Restoring Rivers

Integrating a renaturalised Maas river basin with the cultivated landscape to enhance climate resilience

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Abstract

River basins are becoming increasingly vulnerable to climate change. The Maas (Meuse), a rain-fed river, depends on precipitation for its discharge. Changing rainfall patterns are expected to intensify floods due to wetter winters and summer storms, while also increasing water shortages in summer. Historically, the river naturally adapted to extreme changes in discharge, but the engineered, fixed-course river landscape has reduced its resilience and adaptability.

Renaturalisation of the river morphology could restore these natural processes. However, this requires a transformation of the surrounding ecological, agricultural, and urban landscape. Therefore, this thesis investigates how the cultivated landscape can be integrated into a more natural river system in the Noordelijke Maasvallei by 2100, under the most extreme dry and wet scenarios following a systemic design approach. A pattern language defines measures related to renaturalisation, ecology, agriculture, and urbanisation. The maximisation method then identifies the best spatial outcomes per theme as input for the integrated design.

The research led to an integrated design for the Noordelijke Maasvallei, where the Maas has space to flow and sedimentate naturally. This improves the water safety, water quality, and ecological resilience of the area towards 2100. The design applies measures from the pattern language across multiple scales, revealing different possibilities to enhance climate resilience for the river, ecological, agricultural, and urban landscapes. The systemic approach of this research allows for transferability to other contexts. Although this design prioritises renaturalisation and ecological resilience, the focus can be shifted by adjusting the inputs from the maximisation method. Furthermore, the pattern language provides a toolbox with measures that can be used separately and in different contexts. Overall, this thesis demonstrates the potential of restoring rivers to enhance climate resilience when the landscape adapts to the river, rather than forcing the river to fit human needs.

Keywords | River renaturalisation – climate resilience – landscape integration - systemic design – River Maas - Noordelijke Maasvallei


De Maas bij Neer - Peter Cox

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Reading guide

This thesis consists of five main chapters, with subchapters as outlined in the table of contents. This reading guide briefly explains the content of each chapter.

The first chapter introduces the problem by outlining the broader context of the Maas river basin. It explaines the pressures from climate change and human interventions. It concludes with the problem statement, research area and research questions.

The second chapter describes the methods, theories, and concepts used within this thesis.

In the third chapter, the river, ecological, agricultural, and urban systems of the Noordelijke Maasvallei are analysed. It concludes with SWOT analyses and a Future Autonomous Situation for 2100, highlighting the system's strengths and opportunities, as well as the weaknesses and threats that require change.

The fourth chapter explains the design phase of this thesis, including the use of the pattern language and maximisation method. It concludes with a proposed design for the Noordelijke Maasvallei towards 2100.

Finally, the fifth chapter presents the conclusion of this thesis, followed by a discussion of limitations and recommendations. It ends with a reflection on the project's approach, outcomes, and implications.

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Motivation

The Netherlands is known for its river delta and one important river in this system is the river Maas (Meuse). The Maas is a transboundary river flowing from France, where it enters the Netherlands in Zuid Limburg. The river is important for the country, as it is used for transport and other means. However, climate change has made the river flow volatile between extremes. Discharges of the river Maas have become limited in summer, and periods of drought across the basin are becoming more common. Moreover, in 2021, high water surges and summer rainstorms flooded large parts of Limburg. On top of this, due to climate change more rainfall is expected in winter, so there is still a need to strengthen the dikes. (KNMI, 2023)

So, every year, the impacts of climate change become more visible and create large fluctuations in river discharge, especially for the Maas, a rain-fed river dependent on precipitation. These changing weather patterns impact the entire basin. Consequently, protection from both increasing water shortages and high water surges is necessary. (IRM, 2023)

Since the first settlements, people have used and battled the river. Since the industrial revolution, the Dutch economy has become heavily dependent on it and dikes have been built to protect the growing towns and cities. The river is used for transportation and water extraction. It is connected to the water system of the surrounding land, providing water for agriculture, drinking water, and nature areas. However, the river has been completely altered over the years. In the past, it was free to meander and create branches, but today dikes, dredging, and weirs confine the river to a fixed course. The natural river system was able to adapt to changing weather conditions. However, now the Dutch cities keep heightening dikes and deepening the riverbed, which has removed the river's natural capability to adapt. Consequently, this has increased the landscape's vulnerability to both extreme flooding and prolonged drought.(Kleinhans et al., 2013)

This thesis will investigate ways to make the landscape surrounding the river system resilient to climate change and the impact it brings by looking at the original natural system. It will show ways to restore a (partly) natural river flow and how the cultivated landscape can adapt. Society has prioritised its own interests and benefits over the health of the ecosystem, rather than considering the needs of the ecosystem itself. A resilient ecosystem is able to adapt and change, yet current practices resist these natural processes. Therefore, I will investigate possibilities that examine the natural water system first, and then find ways to integrate other land uses. Change is necessary and restoring rivers could be the answer.

Figure 1.1: Low water in the Maas (Rijkswaterstaat, 2022).

Figure 1.2: Floods of 2021 in Limburg (NU, 2022).

Introduction 1

This chapter introduces the problem by outlining the broader context of the Maas river basin. It explains the pressures from climate change and human interventions. It concludes with the problem statement, research area and research questions.

1.1. Problem context

1.1.1. The Maas river basin

The Maas (Meuse) is a short transboundary river of 905km. It is a rain-fed river with its origin on the Langrès plateau in France and a total catchment area of 35,548 km² (Descy et al., 2022). From the plateau it flows towards the Ardennes in Belgium and on towards Zuid Limburg in the Netherlands. From here it flows through Limburg north and then west, where it partly merges with the Rhine, creating a delta. It then flows out in the North Sea in the Hollands Diep. Van der Krogt et al. (2022) divides the river basin into four parts: Upstream (Lorraine), the Ardennes, Midstream and Downstream (see figures 1.3 and 1.4) The four parts of the basin all have distinctive characteristics.

Upstream

Upstream, the Maas basin is long, narrow and has a small gradient with a wide winter bed (Kramer, 2021). This creates a relatively calm discharge until the Chiers tributary. The permeable limestone in the area allows quick infiltration when excess water is caught in depressions of the sloping terrain. It is the most natural part of the river and has suffered the least amount of human interference. However, the water is used for drinking water extraction, irrigation for the arable farming in the area, and industry cooling for power plants (Kramer, 2021; Descy et al., 2022).

The Ardennes

The Ardennes is the largest part of the basin and contains important tributaries, including the Sambre, Semois, Viroin, Lesse, and Ourthe (Kramer, 2021). The gradient is steep, and the narrow river and its branches are incised into bedrock. The soil in this area is almost impermeable due to the presence of rocks such as slate. This, combined with the steep slopes, results in rapid runoff during rainfall events, making the Ardennes the main source of high water surges farther downstream. The area is mainly occupied by forest and agriculture. In this part of the basin, the river has been more heavily modified to meet human needs. Reservoirs are created for industrial cooling, and the Sambre (the most important tributary) has been canalised in certain parts to accommodate transport.

Midstream

The Midstream basin consists of the triangle Dinant-Namur-Liege and then goes north until Maasbracht in the Netherlands (Kramer, 2021). It has a lower gradient than the Ardennes, with more permeable soils like limestone and loess. The water supply is low but constant, making tributaries important in dry periods. Land use includes urbanisation, agriculture, and some forestry (Kramer, 2021). The Midstream water is important for Belgium, as 40% of water from the Albertkanaal is used for drinking water, making a constant flow crucial. From Maastricht, the Juliana Canal and Zuid-Willemsvaart diverge from the Maas. They require a constant discharge for shipping, which places pressure on the river system, especially during dry periods.

Downstream

The Downstream part stretches from Maasbracht to the Hollands Diep and includes important tributaries like the Ruhr, Niers and Dieze (Kramer, 2021). The Ruhr is fed by reservoirs and is a crucial factor for managing both low discharges and flood peaks. The Dutch part of the Maas is heavily modified, first to deal with flooding, but now also to accommodate increasingly larger ships. The river is straightened and diked, especially in Noord-Brabant where it partly merges with the Rhine. In northern Limburg, the Peel nature reserve relies on canal-fed flows to maintain groundwater levels, which are threatened by drought (Rijkswaterstaat Zuid-Nederland et al., 2022).

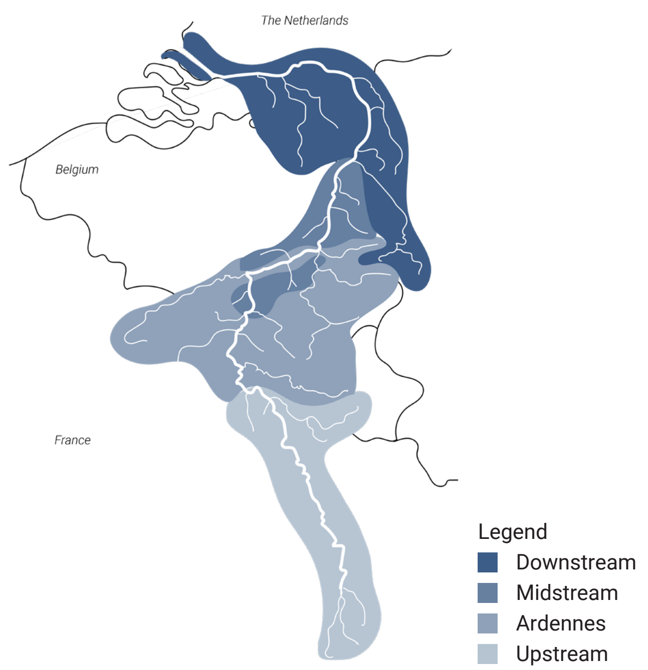


Figure 1.3: Divisions of the Maas river basin. Based on IRM (2023).

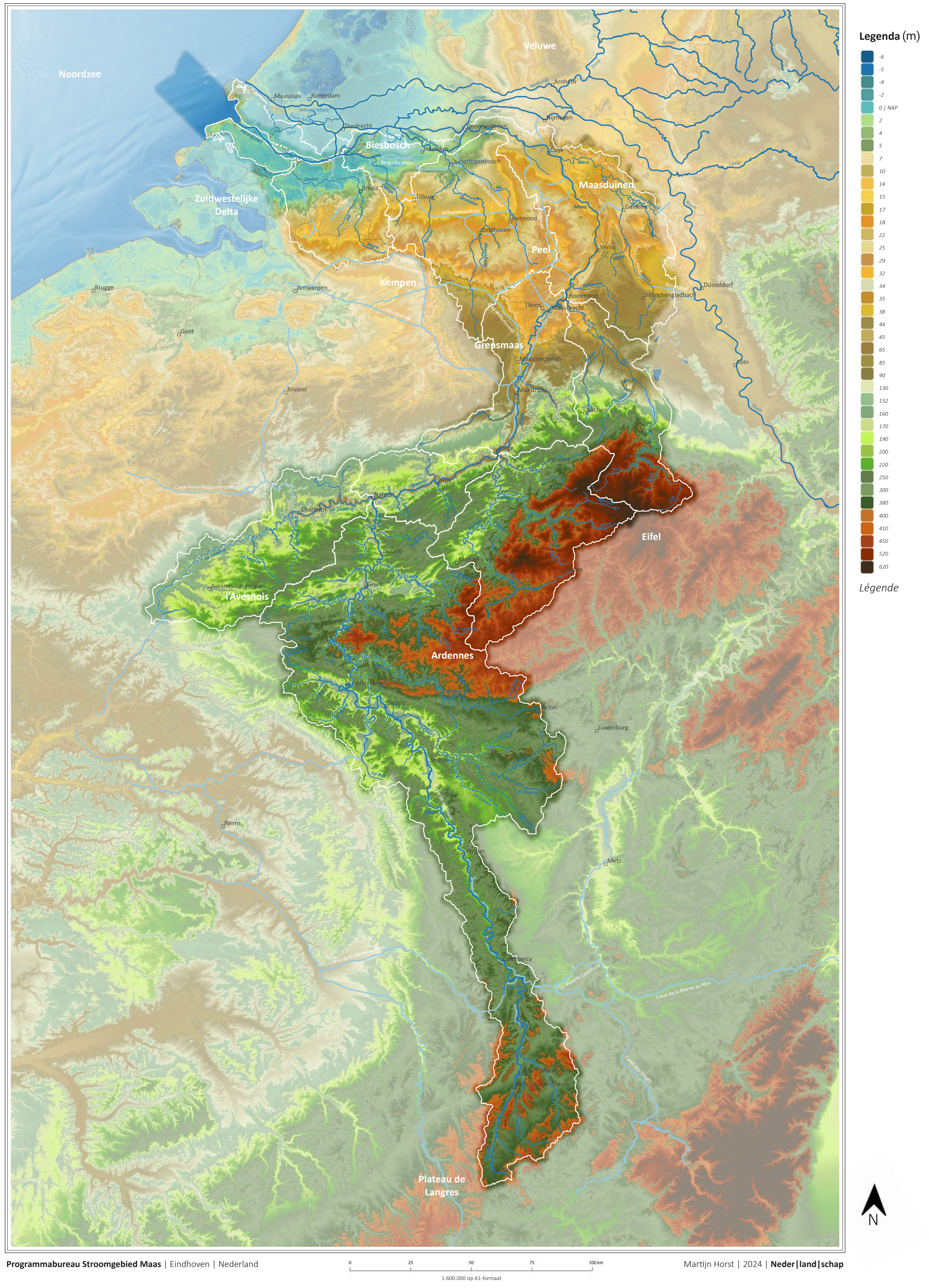


Figure 1.4: Height map of the Maas river basin (Horst, 2024).

1.1.2. A rain-fed river

As the Maas is a rain-fed river, fluctuations in precipitation have a significant impact on its discharge. The discharge of rain-fed rivers is dependent on the amount of rainfall supplied by the tributaries as well. Consequently, differences in high and low discharges can be extreme. As a comparison, the highest measured discharge of the Maas is 150 times more than the lowest measured discharge, compared to the Rhine (a mixed river of both rain and meltwater) where the highest discharge is 'only' 20 times more (NCR, 2023). Furthermore, the discharge of the Maas is difficult to predict. A quick shift in precipitation upstream in Belgium and France can drastically change the discharge of the river downstream. A heavy rain shower in the Ardennes, for instance, can send a surge of high water over the Dutch border in less than twelve hours (Deltares, 2021).

Changing water discharges impact the Midstream and Downstream parts of the river basin the most. For periods of drought, agreements have been made between Belgium and the Netherlands to divide the water for maintaining shipping on the canals and natural river flow of the Maas. In periods of heavy rainfall, excess water from the Ardennes will be redirected away quickly due to the gradient, causing floods downstream, especially if it is raining there as well.

Because most issues arise in the Midstream and Downstream part of the basin, the focus of this thesis will be on accommodating extremely low and extremely high discharges in the future in this part of the river. This will be further elaborated in chapter 1.3, with a specific focus on the Netherlands.

1.2. Problem field

1.2.1. Climate change

The impact of climate change is becoming more visible every year, with higher annual temperatures and more extreme periods of rainfall and droughts (KNMI, 2023). These impacts are only expected to worsen. Therefore, the Royal Dutch Meteorological Institute (KNMI) has developed four climate scenarios predicting the future of the Netherlands based on high or low carbon emissions until 2080, and whether the climate becomes wetter or drier (KNMI, 2023). In the "wet" scenario there is a strong increase of precipitation in winter and a weak decrease of precipitation in summer. In the "dry" scenario winter precipitation only increases slightly while summer precipitation decreases strongly.

For a rain-fed river such as the Maas, these fluctuations in precipitation have a significant impact. Three variables have the largest impact on its discharge: precipitation, drought, and summer storms.

Precipitation

Since 1906 annual precipitation has increased by about 20% in the Netherlands (KNMI, 2023). Winter precipitation, especically has increased significantly over time. This will continue to grow in all four of the KNMI scenarios, due to winds being expected to come more often from the west (carrying moist air from the Atlantic Ocean). Summer precipitation has risen since 1906 as well. However, in all scenarios it is expected to drop. This is because of the expectation of more winds coming from the east, carrying dry continental air.

More precipitation in winter will lead to a higher river discharge, especially with precipitation also increasing upstream (IPCC, 2023). With higher discharges, the chance of floods will increase if no changes to the protection system are made (KNMI, 2023). As of now, the local water system would have issues with the disposal of the predicted discharge (IRM, 2023). This will create issues for the outer dike areas, which are often agricultural. Moreover, high discharges can also be dangerous for shipping. Not only will high discharges come from upstream, but the rising sea level could also push the issues farther inland (IRM, 2023).

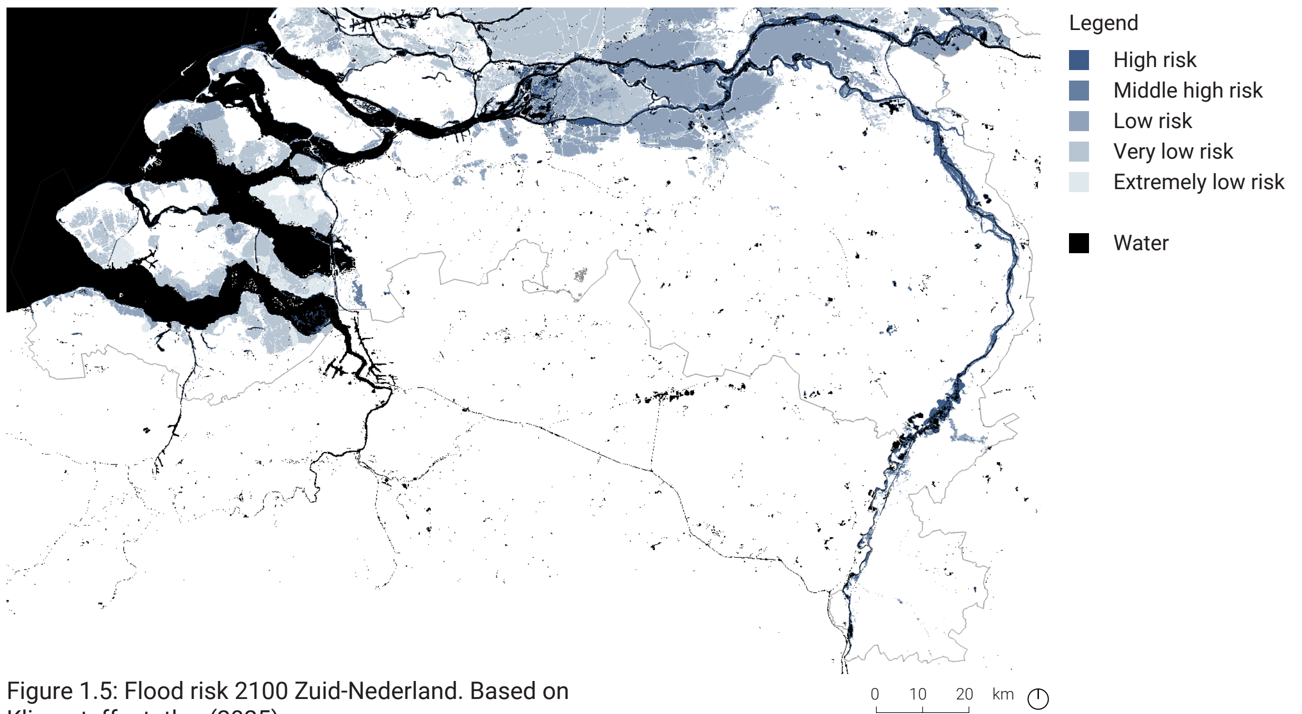


Figure 1.5: Flood risk 2100 Zuid-Nederland. Based on Klimaateffectatlas (2025).

Drought

With a decline of summer precipitation, the incidence of extreme drought is expected to increase (KNMI, 2023). A period of drought happens when there is less precipitation than average, more water evaporating, or both, leading to water shortages. As precipitation in summer is expected to decrease, and temperature expected to increase, periods of drought are expected to occur more often. Although precipitation and evaporation fluctuate every year, the number of dry periods overall is expected to grow. In the most extreme scenario, an extreme dry period today, will become an average dry period by 2100.

More periods of drought in summer will lead to longer periods of low river discharge. Firstly, this will affect the water quality of the river and the connected water system (IRM, 2023). Downstream, this can lead to salinisation with sea water seeping into the river system. In extreme cases this could alter or decline river ecology severely. Secondly, less water will lead to less infiltration of water into the soil, which will cause soil desiccation. This will decrease the availability of drinking water, water for agriculture and water for nature. Thirdly, navigability of the river and the connected canals will be affected. Currently, the low discharges of the Maas are already lower than desired, and there are agreements on the division of water between the river and the canals used for shipping (Asselman et al., 2018). However, with dry periods becoming more common, following the agreement could become an issue.

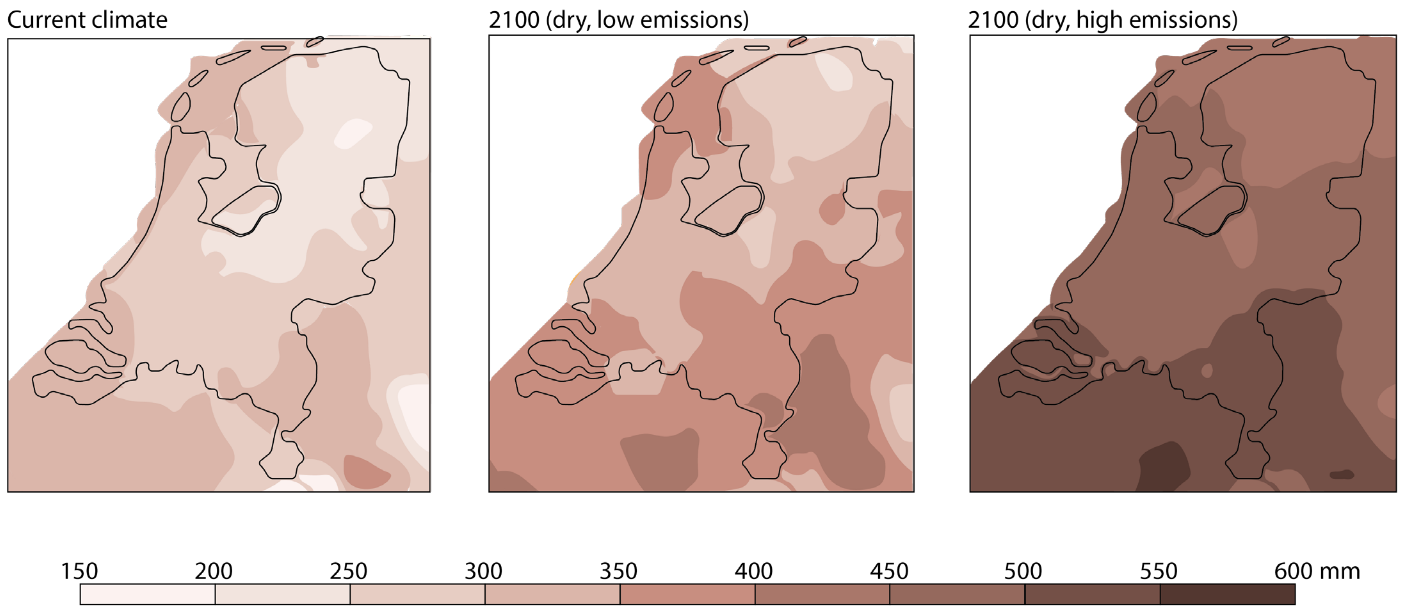


Figure 1.6: Maximum precipitation deficit in the 5% driest years in the current climate and the dry scenarios in 2100. Based on KNMI (2023).

Summer storms

Although total summer precipitation is expected to decrease, summer storms are expected to occur more frequently (KNMI, 2023). Rainstorms form when there is a large difference between surface and atmosphere temperature. Warm air ascends, cools down, and moisture condenses. If the cloud grows tall enough, the top freezes, leading to heavy rain or hail. In a warmer climate, air holds more moisture, causing more rain to fall in a single storm. All KNMI scenarios expect an increase in overall temperature and moisture in summer, increasing the likelihood and frequency of summer storms.

Summer storms are hard to predict, which can be especially difficult with predicting peak discharges of a rain-fed river with small lag times. This could lead to catastrophic floods, like in Zuid Limburg in 2021. During these floods, there was heavy rainfall in the Netherlands itself, and upstream in the Ardennes. Therefore, the main river Maas was already discharging large amounts of water into Limburg, but also had to deal with a large water supply from side branches. This caused the branches (such as the Geul) to flood. With increased frequency of summer storms, the likelihood of such an event happening again will grow if no changes are made to the system.

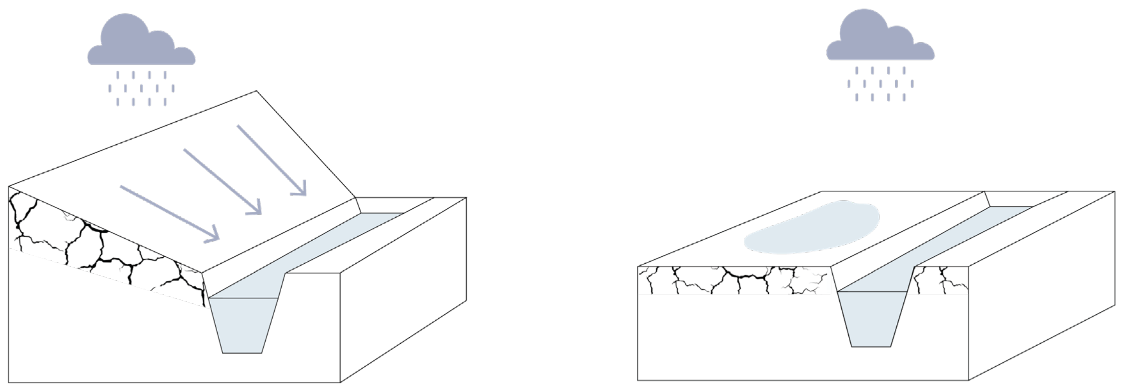


Figure 1.7: Consequences of summer storms on dry soil, upstream (left) and downstream (right).

1.2.2. The cultivated landscape

Control of the river

As mentioned before, the Dutch part of the Maas has been heavily altered for human needs over time. It started when the first settlements were built in the Middle Ages. Dikes were built to keep water from flowing onto the claimed land used for agriculture or housing (Kleinhans et al., 2013). Previously, the river was free to flow and often changed course when discharging large amounts of water. The water was able to thinly overflow the land and infiltrate into the soil. However, with these changes to control the river natural overflowing and slow infiltration was not possible anymore, thus increasing the water level of the river. Issues started arising as discharge distribution was difficult, and as people wanted to use the land reserved for flooding. Therefore, in the 17th century the river was "corrected", meanders were straightened, and canals were built to deal with excess water (Kleinhans et al., 2013).

The most extreme changes were made as a response to the Industrial Revolution in the 20th century. Mining had become a major source of income for Limburg and a more reliable route for shipping was needed (Disco, 1998). This resulted in digging new canals and dredging the riverbed to make sure sediment was not in the way of ships. Furthermore, the discharge of the Maas is managed by weirs to maintain a certain water level in the main river and the canals (van der Krogt et al., 2022). Although mining practices have stopped, transport over rivers is still very important in the Netherlands. Ships have grown over time and are still getting bigger leading to more dredging to remove excess sediment. However, this has completely changed the river discharge. The Maas barely has shallow areas anymore as it is being kept deep by dredging (Kleinhans et al., 2013). Straightening the river has shortened the total distance of the river, thereby increasing the river gradient (Asselman et al., 2018). As a result, the flow velocity has increased and high water surges flow down more quickly and decrease more slowly on their way to the sea. So, although the alterations to the river were originally for flood control, high water surges pose an issue to this day.

Water use

The Maas is not only being controlled for protection and shipping, but the water is also used for different purposes. Increasing periods of extreme drought would decrease water discharge and threaten the way the water is used.

A first water use is drinking water extraction. Extraction is especially done upstream of the river basin. Water from the Dutch Maas is used for drinking water in Limburg, and the Afgedamde Maas also serves drinking water for over one million people (Dunea, n.d.). With droughts, there would be less availability of drinking water. Additionally, certain pollutants take longer to flow out of the river basin with low discharges. With current discharge of sewage or industrial water, the dangers of extracting drinking water will only increase over time (NOS, 2025).

Moreover, water is extracted from creeks and canals for irrigation of agricultural land. In the north of Limburg, the Maas is connected to De Peel nature reserve. This area must have a constant water flow that is provided by canals from which the soil can take water to ensure a constant groundwater level (Seghers et al., 2025).

Furthermore, the basin is also connected to the groundwater system. In Roermond, for instance, large ponds have formed due to gravel extraction. However, gravel pit ponds work as a funnel and pull infiltrated groundwater towards them, drying out the region (Kuchovsky & Ricka, 2008). Increasing periods of drought will result in water shortages making these issues even worse, especially if the water is used as extensively as now.

Although swimming in the river Maas is forbidden, the Maasplassen are known for its recreational purposes. Swimming water needs a certain water quality, which will change with higher temperatures and more summer storms (Roijackers & Lürling, 2007). Pollution of certain bacteria and organisms that are harmful for humans is likely to increase with higher water temperature, especially blue algae. Higher temperatures lead to an earlier growing season of these bacteria. Moreover, extreme summer storms can lead to flooding of surface water bodies. When this water flows back, it could carry certain harmful organisms back into the water, decreasing the quality of the water even more.

Disturbed balance

Het verhaal van de Maas (the story of the Meuse) by (Asselman et al., 2018) lists four major issues the Maas is facing due to human interference that will continue to threaten the river basin in the Netherlands.

1. **The Maas has lost a lot of space**, resulting in water nuisance in times of high discharge.
2. **The summer riverbed is sinking** and there are no sedimentation processes. This makes the riverbed unstable, leading to unsafe conditions for shipping, and the loss of vegetation of the river edges.
3. **The low water discharge is problematic**, and will lead to water shortages in the future, especially if France and Belgium keep extracting water in the way they do now.
4. **River nature has been lost**, and biodiversity has declined due to straightening of the river, hardening of the river edges and removal of sediment.

So, human interference has completely changed the way the river flows and acts. Although the first alterations were to protect the land from the water, such alterations will not be able to keep up with changes from the expected drier summers, wetter winters and more frequent summer storms.

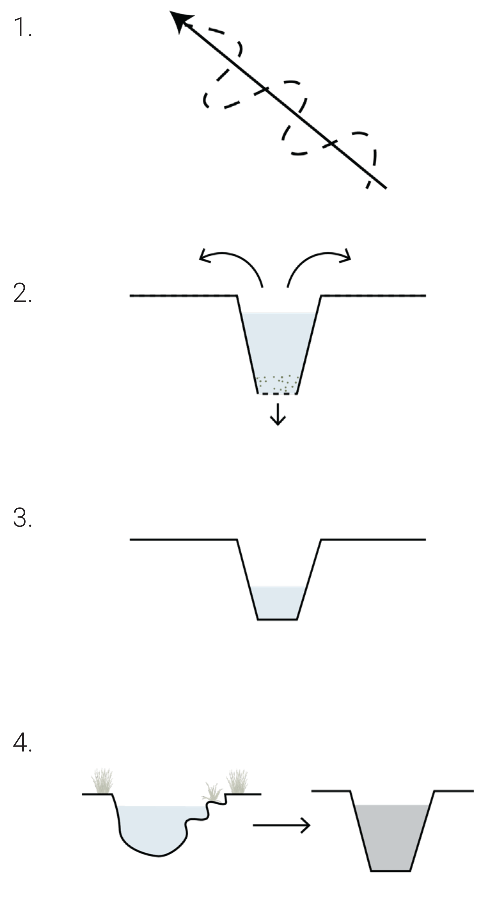


Figure 1.8: The disturbed balance of the Maas. Based on Asselman et al. (2018).

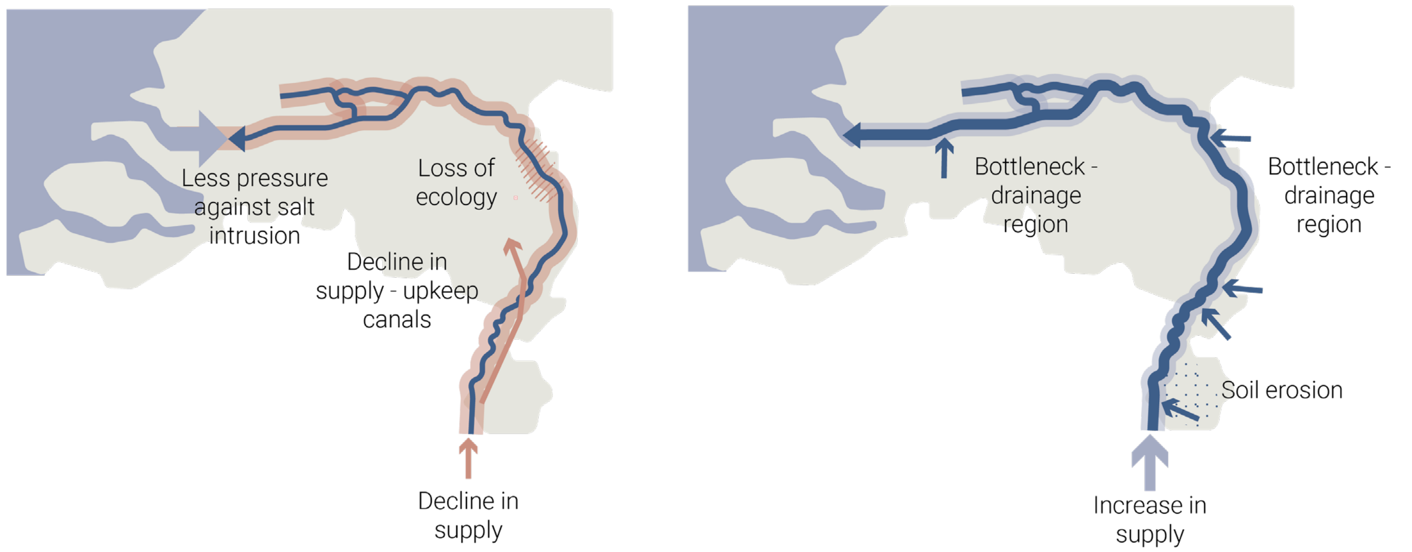


Figure 1.9 Threats for the river Maas for low and high water discharge. Based on IRM (2023).

1.3. Research area

1.3.1. Downstream Maas

The focus of this thesis will be on the downstream Maas and how this part of the river will deal with the dry and wet challenges of the future. Therefore, the focus will be on part of the downstream section, with a more specific focus on the Netherlands. Asselman et al. (2018) divides this area into six trajectories with different characteristics: Bovenmaas, Grensmaas, Plassenmaas, Zandmaas, Bedijkte Maas and Getijdenmaas.

This research focuses on the Noordelijke Maasvallei (Northern Meuse Valley) and includes the Plassenmaas and Zandmaas trajectories (see figure 1.14). This area has been altered by human activities in various ways, such as gravel extraction, canalisation, and dredging.

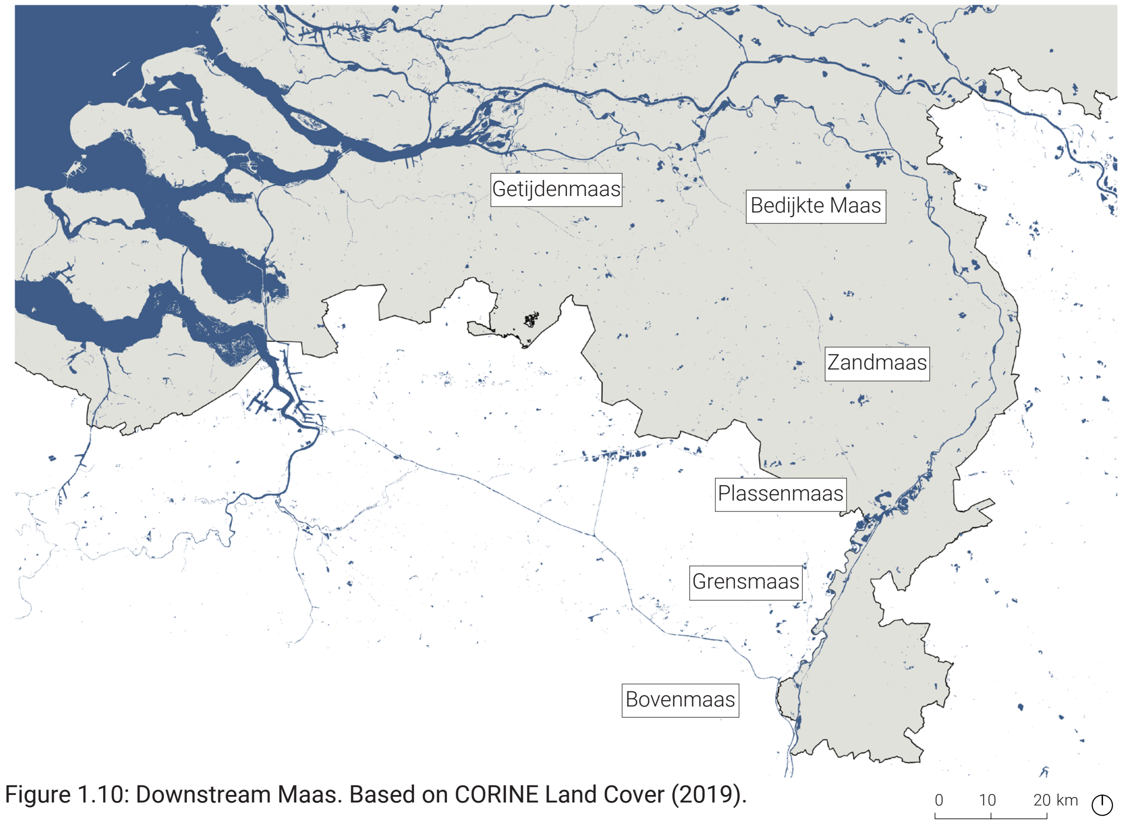


Figure 1.10: Downstream Maas. Based on CORINE Land Cover (2019).

1.3.2. Climate risk in the Noordelijke Maasvallei

The Noordelijke Maasvallei is already one of the downstream regions most prone to drought. This vulnerability is expected to increase in the future as can be seen in figure 1.11. The risk is a main reason for the focus on this area. This trajectory contains multiple ecological areas that are prone to drought and dependent on river discharge. Therefore, it is important to find ways to create a resilient and adaptive surrounding landscape, which is ecologically rich even during periods of drought.

Flood risk will remain a concern, but it is mainly limited to the areas surrounding the Maas and the Ruhr (see figure 1.12). However, 2021 showed that branches of the Maas can quickly flood in times of heavy rainfall and affected surrounding cities and towns. Therefore, this area will have to deal with both drought and floods making it an interesting case study for this thesis.

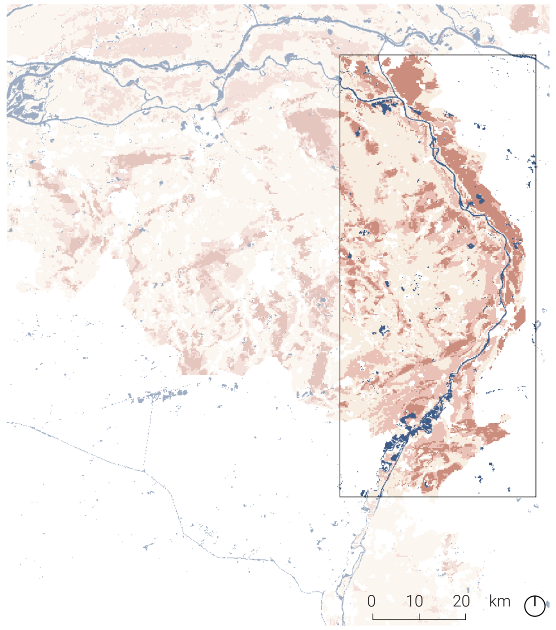


Figure 1.11: Drought risk 2050 high. Based on Klimaateffectatlas (2025).

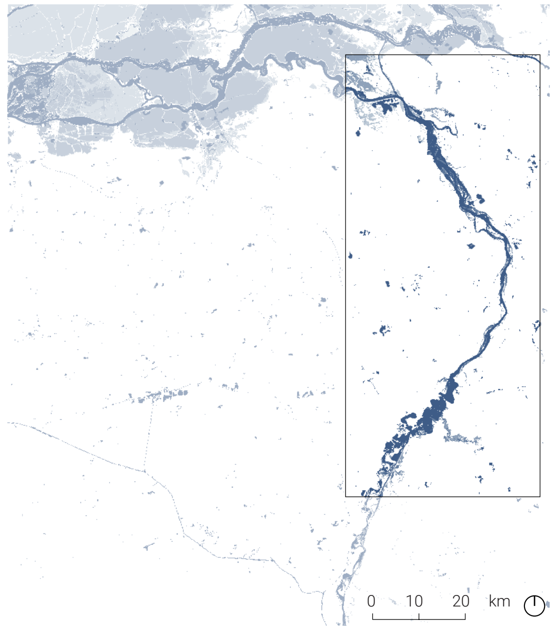


Figure 1.12: Flood risk 2050 high. Based on Klimaateffectatlas (2025).

1.3.3. Land use in the Noordelijke Maasvallei

The research area includes different types of land uses, including cities, towns, agricultural areas, and as nature reserves. It covers the northern part of Limburg, from Roermond to Cuijk, and includes larger cities such as Venlo and Weert. Because the Maas River is an important water source for the surrounding nature reserves, national park De Groote Peel, just across the border in Noord-Brabant, is also included in the research area. Another important nature reserve is De Maasduinen, with the longest row of river dunes in the Netherlands. Agriculture is the other main land use.

The research will focus on this area because of the expectations for climate change by 2100, and the alterations that are created over time. Moreover, there are plans for Noord-Limburg, which creates future opportunities for change in this area.

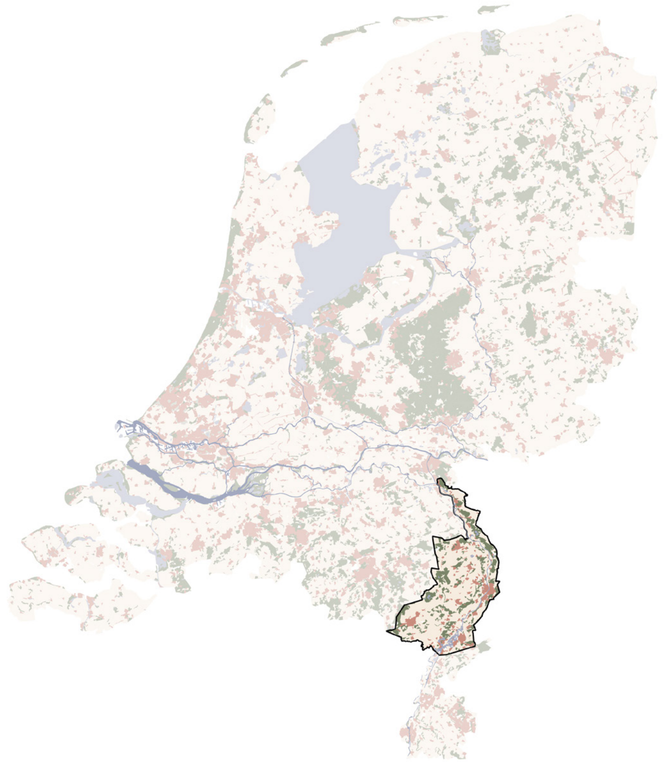


Figure 1.13: The Noordelijke Maasvallei. Based on CORINE Land Cover (2019).

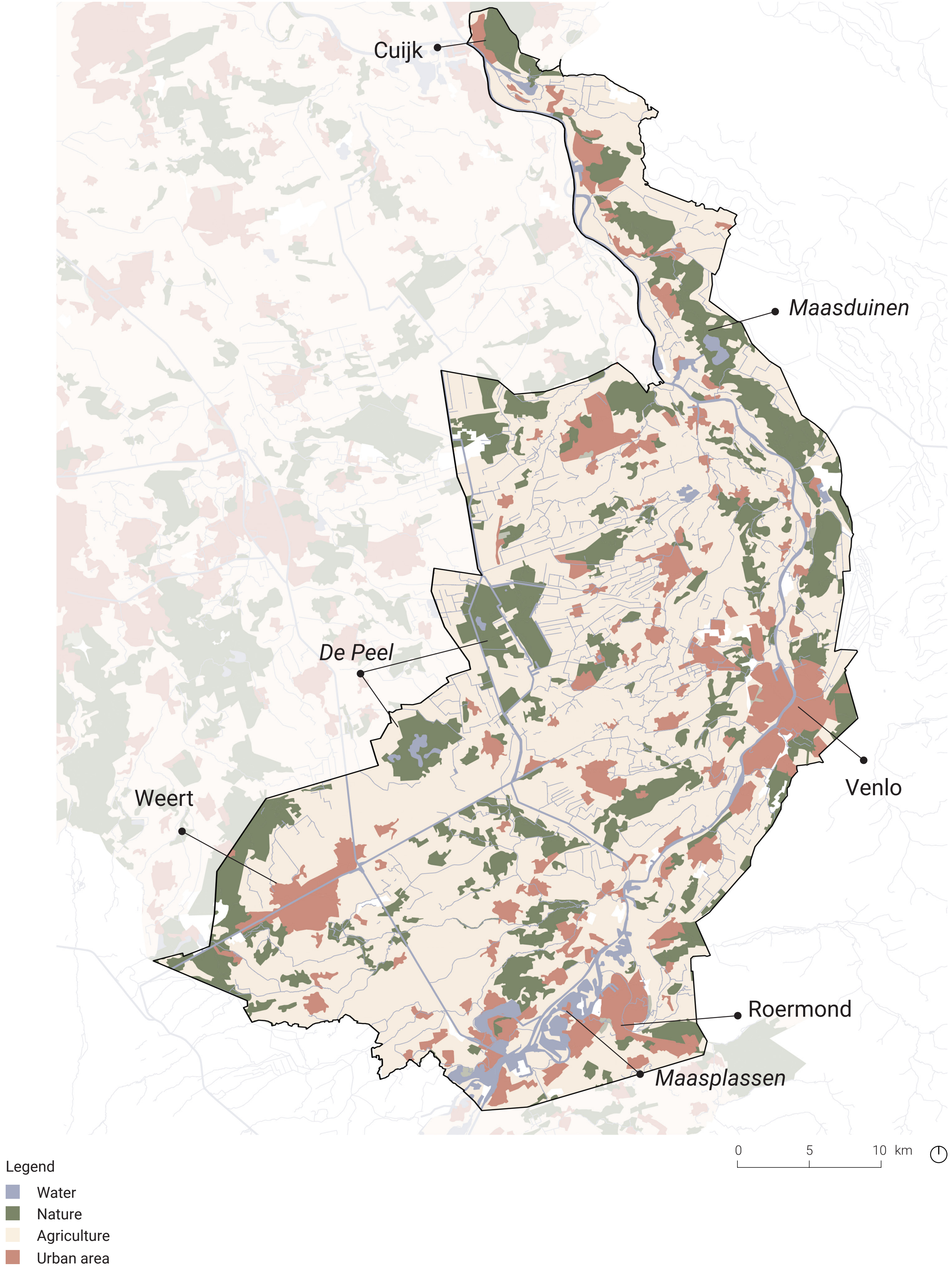


Figure 1.14: Research area - The Noordelijke Maasvellei. Based on CORINE Land Cover (2019).

1.4. Problem statement

The effects of climate change are becoming more visible every year. Precipitation patterns are shifting, with wetter winters and drier summers leading to more extreme droughts, while unpredictable summer rainstorms are becoming more frequent. Even if emissions were to drop, all these factors are expected to intensify over the next 75 years (KNMI, 2023). The Maas, a rain-fed river, is dependent on precipitation for its discharge, and these shifting patterns could become catastrophic, causing flooding due to wetter winters and summer storms, as well as growing water shortages in summer. These issues are not only shaped by conditions downstream, but are also heavily influenced by upstream discharge from France and Belgium. High water surges arrive downstream rapidly, while during low discharge, water may be used upstream before reaching the Netherlands (IRM, 2023). As the problems escalate, **there is a growing need to store and accommodate water downstream**.

In addition, the Maas has been heavily altered over time to support human needs, and is now far from its natural state (Asselman et al., 2018). The entire downstream section is managed by weirs, with large parts canalised and dredged to accommodate shipping. This has resulted in a loss of space for the river, a decline in riverine nature, and a sinking, unstable riverbed. In the past, the river was able to adapt to changes in discharge, but without its natural processes, the Maas is no longer resilient to climate change in this way. Renaturalisation of the river morphology, restoring natural processes that allow room for excess water and create a landscape adaptive to drought could be a pathway to a more resilient basin (Baffert & Casey, 2024). However, the current landscape has been shaped around the engineered river, and **renaturalising the basin would require a shift in land use**. A transformation of the cultivated landscape, integrated with a more natural river flow, is therefore necessary to ensure climate resilience.

With current trends in climate change, there is a need for a change in land use, in which the river and the surrounding land will be able to cope with the unpredictability in weather and discharge from the entire river basin.

Problem framework

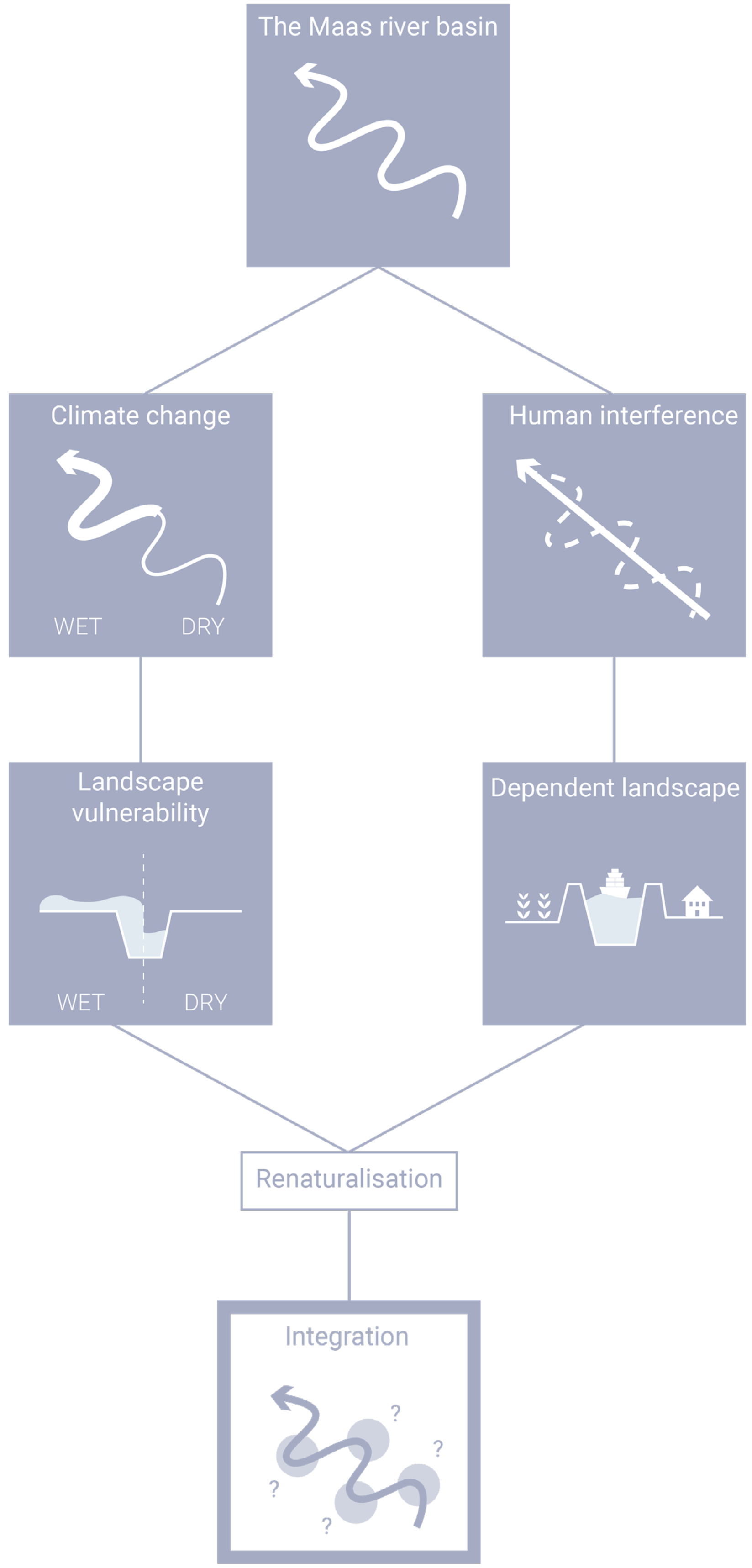


Figure 1.14: Problem framework.

1.5. Research questions

Research aim

The aim of this thesis is to investigate new opportunities for the landscape in the downstream Maas river basin to adapt to increasing extremes of drought and precipitation. Through the lens of renaturalisation, it investigates how a cultivated (urban, agricultural, ecological) landscape can be integrated with a more natural river system to create a resilient and adaptive environment. The goal is to design a pathway towards 2100, presenting multiple nature-based solutions that are needed to create a resilient river basin in times of drought and rain. A selected region will be used to test and show how these solutions can be spatially implemented.

This thesis will look at the Noordelijke Maasvallei as a case study to answer the following questions:

Main research question

How will renaturalisation of the river Maas as a climate resilience strategy transform the Noordelijke Maasvallei under the most extreme dry and wet scenarios by 2100, and how can the ecological, agricultural, and urban landscape evolve with this transformation?

Sub research questions

1. How does the renaturalisation of rain-fed rivers enhance climate resilience?
2. How have the Maas river basin and the Noordelijke Maasvallei changed over time, and what role have human interventions played in this?
3. What are the current opportunities and threats for the Noordelijke Maasvallei spanning the ecological, agricultural and urban landscape, in relation to the river Maas?
4. How would the Noordelijke Maasvallei's ecological, agricultural and urban landscape evolve under the given existing conditions by 2100?
5. What interventions are needed to renaturalise rain-fed river basins, and what interventions are required in the ecological, agricultural, and urban sectors to respond to this transformation and strengthen their climate resilience?
6. How can the cultivated landscape be integrated into a renaturalised Maas river basin in the Noordelijke Maasvallei under the most extreme wet and dry scenarios by 2100 and what are the spatial implications?

The cultivated landscape is divided into the ecological, agricultural and urban landscape.

Method 2

This chapter describes the methods, theories, and concepts used within this thesis.

2.1. Methodology

2.1.1. Methodological background

Systemic design

This thesis follows a systemic design approach to integrate water, ecology, agriculture, and urbanisation into a coherent spatial vision for the Noordelijke Maasvallei. Systemic design is a design approach that combines systems thinking, which studies complex, interconnected problems and their interactions, and design methods, which create practical solutions and spatial interventions (Jones & Kijima, 2018). In this thesis, the river basin is seen as a complex system in which hydrological, ecological, agricultural, and urban subsystems interact across scales. The pattern language and maximisation method make this approach operational: patterns provide building blocks, maximisations explore the best solution for each theme, and the integrated design brings these solutions together. In this way, the design not only addresses individual challenges, but also considers the interactions between different parts of the river landscape, supporting a more adaptive and resilient area.

SWOT analysis

A SWOT analysis examines the strengths, weaknesses, opportunities, and threats (SWOT) of a system or area. It can be applied in different ways, but in this thesis, it is used to conclude the analysis of the various themes of the system. In addition, it provides a starting point for the pattern language and helps formulate the evaluation criteria.

Future Autonomous Situation (FAS)

To understand the urgency of change for the Noordelijke Maasvallei, a Future Autonomous Situation (FAS) is used to conclude the analysis. A FAS shows how a system might develop in the future if no changes are made to the current approach. It highlights the specific threats and weaknesses of the area, making clear where solutions need to be found.

The pattern language

In this thesis, the pattern language will be used to design and collect interventions that will be used to create a design for the research area. The pattern language is a method introduced by architect Christopher Alexander in 1977, and helps to understand and design complex systems, including landscapes (Salingaros, 2000).

A pattern language consists of patterns, which are design principles, providing a systemic way to present solutions while always describing the related problem. Each pattern consists of a theory supporting a hypothesis, practical implications, time, scale, and an informative illustration (Rooij & van Dorst, 2020). This way, interventions are clearly communicated and transferable to different areas.

A limitation of the pattern language is that often the relation between patterns is neglected (Salingaros, 2000). It is important to consider the pattern language as a whole and be reminded of the impact patterns can have on each other as well as the environment. Therefore, the pattern language of this thesis includes an an analysis of which patterns are related or conflict with each other.

In this thesis, the pattern language is not only used to show possible interventions, but also forms a starting point for the maximisation method.

The maximisation method

In this thesis, the maximisation method is used to find the best solutions per theme, to develop a well-integrated design (Aalbers, 2025). It shows the choices made during the process of creating the plan and provides insight into how different solutions interact. Usually, the maximisation method is used in three phases: maximisation, optimisation and integration. However, for this thesis, the focus is on maximising and integrating, for which patterns will be used.

This thesis applies the method to integrate four themes: water, ecology, agriculture, and urbanisation. The maximisations indicate the best possible solutions for each theme, which are then combined. In the integration phase, specific choices are made that best fit the research aim. The method shows which solutions were prioritised and why, making it possible to review and adjust the design by reflecting on the maximisations. In this way, the maximisation method guides the design while keeping the reasoning behind each choice transparent.

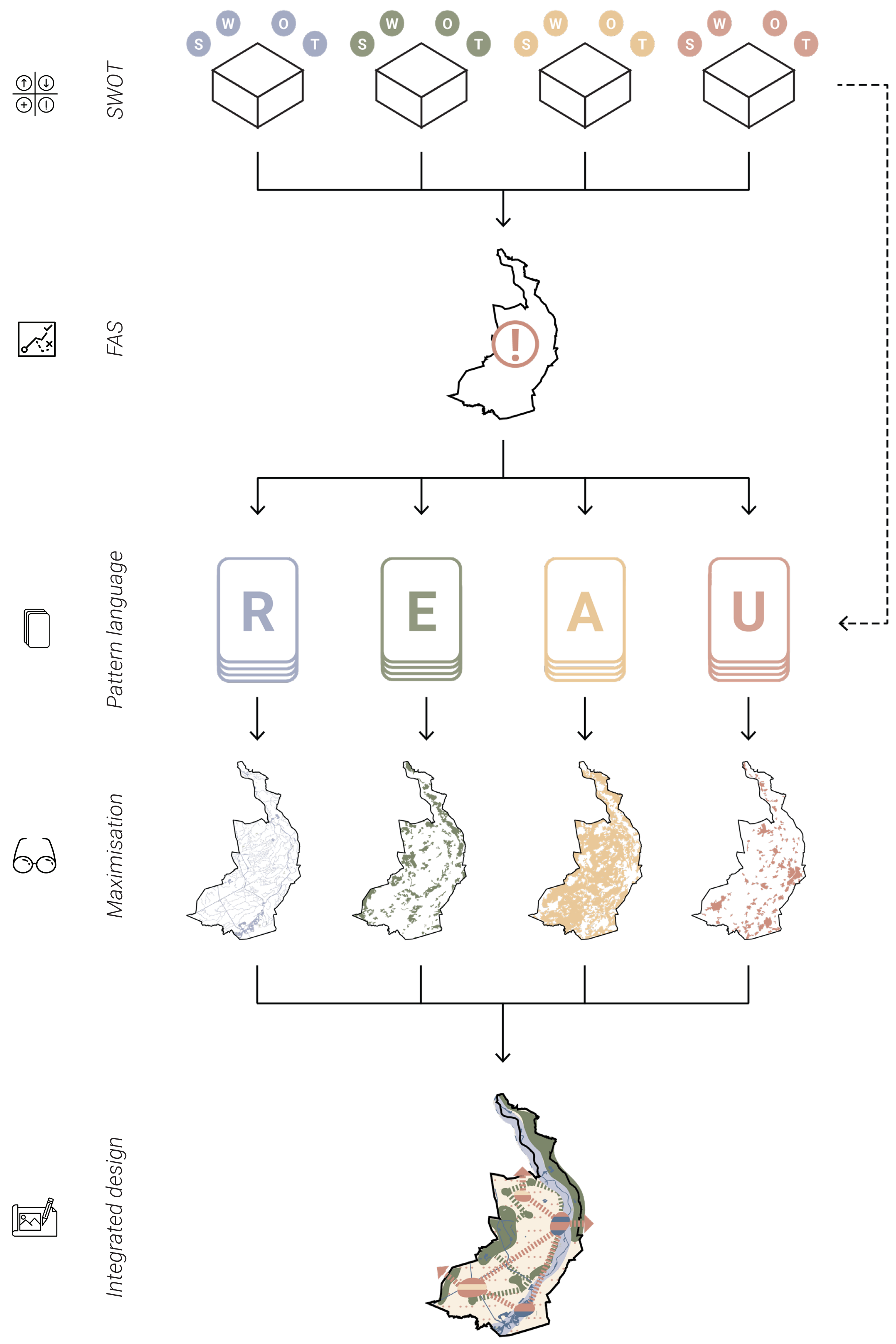


Figure 2.1: Systemic use of methods within this thesis.

2.1.2. Methodological framework

Figure x.x presents the methodological framework of this thesis, consisting of five phases: problem definition and theory, analysis, pattern building, design, and evaluation. The sub-research questions, with their methods and outcomes, are assigned to these phases.

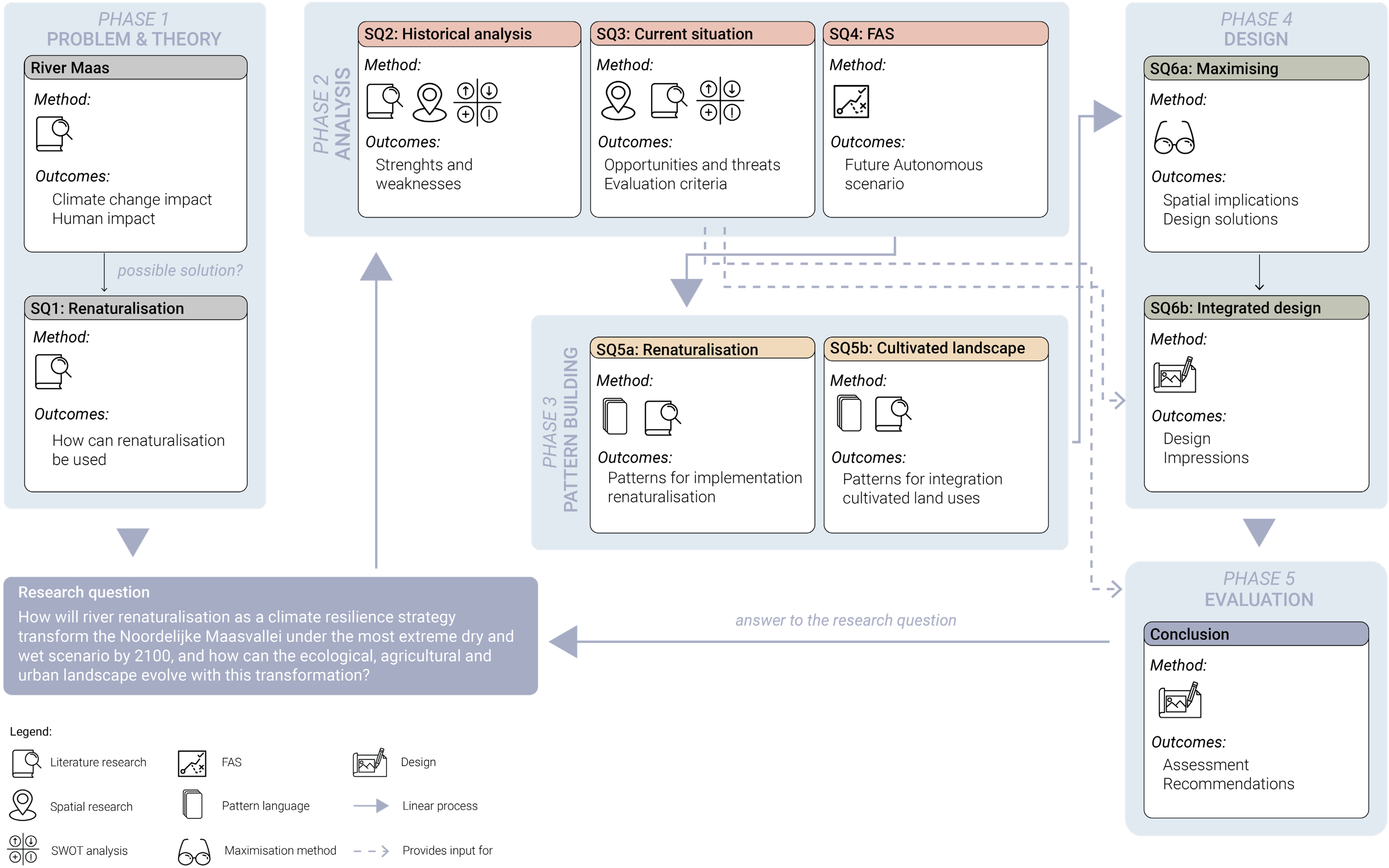


Figure 2.2: Methodological framework.

2.2. Theoretical underpinning

This chapter discusses six different theories and concepts that are used in this thesis. The first three, evolutionary resilience, adaptive planning and water and soil led planning, form the background basis of this thesis. The others, including renaturalisation of rivers, nature-based solutions and ecosystem services, will be used more directly in the design process of this project.

2.2.1. Evolutionary resilience

The term "resilience" comes from the Latin word resilire, which means "to spring back". Therefore, resilience is often described as the capacity to bounce back to a stable state after a shock (Davoudi et al., 2013). It has become an important term over time when talking about climate change, almost replacing "sustainability" as the main notion (Davoudi, 2021). Resilience would allow people and places to deal with sudden shocks, which with growing uncertainties on climate change is becoming more important. Davoudi et al. (2013) distinguishes between three concepts of resilience: engineering, ecological and socio-ecological.

Engineering resilience is a very static form of resilience. It refers to the ability of a system to return to equilibrium or steady state after a disturbance (Davoudi et al., 2013). The emphasis is on return time, in which a system that returns fast is seen as more resilient, with a focus on efficiency, constancy, and predictability. On the other hand, ecological resilience is about the ability of systems to absorb changes. It holds that there does not have to be one equilibrium, but rather, multiple in which instabilities can flip a system into a new steady state. Ecological resilience is about persistence, change and unpredictability, where the emphasis is not on how long it takes for a system to bounce back, but rather how much disturbance it can take.

Both engineering and ecological resilience are about bouncing to a stable equilibrium, be it back (engineering) or forth to a new equilibrium (ecological) (Davoudi et al., 2013). However, socio-ecological or evolutionary resilience rejects the idea that resilience is about returning to a "normal" stable state, but rather focuses on the ability of systems to change, transform, and adapt to disturbances. Davoudi et al. (2013) proposes a framework of evolutionary resilience including four dimensions: preparedness, persistence, transformability and adaptability (see figure x.x). Evolutionary resilience is about embracing uncertainties rather than resisting it like engineering resilience.

Embracing change is why preparedness is at the core of the framework, as a system should be able to learn from the change, and change with it.

Evolutionary resilience will form the basis of this thesis. There are many uncertainties for the river basin of the Maas regarding climate change. However, in the past a river was able to change with the landscape instead of returning to a former equilibrium. Currently, large parts of the Maas are engineered, and after disturbances, efforts are made to restore the river to its previous state. However, maintaining this equilibrium requires continuous intervention, which will only grow over time. Therefore, the river should be able to change and transform after disturbances, in which preparedness plays a crucial role. The goal is to create a river system that is resilient and able to transform, adapt, change and learn from coming future challenges.

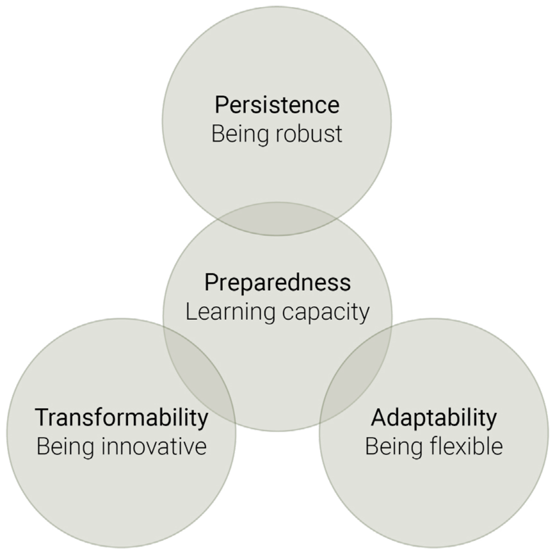


Figure 2.3: Evolutionary resilience framework. Based on Davoudi et al. (2013).

2.2.2. Adaptive planning

Evolutionary resilience goes hand in hand with adaptive planning. The adaptive planning process is a proactive approach that reduces uncertainty by continually assessing the feasibility and effectiveness of planning decisions (Kato & Ahern, 2008). This includes learning by doing and multi-option scenario planning (Rangwala, 2024). However, in current policymaking and disaster studies, the engineered approach of resilience is often still used. This would mean that a system goes back to "normal", but this can be problematic as going back to a previous state is definitely not always desired (Davoudi, 2021). This has also been evident in spatial planning, where modernist planners wanted to create this spatial equilibrium without disorder. This led to a view in which space was seen as an absolute, that could be planned through static blueprints.

However, evolutionary resilience opposes this thinking, and wants to break out of an undesirable "normal" state (Davoudi, 2021). It recognises that the current system could suddenly change and become something new, and that it should adapt. Therefore, evolutionary resilience views space as relational, which is connected to adaptive planning, instead of absolute. It is not about the will to order, like in blueprint planning, but driven by a will to connect.

Adaptive planning is based on the adaptive cycle with four distinct phases: growth, conservation, release and reorganisation (Davoudi, 2021). It shows that if systems grow, their resilience decreases and they become more susceptible to disturbances. When release happens, however, the system can transform and innovate creating high resilience again. The moment of maximum uncertainty becomes the greatest window for opportunity in a crisis.

The adaptive planning mindset will be used to plan for a future in which the Maas river basin can change with impending uncertainties. The river is not just an absolute in the landscape, it is a moving force that relates to other forces in space. Knowing this, and using this to plan for the future, will be important to create a resilient system. This thesis will have a time frame until 2100, and focus on going through one adaptive cycle in which the resilience of the river Maas will be reorganised through renaturalisation. After 2100 the system will change again, in which a new cycle might start. However, the focus of this thesis is to show the possibilities of adapting for evolutionary resilience by using this cycle.

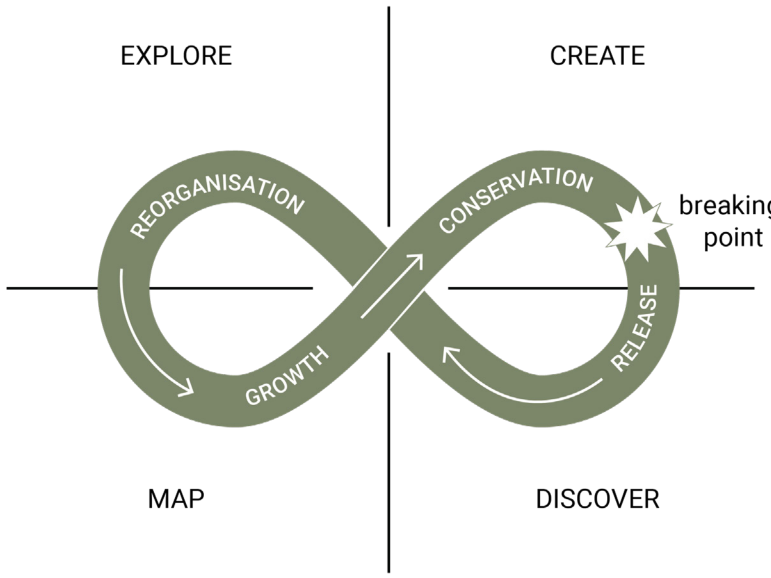


Figure 2.4: The adaptive cycle. Based on Gundersen & Holling (2002).

2.2.3. Water and soil-led planning

Water and soil-led planning ("water en bodem sturend") is a concept developed in Dutch spatial planning and water management. As the name suggests, it means allowing water and soil to guide spatial decisions (College van Rijksadviseurs, 2023). Water and soil systems provide essential resources such as drinking water, agricultural land, nature, and clean air and must remain healthy to adapt to climate change and support human use. Therefore, water and soil-led planning starts with the needs and limitations of these systems, recognising that without a healthy water and soil system, the pressure on society will keep increasing. Instead of shaping nature to human desires, it looks at what nature already offers, starting with the water and soil system (Wageningen University and Research, n.d.). This takes the system's carrying capacity into account, offering interesting opportunities.

The Dutch government created a practical manual for using water and soil led planning with steps to guide the planning process (College van Rijksadviseurs, 2023). It includes analysis, examining different scales and time frames, visualising connections and other spatial plans, creating scenarios, and developing strategies. These steps will broadly be followed during this thesis.

Additionally, Deltares (n.d.) created three main aspects of water and soil-led planning that are important to mention for this thesis. The first aspect is to restore the condition of the water and soil, making it more resilient to shocks, which is connected to evolutionary resilience and adaptive planning as mentioned before. The second aspect is about coordinating land use. Land use should be based on the possibilities of the water and soil system, and not push its boundaries. This will be important when integrating the cultivated landscape with a renaturalised river basin. Finally, the third aspect includes improving spatial development, which is about designing new functions that will not cause harm to the environment, but may even contribute to a better water and soil system.

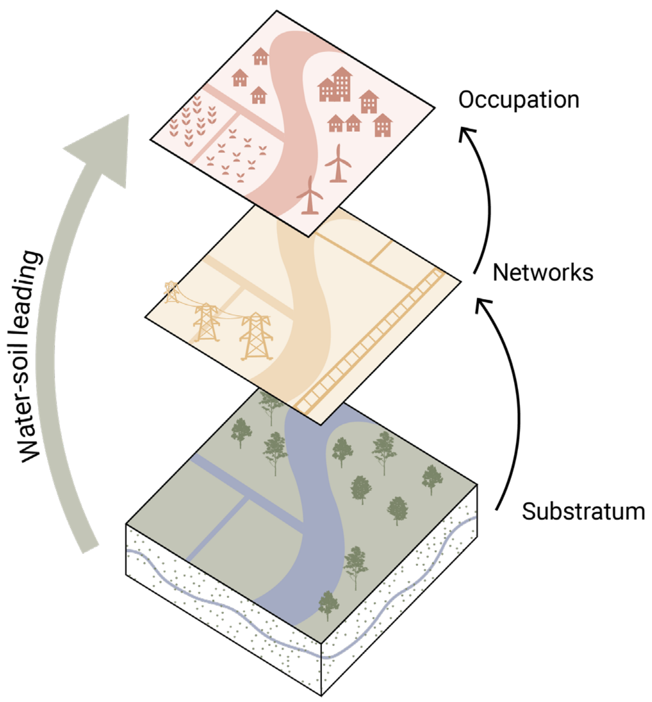


Figure 2.5: The Delft Layer Approach from a water and soil-leading perspective. Based on College van Rijksadviseurs (2023).

2.2.4. Renaturalisation of rivers

Renaturalisation, or restoration, of rivers refers to the processes of restoring the natural hydrology of a river and limiting the amount of human interference (Baffert & Casey, 2024). In the past, rivers have been altered to human needs, in the form of straightening, dredging, and implementing dams and weirs causing some rivers to completely lose their natural flow. However, with the impact of climate change increasing, continuing to rely on engineered solutions would only lead to more extreme interventions. Before human interference with the river's hydrology, it was free to flow where it needed to go in case of extreme events such as floods or periods of drought (Kleinhans et al., 2013). Therefore, renaturalisation of rivers could be an outcome of anticipated climate change.

Restoring rivers will help the rivers and surrounding areas connected to the water system become climate change resilient in multiple ways. Firstly, giving space to free-flowing rivers will provide protection against floods (Baffert & Casey, 2024). Natural meanders slow down the discharge velocity of the river, thereby giving more time for excess water to flow through the trajectory. Moreover, more natural floodplains improve absorption of excess water, as does the creation of side channels. More space for the rivers means there is more space for excess water to flow to, instead of increasing flood risk downstream. Even the removal of dams could decrease flood risk, as dams often remove fine sediment from the water, causing the downstream riverbed to coarsen and become more susceptible to flooding.

Secondly, with the removal of weirs and dams rivers can carry more sediment downstream (Baffert & Casey, 2024). This will help to rebuild floodplains and estuaries in deltas making the area more resilient to storm surges and sea level rise.

Thirdly, restoration of rivers helps mitigate the area against drought (Baffert & Casey, 2024). Nature absorbs water like a sponge, and with more natural floodplains the soil is able to retain water for a longer period of time. This increases infiltration and groundwater recharge and creates a buffer against dry periods. With a natural river basin, drinking water supplies and soil quality can be protected.

Next to climate resilience, renaturalisation of rivers provides other benefits as well. Restored river banks give space for nature to thrive again, increasing the biodiversity of the flood plains. With dam removal, aquatic species are free to move downstream, which could allow the return of species that have disappeared from certain water bodies. Moreover, water quality will also improve, with fewer fluctuations in temperature and flow velocity, improving the nutrient composition of the water. This would benefit the surrounding landscape, for example in terms of drinking water extraction and food production. Although restoration of rivers requires an investment and a change for certain land uses, the long-term benefits weigh up compared to the cost of maintaining the hard infrastructure. Next to that, alternative land use focused on nature could even provide a better environment for human mental and physical health. (Baffert & Casey, 2024)

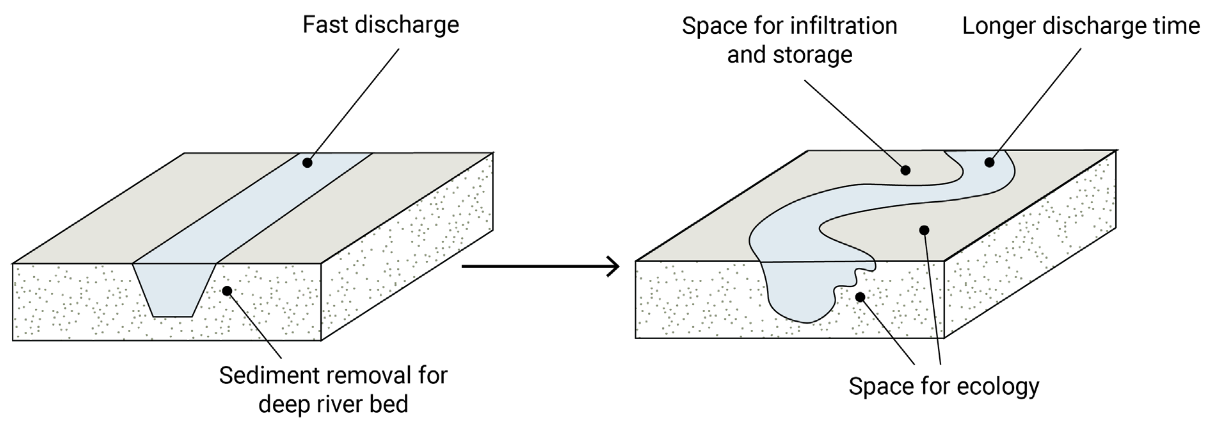


Figure 2.6: Renaturalisation of a straightened river.

2.2.5. Nature-based solutions

The concept of nature-based solutions (NBS) has become increasingly important over the last two decades with climate mitigation taking a central role in policies and planning. There are two definitions that are most used, from the International Union for the Conservation of Nature (IUCN) and from the European Commission. The IUCN defines the concept as:

> "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"
> (Cohen-Shacham et al., 2016).

The European Commission describes NBS as:

> "living solutions inspired by, continuously supported by and using nature designed to address various societal challenges in a resource efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits"
> (Maes & Jacobs, 2017).

The main difference between the two definitions is that IUCN focuses more on the protection, sustainable management and restoration of ecosystems, rather than the focus on the connection to social and economic goals. For this thesis the IUCN's definition is more applicable, as there will be a focus on the ecosystems first, before integrating the cultivated landscape. However, there is interaction between the social system and the ecosystem. Implementing NBS could provide ecosystem services to the social layer, therefore also improving the cultivated landscape (Albert et al., 2019).

Cohen-Shacham et al. (2016) divided NBS into three typologies: (1) using an existing natural ecosystem, (2) restoring a damaged or lost ecosystem, and (3) the creation of a new ecosystem. (see figure 2.7). The focus on this thesis relates the most to the second typology, as the river was once a naturally flowing system that has been altered over the years. The goal of this thesis is to restore the natural ecosystem to create a more climate resilient environment with the use of NBS.

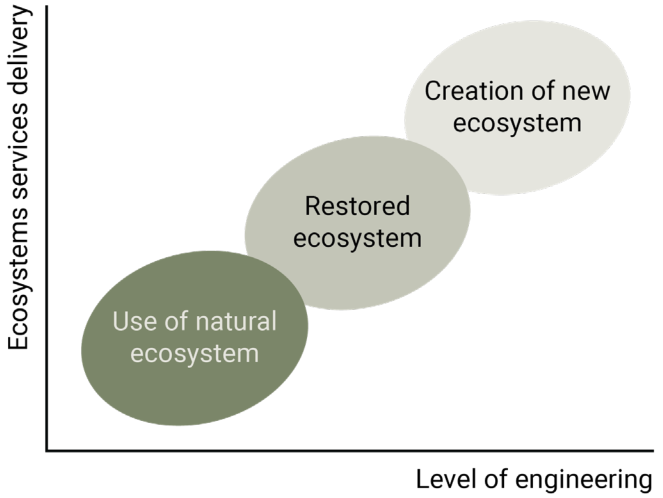


Figure 2.7: Three typologies of NBS. Based on Cohen-Shacham et al. (2016).

2.2.6. Ecosystem services

Ecosystem services are services that ecosystems provide to humankind (MA, 2005). They are often divided into four groups: provisioning, regulating, cultural, and supporting services. Provisioning services provide the opportunity for humans to obtain products from an ecosystem, such as food, water, oil and other resources. Benefits that are obtained from natural processes of ecosystems are identified by regulating services. This includes flood regulation, pollination of crops and cooling of the urban heat island effect for instance. Cultural services are non-physical benefits gained from an ecosystem, such as recreation, aesthetics, and mental and physical health benefits. Finally, supporting services include services to maintain the functions of the habitat itself that humans use. For instance, soil formation, the water and nutrient cycle and photosynthesis.

This thesis will start by looking at the natural processes of the river and landscape to require resilience against climate change, for both the natural environment and the human landscape. Therefore, this thesis is not about just finding ecosystem services to serve us. It begins from the notion that an ecosystem should be healthy first before being able to provide services to humankind. From this, new ecosystem services can be found through the integration of the cultivated landscape in a renaturalised river basin. So, nature-based solutions will be implemented in the eocystem, and from this ecosystem services will arise (Albert et al., 2017), as is visualised in figure 2.8. As the project focuses on climate resilience through natural processes of the river Maas, most focus will be on regulating services. However, the other services will be included in the solutions that will be found throughout the research.

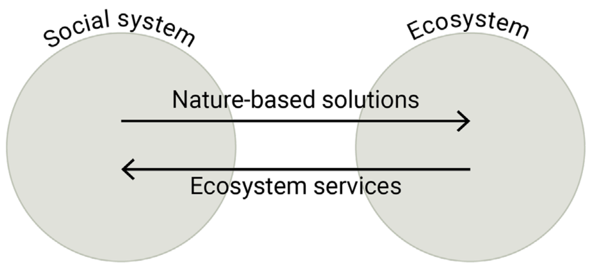


Figure 2.8: Interaction social system and ecosystem through nature-based solutions and ecosystem services. Based on Albert et al. (2017).

2.3. Conceptual framework

The conceptual framework is based on the theories as explained in chapter 2.2. The goal of this project is to create a resilient river basin, based on evolutionary resilience in which the system adapts to change instead of returning to a normal state. Therefore, this thesis will follow one loop of the adaptive cycle, which starts at conservation - the phase of this current time. Climate change is the breaking point that will start the process of change for the river basin. Renaturalisation will be a guide from the release to the reorganisation phase. In the reorganisation phase a new resilient system will be innovated, based on soil-water led planning and NBS. From reorganisation the system will grow. Ecosystem services will arise and also influence the further process. After this the system will return to a conservation phase. There, the scope of this thesis ends. However, in that time period another breaking point may form. Therefore, the system will continue to release, reorganise and grow further in the future.

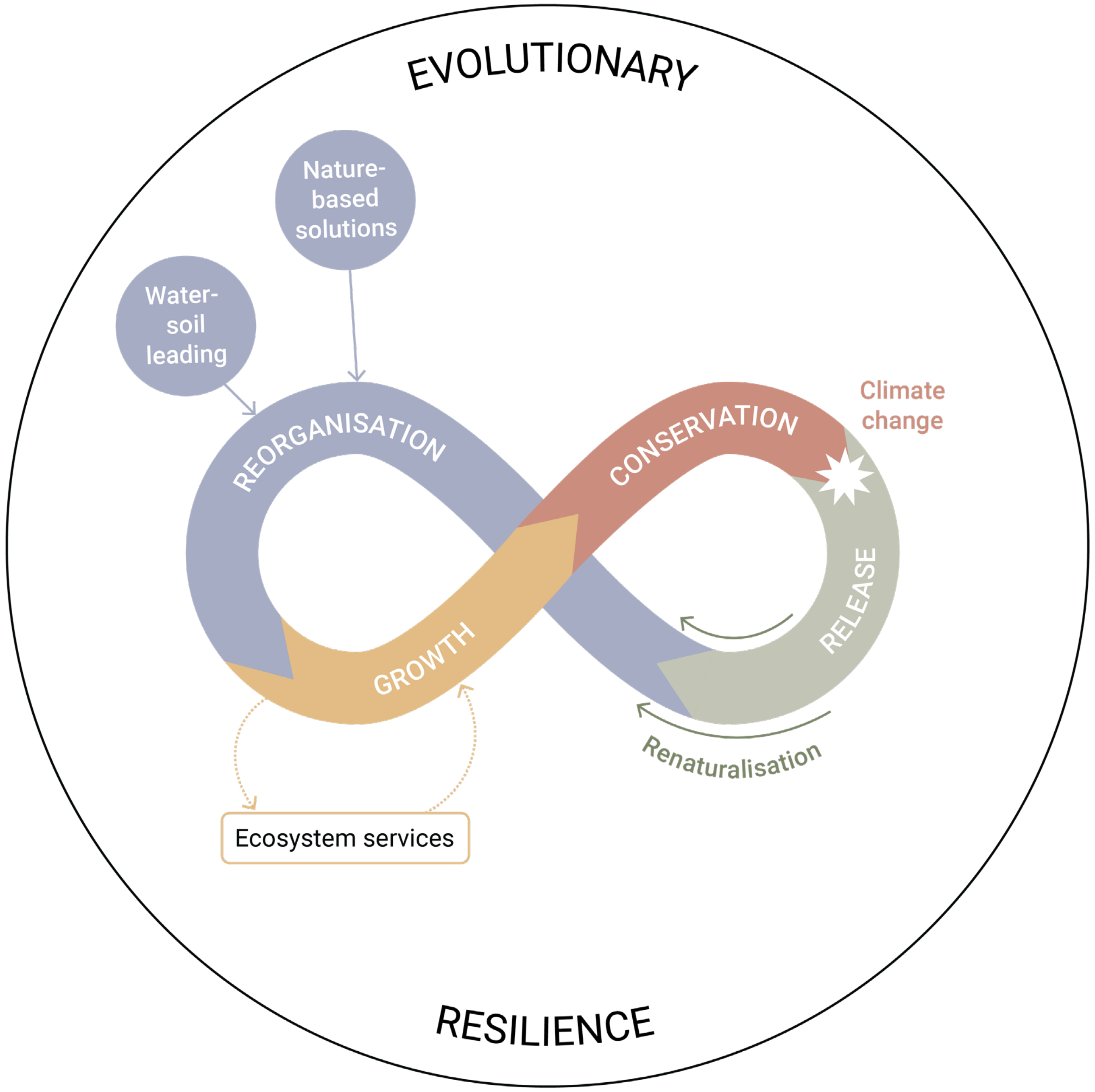


Figure 2.9: Conceptual framework. Made by author, based on the theories and concepts of (Davoudi et al., 2013; Gundersen & Holling 2002; Baffert & Casey, 2024; College van Rijksadviseurs, 2023; Cohen-Shacham et al., 2016; MA, 2005).

Analysis 3

This chapter dives into the river, ecological, agricultural, and urban systems of the Noordelijke Maasvallei. It concludes with SWOT analyses and a Future Autonomous Situation for 2100, highlighting the system's strengths and opportunities, as well as the weaknesses and threats that require change.

3.1. The river system

3.1.1. Formation of the Maas in the Noordelijke Maasvallei

The river Maas is divided into different typologies. In the northern part of Limburg two of these typologies can be found, which are the *Zandmaas* (Sand Maas) and the *Plassenmaas* (Pond Maas). This subchapter will explain how these typologies are formed.

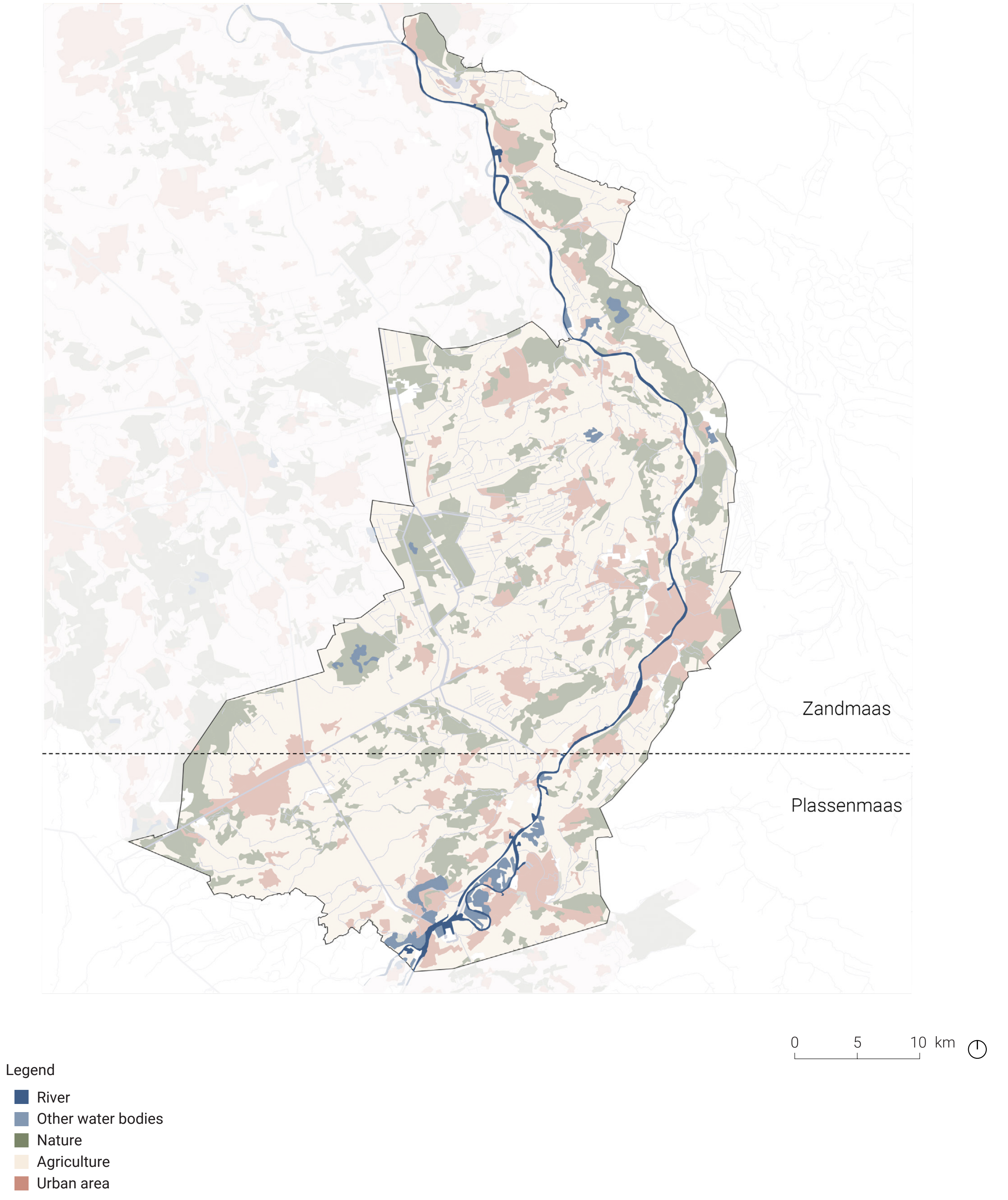


Figure 3.1: The Noordelijke Maasvallei: Plassenmaas and Zandmaas. Based on CORINE Land Cover (2019).

Zandmaas

The river Maas and its surrounding landscape have known various changes over time. The formation of the Maas started in the Pleistocene (circa 2.58 million to 117000 years ago). The Noordelijke Maasvallei was created by terrace formations and plate tectonics. De Noordelijke Maasvallei is located on multiple tectonic blocks: the Roerdalslenk (rift), Peelhorst (horst) and Venloslenk (rift). The vertical movements of these plates has greatly influenced the terrace formation in this area. The Peelhorst lies higher than the other two, resulting in a narrow river bed and close terraces between Roermond and Venlo. However, up- and downstream of this area, the river bed is almost twice as wide (see figure 3.3). During the Ice Age when the Maas would deposit gravel and coarse sand, a large amount was deposited in the subsidence area from the Roerdalslenk towards the Peelhorst. (Bosch, 2024)

These deposits have changed the course of the Zandmaas over time. Figure 3.2 shows these changes and are explained below:

a. Around 130,000 years ago the river basin was a wide and deep valley in which the river meandered freely. Steep edges formed on the sides where the outer curves touched the banks.

b. During the last Ice Age, around 30,000 years ago, the valley was filled with sand and gravel due to the fluctuations in cold and warm weather. The river had become a braided river of about 20km wide, as it could not incise into the frozen land.

c. 4000 years ago, after the last Ice Age, the water discharge was more constant and vegetation protected the upstream riverbanks, resulting in less sedimentation. Therefore, the river could incise into the formed river plain, forming steep edges on the outer riverbanks.

d. In the last 3000 years, the valley became filled with clay due to the removal of forests and implementation of agricultural land. This caused clay and fine sand to flow to the river with rainwater, which the Maas was not able to fully deposit.

Currently, the Maas follows a fixed course with fixed meanders, which in some cases have been cut through. The clay layer is not natural for the Zandmaas. In some places it is already 5m deep and still grows after highwater incidents. If the riverbanks would not be artificially protected, and clay were no longer moved to the Maas anymore, over a couple of hundred years the valley would be cleansed of clay by erosion. However, with the normalisation of the Maas, there are no erosion processes, and the Maas cannot flow in a wide valley as it had.

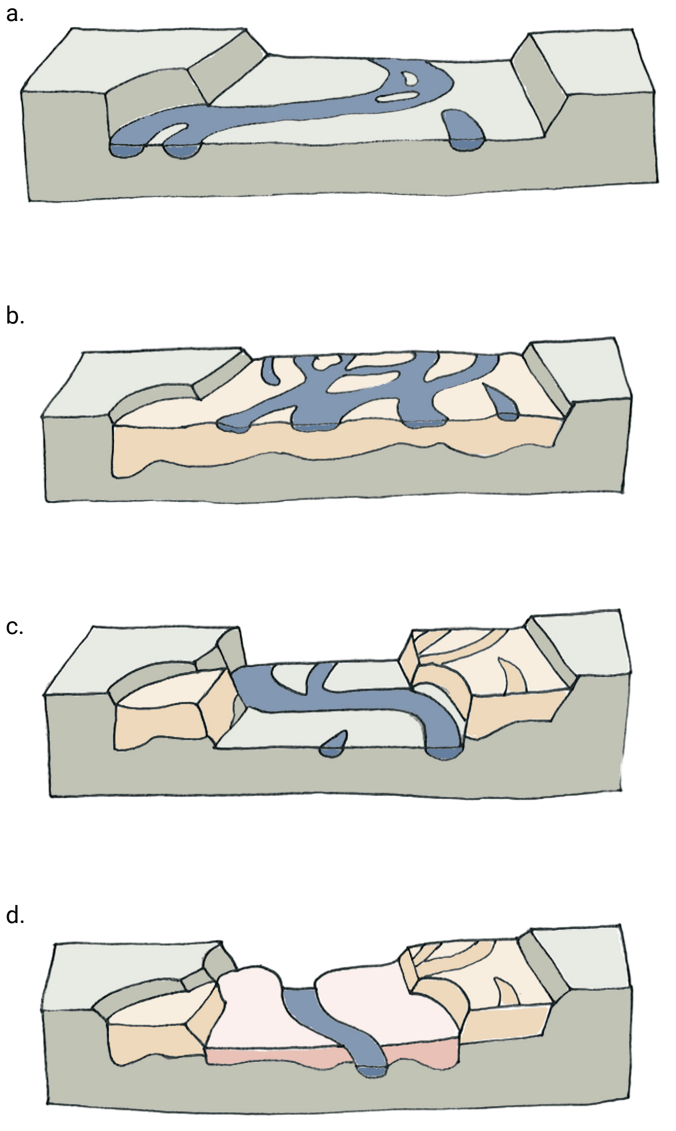


Figure 3.2: Formation of terraces in the Zandmaas. Based on van Winden (1998).

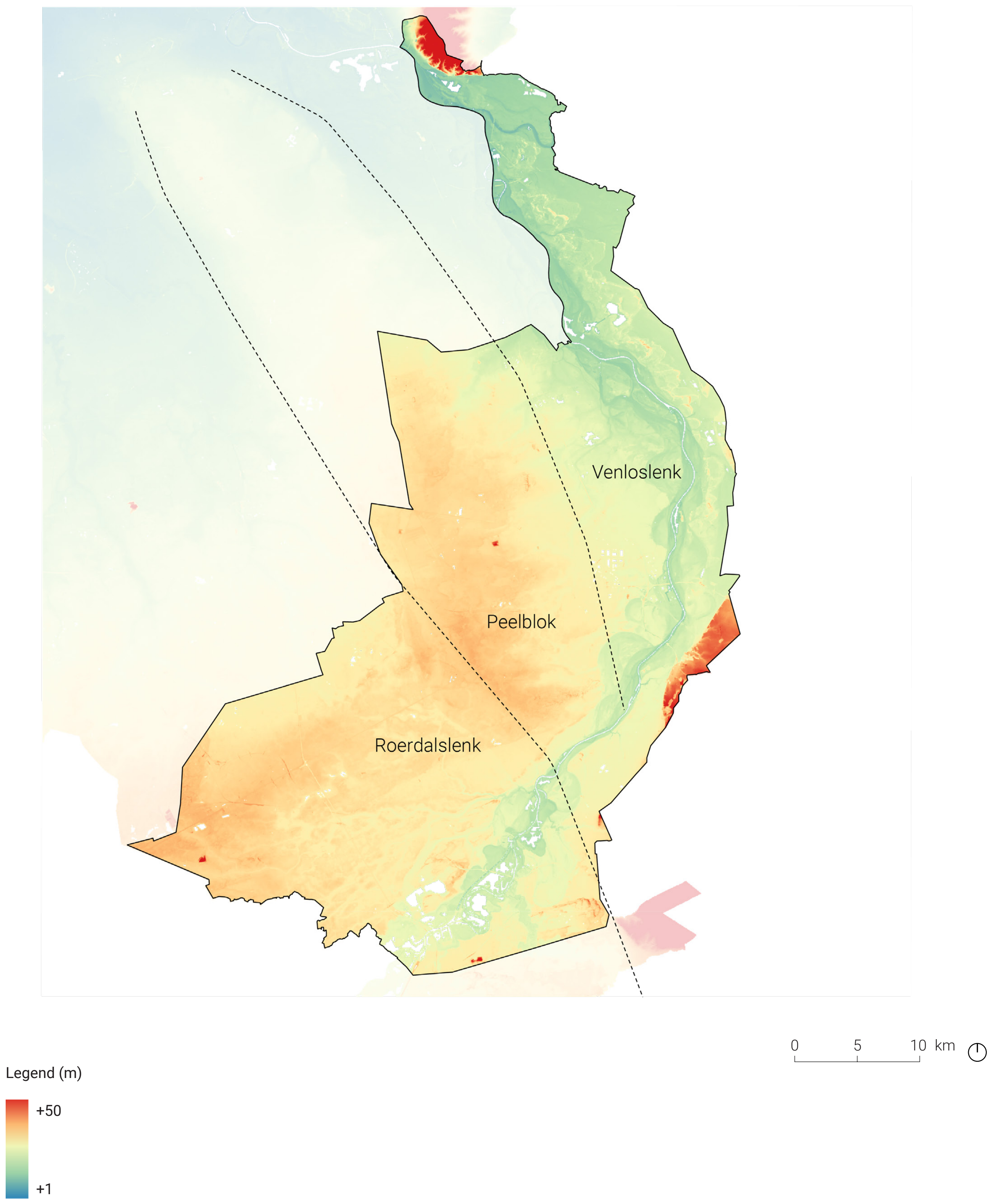


Figure 3.3: Height map of the Noordelijke Maasvallei. Based on AHN (2025).

Plassenmaas

As explained above, in the last Ice Age large packages of gravel and sand had been deposited in the Noordelijke Maasvallei, especially between the Roerdalslenk and Peelhorst, as can be seen in the soil landscape typology in figure 3.6. In the 1950s, when there was a need for building materials after the second world war, the demand for gravel grew. As this area Noordelijke Maasvallei had plenty, large scale gravel extraction started. This has created iconic ponds around Roermond, and formed a new landscape known as the Plassenmaas. Figure 3.5 shows the formation of these ponds. In the 1990s the gravel extraction stopped. Currently, the Maasplassen are mainly used for recreation. Although the ponds can serve as a place for excess water, they are not the most beneficial for the surrounding land in times of drought. When gravel was extracted, the surface level dropped below the groundwater table, which led to the formation of the ponds As a result, when the surface water level was lower, groundwater flowed toward the ponds. (Mollema, 2016)

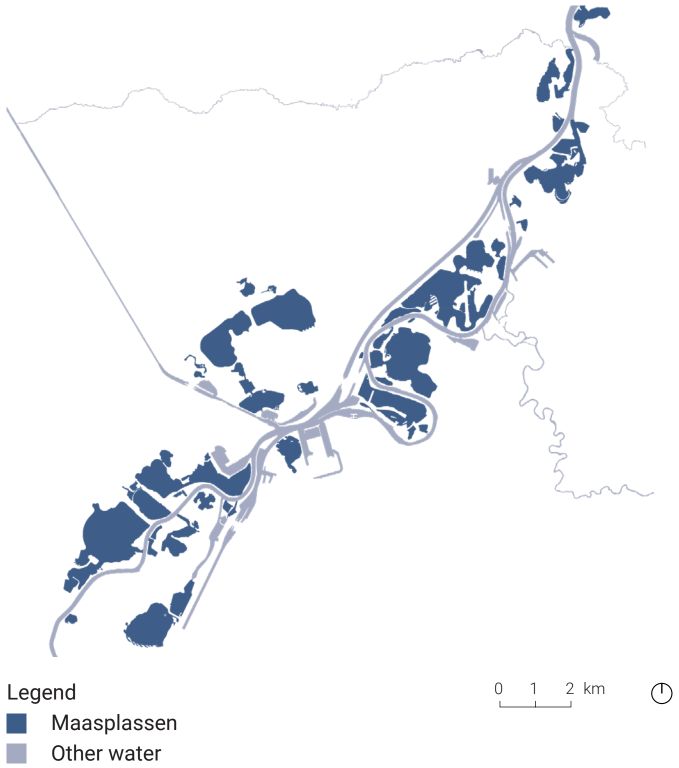


Figure 3.4: The Maasplassen. Based on CORINE Land Cover (2019).

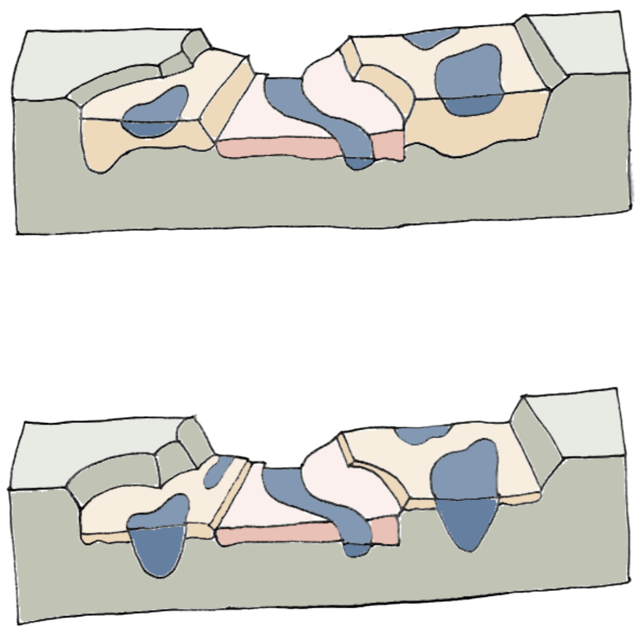


Figure 3.5: The formation of the Maasplassen.

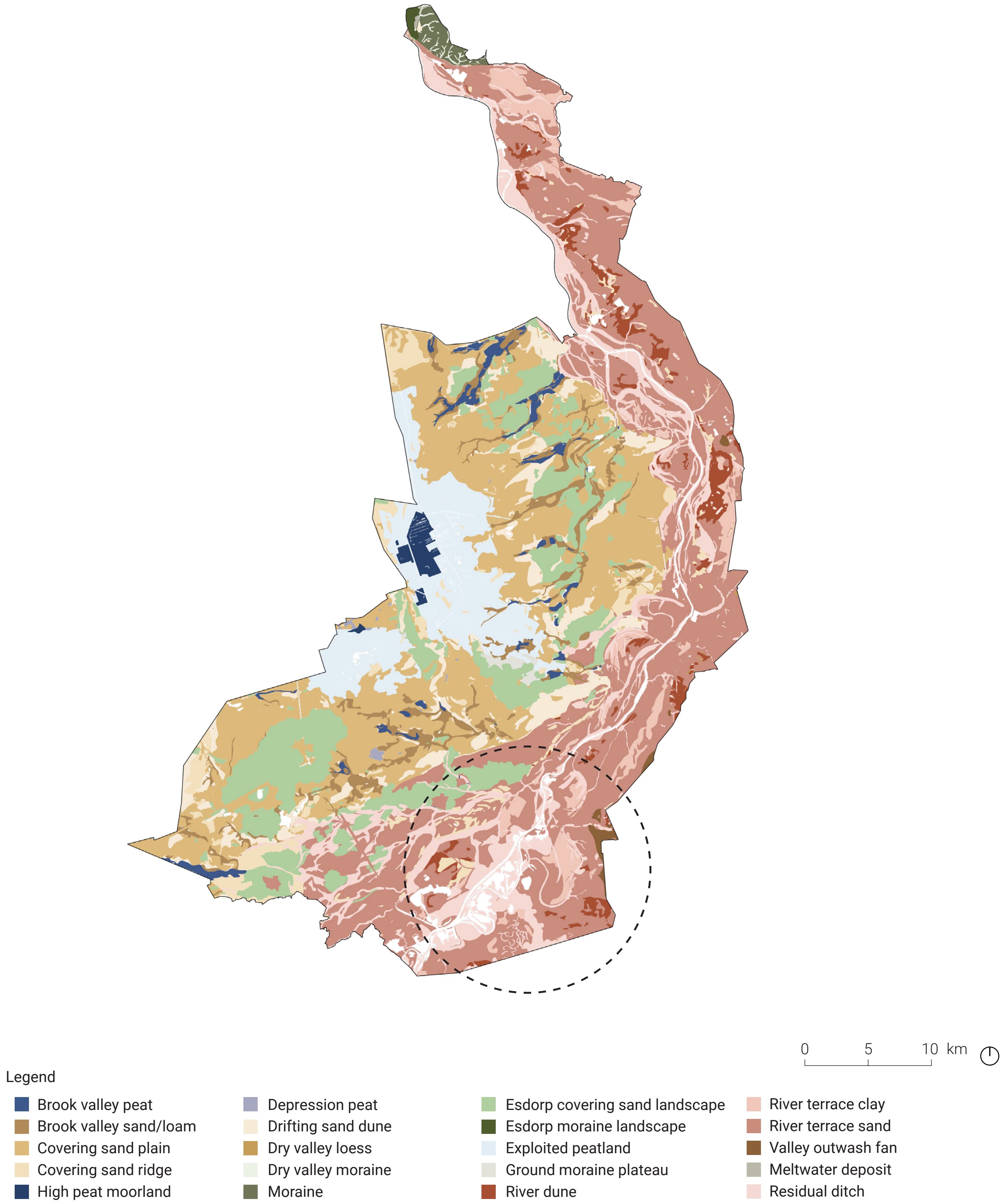


Figure 3.6: Landscape types of the Noordelijke Maasvallei. Based on BKNSN (2023).

3.1.2. Water discharges of the Maas

Since the Maas is a rain river, it is influenced by the amount of rainfall that falls in the catchment area. Floods and droughts are already common, and as said before, will only occur more often and more severely with the current climate change expectations. This subchapter will explain where the river water in the Noordelijke Maasvallei is currently coming from, and what the future expectations are.

Water distribution

The Maas flows into the Noordelijke Maasvallei just below Roermond. From here it gets water from three other tributaries in the area, the Ruhr, Schwalm and Niers. However, the Maas feeds water to artificial canals as well. In the Southern part of Limburg, the Zuid-Willemsvaart needs water for shipping between Belgium and the Netherlands. Just below Roermond, Kanaal Wessem-Nederweert flows towards the Zuid-Willemsvaart and the Noordervaart. The Noordervaart distributes water to nature reserve De Peel to keep the groundwater level sufficient against sinking of the peat layer. The distribution of water is different per wet or dry scenario, as can be seen in figure 3.7.

The Dutch part of the Maas has seven weirs that descend with 45 metres to maintain certain water levels. Four of these can be found in the Noordelijke Maasvallei with a descend of around 13 metres. (see figure 3.8). The weirs have been implemented to control the water level for the Maas to ensure shipping can continue in periods of drought. Moreover, when there are high discharges the weirs will be opened so the water will flow quickly towards the North Sea. (Rijkswaterstaat, n.d.)

In the Noordelijke Maasvallei, dikes are mainly found around city and town centres that are built next to the Maas. Dikes become more common downstream of this area. (Asselman et al., 2018)

Waterstream	*Supply in wet scenario (%)*	*Supply in dry scenario (%)*
Niers	1.4	5.4
Schwalm	0.5	2.3
Ruhr	6.7	15.8
Zuid-Willemsvaart	-2.0	-15.8

Figure 3.7: Rivers, streams, canals and weirs in the Noordelijke Maasvallei. Based on

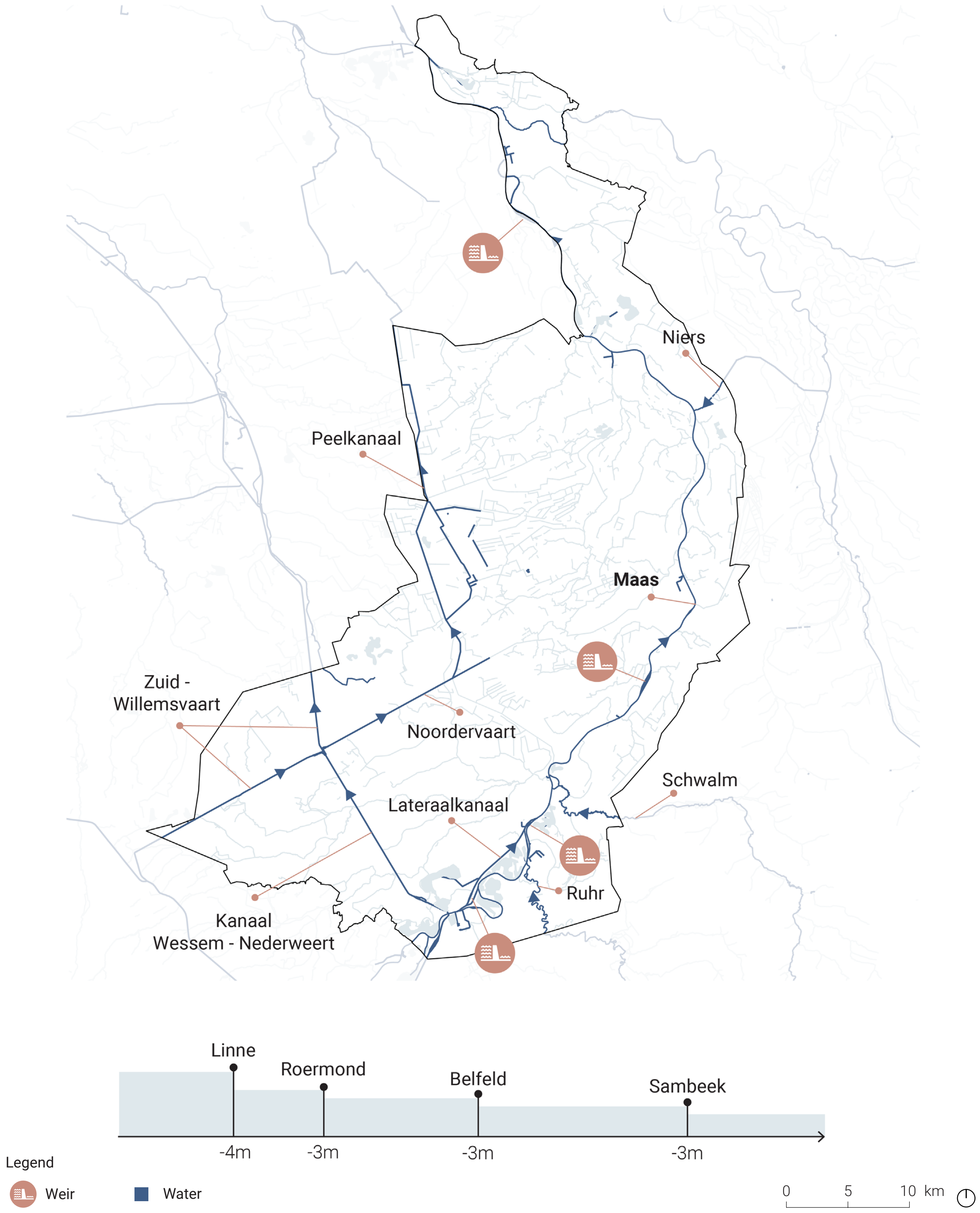


Figure 3.8: Rivers, streams, canals and weirs in the Noordelijke Maasvallei. Based on CORINE Land Cover (2019) and Rijkswaterstaat (n.d.).

Low discharges (dry scenario)

In summer, lower discharges of the Maas are normal, especially with the increase of dry periods and lack of rainfall at this time of year. Currently, a “low discharge” is considered at <50m^3/s and an ”extremely low discharge” at <30m^3/s (Rijkswaterstaat, 2025c). However, in 2025, an average of 40 m^3/s in summer was not uncommon. Low discharges harm the water distribution of the Maas, as canals and the river itself need certain water levels for shipping (Slim Watermanagement, 2025). Just upstream of the research area, Belgium and the Netherlands have made agreements for dividing the water discharges during dry periods. However, discharges below 25 m^3/s are expected to happen more frequently in the future, which will put a lot of pressure on maintaining this agreement and dividing the water equally.

Currently, the agreement between Belgium and the Netherlands states that the discharge of the Grensmaas should at least be 10 m^3/s (Slim Watermanagement, 2025). However, with discharges below 25 m^3/s becoming more common, this aim will be hard to reach. This will have tremendous effects on the surrounding area. As mentioned before, the canals will not have enough discharge to maintain shipping, or the Maas will run dry. Nature reserve De Peel will not receive enough water, which causes the area to emit CO_2 and methane, instead of storing it (Nationaal Park De Groote Peel, n.d.). Furthermore, in periods of drought, groundwater is not sufficient for irrigation under the current practices, so there will be a demand from the river. Finally, 25% of the drinking water in Noord Limburg comes from the river Maas (the other 75% from groundwater), which is extracted mainly in Venlo (WML, n.d.). With lower discharges, not only will there be pressure to supply enough drinking water, but also to maintain drinking water quality, as industrial pollution from upstream becomes more concentrated (NOS, 2025). Figure 3.9 presents a summary of the issues related to low discharges in the Noordelijke Maasvallei.

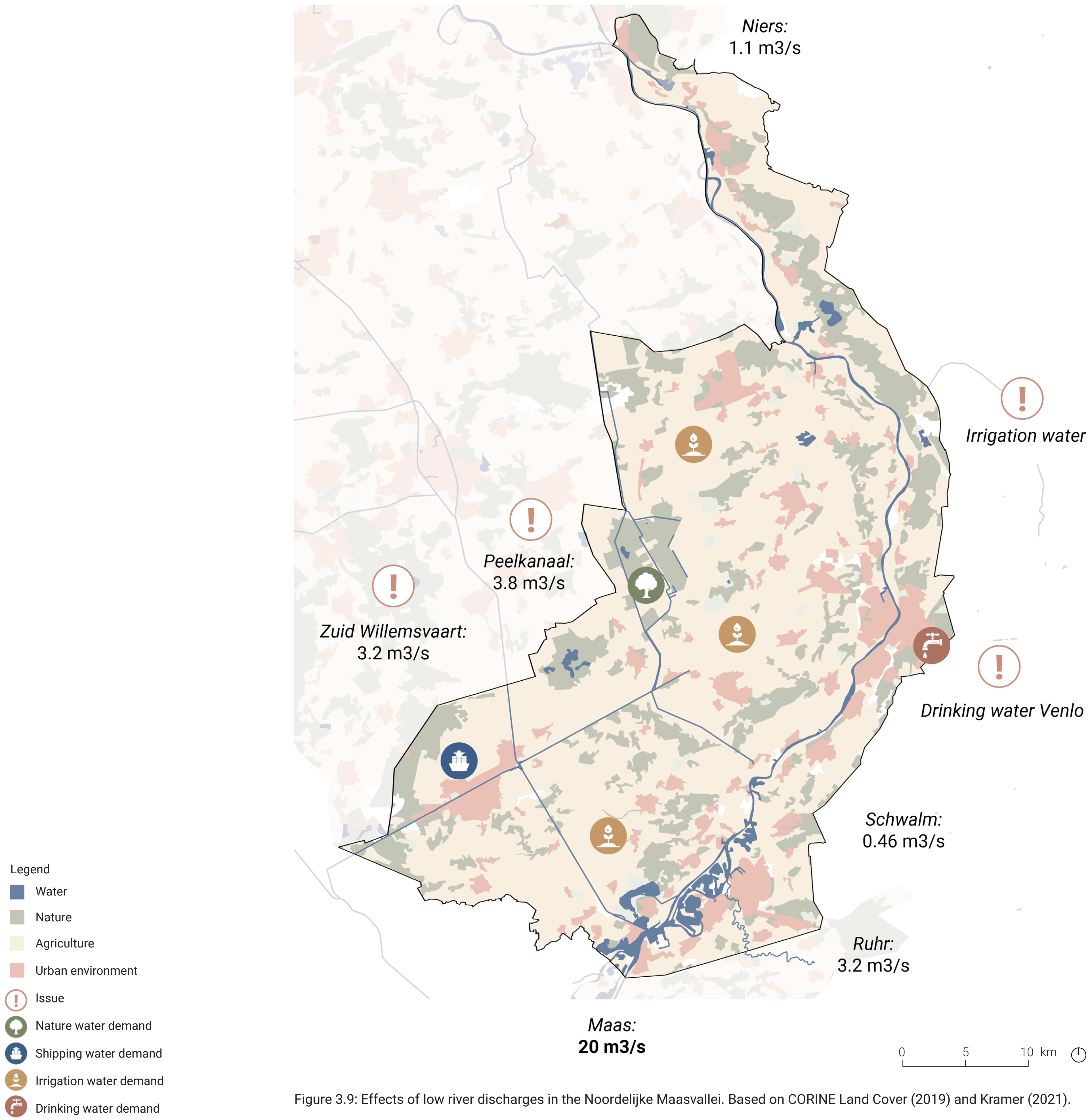
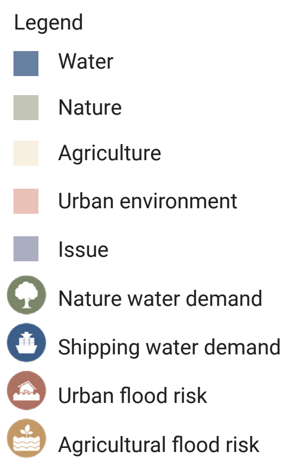


Figure 3.9: Effects of low river discharges in the Noordelijke Maasvallei. Based on CORINE Land Cover (2019) and Kramer (2021).

High discharges (wet scenario)

In winter, rainfall in the catchment is common and a standard discharge during wet periods is around 600m³/s. A "high discharge" is considered greater than 800 m³/s and an "extremely high discharge" above 2000 m³/s (Rijkswaterstaat, 2025c). However, high discharges are not only common during winter, but can also occur in summer. As an example during the extreme floods of July 2021, the discharge was above 3000 m³/s. High discharges have one main issue for the surrounding areas, which is flooding. This includes urban flooding, but also floods on agricultural lands and in natural areas planted close to the river.

In the future, wetter winters are expected to become more common, as are summer storms (KNMI, 2023). Therefore, it is expected that "high discharges" of the Maas will become normal and "extremely high discharges" will occur more often. With the current spatial interpretation of the Noordelijke Maasvallei, areas are expected to flood more often, causing damage in different domains. Cities such as Roermond and Venlo will suffer major consequences, and farmers in the flood risk area will face crop losses if fields become oversaturated with water. In figure 3.10 an example of extreme flooding is shown where the discharge is 3000 m³/s.



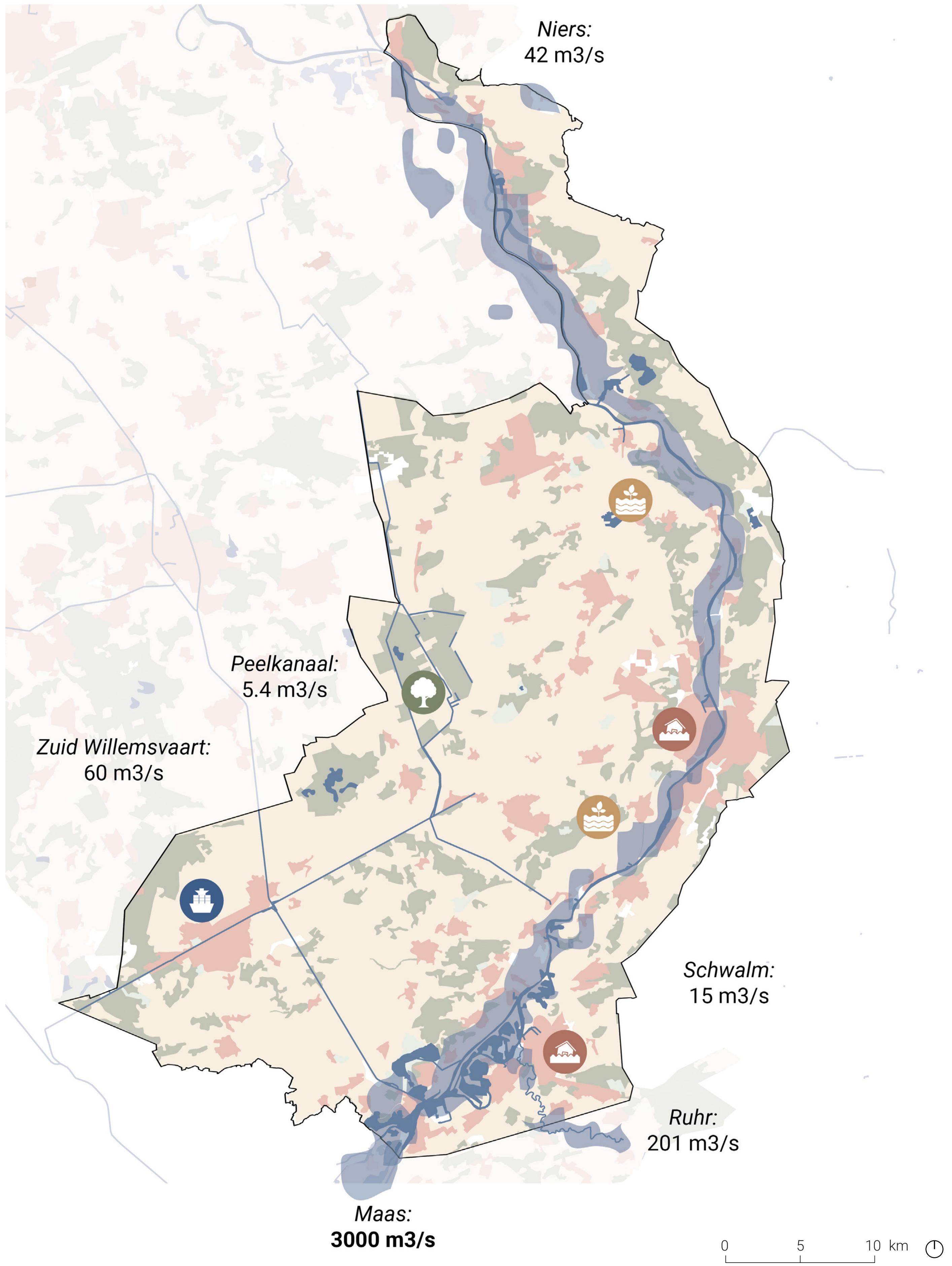


Figure 3.10: Effects of high river discharges in the Noordelijke Maasvallei. Based onCORINE Land Cover (2019) and Kramer (2021).

3.1.4. SWOT analysis: the river system

In conclusion, the Maas River system in the Noordelijke Maasvallei has been changed by both natural processes and centuries of human interventions. Whereas terrace formation, tectonic movements and sedimentation processes used to create a dynamic river landscape, normalisation, weirs, dikes and canals have fixed and controlled the river. As a result, the Maas has lost its ability to absorb extreme weather events. With climate change, this will become increasingly problematic. Droughts will intensify pressure on water distribution between shipping, agriculture, drinking water supply, and natural ecosystems, while high discharges will increase flood risk in urban, agricultural, and natural areas.

However, there are opportunities. The available knowledge of the natural river system will provide insights into modifying the system to absorb extremes. Moreover, new elements such as the Maasplassen also provide space for water to flow in times of extreme discharges and rainfall. Figure 3.11, shows the Strengths, Weaknesses, Opportunities, and Threats (SWOT) of the Maas River system, looking at the current and future system.

Strenghts

S1 There is a well-functioning shipping structure parallel to the river.

S2 The Maasplassen can store excess water in periods of high discharges from the Maas.

Weaknesses

W1 In periods of drought, the division of water discharge is difficult, causing problems for either shipping or river nature.

W2 The Maas has unpredictable discharges, where areas can go from dealing with drought to floods in only a day.

W3 The Maas, once a gravel river, has lost its natural processes due to straightening and dredging of the river bed and bank.

W4 The Peel demands constant water supply, creating an issue in periods of drought.

Opportunities

O1 The canals could be used as drainage in periods of high discharge.

O2 There is a lot of knowledge about the natural Maas to predict what it would do once renaturalised.

O3 De Peel can store more water in periods of high discharges.

Threats

T1 The Maas has no space to move, which could become disastrous for the surrounding area in the future with more extreme weather events.

T2 The Maasplassen extract a lot of groundwater, which will become problematic for the surrounding area in periods of drought.

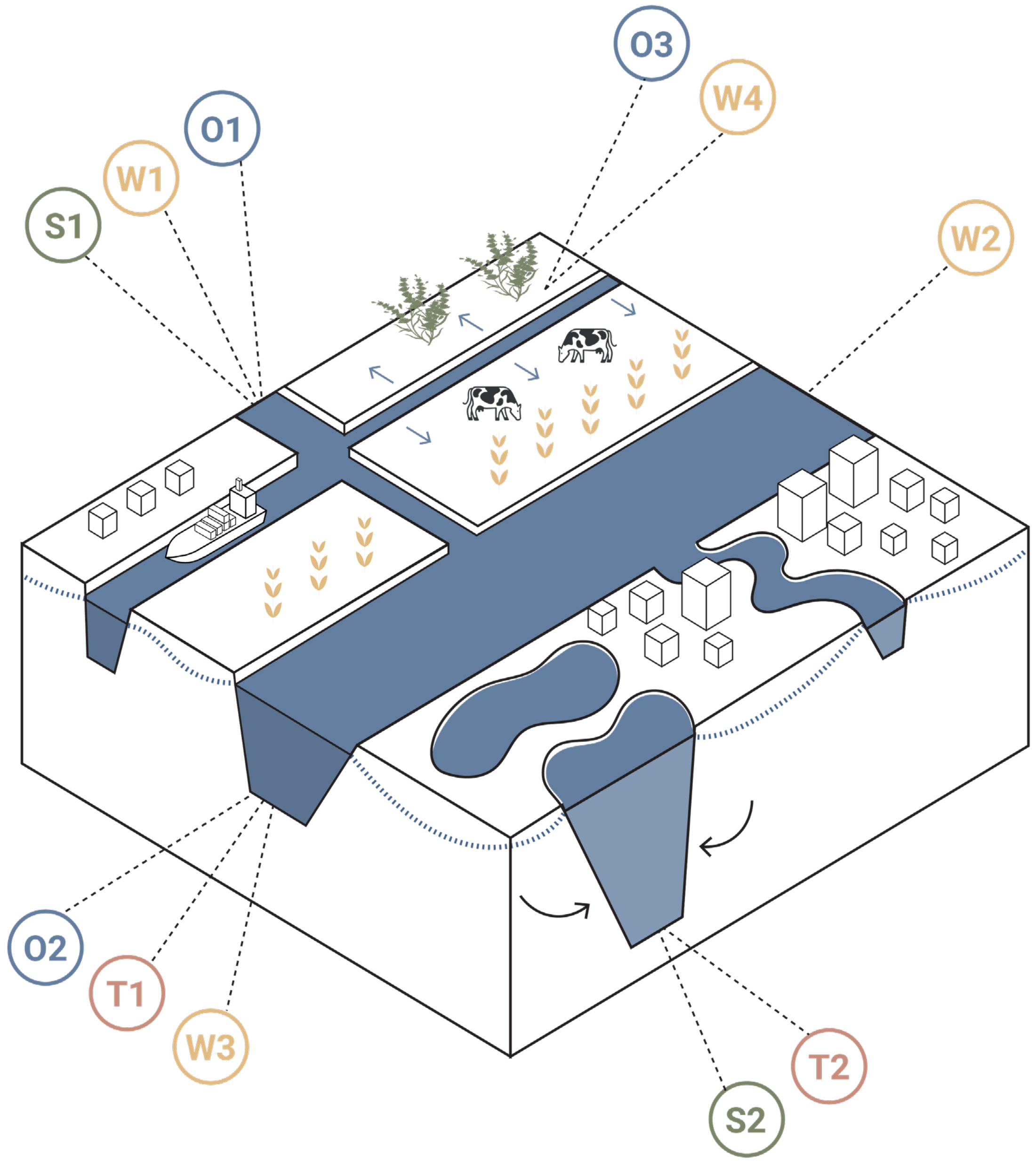


Figure 3.11: SWOT analysis of the river system.

3.2. The ecological system

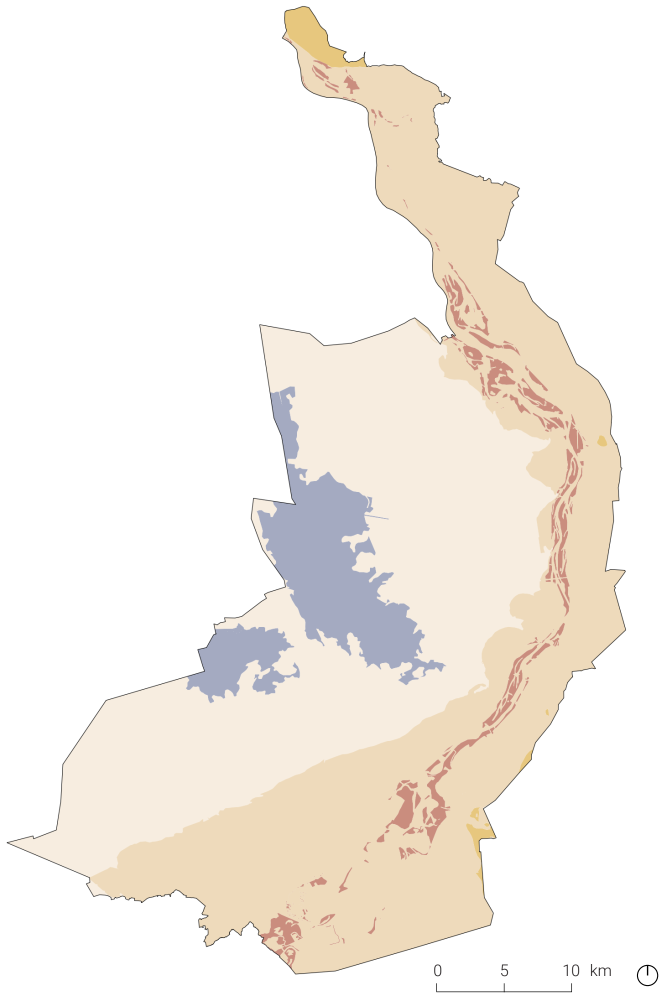
3.2.1. Nature in the Noordelijke Maasvallei

In the Noordelijke Maasvallei, different ecological landscapes can be found, which are mainly determined by differences in soil type. The area is predominantly characterized by sandy soils, which support forests and heathlands, such as those found in National Park De Maasduinen. In contrast, the western part of the region is home to De Peel, a nature reserve situated on peatland with completely different biotopes than the sandy areas.

The Maasheggen is a cultural landscape that could be found along the Maas as a division between fields. It created habitats for certain species, such as breeding spots for birds. Before the use of barbed wire, the hedges were quite common. However, currently the Maasheggen are only found just over the border in Noord Brabant (see figure 3.13).

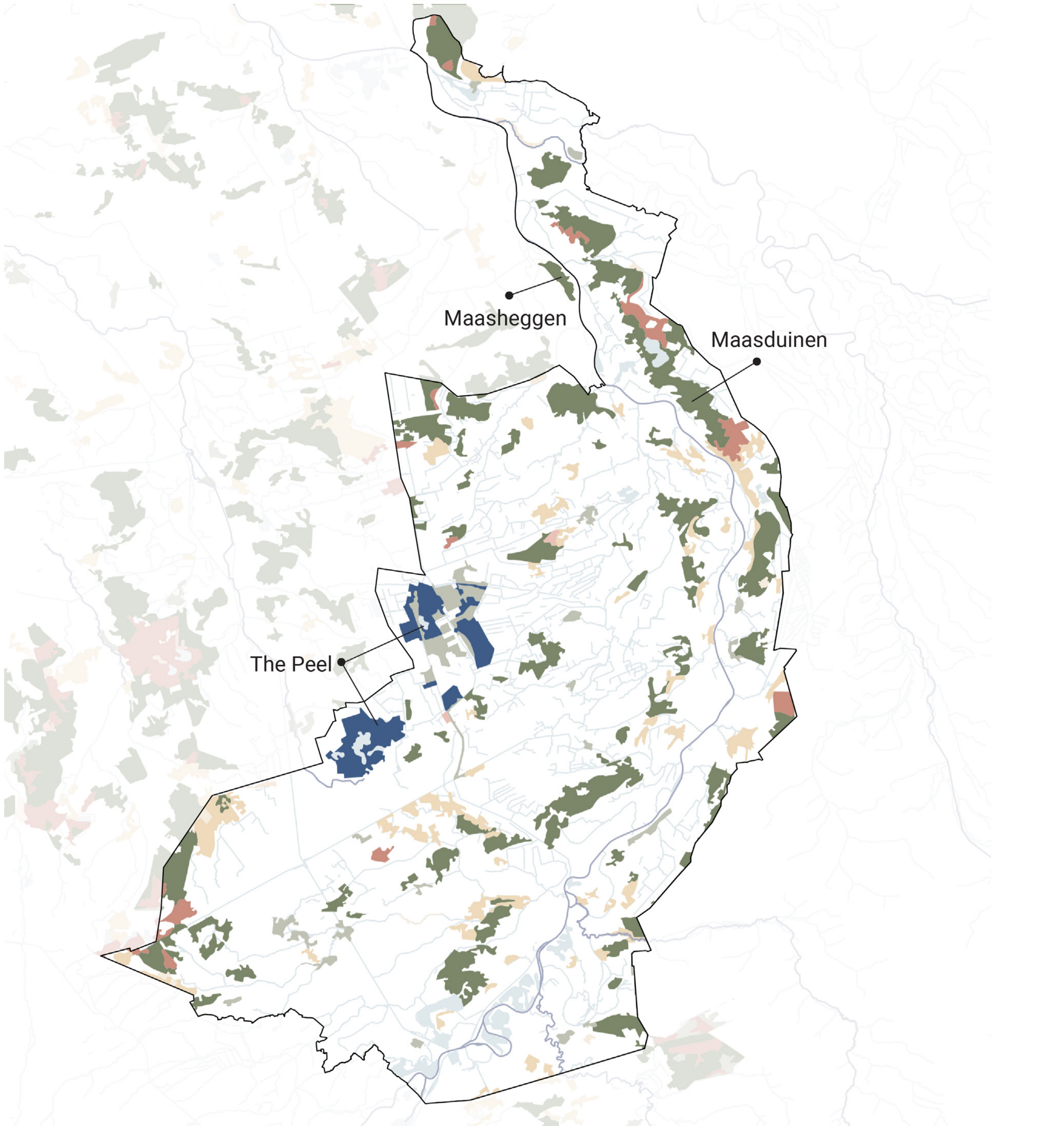
Next to inland vegetation, the ecosystem of the river Maas supports river nature and water species. However, like the inland ecology, humans have interfered with natural processes for shipping, urban protection or agriculture, stripping away nature in the area. Especially since the 20th century, when peat, heath and gravel extraction was common. As a result, ecological areas have become fragmented and connections are lost, limiting the ability of species to move freely between habitats.

Today, the main biotopes found in the Noordelijke Maasvallei are forests and heathlands on sandy soils (see figure 3.12). However, the region as a whole can be divided into three main ecological areas: the River Maas, the Maasduinen, and De Peel. These will be discussed in more detail later in this chapter.



Legend
- Sand (covering plain)
- Sand (river terraces)
- River clay
- Peatland
- Sand (morraine)

Figure 3.12: Main soil types in the Noordelijke Maasvallei. Based on



Legend
- Broad-leaved forest
- Coniferous forest
- Mixed forest
- Natural grasslands
- Moors and heathland
- Sclerophyllous vegetation
- Transitional woodland-shrub
- Peatbog
- River Maas
- Water

Figure 3.13: Nature typologies in the Noordelijke Maasvallei. Based on CORINE Land Cover (2019).

3.2.2. The water system of an ecological system

Nature with diverse vegetation creates a rich soil organic matter layer (SOM) or humus layer right below the surface. Not only does the SOM provide a rich ecology of worms and nutrients, but it has a strong water holding capacity. Therefore, in wet periods, rainfall infiltrates the soil and will be stored in the SOM. Then in dry periods, the vegetation can use this stored water, creating a cycle of storing and using the water. With water stored in the SOM, it will not flow towards the river or other water bodies. (Wösten & Groenendijk, 2019)

Moreover, on hills, vegetation creates a buffer and will slow water runoff, thereby decreasing the risk of erosion and preventing water from flowing into the river (Wösten & Groenendijk, 2019). However, there are exceptions such as seepage ponds. When the groundwater level reaches the surface, water will flow up to the surface again, creating a pond. Some ponds take a few years to form, whereas others might take 25 to 100 years (Paulissen et al., 2024).

Finally, nature areas with canopies can be beneficial in dry periods. Canopy intercepts rainfall and when evaporating, it allows water to go into the local atmosphere, rather than escaping into the air, which happens with direct soil evaporation. This creates a more humid environment in the ecosystem. (Cisneros Vaca et al., 2018)

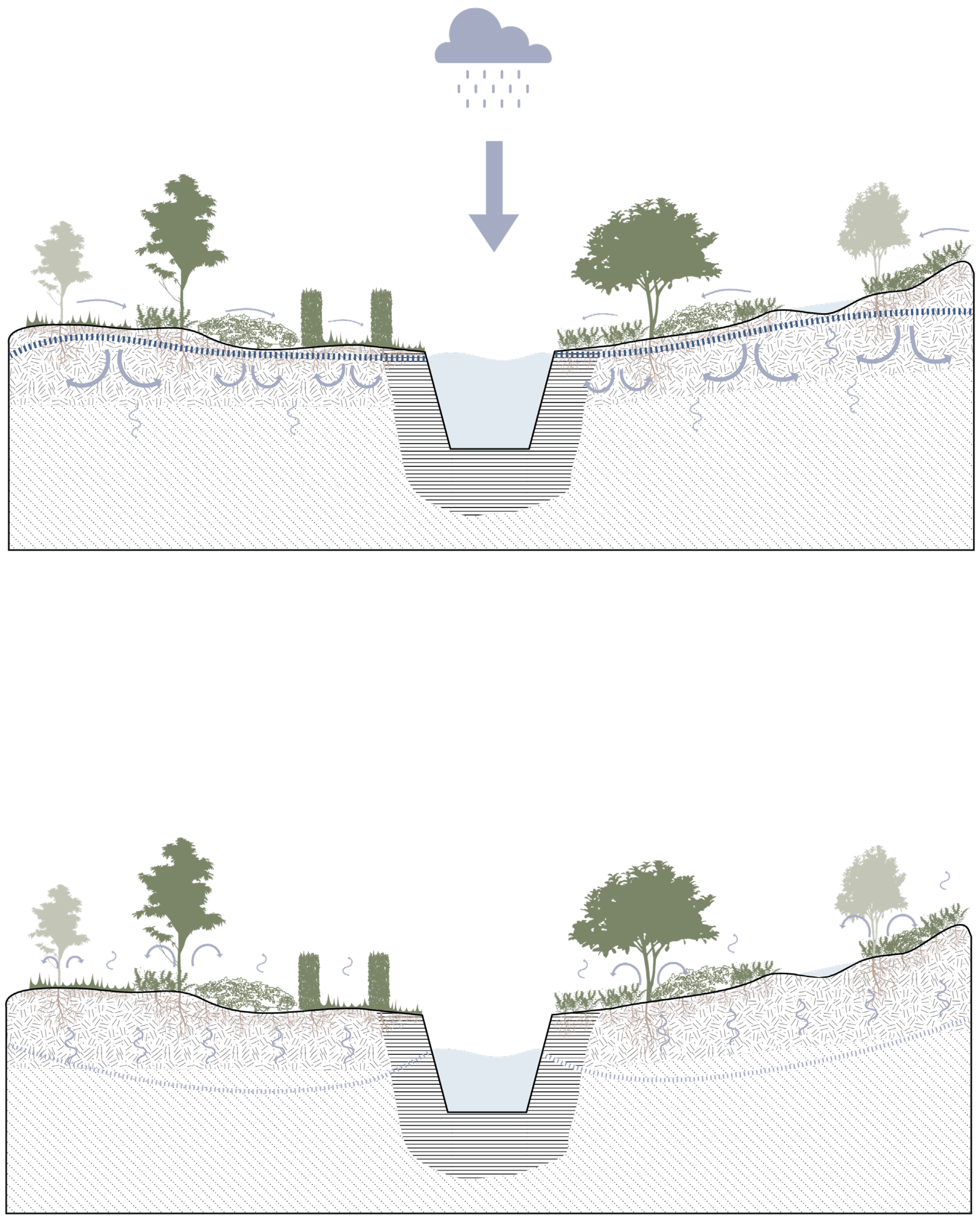


Figure 3.14: The water system of an ecological system.

3.2.3. The river Maas

As explained in chapter 3.1, the Maas has lost of its natural processes. Not only does this have effect on water distribution, but it has also severely impacted the ecology of the river. The Maas is a transboundary water body, important in connecting habitats with each other. Next to that, rivers are also an ecosystem on their own, with iconic river nature. However, since the interference of humans, a lot of vegetation has been lost in the river and on the floodplains resulting in the disappearance of flora and fauna (Asselman et al., 2018). Salmon for instance, used to breed in Belgium, Germany, and the Netherlands whereafter they would migrate to the Faroe islands and Greenland through the Maas and Rhine. However, since the 1950s this species has been gone due to pollution and interference of the rivers (van Rijssel et al., 2024). Although there are programmes to reintroduce the salmon back into the area, they have not been as successful as hoped.

Currently, nature around the Maas in the Noordelijke Maasvallei consists mainly of grasslands with shrubs, followed by forest. However, the Maas used to be a gravel river that had the opportunity to meander, creating a completely different landscape.

An example of this is the Grensmaas, part of the Maas in the south of Limburg, where the Maas has been renaturalised. Natural processes have been introduced by adding gravel to the river, and floodplain forests (ooibossen) have formed. This biotope can handle wet feet and regular occurring floods. Moreover, the side channels provide riparian vegetation and space for aquatic species. Figure 3.16 shows the difference of ecology between the Grensmaas and Zandmaas. (ARK Rewilding Nederland, n.d.)

Although the floodplain forests are resilient against flooding, periods of drought affect the river nature in the river itself and in the side channels. Slow flowing water can impact the existence of fish that are dependent on the current of the river. Moreover, side channels can even run dry, impacting the species in these habitats that need water. The main risk for the Grensmaas in periods of drought is the water division between the river and three other canals (Albertkanaal, Julianakanaal and Zuid-Willemsvaart) who get priority because of shipping. If this happens often, the Grensmaas could lose its potential as a well-functioning ecosystem for river nature. (Schulte & Van Winden, 2024)

Figure 3.15: The Grensmaas. Photo by ARK Rewilding Nederland (n.d.).

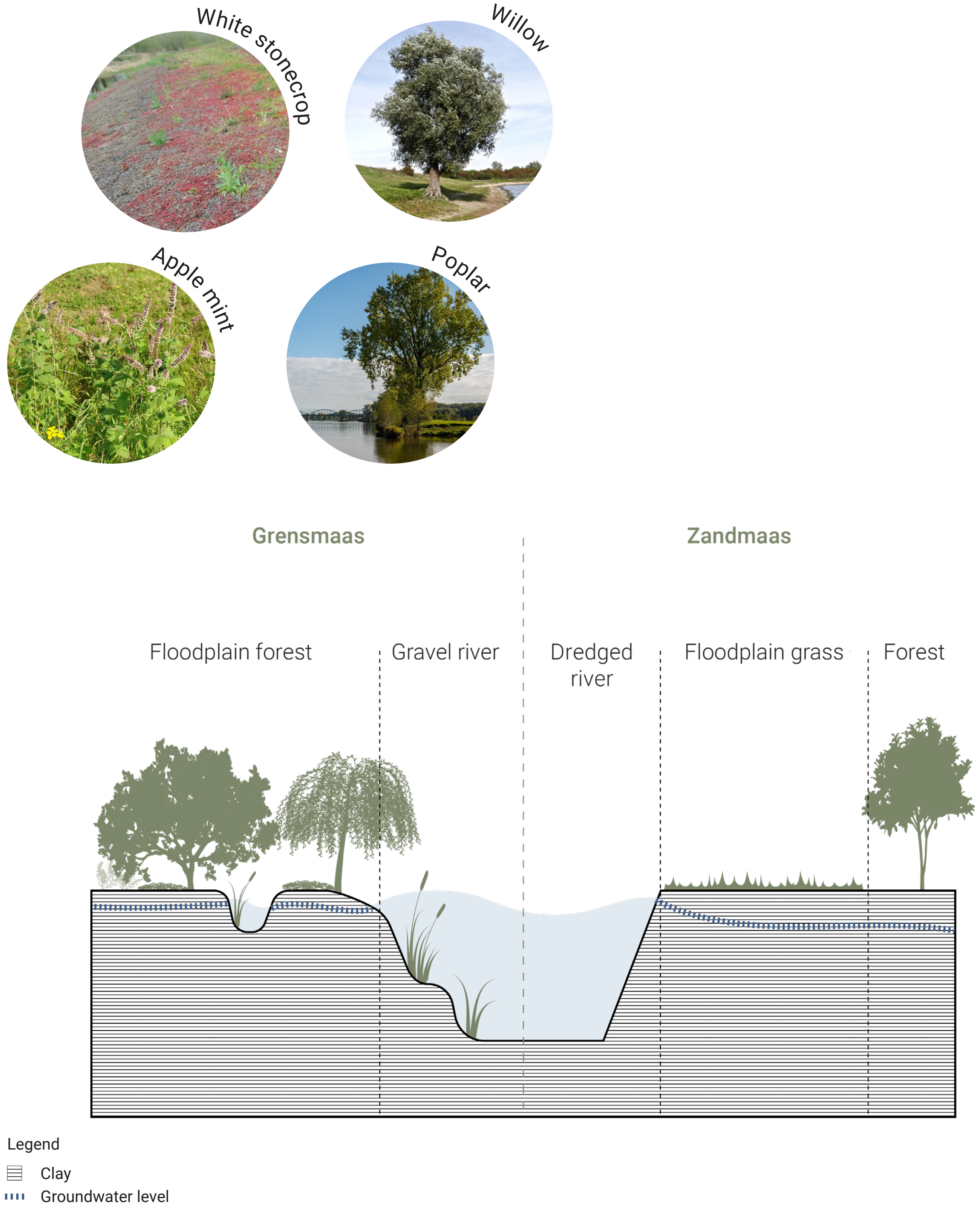


Figure 3.16: Biotopes of the Grensmaas compared to the Zandmaas. Photos by Ecopedia (n.d.).

3.2.4. Maasduinen

The Maasduinen were formed by terrace formations in the Ice Age, as explained in 3.1.2. After the Ice Age, vegetation began to thrive and native species started to pop up in this area. The Maasduinen are fed by rainwater, and in lower areas seepage ponds became common, with different ecological characteristics. Before human interference, the main biotopes were forest and fen that are still found today (see figure 3.18). (Paulissen et al., 2024)

After the Ice Age, the area became inhabited as well, and the landscape was changed by humans, starting with small settlements and small-scale agricultural fields. From the Middle Ages, the landscape started to change towards the culture landscape we know now. Agriculture spread and grazing sheep changed parts of the forest into heath. During this time, hedges were common to divide land and were part of a larger scale network the “Maasheggen”, of which only a small part is still present. During the 1800s agriculture became increasingly more productive, and the landscape drastically changed. Fertiliser was used more often, the fens were extracted from water for crops and the hedges were replaced by barbed wire.

Only after the Second World War, was the Maasduinen recognised for its ecological benefits. Therefore, part of the area has become a national park and natura 2000, in which fens and heathlands have been restored. It is an important stepping stone in the large scale European ecological network. (Paulissen et al., 2024)

However, climate change and the current agricultural practices in the area put pressure on the Maasduinen. In periods of drought, the ponds in the fen landscape run dry, removing breeding spots for certain species. Moreover, moss growth takes over the fens because of the abundance of nitrogen from the agricultural sector, stopping the natural processes of sand drifts in the dunes. Furthermore, forest fires are becoming more common in the area, risking fire to the villages and cattle farms close-by. Therefore, a change in land use will be needed to protect the Maasduinen from climate change. Agricultural practices will need to become more sustainable and less water demanding, to conserve water for the national park. (Redactie Groen Kennisnet, 2023)

Figure 3.17: The Maasduinen. Photo by author (2025).

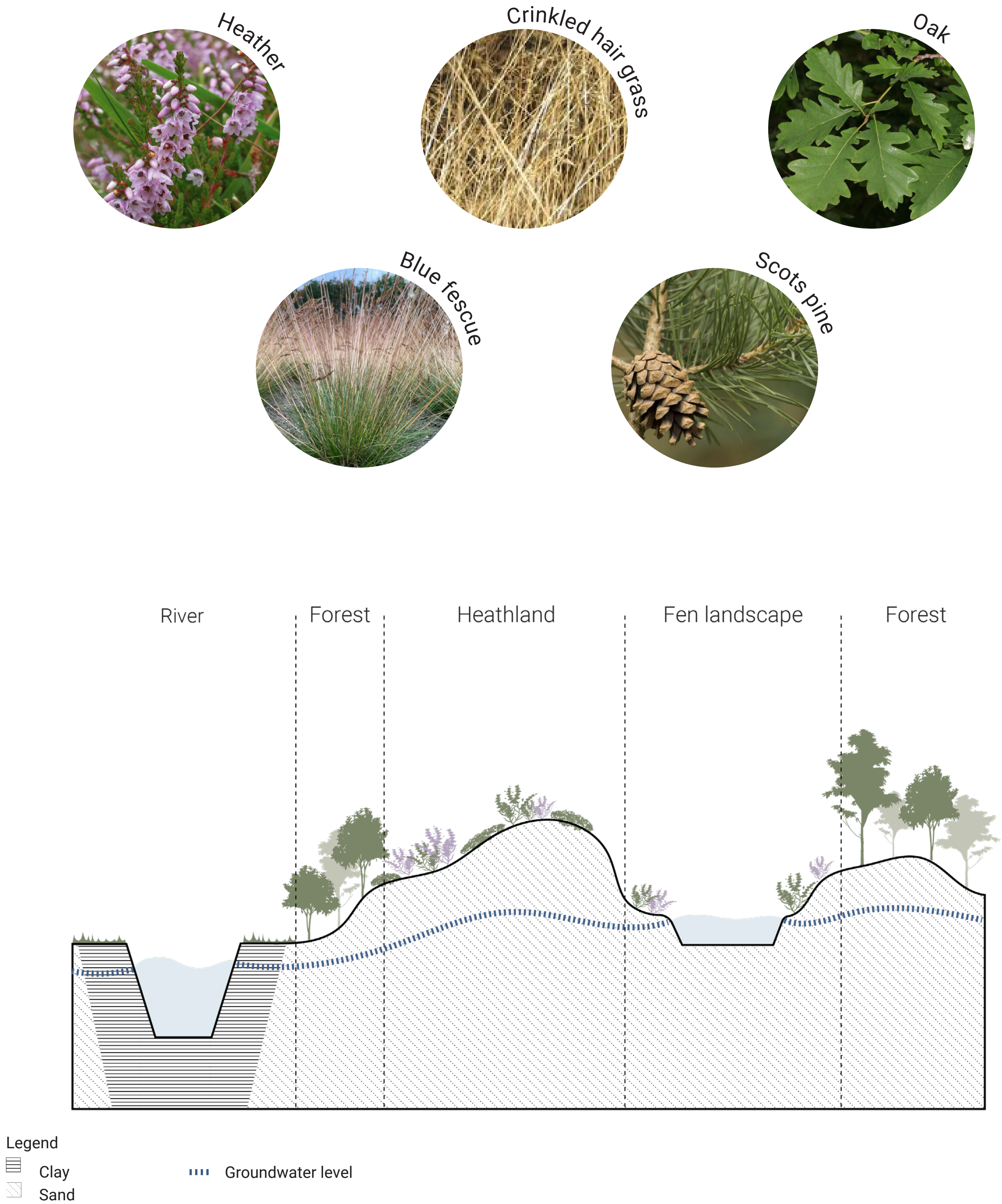


Figure 3.18: Biotopes of the Maasduinen. Photos by Ecopedia (2025).

3.2.5. De Peel

De Peel is an area located on peatland. It started forming after the last Ice Age when the melted ice was not able to flow away, from which fens formed. Many annual plants grew in these fens, which died and could not be broken down due to lack of oxygen. This stacked on top of each other above the water level, which created the “low” peatland (laagveen). Due to the nutrient-poor rainwater in the past, peat moss thrived and gradually covered the land, forming raised peat bogs (hoogveen), which over several centuries developed peat layers up to six meters thick. However, from the 13th century, peat extraction for fuel became popular, removing most of the raised peat bogs. Currently, in the Noordelijke Maasvallei, only a small part is still a raised peat bog. Peatlands can provide carbon storage, however as explained in chapter 3.1.2, they need to be kept wet. If not, they will emit carbon, or even methane, instead of storing it. (Nationaal Park De Groote Peel, n.d.)

Only part of De Peel is protected nature, which is national park De Groote Peel. The other parts of the peatland are used for agriculture. However, to practice agriculture on peatland the groundwater level of the area needs to be controlled to prevent land subsidence and ponding. (Nationaal Park De Groote Peel, n.d.)

The natural areas that can still be found consist of different biotopes (see figure 3.20). As explained, the raised peat bogs contain peat moss and some annual plants. On the exploited peatlands, forests can be found consisting mainly of birch. In the 1960s, coniferous forests were planted, but have since been removed to make space for more diverse vegetation. They can, however, still be found on the sides of De Groote Peel. Peat moss does not transform into raised peat bogs currently, as rain contains too many nutrients. Therefore, fens can be found in the area, with annual plants such as cattails and reed. (Nationaal Park De Groote Peel, n.d.)

Figure 3.19: De Groote Peel. Photos by author (2025).

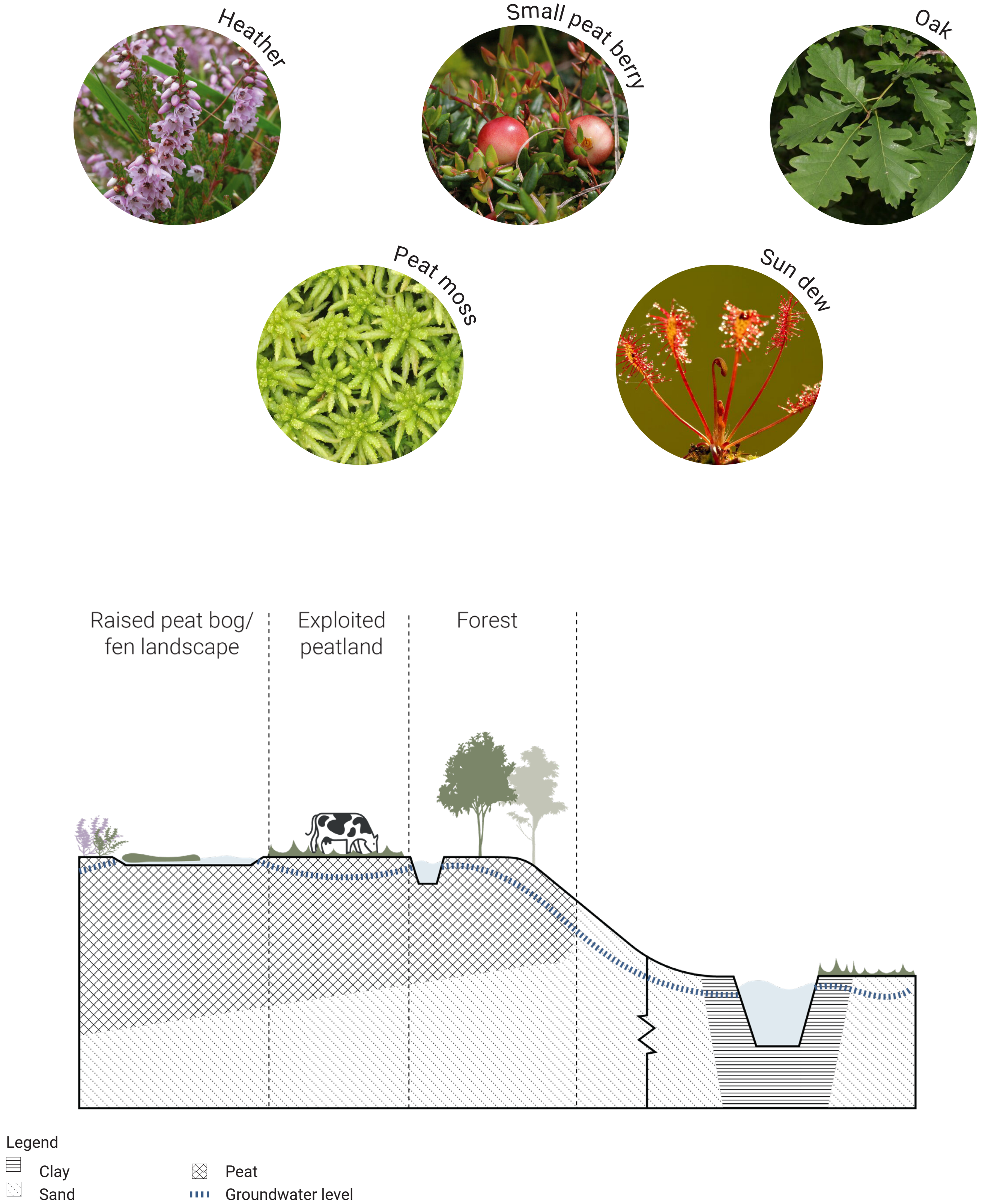


Figure 3.20: Biotopes of De Peel. Photos by Ecopedia (2025).

3.2.6. SWOT analysis: the ecological system

This analysis looked into three main ecological hubs in the Noordelijke Maasvallei: the river Maas, the Maasduinen and De Peel. Each of these areas has its own ecological characteristics, shaped by soil types, hydrology, and human intervention. They, and all other ecological areas, provide important functions such as water storage, ecological connectivity, and habitats for diverse species. However, landscape modification and current pressures from other land uses have weakened these natural functions and reduced resilience against climate extremes.

Although nature could provide a buffer against droughts and floods, the current system fails to do so and will become more vulnerable if current trends continue. Figure 3.21 shows the SWOT analysis of the ecological system of the Noordelijke Maasvallei.

Strenghts

S1 Diverse vegetation can work as a buffer against flooding.

S2 Nature has a large water holding capacity, allowing them to store water for use during periods of drought.

S3 De Peel and Maasduinen (natura 2000) are actively protected for their importance as stepping stones in the national and European corridors.

Weaknesses

W1 There is a lack of green and blue corridors between the natural ecosystems in the Noordelijke Maasvallei.

W2 The Maas has lost its river nature.

W3 De Peel demands constant water supply to stop the peatland from sinking.

W4 Nitrogen from agricultural practices change the ecology of the natural ecosystems.

Opportunities

O1 Extending nature in the Noordelijke Maasvallei would increase the sponge effect, making the area more resilient against the increasing risk of climate change.

O2 When kept wet, De Peel can capture and store carbon.

O3 Cultural landscape the Maasheggen could be expanded as green corridors and protectors against water runoff and erosion.

O4 Seepage ponds in the fen landscape can be used as refuge or water storage ponds.

Threats

T1 Forest fires could become more common if there is not enough water in the forests.

T2 If other land uses do not become more sustainable, certain ecological characteristics could be lost.

T3 Without enough groundwater, De Peel will become a methane producer.

T4 The water distribution between the river Maas and the connecting shipping canals could become problematic for the river nature of the Maas when not provided with enough discharge in dry periods.

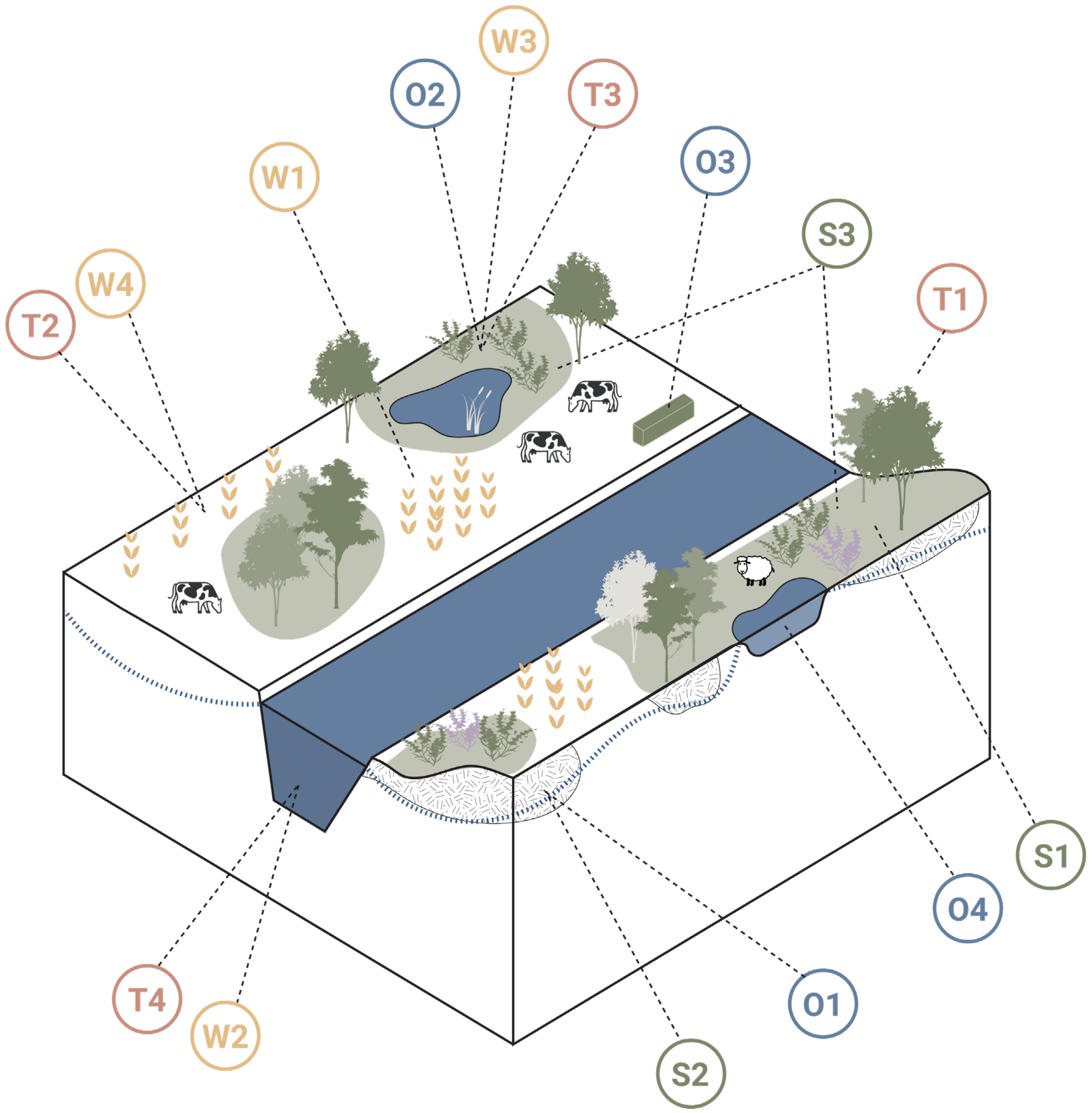


Figure 3.21: SWOT analysis of the ecological system.

3.3. The agricultural system

3.3.1. Agriculture in the Noordelijke Maasvallei

The main land use in the Noordelijke Maasvallei is agriculture. As can be seen in figures 3.22 and 3.23, the typologies of agriculture are mixed. However, agricultural grass is abundant with 38.7% and is the main type of agriculture that can be found close to the river Maas. The main crop that is grown in the area is maize, which grows well on the loamy sandy soils. Oher crops that can be found are potatoes, beets, cereals, orchards, flower bulbs and horticulture.

Over the last centuries, agricultural practices have changed from small-scale to extensive practices. Since the 18th century, technology advanced and farmers now owned the land. Agriculture became a source of income due to the growing demand for food. In this period, cereals were the mainly cultivated. Cattle only became more dominant in the beginning of the 20th century. (Philips et al., 1965)

In the 20th century, fields went from small and scattered to more uniform, productive landscapes due to innovation in agricultural practices. Innovations reduced the need for labour and could stabilise yields. The Second World War became a turning point for the agricultural system. Mechanisation increased the production significantly and agriculture expanded across the Noordelijke Maasvallei. The small plots with the hedges of the Maasheggen were replaced by large plots divided by barbed wire. However, agriculture started to become a secondary practice in the last half of the 20th century. Industry and urban expansion took over, and agriculture had to compete for space. (Jansen & Rutten, 1992)

Over time, agriculture has intensified and is still a major source of income for the Noordelijke Maasvallei. However, current practices are under pressure due to climate change and the effects of nitrogen from this land use (Rijksinstituut voor Volksgezondheid en Milieu, 2021). The current practice is not resilient against the droughts that will occur more often in summer, causing demand for water to grow. The water from the river Maas is sometimes already needed (Waterschap Limburg, 2020), but discharges in the river are low as well. This begs for a change in the present day agricultural system.

Crops	*Amount in area (%)*	*Preferred soil*
Agricultural grass	38.7	loam/clay
Maize	15.1	loam/sand
Potatoes	7.2	sand/loam
Beets	5.2	sand/loam
Cereals	6.6	loam
Orchard	0.2	loam
Flower bulbs	2.2	sand/loam
Horticulture	1.7	~

++ very positive
+ positive
0 neutral
- negative
-- very negative

Figure 3.22: Crop use in the Noordelijke Maasvallei. Based on LGN (2023) & EOS Data Analytics (2024).

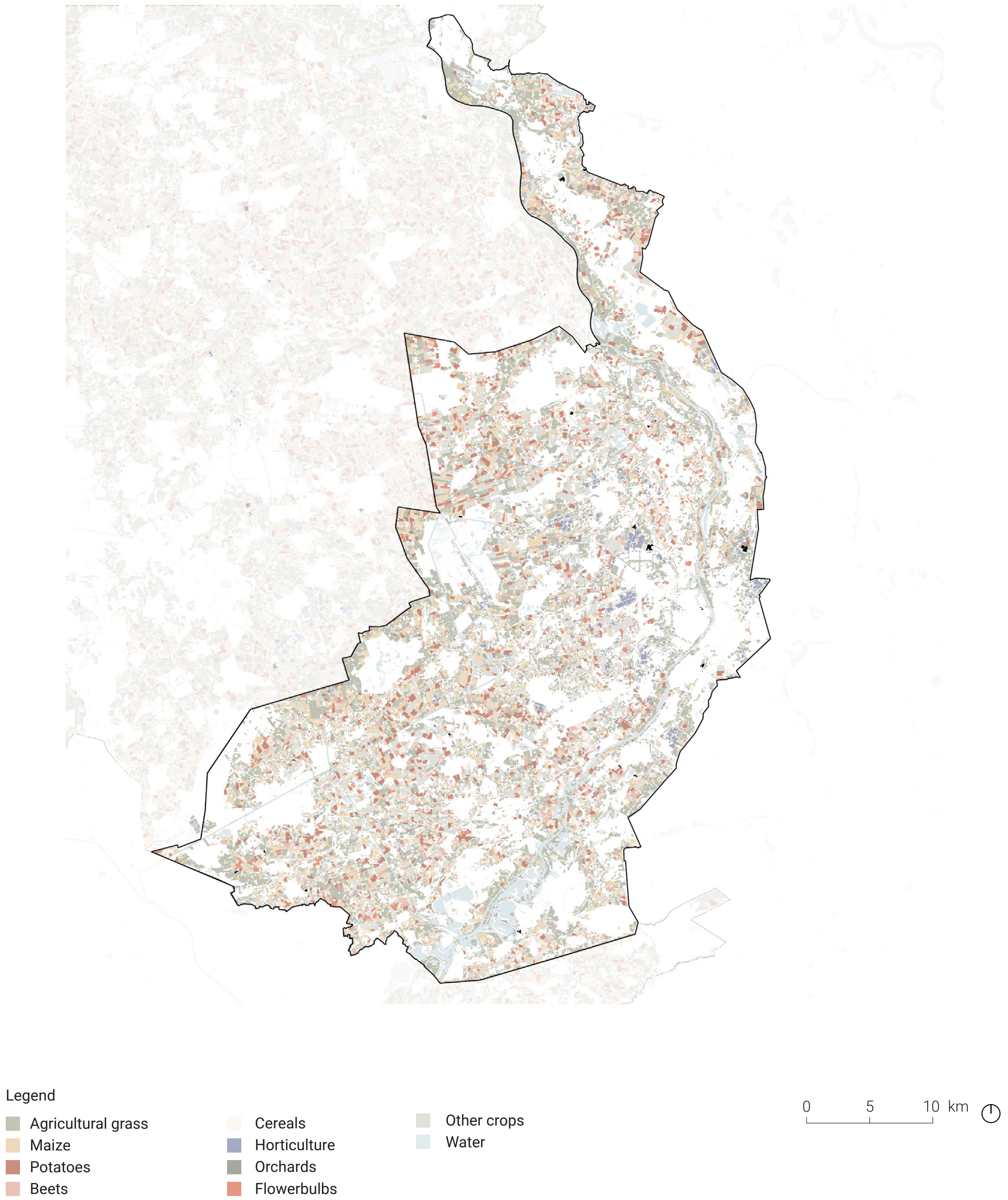


Figure 3.23: Agriculture typologies in the Noordelijke Maasvallei. Based on LGN (2023).

3.3.2. Agriculture and the water system

Current crop practices in the Noordelijke Maasvallei demand a lot of water, but at the same time cannot handle water logging. Figure 3.25 shows a dry and wet scenario on an agricultural field.

As explained in 3.2.2., plants can provide a SOM which provides the potential to store water in the soil. However, the crop use in this area is a monoculture and the plants have small root systems. Therefore, the SOM is not large enough to hold water. Moreover, some fields are left empty in winter, when storing water would be most important. Furthermore, the agricultural grass fields that are largely present in the clay soil around the river cannot handle water logging for long (Wageningen University and Research, 2024). The soil will silt up, preventing water from infiltrating into the soil. Water that does infiltrate into the soil, will not stay in the area but will flow to the closest water body. This will be the river in the areas near the Maas, which already has a high discharge.

In dry periods, the water demand of crops is high. Maize needs a lot of water, due to its high evaporation rate. Because the water is not stored in the soil like in a natural ecosystem, and due to the low water holding capacity of the sandy soils, water needs to come from external sources. This also puts pressure on other sectors. (Wageningen University and Research, 2024)

Unfortunately, crops now grown in the area are not resilient to both wet and dry periods (see figure 3.24.). Therefore, a change in crops would be advised, either through genetic modification or the use of other crops. (Wageningen University and Research, 2024)

Crops	*Water tolerant*	*Drought tolerant*
Agricultural grass	-	--
Maize	--	o
Potatoes	--	--
Beets	-	--
Cereals	--	o
Orchard	-/o	+
Flower bulbs	--	+

++ very positive
\+ positive
0 neutral
\- negative
-- very negative

Figure 3.24: Resilience of crops in a wet and dry scenario. Based on FAO (2017).

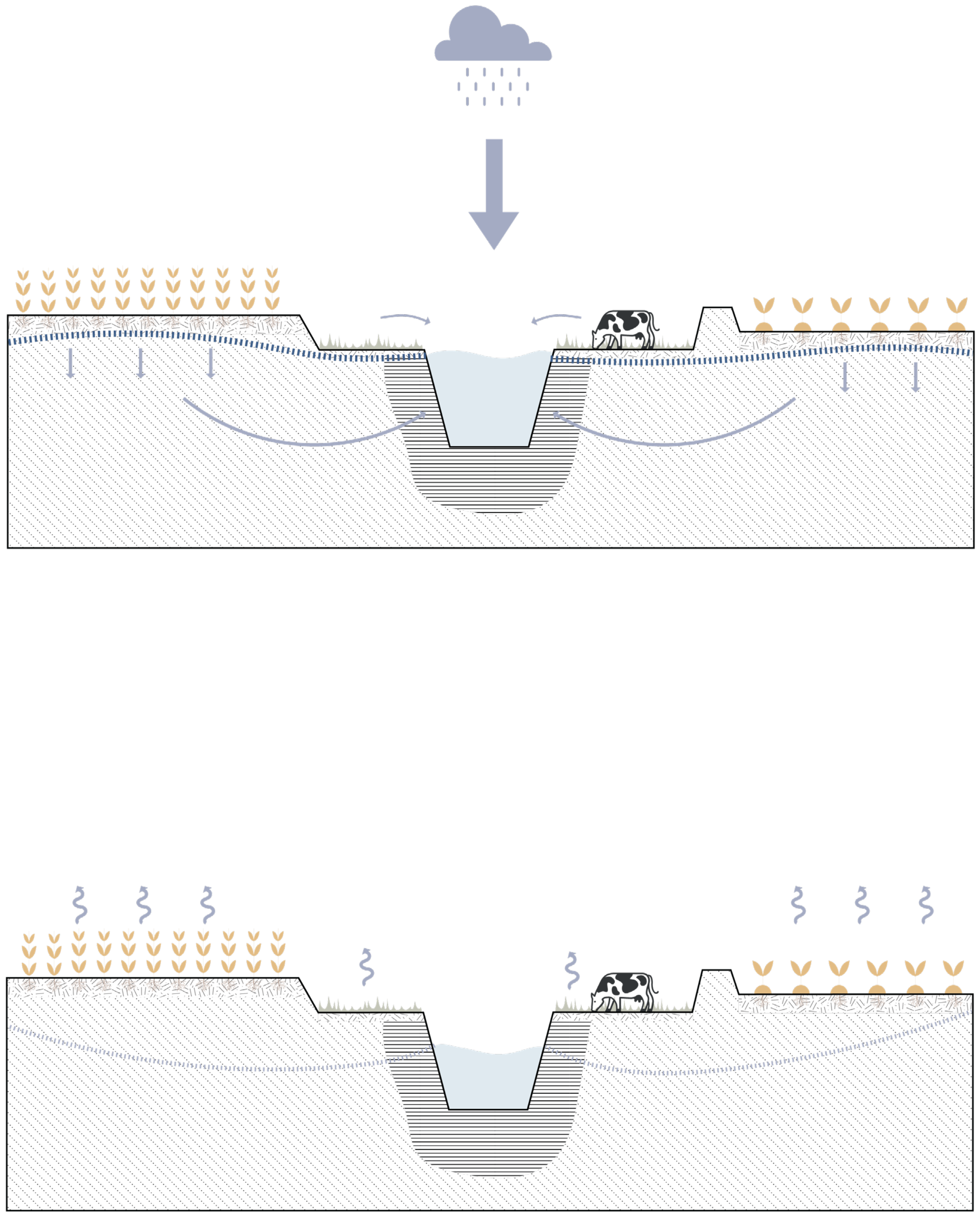


Figure 3.25: The water system of an agricultural system.

3.3.3. SWOT analysis: the agricultural system

So, the agricultural system in the Noordelijke Maasvallei is monocultural and already suffering from the consequences of climate change. Crop yields on the dry sandy soils will decline due to increasing droughts in summer, whereas crops on flood-prone areas will suffer from the increasingly wetter winters. This asks for a change in land use. There are already technical advancements to monitor the water demand of crops, but with the fast pace of innovation today, these technologies could improve even further.

However, a change to crop use that is resilient to climate change, and agriculture in combination with nature to increase the infiltration and water storing capacity of the soil, could offer more natural potential. In figure 3.26, an overview of the strengths, weaknesses, opportunities, and threats is shown.

Strenghts

S1 Crops fields can infiltrate water.

S2 Technical advancements and infiltration systems are used to reduce water demand.

Weaknesses

W1 Agriculture takes up a lot of space, taking away space from the river to flood

W2 Crops have a high water demand, making them susceptible to drought.

W3 Grass fields cannot handle long term water logging.

W4 Soil water availability is too low to support both agricultural production and natural ecosystems.

W5 Monocultures do not support good water storing capacity for use in dry periods.

Opportunities

O1 There is space on empty fields in winter to store water.

O2 Mixing crops with nature could increase the water holding capacity, and thus improve crop yields.

O3 Use technology to monitor crop growth and use water as efficiently as possible.

Threats

T1 The growing demand for water poses a threat to the river Maas as its water may increasingly be used for irrigation.

T2 Crop yields will decrease in areas that are becoming wetter as well as in areas that are becoming drier.

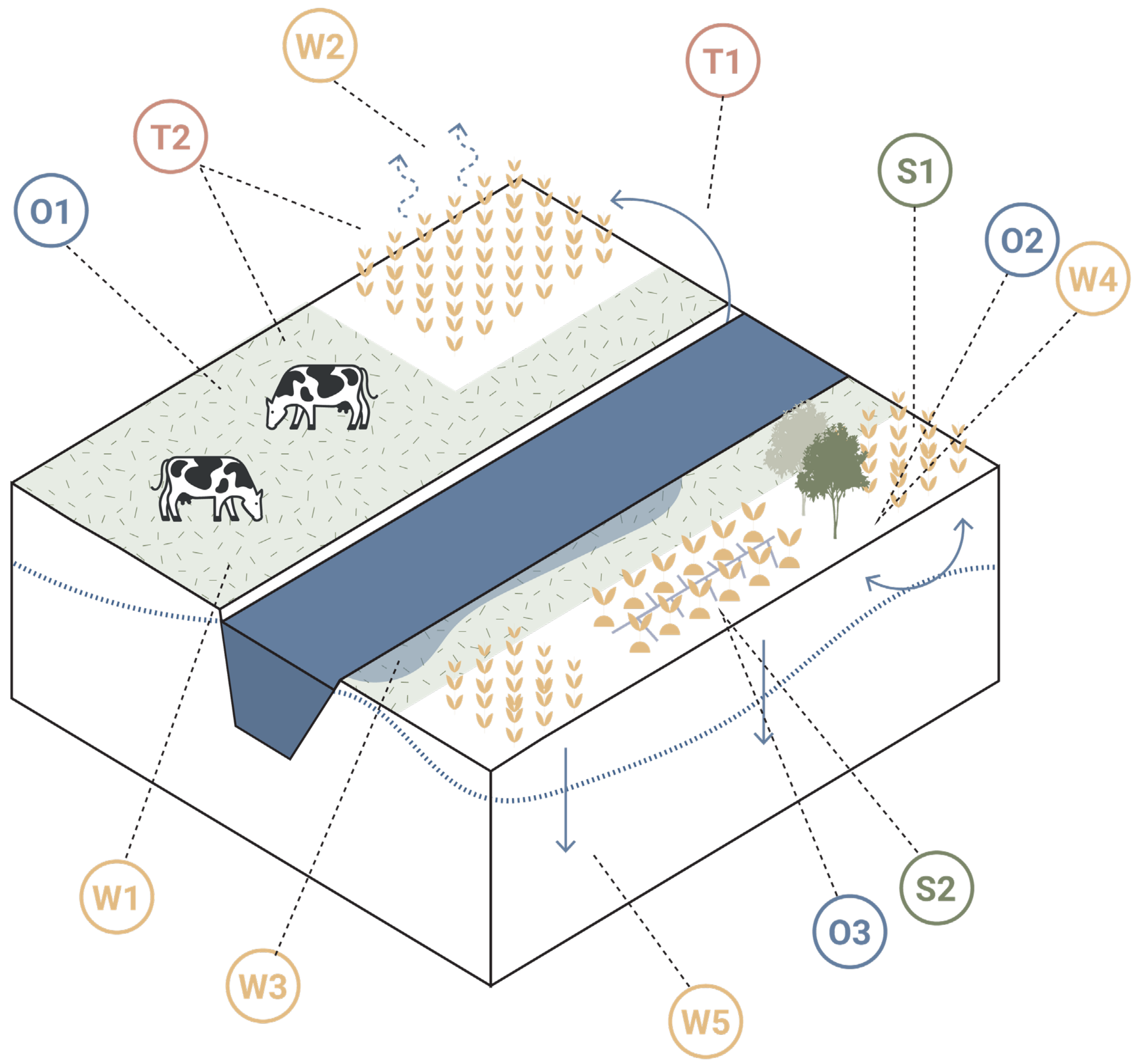


Figure 3.26: SWOT analysis of the agricultural system.

3.4. The urban system

3.4.1. Urban areas around the Maas

The urban areas in the Noordelijke Maasvallei are a mix between smaller villages and towns and bigger cities such as Venlo, Roermond, Weert, and Venray (see figure 3.27). Of these areas, Venlo and Roermond are built on the river Maas, between which smaller towns are settled. More north, Heijen and Gennep can also be found next to the river.

The culture landscape of the Noordelijke Maasvallei started to shape from the Middle Ages. Small settlements were built on places where the land was suitable for agriculture. Most settlements were close to the Maas on high sand ridges to provide protection against flooding. The area between the Maas terraces and flood plains was popular in this time, due to its proximity to both fertile river clay and the high, dry area of the terraces. Other villages settled in the valleys of small tributaries where small scale industries provided a form of income next to agriculture. In the 19th century, the fens and forest on top of the Maasduinen were extracted for agriculture, resulting in the settling of more villages in this area. (Raap, 2023)

The river Maas became more attractive as a mode of transport with the rise of industry. Venlo became a transshipment point, as larger ships could not flow over the Maas south of Roermond. However, after the implementation of the Julianakanaal and Lateraalkanaal in the beginning of the 1900s, ships could continue their route over the Maas and Venlo lost this function. Weert, on the other hand, started to expand after the implementation of the canal Zuid-Willemsvaart and the railway system, from which Weert could grow into an industrial city. (Raap, 2023)

The Second World War severely affected the Noordelijke Maasvallei and many towns had to be rebuilt. Churches were put farther from the river. Land consolidation of agricultural ground changed creating the opportunity for better accessibility between urban areas. The Maasplassen from gravel extraction opened space for recreation and the electrical industry. In the 1960s and 70s cities expanded rapidly, which is especially visible for Venlo. (Raap, 2023)

The province of Limburg has plans to build more houses in Noord and Midden Limburg, with a focus on Venlo and Roermond (Minister voor VRO et al., 2023). However, because of its close proximity to Eindhoven, Weert will become an important location for housing as the Brainport region continues to grow (Gemeente Weert, 2025).

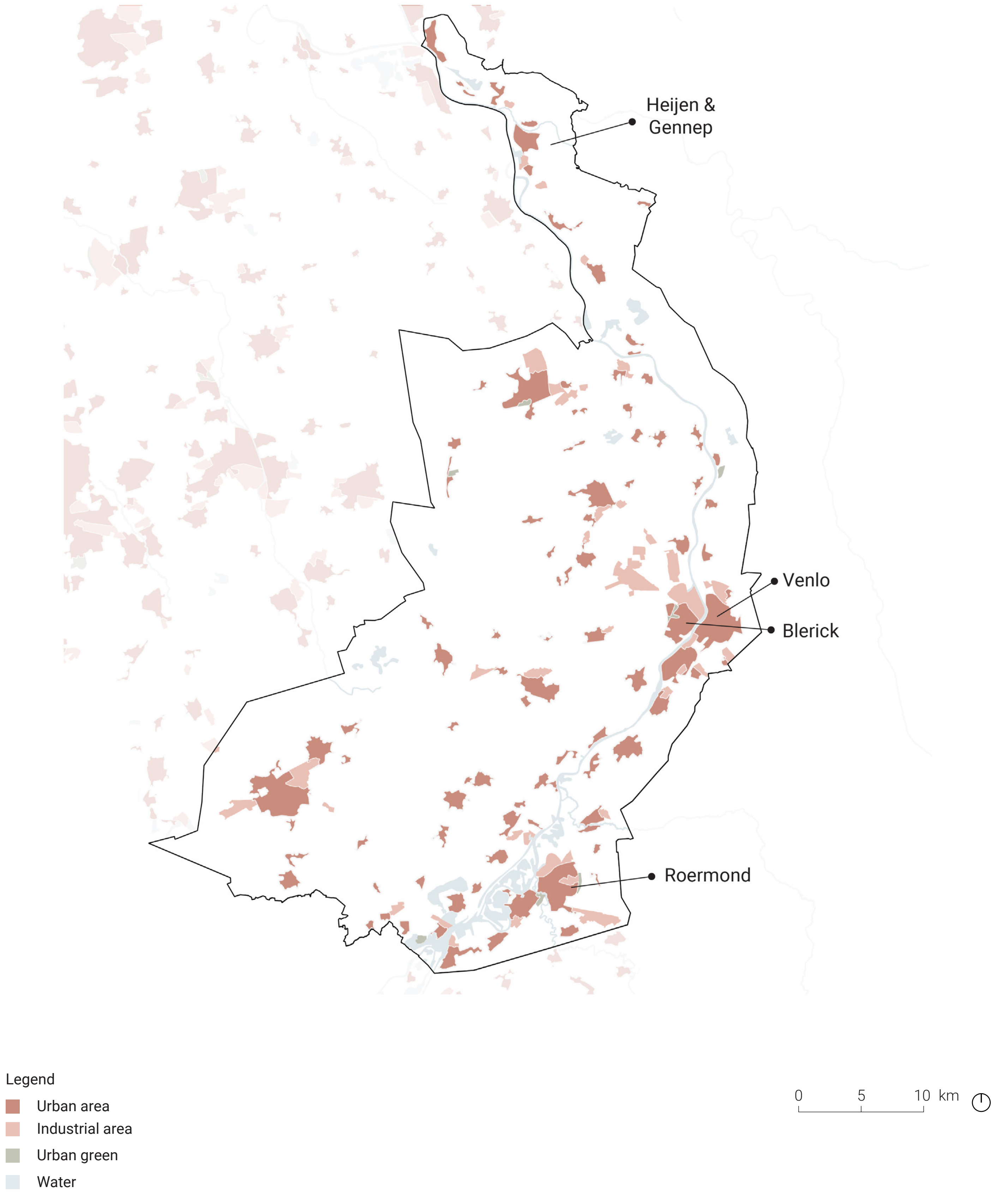


Figure 3.27: Urban areas in the Noordelijke Maasvallei. Based on CORINE Land Cover (2019).

3.4.2. Relation to the river Maas

Towns and cities have been built close to the river Maas. In the Noordelijke Maasvallei, dikes have only been built around city centres due to the protection afforded by the height of the Maas terraces. Therefore, different typologies of river edges can be found as shown in figures 3.28 to 3.31. The different typologies have open and close variants.

The "dike + floodplain" typology is common between Roermond and Venlo, where different smaller towns are situated next to the river. In some cases, the floodplains are also open for recreation. The "slope" river edge can be found close to the Maasduinen, where the terraces provide protection from flooding. Some slopes are open for walking, whereas others are protected by shrubs and other types of vegetation. Finally, the "solid quay" is more common in the bigger cities. They are protected by a dike immediately connected to the river. Some quays are used for recreation, while others are left unused, causing the city to turn its accessibility away from the river.

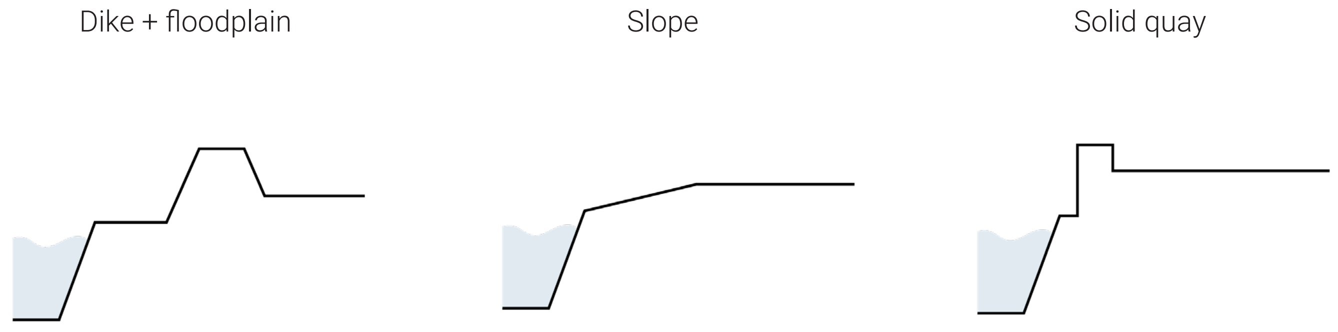
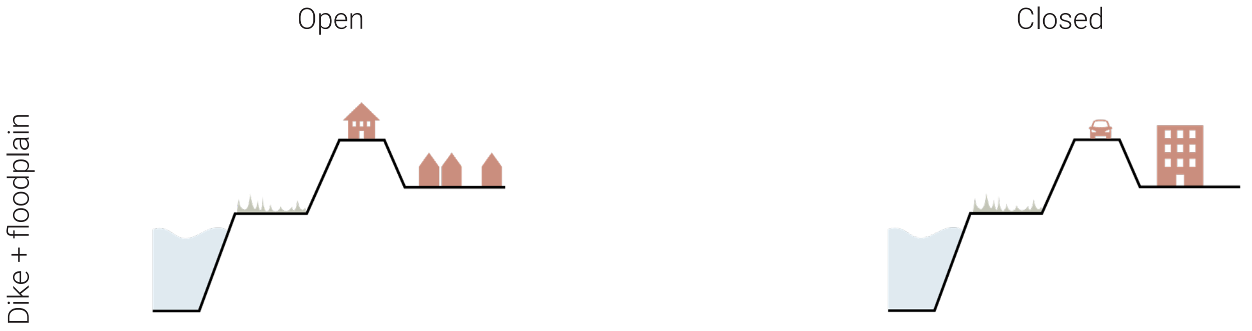


Figure 3.28: Typologies of river edges.



Velden

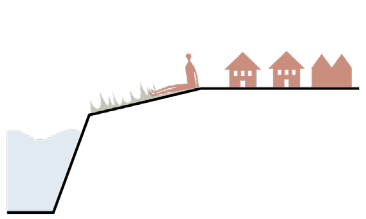
Hout-Blerick

Steyl

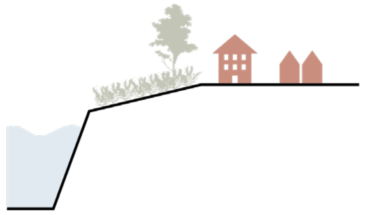
Figure 3.29: The "dike+floodplain"" river edge. Photos by author (2025) HwPB (2025), and Waterschap Limburg (n.d.).

Slope

Open



Closed



Roermond

Roermond

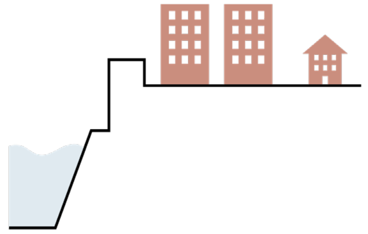
Blerick

Figure 3.30: The “slope” river edge. Photos by author (2025).

Solid quay

Open

Closed



Venlo

Roermond

Venlo

Figure 3.31: The “solid quay” river edge. Photos by author (2025).

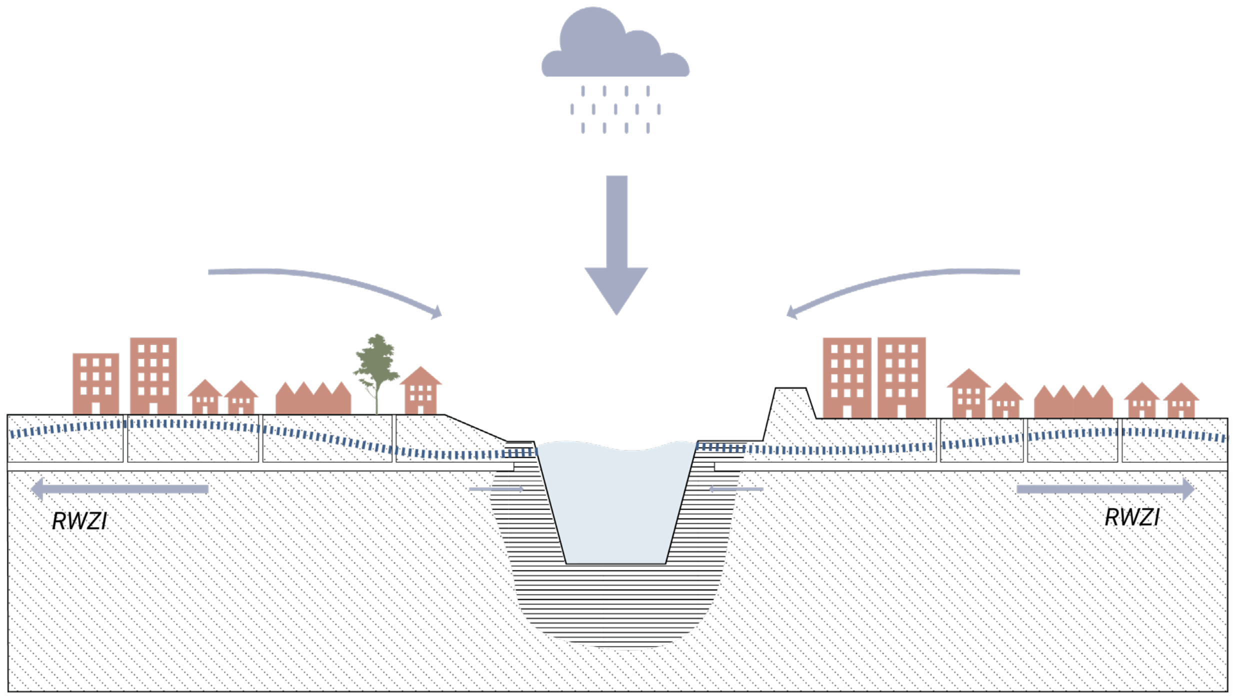
3.4.3. The water system in urban areas

The water system in urban areas functions differently from that in natural or agricultural landscapes because the soil is sealed by pavement and buildings. Therefore, water cannot infiltrate naturally into the soil, but goes through a sewage system, whereafter it is transported to a sewage treatment plant. However, sewage systems can overflow in times of heavy rainfall. In some cases, excess water is discharged into the Maas, resulting in even higher river discharges (Waterschap Limburg, 2023).

In the future, high discharges will become more common due to wetter winters and the increasing risk of summer storms (KNMI, 2023). This will result in an increase in flood risk. The effects were already visible in 2021 when dikes in cities could not handle the amount of water. Cities such as Roermond flooded. Without a change in the water system of urban areas, this risk will only increase and floods are more likely to happen.

On the other hand, drier summers will make cities warmer, resulting in an increased urban heat island effect (UHI) due to the lack of green and blue spots. Low groundwater levels in urban areas can cause wooden pole decay, as the wood will rot due to the absence of water (KCAF, 2020). This will make houses built on poles unstable and dangerous to live in. Moreover, 25% of drinking water in Limburg comes from the river Maas (Provincie Limburg, n.d.). With low discharges, it will be difficult for the river to maintain this supply. Additionally, industry upstream causes water pollution. This concentration becomes higher with low discharges, making the water dangerous for usage (NOS, 2025). Therefore, not only is the quantity of the water becoming an issue, but the quality as well.

So, urban areas have an advanced water system and are dependent on water supply and drainage through a technical approach. However, more cities are seeing the potential of implementing local green areas and retention ponds. This will lead to an increase in water infiltration and storage in wet periods and provide cooling opportunities during warm summers.



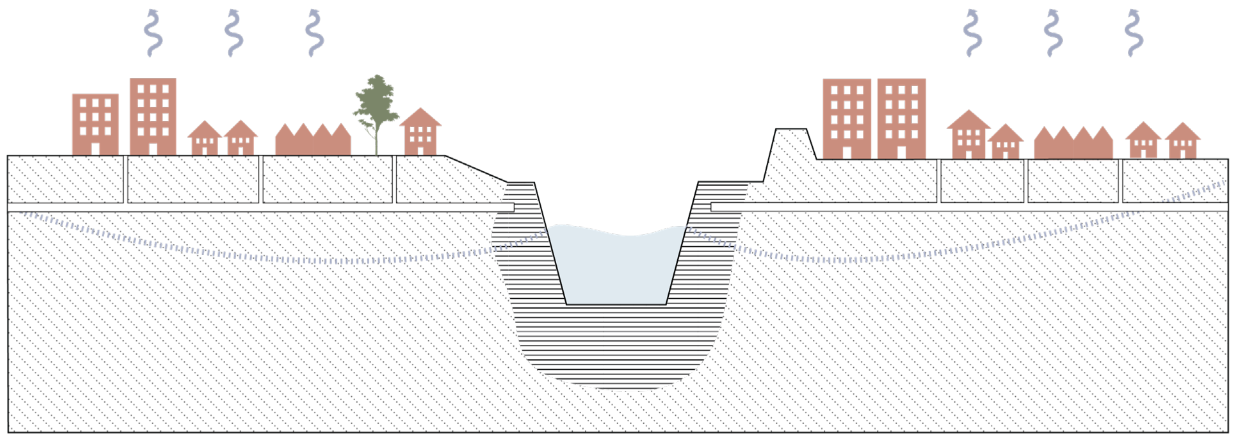


Figure 3.32: The water system of an urban system.

3.4.4. SWOT analysis: the urban system

In conclusion, the urban environment in the Noordelijke Maasvallei has grown quite a bit along the Maas. Dikes have been built around the city centres. However, the flood risk of these areas will only increase with the expected high discharges of the Maas in the future. Although room for the river has been created with floodplain parks, for instance, this might not be enough to remove the risk. On the other hand, in dry periods cities heat up and the UHI effect will only increase over time with summers becoming warmer.

Although cities have been focusing on the implementation of green spots, the question is whether this will be enough in the future. Finally, pressure on the Maas from urban areas is growing as well. Not only is the need for water high in dry periods, but in wet periods cities use the river as drainage when sewage treatment is overflowing. With the sporadic discharges of the Maas, this could also pose issues downstream of the Noordelijke Maasvallei.

Strenghts

S1 Floodplain parks serve a recreational purpose as well as a buffer against flooding.

S2 Quays can be used for protection against flooding and serve a recreational purpose.

S3 Most smaller villages are built high enough to be protected from flooding from the Maas.

S4 There is a focus on urban expansion in Weert, away from the flood risk of the Maas.

Weaknesses

W1 The UHI effect creates issues with comfortability in cities in summer.

W2 Wooden poles suffer from decay in times of drought.

W3 Towns close to the Maas and its tributaries risk flooding and need to be protected by dikes.

W4 The Maas is used as water drainage in periods of extreme rainfall.

Opportunities

O1 Floodplain parks could be used for renaturalisation of the Maas.

O2 Green urban areas could create opportunities for both infiltration and cooling in the city.

Threats

T1 Dikes will need to be heightened with river discharges only increasing in winter.

T2 Urban expansion in flood-prone areas could pose a danger to newly built neighbourhoods.

T3 The drinking water supply could become insufficient with drier periods in summer.

T4 Pollution of the Maas from upstream could threaten the drinking water supply during droughts, when contaminant concentrations become too high.

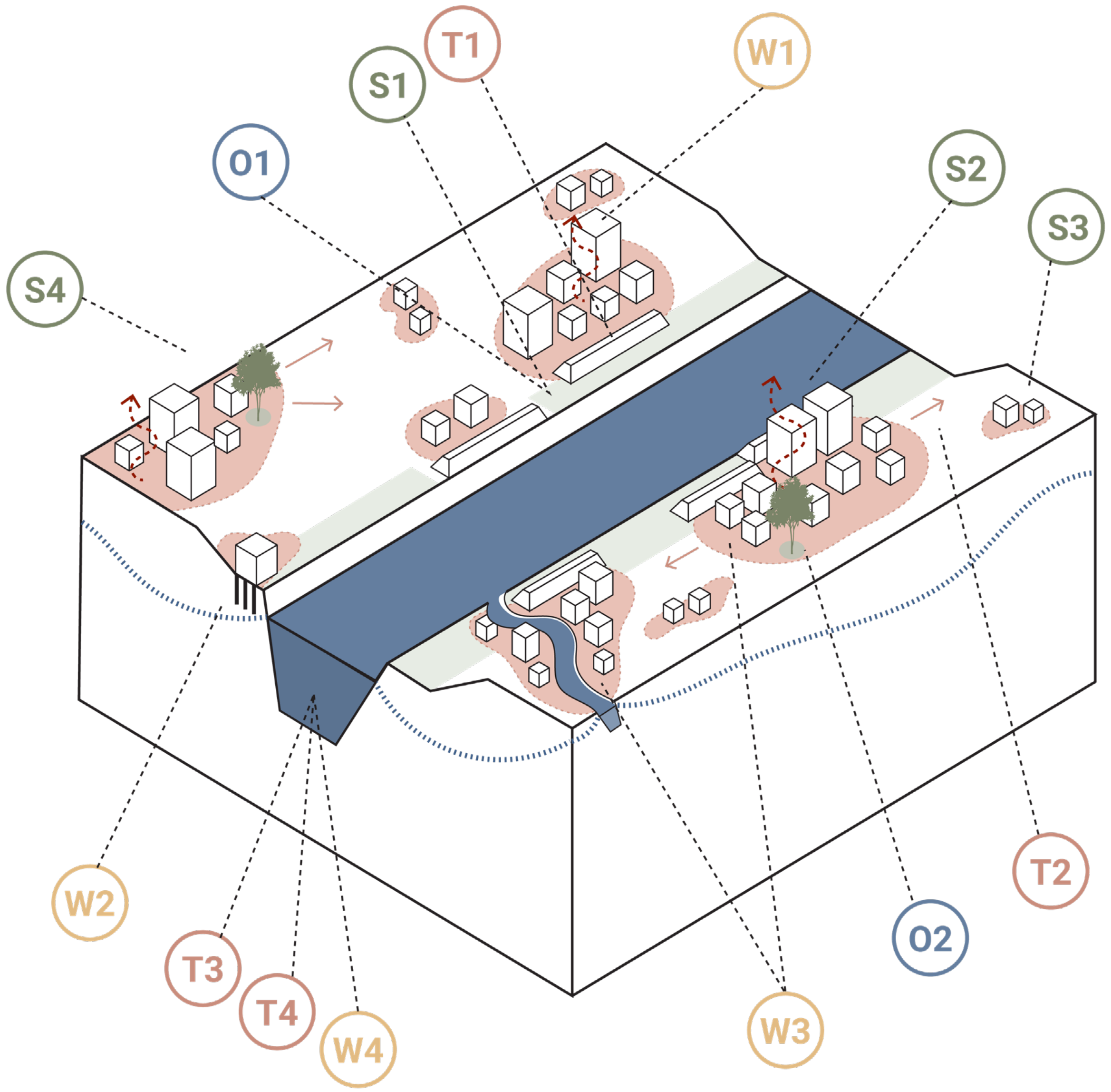


Figure 3.33: SWOT analysis of the urban system.

3.5. Criteria for a desirable future

Different issues related to climate resilience can be derived from the SWOT analyses of the river, ecological, agricultural, and urban system. However, there are three main themes under which these points fall: water availability, water safety, and ecological resilience. Evaluation criteria based on these themes have been formulated to evaluate current and possible future systems. Certain criteria fit under multiple themes, therefore, a fourth group “complementary criteria” has been added. These criteria can be used to give interventions or a system a score.

Water availability

Drinking water supply
Crop water efficiency
Infiltration and recharge
Shipping navigability
Water quality

Water safety

Urban flood safety
Crop field drainage
River space capacity
Infrastructure resilience

Ecological resilience

River nature
Ecosystem connectivity
Peatland stability
Nutrient stability
Heat mitigation

Complementary criteria

Water retention
Natural river dynamics
Land use compatibility
Discharge adaptability

3.6. Future Autonomous Situation

3.6.1. Evaluation of the Future Autonomous Situation

The KNMI predicts that in 2100 extreme weather events will occur more often. This subchapter shows the evaluation of the current system (river, ecological, agricultural and urban) in the Noordelijke Maasvallei, and the evaluation for 2100, where there have been no changes to the current approach. In figure 3.34, this is called FAS 2100, which stands for "Future Autonomous Situation". With the criteria of 3.5, both scenarios are tested.

Today, water availability is still adequate for most sectors, but issues in summer are detoriating every year. This applies especially in agriculture, where crops demand water that is not always present without sufficient rainfall in summer. However, comparing today to a FAS in 2100, water availability will drastically drop, as can be seen in comparing the scores. Drinking water availability will especially become a problem. The river is expected to provide less discharge and there will be less rainfall to be infiltrated and stored into the soil. A similar issue presents itself in crop water availability. Moreover, shipping navigability will become harder over time as water division between the canals and river becomes an issue.

Water safety will become an increasingly worse issue in 2100 as well. According to the KNMI, winters will be much wetter and summer storms will occur more frequently. Current infrastructure is not built for such events. Cities heavily depend on dikes, meaning they will need to be raised, and crop practices will need be able to withstand longer waterlogging. Although the infrastructure is quite resilient for the events of 2025, it is not expected to be resilient for the presumed events of 2100.

Ecological resilience does not score high in today's scenario, and this score will get slightly lower in 2100 without proper changes. Heat mitigation will become harder with the warmer and drier summers, and peatlands will need more water to stay stable. Moreover, certain types of vegetation might not be able to handle the warmer climate, and could disappear from the area. The other criteria, such as ecosystem connectivity and fauna refuge, do not currently score very high, which is expected to remain unchanged in 2100.

Some complementary criteria drastically decrease in 2100 compared to today, whereas others will stay similar. Water retention and discharge adaptability will be especially affected by the increasingly extreme weather events expected in 2100. Since natural river dynamics have already disappeared for the Maas in this area, this will not change much. This is similar for land use compatibility. In this scenario changes will not be made to the current spatial implication of the Noordelijke Maasvallei.

	Criteria	2025	FAS 2100
Water availability	Drinking water supply	+	-
	Crop water efficiency	-	- -
	Infiltration and recharge	-	-
	Shipping navigability	+	-
	Water quality	0	-
Water safety	Urban flood safety	0	-
	Crop field drainage	-	- -
	Infrastructure resilience	+	-
Ecological resilience	River nature	- -	- -
	Ecosystem connectivity	-	-
	Peatland stability	0	-
	Nutrient stability	- -	- -
	Heat mitigation	-	- -
	Fauna refuge	-	-
Complementary criteria	Water retention	0	- -
	Natural river dynamics	- -	- -
	Land use compatibility	-	-
	Discharge adaptability	-	- -

Effect:

++ very positive
+ positive
0 no effect
- negative
- - very negative

Figure 3.34: Evaluation of the current situation and FAS 2100.

3.6.2. Visualisation of the Future Autonomous Situation

Figure 3.35 summarises the FAS for 2100 for the Noordelijke Maasvallei. It shows the main risks for each theme in a dry or wet scenario. On the next pages, figures 3.36 and 3.37 present spatial impressions of what the Noordelijke Maasvallei would look like in this situation. Figure 3.36 zooms in on a rural area, whereas figure 3.37 shows the situation for an urban area.

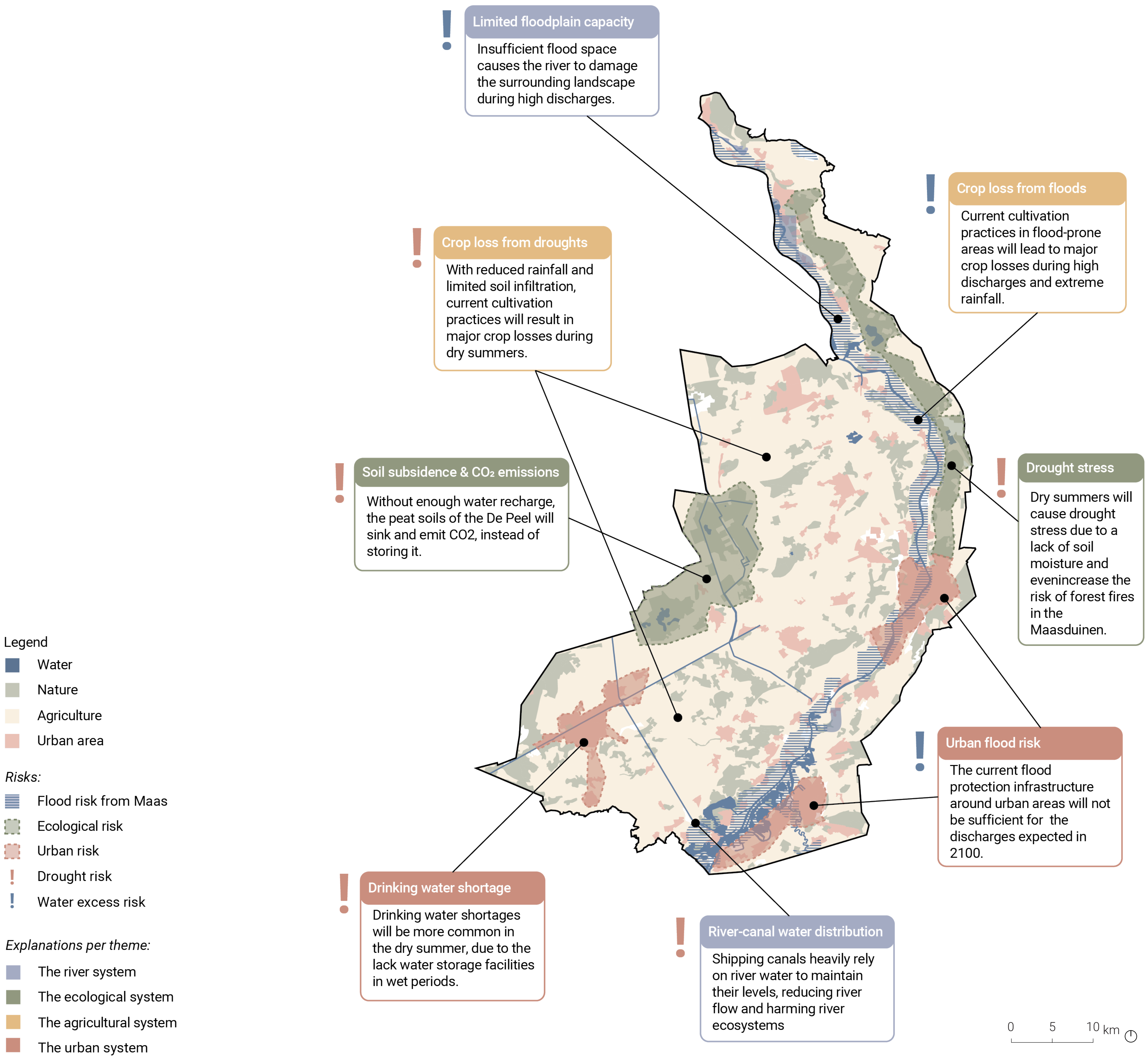
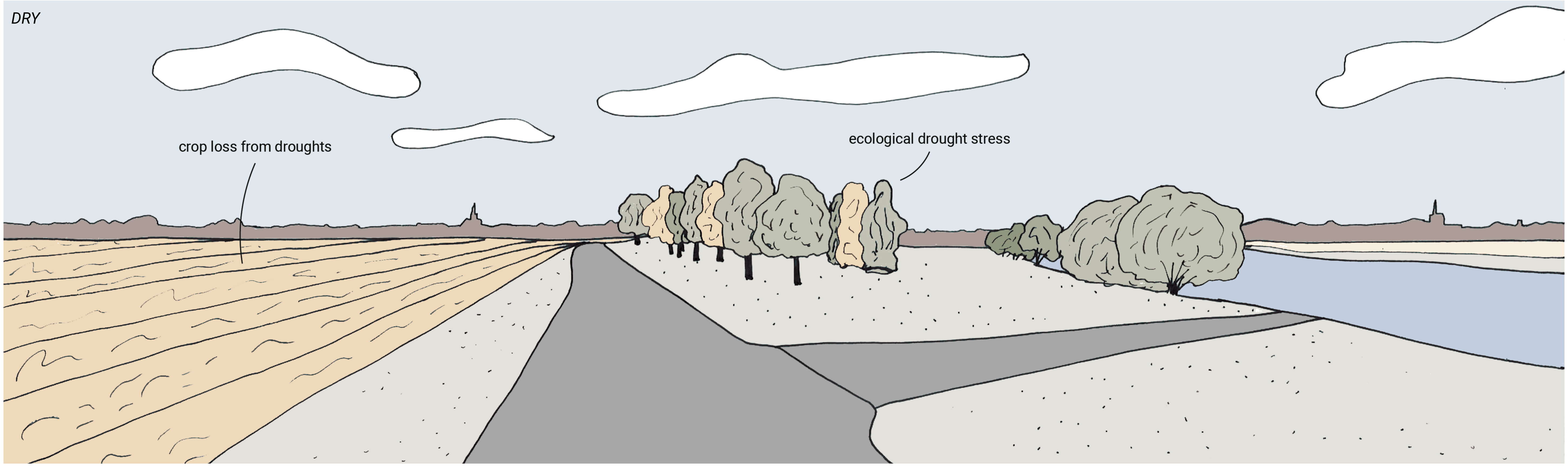


Figure 3.35: Risks of the Future Autonomous Situation for 2100 in the Noordelijke Maasvallei.

Rural panoroma of the FAS in 2100



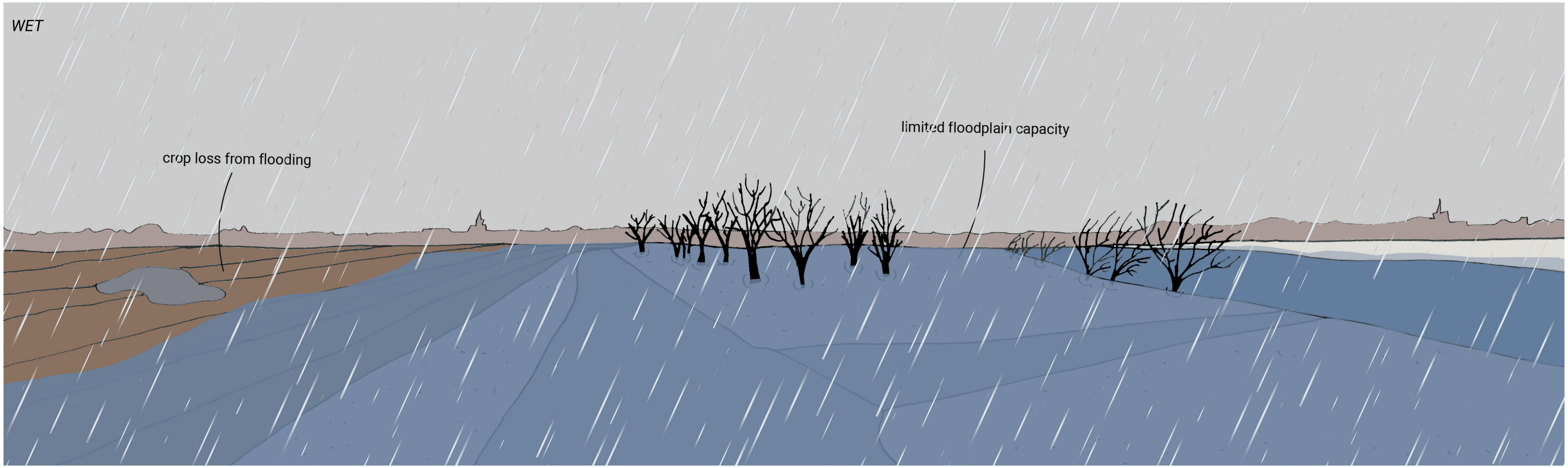
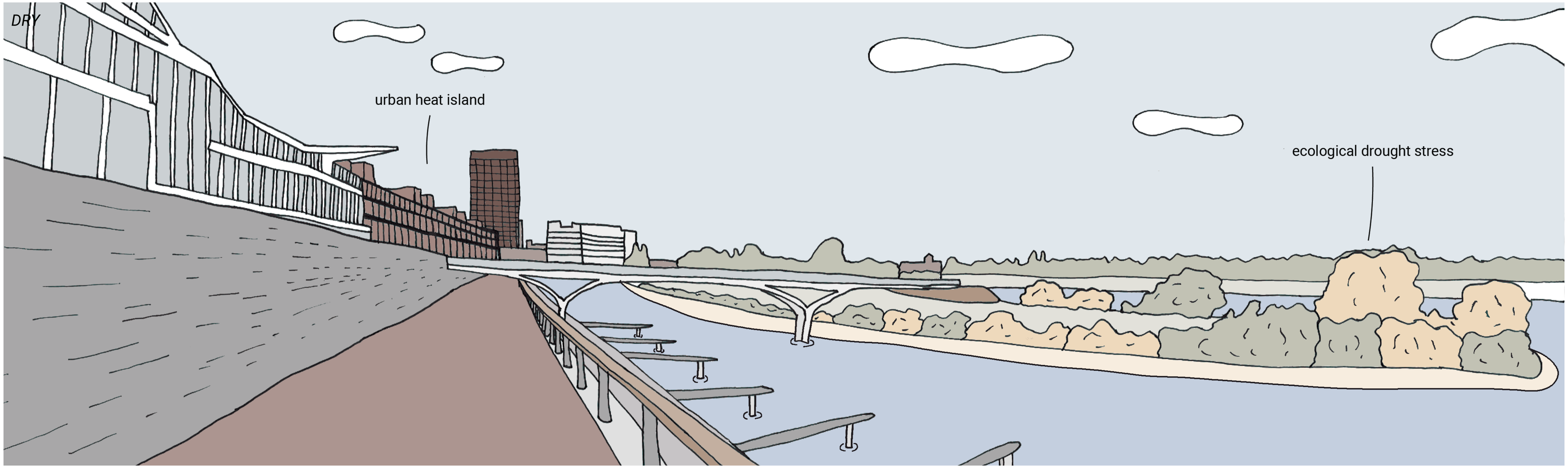


Figure 3.36: Spatial impression of the Future Autonomous Situation close to Velden in 2100.

Urban panaroma of the FAS in 2100



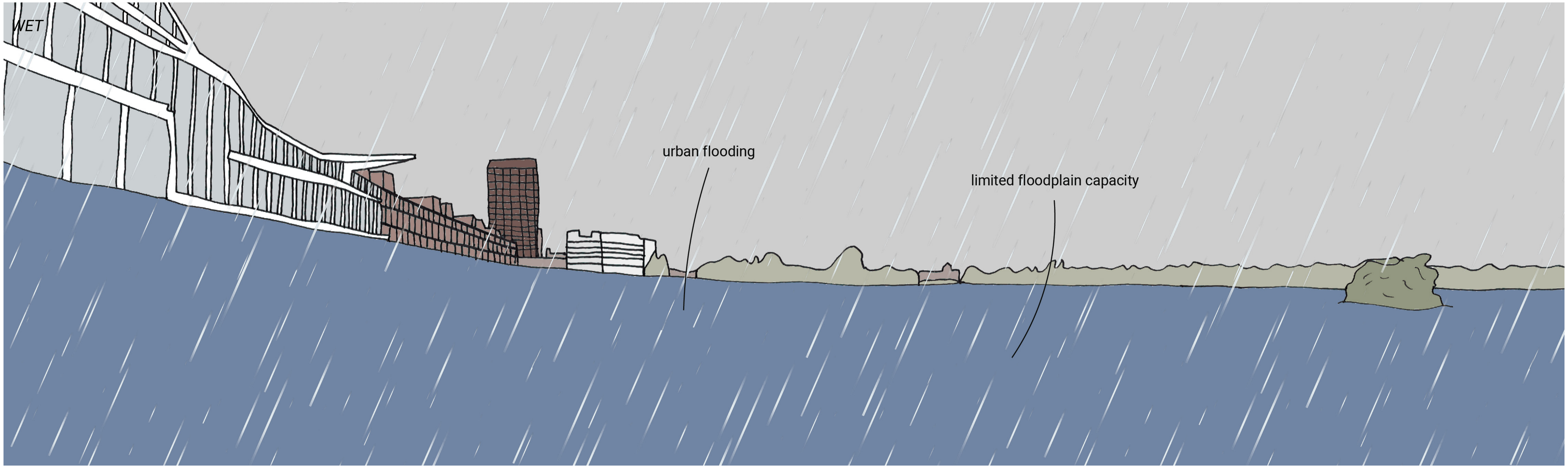


Figure 3.37: Spatial impression of the Future Autonomous Situation in Venlo in 2100.

3.7. Conclusion of analysis

In conclusion, without changes to the landscape in the Noordelijke Maasvallei, the area's resilience to climate change is expected to drastically decrease. There is a need for water storage opportunities to provide enough water in dry periods. On the other hand, a different type of protection against extreme precipitation and (sudden) high discharges is necessary. However, *this is possible*. The ecological SWOT showed that nature provides opportunities for better water infiltration, retention, and protection from runoff. A natural river will be able to withstand high discharges if given space. Moreover, ecological resilience will also get a boost. Therefore, looking through the lens of renaturalisation could create opportunities that are resilient to the changing climate of 2100.

Design 4

This chapter explains the design phase of this thesis, including the use of the pattern language and maximisation method. It concludes with a proposed design for the Noordelijke Maasvallei towards 2100.

4.1. Vision

In 2100, the Noordelijke Maasvallei will be resilient to extreme drought and wet periods that climate change will bring. The river Maas will follow a natural route, chosen by the river itself, and natural river processes will be restored, as will the river's nature. Meanders, side streams, ponds and floodplain forests will provide adaptability to the changing discharges of the river. This natural environment will boost the river ecology, and species that once used the river as a highway will return. **The river Maas will be restored**. Furthermore, **ecology** on land will be **expanded** over a larger area, and important hubs will be connected through green corridors. This will improve water storage, heat mitigation, and provide space for both flora and fauna. **Agriculture** will be **adaptive** to drought and flooding, and be fitted to soil type. It will still play an important role in the Noordelijke Maasvallei, but practices will adjust to the climate of 2100. Finally, all **cities** will be **climate-proof**. Urban areas will have urban forests, waterways, and other green and blue spots to mitigate heat and be able to deal with the fluctuations of precipitation. Cities can grow, but only in areas where this adaptation is possible.

In this vision, the Noordelijke Maasvallei will be shaped by the river Maas, not the other way around. The area will have to adapt to the river's needs. In 2100, we will not resist the river. We will thrive with it.

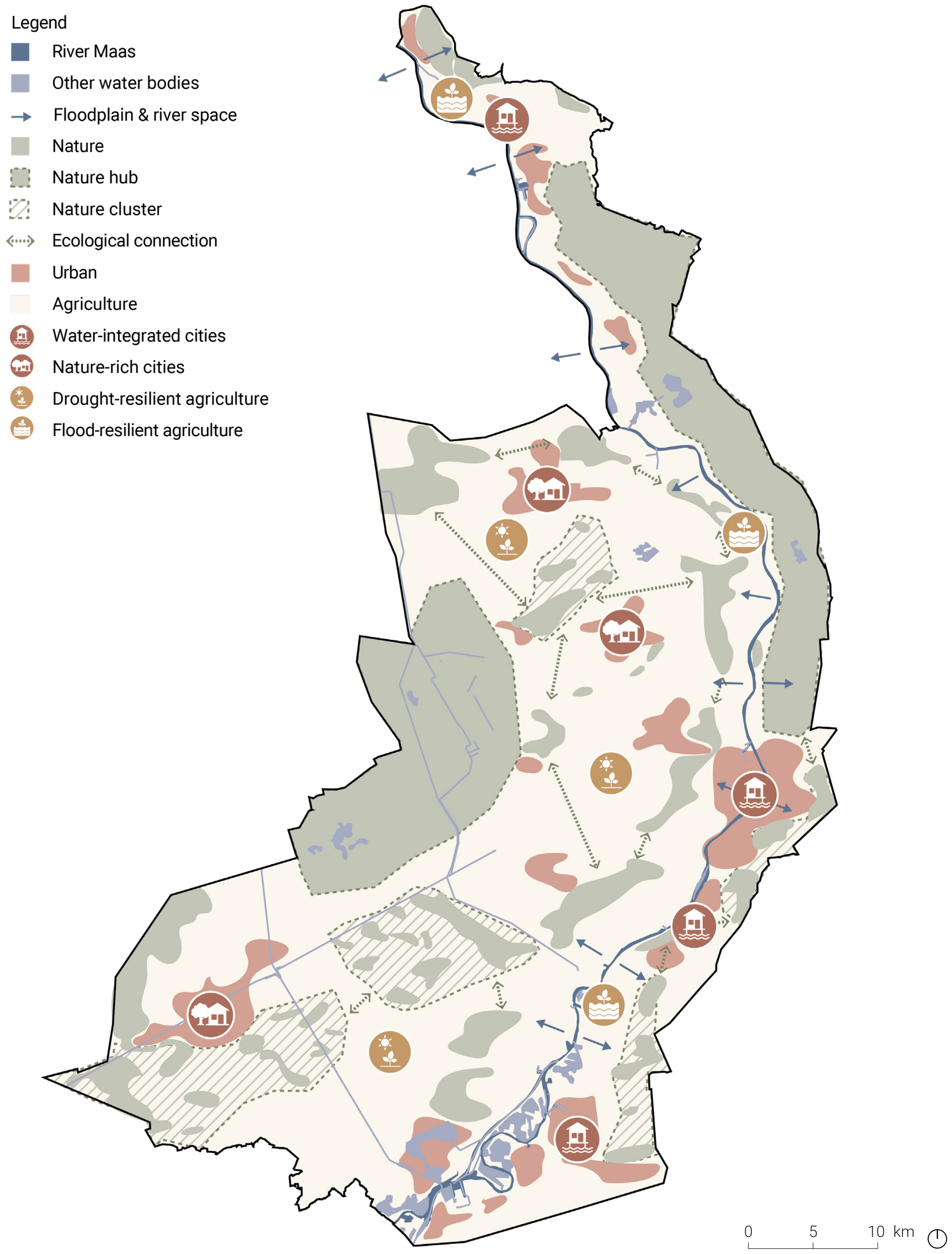


Figure 4.1: Vision for the Noordelijke Maasvallei in 2100.

4.2. The pattern language

4.1.1. Introduction to the pattern language

This chapter introduces the pattern language used for the design. The patterns translate the main challenges from the analysis into spatial principles that support a climate-resilient, renaturalised, river landscape. Each pattern links a problem to a possible intervention, and together they provide the basis for the maximisations and the integrated design.

In this thesis, the pattern language is used as a tool guiding towards an integrated design for the Noordelijke Maasvallei, addressing the main research question of this project. The patterns are divided into four groups that form the basis for the maximisation method. The patterns are applied to maximise the best solution per thematic group. These maximisations are then combined into an integrated design.

Moreover, each pattern is assessed through literature, following the evaluation criteria described in chapter 3.5. These evaluations are subsequently used to evaluate the integrated design by considering which patterns are applied and to what extent. A pattern list can be found in Appendix 7.1, and the pattern evaluations can be found in Appendix 7.2. Figure 4.2 shows a schematic overview of how the pattern language is used in this project.

All patterns can be found in the pattern book.

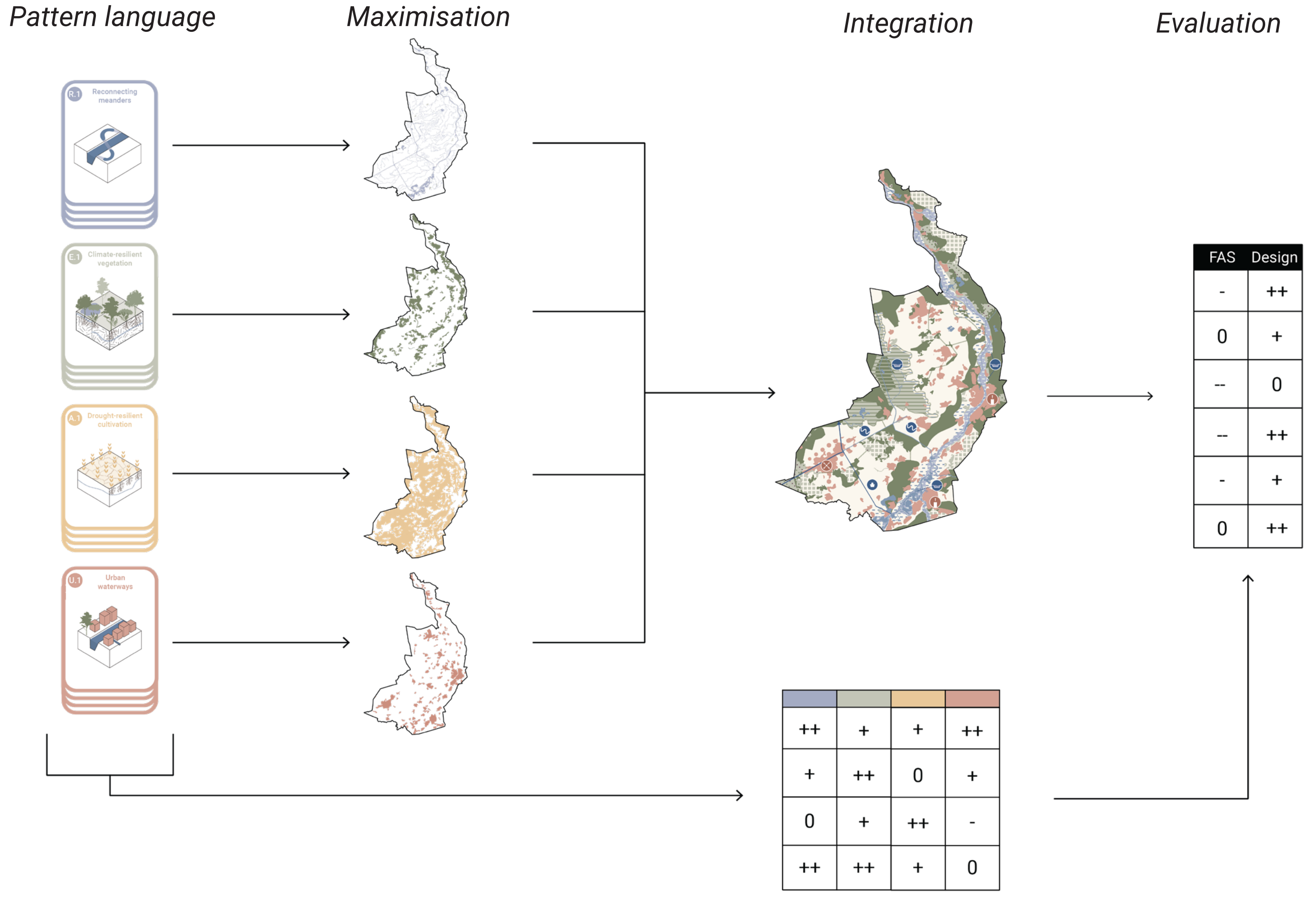


Figure 4.2: Schematic overview of the use of the pattern language in this thesis.

4.1.2. Pattern groups

The pattern language is divided into four groups: renaturalisation, ecology, agriculture and urban. The groups are based on the questions of this thesis and the analysis done before creating the pattern language.

Renaturalisation (R)

The patterns belonging to renaturalisation describe different ways of creating a renaturalised river and surrounding environment. The focus of this topic is related to creating space for water to deal with wetter and drier scenarios of the future.

Ecology (E)

This group contains patterns that relate to improving ecology for a more climate-resilient ecosystem. Whereas some patterns relate closely to the renaturalisation of rivers, some dive deeper into improving the ecosystem as a whole.

Agriculture (A)

Agricultural patterns delve into methods of climate resilient agriculture that can deal with a wetter and drier climate. It focuses on ways to make agriculture more nature-inclusive, in which the natural system is embraced instead of shunned.

Urbanisation (U)

Finally, the urban group consist of patterns that could be used to make cities, towns, and different human activities more climate resilient, whilst including the natural (river) system in the urban environment, or without damaging the natural ecosystem.

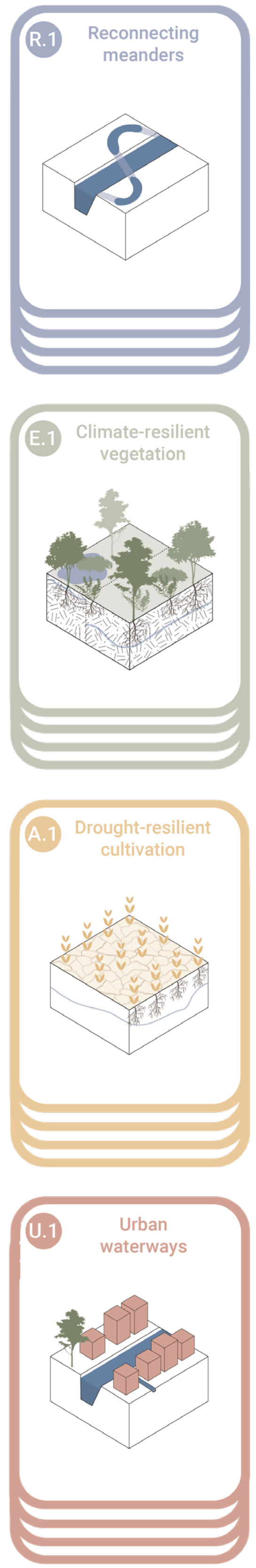


Figure 4.3: The four pattern groups.

4.2.3. A pattern

Number

Each pattern is given a number to easily identify the patterns when used elsewhere. Each pattern starts with the first letter of the group it belongs to (R, E, A, U).

Title

The title indicates a quick idea of what the pattern is about.

Hypothesis

A short description of what the pattern will address.

Illustration

A visual illustration showing the function of the pattern.

Related patterns

Patterns that strengthen, go well together or need to be implemented together within this pattern.

Conflicting patterns

Patterns that cannot be implemented simultaneously or that counteract this pattern.

Theoretical background

An explanation of the pattern, backed up by theory that explains how the pattern works, what principles it builds on, and what it can achieve.

Practical implcation

A description of practical considerations when implementing the pattern, and how to apply it effectively.

Time

Each pattern has an indication of the time it takes to implement the measure and how long it takes until the effect is visible. They will be divided into:

0-10 years
10-25 years
25-50 years
50-75 years

Scale

The scale of the pattern will also be shown by implementation and effect. This will be on one of the following scales:

Micro: *Local*
Meso: *The Noordelijke Maasvallei*
Macro: *Downstream Maas*

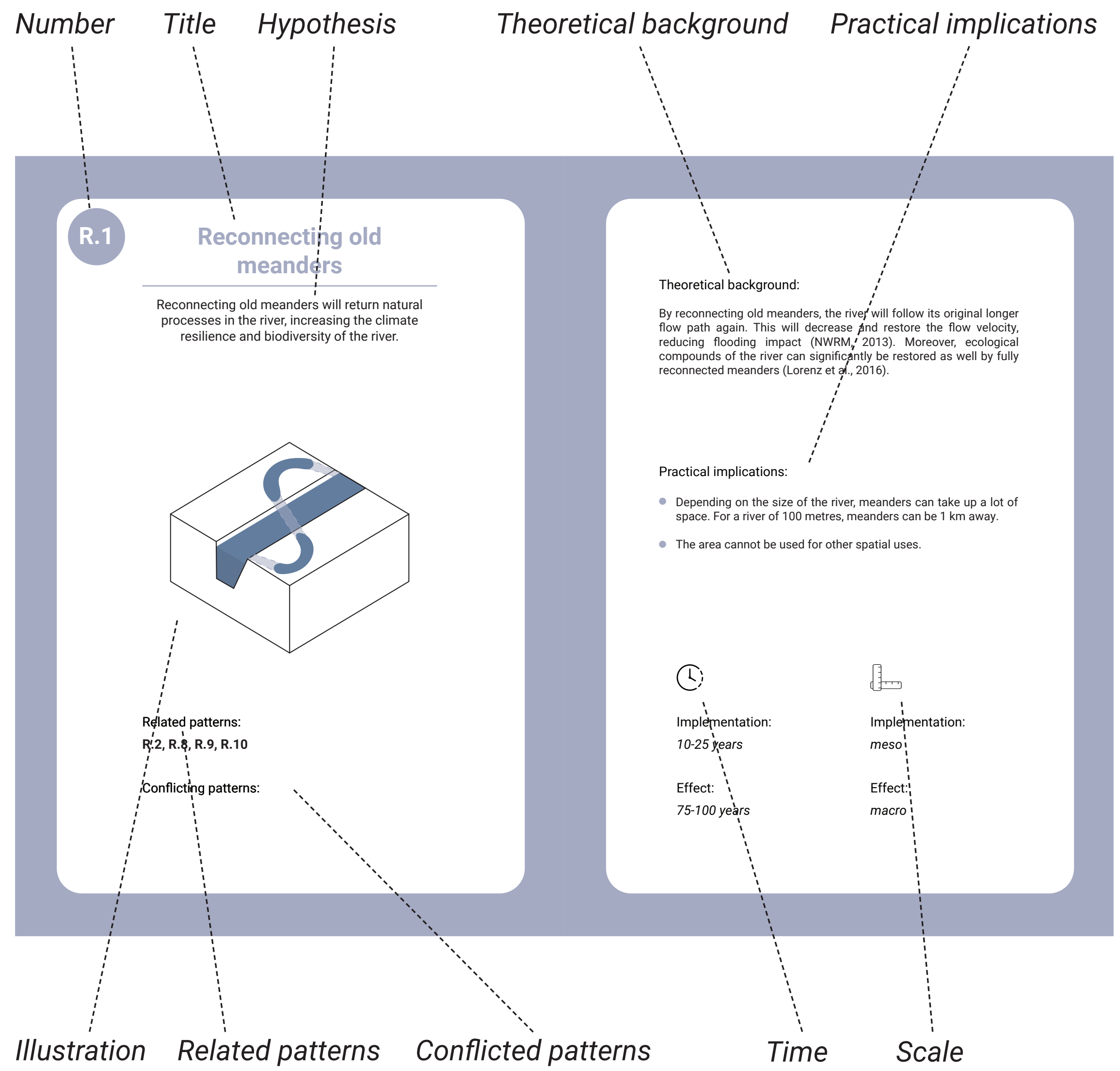


Figure 4.4: Example of a pattern showing the pattern layout.

4.2.4. Implementation effect of the patterns

The patterns of this pattern language serve as starting points for the maximisation method in chapter 4.3. However, each pattern can also be implemented separately. The effects of the patterns differ. Some patterns are quick to implement and easy to reverse, while others are more challenging to implement and have a lasting impact on the area. Additionally, the scale of their effect can play a crucial role in deciding which patterns to apply.

Pattern fields are used to visualise characteristics and relations of the patterns. The pattern field in Figure 4.5 presents the effects of implementing the patterns based on their scale and flexibility. This pattern field can support decision-making by indicating which patterns are suitable to apply, and at what moment in time.

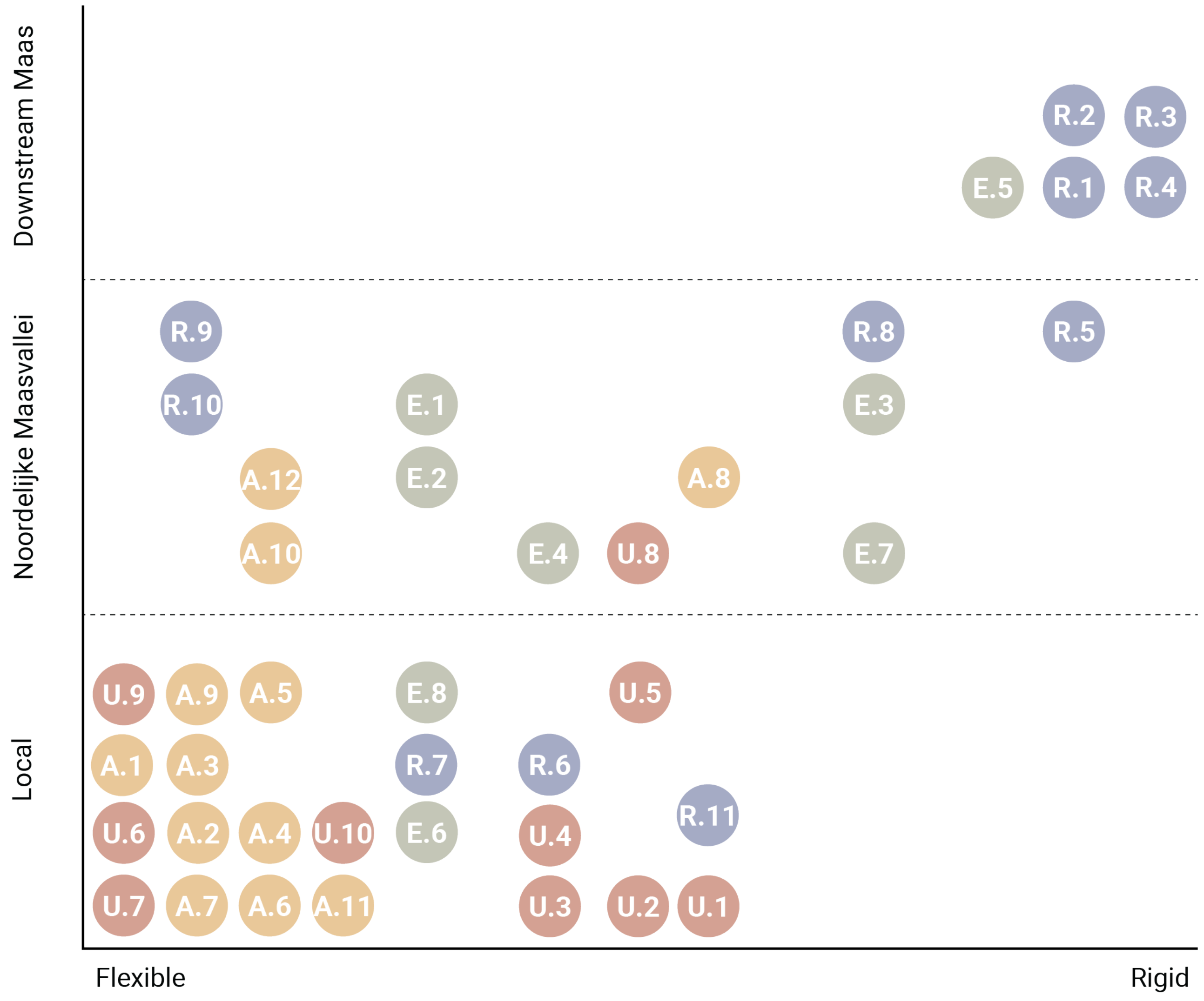


Figure 4.5: Pattern field dividing the patterns by their effect of implementation on scale and on flexibility.
The patterns connected to the pattern numbers can be found in Appendix 7.1.

4.3. Maximising for climate resilience

4.3.1. Maximisation for water and the river system

In this maximisation, the river and the water system are central. It shows the best way to retain, store and drain water, and how much space is needed for the river to flow. Moreover, it considers the historic flow of the river to understand where the water may naturally want to flow.

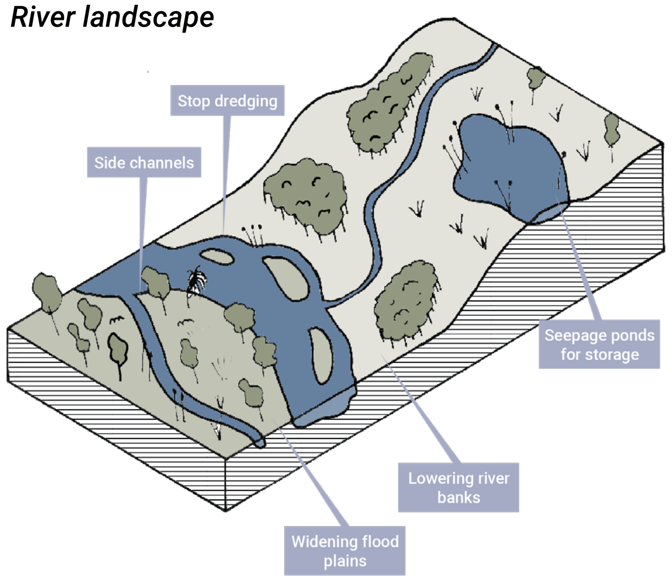
The interpretation of elements is primarily based on height and soil components, which also shows the previous flow of the Maas. As can be seen in figure 4.7, more space for the river is needed after the Venloslenk (as explained in 3.1.1). For optimal water retention, other water bodies are also renaturalised. This will create space for flooding and a buffer against drought.

Diversity of vegetation boosts water infiltration, creating a buffer for dry periods. Therefore, inland on the sandy soils, the focus is on expanding nature for maximum capacity of water storage in the soil. Peatlands will be used for surface water storage where wetlands could play a focal role in storing and filtering water. Excess water should be located in peatlands to avoid sinking of the peat bog. Furthermore, natural height will be used as protection from the river, completely focusing on renaturalisation. Consequently, dikes will become redundant in this maximisation. Slopes will be protected with green borders to prevent erosion and water runoff.

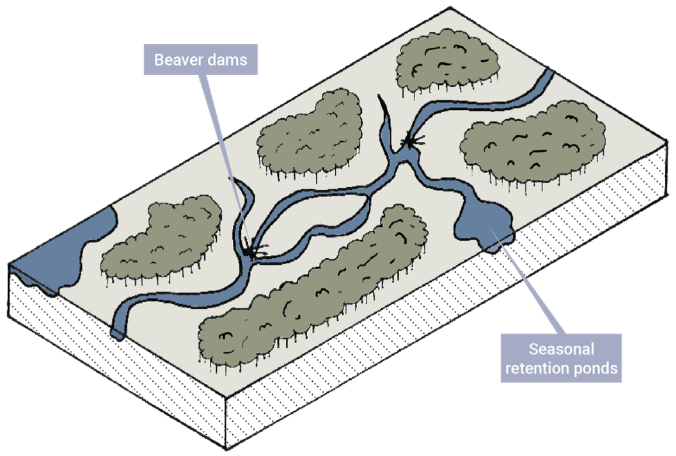
Finally, the Zuid-Willemsvaart is used for shipping, and other water bodies will be left alone..

Figure 4.6 shows parts of the Noordelijke Maasvallei where certain patterns have been implemented to maximise the natural potential of the river and water system.

River landscape



Sandy soils



Peatland

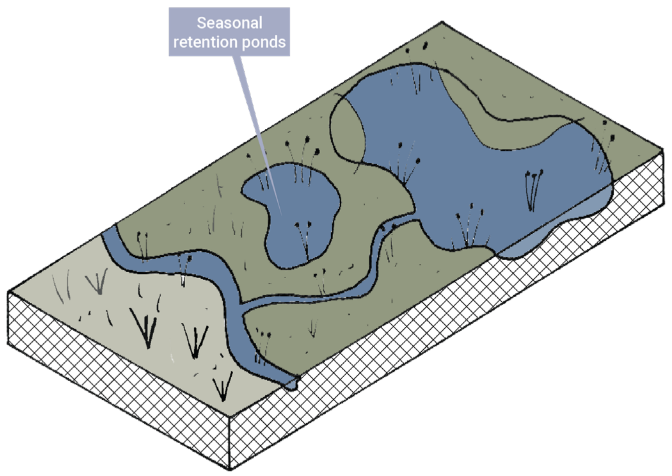


Figure 4.6: Zoom-ins of the maximisation for water and the river system.

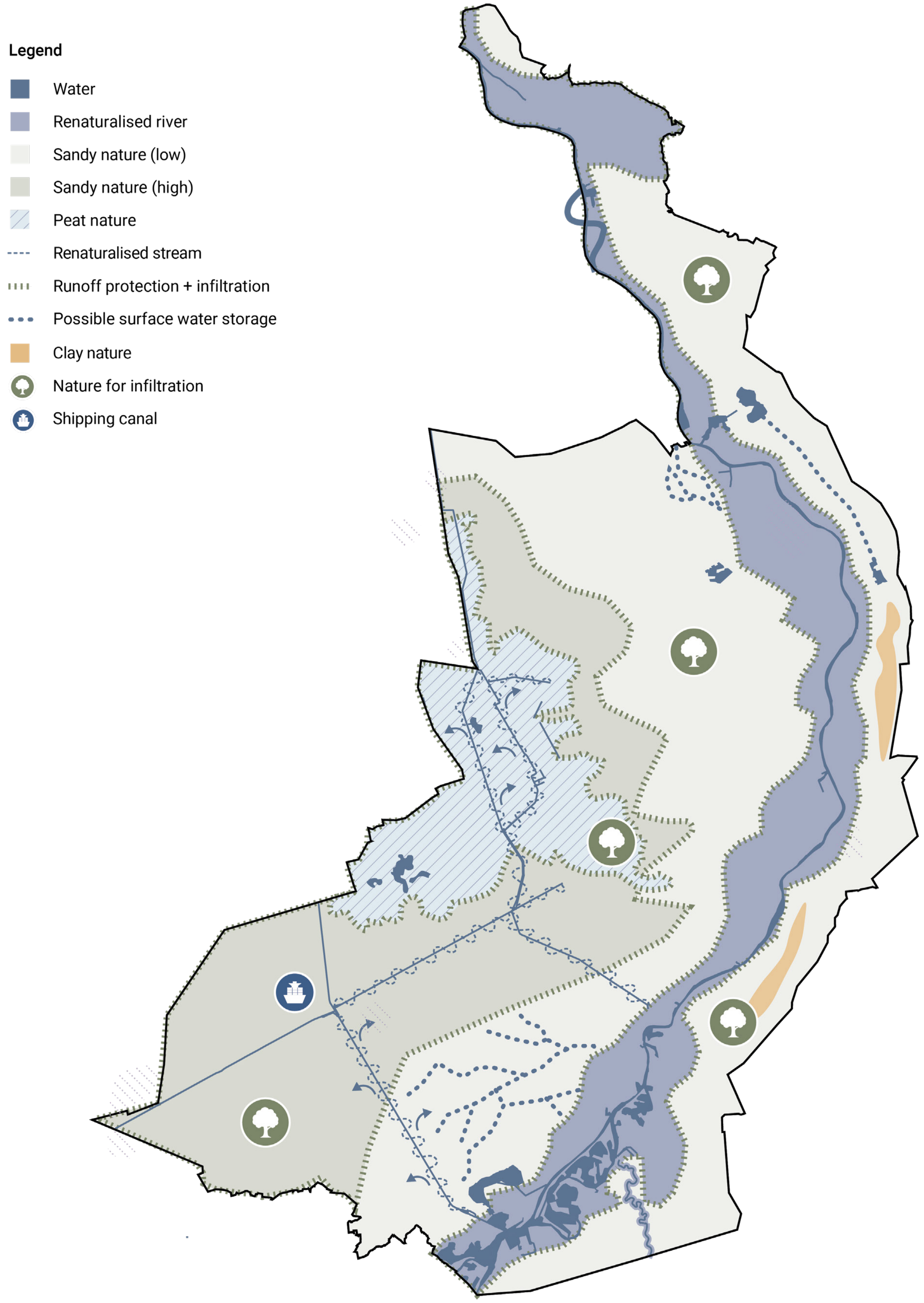


Figure 4.7: Maximisation for water and the river systemin the Noordelijke Maasvallei.

4.3.2. Maximisation for ecology

This maximisation looks exclusively at what would happen to the Noordelijke Maasvallei if nature takes over. This maximisation is based on soil types and current nature and focuses on general biotopes. Therefore, it does not consider specific species.

As in the maximisation for the river and water system, the river will be renaturalised, revealing its unique nature. Floodplain forests (ooibossen) will be present along the river. There will be space for fish to safely pass through the river again.

The Maasduinen will be expanded. The monocultural agriculture will disappear, making space for forests and fens. Heathlands would not exist without human interference. However, they have such an important cultural value that grazing will still be allowed to keep this biotope.

De Peel will also be protected. Peat bogs will get the opportunity to grow again. Importantly, enough water must be provided to this area. Furthermore, the Mariapeel and Groote Peel will be connected through a green corridor.

Forests are most likely to return on sandy soils. However, as for the Maasduinen, existing heathlands will be protected. Water bodies will be renaturalised and provide connections between rivers, lakes, ponds and other water bodies.

In this scenario, fauna will be able to travel as they did in the past. However, extra protective measures should be taken in times of drought. The Maasplassen could exist as a refuge for aquatic species. Moreover, it is important to monitor water availability in natural areas for the prevention of forest fires.

Finally, the cultural landscape of the Maasheggen will be expanded. It will serve as a refuge for certain species and protect the area from water runoff and erosion.

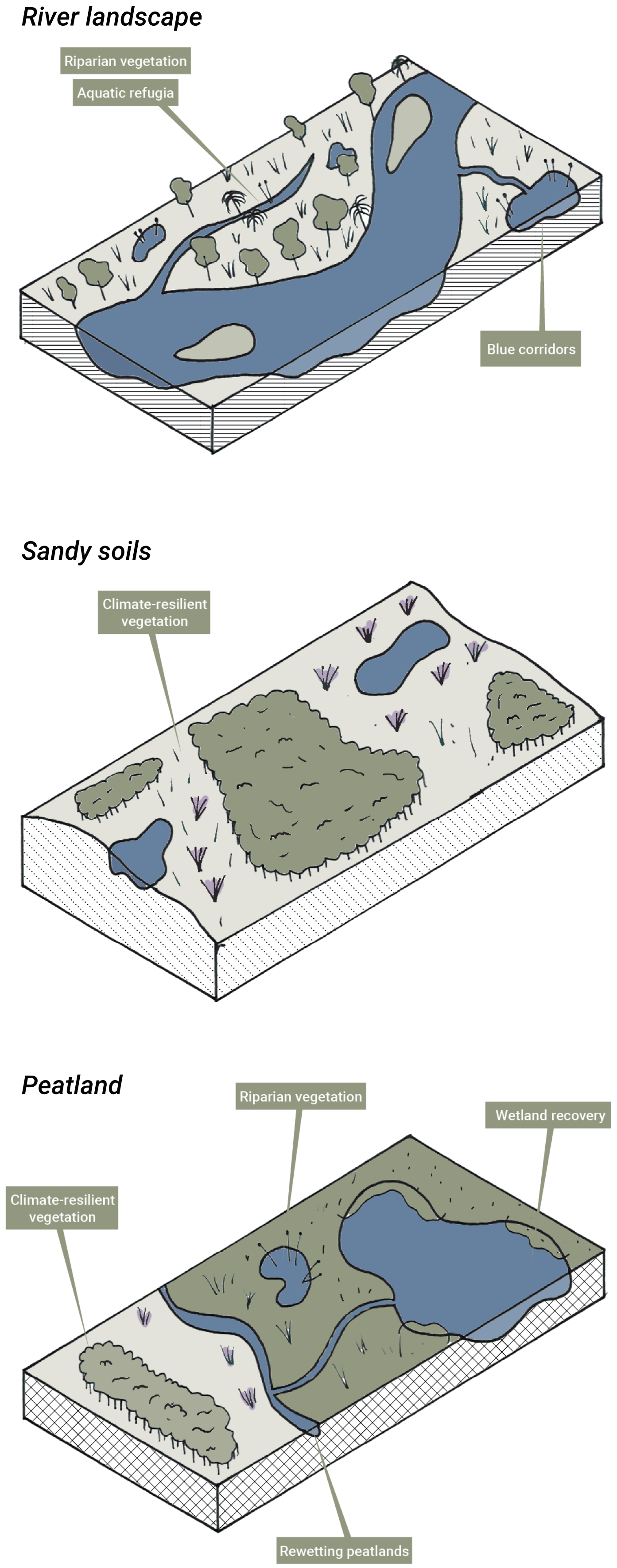


Figure 4.8: Zoom-ins of the maximisation for ecology.

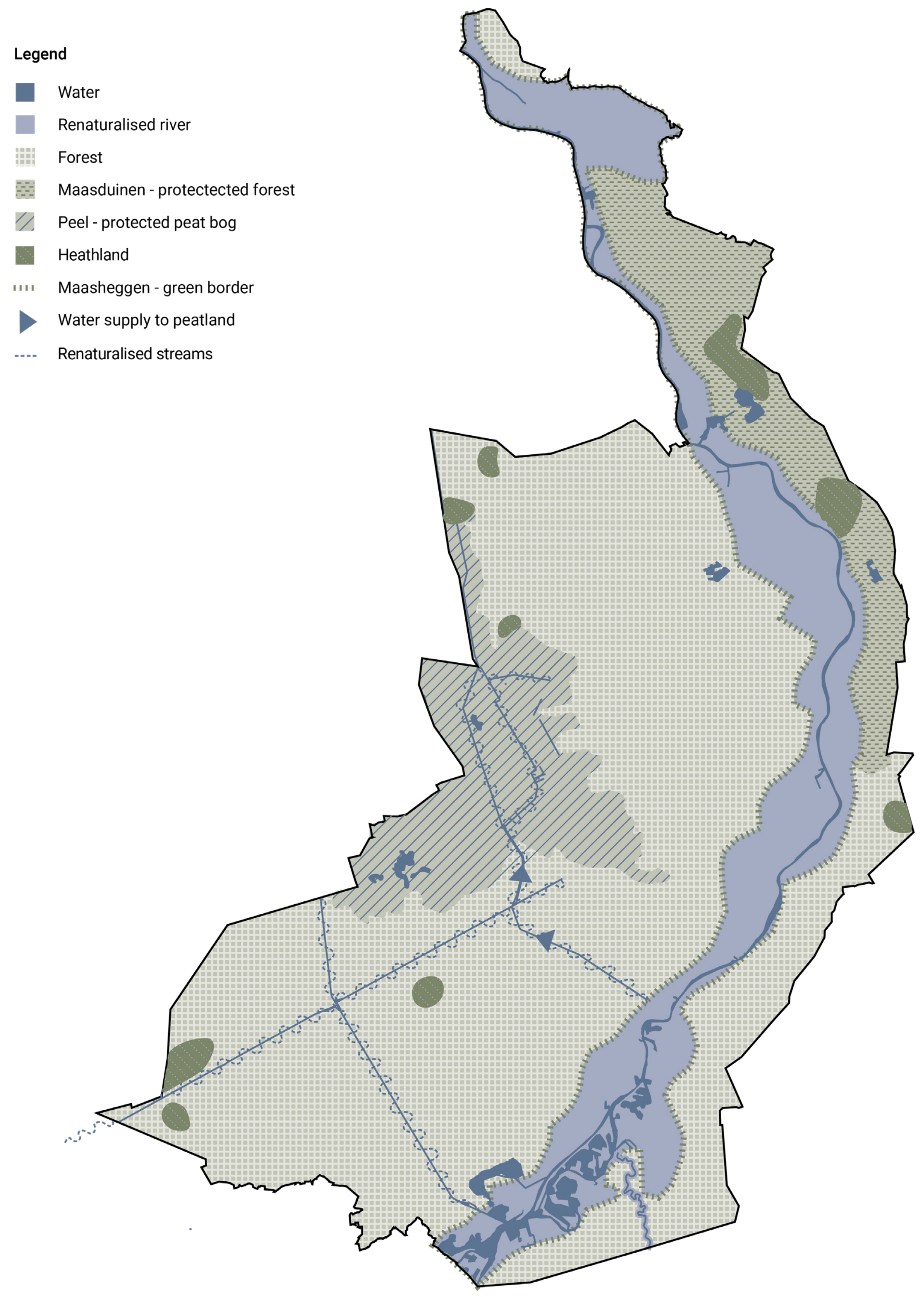


Figure 4.9: Maximisation for ecology in the Noordelijke Maasvallei.

4.3.3. Maximisation for agriculture

With periods of extreme precipitation and drought, agricultural practices must adapt to provide optimal yield. As became clear from the analysis, current practices will not be able to withstand climate change. Therefore, the pattern language consists of patterns that provide climate-resilient agriculture. This maximisation focuses on these specific patterns and creates a spatial interpretation in which the agricultural system in the Noordelijke Maasvallei would thrive under the given expectations for 2100.

For the regional scale, the agricultural system has been divided into three groups: drought-resilient, flood-resilient, and wet agriculture. Certain patterns belong to each of these groups. Their spatial distribution is determined by soil, height, and river flow.

Drought-resilient agriculture is mainly located on sandy soils, where half-moons, intercropping, and agroforestry are used to improve water infiltration capacity. The focus is on retaining rainwater from wet periods for the growing season by keeping the soil covered and designating certain fields for water storage.

Flood-resilient agriculture is primarily located next to the river, but also in peatlands where the groundwater level is high. Raised beds are used in floodplains to prevent waterlogged crops, and half-moons are located on hills for runoff protection. Grass fields can have cattle in dry periods and will require diverse vegetation to prevent soil compaction in wet periods.

The wet typology will be used in areas with wetlands, such as peat bogs or fens. Crops such as cattail and reed can grow in the ponds.

Finally, the Maasplassen can potentially be used for aquaculture.

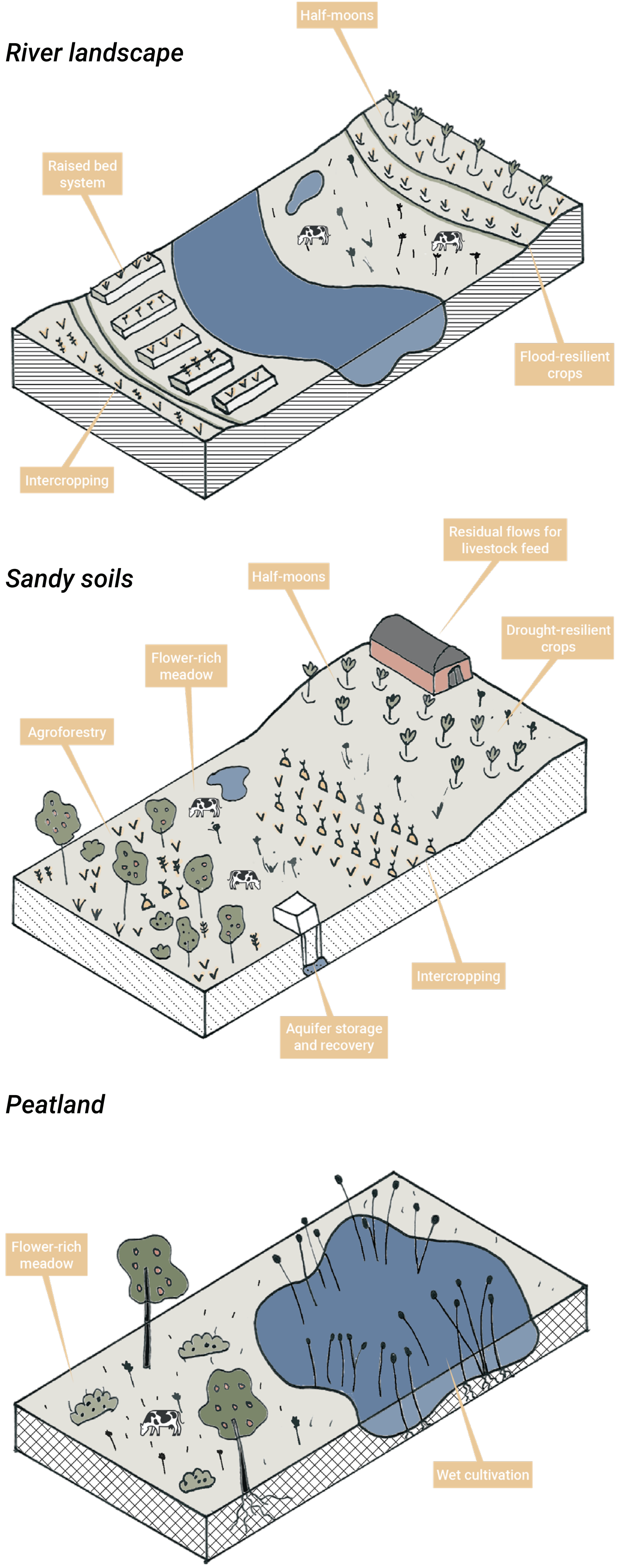


Figure 4.10: Zoom-ins of the maximisation for agriculture.

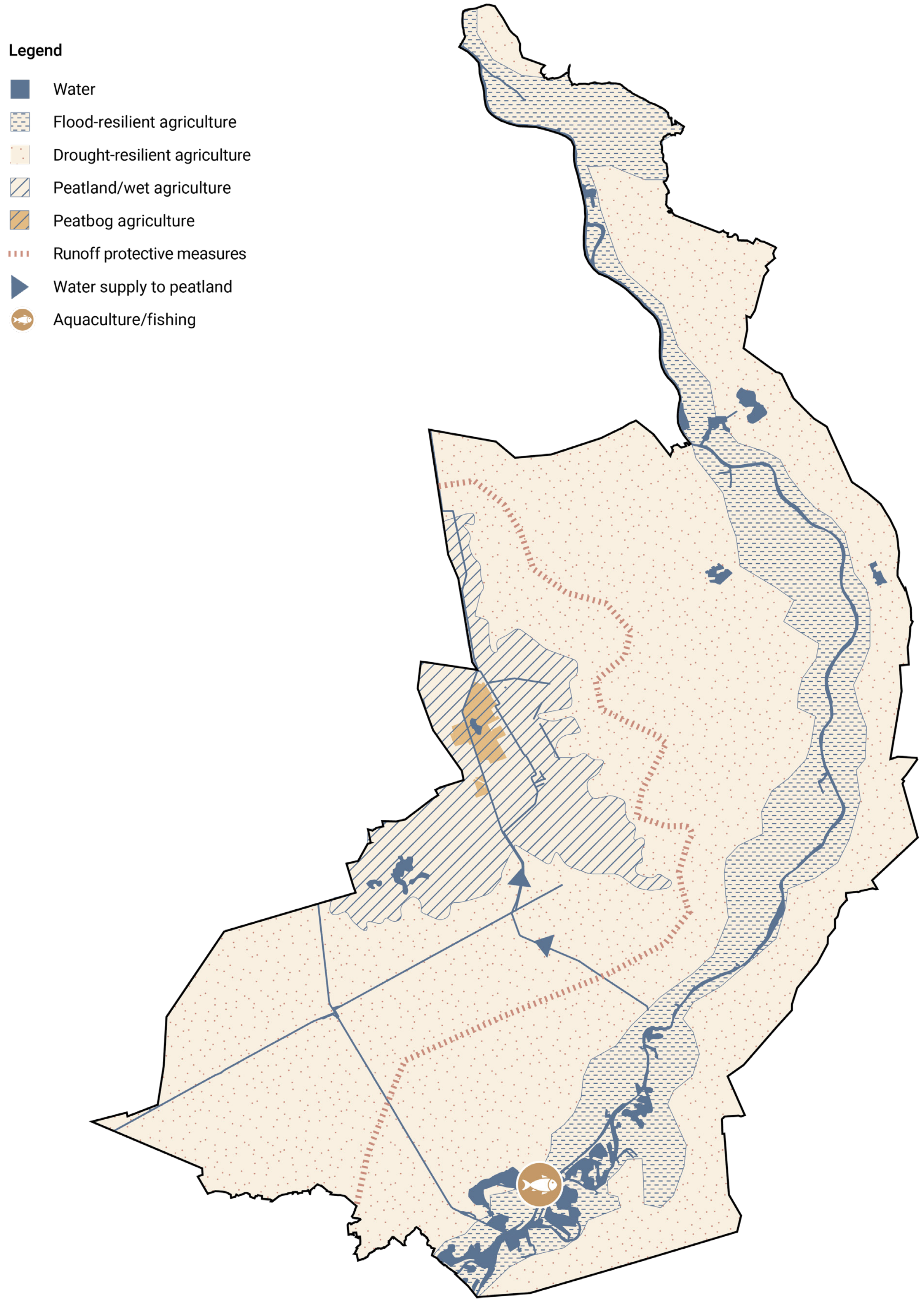


Figure 4.11: Maximisation for agriculture in the Noordelijke Maasvallei.

4.3.4. Maximisation for the urban environment

Urban areas must also adapt to climate change. This maximisation identifies the best solutions for growth and adaptation to the expected climate risks of 2100. It focuses on natural solutions beyond traditional dike raising, in line with the research aim.

Noord and Midden-Limburg are expected to expand until 2040 (Minister voor VRO et al., 2023). The focus on expansion is currently on Venlo, Roermond, and Weert. However, due to the unpredictability of river discharges, this maximisation focuses on densification of cities along the Maas and a more intense expansion of Weert. This is beneficial for the growth of the province as well, due to Weert's proximity to the growing innovation hub *Brainport* in Eindhoven. Connectivity between Weert and Venlo will be improved, while Roermond will continue to develop as a recreational hub, utilising the Maasplassen.

If new towns are built in floodplains, patterns related to building on raised structures such as poles or terpen should be applied. Furthermore, water storage-related patterns should be implemented in all cities, with more focus on surface water in Venlo and Roermond, and more infiltration and retention-related patterns in Weert.

Overall, this maximisation shows three typologies that contain different patterns: river villages, dry cities, and wet cities. These typologies are illustrated in figure 4.12.

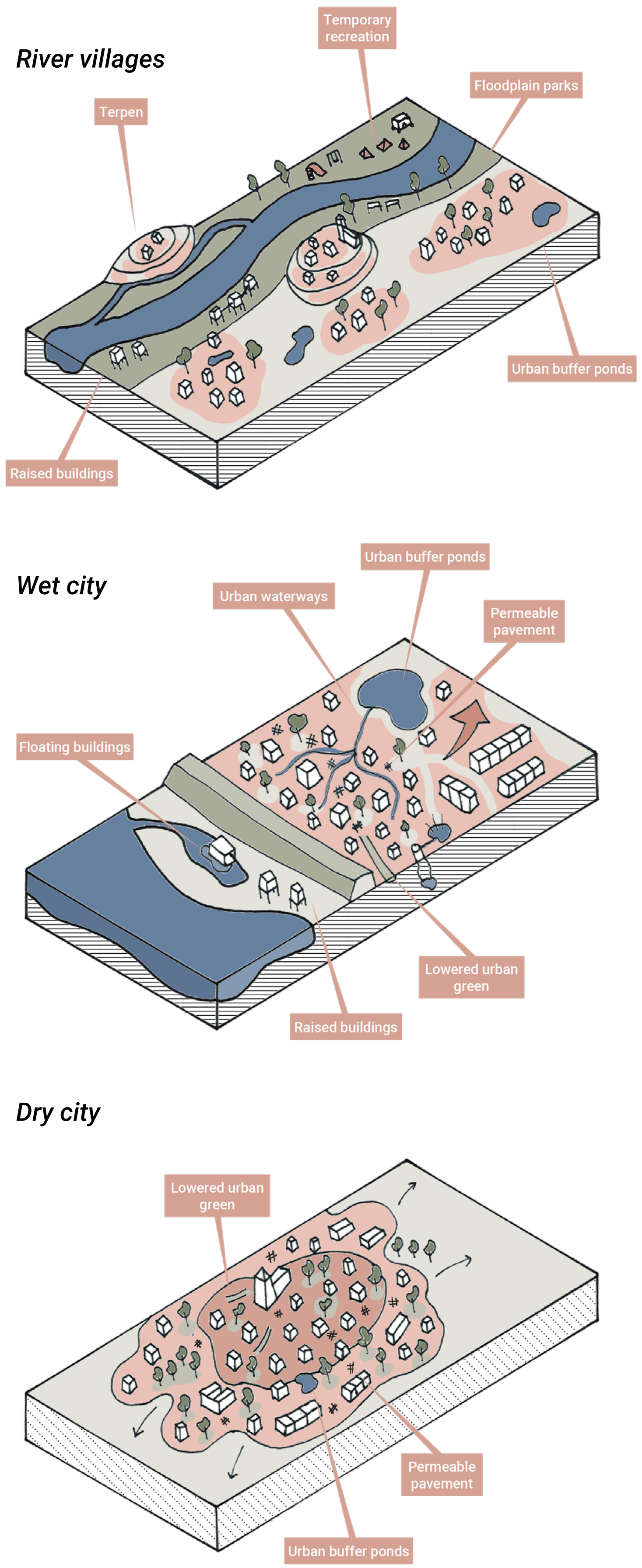


Figure 4.12: Zoom-ins of the maximisation for urbanisation.

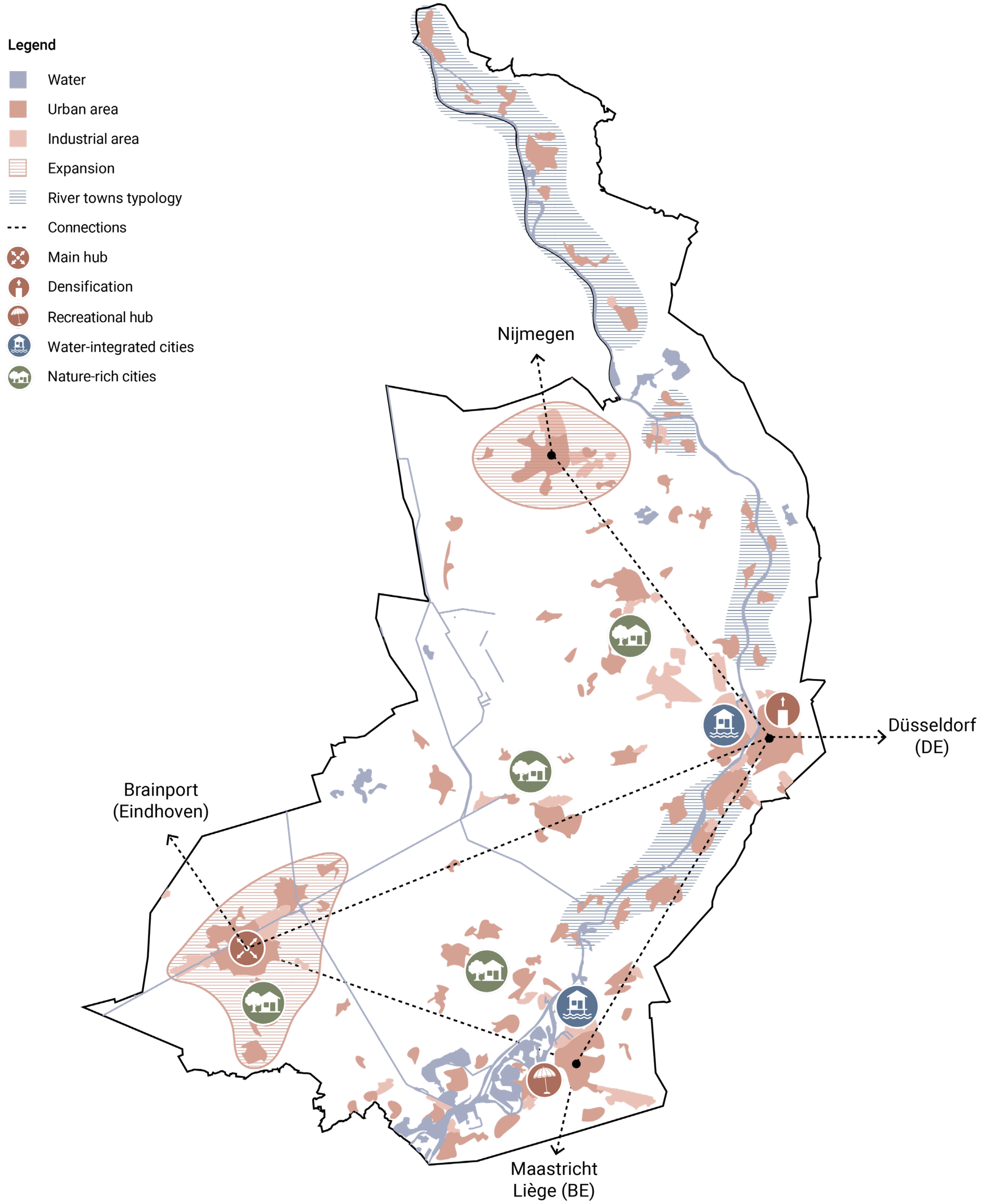


Figure 4.13: Maximisation for urbanisation in the Noordelijke Maasvallei.

4.4. Integrated climate-resilient design

After maximising each theme across the area, the four themes were overlaid to determine the best possible option for a climate-resilient Noordelijke Maasvallei based on renaturalisation. Figure 4.16 shows the integration on the scale of the entire Noordelijke Maasvallei for 2100. Since this research has a strong focus on using river renaturalisation, the water and ecology maximisations have had a stronger input into the integration. The integration is based on the pattern language as explained in 4.2. The legend items contain a cluster of patterns to illustrate the integration on this scale. On the next pages, the integration is visualised on a smaller scale in which certain patterns have been highlighted.

The focus points of the integration are based on the previous maximisations of the themes:

- Renaturalised River
- Expanded Ecology
- Adaptive Agriculture
- Climate-proof Cities

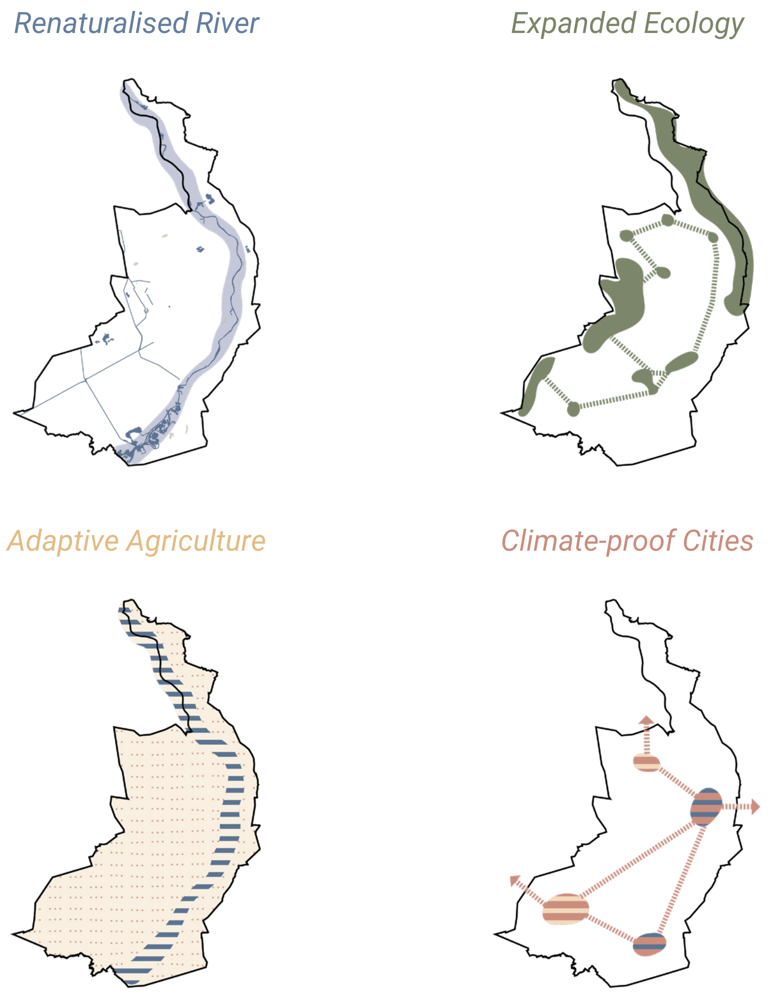


Figure 4.14: Focus points of the integrated design.

4.4.1. Renaturalised River

During the floods of July 2021, the Maas had a discharge of 3310 m^3/s, one of the highest numbers ever measured in the Dutch Maas. This had disastrous consequences, as the current floodplains were not able to handle such volume. Accordingly, this design widens the space for the river. This space can be used for accomodating high discharges and is determined by height differences and former river courses. In this design, existing urban areas are taken into consideration. The river will go around these areas. However, some current agricultural land will have to make space for the river in this approach.

A discharge of 3500 m^3/s is considered for water safety. This is higher than what was measured in 2021, but is likely with the current trend of climate change. The necessary floodplain width of two regions along the Maas has been calculated (see Appendix 7.3 for the calculations). It was found that the needed space in width is between 390 and 570 metres. Because there are certain bottlenecks in the area, space needs to be gradually increased over the areas where existing space can be utilised. Therefore, where there is space, more width has been designed, which translates to 400-650 metres. This would be 200-325 metres on each side of the river, if the area allows.

Renaturalisation of rivers is not only beneficial for creating space for high discharges. Renaturalisation also increases the river's resilience in times of low discharges by forming side streams and/or ponds. A longer, meandering, river will let water flow with decreased velocity. Consequently, water will not quickly leave the area in dry periods. However, currently weirs are used in the river to prevent water flow from slowing down too much in dry periods. A naturally flowing river would reduce the occurrence of unnatural drying. Immediately removing the weirs would have a negative impact on river flow, as it needs time to adjust. However, gradually they could be removed. It is important to note that this would be for the Noordelijke Maasvallei only. Weirs might still be needed when looking at the entire Maas river catchment.

In this design, (large-scale) shipping will no longer be allowed on the river Maas. Large ships will have to go over the Zuid-Willemsvaart. Smaller ships can be used on the Wessem-Nederweert canal to transport goods to the East of the Noordelijke Maasvallei. Although this will improve the part of the river Maas in this area, the Zuid-Willemsvaart still takes water upstream of the river. It is hard to say how water will be divided. In dry periods, smaller ships might have to be used on this canal as well. The river Maas can handle low discharges, but letting it run dry will have a damaging impact on the river's nature.

4.4.2. Expanded Ecology

Nature will have an important role in the Noordelijke Maasvallei in 2100. More water storage is needed, and as of now, there is a disconnection of ecological areas. Therefore, nature will be largely expanded over the area, with two major nature parks: the Maasduinen and De Peel. Each park has different characteristics. The expansion of De Peel is based on peatlands, and the Mariapeel and Groote Peel will be connected through forest. As peatlands need a certain amount of water, this area will be used for water storage and ensure the prevention of land subsidence and CO_2 emissions. The Maasduinen will also expand. Certain areas will be left alone and become forest or fens. Heathlands will still be present due to their cultural heritage.

Other existing natural areas will either be expanded or the agriculture between them will have to become nature-inclusive. Moreover, all nature will be connected through green corridors if not divided by a natural border such as the Maas. Finally, the cultural landscape element, the Maasheggen, will be used along the renaturalised Maas as a border from the elevated drier area to the lower floodplains.

4.4.3. Adaptive Agriculture

Agricultural land in this design is divided into four typologies: drought-resilient, flood-resilient, wet, and nature-inclusive. These typologies are based on soil type, elevation, and location in the area.

Drought-resilient agriculture is mainly present in this area. For this typology, changes will need to be made in current agricultural practices. Different crop types are necessary with more opportunities for water storage - as shown in the patterns used. Flood-resilient agriculture is located along the renaturalised Maas, based on the lower elevation. This area could potentially flood, so resilient practices would be needed here. The wet agriculture typology is present on the peatlands. Although most of De Peel will become nature, some areas can still be used for certain types of cultivation. Finally, nature-inclusive agriculture is a prime focus in this design in areas connected to nature. Although this will lead to decreases in yield, it will create different opportunities for the growth of more diverse crops and increase water availability in the area.

As mentioned in 4.4.1, some agricultural land will need to make space for the river. Important considerations would include focus on the use of residual flows (pattern A.12).

4.4.4. Climate-proof Cities

As mentioned in 4.3.4, Noord and Midden-Limburg are expected to grow until 2040. However, with the Brainport of Eindhoven growing, there are plans to focus on Venlo and Weert, which would lead to the growth of the cities. However, looking at climate resilience, Venlo (and Roermond) cannot expand much in space anymore. Accordingly, this design proposes to focus on Weert for expansion, which would create a strong urban hub. For Roermond and Venlo the focus is on densification. Venlo would still hold an important function in the connection towards Germany. Roermond would get a more recreational focus. Other smaller villages removed from the Maas and towns such as Venray could still grow.

The integration of urban patterns is more visible on a smaller scale. Where Weert and the inland cities will have to integrate more "green" patterns for heat and rainfall storage, towns next to the river Maas will have to consider the Maas and tributaries such as the Ruhr. This could be translated into the implementation of patterns such as water storage, or building on stilts or terpen.

4.4.5. The integration map

Figure 4.15 shows the spatial interpretation of the integration of the themes as just described. This map represents a possible design for the Noordelijke Maasvallei, resilient to the climate extremes expected in 2100.

The interpretation has been given specific fills, each representing a set of patterns (see figure 4.15). Because of the scale of the drawing and the smaller scale at which many patterns operate, the map indicates zones where these patterns could be applied. The spatial impressions in 4.4.6 will show more specifically what the patterns could look like when applied in space, rather than grouping them.

Legend	*Related patterns*
Water	
Space for renaturalised river	*R.1-5, R.8 , R.11, E.6*
Forest	*E.1*
Heath	*E.1*
Peat bog	*E.1, E.2, E.7, E.8*
Fens and wetlands	*R.6, E.1, E.7*
Drought-resilient agriculture	*A.1, A.4 -7, A.11*
Nature-inclusive agriculture	*A.8, A.10*
Flood-resilient agriculture	*A.2, A.6, A.7, A.9*
Wet agriculture	*A.3*
Urban area	*U.1-10*
Urban expansion	*U.1-10*
Green corridor	*E.3, E.4*
Erosion protection	*E.3, A.5*
Shipping canal	*R.9, R.10*
Renaturalisation	*R.1-5, R.8 , R.11*
Densification	
Urban hub	

Figure 4.15: Legend of the integrated design and its related patterns.

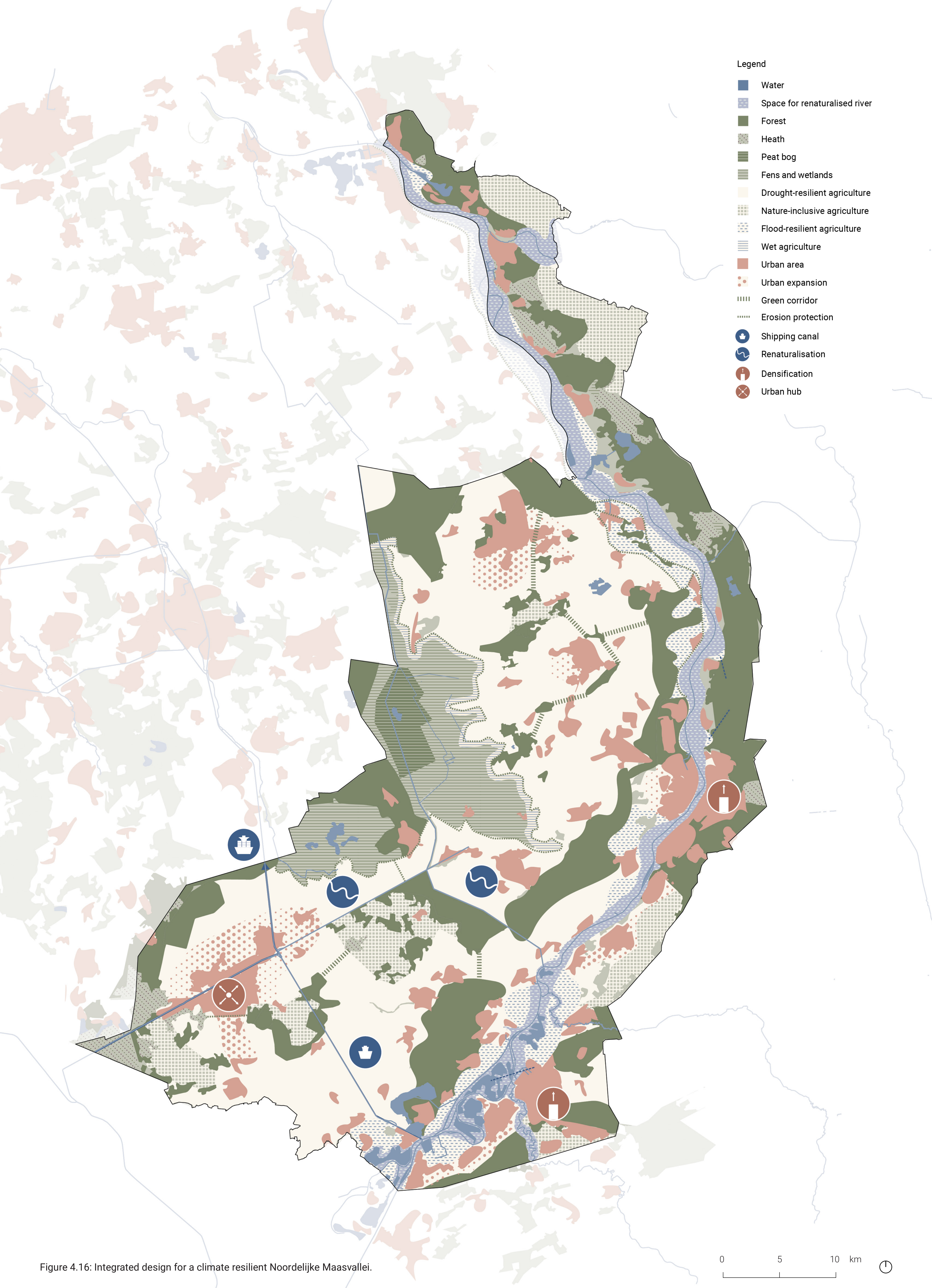


Figure 4.16: Integrated design for a climate resilient Noordelijke Maasvallei.

4.4.6. Pattern implementation

Figures 4.18 to 4.20 are zoom-ins that show how the patterns are implemented in the integrated design. Three areas have been selected based on transition zones between the river, nature, agriculture, and/or the urban environment. Figure 4.16 shows the approximate location of these zoom-ins.

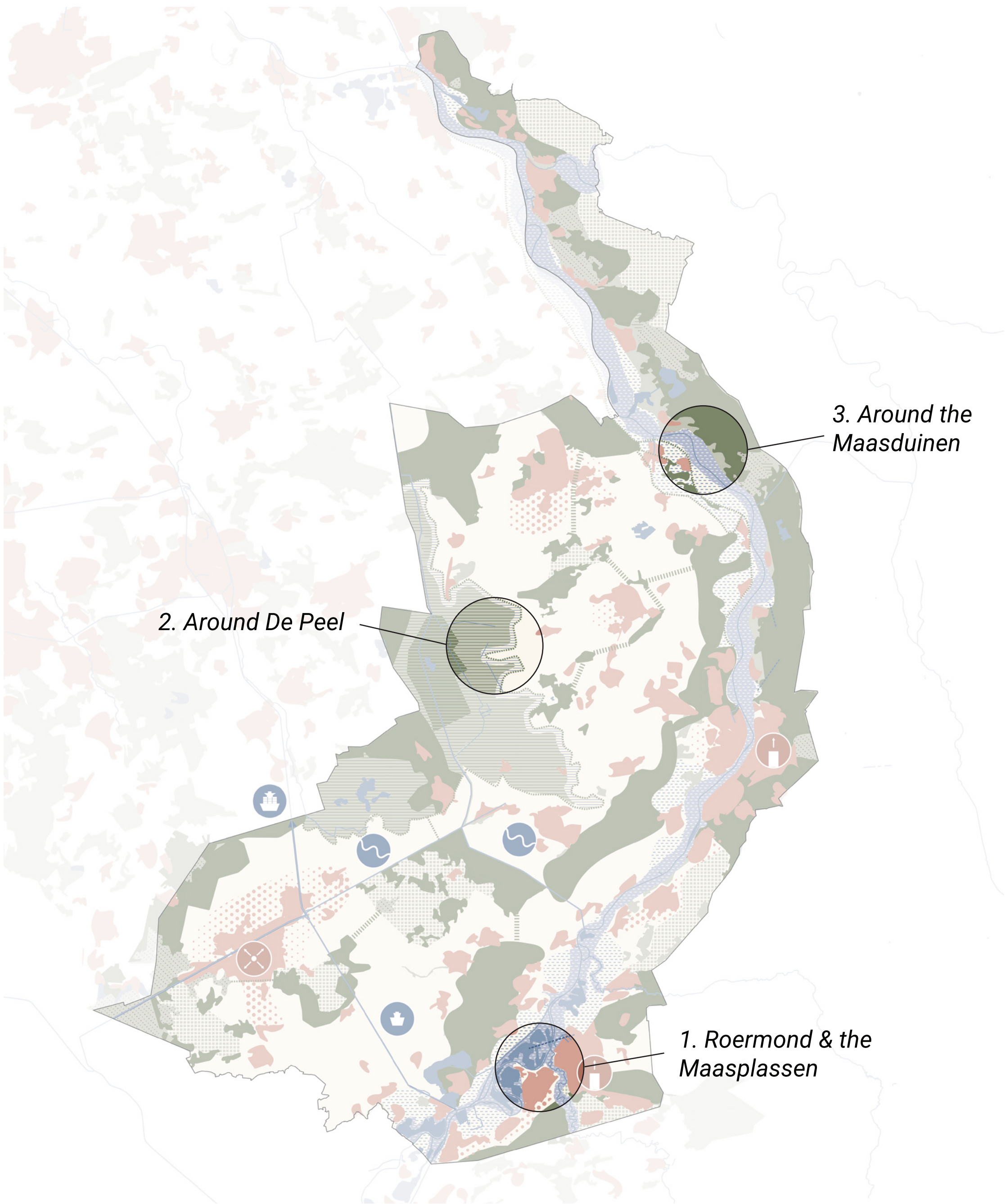


Figure 4.17: Location of zoom-ins.

1. Roermond & the Maasplassen

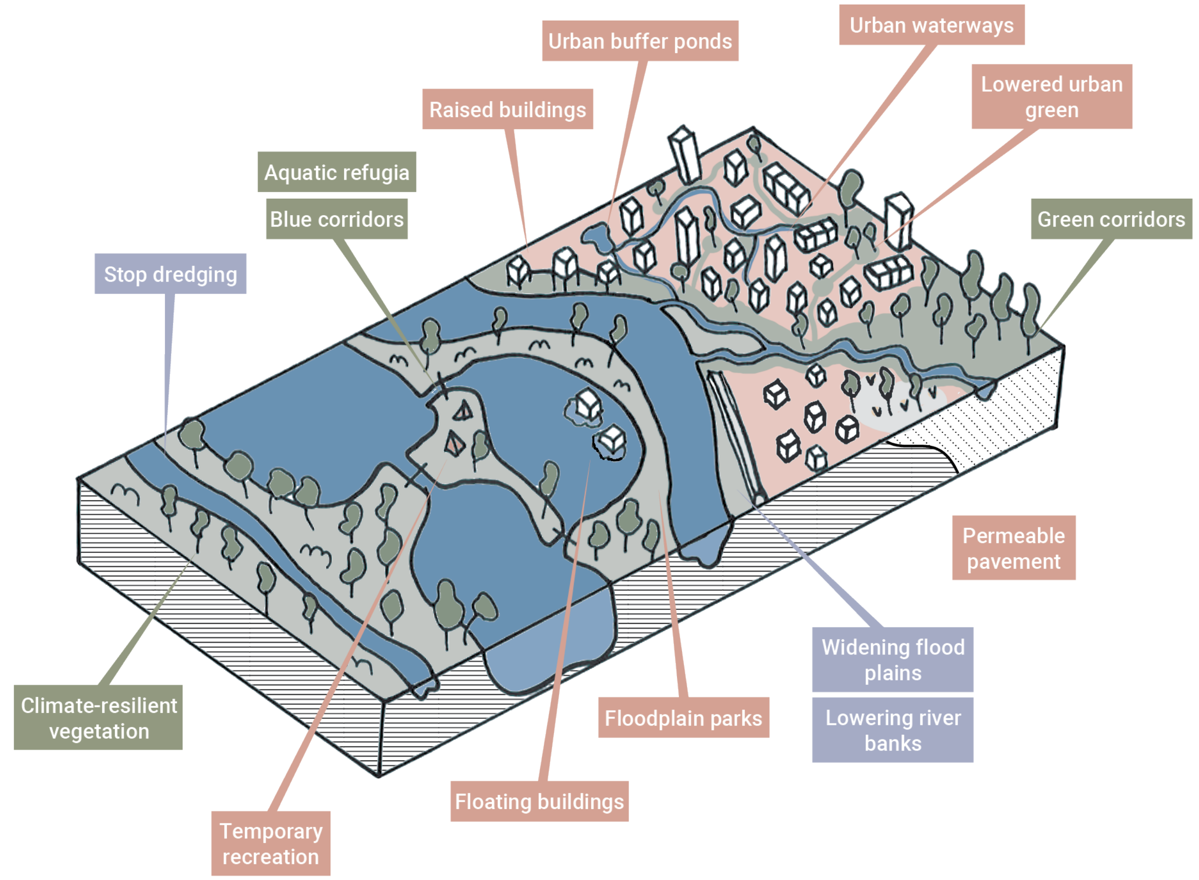


Figure 4.18: Zoom-in of part of Roermond and the Maasplassen showing the pattern implementation of the integrated design.

2. Around De Peel

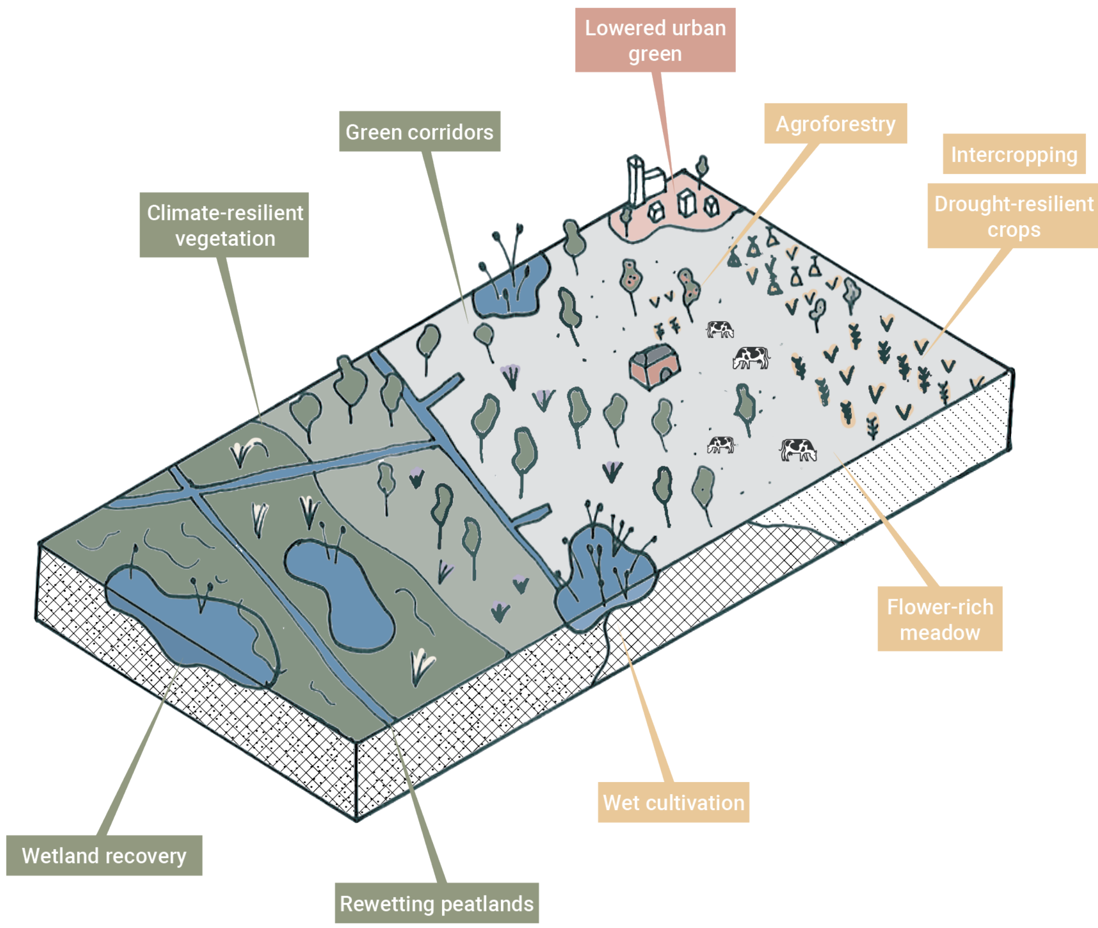


Figure 4.19: Zoom-in of part of De Peel showing the pattern implementation of the integrated design.

3. Around the Maasduinen

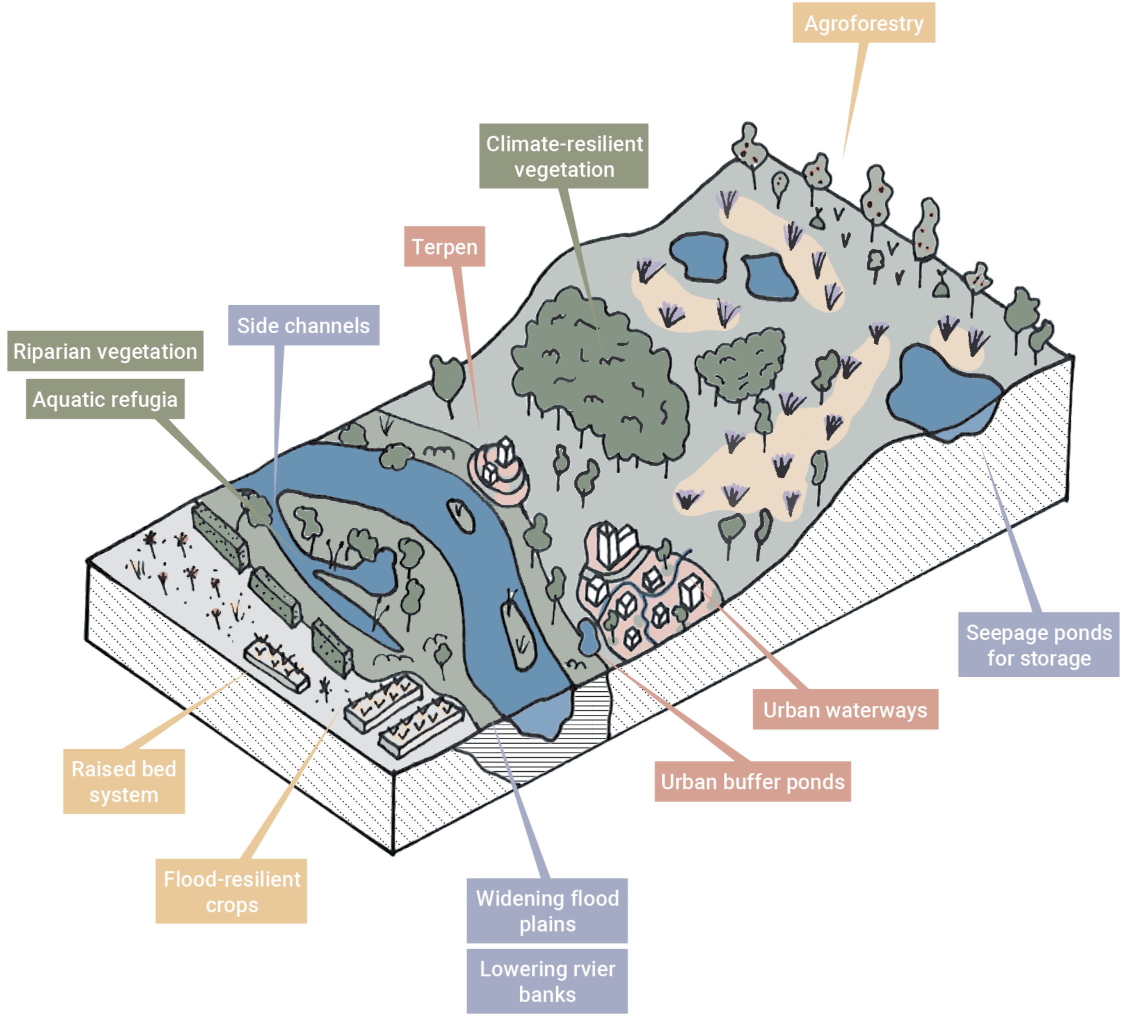


Figure 4.20: Zoom-in of part of the Maasduinen showing the pattern implementation of the integrated design.

4.4.7. Panaromas of the future

Although the integrated design visualises a possible design for 2100, the situation will not immediately reach this. Therefore, the following figures (4.23-4.25) show panoramas based on the locations of the Future Autonomous Situation in 2100 of chapter 3.6, visualising the change between 2050 and 2100 for a rural and an urban situation. Both dry and wet scenarios are visualised in the different years and locations.

Figure 4.21: Future Autonomous Situation for a rural location in 2100, close to the village Velden.

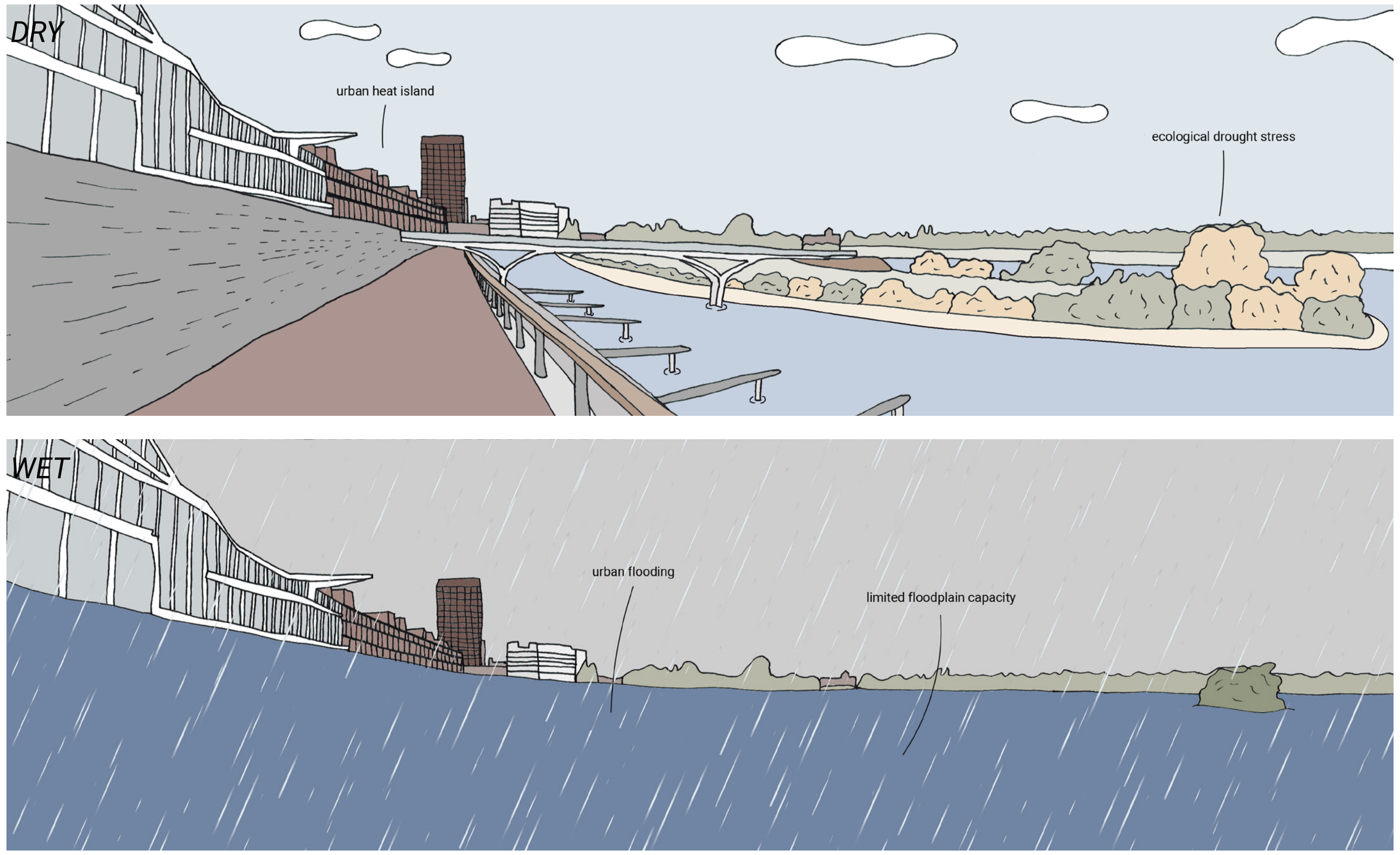


Figure 4.22: Future Autonomous Situation for an urban location in 2100, in Venlo.

Rural panaroma 2050

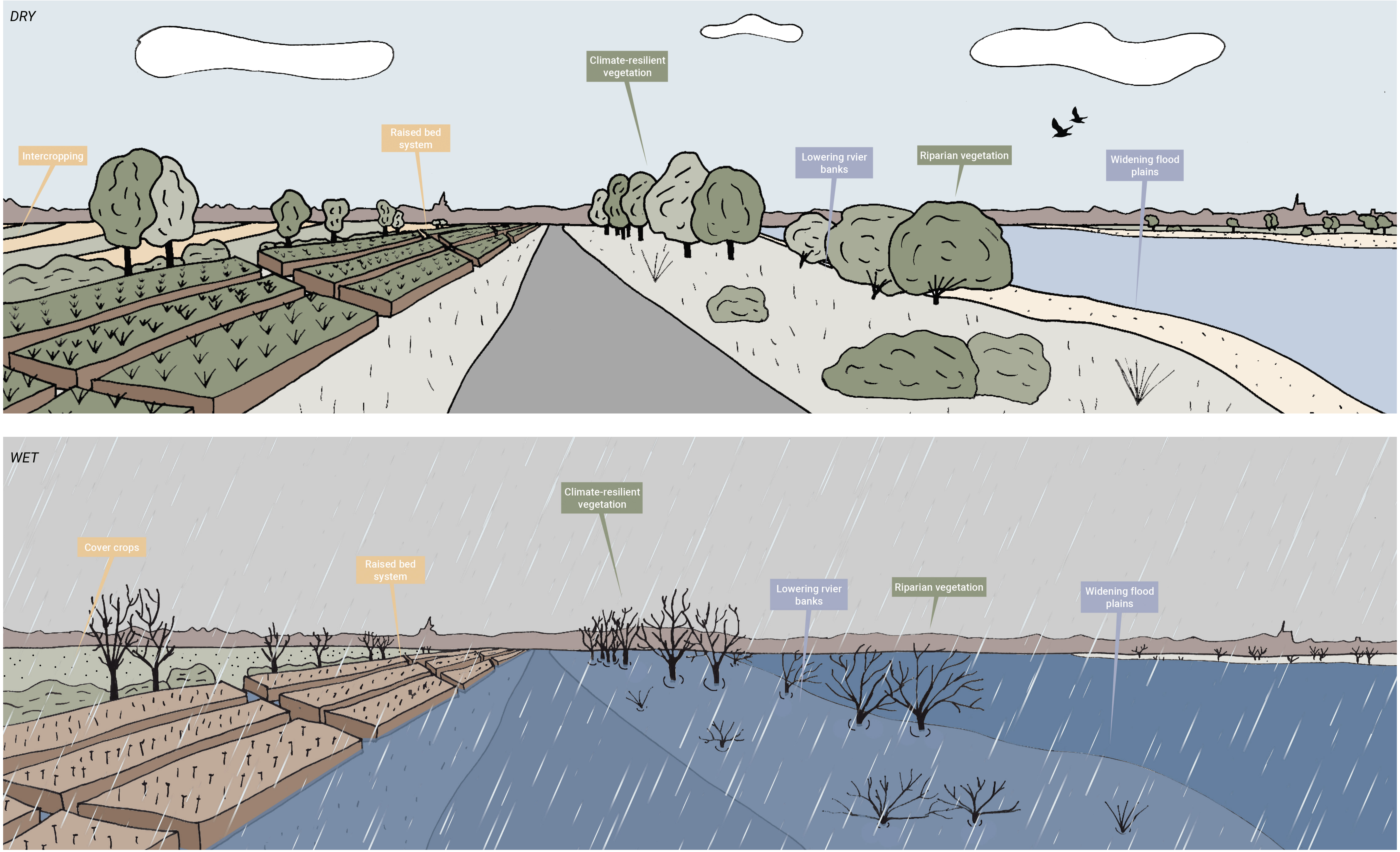


Figure 4.23: Spatial impression of the design close to Velden in 2050.

Rural panaroma 2100

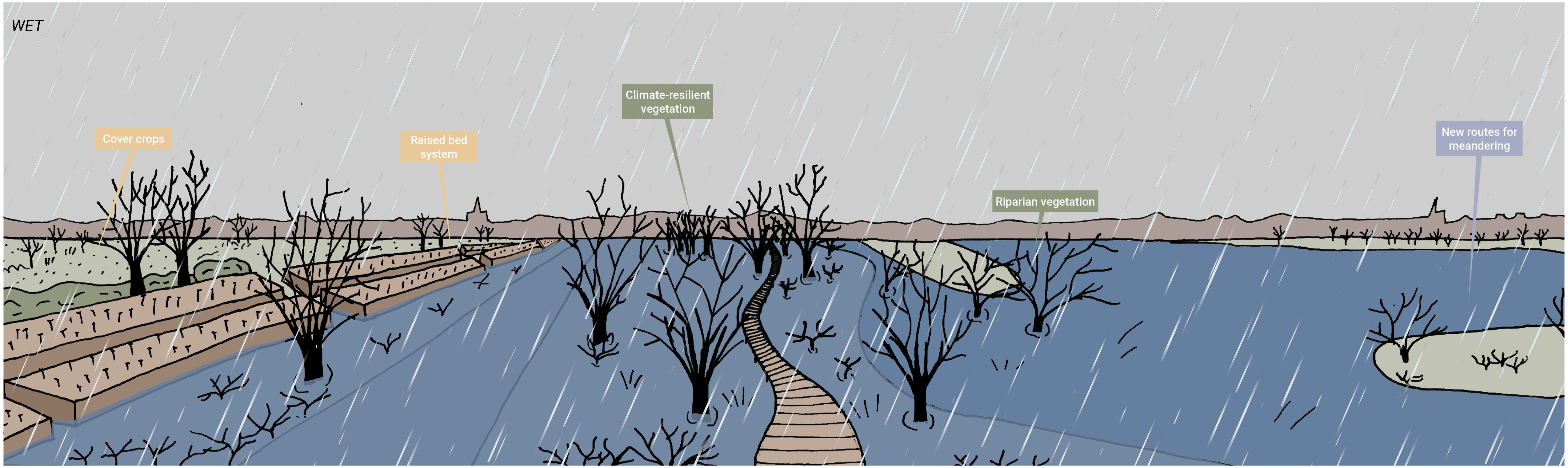


Figure 4.24: Spatial impression of the design close to Velden in 2100.

Urban panaroma 2050-2100

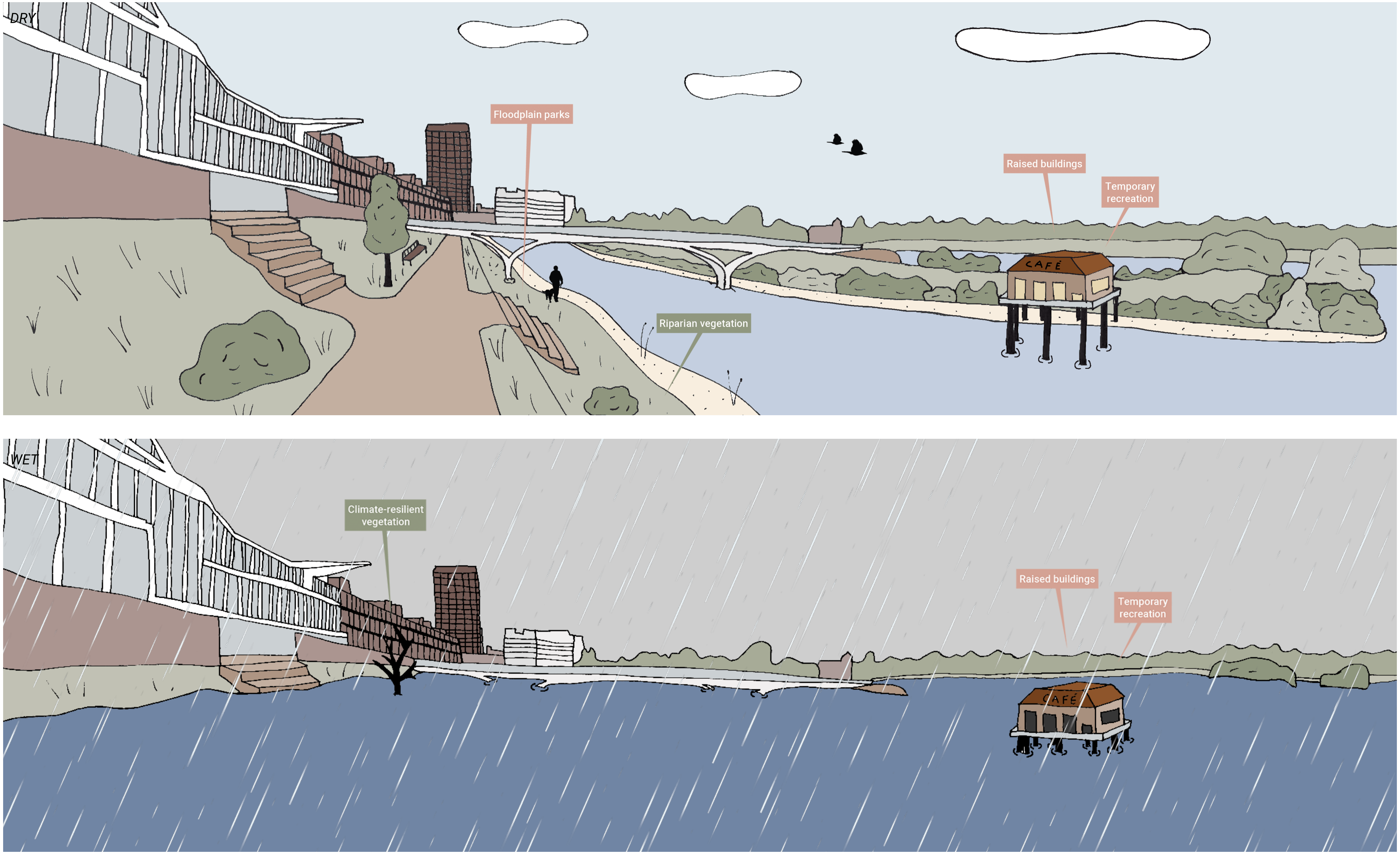


Figure 4.25: Spatial impression of the design in Venlo between 2050 and 2100.

4.5. Evaluation of the design

To evaluate the design, the evaluation table was completed, comparing the design to the current situation and the FAS-2100 scenario. The score for the design is based on the patterns used. This includes consideration of potential negative consequences. This has led to the assessment, shown in figure 4.26.

When comparing the design to the current situation and the FAS, a large improvement can be seen, especially on the complementary criteria and the water safety criteria. There are a few points that score similar to or lower than today. Shipping navigability will not improve in this design as the river Maas will no longer be open for large-scale transport. However, this limitation is specifically for this area. Ships will have to follow different routes from which they can still move from the port of Rotterdam to Belgium and France. Furthermore, peatland stability does not score higher than today. This is because of the ecosystem's water demand. It will take more than 75 years for peatlands to become completely stable and self-sufficient. Until then, water will need to be sent to the area to prevent sinking and carbon emissions. Criteria such as drinking water supply and water quality do score slightly better, but will need other interventions that are not included in this research to become completely climate resilient. Finally, land use compatibility is a complicated criterion point. For renaturalisation of the river, it is necessary to give up the space that is currently used for agriculture. Moreover, part of this space cannot be used for other land uses. However, other land uses do fit together in the design considering nature and certain typologies of agriculture, for instance.

So, if this design were implemented in the Noordelijke Maasvallei, water safety, water availability, and ecological resilience would improve. However, this would require correct implementation and changing certain land uses that will need the collaboration of different stakeholders. Nevertheless, integrating certain interventions into the area would already improve the climate resilience of the area, which as reviewed through the evaluation table.

	Criteria	2025	FAS 2100	Design 2100
Water availability	Drinking water supply	+	-	+
	Crop water efficiency	-	- -	++
	Infiltration and recharge	-	-	++
	Shipping navigability	+	-	-
	Water quality	0	-	+
Water safety	Urban flood safety	0	-	++
	Crop field drainage	-	- -	++
	Infrastructure resilience	+	-	++
Ecological resilience	River nature	- -	- -	++
	Ecosystem connectivity	-	-	++
	Peatland stability	0	-	0
	Nutrient stability	- -	- -	++
	Heat mitigation	-	- -	+
	Fauna refuge	-	-	++
Complementary criteria	Water retention	0	- -	++
	Natural river dynamics	- -	- -	++
	Land use compatibility	-	-	+
	Discharge adaptability	-	- -	++

Effect:

++	very positive
+	positive
0	no effect
-	negative
- -	very negative

Figure 4.26: Evaluation of the current situation, FAS 2100 and the design for 2100.

Conclusion 5

This chapter presents the conclusion of this thesis, followed by a discussion of limitations and recommendations. It ends with a reflection on the project's approach, outcomes, and implications.

5.1. Conclusion

This thesis investigates a new approach for rain-fed river basins to become resilient to the expected increasing periods of drought and extreme precipitation in the coming decades. The aim is to research how the cultivated landscape could spatially adapt to a renaturalised river basin and how this will improve an area's climate resilience, in this case, the Noordelijke Maasvallei. These objectives have led to the following research question:

How will renaturalisation of the river Maas as a climate resilience strategy transform the Noordelijke Maasvallei under the most extreme dry and wet scenarios by 2100, and how can the ecological, agricultural, and urban landscape evolve with this transformation?

The scope of this research was the Noordelijke Maasvallei, consisting of part of the downstream Maas and its surrounding area. The conclusions as discussed in this chapter are drawn from this specific scope. This thesis followed a systemic design approach as visualised in figure 5.1.

Analysis

Over time, the Noordelijke Maasvallei has been shaped to the needs of humans. Where the Maas used to follow its own course, now weirs, dikes and dredging practices decide its flow. Inland nature has made way for monocultural agriculture, which is expected to suffer more severely from increasingly dry summers. The analysis (chapter 3) examined past, present, and future trends of the Noordelijke Maasvallei from which SWOT analyses were constructed. With river discharges becoming more unpredictable, water safety and availability are under pressure, impacting both urban and agricultural sectors. At the same time, nature and natural processes show great potential to improve water uptake and allocation, enhancing both water safety and availability. Nevertheless, the ecological system has been deteriorating, limiting the potential for climate resilience and reflecting a continuing decline in ecological resilience. These identified SWOTs have led to the evaluation criteria, divided over water safety, water availability, ecological resilience, and complementary criteria. These were used to assess both the current system and the autonomous system for 2100. Without changes to the current approach, the vulnerability to extreme droughts and precipitation is expected to increase significantly towards 2100.

Design

A pattern language has been built for the design (chapter 4.2). The patterns depict different methods to renaturalise a river basin and reveal different ways toward climate resilience in all sectors, as shown through the four maximisations (chapter 4.3). However, the integration of the four themes revealed different implications between the sectors. In the integration (chapter 4.4), the river and ecological system were given more weight than the urban and agricultural system, reflecting the research aim. A large area will need to be allocated to the river, because of the river's unpredictability, particularly over the far future. Therefore, in the design, the choice to go around the current urban fabric has been made to accommodate the river. Consequently, agriculture will have to make space for the river. Overall, it can be concluded that agriculture will have to make the biggest change towards climate resilience in the Noordelijke Maasvallei. However, if done so, the evaluation shows that, by incorporating the patterns as applied in the integrated design, renaturalisation can indeed increase the resilience towards increasing periods of drought and precipitation in 2100.

In conclusion, this thesis shows that climate resilience for the future can improve through renaturalisation of rivers and with the right change of the cultivated landscape. Although this design focuses on an entire region, some of the interventions of the pattern language can be implemented by themselves to already increase climate resilience across the cultivated landscape. However, to make big improvements towards resilience against extreme dry and wet periods, a regional, systemic change, as done in the integration, would provide sufficient outcomes. There is potential for climate resilience through renaturalisation, if we allow the cultivated landscape to shape according to the river, and not let the river be shaped to us.

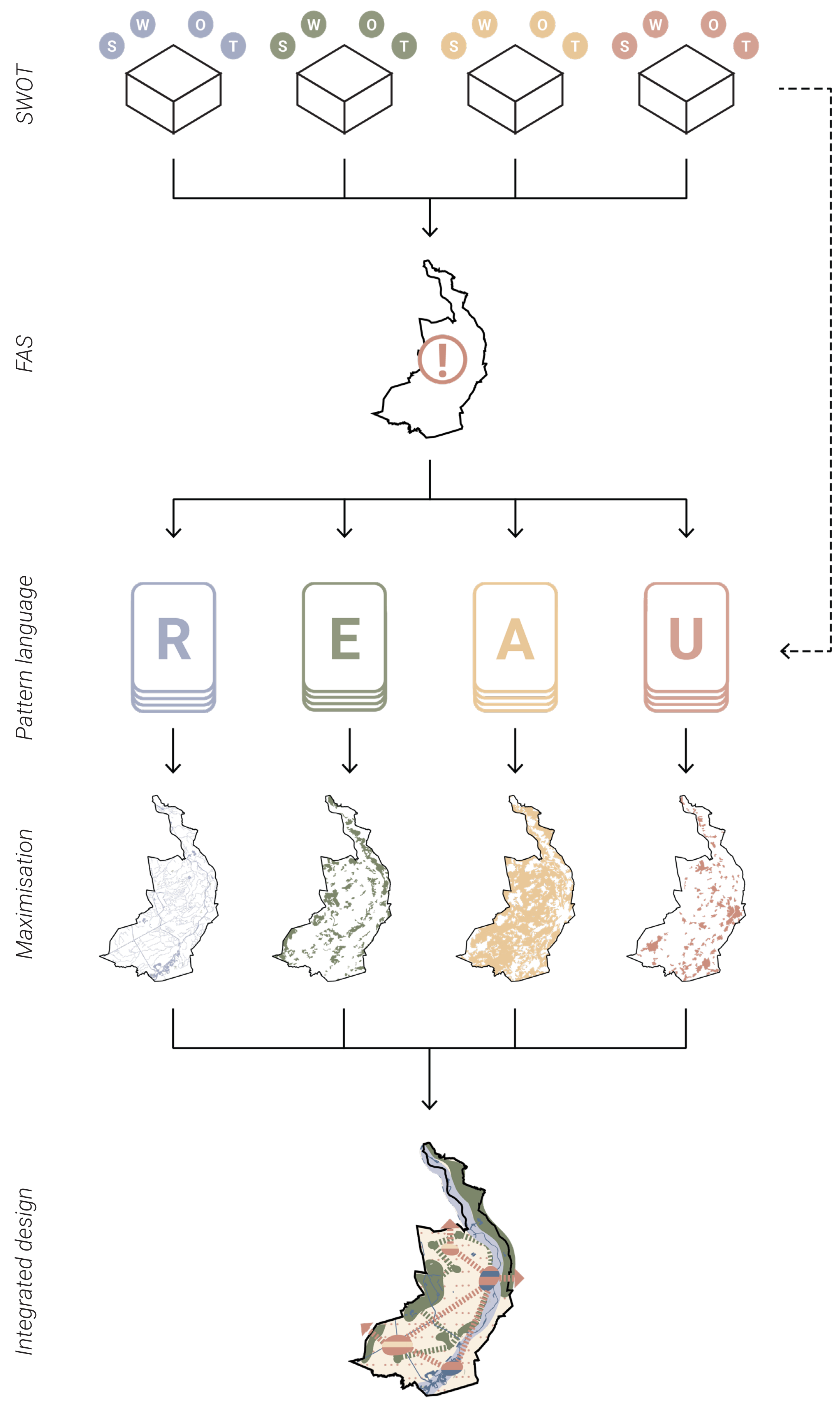


Figure 5.1: Systemic design approach of this thesis.

5.2. Discussion

5.2.1. Limitations

Methods

This thesis followed a systemic approach from which a design has been created to answer the research question. The research started with SWOT analyses, specifically specifically for the research area, to formulate evaluation criteria. Although it would cover the main objectives for areas with similar issues and characteristics, it is important to check specific challenges and adapt the evaluation criteria accordingly.

A similar limitation can be mentioned for the pattern language. The patterns of this thesis are based on the analysis of the Noordelijke Maasvallei, solving specific issues related to this region. While this method proved useful in providing solutions, if applied elsewhere, additional or adapted patterns may be necessary.

The maximisation method proved to be useful for this thesis and provided insights that would otherwise not have been found. However, the scale of this research was quite big for this method. It was difficult to go into detail in certain areas. This was especially the case for the agricultural maximisation, which became quite broad, as did the ecological and urban maximisations. Since the focus of this design is on renaturalisation, water and ecology have weighed more than agriculture and the urban environment in this design. Therefore, the level of detail differs between the themes, with agriculture and urbanisation serving mainly to support the overall river and ecological strategy.

Research scope

The chosen time-scale of 75 years created several limitations. On the one hand, looking this far ahead in future provides uncertainty, which limited the level of detail the design could provide. On the other hand, 75 years is relatively short for renaturalisation of the river Maas, as a river changes its course slowly. Therefore, the design can only suggest a potential zone for future river movement rather than a precise course for this timeframe.

The evaluation of the design (chapter 4.5) consists of different criteria relevant to the research aim of this thesis. The potential of the design is evaluated by a score. However, the scoring has limitations in its quantitative significance, as the data of this research does not consist of specific numbers. It is therefore important to note that this evaluation is primarily based on interpretation of qualitative literature, rather than measurable data.

Finally, the scope of this research focused more on specific challenges in the area, thereby not including all connected sectors to the same extent. This is reflected in the evaluation where water quality, shipping, and peatland stability score lower for instance. Furthermore, the scope of this research did not go beyond the Noordelijke Maasvallei. Upstream and downstream factors have not been included as much, but could play a significant role in increasing or decreasing the climate resilience.

5.2.2. Recommendations

Since the Noordelijke Maasvallei is just a small section of the river Maas catchment, further research on a larger scale is necessary to understand the full impact of renaturalisation. Examination of the entire river system, including canals, and the governance of water distribution is critical, in particular for shipping and renaturalisation.

As mentioned in 5.2.1, not all sectors have been included to the same extent in this thesis. Therefore, it is recommended to do further research into these sectors, such as water quality and, as mentioned, shipping. Water quality could be a different scope for the Noordelijke Maasvallei, in which we will find different interventions through the pattern language.

In this thesis, the maximisations of water and ecology had a stronger focus in the design because of the research aim. However, for more specific strategies on the agricultural and urban sectors, the maximisation method could be applied in greater detail to these sectors.

Finally, researching the spatial interpretation on a smaller scale could provide useful results on how a specific neighbourhood could actually implement the patterns that are created for this design. This thesis, therefore, offers opportunities to zoom out or zoom in to examine the integration of cultivated landscape and river renaturalisation.

5.3. Reflection

This section presents a reflection on the graduation project, guided by eight topics adressing different aspects of this thesis.

On the relation between the graduation project topic, master track, and master programme

The main focus of my thesis was to investigate the integration of a new natural river landscape with a cultivated landscape, exploring solutions connected to different disciplines. This aligns with the Urbanism master track. Urbanism emphasises an interdisciplinary approach to planning and designing sustainable urban landscapes that are climate-adaptive and ecologically inclusive across multiple scales. This project developed new spatial perspectives. It brought various solutions together, based on climate adaptability and ecological resilience. It used systemic design to visualise a climate-resilient future for the Noordelijke Maasvallei. Moreover, it followed a multi-scalar approach, exploring solutions on different scales, from regional to local, to gain a clear understanding of the entire landscape. The combination of methods, such as the pattern language and maximisation method, reflects the holistic approach of Urbanism. It allows for different systems to be explored and visualised in a coordinated way.

On the mutual influence between the research and the design

Before P2, I focused on different theories that have shaped the analysis and design I have made in the end. During the pattern building, maximisations, and design phase, soil- and water-led planning were always central. Furthermore, the analysis shaped which solutions were needed, which are then incorporated into the design.

However, from the start of this thesis, it was clear that the design would focus on renaturalisation. A natural Maas river has been a focal point throughout this thesis. Therefore, the design has influenced the research to focus on natural and human-influenced processes of all systems. Moreover, it pushed the SWOT analysis in a certain direction, thereby selecting between certain issues as described in the discussion (5.2).

On the way of working, the used methods, and the methodology

The systemic approach of this thesis was valuable in developing a spatial design for a climate-resilient Noordelijke Maasvallei while integrating multiple themes. The SWOT analysis provided a structured basis for the evaluation criteria. However, some criteria received a stronger focus. Consequently, the design was less attentive to certain sectors. The pattern language offered practical ways to address specific challenges. The maximisation method explored their spatial interpretation and integration across water, ecology, agriculture, and urbanisation. The 75-year time scale provided a long-term perspective but introduced uncertainty, especially regarding river dynamics. The evaluation highlighted the design’s potential, though it relied mainly on qualitative interpretation. Overall, the methodology proved effective in developing the design. Despite prioritising water and ecology, it nonetheless provides useful insights for agriculture and urbanisation that could be explored from a different perspective.

On the academic and societal value, scope and implications, and ethical aspects

The academic value of this thesis lies in contributing to a better understanding of how renaturalised rain-fed river basins can strengthen climate resilience, and how this can be integrated with the human-altered landscape. Although projects such as “Room for the River” have proven useful, the spatial integration of the cultivated landscape is often overlooked. This thesis, therefore, addresses this gap by offering new perspectives on climate-resilient, adaptive river basins and by connecting different disciplines to gain a complete picture.

The societal value relates to the growing impact of extreme precipitation, drought, river discharge unpredictability, and therefore, the urgent call for resilience. This thesis looks through a different lens, where natural river processes return while providing space for cultivated functions and new ways for stakeholders to use the landscape. The developed design offers insights for policymakers, planners, and communities, and encourages actors to consider the future differently. Additionally, the developed design acknowledges the ethical importance of strengthening the ecological resilience of the area and providing long-term safety for extreme weather events for the communities living in the area.

On transferability of the project results

The methodology of this thesis follows a linear, systemic approach that could be transferred to different regions with similar characteristics and challenges. However, certain outcomes are specific to this research area and have guided the research in a direction it might not have taken in a different context. For example, the evaluation criteria are based on the SWOT analysis of the Noordelijke Maasvallei, which could differ for another area. This, in turn, influenced the results of the patterns, maximisations, and final design. Moreover, in this design, water and ecology were given stronger focus, making the agricultural and urban maximisations less detailed. If the methodology were applied elsewhere with more emphasis on agriculture or urbanisation, these maximisations would need more emphasis. Nevertheless, the methodology is verifiable and adaptable, and can provide a structured approach toward climate-resilient design in different contexts.

On phasing

Although this thesis researches a possible design for 2100, supported by a structured methodology, it can be argued that it lacks a phasing strategy. In earlier stages of the thesis, there were thoughts of designing a decision tree, in which different choices would lead to different designs for 2100. However, during the process, more focus was put into the integration of different maximisations. The choice was made to show only one possible design. Moreover, designing a phasing strategy proved to be difficult by following the principles of evolutionary resilience as described by Davoudi et al. (2013). This thesis focuses on allowing the river and ecological system to regain their natural processes, so that the system will find its equilibrium. However, these processes are difficult to predict. Nevertheless, a guideline, or decision tree concept, could be useful for making decisions for the cultivated landscape. Different patterns could be applied depending on changes in the natural system. Still, this thesis provides solutions required to enhance climate resilience and prepare the area for future changes even without a detailed phasing strategy.

On the relation to the entire river catchment

This thesis starts from a perspective based on the Maas river catchment, highlighting issues related to water distribution and climate change. For this research, the focus was narrowed to the Noordelijke Maasvallei to better explore the relationship between the cultivated landscape and the river. As a result, only part of the river system is considered. Research on upstream and downstream interactions is limited. Nevertheless, these interactions are important. Changes upstream in France affect the Noordelijke Maasvallei, which in turn, influences the Maas in the Netherlands. This limitation is partly related to the difficulty of evaluating the design. Data on water distribution and discharges is scattered and presented differently across disciplines. Nonetheless, studying renaturalisation at the catchment scale would be valuable, emphasising both the urgency and benefits of a renaturalised river basin.

On unforeseen impacts of the design

River renaturalisation has a huge impact on the surrounding landscape. Especially in this context, where the entire landscape has been planned around the current engineered river. Although this thesis addresses multiple possibilities for integration, there may be unforeseen impacts that are not discussed.

Firstly, the design creates space for the river to flood, including areas that currently have a different function. This land cannot be used during floods, which may remove recreational spaces that provide income for certain people. Additionally, it may be difficult for farmers to reach their fields. Therefore, it can be argued that this design lacks an infrastructure strategy that fully considers this. Moreover, the design presents possibilities for certain activities, but safety factors related to the river are not considered. Therefore, safety measures should be addressed before implementing certain patterns. Finally, the renaturalisation patterns will drastically change the landscape and are difficult to reverse. Although this project advocates for this change, the long-term effects may differ from expectations. This relates to the phasing reflection, in which "no-return" patterns could be highlighted. Overall, it is important to note that this thesis does not include all the potential impacts of renaturalisation. More detailed research into these gaps could strengthen the design and its practical implementation.

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Appendix 7

7.1. Pattern list

Patterns for renaturalisation

R.1 Reconnecting old meanders
R.2 Providing new routes for meandering
R.3 Widening flood plains
R.4 Lowering river banks
R.5 Side channels
R.6 Seepage ponds for water storage
R.7 Seasonal retention ponds
R.8 Stop dredging
R.9 Shipping on specific canals only
R.10 Smaller vessels
R.11 Beaver or branch dams

Patterns for ecology

E.1 Climate resilient vegetation
E.2 Riparian vegetation
E.3 Green corridors
E.4 Stepping stones
E.5 Blue corridors
E.6 Aquatic refugia
E.7 Wetland recovery
E.8 Rewetting peatlands

Patterns for agriculture

A.1 Drought resilient crops
A.2 Flood resilient crops
A.3 Wet cultivation
A.4 Mulching
A.5 Half-moons
A.6 Cover crops
A.7 Intercropping
A.8 Agroforestry
A.9 Raised bed system
A.10 Flower-rich meadow
A.11 Aquifer storage and recovery
A.12 Residual flows for livestock feed

Patterns for urbanisation

U.1 Urban waterways
U.2 Underground water buffers
U.3 Urban buffer ponds
U.4 Lowered urban green
U.5 Floodplain parks
U.6 Raised buildings
U.7 Floating buildings
U.8 Terpen
U.9 Temporary recreation
U.10 Permeable pavement

7.2. Pattern evaluation

Evaluation of patterns for renaturalisation

		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
Water availability	Drinking water supply	0	0	0	0	0	+	++	0	0	0	0
	Crop water efficiency	0	0	0	0	0	0	+	0	0	0	0
	Infiltration and recharge	+	+	+	+	+	++	++	0	0	0	++
	Shipping navigability	-	-	-	-	0	0	0	--	+	+	0
Water safety	Water quality	0	0	0	0	0	0	0	0	+	+	++
	Urban flood safety	++	++	++	++	++	0	+	+	0	0	0
	Crop field drainage	0	0	0	0	0	0	0	0	0	0	0
	Infrastructure resilience	0	0	0	0	0	0	0	0	++	+	0
Ecological resilience	River nature	+	+	+	+	++	0	0	++	++	++	++
	Ecosystem connectivity	+	+	0	0	++	0	0	+	+	+	+
	Peatland stability	0	0	0	0	0	0	0	0	0	0	0
	Nutrient stability	0	0	0	0	0	0	0	0	0	0	0
	Heat mitigation	0	0	0	0	0	0	0	0	0	0	0
	Fauna refuge	0	0	0	0	++	0	0	0	0	0	++
Complementary criteria	Water retention	0	0	0	0	+	++	++	+	0	0	+
	Natural river dynamics	++	++	++	++	++	0	0	++	++	++	+
	Land use compatibility	-	-	-	0	0	0	+	0	0	0	0
	Discharge adaptability	++	++	++	++	++	0	++	++	+	+	0

Effect:
++ very positive
\+ positive
0 no effect
\- negative
-- very negative

Figure 7.1: Evaluation of renaturalisation patterns.

Evaluation of patterns for ecology

		E1	E2	E3	E4	E5	E6	E7	E8
Water availability	Drinking water supply	0	0	0	0	+	0	+	0
	Crop water efficiency	0	0	0	0	0	0	0	0
	Infiltration and recharge	++	0	++	++	+	0	++	+
	Shipping navigability	0	0	0	0	0	-	0	0
Water safety	Water quality	0	++	0	0	+	0	++	0
	Urban flood safety	0	+	0	0	+	0	0	0
	Crop field drainage	+	0	0	0	+	0	0	0
	Infrastructure resilience	0	0	0	0	0	0	0	0
Ecological resilience	River nature	0	++	0	0	++	++	0	0
	Ecosystem connectivity	+	+	++	++	++	+	++	+
	Peatland stability	+	+	0	0	+	0	++	++
	Nutrient stability	++	0	++	++	0	0	+	+
	Heat mitigation	+	0	+	+	+	0	+	+
	Fauna refuge	+	+	++	++	++	++	++	+
Complementary criteria	Water retention	0	0	0	0	+	0	++	-
	Natural river dynamics	0	++	0	0	0	0	0	0
	Land use compatibility	+	0	+	+	+	+	+	0
	Discharge adaptability	0	+	0	0	+	++	0	0

Effect:
++ very positive
\+ positive
0 no effect
\- negative
-- very negative

Figure 7.2: Evaluation of ecology patterns.

Evaluation of patterns for agriculture

		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
Water availability	Drinking water supply	0	0	0	0	0	0	0	0	0	0	++	0
	Crop water efficiency	++	0	0	++	++	+	+	++	0	+	++	0
	Infiltration and recharge	+	+	0	++	++	++	+	++	0	+	+	0
	Shipping navigability	0	0	0	0	0	0	0	0	0	0	0	0
	Water quality	0	0	0	0	0	0	0	0	0	0	0	0
Water safety	Urban flood safety	0	0	0	0	0	0	0	0	0	0	0	0
	Crop field drainage	0	++	++	+	+	++	+	++	++	+	0	0
	Infrastructure resilience	0	0	0	0	0	0	0	0	+	0	0	+
Ecological resilience	River nature	0	0	0	0	0	0	0	0	0	0	0	0
	Ecosystem connectivity	0	0	0	0	0	0	0	++	0	++	0	0
	Peatland stability	0	0	0	0	0	0	0	0	0	0	0	0
	Nutrient stability	0	0	0	+	+	++	++	++	0	++	0	0
	Heat mitigation	0	0	0	0	0	0	0	+	0	0	0	0
	Fauna refuge	0	0	0	0	0	0	0	++	0	++	0	0
Complementary criteria	Water retention	+	++	0	+	+	+	+	+	0	+	++	0
	Natural river dynamics	0	0	0	0	0	0	0	0	0	0	0	0
	Land use compatibility	0	++	++	0	0	0	0	++	++	++	0	++
	Discharge adaptability	0	++	0	0	0	0	0	0	++	0	0	0

Effect:
++ very positive
+ positive
0 no effect
- negative
-- very negative

Figure 7.3: Evaluation of agriculture patterns.

Evaluation of patterns for urbanisation

		U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
Water availability	Drinking water supply	0	++	+	0	0	0	0	0	0	0
	Crop water efficiency	0	0	0	0	0	0	0	0	0	0
	Infiltration and recharge	+	+	+	++	+	0	0	0	0	+
	Shipping navigability	0	0	0	0	0	0	0	0	0	0
	Water quality	0	+	++	0	0	0	0	0	0	0
Water safety	Urban flood safety	++	0	++	++	++	++	++	++	+	+
	Crop field drainage	0	0	0	0	0	0	0	0	0	0
	Infrastructure resilience	+	++	0	+	+	++	++	++	++	++
Ecological resilience	River nature	0	0	0	0	+	0	0	0	0	0
	Ecosystem connectivity	+	0	+	++	+	0	0	0	0	0
	Peatland stability	0	0	0	0	0	0	0	0	0	0
	Nutrient stability	0	0	0	0	0	0	0	0	0	0
	Heat mitigation	+	0	+	0	0	0	0	0	0	0
	Fauna refuge	+	0	+	+	+	0	0	0	0	0
Complementary criteria	Water retention	++	++	++	++	0	0	0	0	+	++
	Natural river dynamics	0	0	0	0	+	+	0	+	+	0
	Land use compatibility	+	++	+	+	++	++	++	++	++	0
	Discharge adaptability	++	0	++	++	++	++	++	++	+	0

Effect:
++ very positive
+ positive
0 no effect
- negative
-- very negative

Figure 7.4: Evaluation of urbanisation patterns.

7.3. Floodplain calculations

Necessary widening of the floodplains is shown in the intregation map. This is based on calculations using a discharge of 3500 m³/s, and an average velocity of 3 m/s, based on Barneveld et al. (2025).

For a flow rate (Q) of 3500 m³/s and a velocity (v) of 3 m/s, a cross-sectional area (A) of 1166.67 m2 is needed.

$Q = A * v$
$3500 = A * 3$
$A = 1166.67$ m2

The depth of the Maas varies along the trajectory, but is between 6 and 13 metres deep while dredged. Because renaturalisation would remove dredging practices, the Maas could become shallower in certain places. Therefore, for the calculation of the width, a depth of 6m is taken.

The first trajectory is 100 m wide:

$A_{river} = h * w$
$A_{river} = 100 * 6$
$A_{river} = 600$ m2

Therefore, the needed area of the floodplain would be:

$A_{fp} = 1166.67-600 = 566.67$ m²

Assuming a depth of 1m

$W_{fp} = 566.67/1 = 566.67 \approx 570$ m

However, compensation for bottlenecks in cities is necessary. Therefore, 50m is added to each side of the river. This would result in 670 width of floodplain extra for the river.

The second trajectory is 130 metres wide:

$A_{river} = h * w$
$A_{river} = 130 * 6$
$A_{river} = 780$ m2

Therefore, the needed area of the floodplain would be:

$A_{fp} = 1166.67-780 = 386.67$ m²

Assuming a depth of 1m

$W_{fp} = 386.67/1 = 386.67 \approx 390$ m

However, compensation for bottlenecks in cities is necessary. Therefore, 50m is added to each side of the river. This would result in 490 width of the floodplain extra for the river.

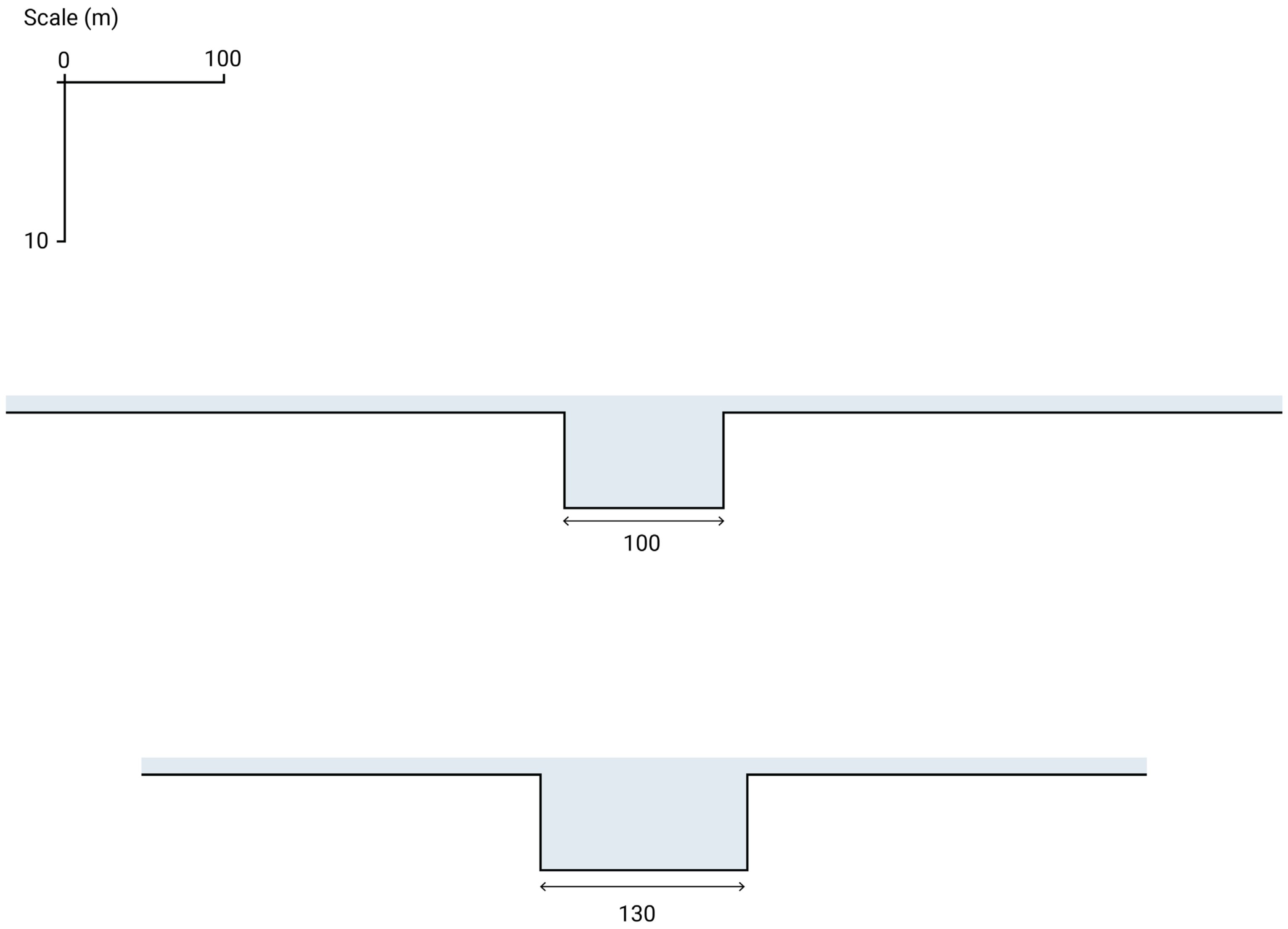

Figure 7.5: Visualisation of floodplain widening.