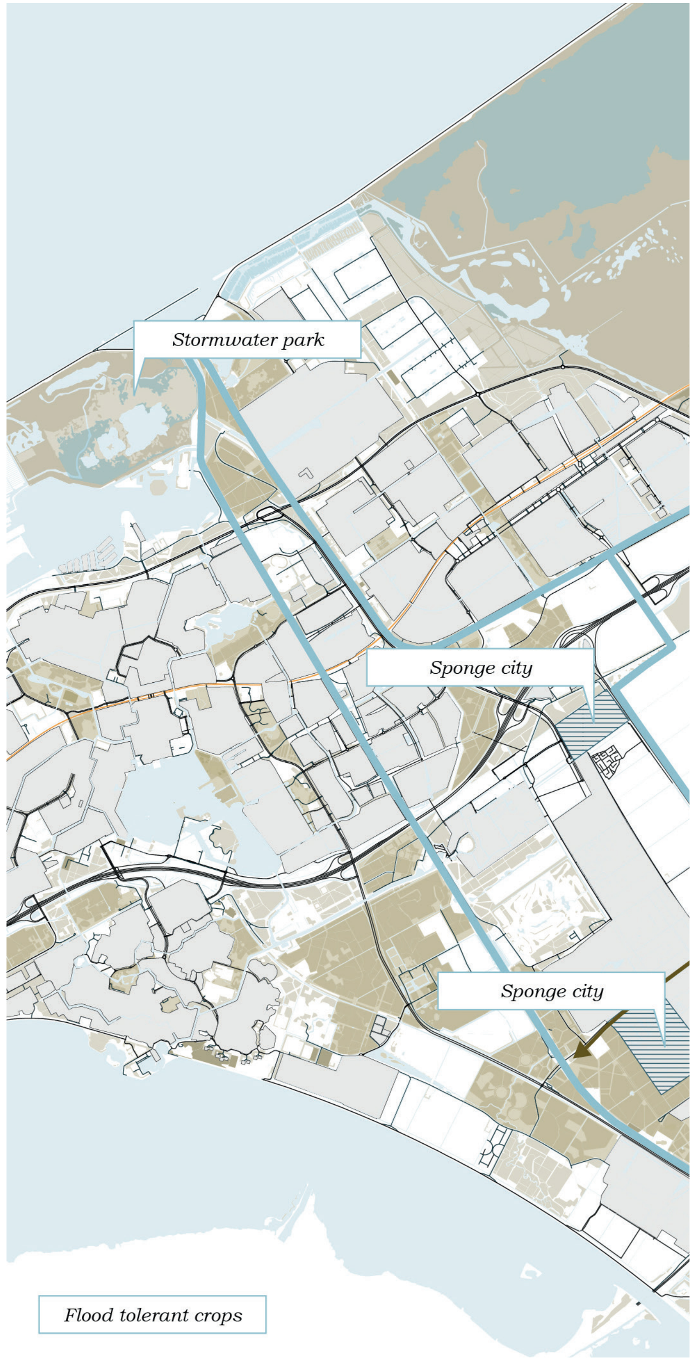
Fig. 48: Maximisation water nuisance

To reduce the water nuisance in rural areas, it is necessary to improve the blue-green network. This design intervention creates more water storage. Additionally, it is possible to add new water storage for each peilvak. The water storage needed for the low peilvak (fig. 49) in the Flevopolder is 300 hectares, and the depth of this water storage unit is one meter deep.

For the urban areas, it becomes more necessary to invest in the sponge city method, so that there will be less water nuisance on the streets.

The already existing parks could be used as stormwater parks. The Oostvaardersplassen and the Noorderplassen already have this function and could help solve water nuisance when the Blocq van Kuffeler cannot pump the water out fast enough.

Stakeholders:
To realise the water storage, farmers need to rethink their practices, and it could be possible that they need to sell their parcels, because there is a chance that the farm is not profitable anymore. By selling the parcels, the land becomes available to realise nature-based solutions such as water storage.
The municipality and province need to make a clear vision for the design of the sponge city methods, and they should take into consideration the different priorities of farmers and natural sites. The waterboard should visualise the limitations and possibilities of the water system in the region. The blue-green networks could be realised by the province as part of the forest strategy, and after the realisation, Staatsbosbeheer is an important stakeholder in the management of these areas.



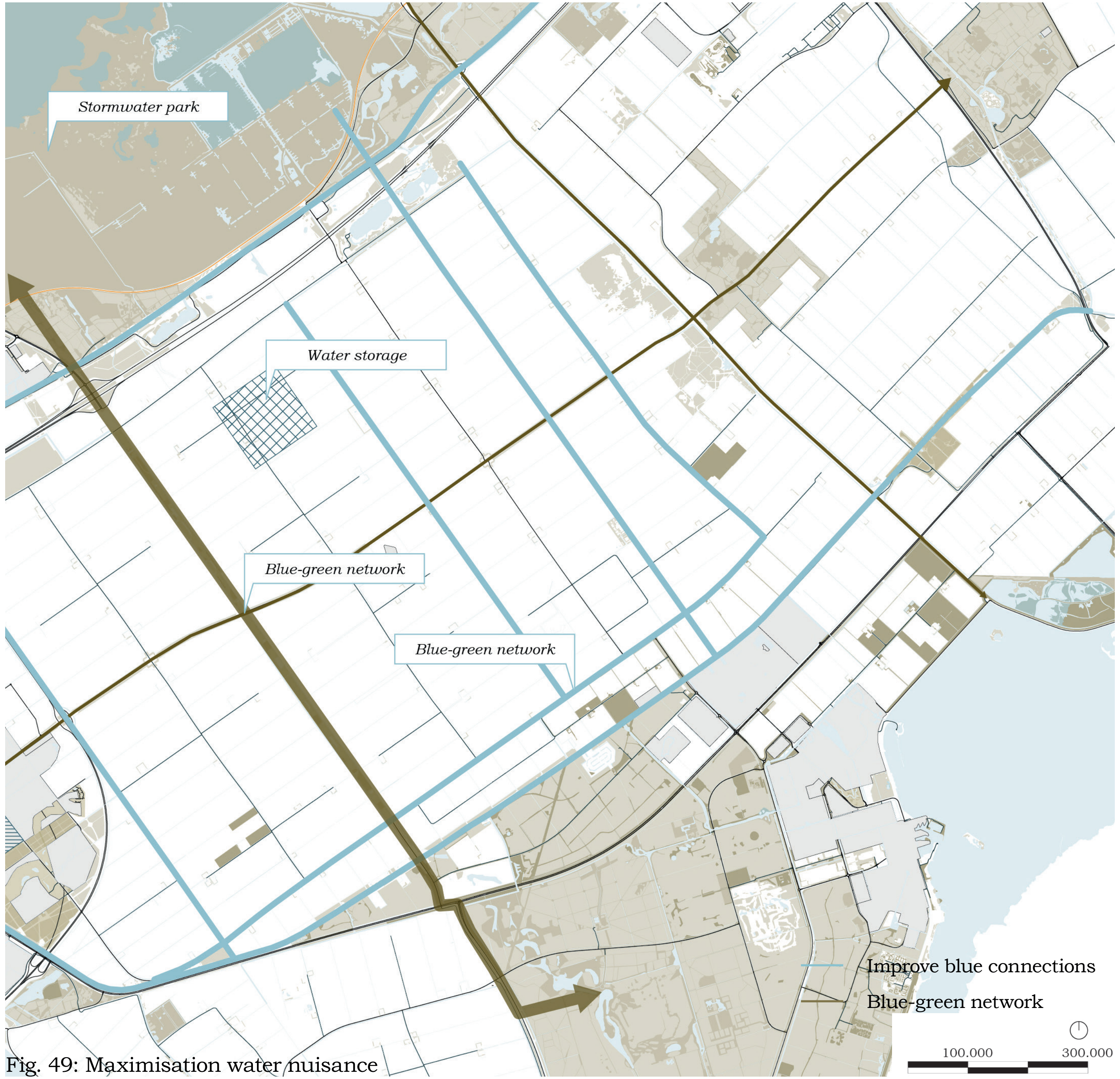


Fig. 49: Maximisation water nuisance

5.1.2 Drought

To improve the resilience of Flevoland against drought, both solutions for the consequences of drought and measures against drought are necessary. This means that solutions such as aquifer storage and recovery and rainwater harvesting systems in urban areas are becoming more important. Rainwater harvesting systems are especially important in areas where drought is already causing problems for urban areas, such as in Urk.

Furthermore, some parts of the natural areas are also dealing with drought. A good example of improving drought is to create freshwater storage in these areas or to create wetlands. A wetland could become dry in summer, but stores more water in wet periods. The water that is stored in wet periods could be used in dry periods, leading to less drought stress.

Drought is not only a problem for urban areas and nature, but also has large effects on agriculture as well, as visible in figure 50 . Therefore, farmers should invest in research for drought-resistant crops. Drought-resistant crops will have less damage to their root system and leaves than other crops; therefore, the chances of a good yield are higher for a farmer.

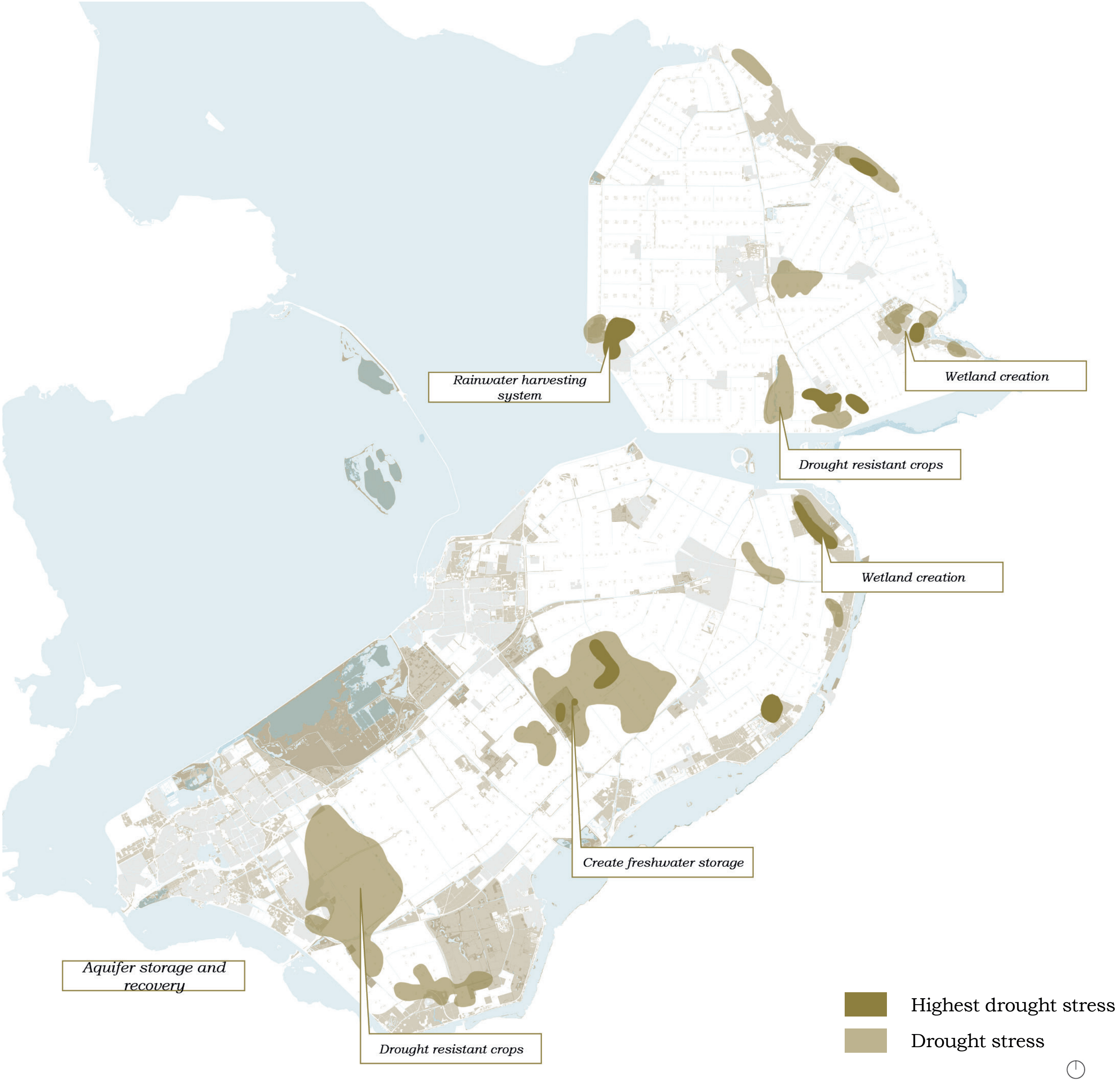
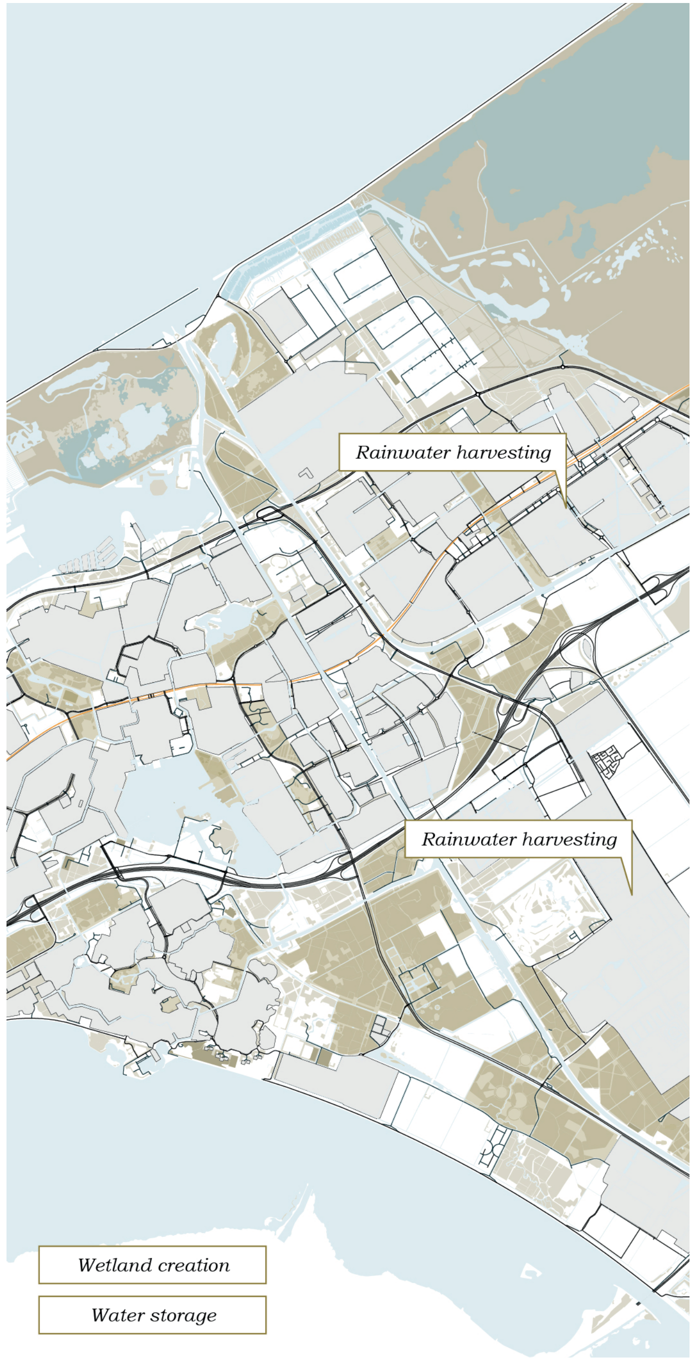


Fig. 50: Maximisation drought

Right now, the urban areas are not affected by drought, but it could become important to invest in rainwater harvesting systems. Therefore, the urban areas will be ready when drought happens more often and more extreme in the future.

Stakeholders:
The wetland restoration is a project that could be designed in either already existing natural areas, but it could also be designed in agricultural land. Therefore, the municipalities and the province should decide with the waterboard what the best location is for the creation of this nature-based solution. Depending on the location, Staatsbosbeheer and farmers should be involved in the process of future developments. Aside from biodiversity and drought, recreationists could also be considered because new nature/wetlands could give more space for recreation.

The higher water level is a policy that needs to be applied on a larger scale; therefore, the waterboard Zuiderzeeland will research the possibilities and give advice on the best implementation methods. The province will then implement this solution for the region.



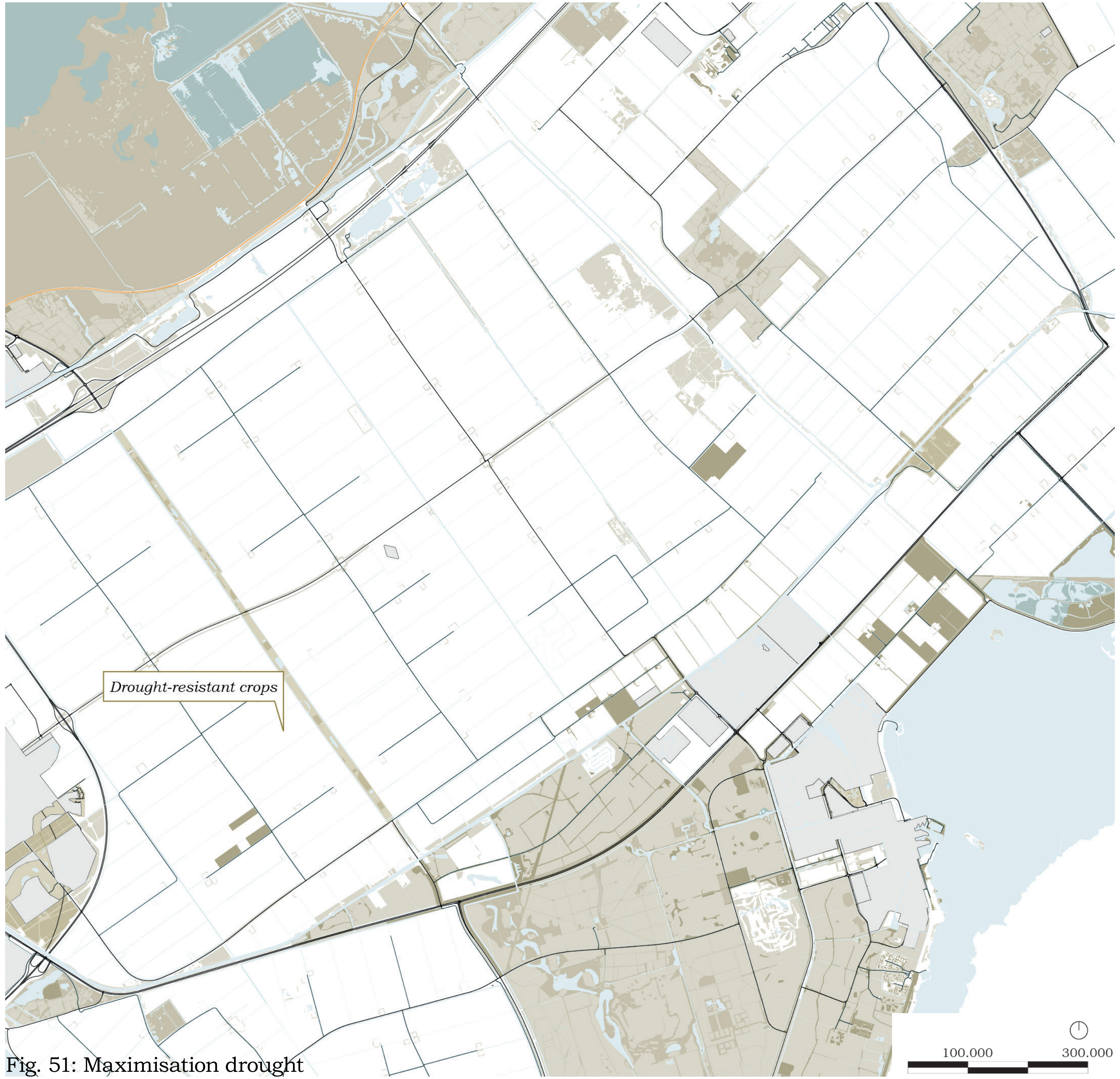


Fig. 51: Maximisation drought

5.1.3 Salinisation

The expectation is that salt will not cause large problems in the future if the washout of salt is still possible. Right now, the salinisation levels are only higher in a small part of Almere and around Lelystad (fig. 52). Therefore, the focus for nature-based solutions should be on these locations. The patch around Lelystad is next to the Lage Vaart, and this water should be used for a freshwater buffer zone. This creates a larger area for clean water and puts more pressure on the soil. Therefore, there is a higher chance that the salt water will stay in the lower layers of the soil.

In Almere, the area with salinisation is used for agricultural practices. The farmers in this region should focus on salt-tolerant crops to maintain their crop yields. This also needs to be applied in the area above Urk, even though this is on a much smaller scale.

Lastly, it is possible to use aquifer storage and recovery to provide more freshwater if necessary. This water storage could be used in times when there is drought, and in these moments, salinisation becomes a larger problem. Therefore, the freshwater from the aquifer storage could either be used for watering the crops or for the washout of salt.

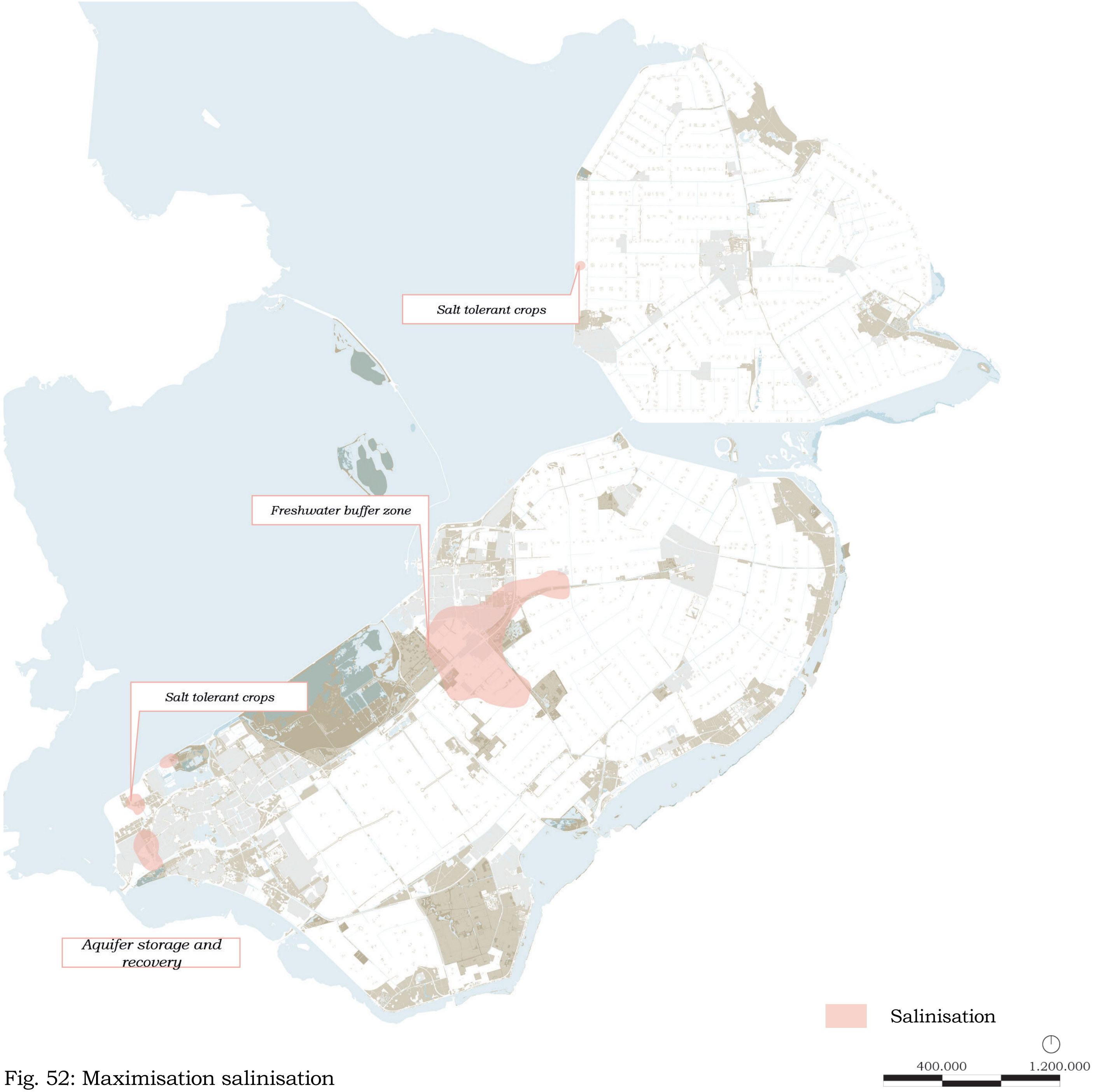
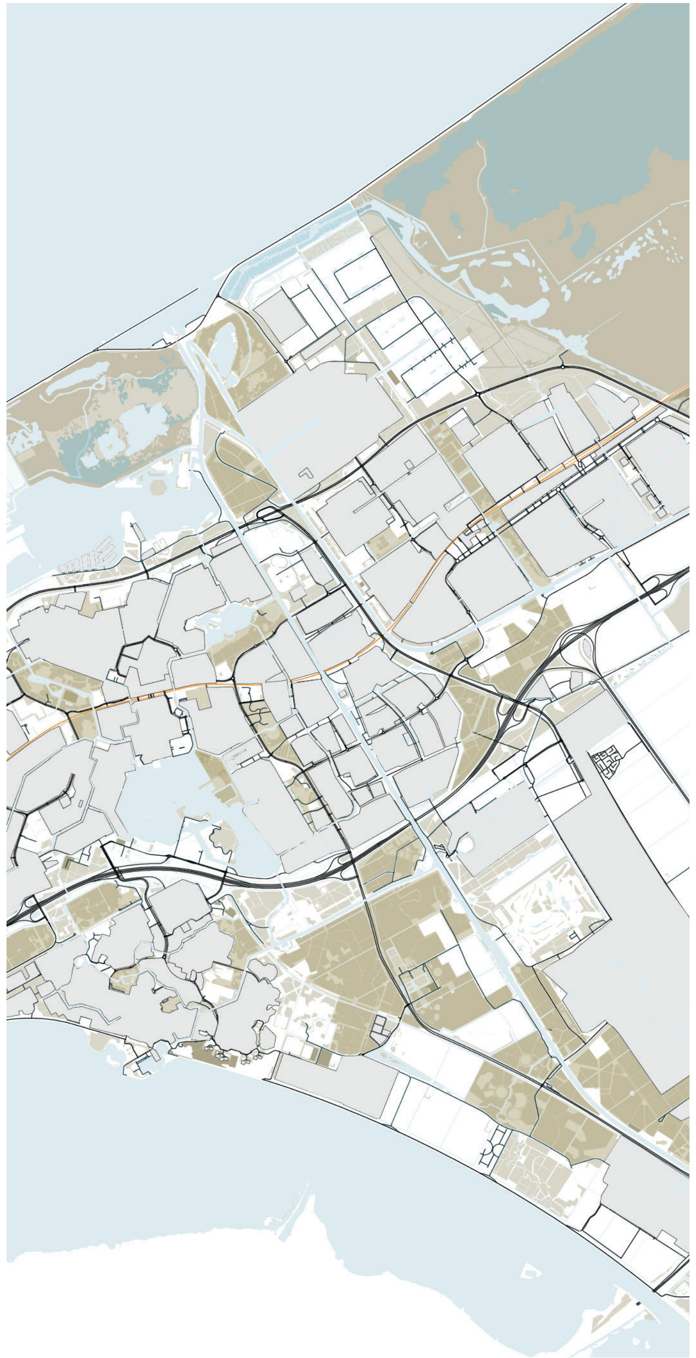


Fig. 52: Maximisation salinisation

Zoomed in on Zeewolde and Almere, there is not much salinisation that could cause problems for the agriculture sector, nature and the urban environment. There is one spot where there is some salinisation, so there the focus should be on salt-tolerant nature and crops to realise a more resilient environment.

Stakeholders:
Farmers are mostly affected by salinisation. Therefore, it becomes important that they already try to deal with it in such a way that they will not be affected further in the future. This could be realised by using salt-tolerant crops or by not using the ditches anymore for sprinkling crops. The province could help regulate the shift towards salt-tolerant crops.



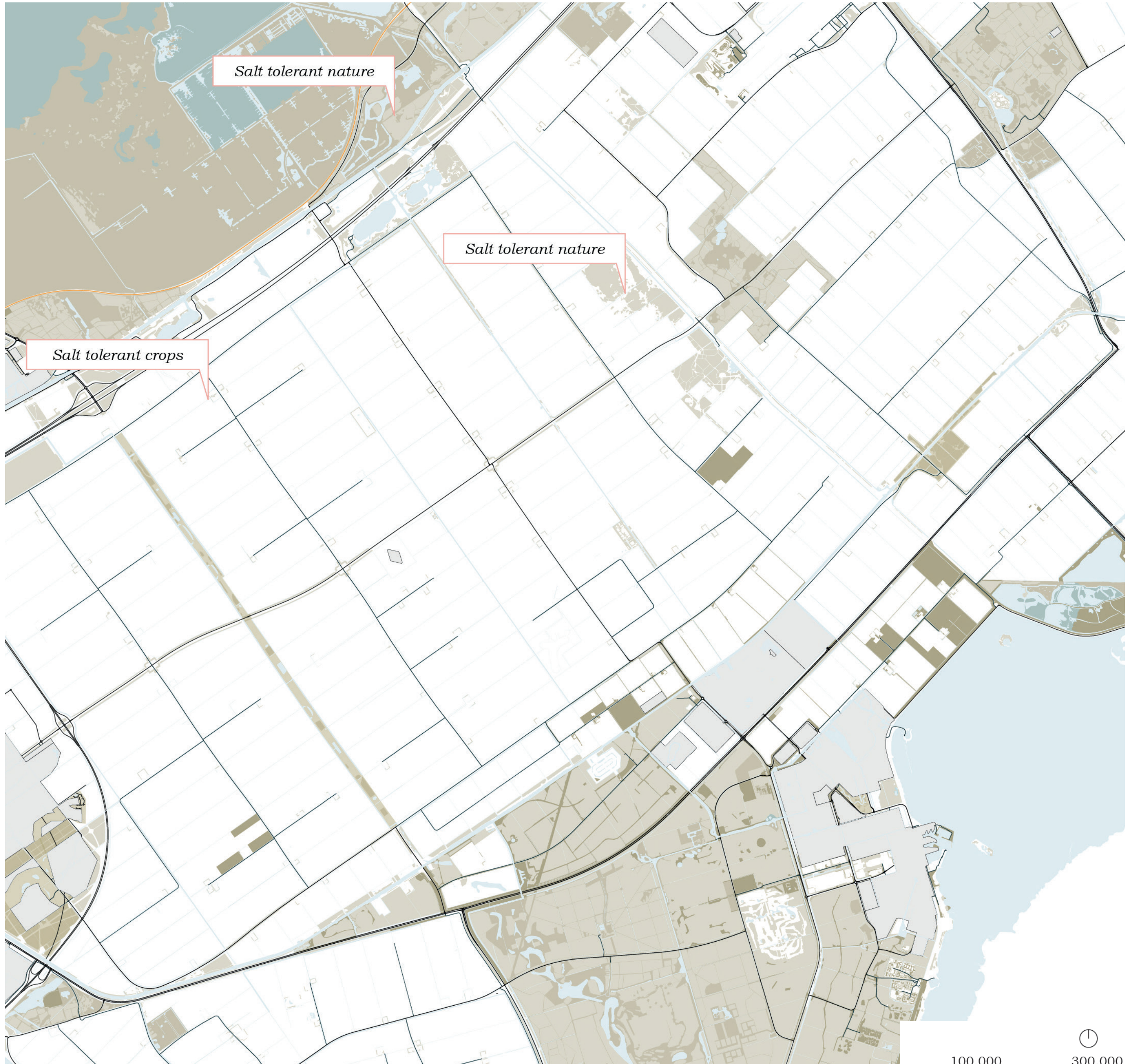


Fig. 53: Maximisation salinisation

5.1.4 Soil subsidence

Soil subsidence, as seen in the analysis chapter, is happening in a lot of places in Flevoland. Therefore, urban and rural areas should be designed with the idea that the soil will subside. For urban areas, municipalities must work on subsidence-proof neighbourhoods and cities. This will help reduce the damage to buildings and public spaces. In rural areas, the farmers experience the most problems with soil subsidence. One way to deal with this is to farm in a more sustainable way to improve the quality of the soil. If the soil is healthy and wetter, it will subside less, therefore it will cause fewer problems for farmers.

It is possible to build in areas with soil subsidence. However, the advice is not to build in areas with the most soil subsidence, because this is not sustainable. The locations where not to build are the darkest orange spots in fig. 54, such as Urk and Schokland.

For Urk and Schokland, it is also important to implement nature-friendly agriculture. If this is not possible, then the agricultural function should transform into a natural area, because this does not need as much maintenance and there are fewer issues for nature in soil subsidence areas.

Lastly, a higher groundwater level must be implemented, as it either reduces or stops soil subsidence.

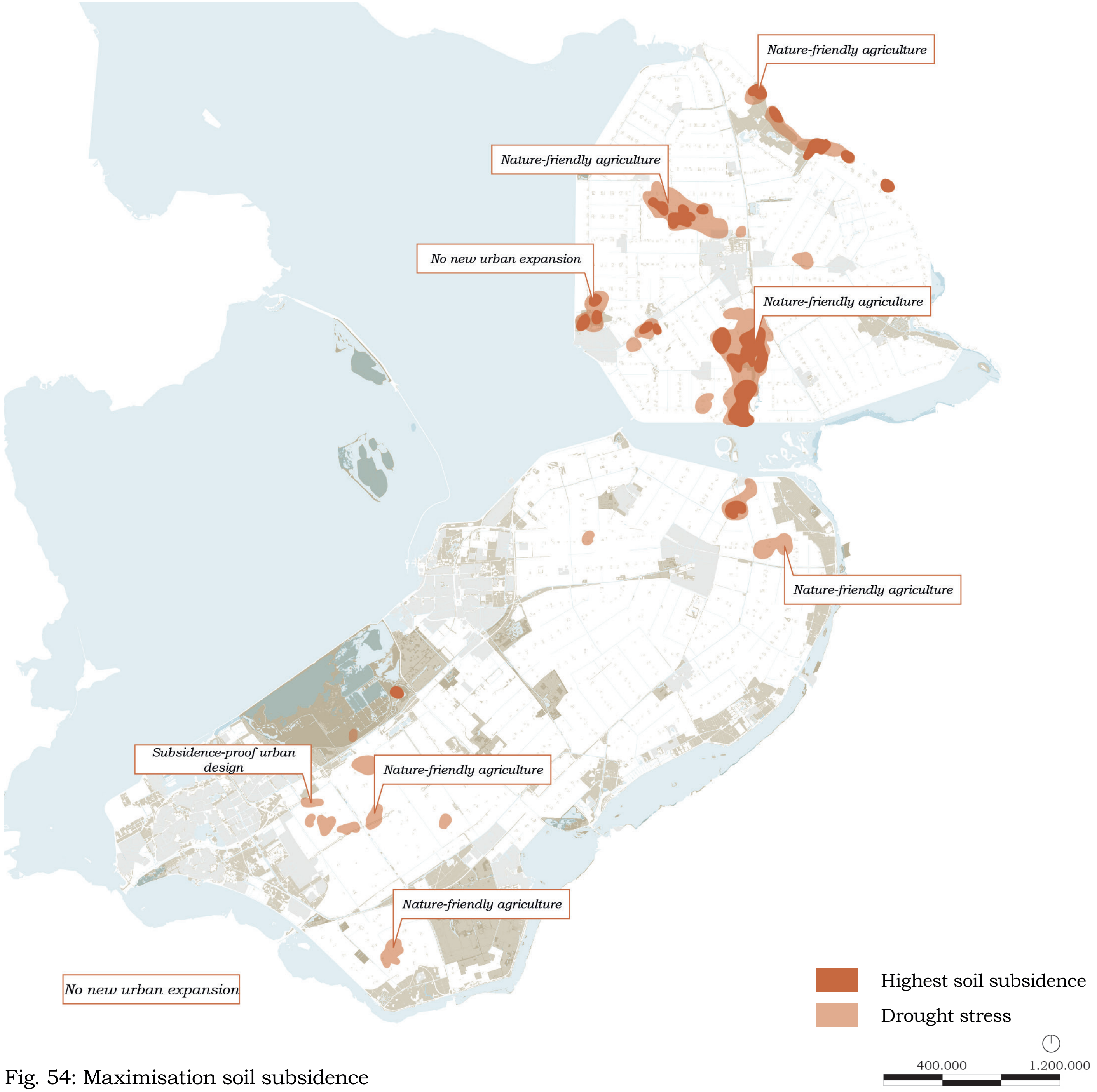
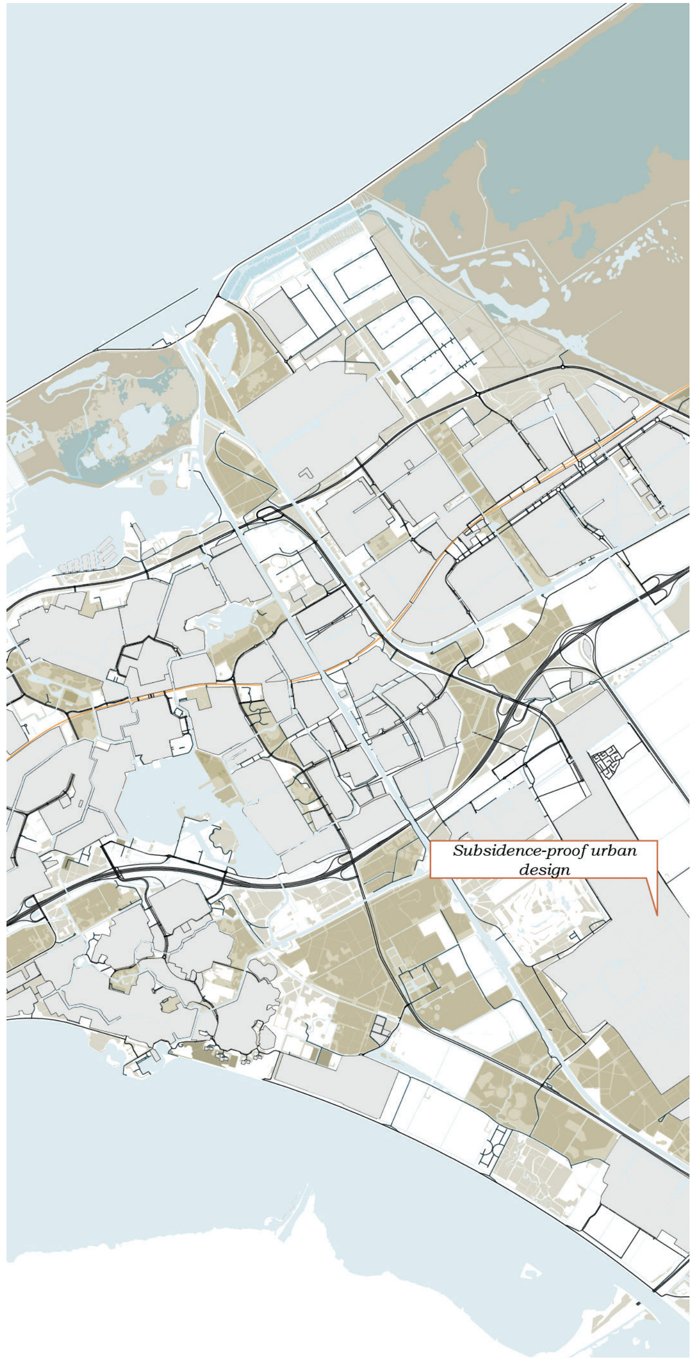


Fig. 54: Maximisation soil subsidence

In Almere and Zeewolde, the damage is somewhat in urban areas and mostly in agricultural lands. Both municipalities should implement new rules for nature-friendly agriculture to improve the soil quality. Future urban developments must not be located in areas with the most soil subsidence.

Stakeholders:
Subsidence-proof urban development must be a goal of the municipalities, especially for Lelystad and Almere, because these municipalities have a high building task.

The higher water level is a policy from the province and is managed by the waterboard, as said earlier. Nature-friendly agriculture should be realised in order to improve the soil quality. When the soil quality becomes healthier, it will start working as a sponge and therefore could reduce soil subsidence to a small amount. This will also happen with rewetting the topsoil.



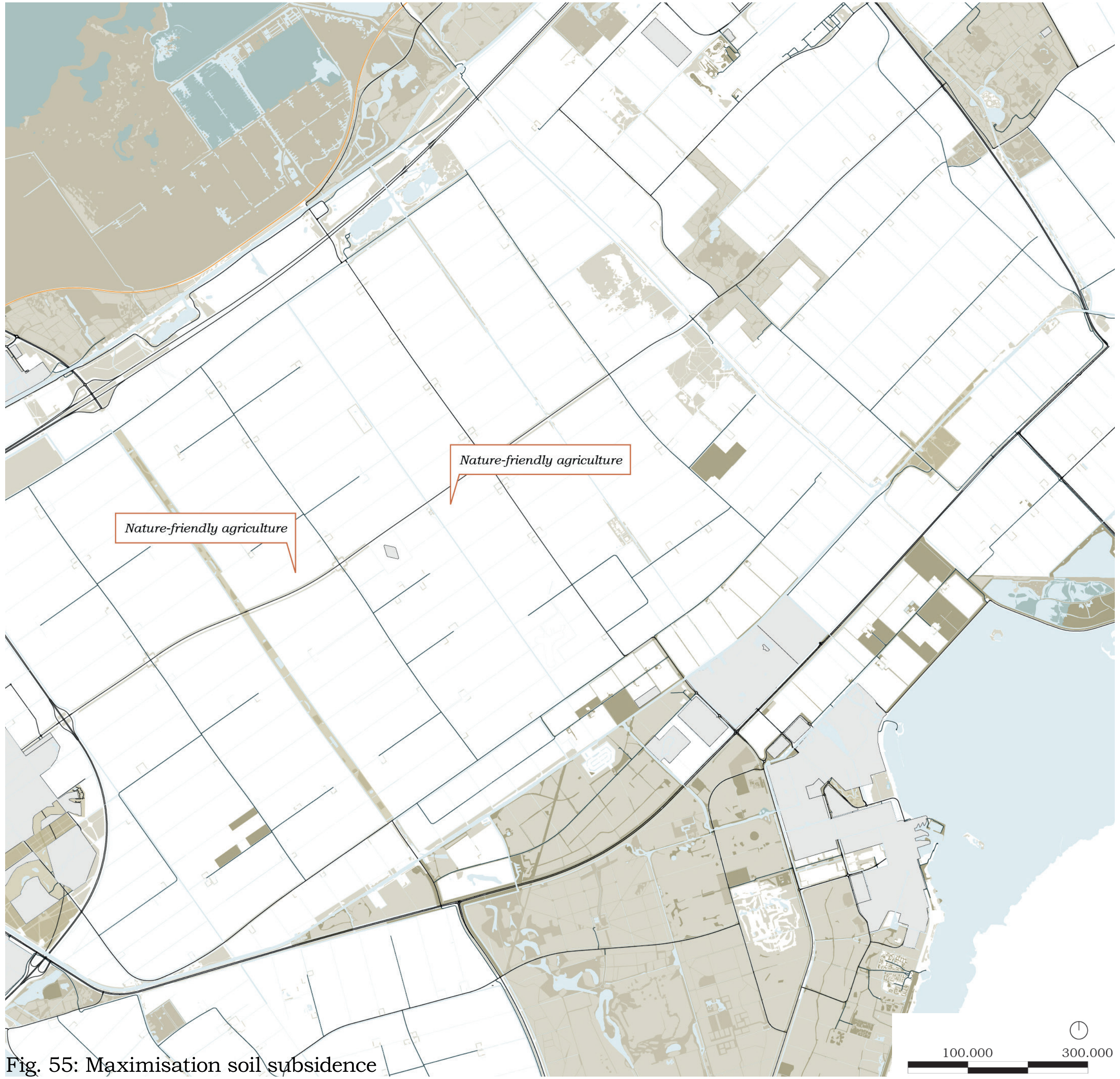


Fig. 55: Maximisation soil subsidence

5.1.5 Flooding

Flevoland has one border between the water and the polder: the dike system that covers almost the entire border of Flevoland (fig. 57). This is the only defence against flooding, and the dikes should be improved. However, the dike system is a technical solution, and it will eventually lead to a lock-in. Another way of keeping Flevoland safe from flooding is by implementing living shorelines. These are natural zones before a coast, and they catch the waves, reducing the speed of the waves before the waves hit the dikes. The reduction of speed reduces the damage from waves on dikes. In Flevoland, the main focus should be on reducing the risk of flooding, because once a flood does happen, Flevoland will be completely under water (fig. 56).

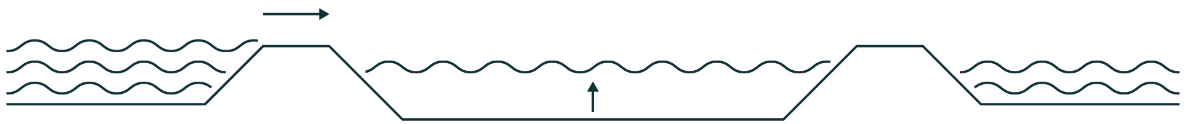


Fig. 56: Maximisation flooding

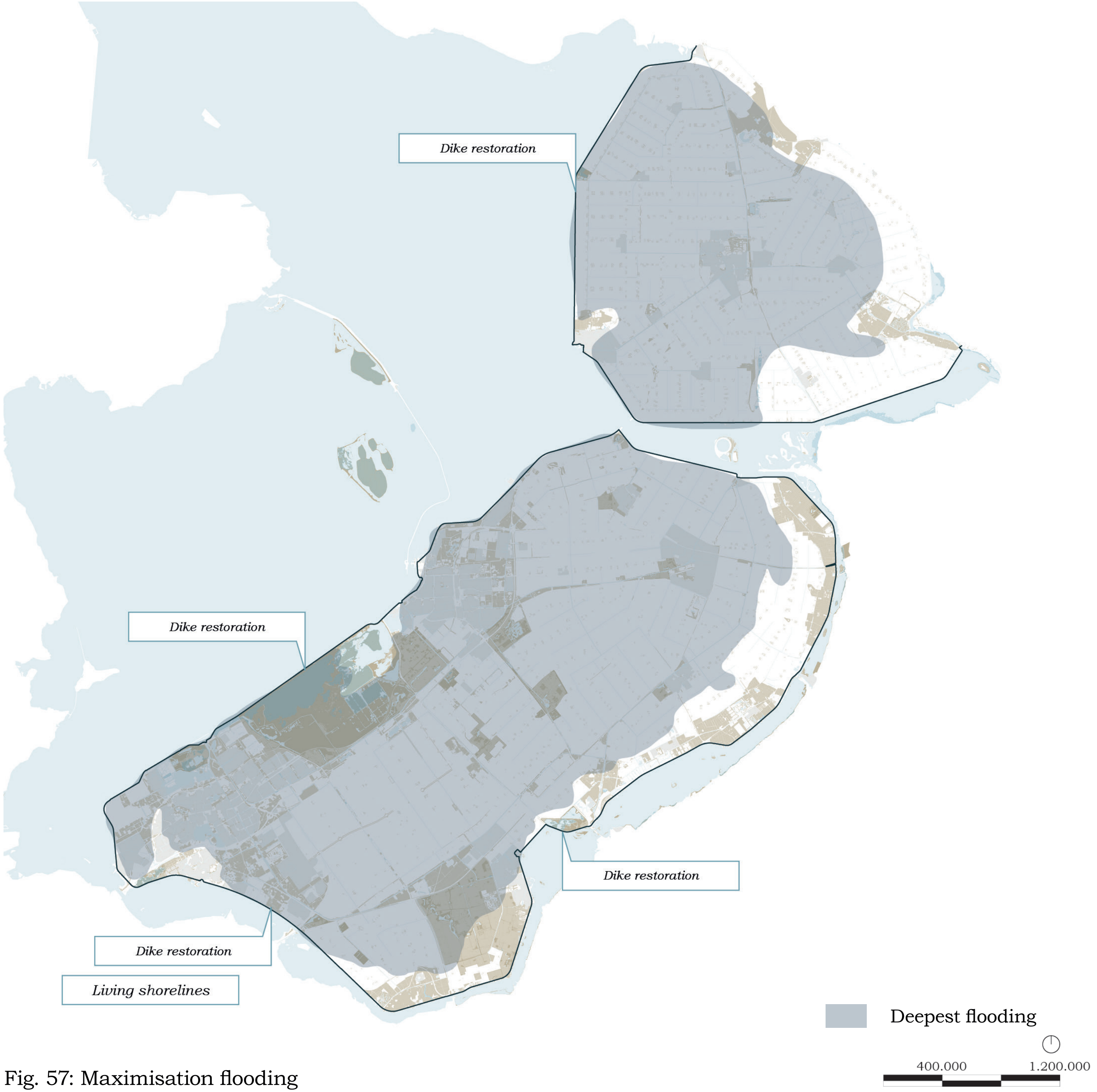


Fig. 57: Maximisation flooding

Another way of reducing the damage from floods is by implementing multilayer safety. This could mean that it will not be allowed to build on the lowest locations and that other areas need more protection.

Stakeholders:
The dikes are managed by the waterboard Zuiderzeeland. The strengthening of the dikes is managed through a collaboration of the Ministry of Infrastructure and Water, Rijkswaterstaat and the waterboard Zuiderzeeland. The ministry provides a fund for the improvement of dikes in the Netherlands.

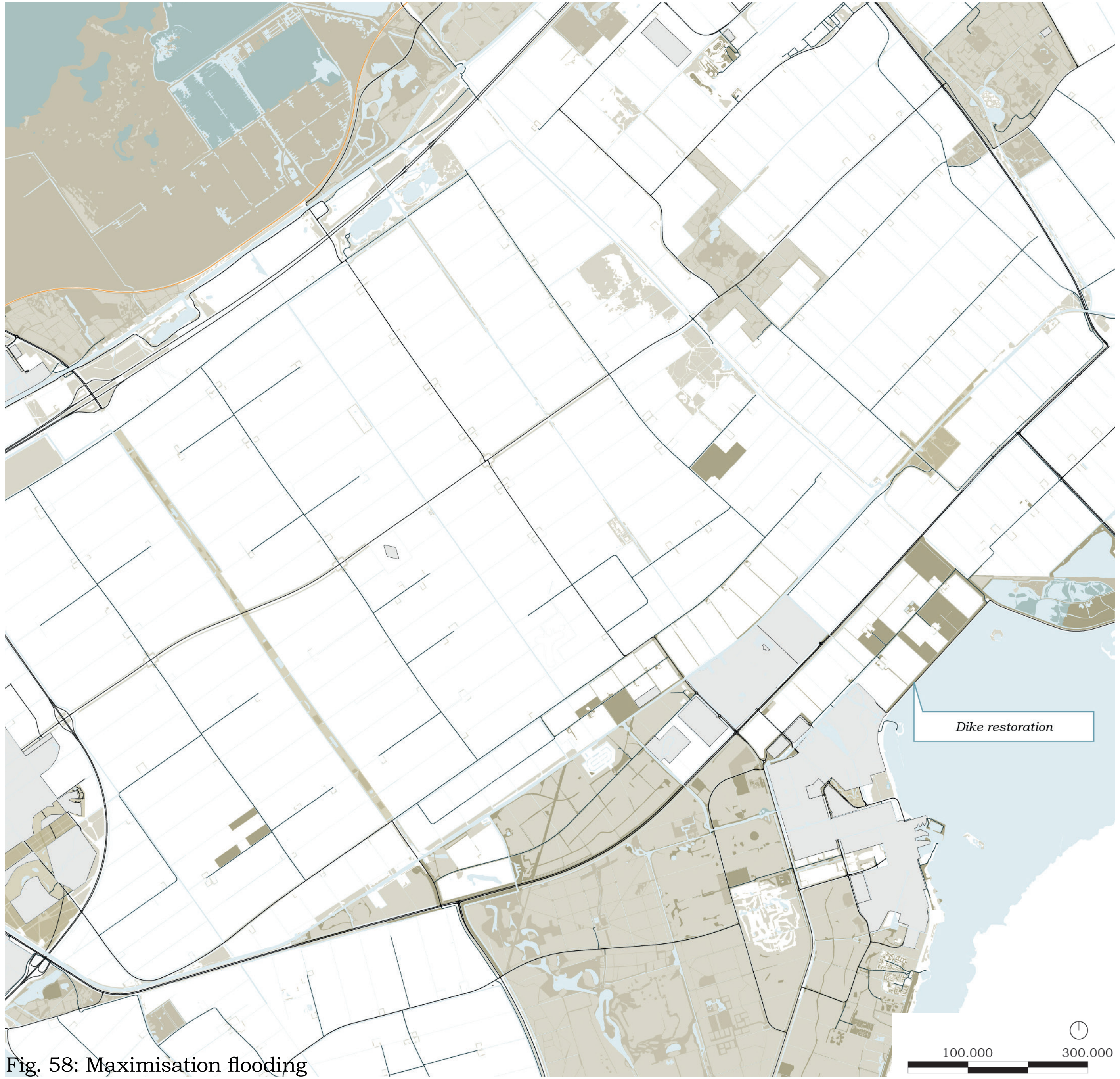


Fig. 58: Maximisation flooding

5.1.6 Housing

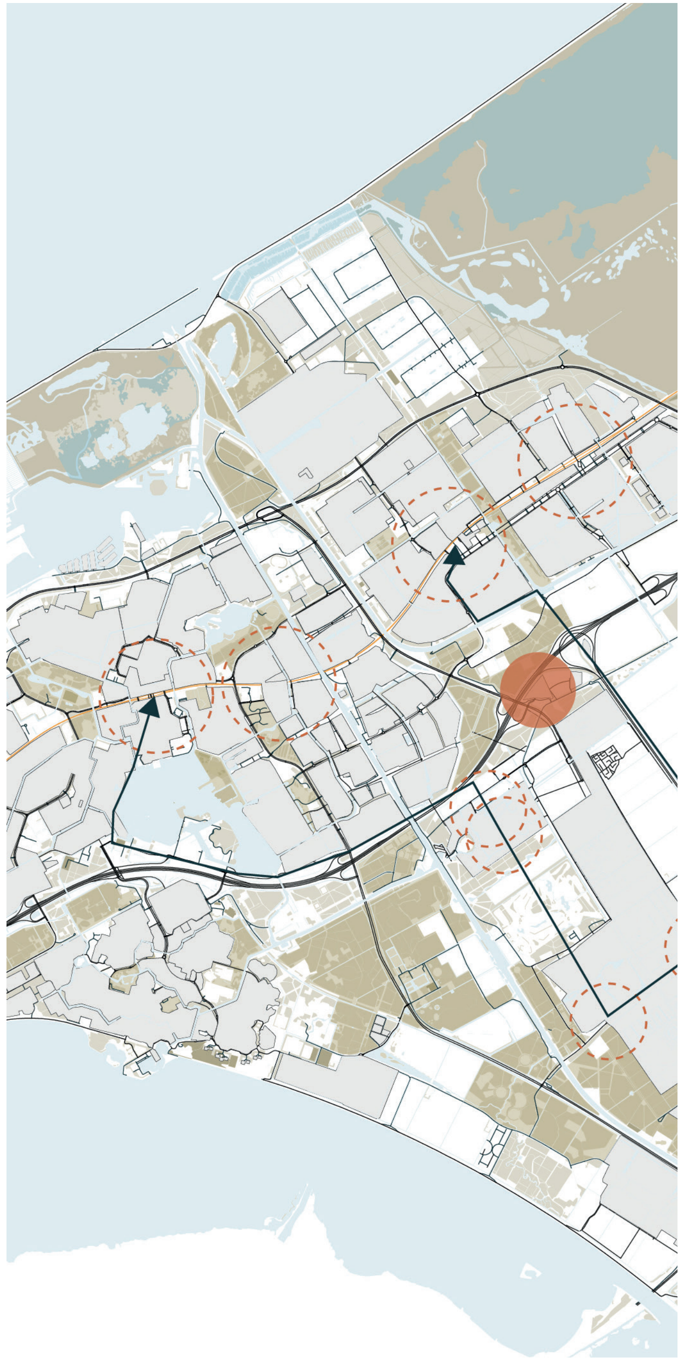
The urban growth is expected to be mostly in the Flevopolder. There are three locations for urban expansion. One of these areas is Oosterwold, part one is in Almere and is already in development, but part two still needs to be built. This part will be in Zeewolde. For urban development, there must be a good mobility system. Therefore, the expected development in Emmeloord (fig. 59) has changed from its original location towards a place closer to the expected train station. The Lelylijn will be built in the future as well.

Fig. 59: Maximisation urban expansion

In Almere and Zeewolde, the vision is shown more clearly. The housing is the expectancy of a total of 15.000 houses in Oosterwold. The part in Zeewolde will get in this design 35 houses per hectares (fig. 60). This puts less pressure on the urban area, because facilities and transport hubs will be closer than if everything is spread out over the whole area.

Stakeholders:
For the development of new urban areas, the municipalities are one of the most important parties. They should create a vision for the realisation of the development goals and should think about the different necessities, such as facilities, parks, and (bus) stations.

The residents of surrounding neighbourhoods are important as well, because they could give more information about the living experience and could help designers with the design of a nice neighbourhood.



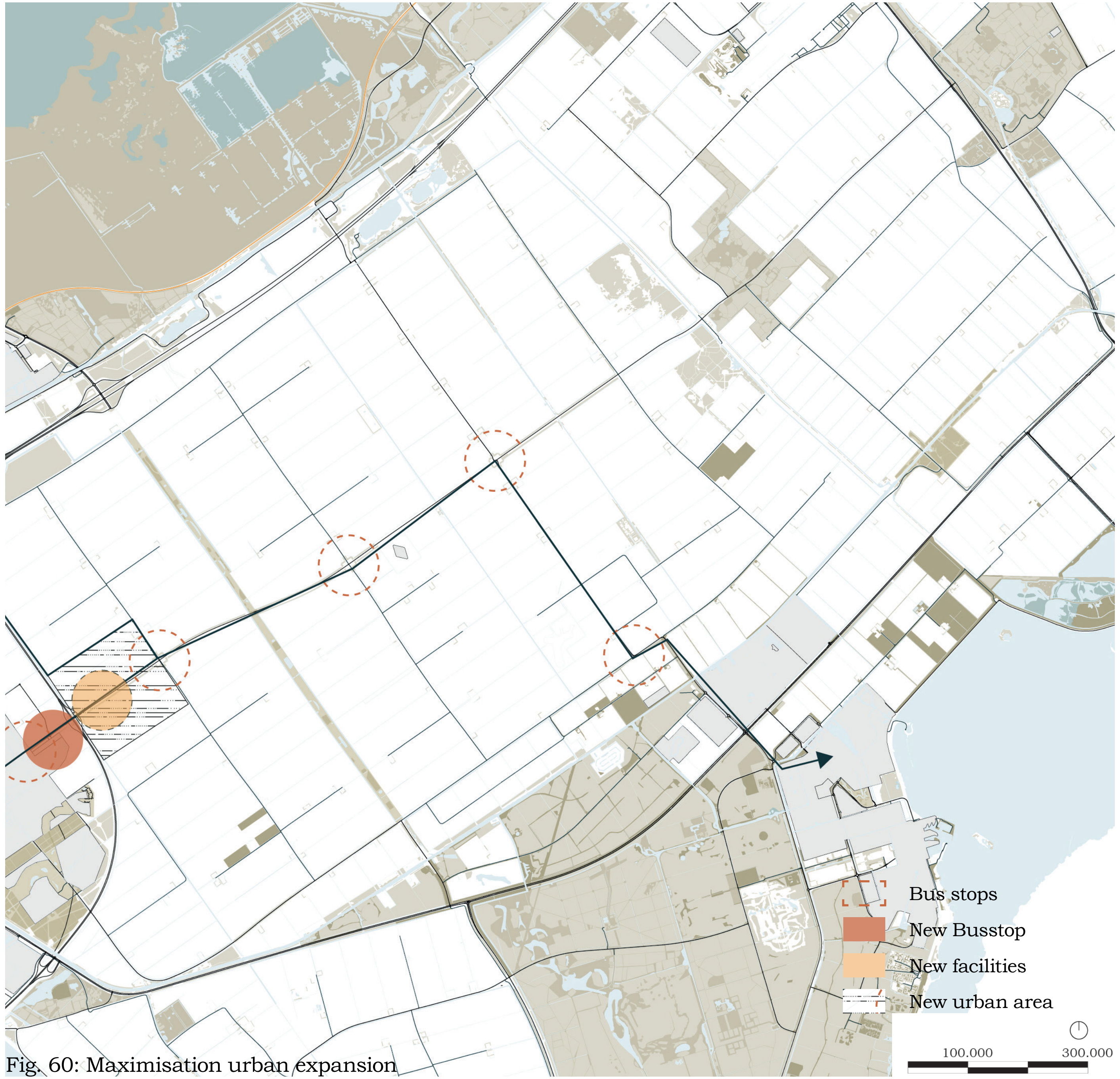


Fig. 60: Maximisation urban expansion

5.1.7 Ecology

The ecology is just as important for the region as the other functions. Therefore, the idea is that all search areas will be realised and thereby develop a stronger biodiversity in the region. The realisation of the forest search areas will create a large new natural area in the Noordoostpolder. Also, there are new connection lines to improve the natural network between nature (fig. 61). These lines will be either green networks or blue-green networks. Blue-green networks could especially be used around the vaarten and the tochten.

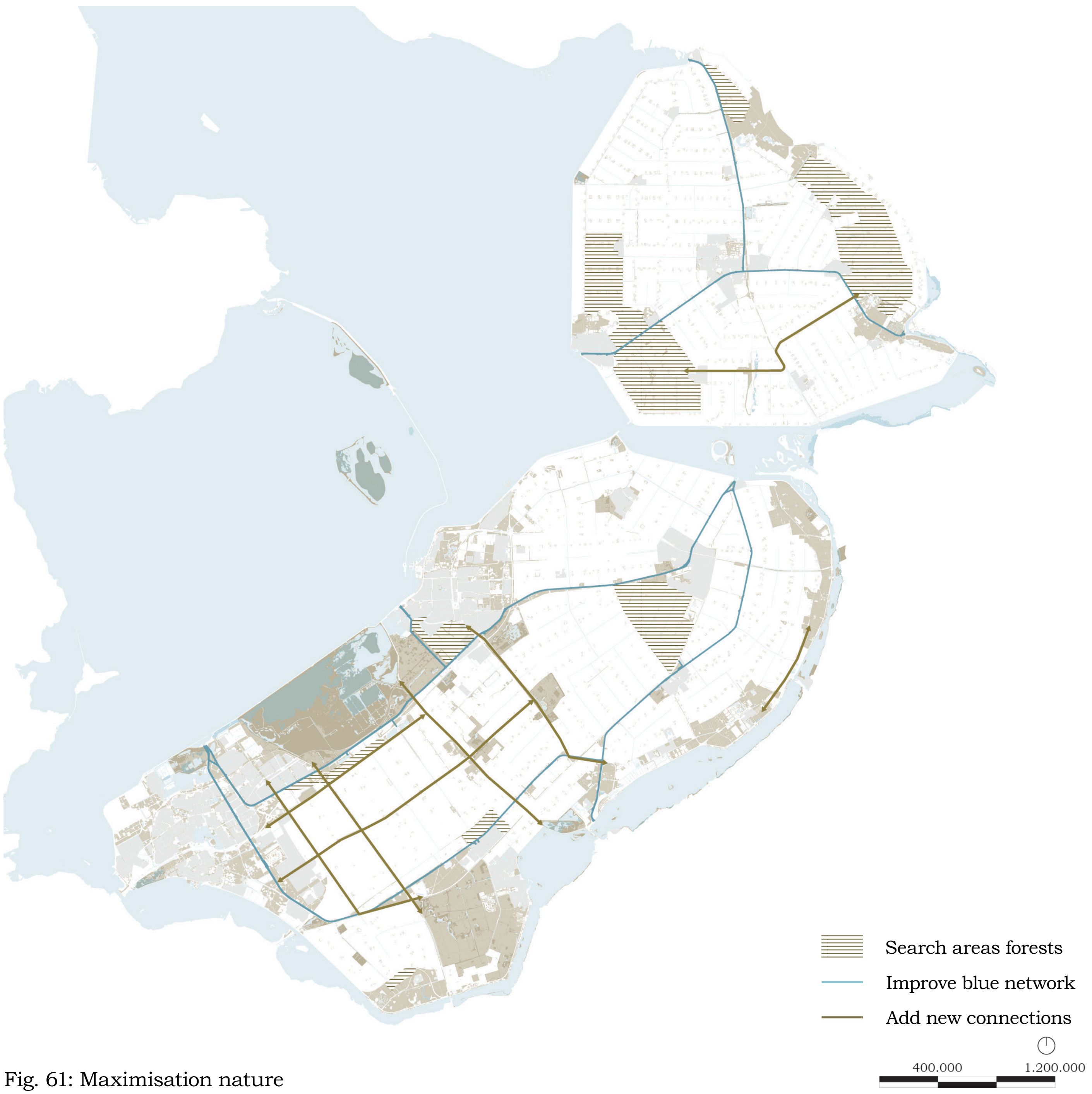


Fig. 61: Maximisation nature

On the smaller scale, it becomes visible that many connections are still missing between the Horsterwold and the Oostvaardersplassen. The already existing connection is not even fully connected because of the wildlife grilles that are located next to the road. Therefore, it becomes important that these connections are made in the future to provide a larger ecosystem for animals, and this will improve biodiversity. Furthermore, the vaarten and tochten should not only be used for water management. The tochten and vaarten must be transformed into blue-green networks (fig. 62) and riparian buffer zones to improve the water system and to create a larger network through the polder.

Stakeholders
The stakeholders related to this maximisation are multiple nature organisations. These parties have similar interests and therefore, their knowledge and power could be combined to improve the network in Zeewolde and Almere. Furthermore, the municipalities should focus on these blue-green networks as well, because they could be combined with urban development. This improves the quality of a living environment as well. This will be better for the citizens as well because they could use the blue-green networks to access nature.

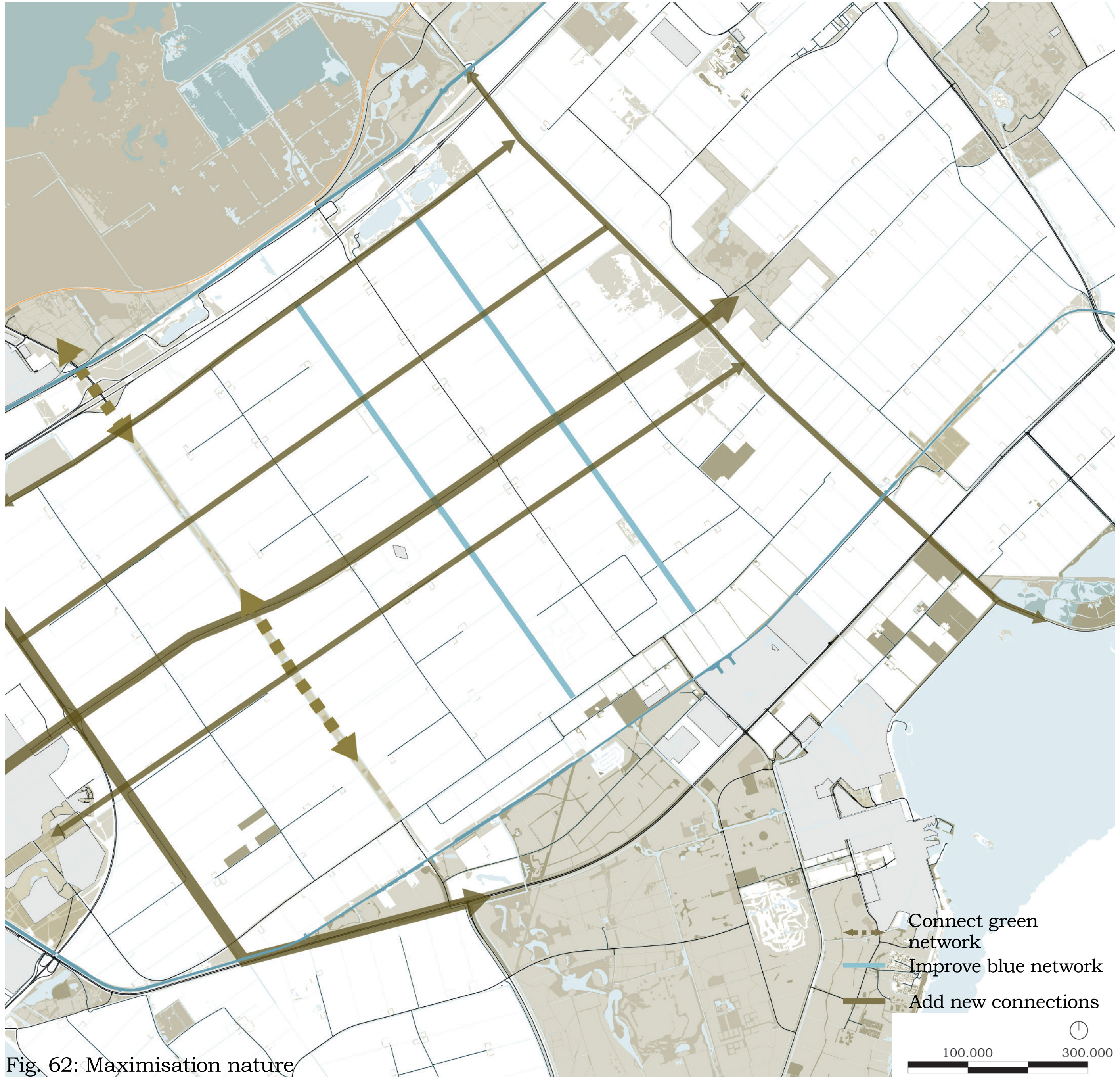


Fig. 62: Maximisation nature

Integration

When all patterns are combined with the visions of nature and urban development, it shows (fig. 62) that some areas will have more solutions than others. This has to do with the different water problems that are more clustered in the region. Furthermore, for farmers, it becomes important that they transform their agriculture into nature-friendly agriculture with crops that are resilient against climate change.

There are no real clashes between different patterns except for a higher groundwater level to reduce soil subsidence. This clashes with water nuisance, so if this intervention is implemented, there needs to be more water catchment areas, and the waterboard, in combination with farmers, should further investigate the effects and how the water nuisance could be mitigated. The choice to implement this pattern is based on the idea that drought and soil subsidence both benefit from this solution, and if it will not be used, only one water problem will have a positive outcome for this.

In the Noordoostpolder, multiple solutions could be combined with new nature. This will help balance the different water problems because the water level for nature is less strict than for agriculture.

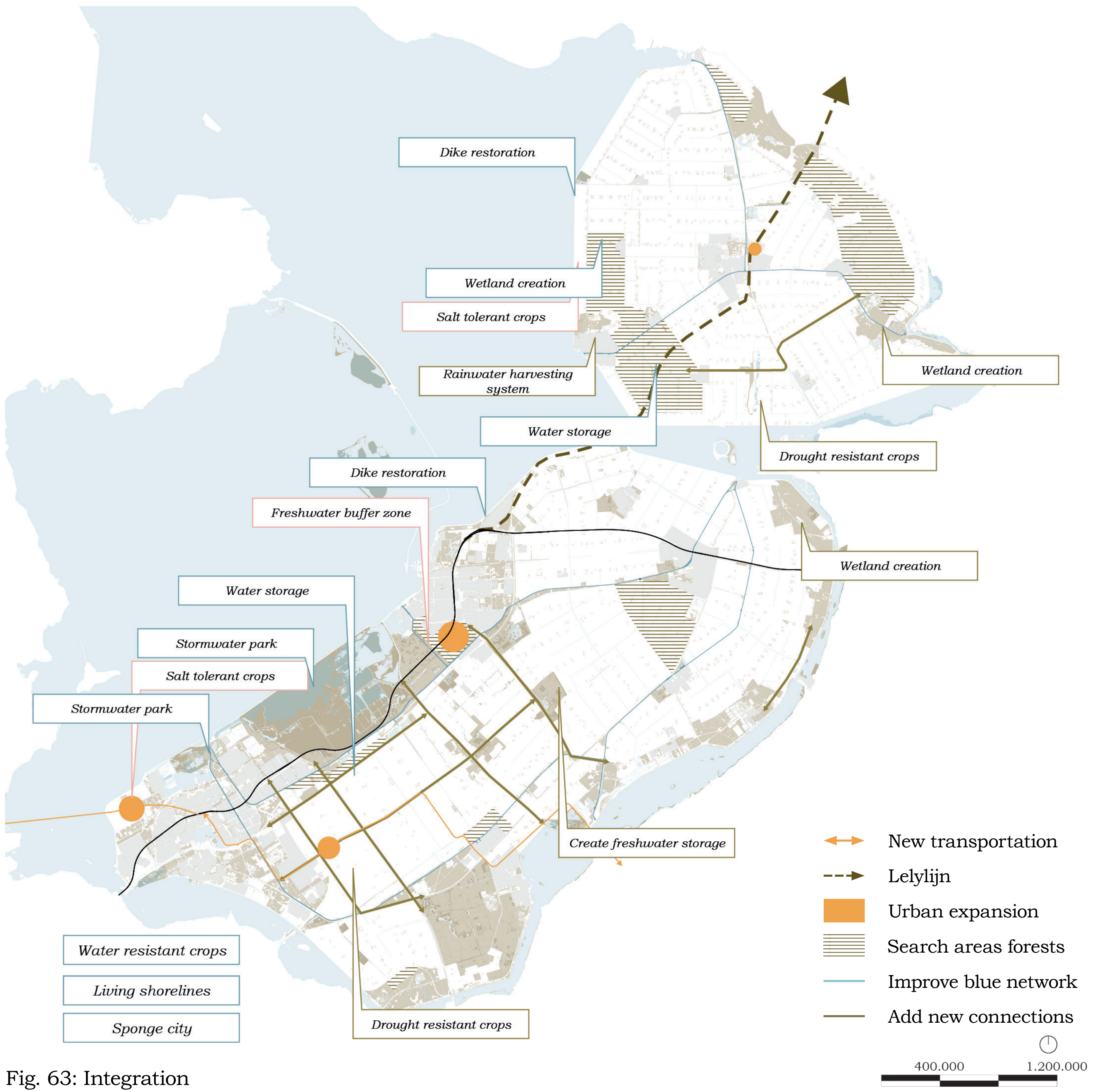
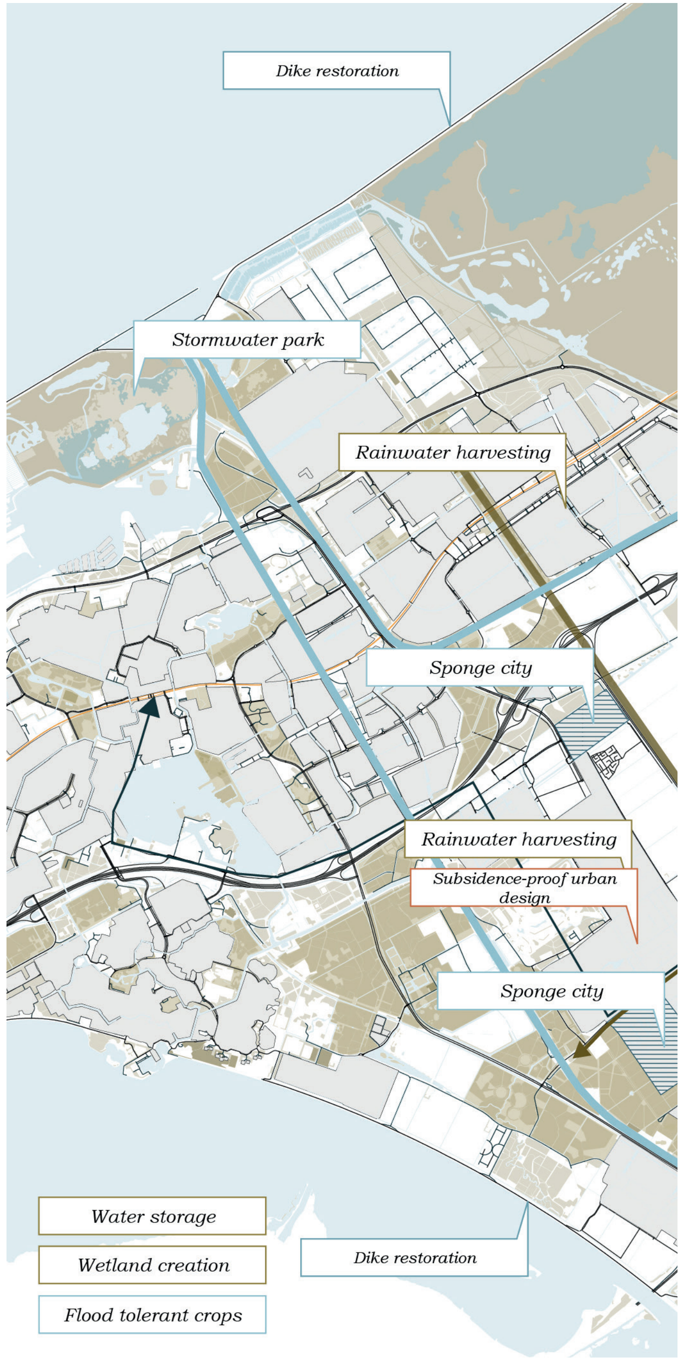


Fig. 63: Integration

On the smaller scale, the nature ambitions of improving the blue-green networks overlap with the solutions for water nuisance and drought. Furthermore, the water storage could be combined with the creation of a wetland. By combining these patterns, there will be an improved new natural site. This would also be interesting for Staatsbosbeheer, and citizens could use the wetlands as a new recreation area, just like the Oostvaardersplassen and Hosterwold.

The urban area could stay in the same place because it does not overlap with other functions except agricultural land. But with the higher housing density, the space that is needed for the realisation of the neighbourhood is already minimised to a smaller plot. Therefore, more farmers could keep their farms and focus on nature-friendly agriculture.

The new neighbourhood should also be designed with the sponge city concept, subsidence-proof urban design and with rainwater harvesting systems. This will provide a resilient urban area that could deal better with climate change in the future than other neighbourhoods. These design tools do ask for clear communication from the municipality towards urban designers, but also to citizens who might be interested in living in Oosterwold.



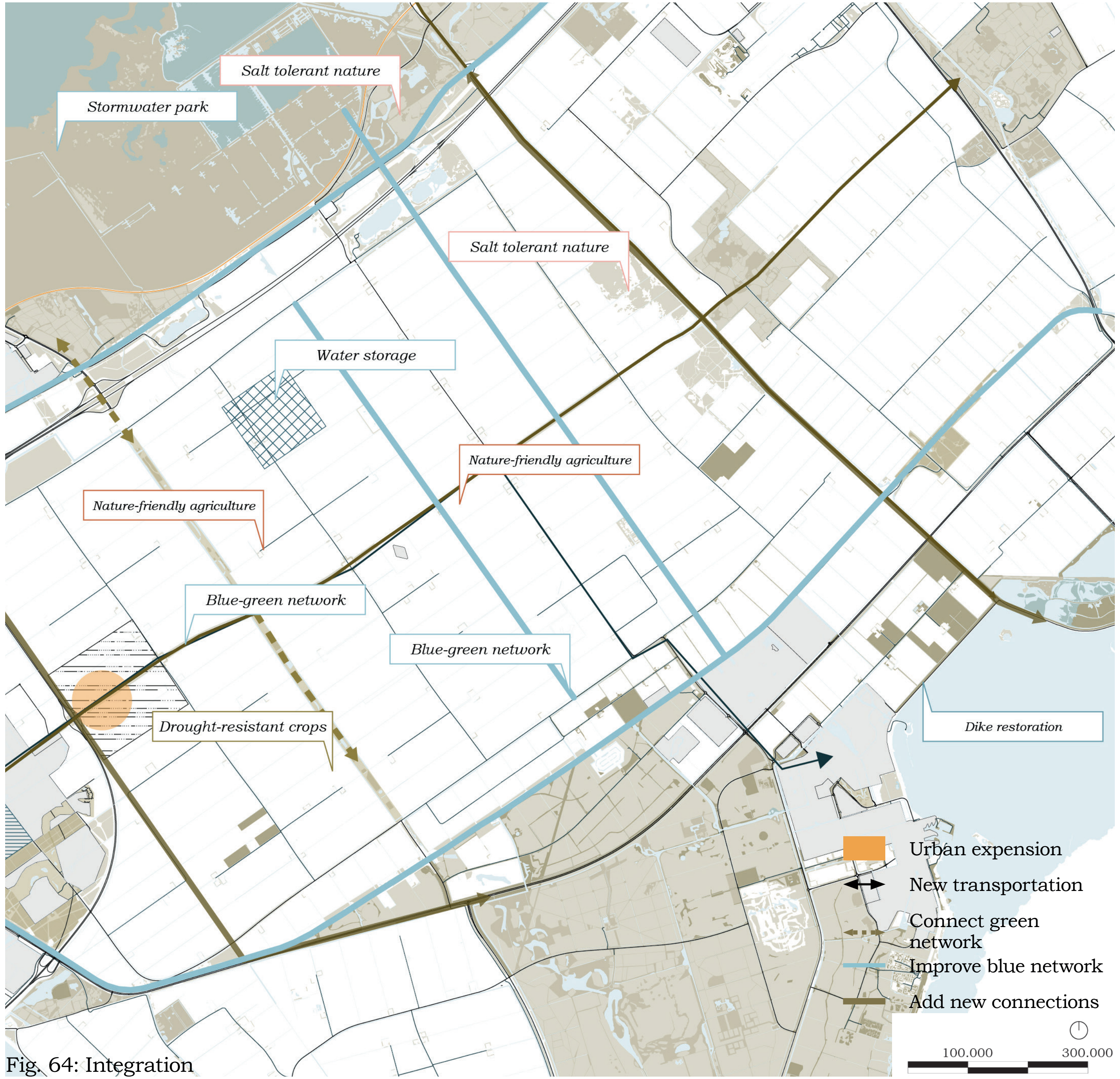


Fig. 64: Integration

Governance

The phasing has four different phases, and the period is until 2050. The four stages start with the 'research and vision' phase, in which the first stakeholders start their vision process to realise certain plans, and it will be used as a phase where stakeholders such as Aeres Hogeschool and Wageningen University and Research (WUR) do research for new types of farming and crops. This first phase is necessary to motivate stakeholders in the second phase. These stakeholders are farmers, citizens and Staatsbosbeheer. The plans will become more known in this phase, and the start of policies is needed as well. For example, the transition fund is an important pattern to motivate people and agricultural businesses to improve their working methods and to make a shift towards nature-based solutions.
In the third phase, the focus is on the realisation of the plans. This means that the start of the wetland design in combination with water storage will be designed, and that farmers will start the transition of their farms.
Right next to these plans, citizens and farmers could also participate in the design of Oosterwold. The first plans have already been made in the first two phases, but input from the landowners/ farmers is necessary, and citizens could give their opinion about the plans for Oosterwold.
In the last phase, Oosterwold and the wetlands will be developed. It is expected that the wetlands may take longer than 2050 but the first three phases will be finished. The crop transition will also keep happening. The water problems could change over time and therefore, it is possible that new solutions or new research are needed for agriculture. Therefore, Aeres Hogeschool will come back in the implementation phase to further analyse the effects of the changed crops on the soil and water system.

Dike restoration is a slightly different process because the plans for dike restoration have already started, and the waterboard Zuiderzeeland and Rijkswaterstaat are already working together on the realisation. Dike restoration is therefore already happening earlier in the process and has to be finished by 2050.
The phases are visualised in the next pages (fig. 66 to 69).

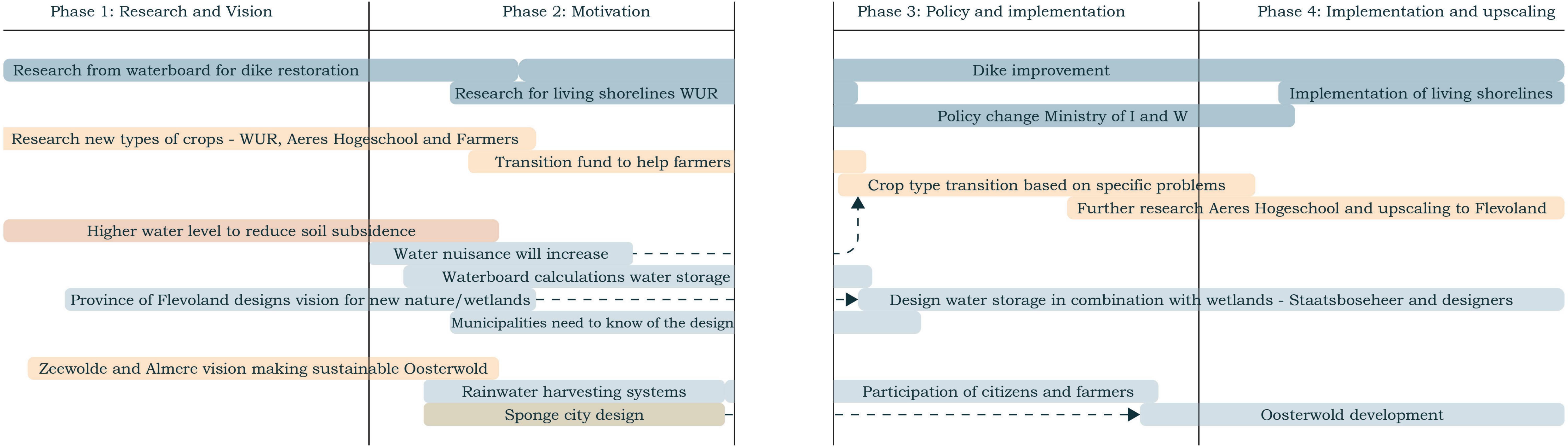


Fig. 65: Phasing

Phase 1:
The dike restoration has started.

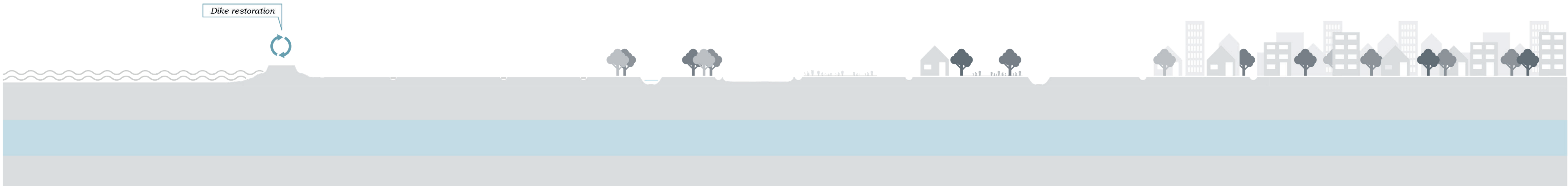


Fig. 66: Phase 1

Phase 2:
Rainwater harvesting, aquifer management and riparian buffers are implemented to improve water catchment.

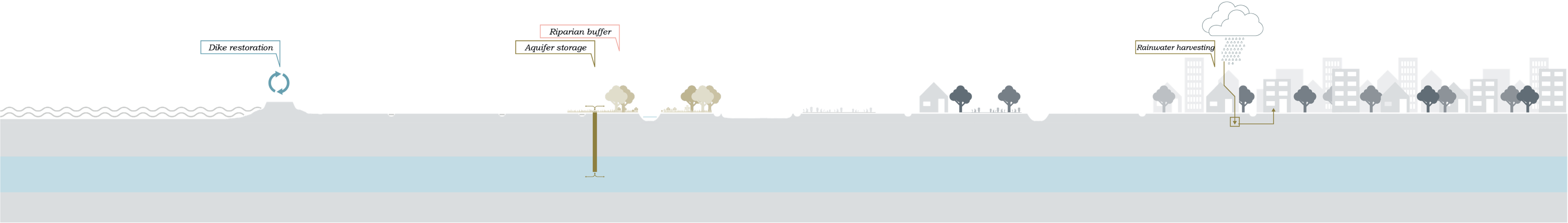


Fig. 67: Phase 2

Phase 3:
The research for new crops has been done, and the new crops are implemented next to nature-friendly agriculture. Agriculture will be more nature-based and more sustainable.

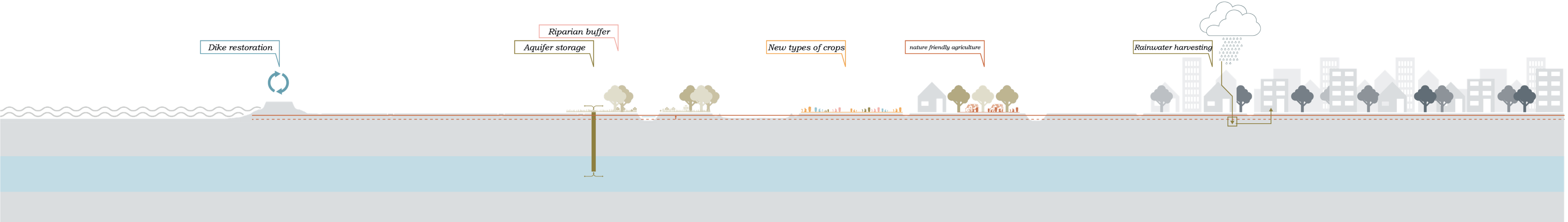


Fig. 67: Phase 3

Phase 4:
Living shorelines are researched and implemented. Dike restoration is realised just like stormwater parks. This means that the area is more flood-proof and will experience less water nuisance. Lastly, Oosterwold will be developed with the sponge city method and rainwater harvesting system.

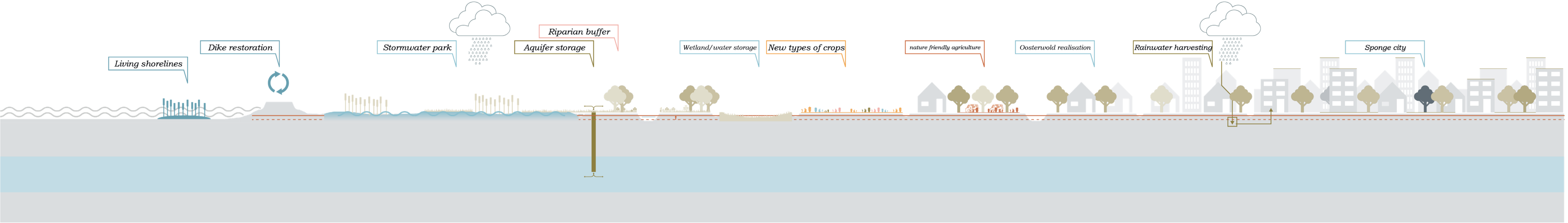


Fig. 68: Phase 4

Visualisation of nature-based solutions in the Flevopolder

This visualisation represents new types of agriculture in the Flevopolder. The Flevopolder deals with water shortages, droughts and soil subsidence. Therefore, farmers must transition their farms towards more climate-resilient agriculture. The ditches are transformed into riparian buffers to increase the water catchment area and to improve biodiversity. The waterways are an important connection between natural areas. The trees from the riparian buffer could be nut trees or fruit trees, depending on the conditions of the soil.
Furthermore, instead of one crop per farm, the farmer now has strip cultivation. The cultivation is climate-adapted and can withstand drought and/or water nuisance.

Peat
Clay
Groundwater level summer
Groundwater level winter

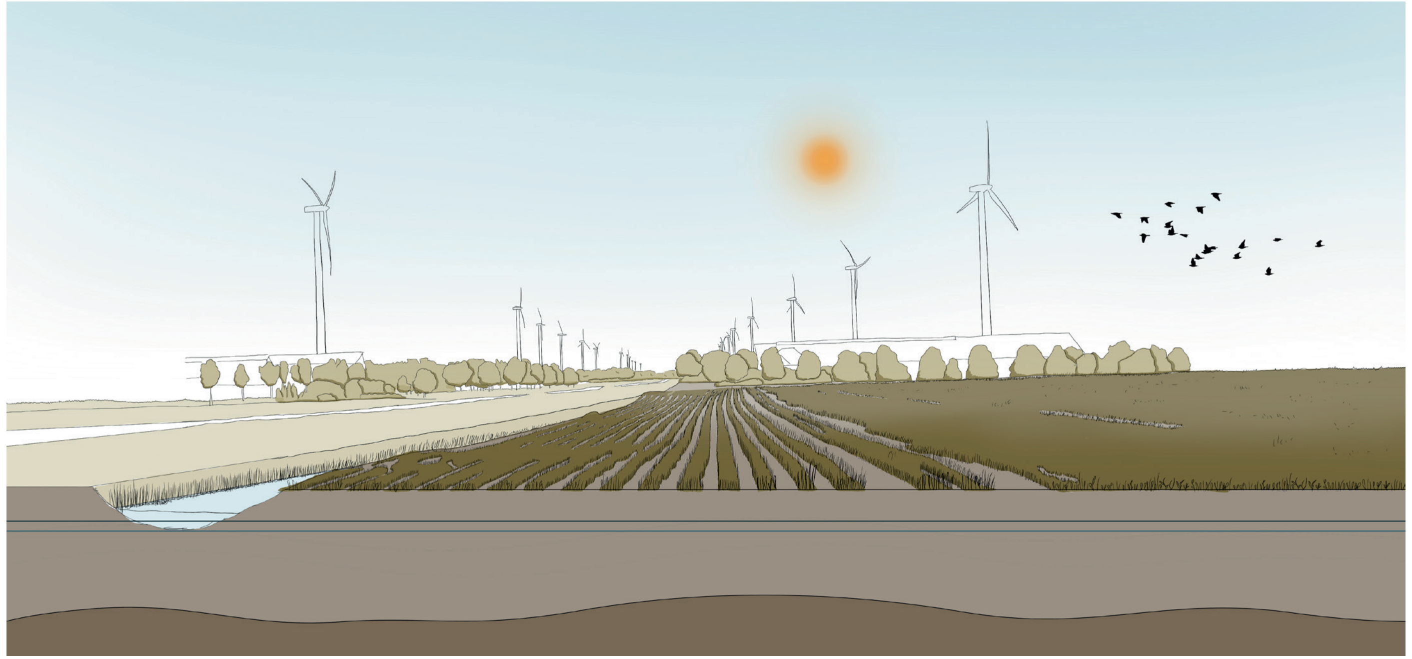


Fig. 69: Current situation

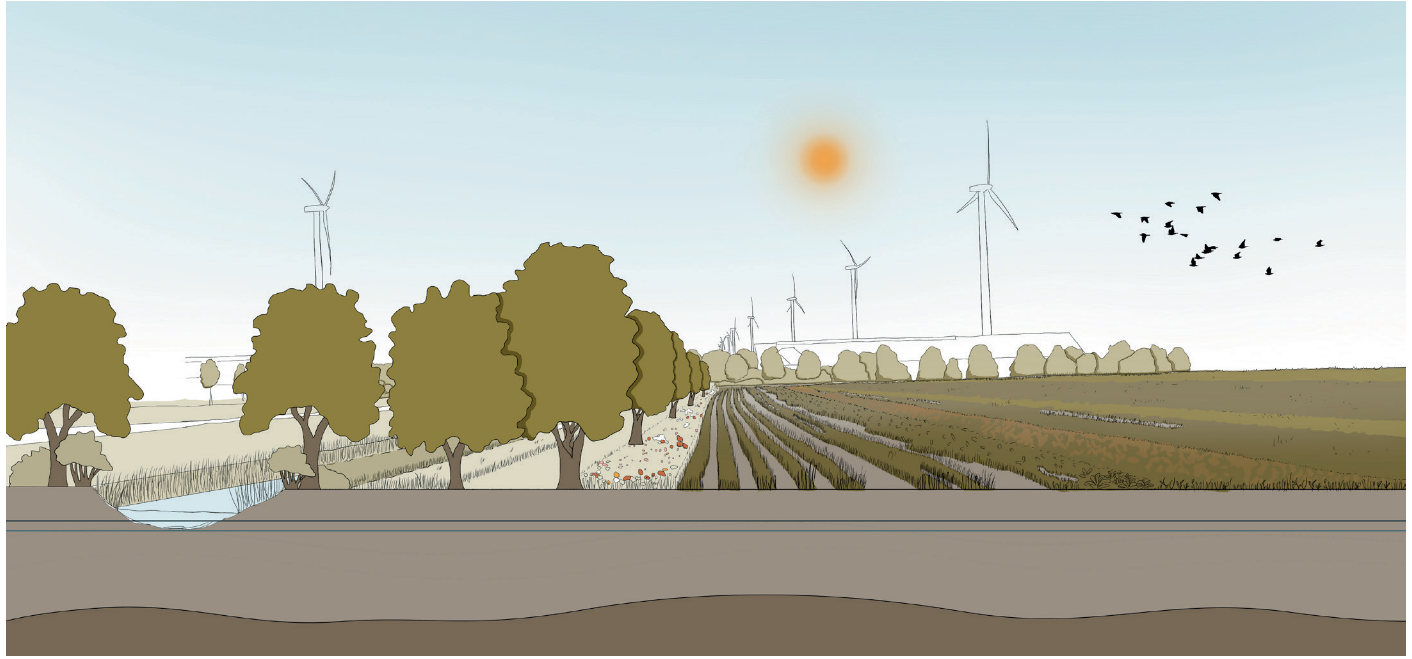


Fig. 70: Future situation

Visualisation of nature-based solutions in the Noordoostpolder

The visualisation of the Noordoostpolder shows a large transition. This is because the Noordoostpolder deals with a lot of water-related problems, and the location is used for the development of new nature, based on the forest strategy. Therefore, the land use will transform from agriculture to nature, specifically to wetlands. These wetlands are created to improve biodiversity and to catch more rainwater. This water could be used for nearby farms, and the water will partially stay in the area as well. The transformation towards wetlands is a new opportunity to improve the natural areas in the Noordoostpolder. Right now, these are not connected, but with new large nature areas, it is possible to improve the connections with blue-green networks. These networks could be used for recreationists, and the wetlands are created with the idea that recreation is possible.

Peat
Clay
Groundwater level summer
Groundwater level winter

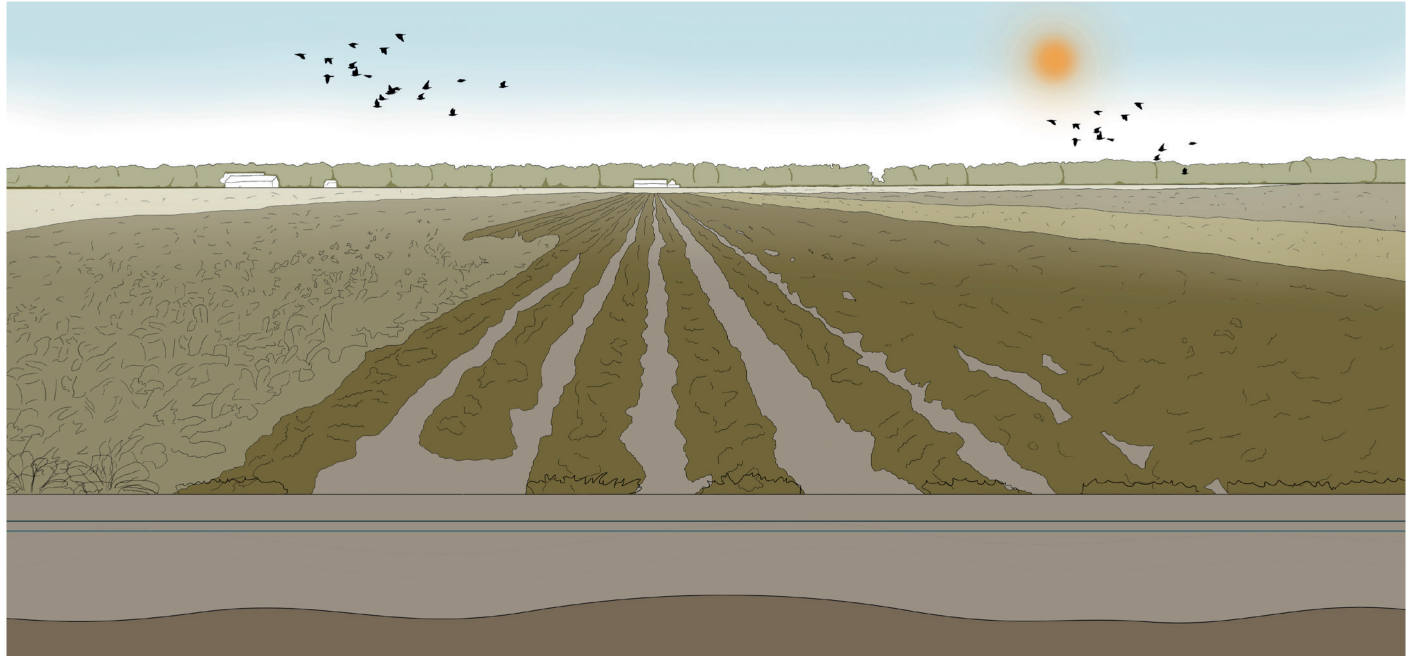


Fig. 71: Current situation

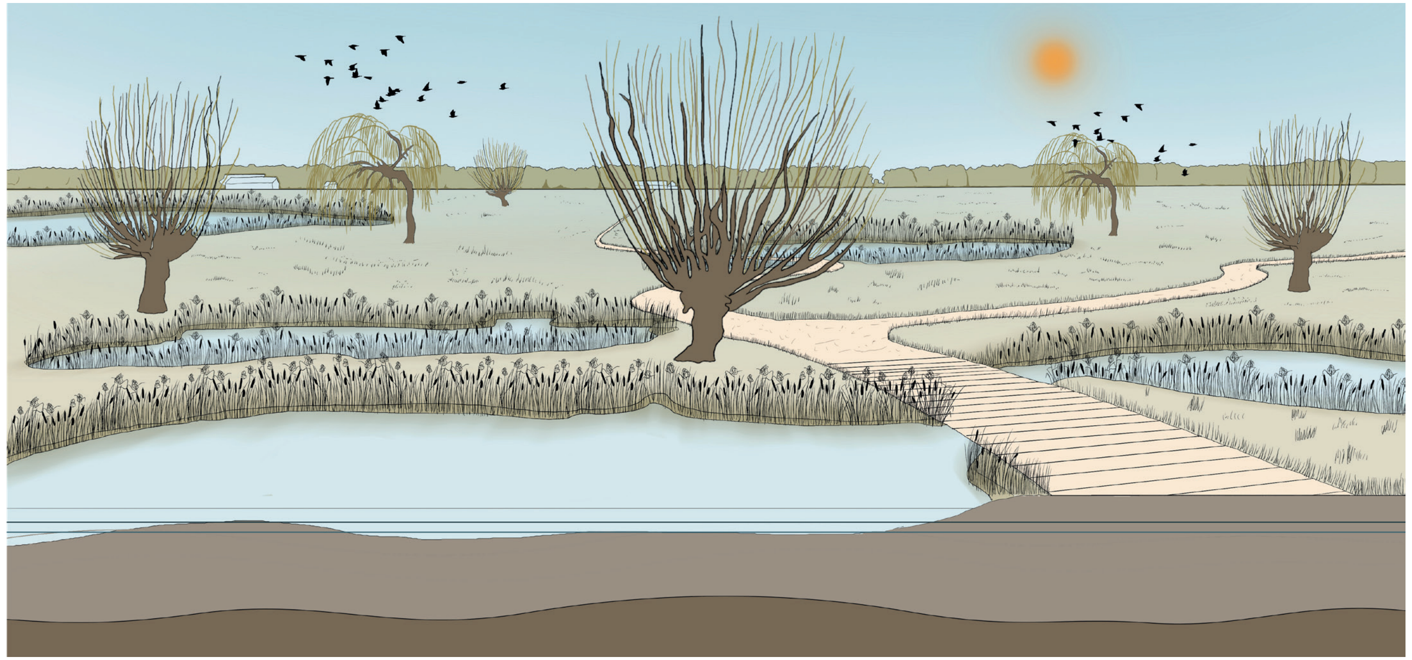


Fig. 72: Future situation

Conclusion

Recommendations

Main research question: How could nature-based solutions be utilised to enhance the water system and improve the resilience of Flevoland?

Flevoland, as a large polder province, has the water system in control through technical interventions. However, with climate change, more water nuisance, drought, salinisation and soil subsidence, this system could reach a technical lock-in. Furthermore, there will be more water pressure on the dikes when the water level of the IJsselmeer rises.

To answer the main research question of this thesis: 'How could nature-based solutions be utilised to enhance the water system and improve the resilience of Flevoland?', the answer is split up into two different parts. First, the characteristics of Flevoland in combination with the water problems will be discussed. Then, the implementation of nature-based solutions in Flevoland will be discussed.

Analysis of Flevoland and water problems:
The analysis of the water system shows that the water problems are related to each other and that solutions for one problem could lead to more problems for other subjects. This could cause difficulty for the implementation of nature-based solutions. Three water problems will become worse over time, and these are connected as well. Soil subsidence will accelerate if there is more drought, because the clay and peat lands will become dry, activating different soil subsidence-related processes. Higher water levels could resolve this, but this could cause more water nuisance in wet periods.
The consequences of salinisation remain uncertain: it may improve, depending on future development and the amount of salt in the soil.
While the likelihood of flooding could increase due to climate change, the associated damage will stay the same, since the risk in Flevoland already follows an 'all-or-nothing' scenario.
These problems are already causing damage to urban areas, agriculture and nature. The urban areas will grow, and nature has to expand as well, because of the forest strategy. These two developments lead to more pressure on the agricultural land. However, the province still wants to maintain the image of an agricultural province.

Future scenario:
In the nature-based solutions scenario for 2050, Flevoland will be a more resilient region. Agricultural practices are adapted to changing climate conditions through crop diversification and nature-friendly agriculture, supported by academic research and innovation. While water issues will become worse over time, their negative impacts on urban areas, nature and agriculture are mitigated. Newly created wetlands and water storage areas also strengthen the ecological network, enhancing biodiversity and improving the quality of life for humans and wildlife.

To reach these goals, collaboration is key. The public parties, nature organisations and farmers should work together, with water as a connector through the whole process, to design a more sustainable and resilient Flevoland.

6.3 Reflection

Introduction:
The reflection is used to show the limitations and considerations of this master's thesis. It is also used to look back at the internship that started halfway through the thesis. Lastly, the reflection is used to explain the difficulties and limitations of nature-based solutions.

Graduation topic related to the master:
This master's thesis about the implementation of nature-based solutions for water problems in Flevoland is based in the department of urbanism. This thesis fits here, because the research is approached on different scale levels and goes back and forth between design and research.
The project is mostly on the landscape scale and is focused on the rural elements instead of the urban areas. Still, this thesis fits urbanism because of the spatial implications of nature-based solutions. Besides the spatial implications, the different stakeholders are also considered in the integration phase of the project. A stakeholder analysis and governance chapter is an important part of urbanism, because an urbanist designs space for many people.

Furthermore, the project is related to Q3 of the first year of the master's. In this quarter, the project was more focused on the landscape scale and on the design of a vision and strategy. The pattern language was also used as a design tool, and policies and stakeholders were considered in this project as well. That project was an inspiration for this thesis because it showed the possibilities of design on a larger scale. This helped me find out about this scale level, because I was not yet used to this scale level during my master's and bachelor's.

Research and design:
For the design of a vision, research and understanding of the region are necessary for the project. At the beginning of this thesis, the information needed about the water system was still missing. Without analysis and reading through the literature and policies, it would not have been possible for me to make a design. During the design process, I have realised that sometimes still information was missing, especially about salinisation and other water problems. This was solved because of multiple consultations with hydrology experts at the waterboard. The realisation of the missing information made me look back at the design as well. You cannot design something or conclude if you do not understand the subjects yet.

Going back and forth between research and design is an ongoing process throughout the year. The research is never really finished because it is possible to research more to try and grasp all aspects of your research.

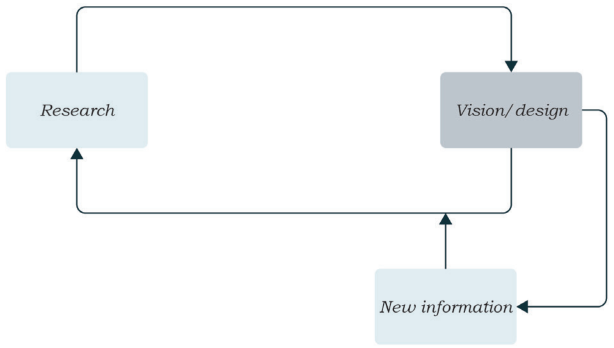


Fig. 73: loop research and design

Approach and used methods:
My project approach consists of three parts: context and theory, analysis, and design and strategy. This was not a linear process, because sometimes, after starting designing, the realisation comes that information is still missing in the analysis chapter. Then, I had to go back to the research and find out what information I was missing. This is already further explained in the research and design part of this reflection.

There were two methods used for the design and analysis part: the pattern language and the maximisation strategy.

The pattern language is used for the development of nature-based solutions and is used to see connections with other patterns (NbS) as well. It is an accessible way of structuring information systematically. Each pattern has the same layout, and with colour codes, the patterns are connected. Alexander (1977) says: *'No pattern is an isolated entity. Each pattern can exist in this world, only to the extent that is supported by other patterns: the larger patterns in which it is embedded, the patterns of the same size that surround it, and the smaller patterns which are embedded in it.'*

At the beginning of this research, it was indeed the case that there were multiple nature-based solutions combined in one pattern. Therefore, the implementation of the patterns became more difficult, as well as writing these patterns. By categorising these patterns and splitting them into smaller patterns, they became more accessible again, and the relation between the patterns became visible. Therefore, the patterns are deeply connected, and some patterns could probably be narrowed down even further.

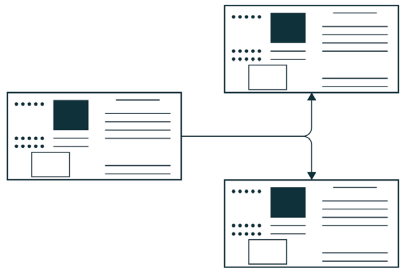


Fig. 74: Split up one pattern into two patterns.

The maximisation strategy consists of two parts in this research: maximisation and integration. This method is used to focus solely on one problem/ subject at a time, and with this subject, there will be a maximised design made. This will be done for each subject. In this project, the topics were the five water problems, urbanisation and nature. In the second phase of the maximisation, the subjects were combined and presented as a vision for Flevoland. The focus on one subject is difficult as an urban design student, because as a designer, the focus is on the bigger picture. It is always about connections between different subjects and how they could come together to improve an existing system/space. The maximisation in the end helped me visualise the patterns in a map, and in the end it became easier to see which patterns worked against each other, while others could be combined.

The result of the maximisation is still very broad. This could have been narrowed down further to see more spatial transformations in a map. Because two methods were used and the combination was difficult in the beginning, especially the start of the maximisation took longer than intended, the maximisation is less detailed than envisioned. For a future project, the maximisation should be developed earlier and better combined with the nature-based solutions.

Scientific relevance:
The final vision of the research shows where nature-based solutions could be implemented in Flevoland. This is done, based on the knowledge gathered from literature, policies and information from the waterboard. However, nature-based solutions in a Dutch polder have not been studied extensively, causing the project to be based on limited literature studies. This project could still be used as a framework in which more research could be done. For instance, there is still a missing link in the more detailed effects on urban areas for the design of nature-based solutions.

Societal relevance:
The urgency for the implementation of nature-based solutions is rising, and so is the urgency for this research. As said earlier, the temperatures will rise and the climate is changing (KNMI, n.d.). This project could be used as an inspiration or if it is implemented, it could help farmers, the waterboard and other stakeholders in the reduction of the effects of water problems. If it works in Flevoland in the polder, it could help other polders in the Netherlands as well.

Ethical considerations:
This research focused on the implementation of nature-based solutions for water problems, but the effects are the largest for the agricultural sector. This has been taken into account, but the focus was mainly on the nature-based solutions. Therefore, the agricultural sector was not the highest priority. This could mean that, because of costs, the realisation is not possible. Furthermore, in Zeewolde, farmers already often deal with water nuisance. If the groundwater level becomes higher, the water will take to go away during heavy rainfall. This leads to more crop damage for farmers and is therefore not cost-effective.

If the vision is entirely finalised and implemented, good research and participation are needed. Particularly for those farmers who are already experiencing water problems.

Internship:
During the last half year of the master's thesis, I started an internship at the waterboard Zuiderzeeland. This internship made me more aware of how the different water problems are related and how they affect each other. But it also made me realise that the different water problems are much more complicated than I first thought. The waterboard was a completely new learning community than the learning community from the university.

Kilpatrick et al. (2003) explain that learning communities are a group of people linked together by shared interest and are a powerful tool for cultural development. It has the potential to create new knowledge, and there is a chance for sharing knowledge as well.

The learning community became visible at the beginning of the internship. The colleagues from the waterboard reacted differently to my research than people at the university. It is interesting to watch how colleagues at the waterboard react to urban design. One of the colleagues called it a fresh breeze of air, because I did not look at the political discussions behind nature-based solutions, as this was not the scope of my project. In such moments, I realised that I am part of a learning community that does not entirely fit in at the waterboard yet, because the mindset and the view towards design are very different. During this half year, from my perspective, two completely different worlds, two learning communities, came together through my project.

The other perspective of nature-based solutions:
In this research, only the benefits of the nature-based solutions are discussed. Cost effectiveness and the costs for realisation are not taken into account in this project, because these are often not visible. Seddon et al. (2020) explained that it is difficult to measure or predict the effectiveness of NbS, which leads to uncertainty about cost-effectiveness compared to other (technical) solutions. Second, inadequate financial models and flawed approaches to economic appraisal lead to under-investment in NbS. Last, sectorised governance leads to hindrance in the uptake of NbS, while still creating space for grey interventions for climate adaptation and mitigation. To overcome these challenges, the system requires a systemic change in how interdisciplinary research is conducted and communicated (Seddon et al., 2020).

The systemic change in interdisciplinary research is not done in this research. Therefore, the effects on costs should be calculated and researched before the discussion of implementation can be discussed.

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Appendix

Excel calculations for water storage

Excel calculation for water storage

Kolom1	Diepte wateroverlast in cm	Diepte wateroverlast in m	Opp. inundatie	Opp. Inundatie in %	In peilvlak 1	In peilvlak 2 in m2	Peilvlak 1 m3	Peilvlak 2 m3	Peilvlak in m2	Peilvlak in m3
	0,08	0,08	14466673,1	4,2%	11505804,8	2960868,3	920464,4	236869,5		0
	0,16	0,16	5630222,241	1,6%	2873863,028	2756359,213	459818,1	441017,5		0
	0,23	0,23	2004359,7	0,6%	434850,6	1569509,1	100015,6	360987,1		0
	0,31	0,31	1203574,4	0,3%	249776,551	953797,8	77430,7	295677,3		0
	0,39	0,39	206905,1	0,1%	0	206905,1	0,0	80693,0		0
opp. water	0,391	0,00391	6901000,0	2,0%		6901000,0	0,0	26982,9		0
Totaal			30412734,48	8,8%			1557728,8	1442227,2		0
Totaal peiloppervlak					**16737016,3**	**146061,415**			**345.050.000**	34505
Max waterstand m					-4,809	-4,727				0
Streefpeil m					-6,2	-6,2				0
bgin inundatie					-5,2	-5,2				0
WS-Streefpeil m					1	1				0
Hoeveel m2 heb je nodig bij WS-Streefpeil?							**1.557.729**	**1.442.227**	**2.999.956**	299,995607

BIJ 1 m diep	1248,090077	1200,927654	1732,038126	
Bij 0,5 m diep	1765,065914	1698,368175	2449,471808	
		Totale m2	2999956,1	1732,0:
			954915,6752	
		Straal voor cirkel	977,197869	
		Diameter	1954,395738	
		0,86942648		

Oppervlaktes van beekdalen	id	Opp.	opp._1	oppervlakt	OPPERVLAK
MultiPolygonZM (((148892.035455	2	0	0	0	7670
MultiPolygonZM (((148999.142667	3	0	0	0	24024
MultiPolygonZM (((149675.199727	4	0	0	0	47054
MultiPolygonZM (((151988.074696	8	0	0	0	50555
MultiPolygonZM (((152989.572901	9	0	0	0	77963
MultiPolygonZM (((150502.305421	5	0	0	0	79133
MultiPolygonZM (((152552.905036	10	0	0	0	92656
MultiPolygonZM (((151993.567373	7	0	0	0	114440
MultiPolygonZM (((148427.303098	1	0	0	0	168375
MultiPolygonZM (((151408.597215	6	0	0	0	391677
					1.053.547