DESIGNING DROUGHT RESILIENT FORESTS

An explorative design approach for drought resilient forests at high sandy soils

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MSc Thesis Landscape Architecture

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COLOPHON

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ABSTRACT

The Netherlands has experienced long periods of drought in the past years due to climate change. During the dry summers, it became clear that the Dutch forests will be more vulnerable due to the prolonged periods of drought. Especially forests at high sandy soils are suffer due to their dependency on precipitation. The vulnerability is reinforced by the characteristics of the Dutch forests; monotonous plot structure, poor soil quality, and little biodiversity. The effects of climate change, combined with the current forest characteristics, will lead to increased diseases and tree death. Meanwhile, the Dutch forests have an important ecological and social position.

The concept of resilience considers the landscape as a system that can absorb disturbances. Currently, the forest has difficulties to absorb the longer periods of droughts. Hydrological interventions will be insufficient because forests at high sandy soils rely on precipitation. Therefore, the all-encompassing system approach of resilience will help to consider the complexity of the forest landscape. This thesis applies the concept of resilience to the forest landscape at high sandy soils, resulting in design guidelines that improve drought resilience of forests at high sandy soils.

Four attributes of resilience were formulated, on which twelve design principles were developed. Based on the design principles, design guidelines were developed which were tested on three design alternatives. The design alternatives and design guidelines were evaluated in an expert meeting. The outcome of the expert evaluation resulted in revised design guidelines which were implemented into a final design.

This research integrates the concept of resilience into design guidelines, resulting in a drought resilient landscape design for forests at high sandy soils. The design guidelines illustrated the spatial application of resilience. This drought resilient forest design has the ability to absorb disturbances by improving the forest quality based on diversity, connectivity, variability, and redundancy.

Key words: forest landscapes, resilience, landscape architecture, climate change

PREFACE

This thesis is the final product of the MSc Landscape Architecture at Wageningen University. With this thesis, I complete my academic education at Wageningen University. During my studies, I developed a personal interest in the relation between landscape design and natural development. I discovered that nature is a force that can sustain itself. Inspired by the capabilities of nature, natural development became an integral part of my design process. Ultimately, we can only rely on the capacity of natural systems to adapt to the consequences of climate change. Therefore, as landscape architects, we can prepare for the future by using the capabilities of nature in our designs.

I could not have completed this thesis without the people supporting me. First of all, I would like to give many thanks to my supervisor Homero M. Penteado for his feedback and support. His critical reflection on my work's essence helped me to remain close to the scope of the research. Furthermore, I would like to thank the experts who participated in the expert evaluation. Their expertise and experiences generated valuable feedback, improving the outcome of this research. Finally, I would like to thank my husband, family, and friends. Many thanks for the unconditional support and moments of joy. These moments gave me new energy to proceed with my thesis. I hope you will enjoy reading this thesis.

Esther van der Meer

TABLE OF CONTENT

1. INTRODUCTION

This chapter introduces the scope of this research. First, the problem statement illustrates the current situation. Second, the knowledge gap explains the contribution of this research. Finally, the thesis statement concludes with the objective of this research and the formulated research questions.

1.1 PROBLEM STATEMENT

The publication of the first national forest policy brought attention to the forests of the Netherlands (Ministerie van LNV, 2020). The current forest resulted from large-scale reforestation at mostly depleted soils, leading to young forests with a monotonous species and age structure. Meanwhile, forests have an important role in CO_2 capture, natural systems, and biodiversity. Improvements have been made by increasing the diversity within the forest. However, the forest policy still concludes that the forests in the Netherlands are vulnerable to disturbances due to their monotonous structures, poor development, and increased droughts (Ministerie van LNV, 2020).

These conclusions are consistent with the observed trend of forests in Europe, where research shows that the quality of forests in Europe is declining. Drought damage to forests is difficult to identify. Therefore, there is little data on the direct effects of droughts on forests. However, indirect effects, such as vulnerability to diseases, declined tree growth, and tree death, show that the forest is experiencing the negative impact of droughts (Patacca et al., 2022).

CLIMATE CHANGE

Periods of precipitation deficit in the growing season have increased in the Netherlands (see figures 1 and 2). In addition, the temperature increase enlarges evapotranspiration and solar radiation, leading to more warm days and a longer growing season.

The prognosis of the KNMI regarding climate change anticipates more extreme weather events and even more extented periods of droughts (KNMI., 2021). High sandy soils especially are vulnerable to droughts because of the permeability of the sand and the dominance of pine trees (Jeuken et al., 2021).

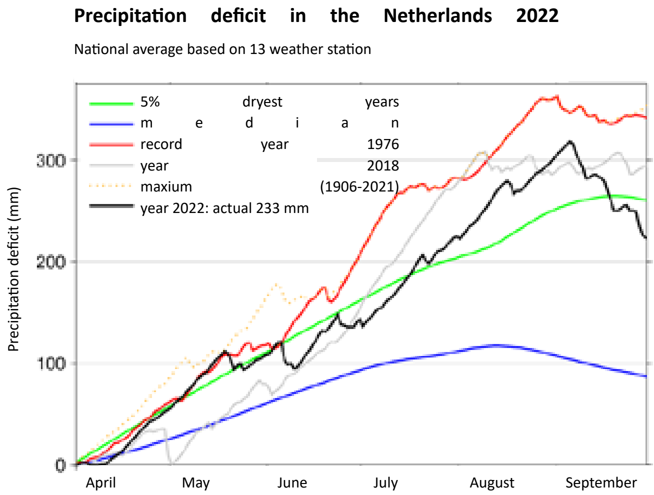


Figure 1: Precipitation deficit in the Netherlands during the growing season (KNMI, 2022)

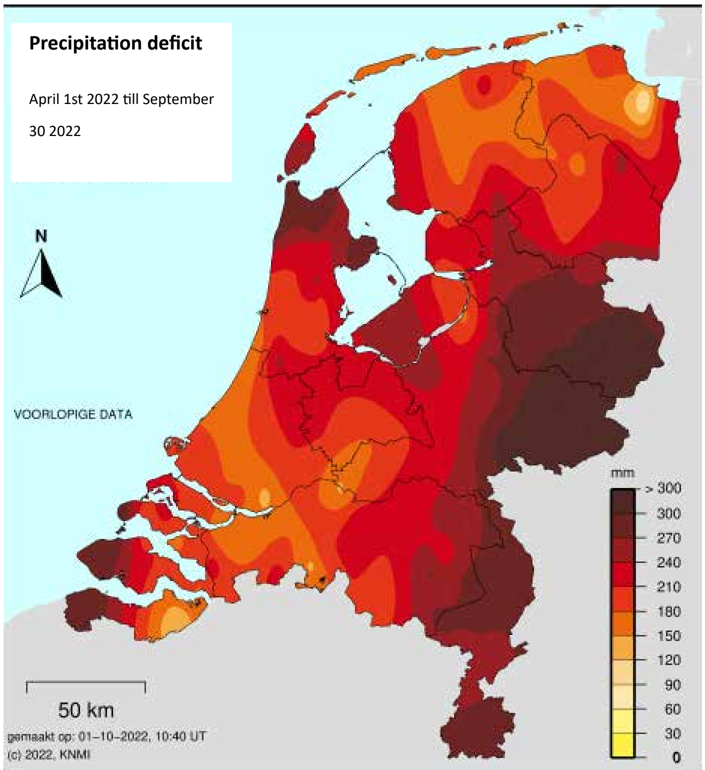


Figure 2: Map of precipitation deficit (KNMI, 2022)

EFFECTS ON HIGH SANDY SOILS

Two-thirds of the Dutch forests, 25.000 ha, are located at high sandy soils. Here, problems from climate change, drought, monotonous structure, and acidification reinforce each other (see figures 3 and 4) (Ministerie van LNV, 2020).

Monotonous plots with spruce trees are a vulnerability of Dutch forests because the harmful effects of droughts severely impact them. Widespread tree death within these monotonous plots is expected (Ministerie van LNV, 2020). Furthermore, the depleted soils and little specie richness decrease the opportunity for the forest to develop a new resilient system in case of severe decline. Subsequently, natural reorganization of the forest system is undesirable due to the important social function of forests in the Netherlands. Natural reorganization first leads to severe forest degradation before a new stable forest is developed (En et al., 2022).

The tree species at high sandy soils are well adapted to no contact with groundwater and dependency on precipitation. However, the prolonged periods of drought due to climate change, on top of the dependence on precipitation, are problematic. Especially since the forests at high sandy soils have to deal with extremely depleted soils, resulting in little water-retaining capacity.

The monotonous plots of spruce trees evapotranspirate year-round more than deciduous trees, leading to less infiltration of water into the soil. Contributing to the loss of seepage flow towards valuable wet nature areas. On top of the increased evapotranspiration and decreased infiltration (Ministerie van LNV, 2020), agricultural interventions, further down the hydrological system, also negatively enlarge the water deficit at the high sandy soils. Intensive drainage of agricultural fields suppresses seepage flows and results in droughts in natural areas (Jeuken et al., 2021). These circumstances reduce the natural functioning of the hydrological system. At the same time, the improvement of the hydrological system is an opportunity to increase the resilience of the forest system (Hydrologics, 2021).

Finally, external factors of acidification and eutrophication deteriorate growing circumstances (Ministerie van LNV, 2020), increasing vulnerability to diseases and biodiversity loss. Losing a tree species due to illness has a more profound impact on monotonous forests.

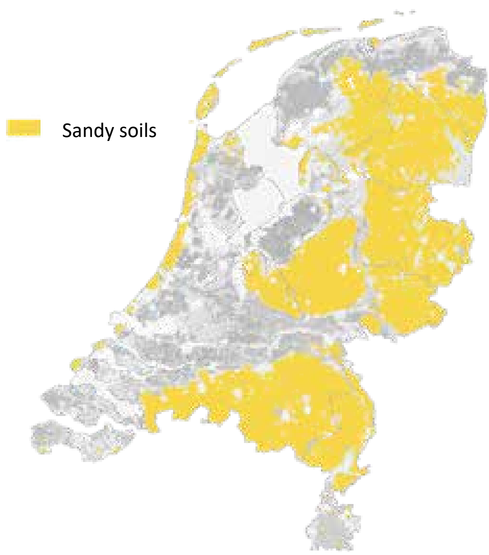


Figure 3: Sandy soils in the Netherlands by author, based on (WUR, n.d.)

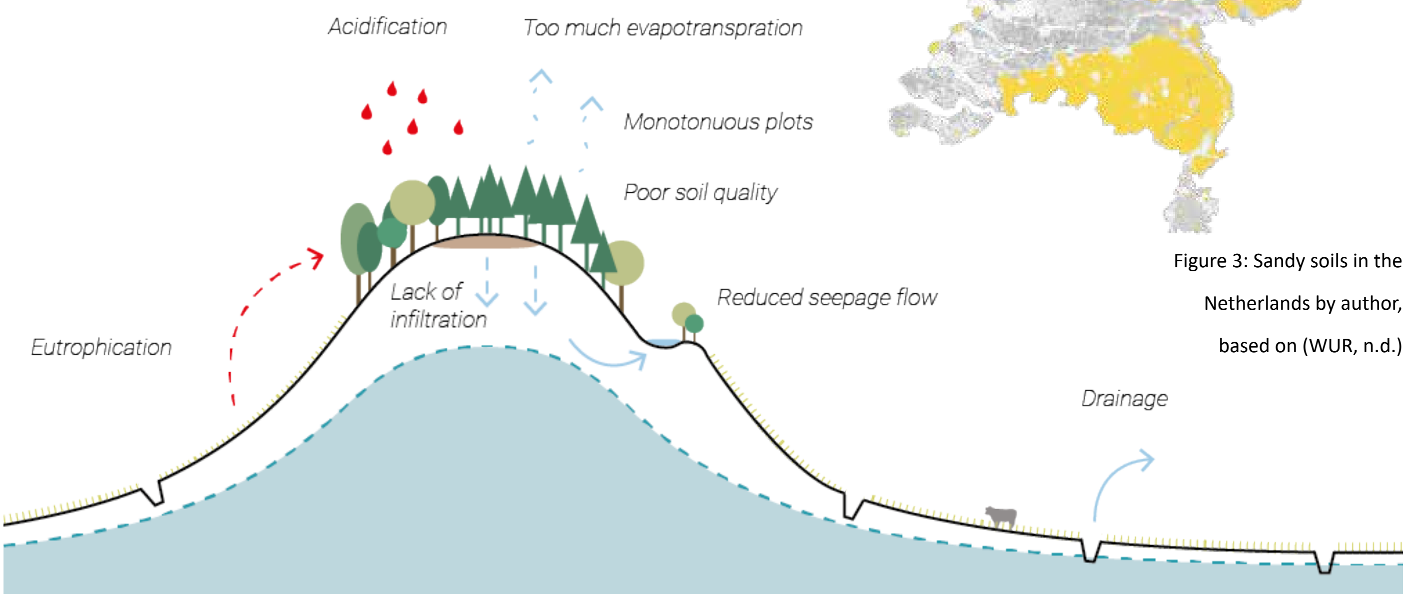


Figure 4: Section of problems at high sandy soils (Author, 2022)

RESILIENCE

This research focuses on the concept of resilience in relation to forests at high sandy soils. The definition of resilience is described best as the capacity of a system to absorb disturbances without collapsing (Allen & Holling, 2008)

A resilient system is characterized by its ability to adapt to changing circumstances. It is a dynamic system that is flexible to change over time and can deal with uncertainties. Disturbances are not considered a vulnerability but an integral element of the system and an incentive to change and adapt (Allen & Holling, 2008).

As described in the problem statement, the forests at the high sandy soils are facing multiple problems. The concept of resilience guides us to understand the patterns and processes with a system perspective.

FOREST LANDSCAPES

The forest structures within the Netherlands can be seen as static protected natural structures. However, the Dutch forest landscape is severely altered by human activities. Furthermore, the forest itself is ever-developing, whether it is forest succession, seasonal transformation, or overcoming a wind storm.

There is an interplay between natural variability and human interference. On the one hand, we should interfere less with the natural structure enabling the forest to find its balance and natural variability. Retaining the forest structure as it is by protecting nature minimizes the natural development and variability in the forest increases its vulnerability to disturbances (Bell & Apostol, 2008). On the other, conditions have worsened so much that the forest is moving towards a collapse. Only human interference can improve the conditions fore the forest in such a way that the forest can find its balance again.

1.2 KNOWLEDGE GAP

The forests at high sandy soils face ecological and hydrological problems stretching further than the natural boundaries of the forest. Therefore, spatial design can have an significant role in integrating the interventions into the landscape.

In the hydrological expertise, research has formulated interventions for the hydrological system at high sandy soils (Hydrologic, 2021; Jeuken et al., 2021). In the ecological expertise, interventions in the Dutch forest at high sandy soils have started to develop with policy documents and recommendations (Ministerie van LNV, 2020). Both ecological and hydrological expertises discuss the relevance of the adaptability of the system. However, this only focuses on their research subject and does not consider in the broader scope of the landscape.

Resilience is a concept that considers the landscape scope, integrating complex hydrological and ecological processes. Research on resilience thinking for forest landscapes can be found in other countries, such as the Scandinavian countries with a large share of forests (Rist & Moen, 2013). However, research in the context of the forest at high sandy soils in the Netherlands barely exists.

Therefore, this research couples the ecological and hydrological interventions present for forests at the high sandy soils with the resilience concept to integrate the complex processes into the landscape. The outcome will be design guidelines for drought resilient forests at high sandy soils.

1.3 CASE STUDY AREA

The case study area for this research is the southern part of the Utrechtse Heuvelrug. Together with the Veluwe, the Utrechtse Heuvelrug represents one of the largest continuous forest structures in the Netherlands (see figure 5). The area is severely impacted by drought problems (Hydrologic, 2021).

Figure 5: The Utrechtse heuvelrug and the Veluwe (Author, 2022)

The Utrechtse Heuvelrug has a significant height difference, with 69 m above NAP (Nederlands Amsterdams Peil) at the Amerongse berg as the highest point and around 2,5 m above NAP at the low-lying agricultural fields. The structure of the forest itself is dense. Agricultural fields surround the forest. Villages are located close to the forest edge (see figure 6).

Recently, the province has published its forest policy (En et al., 2022) based on the National forest vision (Ministerie van LNV, 2020), stretching the importance of the preservation of the forest and strengthening its qualities to anticipate on future challenges.

This case study represents the situation of forests at high sandy soils in the Netherlands and is a suitable location to test and apply drought resilient guidelines.

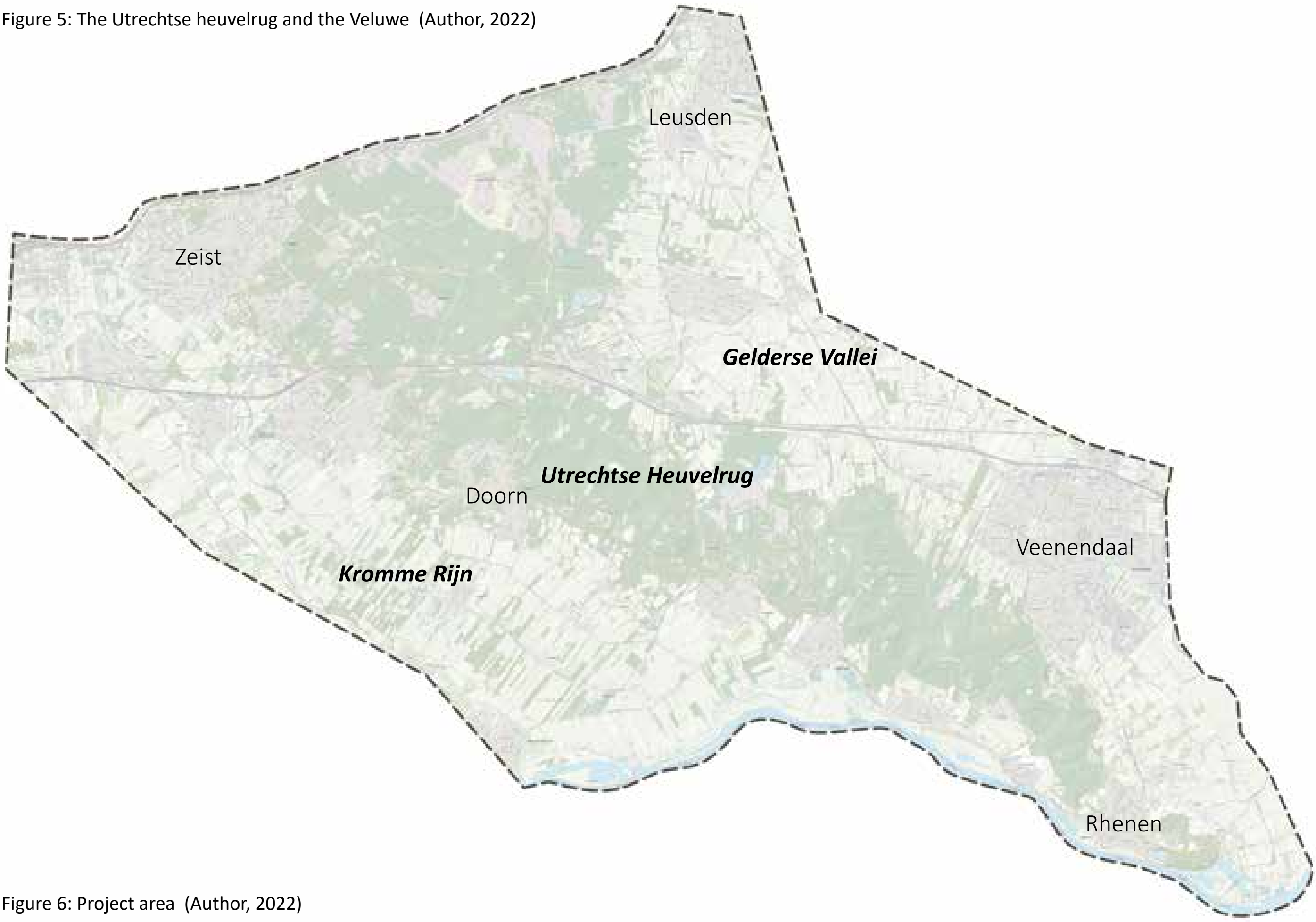


Figure 6: Project area (Author, 2022)

1.4 THESIS STATEMENT

This research aims to develop and apply design guidelines to the forest at the Utrechtse Heuvelrug that increase drought resilience of forests.

The objective of this research is accomplished by answering the following research question:

Design Question:

Which design guidelines enlarge forest drought resilience at high sandy soils?

The formulated sub-research questions will answer the design questions. The outcome of each question contributes to the development and application of resilient design guidelines for the forests at the Utrechtse Heuvelrug.

SRQ 1:

What spatial characteristics define a resilient forest system?

SRQ 2:

How does a forest ecosystem at high sandy soils function?

SRQ 3:

What is the effect of resilient guidelines to drought resilience of forests at high sandy soils?

2. METHODOLOGY

This chapter describes the used methodology and methods. First, the methodology approach will be explained by discussing the interplay between landscape ecology and design. Second, the research structure is explained with research for design (RFD) and research through design (RTD) as guiding methodology. Third, the used methods are described, leading to answering the research questions.

2.1 METHODOLOGY

APPROACH

The starting point for the methodology of this research is the search for integration of hydrological and ecological processes within landscape architecture. The configuration of a landscape is the result of these processes. However, landscape structure changes simultaneously impact the hydrological and ecological processes.

Ahern (2005) explains the complex relation between landscape ecology and landscape architecture. He defined three stages emphasizing the reciprocal nature of landscape design and ecology (see figure 7). In the first stage, landscape ecology informs landscape architecture with theories and principles. Once this knowledge is implemented in a design, new questions about landscape ecology are generated in stage two (Ahern, 2005).

Within the third stage, landscape ecology informs landscape architecture with knowledge, and landscape architecture informs landscape ecology with design. This reciprocal dialogue is an ongoing process and ever-improving (Ahern, 2005).

Uncertainties are part of ecology and landscape architecture. However, Ahern (2005) uses uncertainties as a strength to explore the multiple possibilities with landscape design. Uncertainties and the complexity of different scales are an integral element of landscape design.

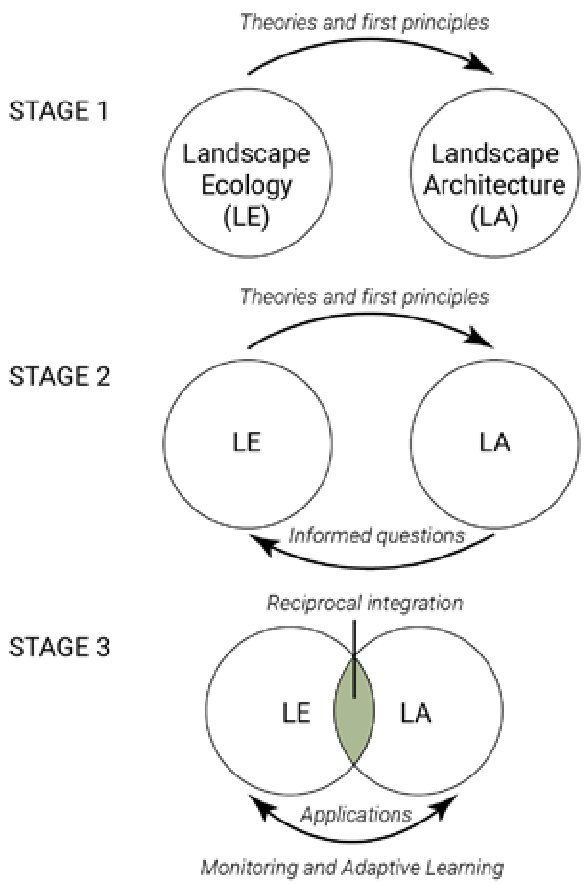


Figure 7: The three stages for the intergration of LE into LA (Ahern, 2005)

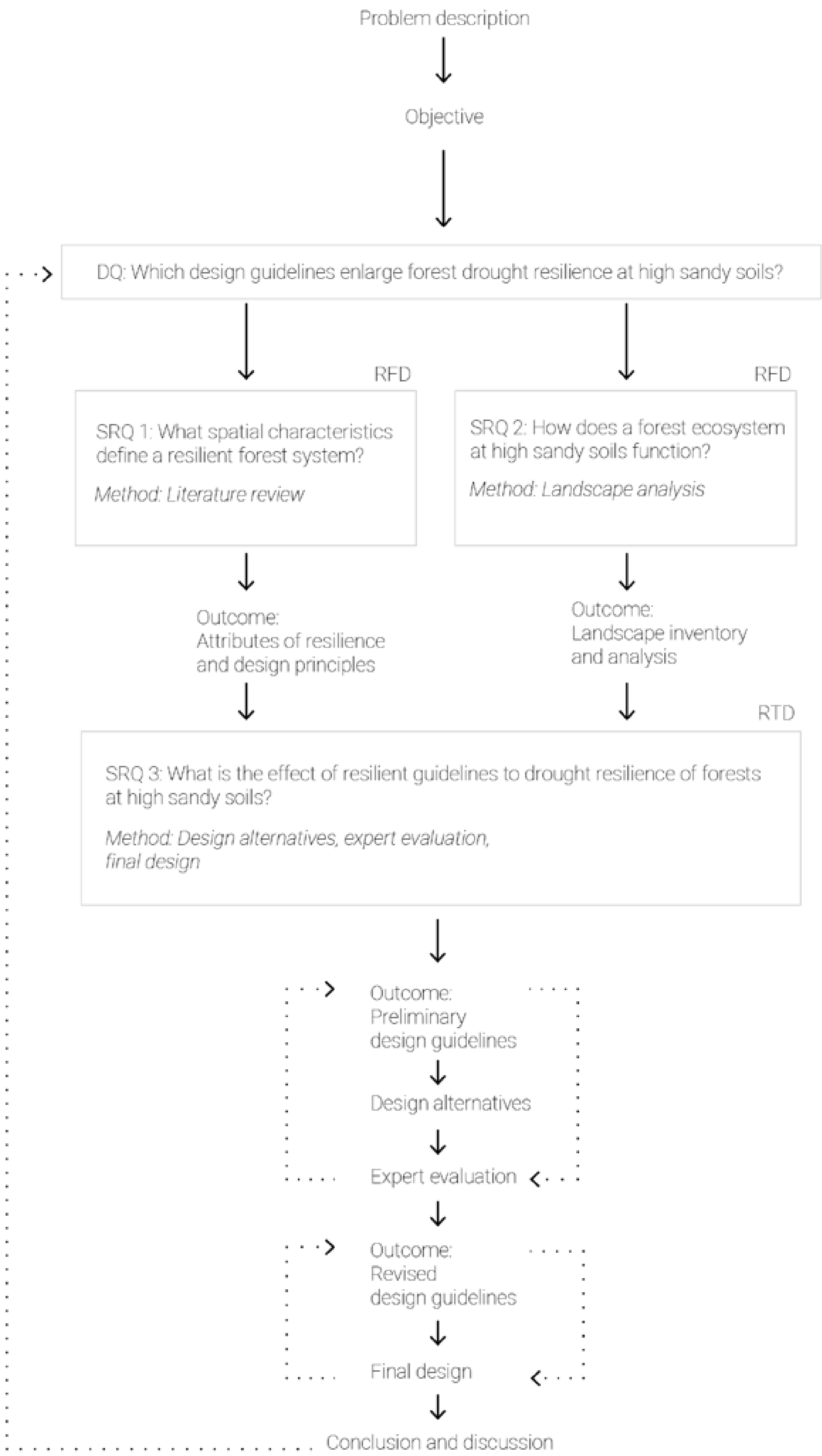


Figure 8: The methodological framework for this research (Author, 2022)

RESEARCH FOR DESIGN AND RESEARCH THROUGH DESIGN

Regarding the complex relation between natural processes and landscape architecture, research for design and research through design (van den Brink et al., 2016) are the chosen methodology for this research to answer the design question (see figure 8):

MRQ: *Which design guidelines enlarge forest drought resilience at high sandy soils?*

Research for design (RFD) is applied for SRQ 1 and SRQ 2. RFD generates knowledge that is substantiative to the design (van den Brink et al., 2016). For this thesis, knowledge of forest resilience and systems will inform the design.

Research through design (RTD) will take place in SRQ 3. RTD generates new knowledge by designing (van den Brink et al., 2016). The generated knowledge from SRQ 1 and SRQ 2 serves as a theoretical fundament for the design to build upon.

Within RTD, two iterations take place. The first iteration starts with a preliminary set of design guidelines based on the spatial principles and outcome of the landscape analysis. Subsequently, these preliminary design guidelines are applied to three design alternatives. Finally, the design alternatives and preliminary design guidelines, are evaluated by experts.

The second iteration is the final design, revising the design guidelines for drought resilient forests at high sandy soils. The final design integrates the advantages of each design alternative based on the expert evaluation.

2.2 METHODS

To answer the research questions, the following methods are used:

2.2.1 LITERATURE REVIEW

To generate drought resilient design guidelines, the first step is to create a profound understanding of the concept of resilience. In this understanding, both ecological and landscape architectural characteristics should be considered, leading to the first sub-research question;

SRQ1: *What spatial characteristics define a resilient forest system?*

The literature review will generate the knowledge needed to answer this question. It is a research for design method where the gathered knowledge informs the design process and leads to informed design decisions (van den Brink et al., 2016).

The concept of resilience can be applied in many fields of study. For this research, the ecological perspective is chosen, considering the landscape as a system that can absorb and adapt. The definition of resilience and its spatial applications are studied.

Various research documents are reviewed both from a more technical perspective and interpretative perspective. The technical perspective helps to understand the complexity of the concept. The interpretative perspective helps to translate the more technical perspective into spatial interpretations.

The final result of the literature review is the attributes of resilience expressing the characteristics relevant for this research and spatial principles illustrating the spatial implications of the resilient characteristics.

2.2.2 LANDSCAPE ANALYSIS

To apply spatial resilient principles, the current landscape needs to be understood. The landscape analysis generates information and an understanding of the current landscape using RFD to inform the design process. From a resilient perspective, the landscape is considered a system with patterns and processes. Therefore, the following sub-research question is formulated:

SRQ 2: *How does a forest system at high sandy soils function?*

The landscape analysis is a method to generate a profound understanding of the landscape pattern and its processes. Here the landscape is considered from different layers or perspectives. The landscape analysis is focused on elements relevant to the concept of resilience.

The hydrological system is considered the most important process regarding drought resilient forests. For the pattern, the most occurring land cover is considered; natural structures, agricultural fields, and villages. Finally, the interdependent relationship between land cover and process is evaluated, resulting in an overview of problems and opportunities to design with.

The landscape analysis considers a regional scale because the hydrological processes influencing the forest system take place at a regional level, beyond the boundaries of the forest itself.

2.2.3 DESIGN ALTERNATIVES

The development of the design alternatives, based on a preliminary set of design guidelines, together with the expert judgement, answer sub-research question three:

SRQ 3: *What is the effect of resilient guidelines to drought resilience of forests at high sandy soils?*

With this sub-research question, the first design iteration takes place. Every design iteration tests a range of design guidelines and generates new knowledge questions and design outcomes (A. van den Brink et al., 2016)

In the design alternatives, a preliminary set of design guidelines is applied to three design alternatives. The knowledge and information gathered with SRQ 1 and SRQ 2 are the foundation for the integration of the design guidelines.

The preliminary design guidelines are not listed individually but integrated into the design alternatives discussing their strengths and weaknesses.

The development of design alternatives is a research through design (RTD) approach where design is used to research the effect of the formulated design guidelines. By formulating three design alternatives, the most suitable way to implement the design guidelines for the case study area is evaluated.

2.2.4 EXPERT EVALUATION

For the evaluation of the design alternatives, an expert meeting was organized to generate feedback from multiple disciplines. Based on the meeting and given feedback, informed decisions were made for the last iteration of the final design.

Experts from the field of both hydrology and ecology were consulted. Two meetings of about one hour took place, one with two hydrology experts and one with an ecology expert.

The meeting consisted of a presentation about the research on resilience, landscape analysis, and design alternatives. After this presentation, a discussion of the three alternatives took place. The feedback from the experts was used to select preferred design guidelines and guide the integration of the design guidelines. The outcome of the meetings is summarized in the expert evaluation of Chapter 5.

2.2.5 FINAL DESIGN

In the final design, the revised design guidelines are applied to the project area, answering the main design question:

Which design guidelines enlarge forest drought resilience at high sandy soils?

This is the second iteration in the research through design process. The outcome of the design alternatives and expert evaluation resulted in the revised design guidelines. The final design (1:25000) shows the relation of the applied guidelines with the landscape. The detailed sections show the spatial implications of the design guidelines.

3. THEORETICAL FRAMEWORK

In this chapter, the concept of resilience will be discussed. First, the general definition will be described. Second, the system perspective and applicability to forest systems are explained. Lastly, the spatial characteristics of resilience are specified, and spatial principles are defined.

3.1 RESILIENCE

Resilience is defined as the capacity to absorb disturbance without the collapse of a system (Holling, 1986). It can be illustrated as a ball in a cup (figure 9). Within the cup, stability domain, the ball is able to move. Disturbances push the ball out of its equilibrium. If the ball tips over the threshold, it rolls into a new stability domain. With a flat cup, the ball will quickly hit the threshold, and little variety is possible. Within a resilient system, the cup is deep and much variety is possible before hitting the tipping point (Holling, 1986).

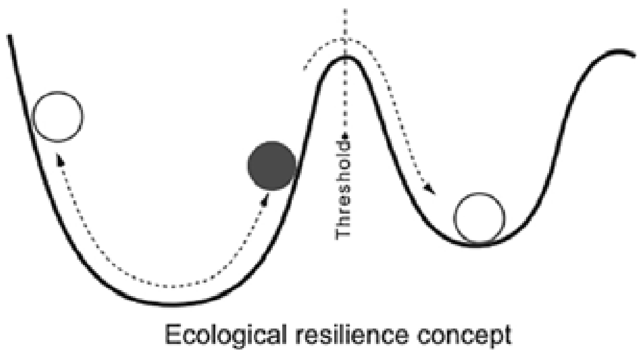


Figure 9: Ball-cup diagram based on Holling (1986) (Keane et al., 2018)

ADAPTIVE CYLE

Allen & Holling (2008) structure resilience through the concept of panarchy. Panarchies describe flexible stages of socio-ecological systems (Figure 10). Within panarchies, a system is considered flexible and changes through time - the adaptive cycle. The adaptive cycle show a system's stages: exploitation, conservation, release, and reorganization. A system's collapse is not considered a failure but a natural state of the system's cycle (Holling, 1986).

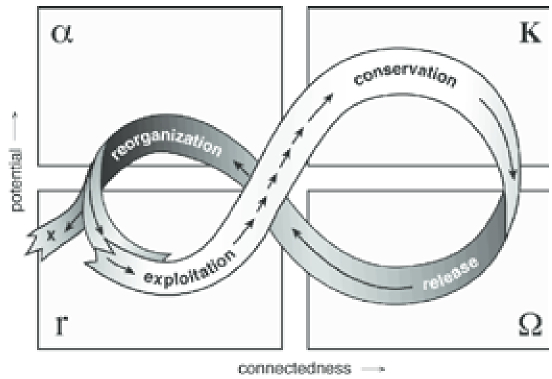


Figure 10: The adaptive cycle (Schoon & van der Leeuw, 2015)

Panarchies differentiate due to space and time elements. The bigger scale of a variable, the slower changes in the process take place (Figure 11). A smaller scale has a faster time cycle. With scale and time elements, the variables are positioned in a hierarchy where one cycle influences the other (Allen and Holling, 2008).

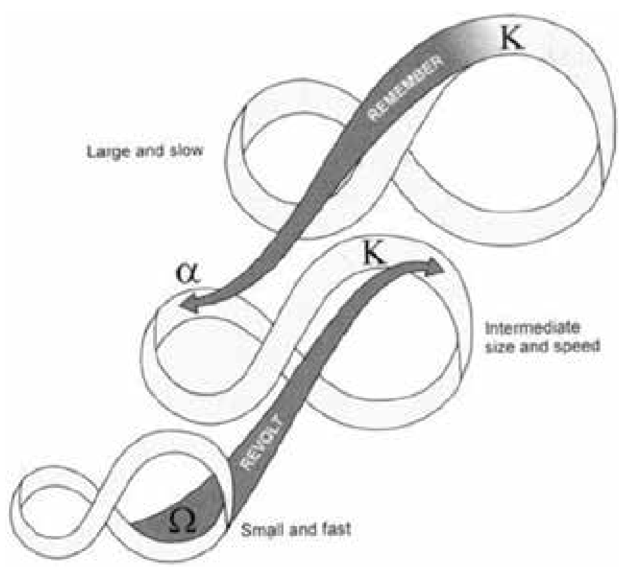


Figure 11: Scale and time dimensions (Sundstrom & Allen, 2019)

DISCOURSES

Regarding the discourse of resilience, two main visions exist on the stability domain (Folke et al., 2004). The more technical or economic approach is engineering resilience, where a system always returns to its stability domain. On the other hand, multiple stability domains are possible for ecological resilience as long as the system can adapt to them. Here the collapse of a system is not seen as a failure, but rather an opportunity to adapt to a more suitable and resilient situation (Holling, 1996).

Within socio-ecological systems, resilience is not only constructed by ecological characteristics but also by human activities. Human activities stress the ecological system, top-down disturbances, and can push the system over its tipping point into a new stability domain (Folke, 2006). At the same time, society relies on the services ecosystems provide. For a long time, the ecosystem was considered a static phenomenon and changes could be controlled to generate the best services for society. Until human activities pushed the system towards its tipping point and society's stress on ecosystems became visible.

DISTURBANCE REGIME

Besides top-down anthropological disturbances, bottom-up impacts are also putting stress on the system. Unlike top-down anthropological disturbances, bottom-up disturbances face more difficulty returning to the stability domain. Disturbances due to climate change cause such a fundamental change in conditions that the disturbance regime is altered and a new equilibrium needs to be found (Folke, 2006; Seidl et al., 2016).

The fundamental change in bottom-up disturbances due to climate change combined with the stress of anthropological disturbances resulted in a perspective shift on resilience from controlling change to return to a static state into coping with and adapting to the expected changes that belong to socio-ecological systems (Allen et al., 2016). However, research on the resilience of socio-ecological systems is complex and still in the explorative phase (Folke, 2006).

THE FOREST SYSTEM

In the socio-ecological system (later referred to as 'system') of forests, the anthropological disturbances combined with climate change push the system towards a tipping point (Nikinmaa et al., 2020; Seidl et al., 2016). The management of forests for several purposes, such as harvesting, has diminished the variability of forest systems and, therefore, its ability to respond to disturbances. Controlling forest systems for socioeconomic interest suppressed the natural disturbances a forest system experienced, decreasing natural variation. Finally, Change in precipitation due to climate change affects the current characteristics of forest systems, leading to a regime shift (Seidl et al., 2016).

Completely adapting to the regime shift could ecologically result in the most resilient situation for forests. However, sociologically this approach would not be desirable. Such a regime shift could take decades and could possible not provide societal services (Seidl et al., 2016). While the second most important function of forests in the Netherlands, besides ecological services, is the recreational function (Ministerie van LNV, 2020). Forests are just as much part of ecosystems as society. Therefore resilient forests should maximize the adaptive capacity of the forest system while being congruent with the social system.

The concept of resilience helps to understand system changes. However, the mechanisms, feedback loops, and processes involved in forest system resilience are complex and difficult to understand (Reyer et al., 2015). Therefore more research on the effect of system change on resilience is needed.

FOREST AESTHETICS

'Ecology and aesthetics are related, but they are not necessarily mutually dependent' ((Bell & Apostol, 2008)p. 71)

Appreciating landscapes and forests is an intuitive process (Ribe, 1989). Bell & Apostol (2008) describe the landscape as a 'prospect of scenery' with which they argue it is both physical and experiential. The physical element of landscape is about the configuration of spatial components, which can be appreciated as beautiful. The experiential aspect of the landscape is about our interaction with the landscape; smell, hear, touch, the memories. We are not merely an observer of the landscape but constantly interact with it. Research shows that aesthetic quality is complicated to measure due to its subjectivity (Bell & Apostol, 2008; Daniel & Boster, 1976). But it mostly ends up somewhere in the middle; not too much, not too few trees, openness, light, understory, et cetera. Characteristics of how we appreciate and try to make sense of a landscape are mostly related to; coherence, legibility, readability, and mystery (Bell & Apostol, 2008).

In this research the aesthetic quality of the forest is an integral part of the design decisions. However, it is not considered an element to be evaluated regarding the resilience of the system.

3.2 ATTRIBUTES OF RESILIENCE

To develop design principles, spatial attributes are formulated, representing the characteristics of resilience. Spatial attributes regarding resilience are informed by knowledge of general resilience, considering ecological and socio-ecological resilience (Chambers et al., 2019). The literature addresses multiple attributes with different time and scale dimensions. This thesis will focus on the spatial implications of resilience for forest systems, resulting in the following attributes.

CONNECTIVITY

Connectivity within a landscape is defined by the ability of species and flows to move through the landscape (Chambers et al., 2019). A well-connected landscape can respond faster to a disturbance. This connectivity is not merely about physical connection but mainly the connection of processes through the landscape (Cumming, 2011). Too much connectivity makes a system vulnerable to disturbances such as wildfires. While too little connectivity, such as anthropogenically fragmented landscapes, decrease the ability of a system to respond to disturbance (Allen et al., 2016). Connected landscapes have ecological benefits by enabling species to move through the landscape among different habitats. In this research, the focus of connectivity will be on the movement of fauna, continuation of processes, and connected patterns.

DIVERSITY

Diversity in socio-ecological systems is referred to as 'biological diversity', 'response diversity', or 'functional diversity'. Functional will be discussed at the attribute of redundancy. Response diversity and biological diversity are focused on the ecological characteristics of the system regarding the species and biodiversity. Biodiversity is fundamental to resilient ecosystems. Biodiversity creates landscape diversity by differentiation in the spatial component of a landscape. Fauna species and related habitats are indicators for biodiversity in a landscape (Cumming, 2011).

Vice versa, a diversity in geospatial characteristics results in a diverse landscape with diverse species and biodiversity (Allen et al., 2016). A diverse landscape is an indication of resilient systems representing both geospatial and ecological diversification (Cumming, 2011).

VARIABILITY

Variability represents the flexible stages a system naturally moves through when facing disturbances. The ability of a system to absorb dynamic processes and regular disturbances deepens the cup of the system (Allen et al., 2016). For spatial variability, it is important to understand the patterns and processes constructing the natural changes in a landscape. Creating space for processes to happen requires flexibility within landscape patterns.

Variability is increased by a well-connected landscape, high diversity, and adaptation to the environmental circumstances of the landscape (Chambers et al., 2019).

REDUNDANCY

Redundancy is about a 'safe to fail' system. When one response is not functioning and breaks down by a disturbance, another response can take over. Concepts in the literature that describe the same phenomenon are 'functional diversity' or 'functional redundancy'.

Functional diversity is defined as the diversity of responses among species to carry out the same ecosystem function (Chambers et al., 2019). The other definition is functional redundancy, which is the number of species that perform the same function (Folke et al., 2004). The diversity of responses and the number of species is an ecological phenomenon that is too complex to study within this system oriented landscape research. However, some landscape characteristics can represent the complex underlying redundancy within a system. In this research, the focus of redundancy will be on small-scale diversity in habitats for fauna species and the number of habitats available for fauna species. Resulting in a flexible landscape that facilitates multiple options.

Redundancy requires diversity to establish multiple ways to perform the same function. Offering a variety of responses increases variability by strengthening the ability of a system to respond to disturbances (Cumming, 2011).

3.3 CONCEPTUAL FRAMEWORK

The conceptual framework of the described theory organizes the theory and integrates it into the design steps of this research (see figure 12).

The theoretical lens highlights the relevant information within the landscape for the landscape analysis. The landscape's abiotic, biotic and cultural patterns and processes are analyzed to generate a profound understanding of the forest system. Analyzing the disturbance regime generates insight into the forest system's problems and opportunities. Eventually, the landscape analysis informs the creation of the design alternatives.

The attributes of resilience inform the development of design principles, leading to the formulation of the preliminary design guidelines. The design guidelines are applied to three design alternatives, resulting in revised design guidelines. The revised design guidelines are incorporated in the final design. Subsequently, the feedback loops inform and evaluate the design steps.

This approach generates a holistic understanding of the landscape and its weaknesses based on which potential design guidelines can be formulated to increase resilience.

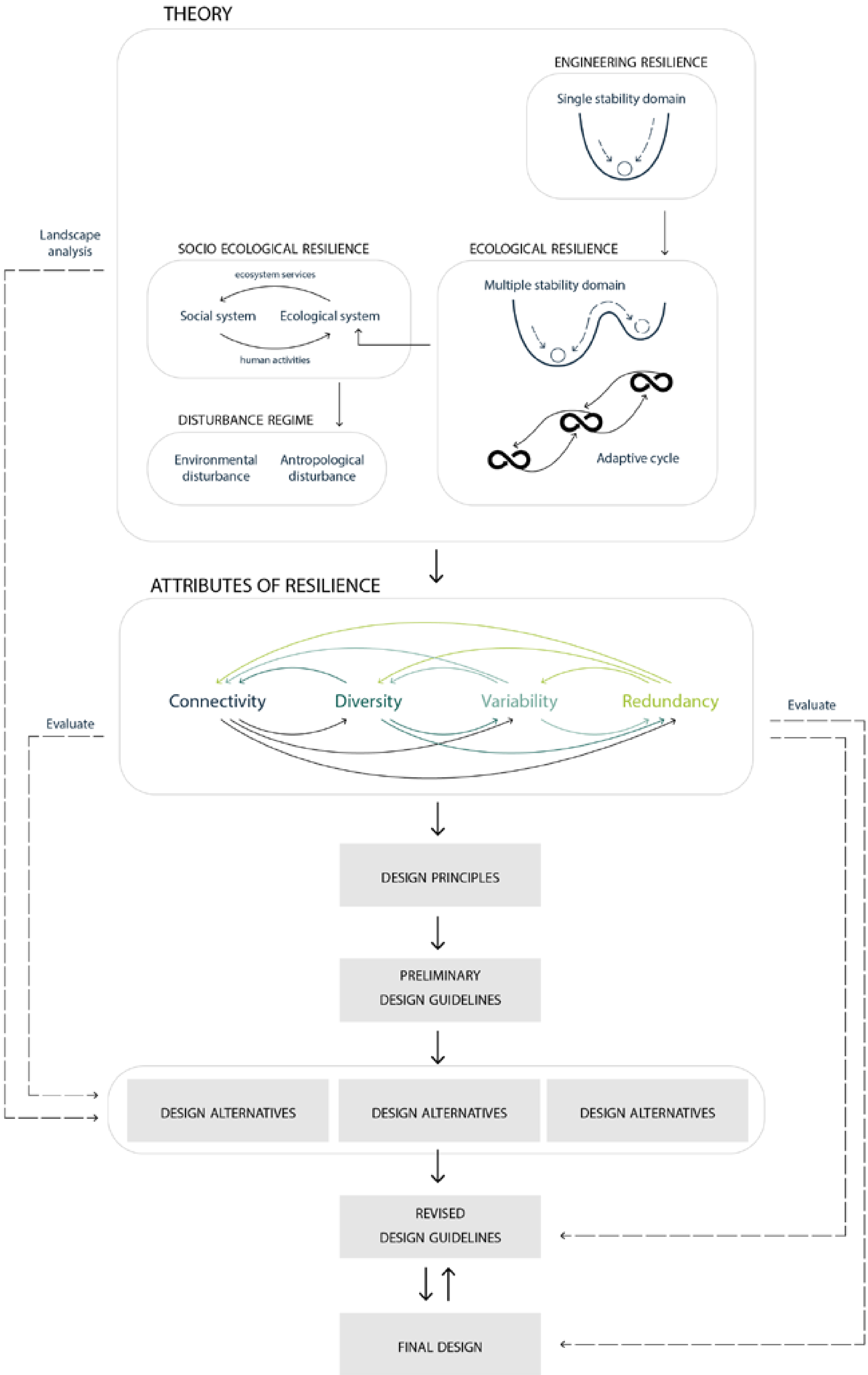


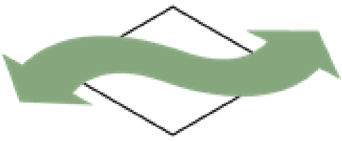
Figure 12: Conceptual framework (Author, 2022)

3.4 SPATIAL DESIGN PRINCIPLES

The spatial design principles translate the attributes of resilience into principles for a forest system. The spatial principles are the foundation on which the design guidelines will be established. For the formulation of the design principles, two types of literature are used, scientific articles and policy documents.

The principles are structured through the attributes of resilience. Connectivity considers the ability of fauna to move through the landscape. Diversity is about both biodiversity and forest diversity. Variability enables the forest system to absorb disturbances. Lastly, redundancy is about the abundance within the system.

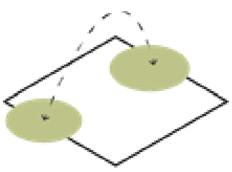
CONNECTIVITY



1. CORRIDORS

Corridors are continuous structures of land cover that enable fauna species to move through the landscape. Corridors offer a physical continuity for species that cannot transfer by stepping stones, like mammals, reptiles, and small insects.

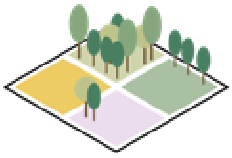
Compared with a buffer, the goal of a corridor is to move species through the landscape, while a buffer protects the existing landscape as a shield. Compared to an edge, the corridor is broader and more continuous in structure (Cumming, 2011).



2. STEPPING STONES

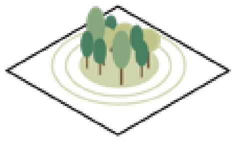
Stepping stones are patches of landcover that can be used for fauna species to move through the landscape. The type of fauna specie defines the proximity and size of the stepping stones, birds can cover a larger distance than insects (Cumming, 2011).

DIVERSITY



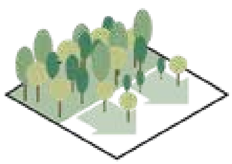
3. MOSAIC LANDSCAPE

A mosaic landscape is a landscape-oriented definition focused on the spatial configuration of patches. A mosaic landscape is constructed out of different patch types. The patches are a representation of processes going on in the landscape (Bell & Apostol, 2008). For this research, hydrological and ecological diverse patches represent the diversity of the mosaic landscape. A mosaic landscape represents a diverse landscape.



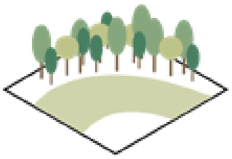
4. PRESERVE EXISTING FOREST

Existing forests host a diversity of species, rich soil composition and are historically adapted to the local circumstances (Wildschut et al., 2004). It takes a long period of succession for a forest to reach a stabilized state, especially in the Netherlands, where the general age of forests is low (Oldenburger et al., 2021). A healthy and stabilized forest contains a diversity of habitats like death wood or rotten trees. This unique forest diversity is a habitat for characteristics species of mushrooms and lichen, but also specific types of fauna like pine marten, bat and the woodpecker (Wildschut et al., 2004).



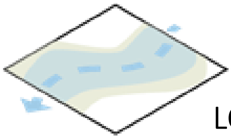
5. FOREST EDGE

Forest edges are gradual transitions from the forest patch into another land cover such as agriculture or grassland. A forest edge has specific environmental conditions which contribute to biodiversity. Birds, bats, and butterflies find shelter and food within the diversity a forest edge entails. Moreover, forest edges can be used as corridors to connect forest areas and increase variation within mosaic landscapes (Nijssen et al., 2021)



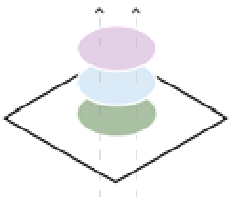
6. BUFFER ZONE

The buffer zone contains multiple objectives and uses that contribute to variability. First, the buffer zone creates a gradual transition from a natural landcover, such as the forest, to a non-natural landcover, such as agriculture or villages. Second, the buffer zone allows disturbances to be absorbed, such as flooding. Third, a buffer zone can be used to connect natural areas. The buffer zone can have multiple types of land cover. From more natural with heathland and natural grassland to more agricultural with extensive or wet agriculture (Nijssen et al., 2021).



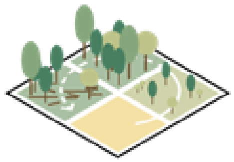
7. ADAPTED TO LOCAL CIRCUMSTANCES

This principle is based on 'form follows function'. The landcover is inherently connected and defined by the flows moving through it. With the effects of climate change, the future flows through the landscape change and the landcover should be adjusted to these changes even so. Because a landcover that fits the local circumstances is less vulnerable and, therefore, better capable of absorbing disturbances (Bell & Apostol, 2008).



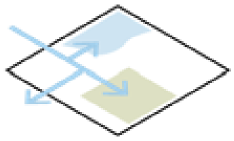
8. FLEXIBLE POCKETS

The flexible pockets are related to the buffer zones by creating space for disturbances to be absorbed (Bell & Apostol, 2008). However, these flexible pockets focus on the landscape flow and the expected problem areas. The pockets anticipate on temporal changes regarding seasonal or yearly fluctuations.



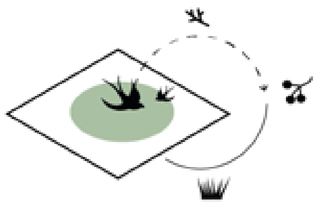
9. MULTIPLE SUCCESSION STAGES

Multiple succession stages are based on the natural process of forest growth, from the pioneer stage with grasses to intermediate stages with shrubs and small trees, into the climax stage of a mature forest with shade-tolerant trees. Integrating these various stages in design increases the capacity of a system to recover from disturbance (Bell & Apostol, 2008).



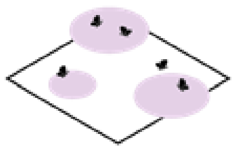
10. MULTIPLE PATHWAYS

Multiple pathways are about the range of responses a system can have facing a disturbance. Within this research, the disturbance of drought due to climate change causes multiple vulnerabilities in the system. Combining opportunities at various scales strengthens the system's vulnerability (Bell & Apostol, 2008).



11. DIVERSITY AMONG HABITATS

Resilience is increased when species have access to multiple types of habitat. The fauna species are less vulnerable when one habitat disappears due to disturbances because there are other habitat options to go to (Chambers et al., 2019).



12. PLURALITY OF HABITATS

Besides the diversity of habitat types, the amount of a particular habitat type present in a system also contributes to redundancy within a system. For example, when a patch of heathland fails due to a disturbance, the species living there suffer from extinction, increasing the system's vulnerability. However, if another patch of heathland is present somewhere else in the system, these species remain within the system (Chambers et al., 2019).

4. LANDSCAPE ANALYSIS

This chapter comprises two parts. The first part is the inventory of the characteristics of the Utrechtse Heuvelrug and its surrounding. The second part analyzes these characteristics and discusses the strengths and weaknesses within the landscape.

4.1 INVENTORY

The inventory describes the genesis, hydrological processes, and ecological structures of the Utrechtse Heuvelrug.

4.1.1 GENESIS

The Utrechtse Heuvelrug was formed in the Saalian, about 15.000 years ago. Glacial ice was covering the North of the Netherlands, pushing forward rocks and soil. When the ice package withdrew, lateral moraines like the Utrechtse Heuvelrug and the Veluwe remained (see figures 13 and 14). With the melting ice, large amounts of material were deposited by water, better known as 'Sandr'. The 'Darthuizerpoort' is the largest Sandr of the Utrechtse heuvelrug (OKRA landschapsarchitecten, 2011).

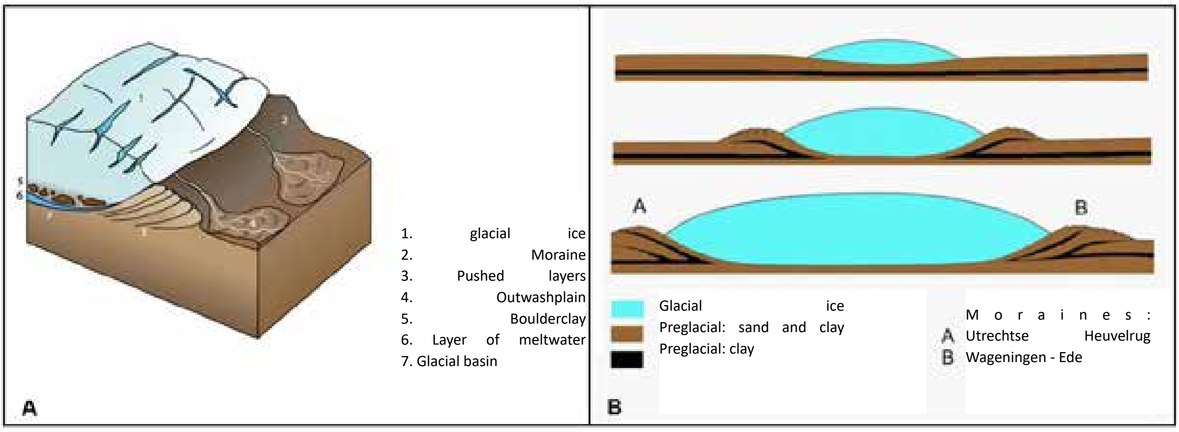


Figure 13: Formation of moraine ridges during the Saalien (van den Brink, 2020)

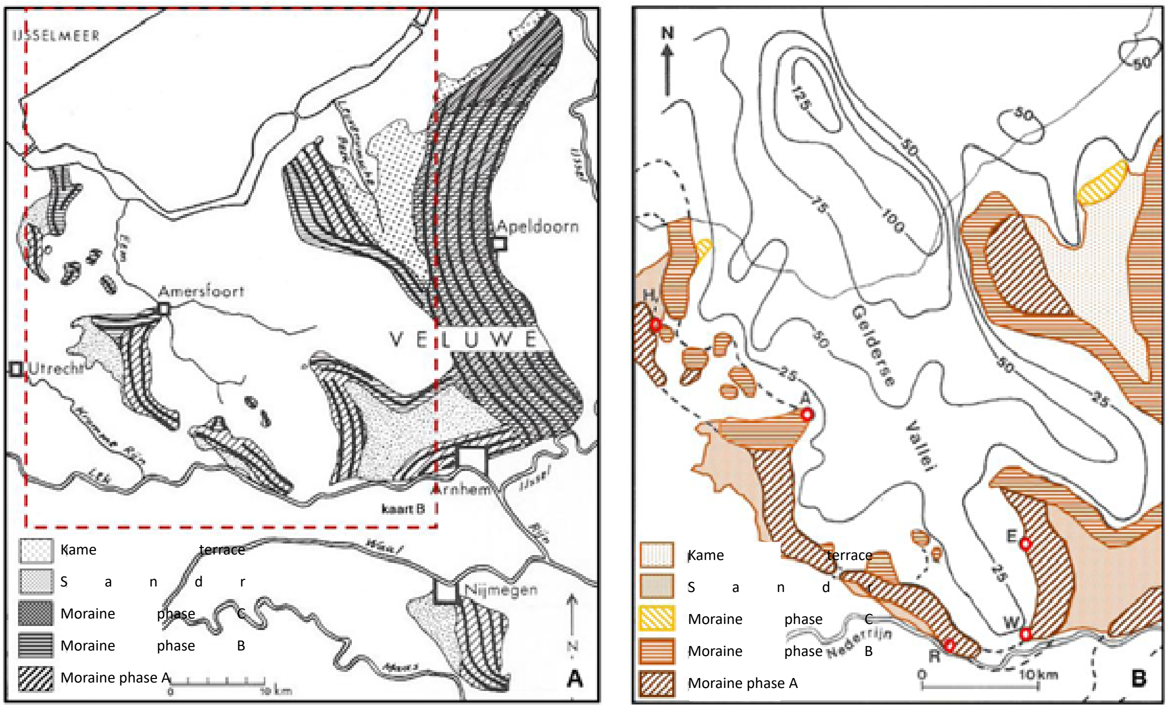


Figure 14: Schematic visualisation of glacial ice pushing the moraines.

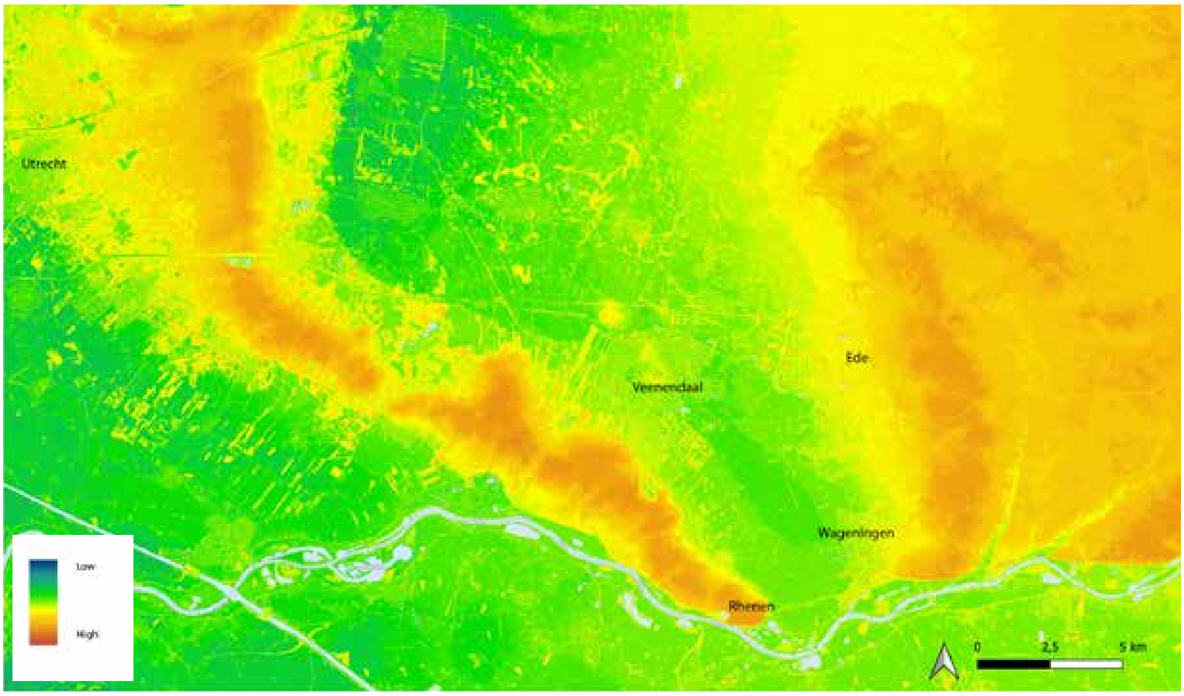


Figure 15: Height map (AHN, n.d.)

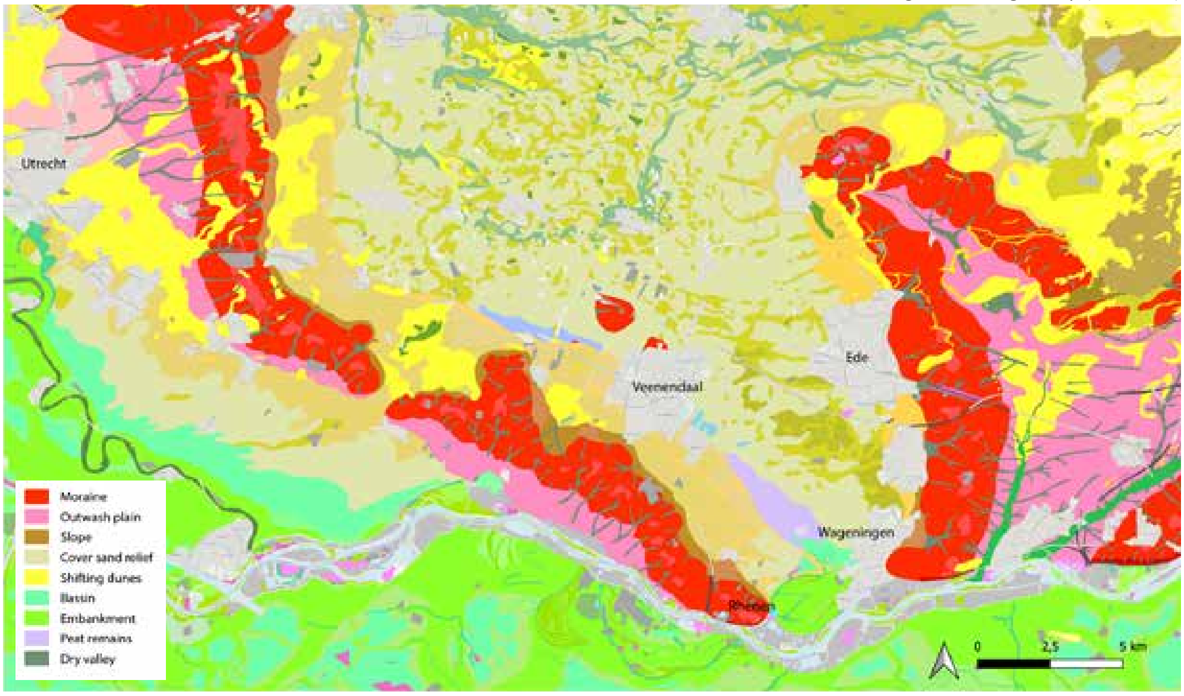


Figure 16: Geomophology map (Kadaster, n.d.)

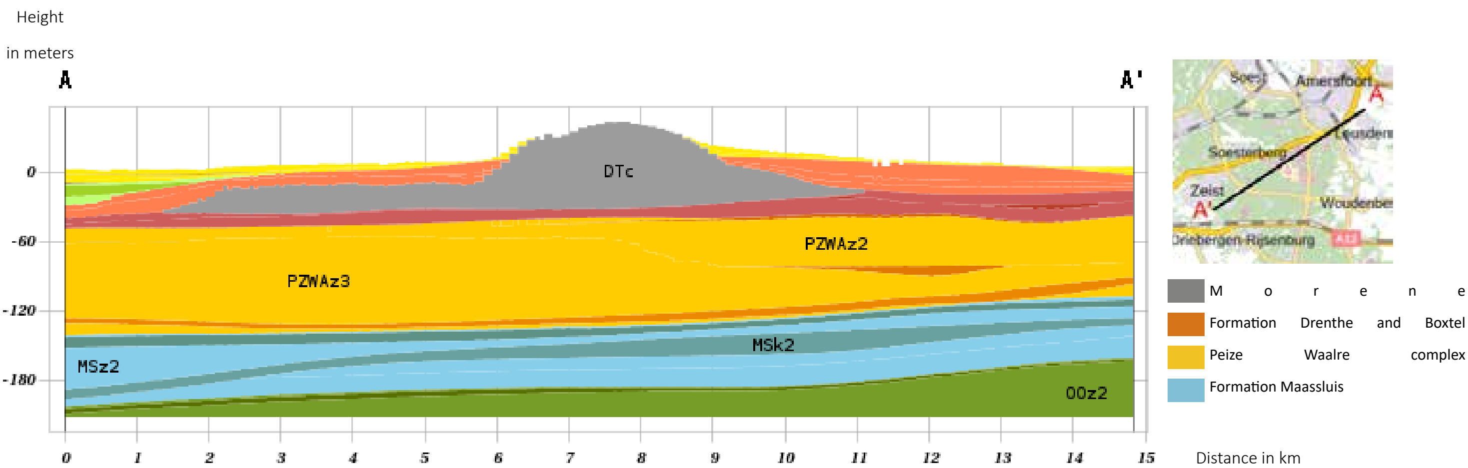


Figure 17: Geomophological section of the Utrechtse Heuvelrug (TNO, 2022)

The second development that shaped the Utrechtse Heuvelrug occurred around the last ice age, 15.000 years ago in the Weichselian. There was no glacial ice this time in the Netherlands but sandstorms covered the Utrechtse Heuvelrug with sand (OKRA landschapsarchitecten, 2011).

The sandy moraine ridge characterizes the structure of the Utrechtse Heuvelrug (see figures 15 and 16). At the slopes of the Utrechtse Heuvelrug a mix of outwash plains, coversand, and dry valleys, the formation of Drenthe and Boxtel, define the landscape (van den Brink, 2020) (see figure 17).

After the ice ages, climatic conditions stabilized, and trees could establish at the Utrechtse Heuvelrug. Nowadays, we refer to these forests as primeval forests (Wildschut et al., 2004). These primeval forests almost completely disappeared around the 17th century due to grazing, sod cutting, and wood chopping. These activities resulted from the settlements at the slopes of the Utrechtse Heuvelrug. Heathland and shifting sands remained (see figure 18) (OKRA landschapsarchitecten, 2011).

Due to overgrazing, the heathland and shifting sands became larger and threatened the adjacent agricultural land. Around the 19th century, heathlands were considered useless, and reforestation increased to hold down the sand and use the trees for wood production. A second incentive for reforestation was establishment of estates around the Utrechtse Heuvelrug. They used the forest for hunting lodges and created sightlines with tree-lines avenues (see figure 19) (OKRA landschapsarchitecten, 2011).

Figure 18: Historical map 1820, heathland and shifting sands (Kadaster, 2022)


Figure 19: Historical map 1940, planted forests (Kadaster, 2022)

4.1.2 HYDROLOGY

Hydrologically the project area can be divided into three zones, each with its characteristic; plateau, slope, and foot (see figure 20).

PLATEAU

The plateau is the highest part of the Utrechtse Heuvelrug, + 8m Normaal Amsterdams Peil (NAP). In this area, the groundwater level lies between 3 and 60 meters below the surface (see figure 21). The groundwater is not available for vegetation, which makes the vegetation dependent on the infiltration of rain water. Rainwater eventually infiltrates into the groundwater. Due to local clay layers in the soil, some fens are present at the plateau. Large parts of the plateau are used for drinking water extraction (see figure 22) (Hydrologic, 2021).

SLOPES

At the slopes, the groundwater level is between 5 and 0 meters below surface. Here, infiltrated water at the plateau surfaces as seepage or springs. The extend of seepage varies due to changes in the seasons. The vegetation at the slopes is dependent on the groundwater level. The seepage water at the slopes is influenced by both infiltration at the plateau upstream as well as the drainage at the foot downstream, resulting in large fluctuations of the groundwater level (see figure 23) (Hydrologic, 2021).

FOOT

At the foot, more ditches are present, and the groundwater level is 3 to 0 meters below NAP. In this area, deeper seepage flows increase the groundwater level. Drainage of the fields at the foot influences the whole upstream water system (Hydrologic, 2021).

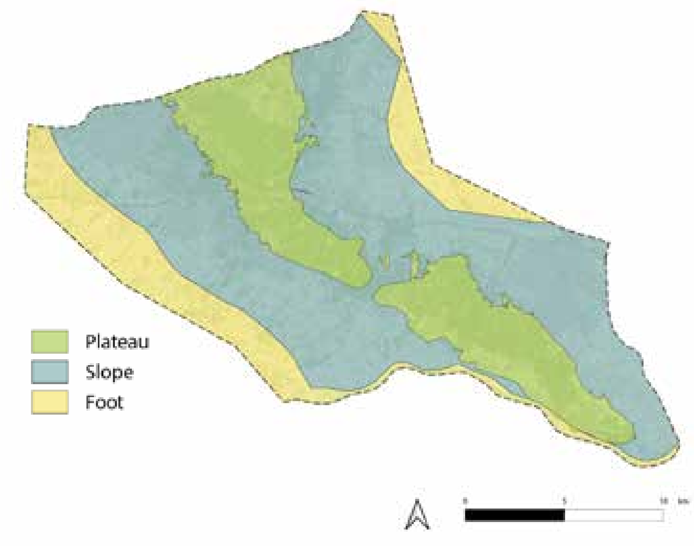


Figure 20: Map hydrological zones (Provincie Utrecht, 2018)

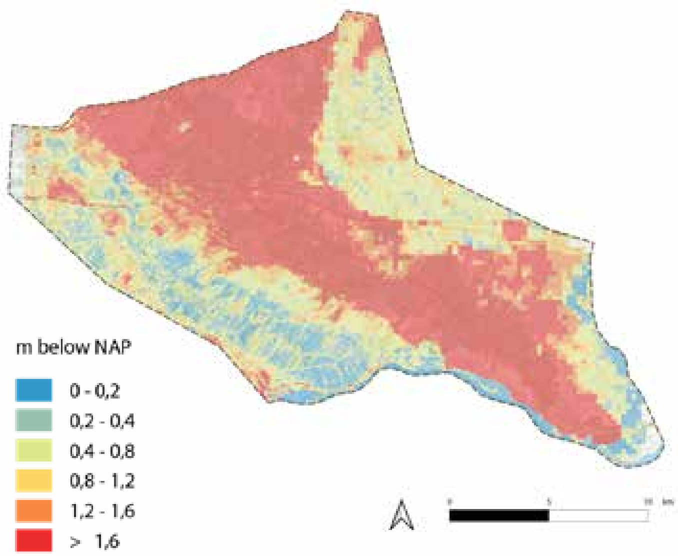


Figure 21: Map average highest groundwater level (Provincie Utrecht, 2018)

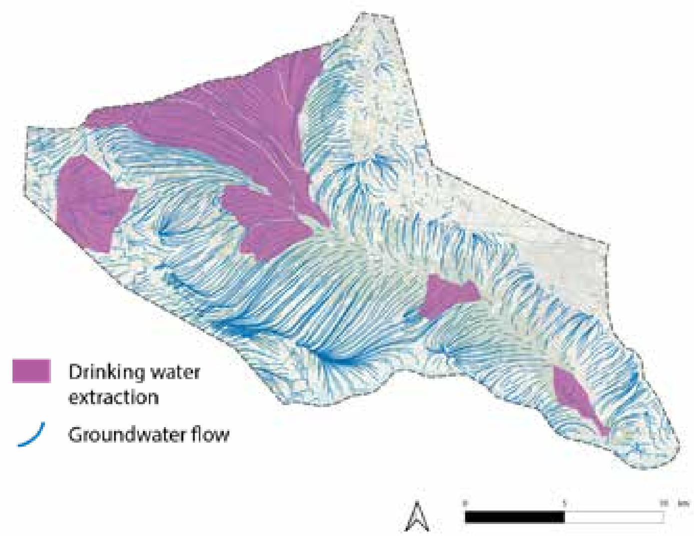


Figure 22: Map groundwater flow (Provincie Utrecht, 2018)

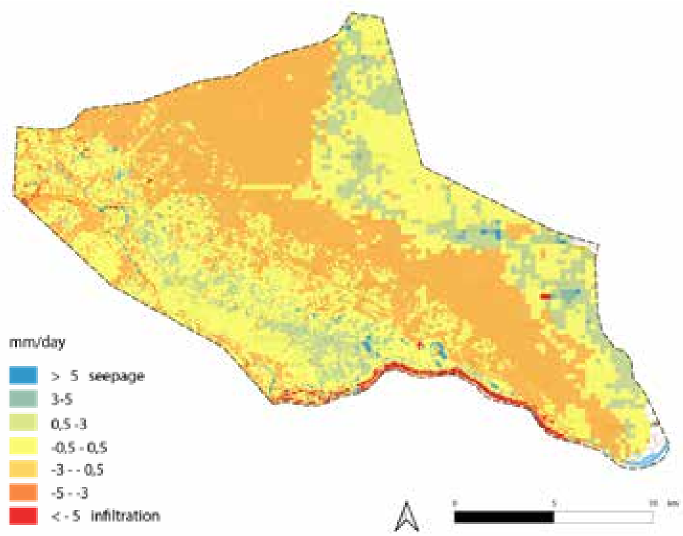


Figure 23: Map seeapge and infiltrationl (Provincie Utrecht, 2018)

The groundwater system of the Utrechtse Heuvelrug has slow processes, where water travels weeks or months through the ground before creating a noticeable effect on the groundwater level (see figure 24). The seepage flows at the slopes can lead to an improvement of groundwater levels. However, a combination of several measures is necessary, adapted to the local circumstances. Some measures will be more regional, and others more local (Hydrologic, 2021).

HYDROLOGICAL FLUXES

Hydrologic (2021) calculated the fluxes of the water system based on a regular year (2015) and a dry year (2018) (see figure 25), simulating where and how water moves through the different zones of the Utrechtse Heuvelrug.

At the plateau, most of the precipitation recharges the groundwater (G). The most important extraction is for drinking water, representing 20% of the groundwater recharge (O). However, in a dry year, drinking water extraction represents 45% of the groundwater recharge. The amount of runoff depends on the groundwater levels downstream (R). At the slope and the foot, most of the groundwater recharge is drained by ditches (A). In a dry year, the drainage is reduced.

Comparing the year of 2015 and 2018, the water storage increases (Δ B), which means that the groundwater level decreases more (Hydrologic, 2021).

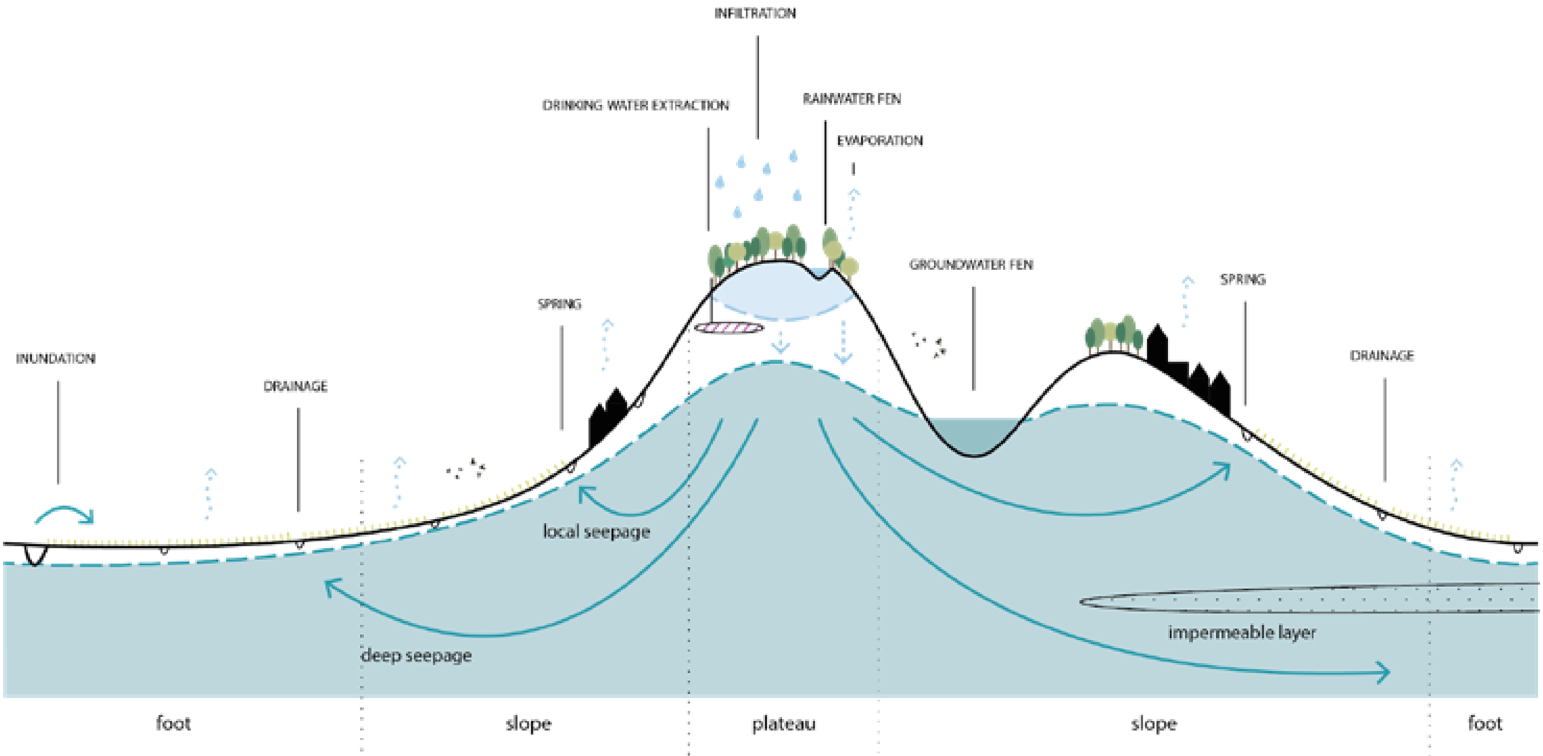


Figure 24: Section of the hydrological system of the Utrechtse Heuvelrug based on Hydrologics (2021) (Author, 2022)

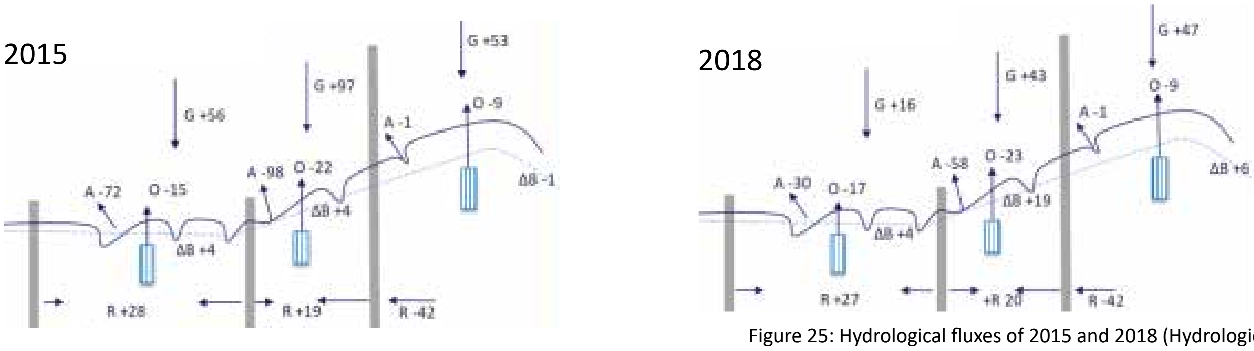


Figure 25: Hydrological fluxes of 2015 and 2018 (Hydrologic, 2021)

CLIMATE CHANGE

The newest KNMI report, Klimaatsignaal 21’ (KNMI., 2021), monitors the climatic developments of the Netherlands. They summarize the climatic trends based on the last thirty years as follows:

‘The last thirty years, the temperature, solar radiation, precipitation, evapotranspiration, and precipitation deficit increased.’ (Beersema et al., 2021, p. 10)

The temperature rise was 1,1 degrees Celsius. The increase in solar radiation partly causes the temperature increase in spring and summer. Solar radiation increased by 4%, especially in spring. Precipitation did increase by 8%. This mainly resulted in more precipitation on a wet day. It did not increase the number of precipitation days. In spring, the number of dry days increased strongly. Evapotranspiration increased in all seasons but most strongly in spring. These events together led to an increased precipitation deficit of 22% at the end of spring.

Extreme weather increased in the past thirty years, with a twofold increase in warm days and a 25% increase in days with extreme precipitation (KNMI., 2021).

Predicting the effects of climate change is uncertain. However, greenhouse gases reinforce the effects of climate change. Including greenhouse gasses (red line: highest predicted increase of greenhouse gasses, yellow line: lowest precited increase of greenhouse gases), the evapotranspiration and precipitation deficit will increase (see figures 26, 28, and 29).

Within the range of scenarios the KNMI uses, an increase in extreme weather in the future is uncertain. However, with increased humidity caused by increased evapotranspiration, the likelihood of more extreme weather events increases (see figure 27).

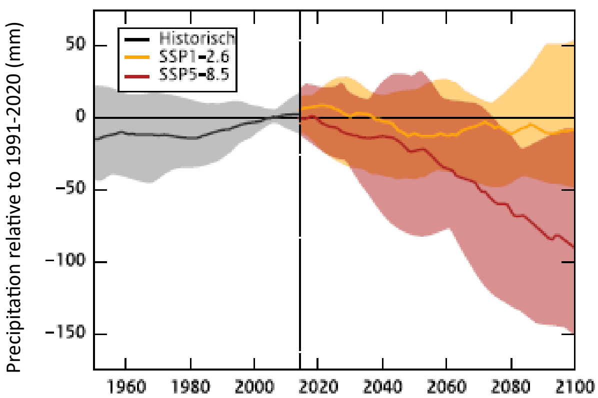


Figure 26: Predicted precipitation (Beersema et al., 2021)

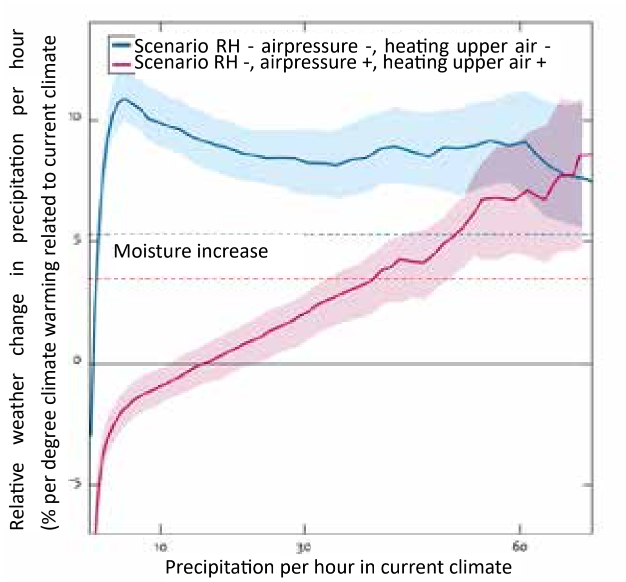


Figure 27: Predicted extreme weather (Beersema et al., 2021)

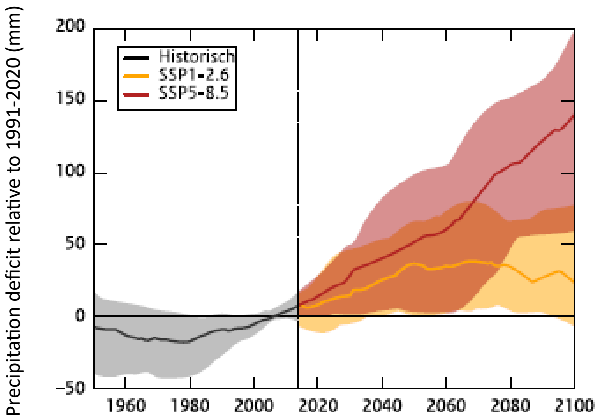


Figure 28: Predicted precipitation deficit (Beersema et al., 2021)

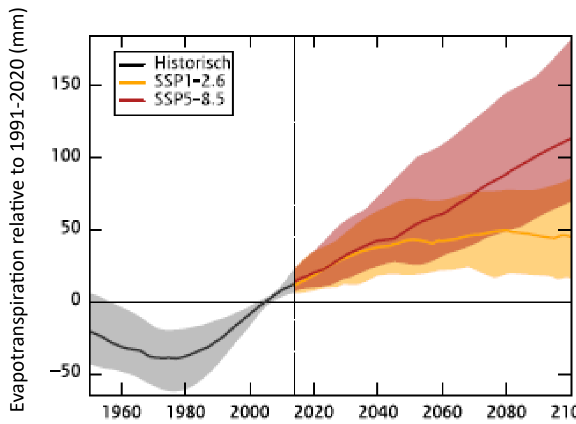


Figure 29: Predicted evapotranspiration (Beersema et al., 2021)

More extreme weather unfortunately does barely contribute to fewer droughts. The soil cannot take up a large amount of precipitation in a short time span.

Spring is the season when multiple events come together and reinforce each other; there is an increase in evapotranspiration, the least precipitation in the year and an increase in solar radiation.

CONSEQUENCES FOR THE UTRECHTSE HEUVELRUG

Hydrologics (2021) published a report that researches the effect of climate change on the hydrological system of the Utrechtse Heuvelrug and its landcover.

The conditions for moist and wet nature around the Utrechtse Heuvelrug decrease further with the predicted effects of climate change (see figure 30). Technically the conditions for the forest at the plateau do not decrease since the forest is classified as 'groundwater independent'. However, with less precipitation in spring and summer (KNMI., 2021), the growing season of deciduous trees, the trees will experience a water deficit (Hydrologic, 2021).

Within the hydrological system, agricultural plots are located at the slope and foot of the Utrechtse Heuvelrug. At the slope, the plots will experience the negative effects of the prolonged periods of drought (see figure 32 and 33), especially in spring with the growing season. At the foot, flooding due to extreme weather is a subject of concern.

The villages at the Utrechtse Heuvelrug are located closely to the forest at the high slope. Especially on the western side, the slope is steep, whereby surface runoff can cause flooding in the villages with extreme weather (see figure 29).

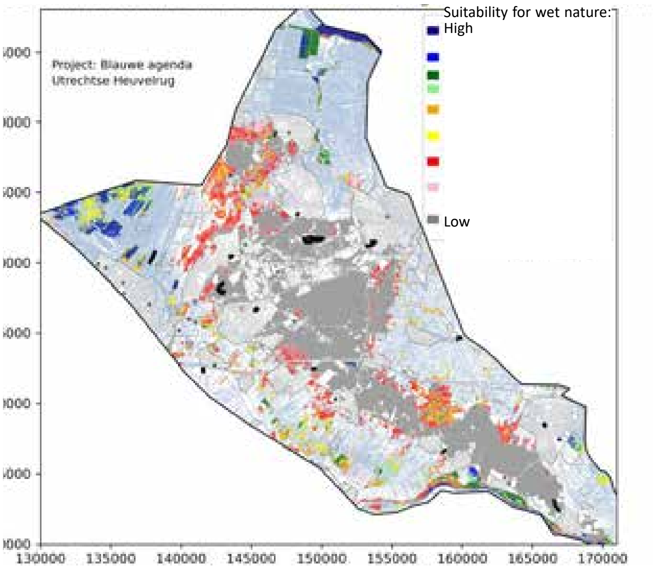


Figure 30: Potential for nature development (Hydrologic, 2021)

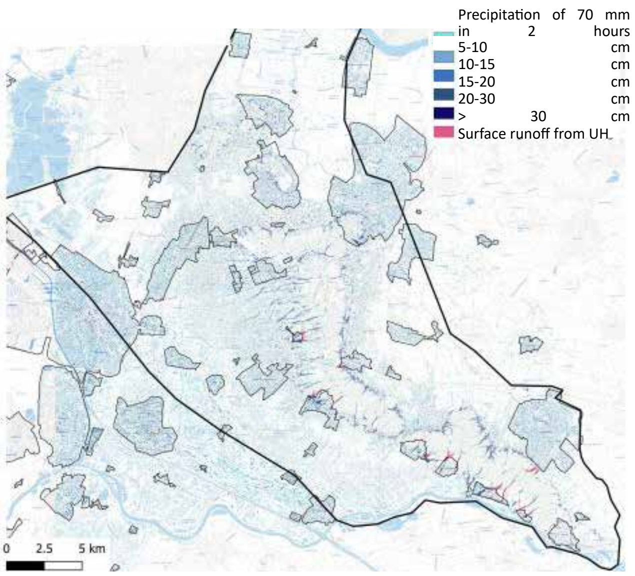


Figure 31: Surface run off to villages (Hydrologic, 2021)

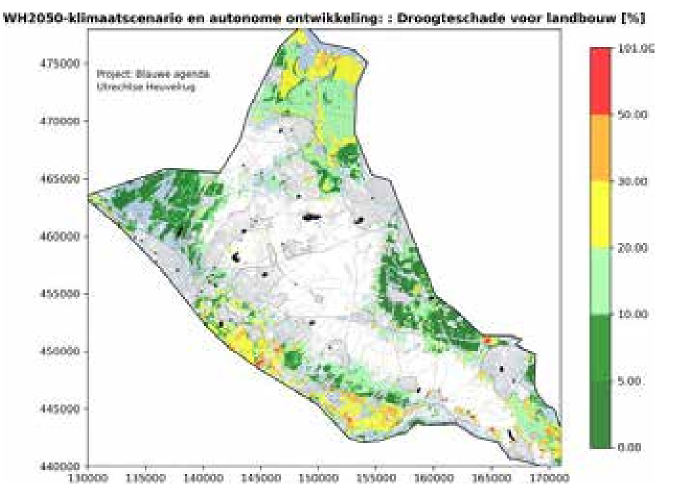


Figure 32: Drought damage (%)of agricultural fields (WH2050) (Hydrologic, 2021)

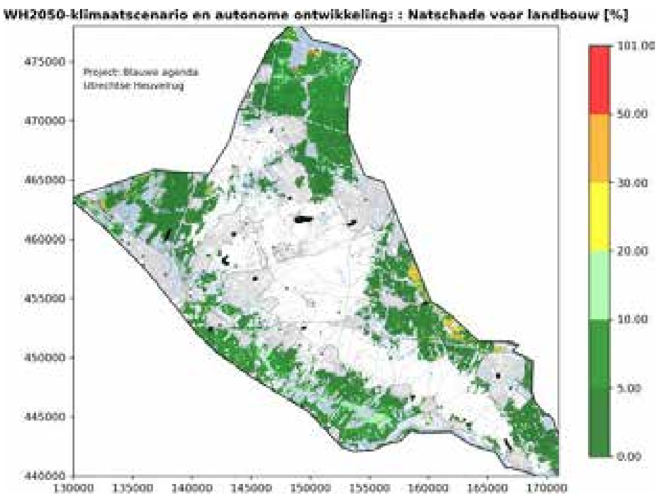


Figure 33: Flood damage (%) of agricultural fields (WH2050) (Hydrologic, 2021)

4.1.3 ECOLOGY

The ecological inventory categorizes the landscape structures into habitat zones and fauna species zones. Furthermore, the forest quality is discussed.

NATURAL LANDSCAPE STRUCTURES & HABITATS

The map of the Nature Network of the Netherlands (NNN) and the Green Contour clearly illustrate the dense structure of the Utrechtse Heuvelrug (see figure 34). However, in eastern and western directions nature patterns reach out to the surrounding area. The province defined valuable nature types with their nature pearls map (see figure 35). Together with the landscape pattern, the following landscape types with accompanied habitat zones were defined (see figure 37):

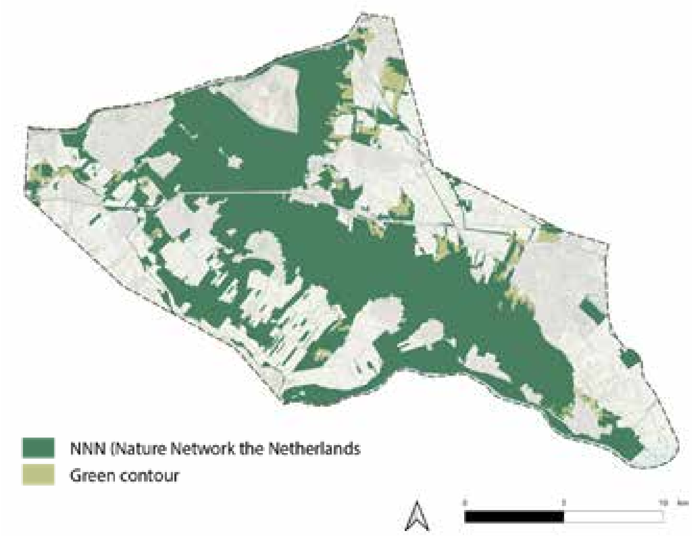


Figure 34: Natural structures (Provincie Utrecht, 2018)

LANDSCAPE TYPE: FOREST

Habitat type: Dry production forest

The dry production forests is characterized by wood production and a large share of exotic species at nutrient poor sandy soils. This planted forest type with a dense structure covers a large part of the Utrechtse Heuvelrug. Diversity is low due to the large share of Norway spruce. Historically, coppice areas, heath land, shifting sands or poor agricultural land were transformed into production forests. Grazing and bedding improvement with species can improve the diversity and quality of these forests (Natuurtypen, n.d.).

Habitat type: Deciduous forest

This forest type is the native forest at the nutrient-poor sandy soils of the Utrechtse Heuvelrug. A mix of oak, beech and pine trees characterises this forest type. Without maintenance, this forest type can develop into a closed forest structure with a thick layer of bedding, decreasing diversity. However, with grazing or disturbance, multiple succession stages can develop, and undergrowth increases (Natuurtypen, n.d.).

Habitat type: Old forest growth

The places with old forest (since 1850) or places that have been forested for a long while resulted in high resilience because of good soil development and trees adjusted to the local circumstances (see figure 36).

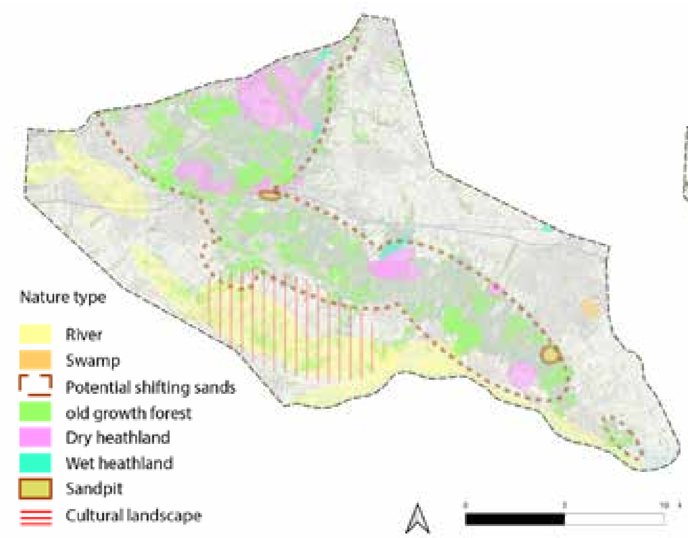


Figure 35: Nature types (Provincie Utrecht, 2018)

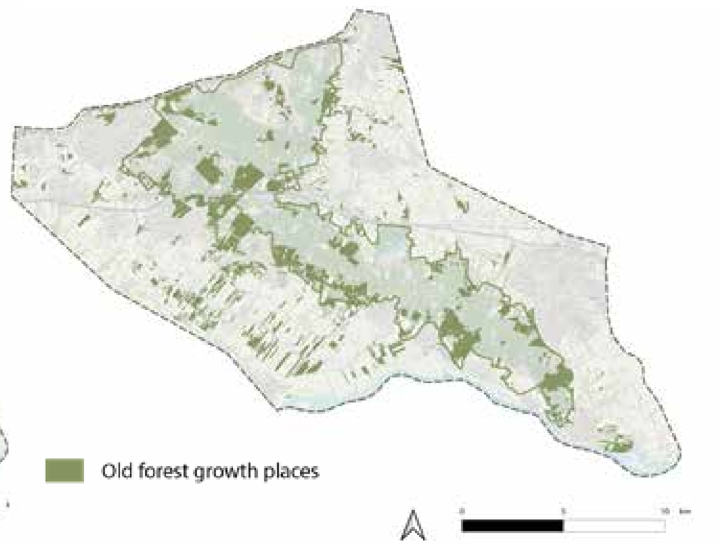


Figure 36: Old growth forest (Provincie Utrecht, 2018)

LANDSCAPE TYPE: DRY NATURE

Habitat type: Dry heathland

Due to the exhaustion of the dry sandy soils, this intermediate stage of forest development remained. Nowadays, this landscape type is maintained by grazing. Heather fields are a food source and shelter place for insects, birds, and reptiles, especially in proximity to other open landscape types (Natuurtypen, n.d.).

Habitat type: Shifting sands

The shifting sands barely occur at the southern part of the Utrechtse Heuverlug. This landscape type is a primary succession stage of forest development at high sandy soils. With secondary succession, shifting sands result from overexploitation of high sandy soils. This landscape type is a habitat for some specific species of butterflies, birds, and reptiles (Natuurtypen, n.d.).

Habitat type: Herbaceous grassland

Herbaceous grassland is a natural landscape type that can be found both within the forest and the agricultural fields. It consists of extensively grazed fields with little fertilizers and occurs on diverse soil types. The variation in structure and height creates multiple microclimates for a diversity of flora and fauna (Natuurtypen, n.d.).

LANDSCAPE TYPE: LOCAL WET NATURE

Habitat type: Wet heathland

Wet heathland contains a mix of heathland, grasses, mosses, sand, and little fens in wet places. At the Utrechtse Heuvelrug the wet places are mostly a result of local impermeable layers in the soil. This habitat type is strongly decreased in the Netherlands and is therefore important for landscape diversity (Natuurtypen, n.d.).

Habitat type: Fen

A fen is fed by rainwater and can be found in wet places where water stagnates due to the impermeable layers in the soil. The fen and its surrounding are a habitat for dragonflies, reptiles, amphibians, butterflies, and birds. The fens mostly have an isolated location in the forest surrounded by wet heathland, grassland, or dry heathland(Natuurtypen, n.d.).

LANDSCAPE TYPE: AGRICULTURAL FIELDS

The ecological qualities of agricultural fields has decreased drastically the past decades, due to agricultural intensification. However, the so-called 'cultural landscape' (see figure 35), fields that still have some of the characteristics of historic agricultural fields, can be a habitat for multiple species. For example, birds, butterflies, bees, and amphibians can benefit from historic hedgerows, herbaceous grassland, and herbaceous field edges.

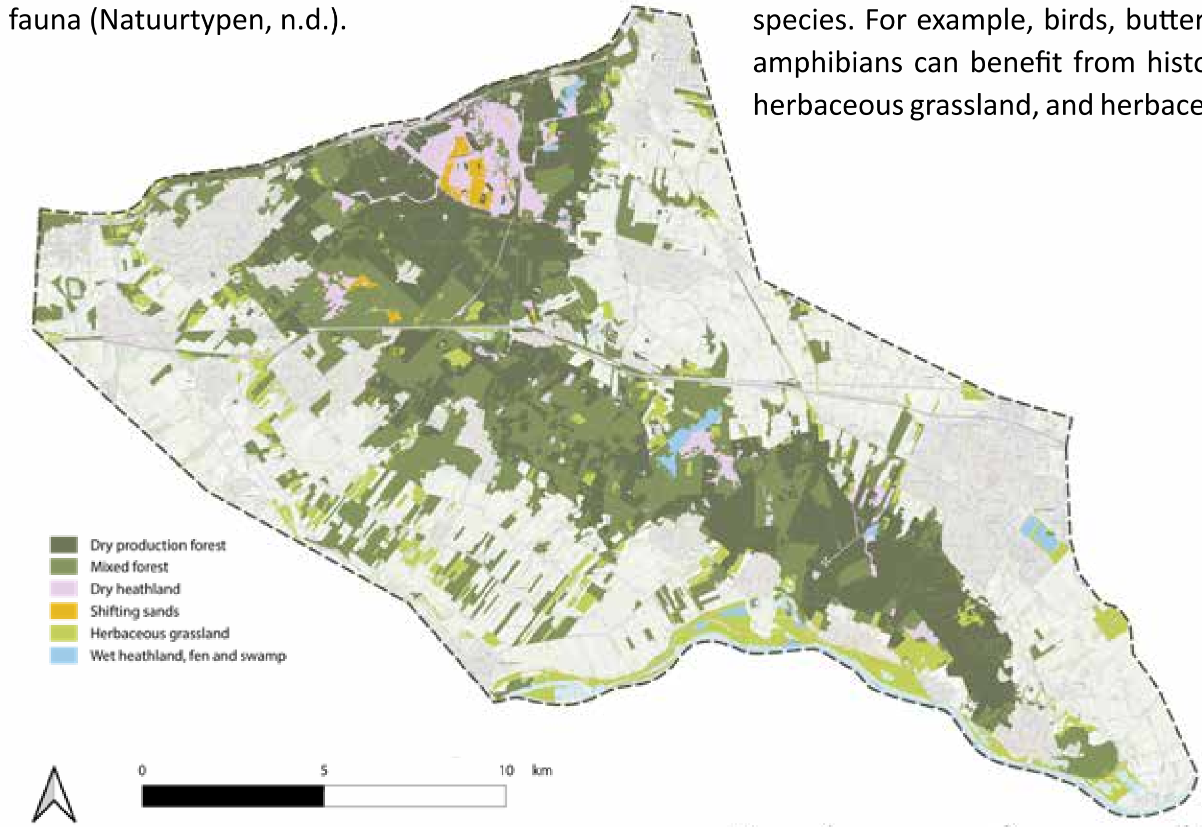


Figure 37: Landscape types based on Provincie Utrecht (2018) (Author, 2022)

FAUNA

Flora and fauna together construct the ecosystem. This inventory of fauna species related to habitat types, helps to understand the relevance and use of continuous natural structures are protective buffers (see figure 38). Because of the large scale of the project area, only fauna groups will be considered further in this research. However, for this inventory, considering the icon species defined by the province in relation to the fauna groups generates insight into the type of key species relevant for this area (see figure 39) (Provincie Utrecht, 2018b).

Small and large mammals and birds live in the forest. Birds can cover large distances to reach the next suitable habitat, such as the Veluwe. Swine and deers are more dependent on a continuous and undisturbed structure to migrate. For the large mammals, this project area is just a little part of their habitat, and the connection to the north of the Utrechtse Heuvelrug is important.

For the small animals, the large-scale connectivity is less relevant. Therefore they can find multiple places to stay in this area.

Multiple species groups can be found at the edge of the forest and in the more diverse landscape: butterflies, birds, bees, and reptiles. These specie groups live in the same habitat types characterized by dry circumstances and a variety of structures; diverse heathland, open forest, herbaceous grassland, forest edges, and agricultural structures. The connection between open areas within the forest and natural plots create opportunities for species to migrate. The habitat structures should be close together since the distance these specie groups cover isn't large.

The amphibians have a more specific habitats related to the wetness of the habitat; local fens, swamp areas, floodplains, and along rivers. In this predominantly dry area, the habitats of these species are isolated.

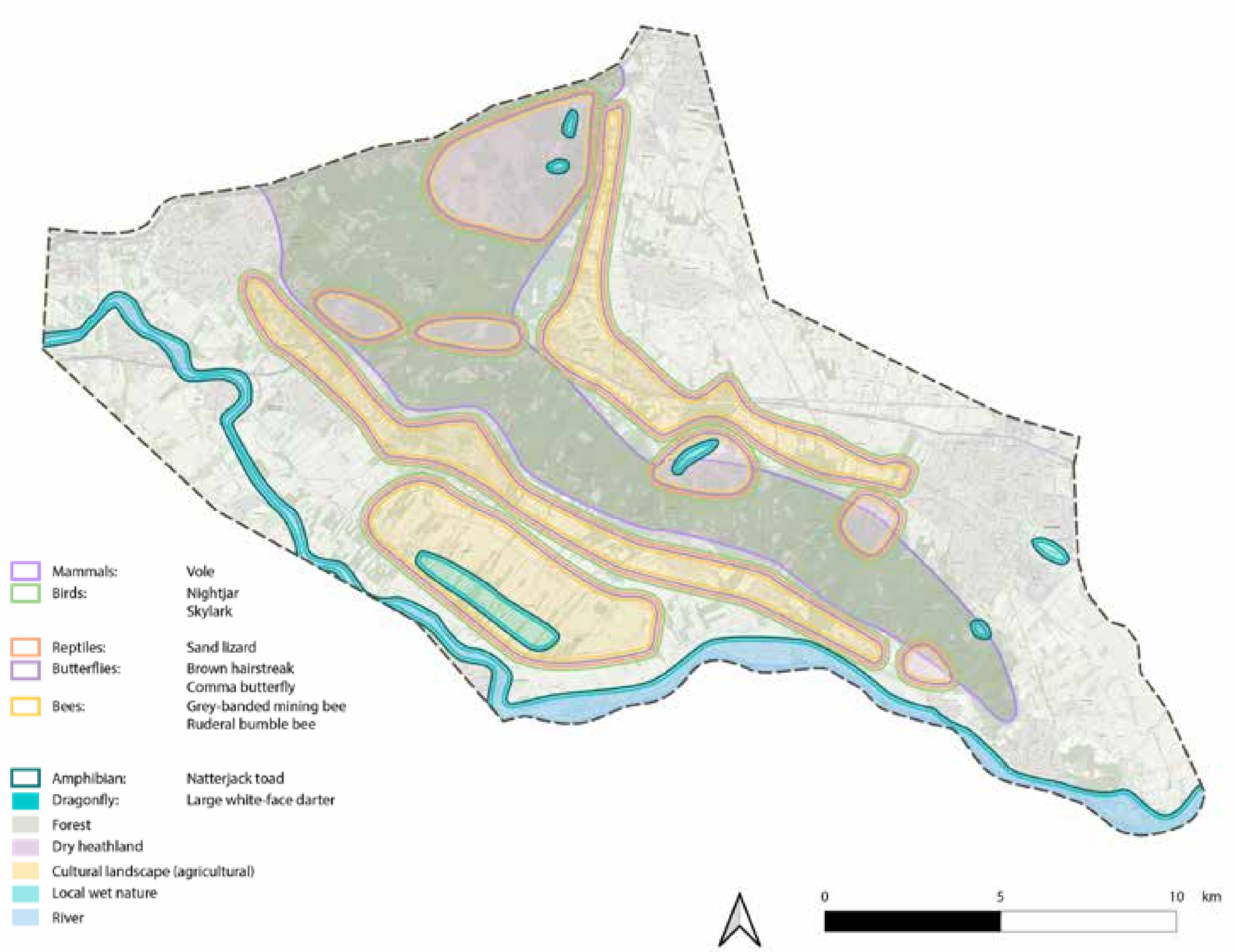


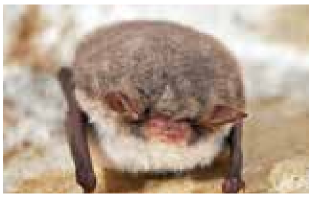
Figure 38: Fauna dispersion based on Provincie Utrecht (2018b) (Author, 2022)

Mammals

Vole

Habitat zone: Swamp areas

Natterer's Bat



Habitat zone: Forest

Birds

Nightjar

Habitat zone: Diverse heathland, dry open forest

Skylark

Habitat zone: Heathland and agricultural

Reptiles

Sand lizard

Habitat zone: Heathland, diverse habitat

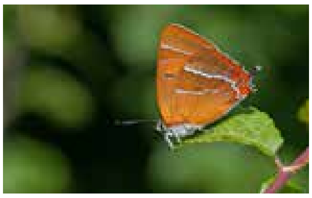
Dragonfly

Large white-faced darter

Habitat zone: Local fens

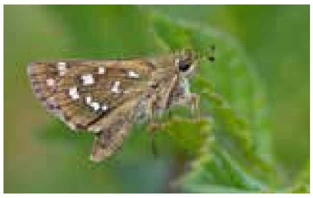
Butterfly

Brown hairstreak



Habitat zone: Heathland, herbaceous grassland, forest edges

Comma butterfly

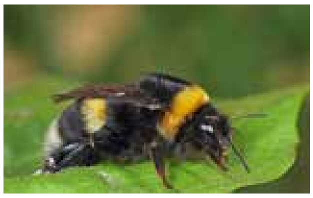


Habitat zone: dry herbaceous grassland

Bee

Habitat zone: Open forest, heathland, forest edges

Ruderal bumble bee



Habitat zone: Wet heathland

Amphibian

Natterjack toad

Habitat zone: Small ditches, floodplains, agricultural

Figure 39: Fauna species (Provincie Utrecht, 2018b)

FOREST QUALITY

Large-scale changes only have an effect if the small-scale conditions are good. For the resilience of the forest system, forest quality at a smaller scale can affect the whole functioning of the forest system.

The first condition to be discussed is tree type and density. The Netherlands' general distribution of deciduous and pine trees is quite equal (see figure 40). However, within production plots diversity of trees is low, and the tree density is high. These plots are weaknesses in the system because trees grow too fast and unstable with a high tree density. Furthermore, high density prevents soil and understory to develop. The monotonous tree species make them vulnerable to diseases (En et al., 2022).

Besides the tree species itself, soil quality is an important element of vital forests. A qualitative soil can process leaf litter into nutrients with worms and fungi. Fungi and trees can even start a symbiosis where both species take advantage of each other's services. Unfortunately, the forest at the Utrechtse Heuvelrug has low quality soil development, decreasing the forest quality (En et al., 2022).

The third condition is the little presence of trees over a 100 years old (Oldenburger et al., 2021). Because of the reforestation, most of the trees are between 60 and 80 years old (see figure 41). Old forests contribute to biodiversity and facilitate new habitats with dead trees. Besides the small share of old trees, the reforestation also led to a small share of young trees. After the reforestation, little new forest was planted, and small trees could not survive in the young mature forest. Due to management of the forest, large disturbances that create opportunities for a new forest to develop were minimized.

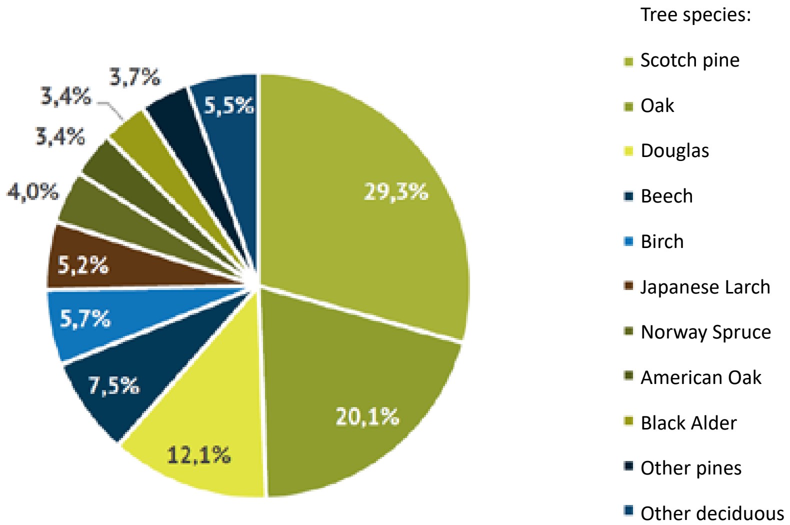


Figure 40: Tree specie distribution in the Netherlands (Oldenburger et al., 2021)

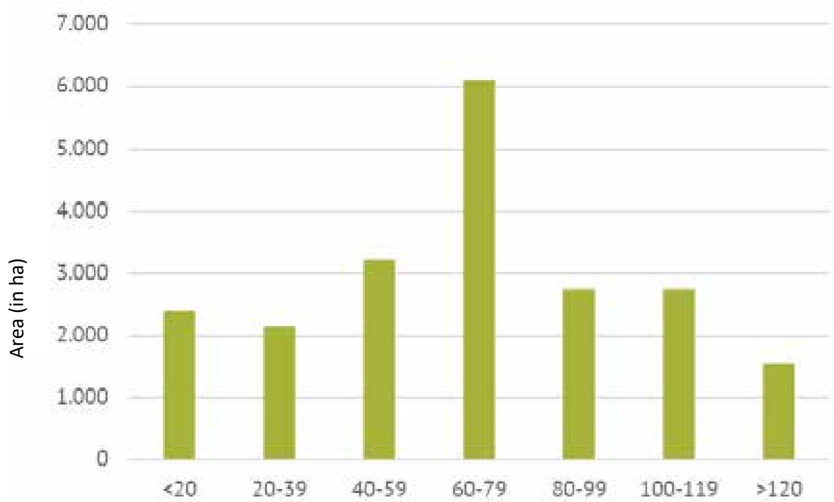


Figure 41: Tree ageing in the Netherlands (Oldenburger et al., 2021)

Forest succession

Primary succession takes place when the starting point of development is bare soil. In the pioneer phase, seeds and little plants reach the soil through the wind or birds. Next, small annuals start to grow and develop into grasses and perennials. Then small light-loving trees start to develop. The pioneer stage takes 0-20 years, wherein the forest develops into a height of 5 to 20 meters.

In the intermediate phase, grasses, shrubs, and light-loving young trees (birch, alder, and aspen) develop further, and species start to compete. Eventually, young trees die off, and a selection of light-loving trees will become dominant. Under this canopy, shadow lowing shrubs develop (see figure 42).

The last phase is the climax state which can take up 100 to over 400 years. Light-loving plants reach their maximum age and die off. More shadow loving trees will grow in the open places that appear in the canopy (Beech, Linden, Oak). In the herbal and shrub layer, characteristic species of old forests are present. Within the climax state, cyclic succession occurs where all stages of succession are represented. The share of dead wood increases and is a habitat for insects and fungi (Arnolds et al., n.d.).

Secondary succession takes place in areas where vegetation has been present. Seeds are already present and mulch and roots of previous vegetation have modified the soil. New seeds can barely establish because the old seeds in the soil can quickly develop and cover the soil. In the Netherlands primary succession barely takes place. Secondary succession is most commonly caused by natural or anthropological disturbances (Arnolds et al., n.d.)

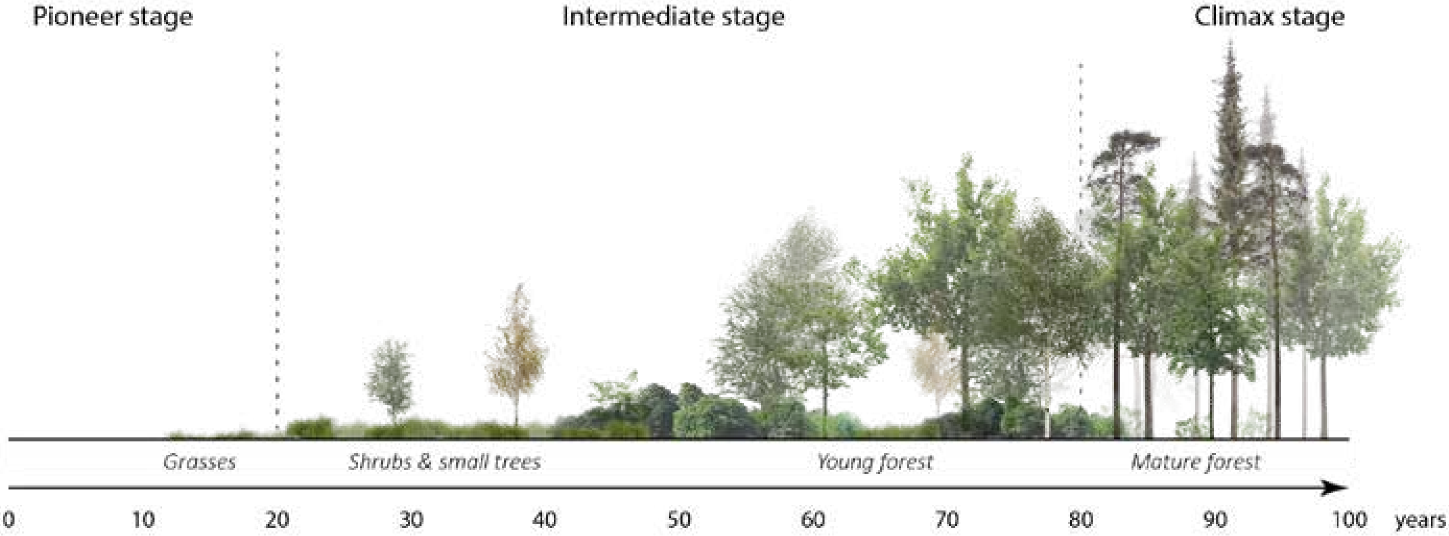


Figure 42: Section of primary forest succession (Author, 2022)

4.2 LANDSCAPE ANALYSIS

The landscape analysis consists of two paragraphs. The first paragraph structures the information gathered from the inventory into landscape units. The landscape units categorize the landscape based on multiple characteristics. The second paragraph builds upon the landscape units by summarizing and discussing the problems and opportunities in the landscape. The problems reveal the weaknesses in the system, while the opportunities can be used to increase resilience of the system.

4.2.1 LANDSCAPE UNITS

The landscape units describe spatially distinct areas based on geomorphology, hydrology, ecology, and land cover. These units are areas with the same character. They face similar problems, are affected by the same landscape flows, and have a similar distribution of land cover (see figure 43).

The first landscape unit is the plateau. The plateau is located at the high ridge of the Utrechtse Heuvelrug. Hydrologically it is not in contact with the groundwater and dependent on rainwater. A dense forest structure characterizes the plateau (see figure 47) mixed with heathland and local wet nature. Within the forest, numerous estates can be found. Landcover other than forest is barely present at the plateau, roads merely intersect it.

The plateau is surrounded by the slope, the transition from high to low. For the slope, two types of landscape units can be defined, each its their own characteristics.

The western slope is a steep slope leading towards the Kromme Rijn. It entails a mixed landcover. The patches have a more rectangular shape of strip allotment (see figure 44). Close to the Kromme Rijn, more agricultural fields can be found. Closer to the forest, more estates are present, better known as the 'Stichtse lustwarrande' (OKRA landschapsarchitecten, 2011). Even further away from the forest, the presence of estates is noticeable by forest plots between the foremost agricultural plots. At this slope of the Utrechtse Heuvelrug, the villages are lined up close to or almost within the forest structure at the plateau (see figure 46).

The eastern slope is a more gradual. Like the western slope, the landscape here is fragmented. The eastern slop leads to the Gelderse Vallei. An area with cover sand an agricultural fields. Block allotment with intensive agriculture can be found here (see figure 45). However, at the higher slope, a mosaic with more nature is present (see figure 48). The gentle slope results in more local seepage and opportunities for wet nature.

At the lowest part of the project area, the foot, a western and eastern foot can be found. Both landscape units entail mostly agricultural land cover. At the western foot, the Kromme Rhine meanders through the landscape, transitioning into a river landscape. The eastern foot is quite similar to the allotment at the eastern slope, with even fewer natural patches in between. Here the landscape transitions into the Gelderse Vallei a valley with coversand in use for intensive agriculture.

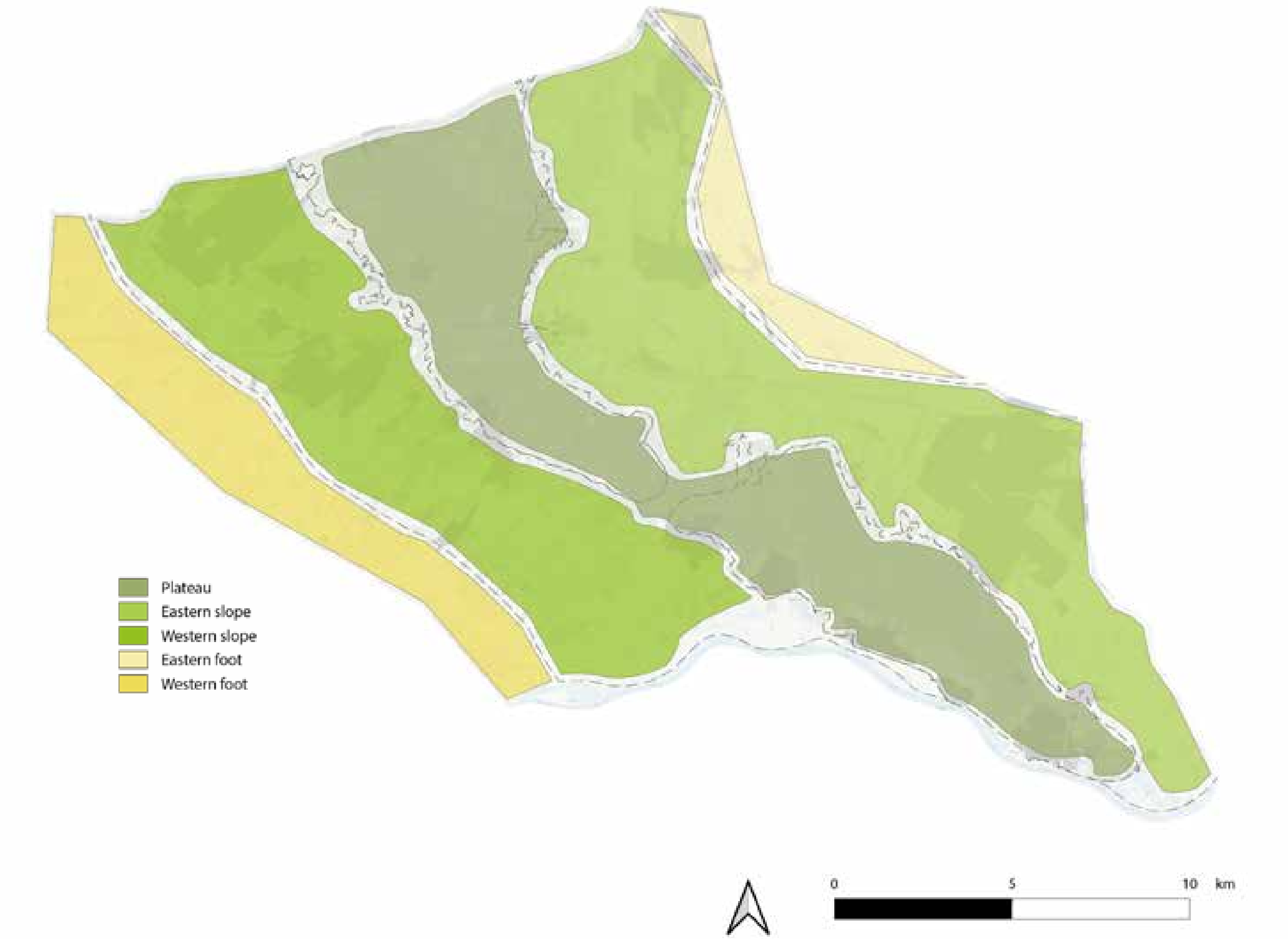


Figure 43: Landscape units (Author, 2022)

Figure 44: Allotment pattern western slope and foot (Google maps, n.d.)

Figure 45: Allotment pattern eastern slope and foot (Google maps, n.d.)

Figure 46: Villages embedded in forest edge (Google maps, n.d.)

Figure 47: Forest at the plateau (Author, 2022)

Figure 48: Natural transition eastern slope (Author, 2022)

4.2.2 PROBLEMS & OPPORTUNITIES

The problems the Utrechtse Heuvelrug is facing regarding drought are complex and stretch beyond the boundaries of the forest itself into the more regional defined landscape units. Based on the landscape inventory and landscape units, this paragraph concludes and summarizes the problems, opportunities, and interwovenness (see figures 49 and 50).

The forest at the plateau (+6 meters NAP) is suffering from longer periods of drought because it is not in contact with the groundwater and is thus dependent on precipitation. This effect is enhanced by the evaporation of the trees, especially pine trees.

Although adaptation in the hydrological system does not affect the droughts within the forest, there are opportunities to prepare the forest for the changing circumstances in the future. One is the adaptation of vegetation, which mainly entails that the least drought resistant tree species need to be reduced to enlarge and strengthen locally adapted tree species. Moreover, an increase of diversity within the forest will enlarge the ability of the forest to respond to disturbances.

At the slope of the Utrechtse Heuvelrug, droughts and flooding are a subject of concern. With more extreme weather, precipitation will lead to flooding close to the villages at the slope. Agriculture at the slopes will experience the negative effects of both droughts and flooding.

At the slope, the groundwater dependent nature will face problems due to the longer periods of drought. This effect will be more severe at the more steep western slopes. On the contrary, the steepness and sharp transition from the forest into agriculture make this landscape less suitable for groundwater dependent nature. The more gradual eastern side consists of a larger share of groundwater dependent nature and will therefore be affected more by longer periods of drought.

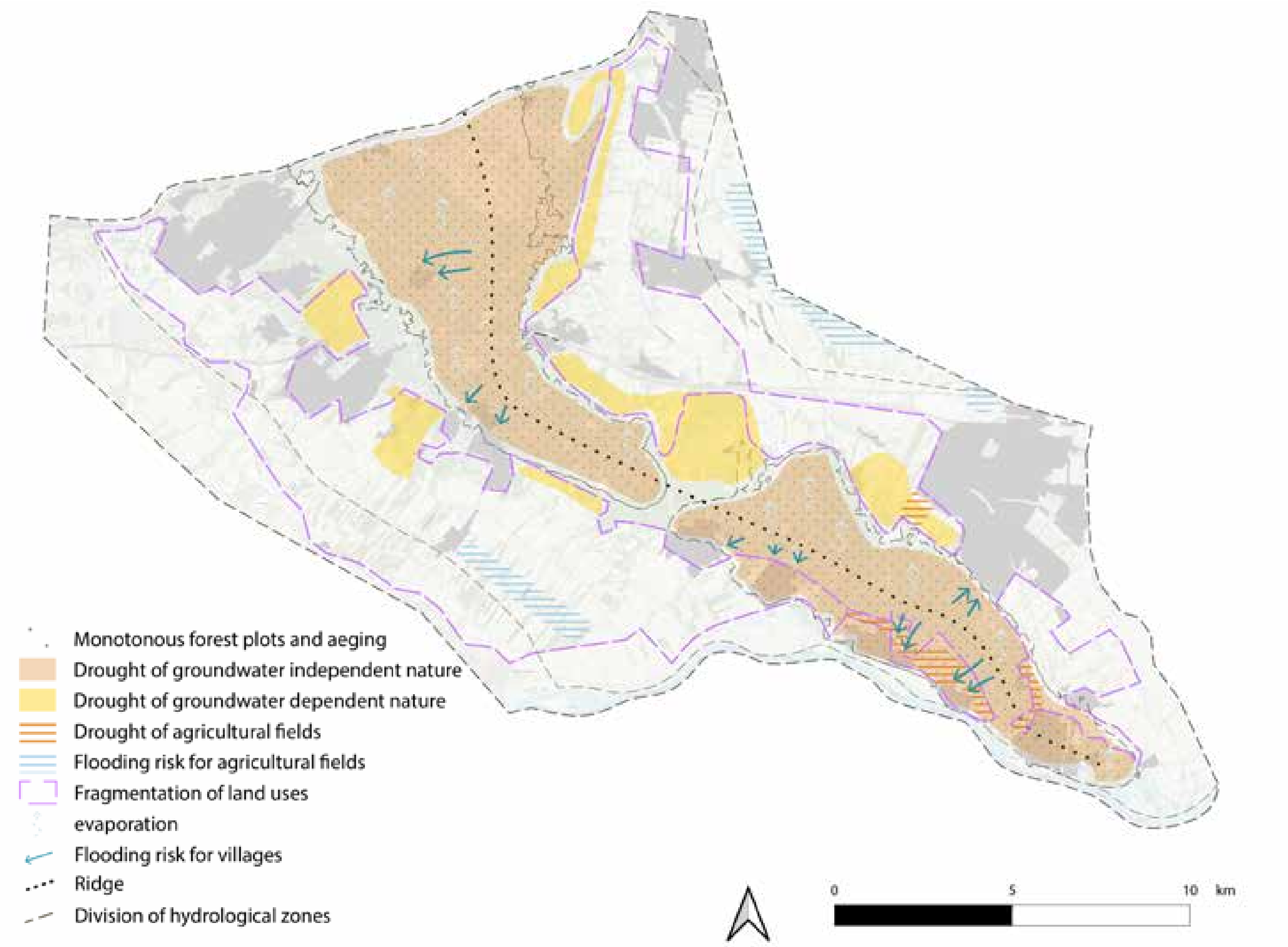


Figure 49: Problem map (Author, 2022)

However, there are also more opportunities to enlarge the future share of wet nature because the more gradual slope makes water run off less quickly.

Surface runoff causes flooding within the villages. Moreover, surface runoff is water lost in the hydrological system and should be retained to prevent flooding and reintegrate into the system. However, being a problem, it is also an opportunity.

With seepage water at the slopes, there are opportunities to retain water. While agriculture at the slopes experiences the negative effects of flooding, this heightened groundwater level creates opportunities for groundwater dependent nature at the slopes, especially the gradual eastern slope has possibilities for wet nature. Groundwater dependent nature close to the villages can protect the villages from flooding while retaining water.

Lastly, the landscape at the slopes faces the most problems regarding fragmentation because the slope is also the area where different types of land cover meet; villages, estates, forest, agriculture, groundwater dependent nature.

With all the different land cover at the slopes, there are opportunities to connect suitable landscape types and improve the connectivity of the landscape.

At the foot, the agricultural land can inundate the land because of its low-lying position. However, with more extreme weather, the low-lying land of the foot faces problems with flooding.

The expected rise in groundwater level creates more opportunities for groundwater dependent nature and wet agriculture at the foot, connected to the hydrological system of the Utrechtse Heuvelrug. Increased groundwater levels at the foot will increase the groundwater levels up stream.

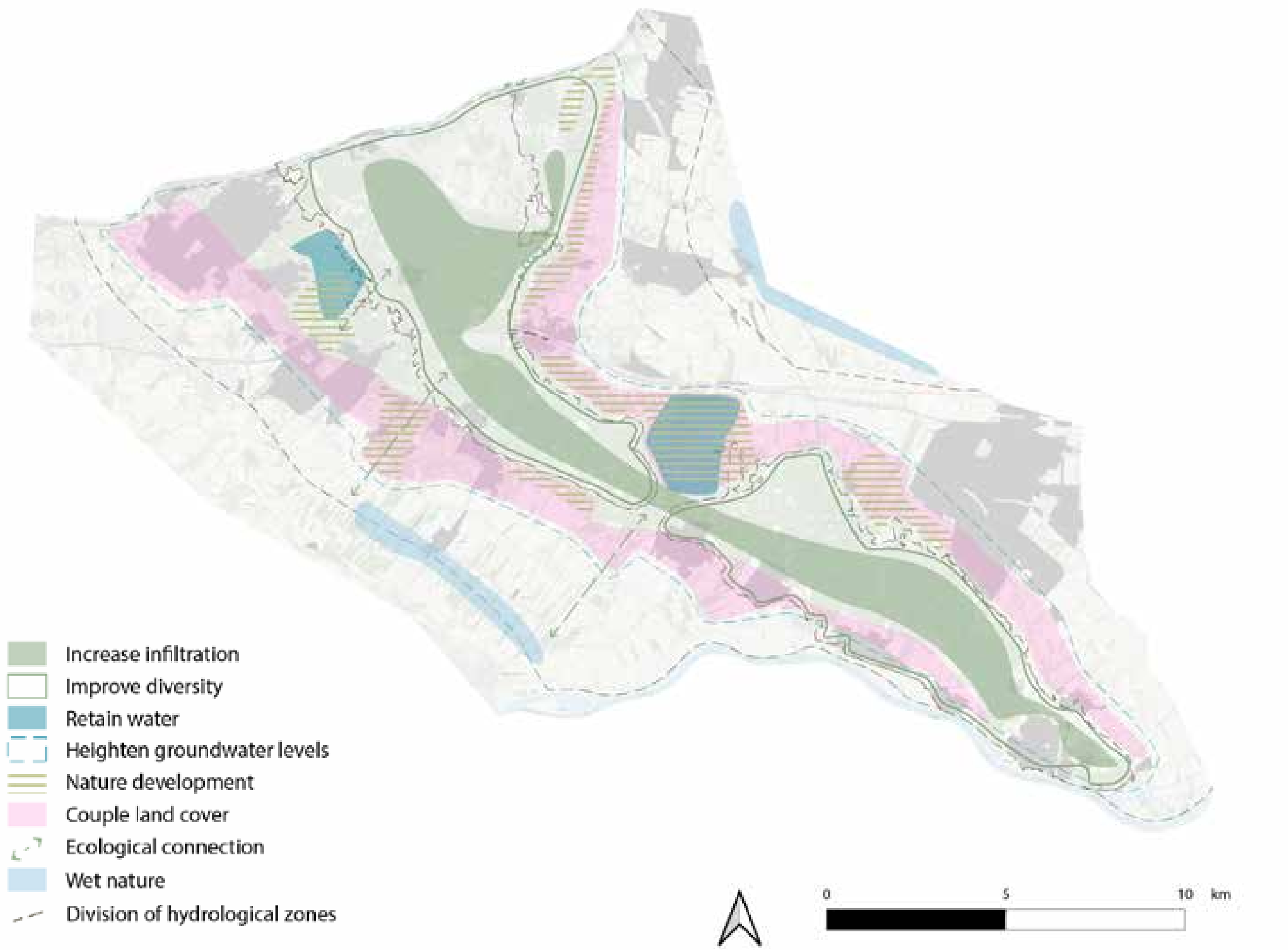


Figure 50: Opportunities map (Author, 2022)

5. DESIGN ALTERNATIVES

In this chapter, the design alternatives will first be described. Second, the outcome of the expert evaluation is discussed regarding the design alternatives and the related design guidelines.

5.1 DESIGN ALTERNATIVES

For this research, three design alternatives were developed; hydrological zones, ecological network and mosaic landscape.

The variable on which the design alternatives are based is the depth of the cup. Using the analogy from paragraph 3.1, the depth of the cup represents a system's ability to absorb disturbances. Based on the literature, four attributes of resilience were formulated; connectivity, diversity, variability, and redundancy. Each attribute increases the depth of the cup.

The spatial principles translate the attributes into spatial characteristics. Based on the spatial principles and the landscape analysis, preliminary design guidelines were formulated. They are listed alongside each design alternative. The preliminary design guidelines are coupled with the corresponding spatial principles, associating the site-specific implementation with literature.

To deepen the cup, a wide range of alternatives can be developed. To extract the essence, the most influential patterns and processes regarding resilience in forest systems were defined. As Bell and Apostol (2008) state in their book 'Sustainable forest design':

'The authors have found it most useful to choose flows that are most representative of the general ecosystem type that uses a significant part, if not all, of the landscape and that are in some way indicative of ecological health.' (Bell & Apostel, 2008, p. 49)

The most influential patterns and processes can be differentiated by scale and time variations. Both small-scale diversity and large-scale processes contribute to the depth of the cup, representing the complexity of resilient systems (Allen & Holling, 2008).

Based on the depth of the cup, three design alternatives were formulated. Representing the most important patterns and processes that take place in time and scale variations (see figure 51)

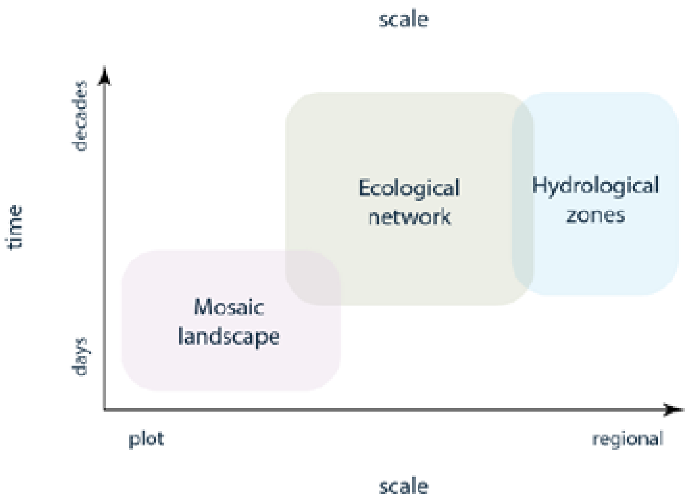


Figure 51: Representation of design alternatives (Author, 2022)

In this introduction, the design alternatives are briefly described. In the following paragraphs of this chapter, the design alternatives are discussed further, and strengths and weaknesses are summarized.

HYDROLOGICAL ZONES

Considering drought resilience, in particular, the hydrological system was the most representative landscape process considering the forest. Nevertheless, other flows like nutrient balance and fauna movement are also integral elements of the resilient system.

The scale of hydrological processes is large and reaches far beyond the boundaries of the forest itself. Furthermore, changing the hydrological process can take years. Seasonal fluctuations are an integral part of hydrological processes over a shorter time span.

ECOLOGICAL NETWORK

The ecological pattern is the most important pattern considering forest landscapes. Besides the forest itself, natural structures surrounding it are also considered.

The ecological pattern has a smaller scale than the hydrological processes. However, the connectivity of ecological structures is an important characteristic that needs a regional approach. Diversity can contain both large-scale structures and small-scale variations. Natural structures can take years to develop. Wile seasonal changes contribute to diversity.

MOSAIC LANDSCAPE

The design alternative mosaic landscape represents the smallest scale and time span. Small-scale differences in plots and hedgerows are important for diversity, and change happens within days, weeks, or seasons. A diverse landscape represents redundancy of habitats and structures.

EXPERT MEETING

Two expert meetings of about one hour took place to evaluate the formulated design alternatives. The meetings had the same structure; first, a presentation took place elaborating on the concept of resilience, the landscape inventory and analysis, and a description of the design alternatives. Second, the design alternatives were discussed and evaluated.

The first meeting was with two hydrological experts from the province of Utrecht. They both were involved in the development of the report 'Bouwstenen Blauwe Agenda' (Hydrologics, 2021). Furthermore, they have a profound understanding of the hydrological characteristics of the case study area.

The second meeting was with an ecological expert from Wageningen University. This expert is engaged with general ecology, considering ecological measures' effects in a broader perspective. With a focus on forest and nature management.

EXPERT EVALUATION

The expert evaluation summarizes the feedback on the design alternatives. The strength and weaknesses of the individual design guidelines were discussed. As well as a suitable combination of design guidlines from the three design alternatives. The results of the expert evaluation are presented in paragraph 5.5.

5.2 HYDROLOGICAL ZONES

This design alternative is based on the three hydrological zones; plateau, slope, and foot. It considers evapotranspiration, infiltration, seepage, and drainage as the main drivers for design interventions. This design aims to increase reslience by focussing on the hydrological system. The design guidelines in this design alternative are of a rather large regional scale to significantly affect the hydrological system.

At the plateau, the main goal is to reduce evapotranspiration and increase infiltration. This is enhanced by transforming the most vulnerable pine production locations into deciduous forests. Second, the forest will be transformed into grassland nature at two locations to maximize the infiltration capacity.

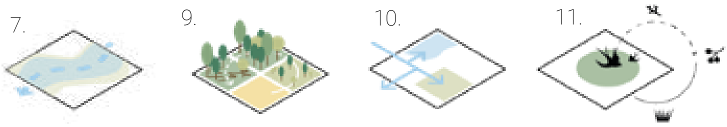
At the western slope, minimal interventions occur except for the dry nature to increase infiltration at the plateau. Other interventions have no significant effect because of the steepness of the slope. At the more gradual eastern slope, an increase in seepage is expected due to increased infiltration at the plateau. Wet nature retains this seepage to keep the water in the system as long as possible.

At the lowest fields at the foot, drainage to streams will be decreased, and wet nature is present to retain the deep seepage from the Utrechtse Heuvelrug.

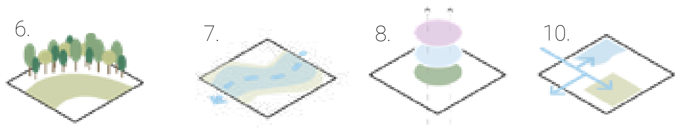
DESIGN GUIDELINES

The design guidelines focus on the increase infiltration and retention of water.

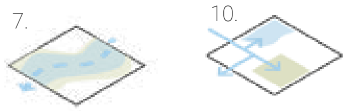
1. Reduce evapotranspiration by replacing pine trees for deciduous trees.



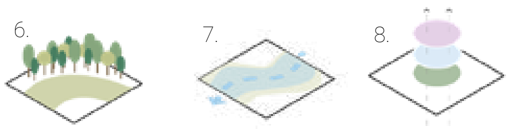
2. Increase infiltration by transforming the forest into dry nature.



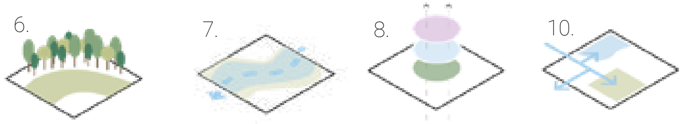
3. Heighten groundwater level at slopes to decrease drainage.



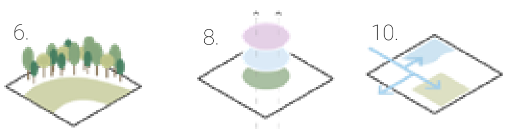
4. Retain the water from local seepage at the eastern slope with wet nature.



5. Protect villages from flooding with flexible pockets.



6. Adapt to the increased deep seepage at the foot with extensive agriculture.



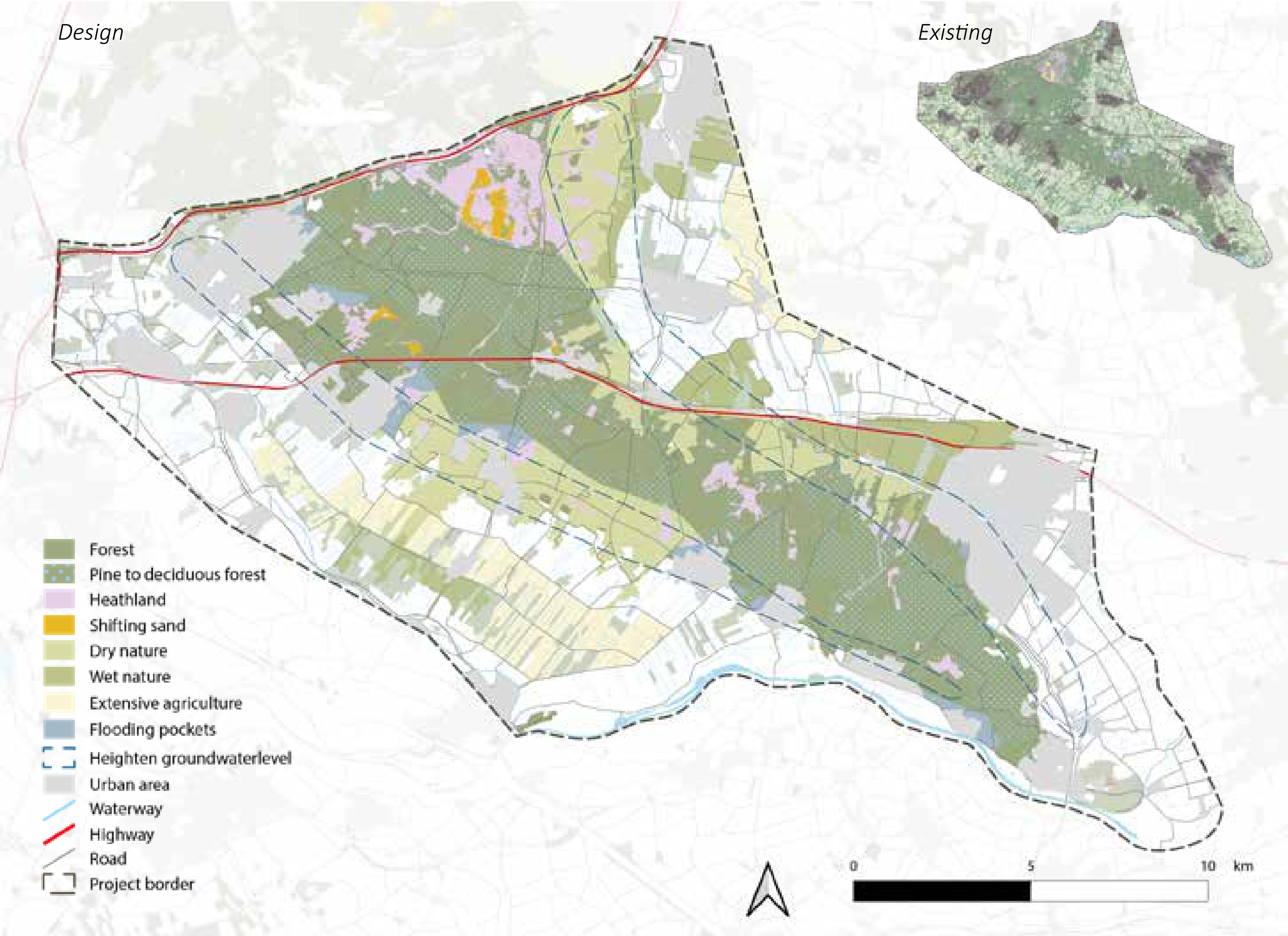


Figure 52: Design alternative hydrological zones (Author, 2022)

SUMMARY

This design alternative considers the whole complexity of the system and proposes fundamental changes in the landscape. It creates space for disturbances to be absorbed. However, it also has the most impact on the current land cover, such as agriculture and the forest itself. Moreover, an important characteristic of a resilient system its ecological structure and functioning. The vegetation is hardly considered here other than the availability of water.

5.3 ECOLOGICAL NETWORK

The ecological network design alternative focuses on interconnected and diverse nature. First, it enables key fauna species to move through the landscape. Second, improved diversity increases the capacity of the system to absorb disturbances. Furthermore, diversity in the forest is enhanced by multiple succession stages. Nature management is important in this design alternative to maintain the diversity of succession stages and prevent all patches from transforming into a climax stage.

Diversity within the forest will be increased by switching to a more deciduous forest. Vulnerable pine tree production plots will be transformed into a deciduous forest. However, old forest growth places will be preserved. In these places, the forest has existed for a long time. Therefore a large specie richness was able to develop. The connection with the northern forest of the Utrechtse Heuvelrug is important for larger mammals such as deer and swine.

The heathland within the forest will be preserved and strengthened by heathland corridors. Dry nature will be added, as a buffer around and close to the heathland plots to enable species such as insects and butterflies to move from the enclosed heathland into the open grassland.

On the eastern side, a buffer of dry nature protects the forest. Furthermore, this thick buffer functions as a corridor for fauna to migrate between patches of heathland at the higher fields or wet nature at the lower fields. At the foot, two main ecological corridors of wet nature and extensive agriculture connect with the Gelderse Vallei.

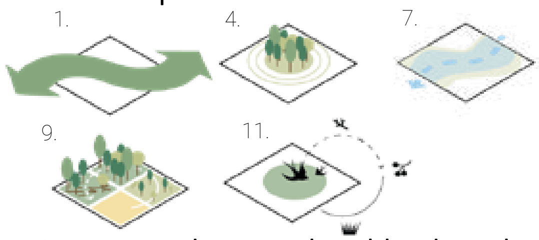
On the western side, the main connections are the forest corridors toward the Kromme Rijn. It gradually transforms into wet nature alongside the Kromme Rhine, connected with the floodplains alongside the Rhine.

DESIGN GUIDELINES

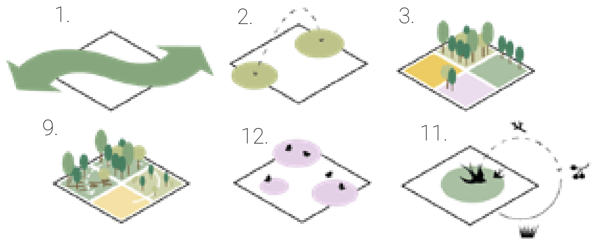
The design guidelines focus on the increase of diversity and ecological connectivity.

1. Increase diversity by transforming pine forests into deciduous forests.

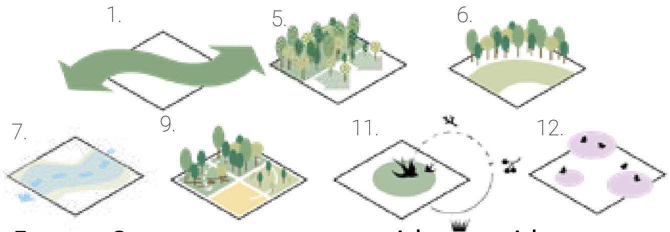
2. Connect the old growth forest with the northern part of the Utrechtse Heuvelrug.



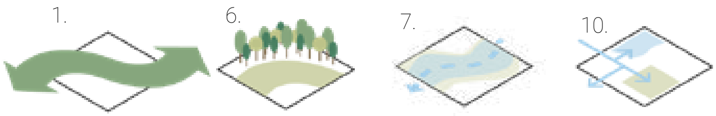
3. Connect and protect heathland patches within the forest.



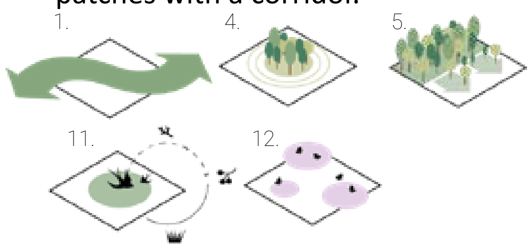
4. Protect the eastern forest with a dry nature buffer.



5. Connect wet nature with a corridor towards the Gelderse vallei.



6. Connect and protect western forest patches with a corridor.



7. Connect wet nature along the Kromme Rhine with a corridor towards the Rhine.

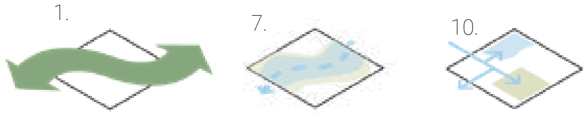


Figure 53: Design alternative ecological network (Author, 2022)

SUMMARY

The strength of this design alternative is the focus on ecological diversity and connectivity, which strengthens the natural structures. However, in some places, hydrological or structural conditions should be improved to ensure the successful implementation of the proposed design guidelines.

5.4 MOSAIC LANDSCAPE

The mosaic landscape design takes the variety in land use as the starting point. With the design guidelines, this mosaic pattern will be strengthened and enriched to face current and upcoming problems. The local implementation of design interventions is characteristic of this design alternative.

The expression of this design alternative takes place mainly at a local scale which is less prominent at the scale used for these design alternatives. However, to understand the implications of the small-scale variety at this large-scale landscape, the types of mosaic can be illustrated with focus zones.

Several focus zones are defined based on the hydrological system, ecology, and landscape pattern. At the higher plateau, the diverse nature focus zones are based on places where natural variation was already present. Diversification of the dense forest will increase infiltration. The current mix will be strengthened and expanded with a natural mix of heathland, shifting sand, natural grassland, and deciduous forest. The diverse nature expands towards the slope, where water from precipitation and local seepage will be absorbed instead of drained.

Close to the villages, the risk of flooding will be diminished by flexible pockets. The flexible pocket consists of open natural fields wthat can retain and infiltrate water if necessary.

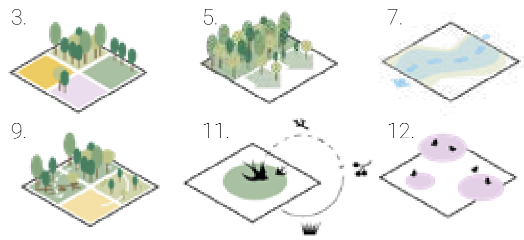
The low-lying fields at the eastern slope consist of an agricultural mix where intensified agriculture alternates with extensive agriculture. The extensive agriculture anticipates absorbing the deep seepage to remain the intensive agricultural fields.

The western focus zone is a mix of agriculture and nature. Besides the agricultural plots here, there are multiple forest patches. The small size of these patches makes them vulnerable. By adding agroforestry, the forest patches are strengthened. Extensive agriculture is integrated to minimize the impact of agriculture on the forest patches. Increase of infiltration at the plateau, combined with less drainage, increases the groundwater level of the low-lying fields. Wet nature creates space for extra water and enlarges the nature mosaic together with the forest patches.

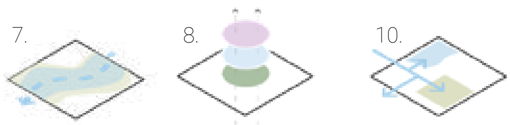
DESIGN GUIDELINES

The design guidelines focus on increasing small-scale diversity based on the current landscape diversity.

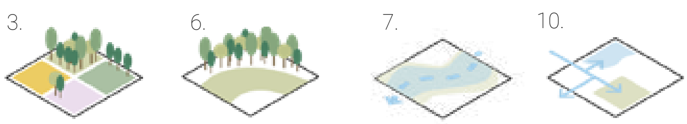
1. Increase diversity with a mix of nature: Deciduous forest, heathland, shifting sand, and dry nature.



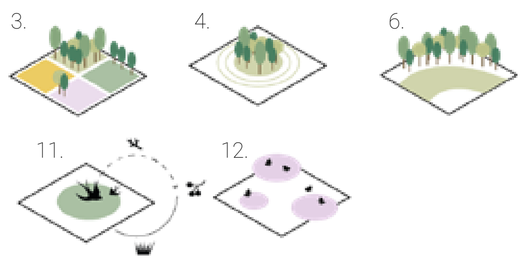
2. Anticipate flooding with flexible pockets.



3. Increase diversity within agriculture with a mix of intensive and extensive agriculture.



4. Preserve and strengthen the mosaic of forest and agriculture in the west with a mix of agroforestry, extensive agriculture, and wet nature.



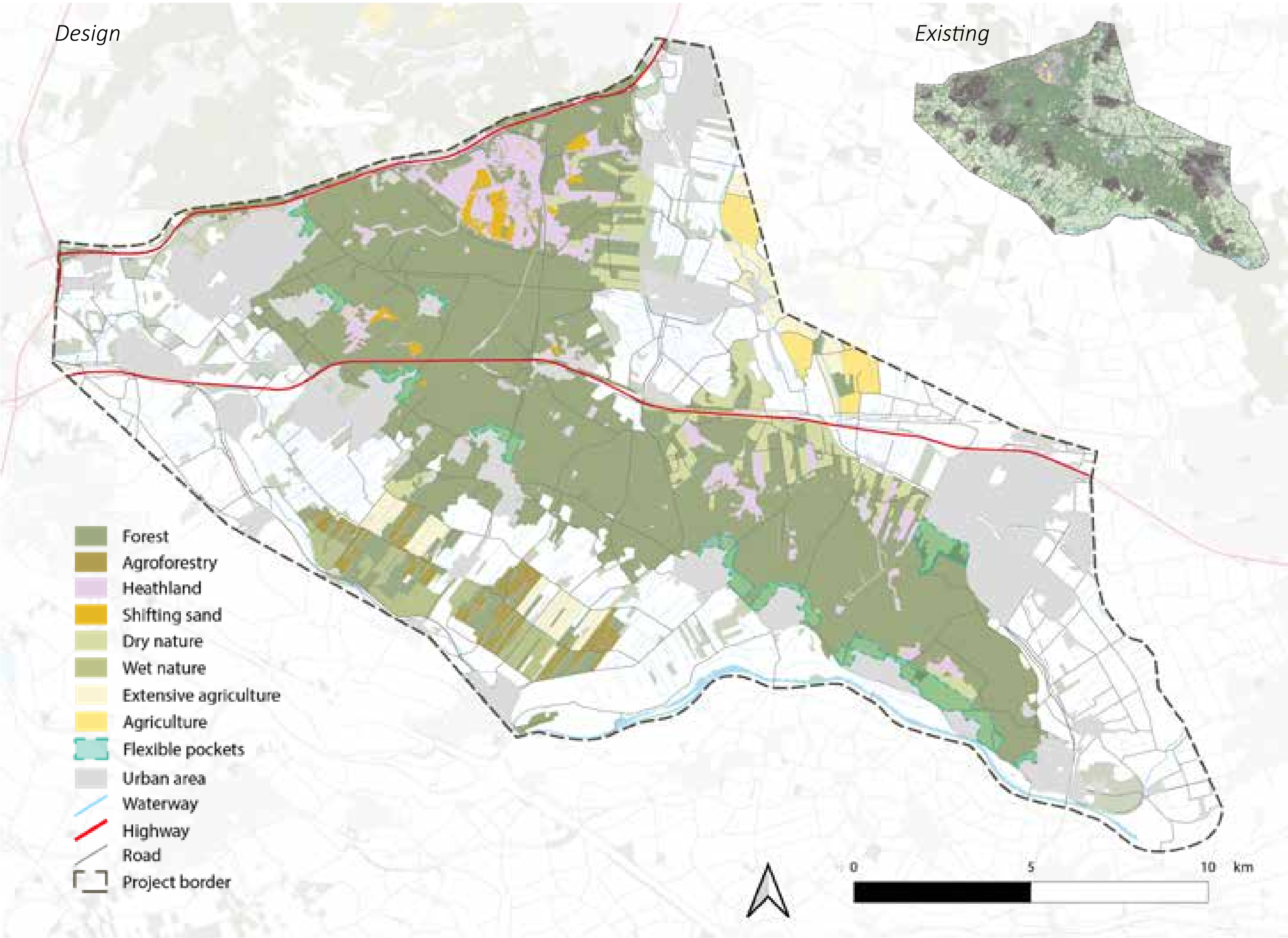


Figure 54: Design alternative mosaic landscape (Author, 2022)

SUMMARY

The strength of this design alternative is the focus on small-scale diversity. The small-scale mosaic landscape creates a redundancy of habitats and species. Moreover, it aligns with the current diverse landscape. However, small-scale interventions do have not such a profound impact on the large-scale system.

5.5 EXPERT EVALUATION

This evaluation results from the expert meetings where the design alternatives were discussed with experts specialized in hydrology and ecology. The outcome of these meetings will not be addressed per design alternative but rather in a coherent story discussing the strengths and weaknesses throughout the three alternatives.

For both the ecological and the hydrological alternatives, the hydrological processes define the type of land use regarding water availability and quality.

EVAPOTRANSPIRATION AND INFILTRATION

A significant increase in infiltration by transforming pine forests into deciduous forests is questionable, especially because the effect of climate change and temperature rise prologues the growing season of deciduous trees,and, therefore, evapotranspiration is increased. However, transforming the forest into dry nature is proven to be effective for the increase of infiltration.

With the transformation of pine forest into deciduous forest, the most effective approach is considering the within-plot diversity. The general forest is already a mix of pine and deciduous trees, while within plots, the diversity in tree species is limited. Besides improved biodiversity, deciduous trees can especially increase the quality of leaf litter and, therefore, the water-retaining capacity of the soil itself. This improves the soil quality, which is fundamental for improvement of biodiversity at poor sandy soils.

HEIGHTENING GROUNDWATER

Heightening the groundwater level on the higher slopes directly affects land cover. Agriculture in these areas is not desirable because the drainage for these plots will diminish the effect of the intervention. Besides, the heightened groundwater level increases local seepage leading to more wet areas on the eastern side. If these more wet areas are suitable for wet nature is questionable. Especially because the predicted increase of groundwater level in the future is uncertain, the new KNMI report will probably integrate more scenarios where this increase will not occur. Nevertheless, the areas with local seepage should be handled differently than the surrounding areas because of the difference in water influx and quality.

WATER QUALITY

Water quality is leading for both hydrology and ecology. First, at the lower slope and the foot, iseepage water with better qualities for nature development should not be not mixed with the more eutrophicated water from agricultural fields. Second, the heightened groundwater level can cause water nuisance within low-lying villages such as Veenendaal and Leusden. This water can be retained at lower fields surrounding Veenendaal. However also here water quality of the city water and seepage water should be separated. The third focus regarding water quality is the fields surrounding the Kromme Rijn. The Rhine feeds the Kromme Rhine with lower water quality than the local seepage. Fruit farmers use this water to sprinkle their orchards, taking this water inwards close to the area of Langbroek with seepage water.

NATURE MANAGEMENT

Dry nature at the high slopes is a good habitat for many fauna species. Management is a subject of consideration here. These areas can be managed by either grazing or extensive mowing like sinus management. Variety in edges and within patch diversity of mosaic patterns define the success of flora and fauna development.

MOSAIC LANDSCAPE

The mosaic design alternative is hydrologically the most difficult to realize at the lower slope and foot because of the small-scale differences in water level and quality. Unbundling land use is desirable to adapt to the local water system. At the higher slopes and plateau, the diversity of the mosaic contributes to an increase in infiltration and is ecologically beneficial. Moreover, strengthening the existing mosaic of the forest at the western slope contributes to ecological diversity and connectivity.

The large-scale connection of the ecological alternative is important for larger animals. However, the smaller fauna species do not cover large distances. For these species, small-scale diversity and connectivity is most important. Keep in mind to design for the habitat a specie uses. For example, if a bee only needs 25 square meters of habitat, ensure that the habitat has sufficient diversity and is well-connected.

AGRICULTURE

Agriculture and the citizens of the area are elements that are minimally considered in these alternatives. All alternatives heavily impact the space available for agriculture. First, locate the areas of extensification of agriculture, and areas where intensive agriculture can remain. Make sure to integrate the future role of the farmers within this landscape. Second, the citizens came here with a perception of the landscape they are living in. If this changes drastically in the future, they should be taken along in the process.

6. FINAL DESIGN

In this chapter, first, the strengths of the three design alternatives are combined, and the expert feedback is incorporated. Second, a scale step is taken to elaborate on the spatial configuration of the design guidelines.

6.1 DESIGN

The hydrological system is the key process defining the local circumstances in the design. Water availability and quality guide suitable land cover. Ecological structures are adapted to the hydrological system. Subsequently, the landcover is defined based on the hydrological processes and ecological structures (see figure 55)

PLATEAU

The forest at the plateau focuses on increating infiltration and improving diversity. The dry nature is interwoven in the structures of the forest enhancing diversity in species and succession stages. Local wet nature that is already present will be preserved. Whether the local wet nature increases in the future is uncertain to design with because it depends on local impermeable layers of the soil. The mosaic landscape of forest with dry nature facilitates a gradual transition to and connection with the natural slopes.

SLOPES

At the high slopes, natural grassland will be the main land cover, absorbing the heightened groundwater level and protecting the natural structures of the forest. At the eastern slope, local seepage will increase. There are opportunities for wet nature to develop. Whether the wet nature development is successful depends on some uncertainties, such as the continuity of the seepage flow, the level of eutrophication, and the effect of climate change on the groundwater level.

FOOT

Besides local seepage, deep seepage at the foot will increase due to the increased infiltration and heightened groundwater level. At places where the deep seepage is the largest and most natural patches are present, an expansion of wet nature is envisioned to decrease the drainage within the whole hydrological system.

AGRICULTURE

Agriculture takes place between the high slope and the foot. These places are not too dry like the high slopes at not too wet like the foot, where a lot of drainage is needed to create suitable circumstances for agriculture. With extensive local agriculture, water can be retained for dryer periods with the least interference with the natural hydrological flows.

VILLAGES

To prevent flooding in the villages, flexible pockets of natural grassland are designed at the steepest slopes of the forest close to the villages. However, some villages will become more vulnerable to the raised groundwater level. Around these villages water, retention basins are designed at the foot to collect the surplus water for agricultural purposes.

This design improves the the hydrological system by adapting the landcover in the whole project area. Showing that improving resilience takes place beyond the subject of design, the forest at the Utrechtse Heuvelrug. All elements need to fall into place to create a resilient system.

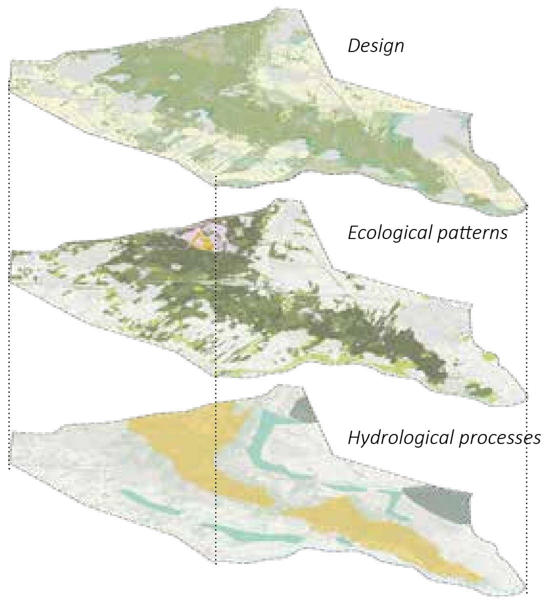
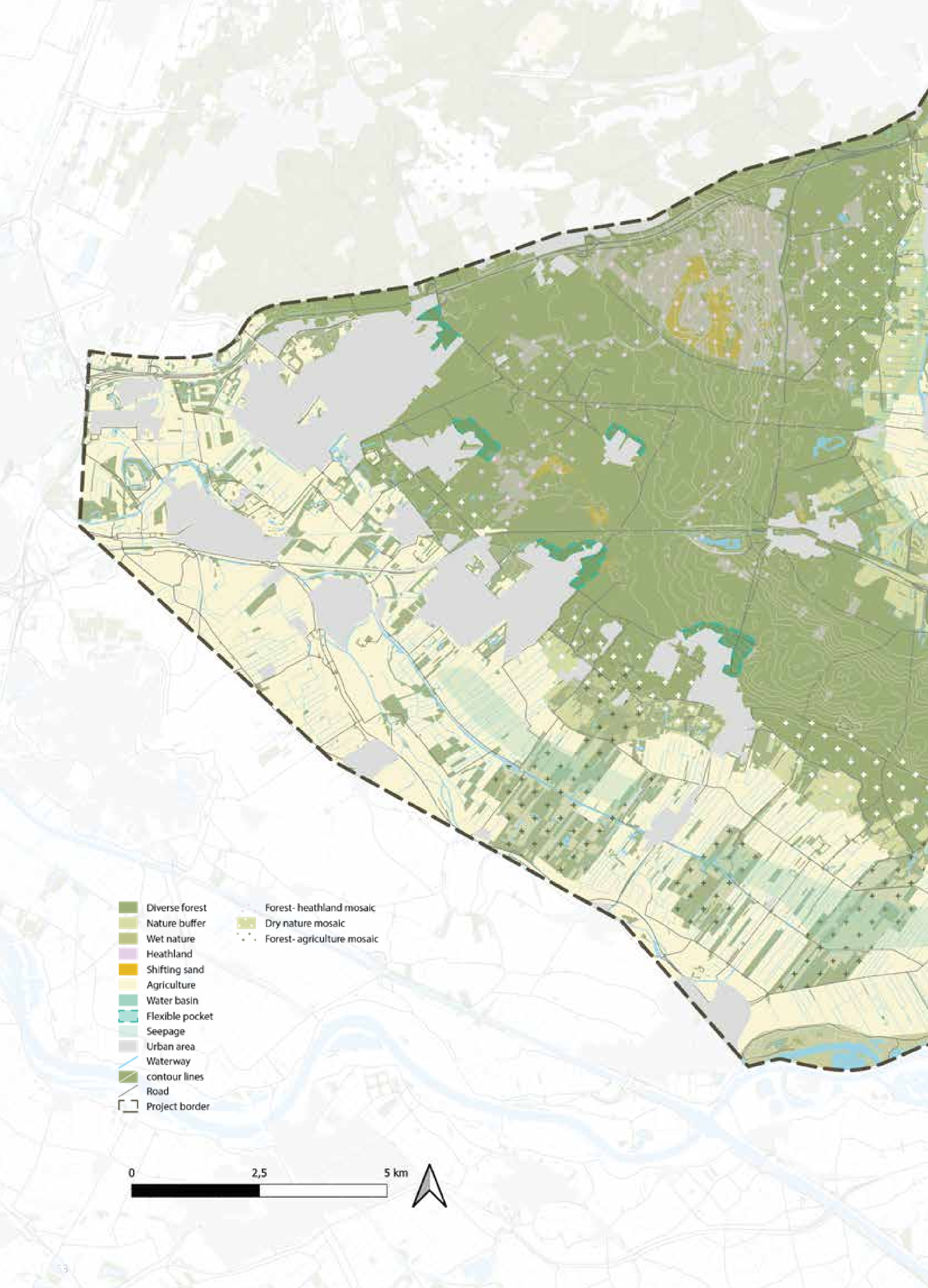


Figure 55: The hydrolgical, ecological and land cover layers (Author, 2022)



Diverse forest
Nature buffer
Wet nature
Heathland
Shifting sand
Agriculture
Water basin
Flexible pocket
Seepage
Urban area
Waterway
contour lines
Road
Project border
Forest- heathland mosaic
Dry nature mosaic
Forest- agriculture mosaic
0
2,5
5 km

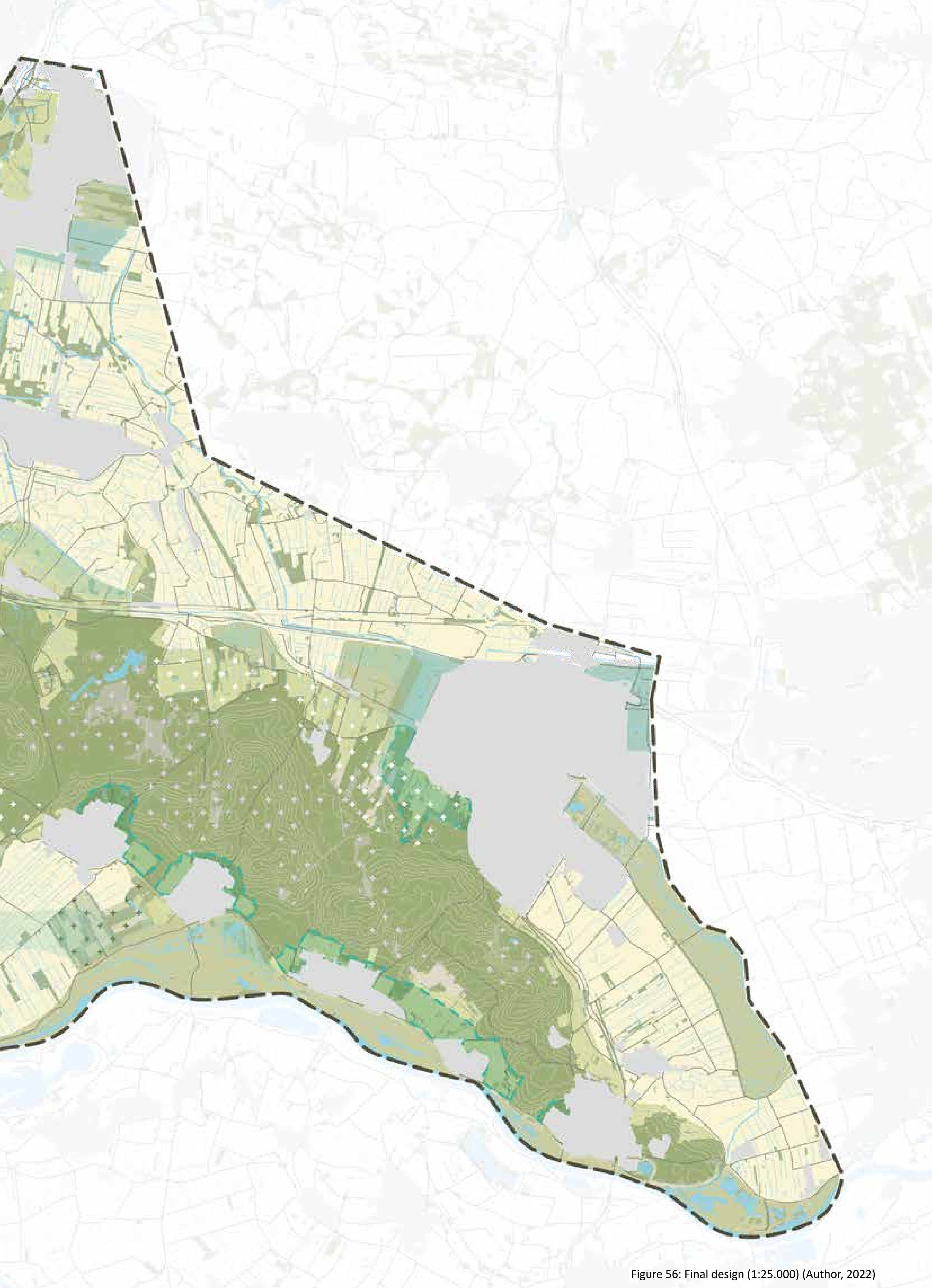


Figure 56: Final design (1:25.000) (Author, 2022)

6.2 FOREST AT THE PLATEAU

The forest at the plateau suffered from droughts and had a monotonous structure. The designed forest increases infiltration and diversity, and leads to a more attractive forest with an ever-changing scenery. The variation of heather fields, young forests, and developed forests creates an interesting landscape.

The design guidelines for the forest at the plateau focus on increasing infiltration and improving diversity. Transforming pine forests into heathland and natural grassland contributes the most to the infiltration increase. Gradually replacing poor pine production forests with deciduous forest slightly contributes to increased infiltration.

However, deciduous trees mainly increase diversity by improving soil quality, diversifying tree species, and multiple succession stages. Soils with well-developed leaf litter can retain more precipitation. The old growth forests improve diversity with their progressed succession stage, which gradually will increase the share of dead wood. The heathland patches represent early succession.

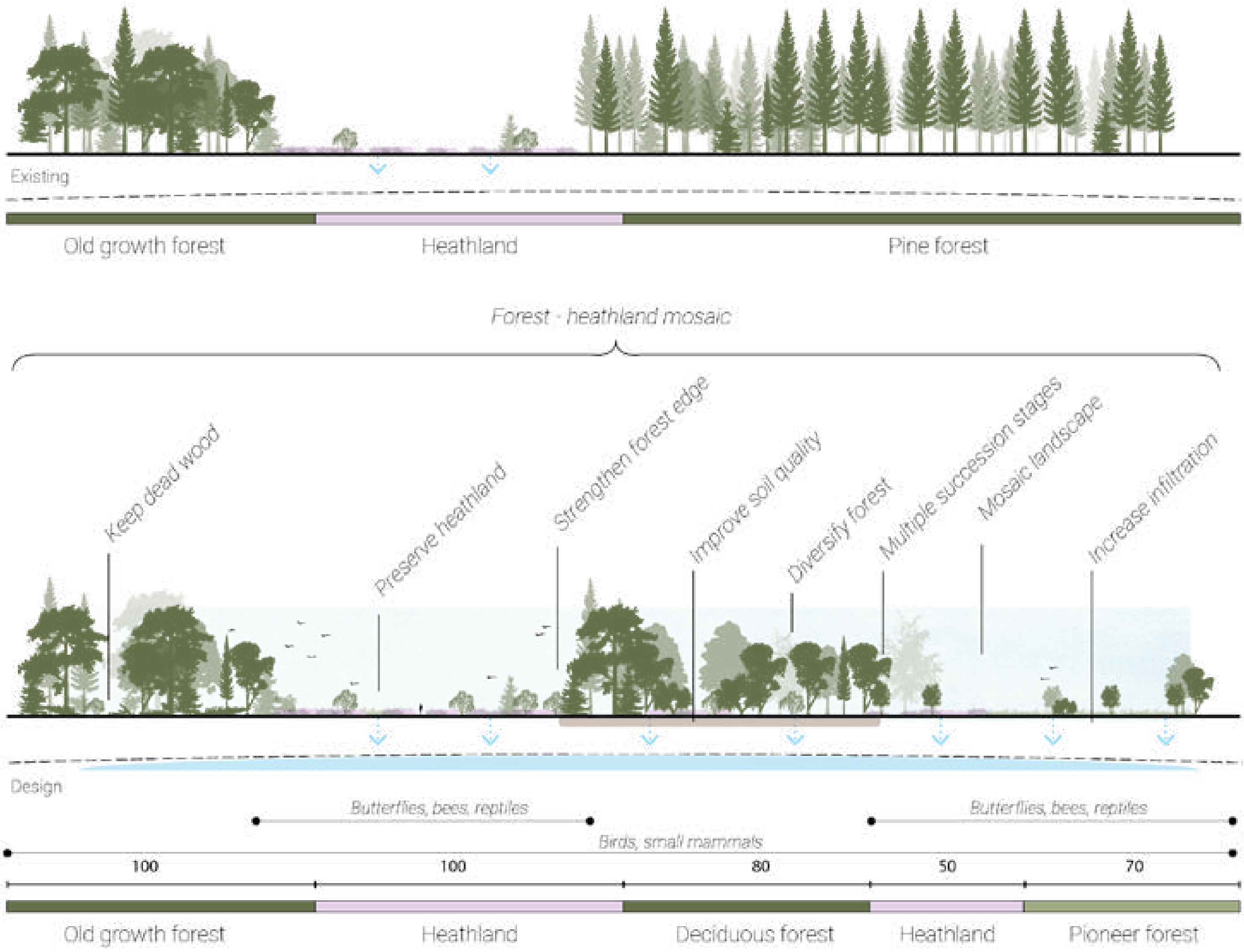


Figure 57 : Section forest at the plateau (Author, 2022)

DESIGN GUIDELINES

The following guidelines are applied to the forest, focussing on improving diversity and connectivity while increase infiltration.

- Diversify forest by transforming pine into deciduous forest
- Increase infiltration by transforming pine into heathland and natural grassland.
- Improve soil quality with tree species that accumulate leaf litter
- Preserve and connect heathland
- Preserve and connect old forest growth places
- Improve diversity with a forest - heathland mosaic of local wet nature, small forest patches, shifting sands, and heathland
- Incorporate multiple succession stages
- Strengthen forest edge

Figure 58: Heathland connectivity (Author, 2022)

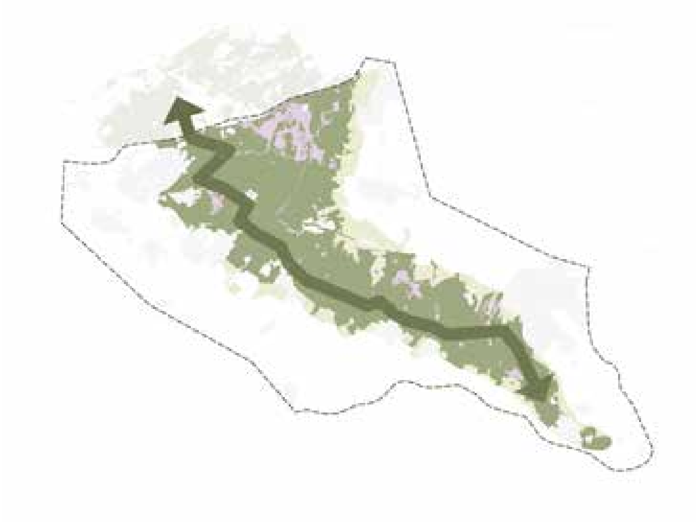


Figure 59: Old growth forest connectivity (Author, 2022)

6.3 NATURE BUFFER AT HIGH SLOPE

At the high slope, the congruence between the hydrological characteristics and suitable land use is emphasized. The current agriculture at the high slopes is affected by droughts, while the agriculture is responsible for the drainage resulting in low groundwater levels. From the perspective of the hydrological system, improvements at the high slopes affect the whole system's resilience. Heightening the groundwater level is a profound intervention with extensive consequences for the land cover.

Applying a buffer of nature at the high slopes, enables the groundwater level to be heightened. Furthermore, it can strengthen the forest edge and protect the forest from disturbances such as eutrophication.

The development of natural grassland depends on the groundwater level and eutrophication of the soil (Natuurtypen, n.d.). Some fields may already be nutrient-poor and immediately develop species rich hayland. Others may have been fertilized for years and years. These former agricultural fields may need a gradual transition from agricultural use to herb-rich grassland and eventually to hayland. Sod cutting and disposal of the grass cuttings can be management interventions that speed up the process.

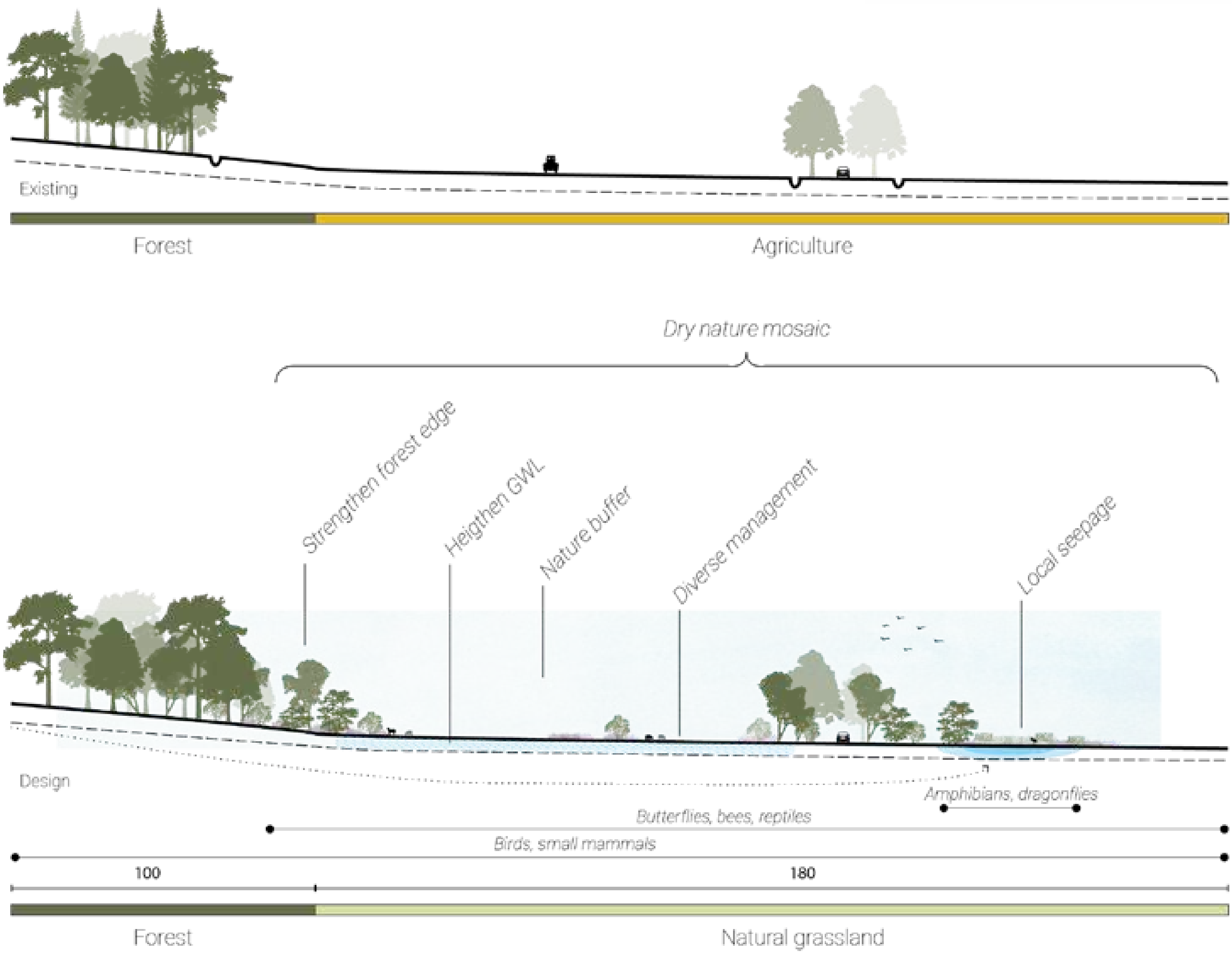


Figure 60: Section buffer at the slope (Author, 2022)

Furthermore, diversified management, like sinus mowing, helps to improve habitat diversity by creating gradual transition, height differences, and microclimates. Height differences with small shrubs and trees add up to the habitat diversity.

Herb-rich grassland may have less biodiversity with rare species. However, it provides shelter for many species like butterflies, bees, birds, reptiles and small mammals. The haylands, dry, moist or wet provide shelter to the same specie groups and contain more rare flora species.

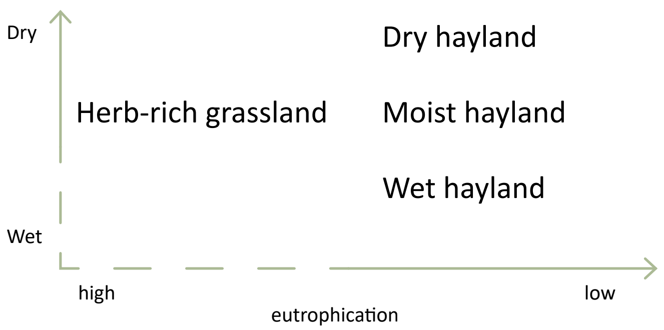


Figure 61: Natural grassland types (Author, 2022)

Finally, the dry nature buffer will be a place where seasonal fluctuations and soft transitions become visible. Resulting in a dynamic landscape that reflects the natural processes.

DESIGN GUIDELINES

The following design guidelines focus on the development of a natural buffer that can absorb the heightened groundwater level while increasing diversity.

- Heighten groundwater level
- Nature buffer
- Adapt to local seepage at the high slopes with natural grassland
- Diversified management
- Strengthen forest edge
- Improve diversity with a dry nature mosaic of natural grassland, heathland, and forest patches

6.4 FLEXIBLE POCKETS

The flexible pockets at the high slope anticipate extreme weather events and the flooding villages can experience. At the steep slope, where villages are close to the forest, surface runoff can cause flooding. Pockets of natural grassland create places for precipitation to infiltrate. Retaining the precipitation benefits the whole hydrological system and prevents water from running into the villages. Furthermore, it breaks up the rather dense forest structure into a more mosaic landscape. The flexible pockets anticipate seasonal fluctuations.

DESIGN GUIDELINES

The following design guidelines prevent flooding and increase infiltration while improving diversity.

- Improve diversity with a dry nature mosaic of natural grassland, heathland, and forest patches
- Prevent flooding with flexible pockets
- Increase infiltration with natural grassland patches

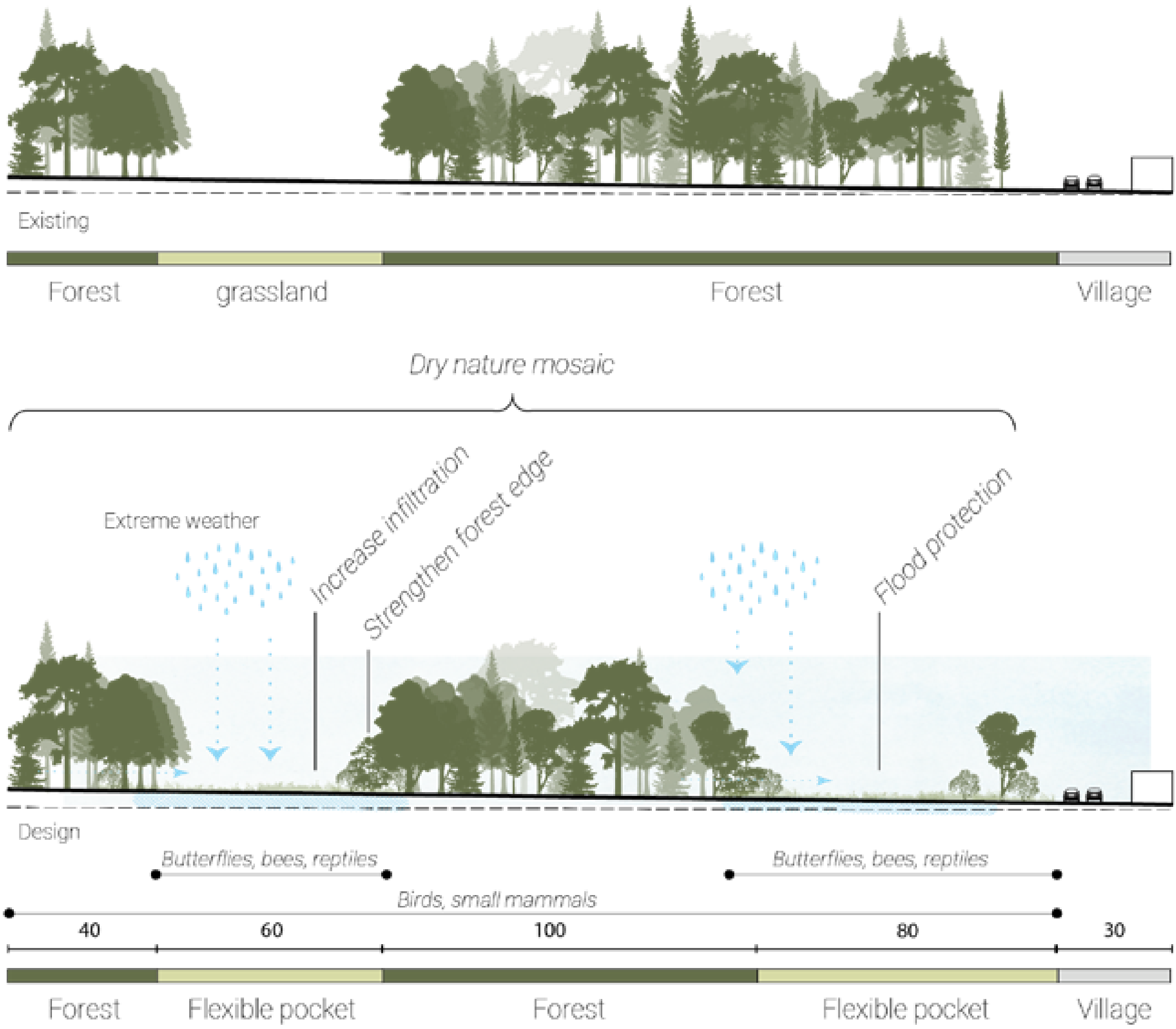


Figure 62: Section flexible pockets (Author, 2022)

6.5 FOREST CORRIDOR

The forest patches at the western slope contain opportunities to add natural structures in a foremost agricultural landscape. A mix of natural grassland and agroforestry is located in between the forest structure to create a robust and diverse natural structure. The mix of patch types increases diversity in habitats for species such as bees, butterflies, birds and reptiles. Furthermore, the structures can provide shelter for species living around the agricultural fields. The agricultural fields at the western slope are considered agricultural cultural heritage. Which already included some habitats for fauna by hedgerows, ditches, and field edges (Provincie Utrecht, 2018b). The agroforestry and extensive agriculture maintain the agricultural nature of this area and simultaneously improve its natural qualities. The extensive agriculture creates a gradual transition in groundwater level and natural structures to the more intensive agricultural fields. The majority of these patches can still be managed by farmers, contributing to nature development.

DESIGN GUIDELINES

The following design guidelines strengthen the natural structure while adapting to the seepage flow.

- Strengthen natural structures with a forest- agriculture mosaic of forest patches, agroforestry, natural grassland patches, and extensive agriculture
- Strengthen forest edge
- Adapt to deep seepage with natural grassland
- Strengthen forest patches with agroforestry
- Create a gradual transition with extensive agriculture
- Couple landcover

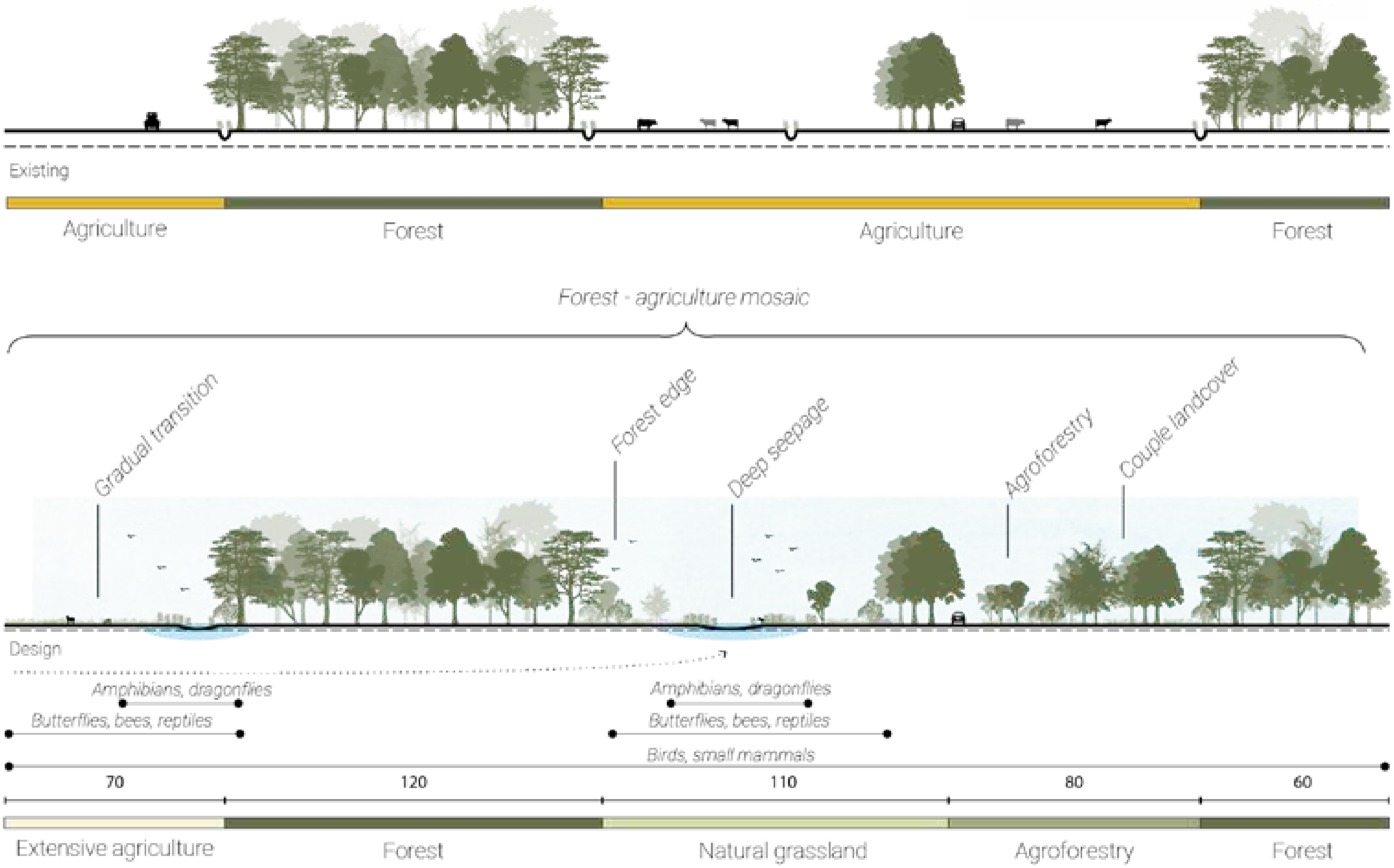


Figure 63: Section forest corridor (Author, 2022)

6.6 WATER RETENTION

Increasing the amount of water in the hydrological system will increase the seepage flow with consequences for the low-lying fields at the foot. The increased seepage flow improves opportunities for wet nature. However, low-lying villages such as Veenendaal and Leusden will experience more flooding. Both the seepage water and the village water should be retained. However, there is a quality difference between seepage water and village water. The seepage water is suitable for the development of wet nature. The village water is of different quality and less suitable for nature development. However, it could be a water source for agricultural field. The deep seepage of wet nature and water supply of the water retention should be separated. Wet nature should be developedat places with the most natural structures and the most seepage. Water retention can be realized at places close to the villages with less seepage and little natural structures. These water basins provide water for agriculture in periods of drought and heighten the groundwater in the surrounding area. Heightening the groundwater level is not always considered desirable in agricultural fields. However, the area around the Utrechtse Heuvelrug is more vulnerable to droughts than to flooding (Hydrologic, 2021). Therefore, a general increase of groundwater could be beneficial for periods of droughts and has little negative effects on flooding the agricultural fields at the low slopes. Moreover, these water basins can collect water in case of extreme weather.

DESIGN GUIDELINES

The following design guidelines lead to water retention by adapting to the local circumstances.

- Adapt to deep seepage with natural grassland
- Collect groundwater from villages into water basins for agriculture
- Strengthen forest edge

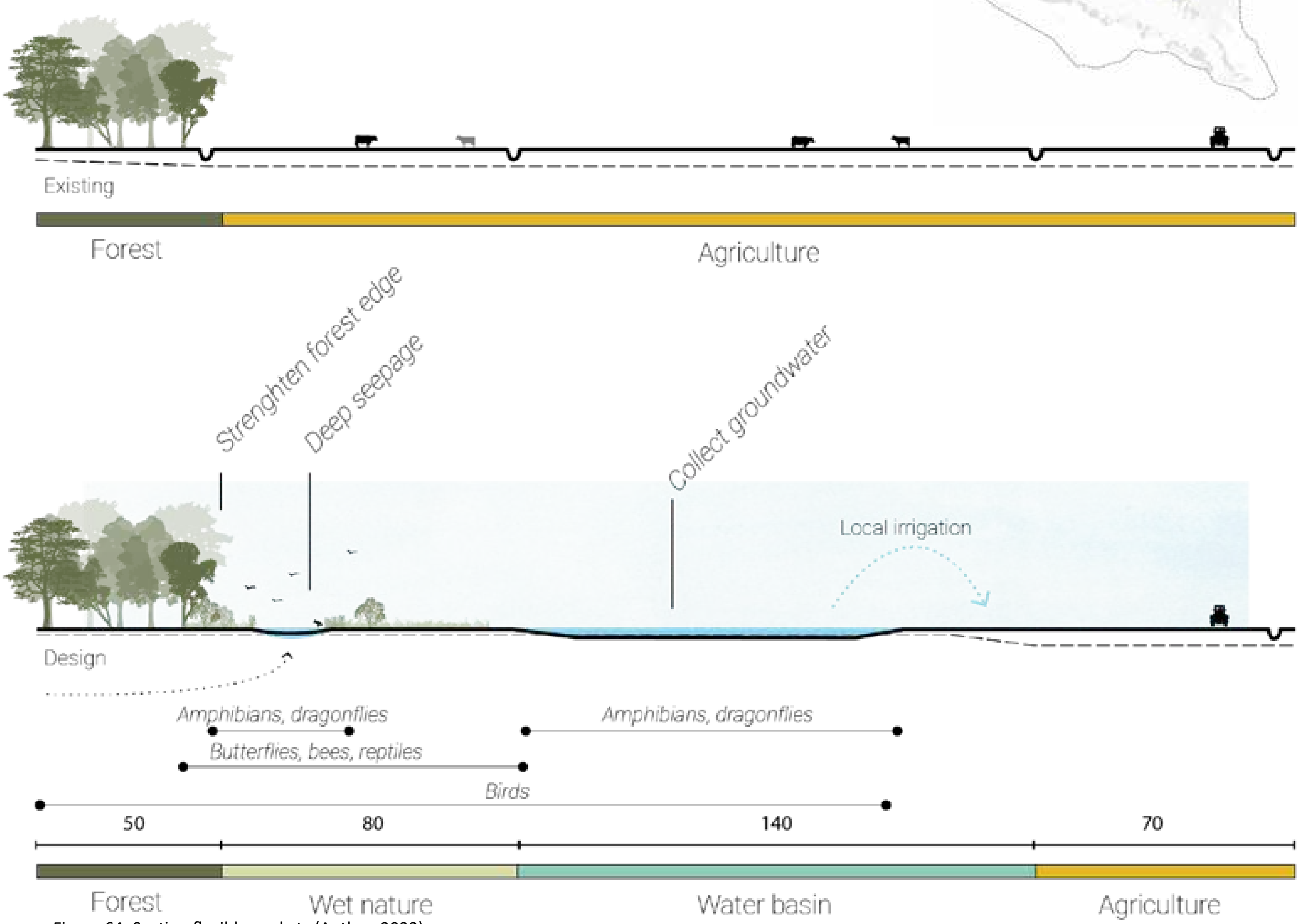


Figure 64: Section flexible pockets (Author, 2022)

6.7 AGRICULTURAL FIELDS

Agricultural fields will be concentrated in places with the least natural patches and not too much seepage. The focus will be on improving the circumstances and preparing for the drought periods. Some fields could be lowered slightly to retain water for dry periods. In these fields, extensive agriculture can take place when the field is not covered in water. At the low slopes, agricultural fields could reduce drainage because the fields could benefit from a slightly higher groundwater level in the dry spring and summer. If the fields are close to natural structures, hedgerows are placed between the fields to improve diversity and connect to the surrounding nature.

DESIGN GUIDELINES

The following design guidelines lead to water retention and connectivity with natural structures.

- Retain water in extensive agricultural fields
- Improve diversity and connect to surrounding nature with hedgerows between agricultural fields

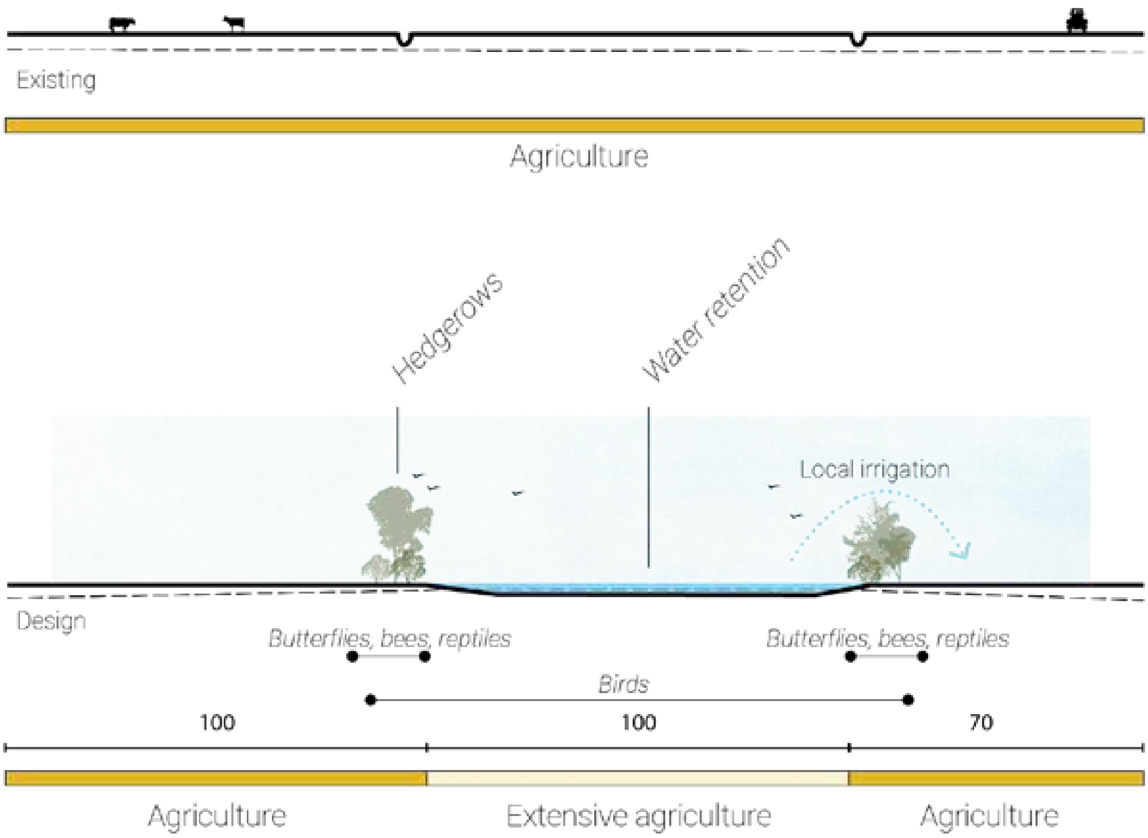


Figure 65: Section forest corridor (Author, 2022)

6.8 DESIGN OUTCOMES

The forests at the Utrechtse Heuvelrug suffers from the effects of droughts and had little future perspective. It deals with monotonuous plots, poor soil quality and a highly modified hydrological system.

This design increases resilience by applying hydrological and ecological interventions, and contributes to an attractive and diverse landscape with site-sensitive design guidelines. Opportunities in the landscape are combined to reinforce each other based on the system approach of resilience.

Addressing all attributes of resilience in a forest system is complex. Diversity, connectivity, variability, and redundancy; they are all interrelated. In the final design, the various elements are combined to reinforce each other. The design deepens the cup by creating space for disturbances to be asborbed, while strengthening and connecting natural diversity.

Within the forest, diversity is increased, resulting in an attractive forest with a mix of heathland, open grassland, old growth forest, and developing forest. This creates an interesting landscape where the forest is an ever-changing scenery.

The gradual transition from forest to natural grassland replaces the hard transition between forest and agriculture with all its negative effects, resulting in a new natural buffer facilitating biodiversity and protecting the forest. The natural diversity in the fragmented landscape is used to connect natural structures. Agriculture will be less prominent. Therefore, a more continuous natural structure can develop, promoting the hydrological system. The natural structures improve the landscape quality resulting in a diverse and ever-changing landscape.

Figure 66: Visualisation natural buffer (Author, 2022)

Consciously designed flexible pockets for surface runoff for villages at the slope and water retention for groundwater flooding for villages at the foot embeds the functioning of the villages into the landscape. As a result, citizens can see that there is space around their villages dedicated to preventing problems, simultaneously increasing the natural values around the villages. Hydrologically, these interventions increase the amount of water that is retained within the system.

The forest-agriculture mosaic strengthens the landscape's diversity, resulting in a compact natural structure for flora and fauna while it becomes an attractive landscape to experience the rural fields. Surrounded by agricultural fields, it is an oasis for fauna. The hedgerows lined alongside the agricultural fields provide a natural corridor towards the larger natural structures. Moreover, the dense natural structure decreases drainage. Lastly, the lowered agricultural fields to retain water show that the opinion on agricultural fields shifts toward a more integrative approach where environmental factors are taken into account.

7. CONCLUSION AND DISCUSSION

7.1 CONCLUSION

CONTRIBUTION

This research aimed to generate design guidelines that improve drought resilience of forests at high sandy soils. First, this was accomplished by formulating attributes of resilience, and transforming the theoretical approach of resilience into spatially applicable principles for the forest landscape. Secondly, design guidelines were implemented into a landscape design for the forests at the Utrechtse Heuvelrug based on a profound understanding of the landscape.

This chapter summarizes the outcomes of this research by first answering the sub-research questions. The outcomes of the sub-research questions lead to answering the design question.

SUB RESEARCH QUESTIONS

SRQ 1:

What spatial characteristics define a resilient forest system?

A literature review on the concept of resilience answers this sub-research questions. First, the definition of resilience and applicability to the landscape context was discussed. Resilience originates from ecology but has evolved into socio-ecological systems integrating both natural and anthropological patterns and processes. Every system has an adaptive capacity, the ability to absorb disturbances. Flexibility and variability are needed for a system to absorb disturbances and deepen the cup.

Second, the concept of resilience was applied to a landscape context focusing on ecological and socio-ecological systems. A literature review on the characteristics of resilience resulted in four attributes of resilience: Connectivity, diversity, variability, and redundancy. All the attributes represent a spatial applicable characteristic that increases the system's adaptive capacity.

Lastly, the attributes of resilience were translated into spatial principles applicable to forest landscapes. A review of several literature documents on resilient forest design in landscape architecture resulted in the following twelve spatial principles; Corridors, stepping stones, mosaic landscape, preserve existing forest, forest edge, buffer zone, adapted to local circumstances, flexible pockets, multiple succession stages, diversity among habitats and plurality of habitats.

SRQ 2:

How does a forest ecosystem at high sandy soils function?

A landscape analysis answers the second sub-research question to generate insight into landscape patterns and processes. Based on the understanding of the landscape, problems and opportunities were described. Revealing the relevance and impact of ecological structures and hydrological processes on the resilience of forest systems.

Due to the location of the forest at a high sandy moraine ridge, there is no contact with groundwater. Therefore, the trees within the forest are groundwater independent and rely on precipitation. However, with the effects of climate change, the periods of drought between precipitation increase. On top of that, the soil quality within the forest is poor, leading to reduced water-retaining capacity of the soil. Furthermore, the monotonous structure of forest plots with mainly pine trees decreases diversity and increases evapotranspiration. Therefore, ecological diversity is an important characteristic to increase the ability to absorb disturbances.

The forest is an isolated natural structure surrounded by villages and agriculture. This decreases the resilience of the forest system because of the poor connectivity to other natural structures. Furthermore, the poor age distribution and monotonous plots of the forest itself decreases diversity within the forest.

There are opportunities to improve infiltration, decrease evapotranspiration and increase water retention, both beneficial for ecological diversity and hydrological adaptation. The effect of these measures stretches beyond the boundaries of the forest itself. An increased infiltration at the plateau, results in an improved seepage flow to the slopes, creating opportunities for nature development close to the forest. Simultaneously, nature development can increase ecological diversity and connectivity for the forest while buffering the negative effects of agriculture on the forest.

SRQ 3:

What is the effect of resilient guidelines to drought resilience of forests at high sandy soils?

Three design alternatives were formulated based on the theoretical understanding of resilience and the most relevant outcomes from the analysis; ecological network, hydrological zones, and mosaic landscape. These alternatives were developed based on the depth of the cup; the ability to absorb disturbances. The hydrological zones is the design alternative considering the large-scale hydrological system with slow processes. Six design guidelines were formulated, most of them dealing with an increase of infiltration, reducing evapotranspiration and retaining water. The ecological network design alternative considers both large-scale connections as small-scale diversity. Seven design guidelines were formulated, most of them dealing with an increase in diversity, connecting natural structures, and protecting existing forest structures. Finally, the mosaic landscape focuses on small-scale plot diversity. It consists of four design guidelines, most of them dealing with increasing small-scale diversity and strengthening existing landscape structures.

Subsequently, an expert evaluation of the three design alternatives took place with ecological and hydrological experts. The proposed design guidelines were validated in the evaluation, and feedback on the design alternatives was given. A a result, there was not a clear preference for one design alternative but rather a combination of design guidelines that reinforce each other.

DESIGN QUESTION

Which design guidelines enlarge forest drought resilience at high sandy soils?

The design question builds upon the knowledge generated from the sub-research questions. The insights gathered from the three design alternatives and the feedback from the expert evaluation were transformed into a final design. The final design consists of over twenty design guidelines, illustrating the site-specific spatial integration of design guidelines. All the design guidelines are based on the formulated spatial principles and relate to one or more attributes of resilience. The detailed sections illustrate the spatial implications of the design guidelines into the landscape. The combination of design guidelines leads to a resilient forest system that is embedded in an attractive landscape.

The design guidelines are applied in a final design that illustrates the landscape qualities and opportunities of integrating the concept of resilience for drought resilient forests. In the final design, the forest is diversified, resulting in an attractive scenery and an increase of infiltration. The natural buffer around the forest promotes the hydrological system, connects natural structures, and improves diversity. Around the villages, natural structures absorb possible negative effects of flooding while increasing the landscape quality. At the western slope, natural forest structures are protected and strengthened, improving the natural qualities while decreasing drainage. Lastly, the situation for the agricultural fields is improved by creating space for extensive agriculture where water can be retained.

For the forest at the Utrechtse Heuvelrug, hydrological and ecological interventions have been formulated. However, a landscape architectural implementation was missing. This research transforms the technical interventions into site-sensitive design guidelines, resulting in an attractive landscape design based on strengthening the qualities of the Utrechtse Heuvelrug.

7.2 DISCUSSION

In this research, the application of resilient design guidelines onto a forest landscape improved drought resilience for forests at high sandy soils. A theoretical review on the concept of resilience and the formulation of design guidelines for a site-specific design enhanced this. The outcome of this research is relevant for other forests located at high sandy soils. For forests in both the Netherlands and surrounding countries dealing with the same problems at high sandy soils, the outcome of this research can be used to improve drought resilience. However, every forest landscape at high sandy soils has its own unique characteristics. Therefore, only a profound understanding of the unique landscape functioning will lead to a successful implementation of drought resilient design guidelines.

THEORETICAL APPROACH

The literature review on the concept of resilience created an understanding of the concept and its attributes. Originating from ecological resilience, the applicability to spatial landscapes is found in the approach of socio-ecological systems (Folke, 2006). This research contributes to new knowledge development by researching the implementation of resilient attributes into a forest landscape with spatial design principles.

The human experience of forest landscapes is briefly touched upon but not further elaborated on. For this research, it was not considered as a factor influencing the resilience of the forest system but rather an integral part of landscape architecture. This research relies on the notion that aesthetic quality and the human experience of the landscape is an integrated element of landscape design (Bell & Apostel, 2008).

The attributes of resilience summarize the most important characteristics of a resilient system. However, the selection of resilient attributes could have had a better foundation if a systematic selection of the attributes took place. An extensive literature review of the concept of resilience regarding ecology, landscape design, and forest landscape could have led to a systematic selection of the resilient attributes.

Furthermore, the time span of this research only provided a summary of possible resilient spatial principles for forest landscapes. A thorough evaluation and research on spatial principles in landscape architectural literature could have improved the theoretical base for the spatial principles. However, the formulated spatial principles summarize the abundance and complexity of spatial implications for resilient forest landscapes.

APPLIED METHODS

This research contributes to design strategies for drought resilient forests at high sandy soils in two phases. First, the theoretical approach of resilience is transformed into spatially applicable principles. The second phase was the formulation of design guidelines and application into a design based on the formulated principles and a profound understanding of the landscape.

Several steps took place to complete this research. First, the literature review resulted in a theoretical understanding of resilience for forest landscapes. Second, the landscape analysis helped to generate a profound understanding of the forest system. Finally, the concept of resilience and the system approach resulted in an analysis of the most fundamental problems and opportunities regarding drought resilience within forests.

Third, the research through design was a suitable method to research the spatial implications of drought resilience. Whereas hydrologists and ecologists suggest a set of interventions (Hydrologic, 2021), a landscape architect considers a variety of options and eventually combines all layers of the landscape in a design. Resulting in place specific design guidelines embedded in an attractive landscape.

Fourth, a preliminary set of design guidelines was applied to three design alternatives. The design alternatives represented a range of possible outcomes based on the depth of the cup; the ability of the system to aborb disturbances.

Fifth, the expert evaluation resulted in an informed assessment of the preliminary design guidelines and design alternatives, considering the complexity of forest systems while simultaneously verifying the technical accuracy.

And lastly, the final design implemented the results of the design alternatives and expert evaluation. The final design illustrated the spatial implications of the design guidelines into the landscape.

The combination of a theoretical understanding of the concept of resilience, a profound understanding of the landscape's functioning, and the design development with experts led to an informed final design with drought resilient design guidelines for forest landscapes. Following these methods, this research is recommended for other forest systems at high sandy soils that aim to improve drought resilience.

However, there are some limitations considering the applied methodology. The first limitation is the development of design alternatives that took place rather early in this research due to time constraints. Therefore some assumptions of the theoretical understanding and site-specific situation needed to be made.

Second, multiple meetings could have improved the reciprocal dialogue fundamental for integrating landscape ecology and landscape architecture (Ahern, 2005). Third, the involvement of experts strengthened the triangulation of this research. However, due to time constraints, only two expert meetings took place with hydrologists and ecologists.

DESIGN PROCESS

The design process implemented a set of design guidelines onto a design for the forests at the Utrechtse Heuvelrug. These design guidelines create space in the landscape for variation and disturbances to take place by adapting to the local circumstances. Furthermore, the design guidelines improve diversity and connectivity in the landscape, increasing the forest system's redundancy and improving the ability to recover from a disturbance. This variability in the landscape is beneficial for drought resilience, and results in a more attractive landscape.

The design guidelines led to a large-scale final design. This final design is not a detailed plan but a proposal of locations where a set of guidelines can be applied. The final design is sensitive to subtle changes in the landscape, like hydrological differences and ecological structures. The subtle changes are used to strengthen natural structures and diversity. The final design is adapted to the local circumstances and creates space in the system for disturbances to be absorbed.

In the detailed sections, implementing a combination of guidelines illustrates the spatial implication on the landscape. Here it becomes visible that the resilience of the forest system is not only enlarged, but the landscape quality simultaneously improves with the design guidelines.

The design process consisted of two iterations. A preliminary set of design guidelines were applied to three design alternatives in the first iteration. The outcome was evaluated through an expert evaluation. The second iteration consolidated the design alternatives, expert feedback, and revised design guidelines into a final design. With the two iterations, and one including experts, validation and triangulation of the proposed design and design guidelines took place.

A limitation of the design process can be found in the focus on ecological structures and hydrological processes in the design. Other important layers of the landscape, such as recreation and cultural history, were not considered. While ecological structures and hydrological processes are most fundamental regarding resilient design (Bell & Apostol, 2008), a recommendation for a broader scope could improve the implementation of the design within the landscape.

Furthermore, the large-scale system and connections were the main topic of this research. The detailed sections, involved a design step from a systematic overview to spatial implications into the case study. However, small-scale effects were not considered due to the time span of this research.

Finally, the formulated design guidelines apply to the case study of the Utrechtse Heuvelrug as a representative for forests at high sandy soils. The design guidelines can be recommended to other forests at high sandy soils suffering from drought. However, the application of these design guidelines on multiple case studies could validate and improve the design guidelines further.

RECOMMENDATIONS

Based on the outcome of this research, there are some recommendations for further research. First, a systematic theoretical review of attributes of resilience for landscape architecture could improve the theoretical fundament and deepen the understanding of the concept.

Second, multidisciplinary research on drought resilience of forests at high sandy soils could broaden the scope considering the multitude of layers within the landscape. In this multidisciplinary research an ongoing dialogue between experts improves the reciprocal nature of landscape ecology and landscape architecture.

Third, research on a smaller scale could further improve the development of design guidelines and integration into the landscape. At a smaller scale, more elaboration can take place on the local circumstances, which specifies the application of design guidelines.

Lastly, research on multiple case studies could improve the reliability of the formulated design guidelines. From multiple case studies, the best applicable design guidelines could be distilled, and incongruence could be filtered out.

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