Graduation Studio Report

Metropolitan Ecology of Places Series

Master Thesis - Report
MSc Architecture, Urbanism and Building Sciences-Track Urbanism
Faculty of Architecture and the Built Environment
Delft University of Technology

Title:
From fields to faucet
Sub title: Safeguarding groundwater quality used for drinking water in the rural areas of the province of Utrecht with integrated solutions

Graduation Lab: Metropolitan Ecology of Places

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From fields to faucet

Safeguarding groundwater quality used for drinking water in the rural areas of the province of Utrecht with integrated solutions

Laetitia Ruiter

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Acknowledgements

Writing this thesis has been a true journey. I would like to express my sincere gratitude to everyone who contributed in this process, both directly and indirectly.

First and foremost, I would like to extend my appreciation to the Faculty of Architecture and the Built Environment, and in particular the Master's programme Urbanism. Within the Urbanism track, I was given the freedom to pursue and explore my own fascinations, which led to a thesis that I continued to enjoy writing until the very end.

I am especially grateful to my mentors for their guidance and inspiration throughout this process. I would like to thank Kristel for the energy and positivity you brought to our conversations, combined with structure and challenging questions. I also wish to thank Remon for your constructive feedback, where honesty, humour, and self-reflection played a central role. I truly appreciated our discussions and feedback sessions. They motivated me to get the most out of the project, while keeping enjoyment and personal growth at the forefront.

I also would like to thank the province of Utrecht, especially Lisz and Mieke, who guided me during the thesis. I have learned a great deal during my time with the Water team, and I will carry this knowledge with me into my professional career. I would also like to express my gratitude to my colleagues for their enthusiasm and willingness to support me.

I have also learned a lot from my fellow students, and I am thankful that although we worked individually, we went through this journey together.

Furthermore, I would like to thank my friends and family for their support and interest in my research.

Lastly, I give my heartfelt thanks to my parents, who have always offered a listening ear and were always willing to help whenever I needed it.

ABSTRACT

Groundwater quality in the Netherlands is under pressure, which has significant implications for the quality of drinking water. Groundwater is a vital source of drinking water—in the Netherlands, 60% of drinking water is derived from groundwater. At the same time, the country faces significant urbanization and a pressing need for an agricultural transition. Urbanization and agricultural practices place increasing pressure on rural areas, while concurrently contributing to the deterioration of groundwater quality.

The purpose of this research is to give insight in possible spatial considerations of safeguarding groundwater quality, used for drinking water. It also aims to provide research-based argumentations for specific spatial choices and to create an integrated future perspective for the rural areas in the province of Utrecht regarding groundwater quality. This thesis adresses the research question: "How could the groundwater quality at groundwater abstractions, for public drinking water, be spatially safeguarded in the rural areas of the province of Utrecht by 2050, by applying integrated solutions for both groundwater quality, agriculture and as well as urbanization?"

This graduation research explores integrated solutions for groundwater quality, agriculture, and urbanization through the application of the 'pattern language' method. By formulating four scenarios, future perspectives were developed for case area the Kromme Rijnstreek, each presenting a distinct set of solutions. In doing so, multiple approaches to safeguard groundwater quality are proposed.

The research identified sweet water storage in rural areas as a key solution. Additionally, buffer zones, groundwater friendly agriculture, agroforestry, and collaboration in circular water management emerged as important strategies for securing groundwater quality. Finally, the study demonstrated that the Pattern Language method is an effective tool for initiating a content-oriented dialogue among professionals from various disciplinary backgrounds.

Key words | Groundwater quality, drinking water, integrated solutions, Pattern Language, province of Utrecht, Kromme Rijnstreek

BESTUURSSAMENVATTING

Grondwaterkwaliteit en ruimtelijke inrichting - problemen en uitdagingen

De kwaliteit van grondwater staat onder druk in Nederland, wat grote gevolgen heeft voor de kwaliteit van drinkwater. Grondwater is een belangrijke bron voor drinkwater - in Nederland wordt 60% van het drinkwater gemaakt van grondwater. Tegelijkertijd is er een grote verstedelijkingsdruk en is er de noodzaak voor een duurzame landbouwtransitie. Naar verwachting zal in Nederland de bevolking in 2035 groeien tot 18,9 miljoen en rond 2050 tot ongeveer 19,6 miljoen. Zowel de verstedelijking als de landbouw zetten druk op het landelijk gebied en beïnvloeden tegelijkertijd negatief de grondwaterkwaliteit. Zo zorgt een overschot van pesticides en nutriënten in de landbouw voor een verslechtering van de grondwaterkwaliteit. In stedelijk gebied zijn zware metalen, medicijnresten en stoffen zoals PFAS een groot probleem voor de grondwaterkwaliteit.

Gezien deze ontwikkelingen staan landelijke gebieden aan de vooravond van een transformatie, en staat Nederland voor cruciale keuzes op het gebied van landbouw, verstedelijking en grondwaterkwaliteit. De vraag naar drinkwater neemt toe, terwijl de druk op de grondwaterkwaliteit eveneens toeneemt. De kernvraag is hoe de kwaliteit van het grondwater, dat wordt gebruikt voor drinkwater, tijdens deze transformatie gewaarborgd kan worden, en welke ruimtelijke afwegingen gemaakt moeten worden voor landbouw en verstedelijking. Er zijn integrale oplossingen nodig om dit aan te pakken.

In dit afstudeeronderzoek wordt deze kernvraag behandeld in de context van de provincie Utrecht. Volgens prognoses van het CBS wordt verwacht dat de provincie Utrecht een van de drie snelst groeiende provincies van Nederland zal zijn. Daarnaast heeft de provincie Utrecht de ambitie om de landbouw te verduurzamen door middel van het Utrechts Programma Landelijk gebied (UPLG). Om deze redenen is het landelijk gebied van de provincie Utrecht gekozen om deze kernvraag te beantwoorden.

Oplossingen

In dit afstudeeronderzoek is naar integrale oplossingen gezocht tussen grondwaterkwaliteit, landbouw en verstedelijking. Dit is gedaan aan de hand van de methode “patronentaal”, waarbij afzonderlijke oplossingen tot elkaar in relatie worden gebracht. Deze patronentaal is in dit onderzoek vertaald naar een kaartspel, dat gespeeld is door diverse professionals werkend op het gebied van grond- en drinkwater, landbouw en stedelijk gebied. De oplossingen variëren tussen technische, organisatorische en ruimtelijke oplossingen. Met het kaartspel hebben de professionals gereageerd op vooraf opgesteld scenario’s met verschillende opgaven (zie figuur 0.1 op volgende bladzijde). De verstedelijkingsgraad en de vorm van de landbouw zijn de hoofdvariabelen in deze scenario’s. De scenario’s en het kaartspel zijn toegepast op casusgebied de Kromme Rijnstreek, een gebied waar veel opgaven samen komen. Deze ontwerpen zijn te vinden in hoofdstuk 7. De volledige uitwerking van de oplossingen zijn te vinden in het patronenboek.

Aan de hand van de workshop is duidelijk geworden dat het kaartspel een geschikte methode is voor een verkenning van de ruimtelijke inrichting van een gebied, met grondwaterkwaliteit als leidraad. Het is gebleken dat de dialoog op deze manier vanuit de inhoud ontstaat en dit bijdraagt aan het maken van afwegingen tussen landbouw, verstedelijking en grondwaterkwaliteit.

Er is daarnaast in het onderzoek naar voren gekomen dat zoetwateropslag in landelijk gebied een sleuteloplossing is in alle scenario’s. Daarnaast kunnen bufferzones, grondwatervriendelijke teelten, agroforestry en samenwerking in circulair watermanagement worden aangemerkt als belangrijke oplossingen voor het veiligstellen van de grondwaterkwaliteit.

Ontwikkelde scenario's in het afstudeeronderzoek

[Fig.0.1]: Ontwikkelde scenario's binnen het afstudeeronderzoek (eigen afbeelding).

Aanbevelingen

Voor de provincie Utrecht worden de volgende belangrijkste aanbevelingen gedaan:

- Maak gebruik van de methode 'patronentaal' (het kaartspel) en organiseer frequent(er) interne workshops waar deze methode wordt gebruikt. Dit stimuleert dialogen gebaseerd op de inhoud en kan bijdragen aan een meer integrale planvorming;

- Stel niet alleen regels op binnen grondwaterbeschermingsgebieden, maar laat zien wat de provincie actief ondersteunt - er is een stimulerende en faciliterende rol nodig om het ongelijke speelveld tussen boeren te verkleinen;

- Ontwikkel ontwerpstrategieën voor scenario's met verhoogde verstedelijking en een toenemende vraag naar drinkwater. Ontwerpgericht onderzoek is hiervoor nodig. Trends wijzen op een toenemende drinkwatervraag en de vorm en locatie van verstedelijking na 2040 is niet geheel duidelijk. Het is essentieel om ruimtelijk ontwerpend onderzoek te doen om te begrijpen hoe zulke strategieën ruimtelijk kunnen worden geïmplementeerd, en om te anticiperen op de noodzaak van moeilijke keuzes rond de toewijzing en prioritering van drinkwaterbronnen.

CONTENTS

1. Introduction

This chapter outlines the problem context within which this thesis has been developed. Subsequently, the study area is introduced, followed by a clear articulation of the main research question and the objectives of the study.

1.1 Problem field

Declining water quality

The quality of groundwater and surface water is under pressure in the Netherlands, which has significant consequences for drinking water quality. The Water Framework Directive (WFD) is a European directive that sets standards and requirements for the quality and quantity of groundwater and surface water. The primary goal of this directive is to achieve good ecological and chemical status for surface water and good chemical and quantitative status for groundwater now and in the future. Like all other member states, the Netherlands has an obligation to meet these goals by 2027 (Informatiepunt Leefomgeving, 2025). However, the Netherlands has repeatedly failed to meet these goals (in 2015 and later in 2021), resulting in delays (Slagter et al., 2024). Despite slight improvements in water quality in recent years, most groundwater bodies and surface water bodies in the Netherlands still do not meet the desired water quality as defined by the WFD (Van Galen et al., 2020).

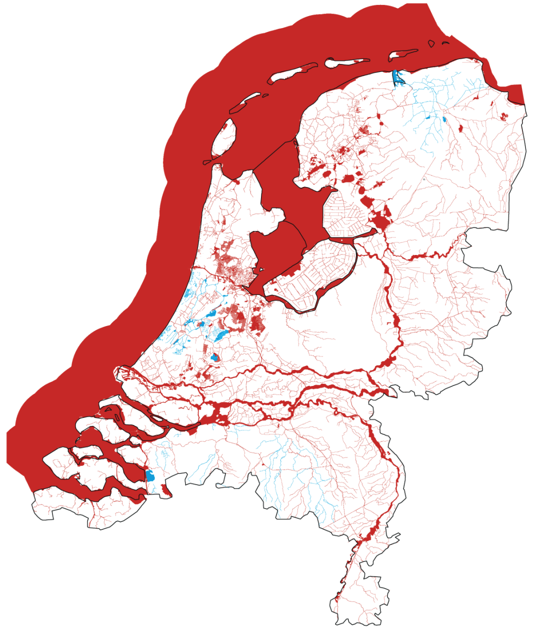
The poor water quality is already having a negative impact on the residents of the Netherlands, farmers, industry, and nature, and this situation is expected to worsen in the future (Van Driezum et al., 2020). As the quality of groundwater and surface water continues to decline, drinking water sources are also at risk. More than half of the 216 Dutch water extraction locations are already facing problems with (future) water quality or the availability of sufficient quantities. This is caused, among other things, by the presence of nutrients, pesticides, and emerging substances, including (veterinary) medicines, industrial substances, and substances from consumer products (Van Galen et al., 2020). Due to increasing and ongoing pollution, it is becoming increasingly difficult and costly to purify the water and convert it into high-quality drinking water (Vewin, 2024).

Environmentally foreign substances in groundwater, 2021

- At least one environementally foreign substance, above standard
- At least one environementally foreign substance, below standard
- No substances found

[Fig.1.1]: Environmentally foreign substances found in groundwater filters in the Netherlands.
Source: (Arcadis, 2023)

Chemical quality of surface water bodies, WFD 2021



- Does not comply to WFD norms
- Complies to WFD norms

[Fig.1.2] The chemical quality of the surface water bodies in the Netherlands, in 2021, according to standards of the WFD
Source: (Planbureau voor de Leefomgeving, 2022a)

Unsustainable agriculture

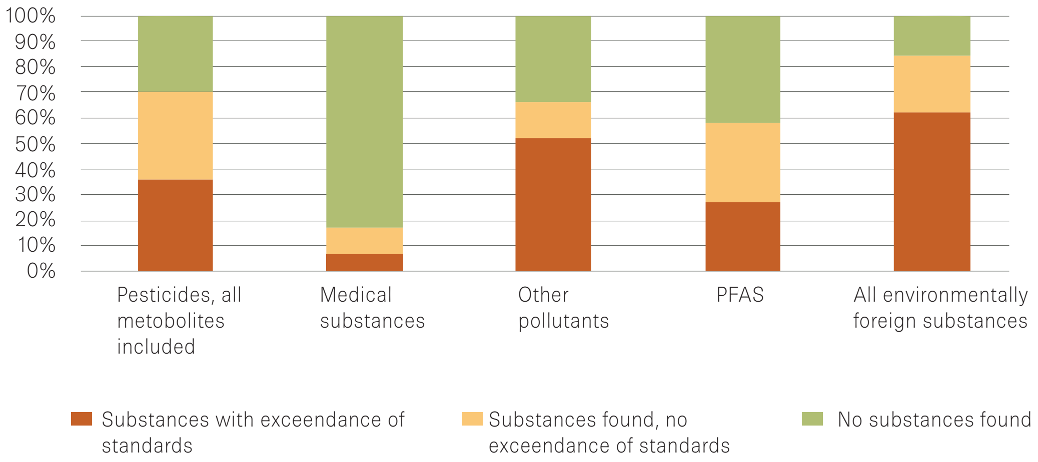
In the Netherlands, there is significant debate about the impact of agriculture on water quality (Arcadis, 2023). Despite measures taken to improve water quality, the situation continues to deteriorate due to an excess of pesticides and nutrients (As et al., 2024). Pesticides can cause serious health issues, including cancer, reproductive problems, and neurological damage (Abanyie et al., 2023). Poor water quality also disrupts the natural balance in ecosystems (Deltares, 2024). These consequences of unsustainable agriculture call for a new approach to farming, where water quality is not compromised.

In addition to the ecological pressure from Dutch agriculture, there are also other challenges for agriculture from an international perspective. Due to climate change, the amount of unusable agricultural land is increasing, which places additional pressure on food production in countries like the Netherlands. The United Nations highlights the importance of maintaining food production while simultaneously making agriculture more sustainable (FAO, IFAD, UNICEF, WFP, and WHO, 2023). There are various dilemmas that, according to Wageningen University, the Netherlands should address, including how the country should position itself in the future global food market (Bos et al., 2023). The type of agriculture is closely linked to water quality.

The Dutch national government has responded to these challenges with the National Program for Rural Areas (NPLG), a program aimed at better aligning agricultural practices with ecological limits, including water quality. However, this program was discontinued on September 4, 2024, due to changes in politics. The cancelation of the program created significant uncertainty about the future of agriculture (Geerts, 2024).

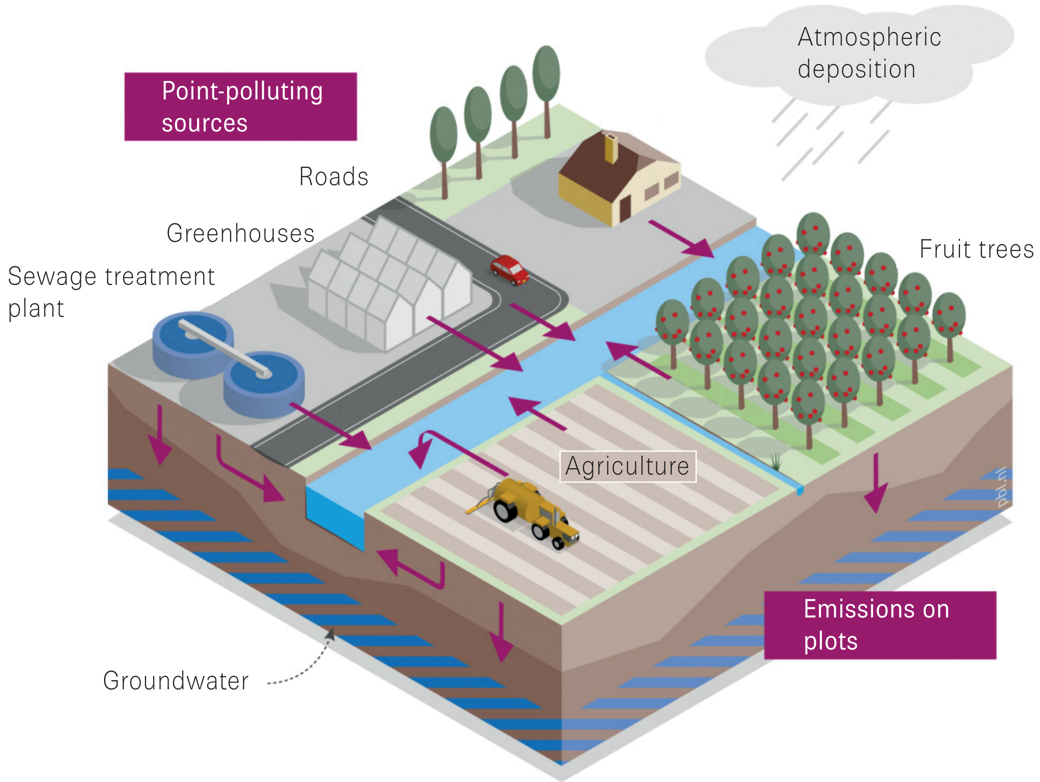
There is considerable ambiguity regarding responsibilities and the division of tasks among lower governments in this context. But even more important: a long-term vision of the agricultural sector and the rural areas in the Netherlands is lacking. This has a negative impact on the water quality goals.

Environmentally foreign substances in shallow filters



[Fig.1.3]: Summary of the occurrence of anthropogenic substances in shallow filters per substance group and for all anthropogenic substances combined. Displayed is the percentage of the monitored shallow filters in which one or more substances exceed the standard (red), in which substances were detected but none exceeded the standard (orange), or in which none of the analyzed substances were detected (green) (Arcadis, 2023). Pesticides form a big part of the total amount of environmentally foreign substances.
Source: (Arcadis, 2023)

Emissionroutes of pesticides to ground- and surface water



[Fig.1.4]: Explanation of different emission routes of pesticides to ground- and surface water from, among other things, agriculture.
Source: (Tiktak et al., 2019)

Urbanization

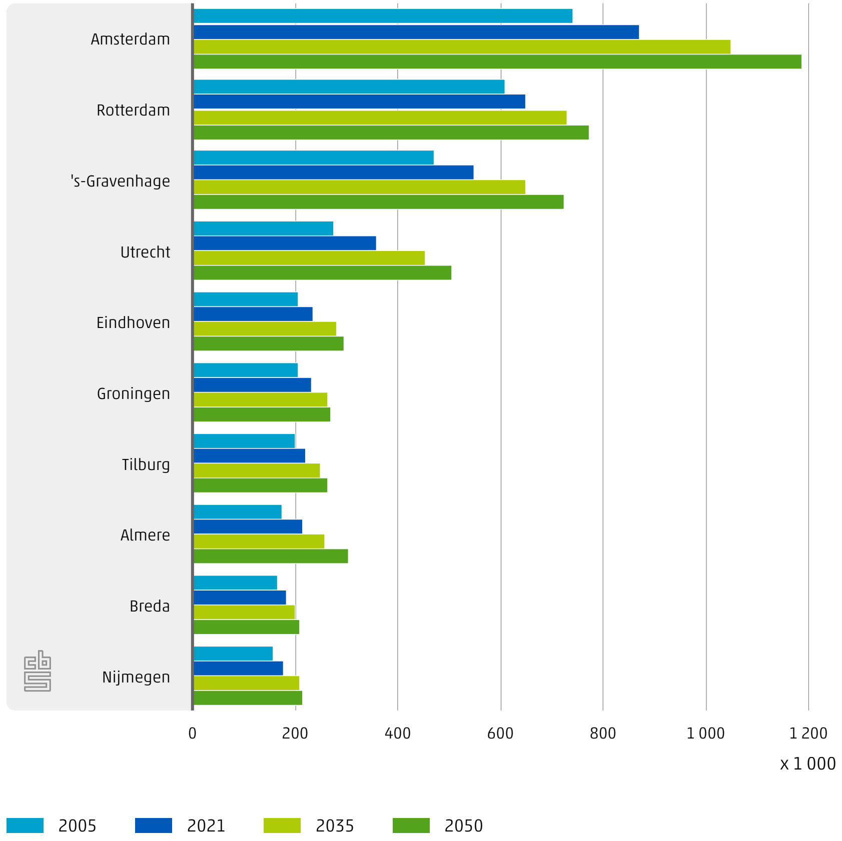
Another major challenge affecting water quality is global urbanization. Currently, 55% of the world's population lives in urban areas, a percentage expected to rise to 68% by 2050 (United Nations, Department of Economic and Social Affairs, 2019). According to the United Nations (2019), the growth of the world's population, along with the steady migration of people from rural areas to urban areas, could lead to an increase in the urban population by 2.5 billion by 2050.

In the Netherlands, it is expected that the population will reach 18.9 million by 2035, and around 19.6 million by 2050. Forecasts from the Netherlands Environmental Assessment Agency (PBL) predict significant population growth in and around major cities, with Utrecht expected to grow the fastest of the four largest cities, by more than 25% by 2035 (PBL & CBS, 2022b).

Research has shown that urbanization is an increasing source of multiple pollutants to rivers (Strokal et al., 2021). Population growth, along with the associated urbanization and infrastructure development, poses a risk to the further deterioration of water quality. Examples of emerging substances originating from urbanized areas include pharmaceutical residues, drug waste, PFAS, and microplastics. In addition, pesticides are used in urban areas, and leaking sewers can introduce a wide range of substances into groundwater (F. Swartjes et al., 2022).

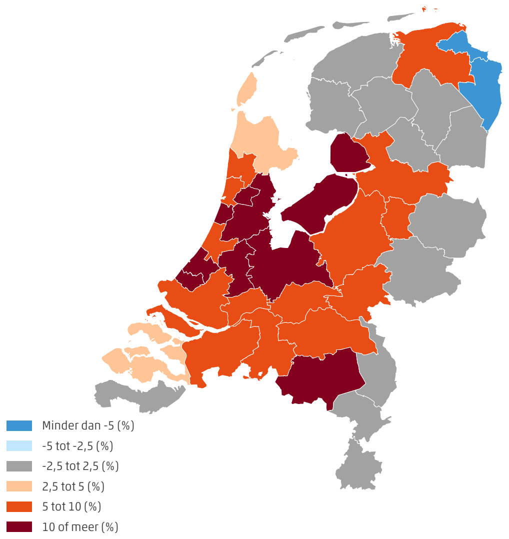
Furthermore, the growing population has led to an increased demand for groundwater for drinking water production (F. Swartjes et al., 2022) and will possibly increase further. In summary, urbanization increases pressure on water quality, thereby posing a greater challenge for maintaining drinking water quality.

Population in the 10 biggest municpalities of the Netherlands



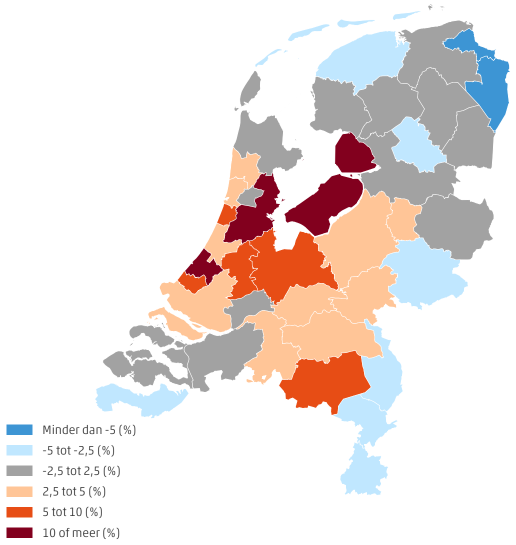
[Fig.1.5]: Prediction of population size in 2005, 2021, 2035 and 2050 in the Netherlands.
Source: (PBL & CBS, 2022b).

Population growth per COROP[1], 2021 - 2035



[Fig.1.6]: Prediction of population growth between 2021 and 2035 in the Netherlands.
Source: (PBL & CBS, 2022b).

Population growth per COROP, 2035 - 2050



[Fig.7]: Prediction of population growth between 2035 and 2050 in the Netherlands.
Source: (PBL & CBS, 2022b).

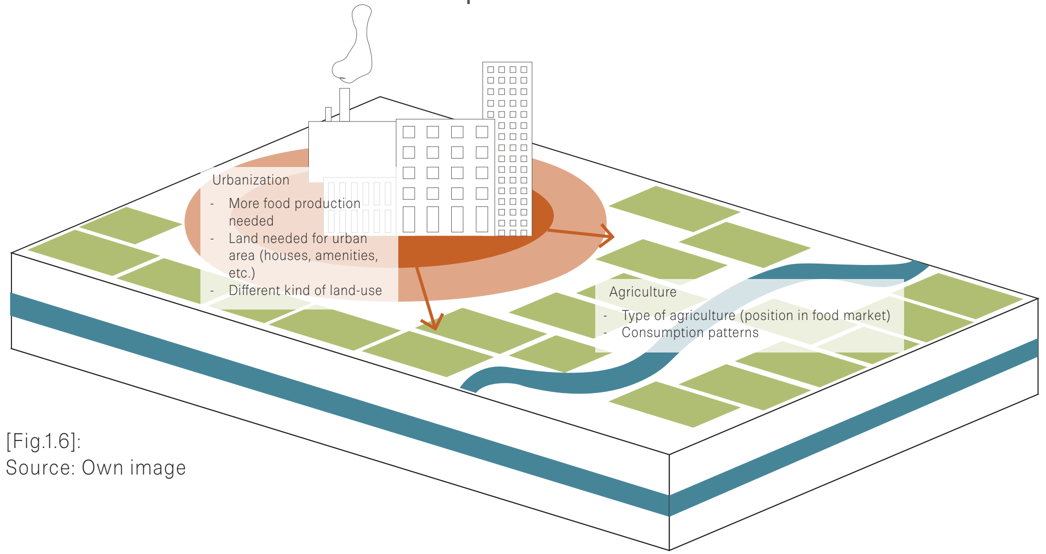
NOTES:

1 A COROP is a cluster of one or more adjacent municipalities within the same province, designed for regional research (CBS, 2025)

Pressure on rural areas

Both urbanization and agriculture require space. They both exert pressure on rural areas and simultaneously affect water quality. Urbanization exacerbates existing challenges, particularly in agriculture. Between 1950 and 2016, for example, approximately 550,000 hectares of agricultural land were lost due to urban expansion, largely replaced by housing, businesses, and infrastructure (Statistics Netherlands, 2017). Urbanization can lead to the loss of agricultural land, caused by the shift of commercial and industrial functions to the urban fringe, and the conversion of productive land into non-productive functions (such as recreation) (Beckers et al., 2020). At the same time, agriculture is needed to feed the growing world population, not only in he Netherlands, but also in Europe and the whole world. The question is what position the Netherlands occupies in the food market and how this translates into rural areas.

Pressure on rural area and its complications

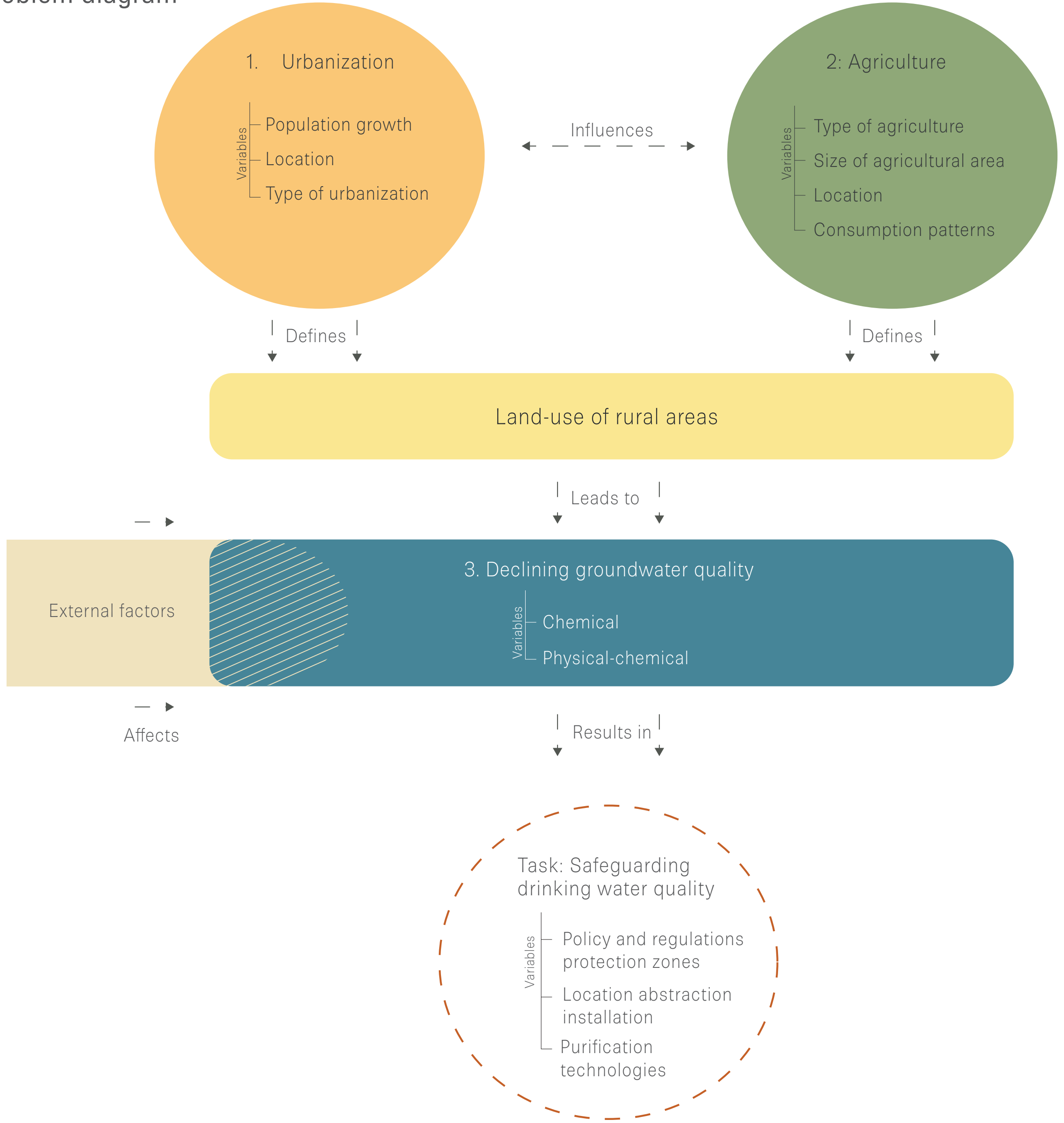


[Fig.1.6]:
Source: Own image

Task: safeguarding drinking water quality with integrated solutions

Given these trends, rural areas are on the brink of a transformation, and the Netherlands faces crucial decisions regarding agriculture, urban development, and water quality. The demand for drinking water is increasing, while pressure on water quality is also rising. Relocating groundwater abstraction sites is becoming increasingly difficult, leading to conflicts between urbanization, agriculture, and water quality. A key question is how groundwater quality, used for drinking water, could be safeguarded during this transformation and what considerations may be possible for agriculture and urbanization. Integrated solutions are needed to address this.

Problem diagram



[Fig.1.7]: Problem diagram
Source: own image

1.2 Location

Research boundary

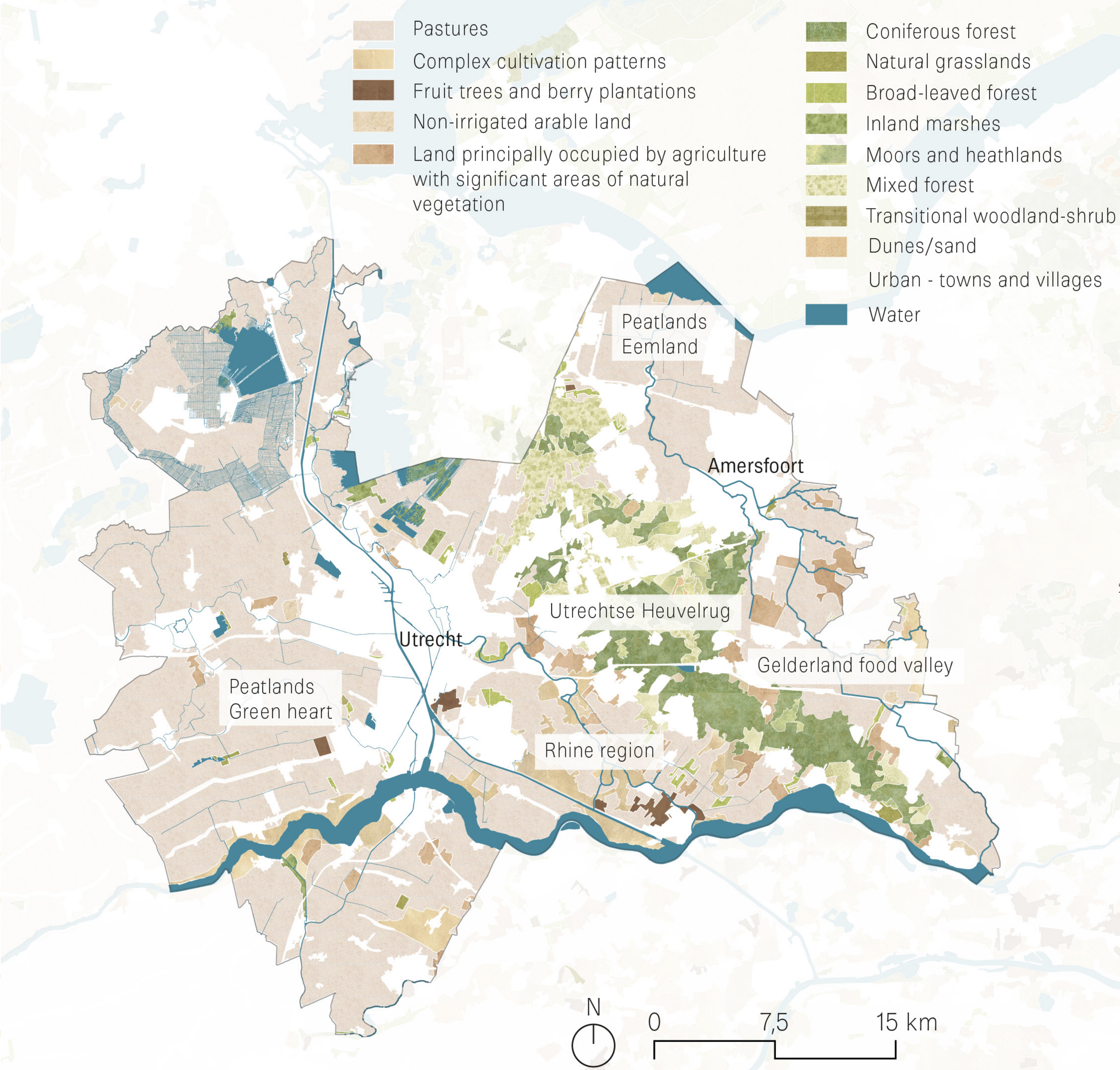
In this study, the geographical area of the Province of Utrecht serves as the spatial boundary. This region is characterized by a diversity of landscape types and includes one of the largest cities in the Netherlands: Utrecht. The region is located in the central part of the Netherlands and is part of the Utrecht Metropolitan Area (MRU). Due to its central location, the region serves as a hub for the Dutch rail and road network, connecting the Randstad to the rest of the country (Province of Utrecht, 2024).

Motivation

Besides personal interest in the region, the landscape diversity was a key factor in selecting this location. The landscape within the provincial boundaries varies from peat and clay soils to sandy soils. Moreover, the regional government aims to continue its policy to transition toward more sustainable agriculture, in contrast to the national government. Finally, the province faces significant urbanization challenges and this has an influence on the rural areas. All these tasks and ambitions combined make this region particularly relevant to the research question.

Province of Utrecht

[Fig.1.8]: Province of Utrecht in the Netherlands
Source: own image

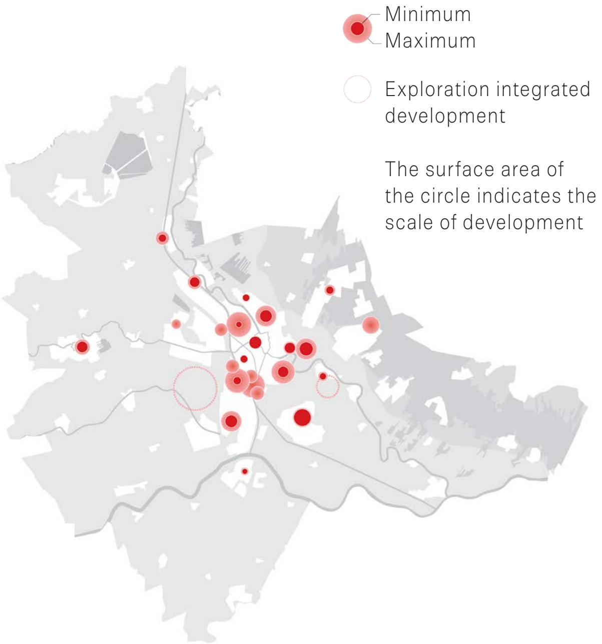


[Fig.1.9]: Landscape variation
Source: own image

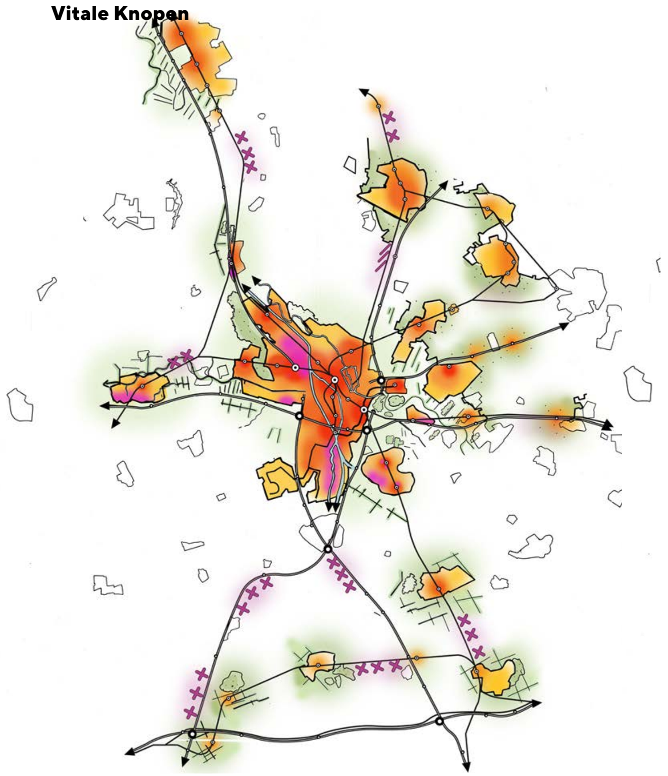
Urbanization challenge

The province faces a significant urbanization challenge: According to projections by the CBS, the province of Urecht is expected to be one of the three fastest-growing provinces in the Netherlands. Currently, the province has a population of approximately 1,370,000, but this number is projected to increase to nearly 1,464,200 by 2050 (Staat van Utrecht, 2025a) By 2030, there is a need for an additional 75,000 homes (Ministry of Infrastructure and Water management et al., 2021).

Utrecht has conducted research on how this urbanization could best be realized. This resulted in a strategy focused on vital nodes, where new housing is concentrated in already urbanized areas and around major regional public transport hubs. Additionally, the strategy includes small-scale growth in smaller towns to maintain their vitality. They are called 'vital towns' (Ministry of Infrastructure and Water Management et al., 2020). This strategy was taken into account when selecting the focus area.



[Fig.1.10] Residential development locations in the region (Provincie Utrecht, 2021)



[Fig.1.11 Visualisation of strategy 'Vital nodes' (Provincie Utrecht, 2021))

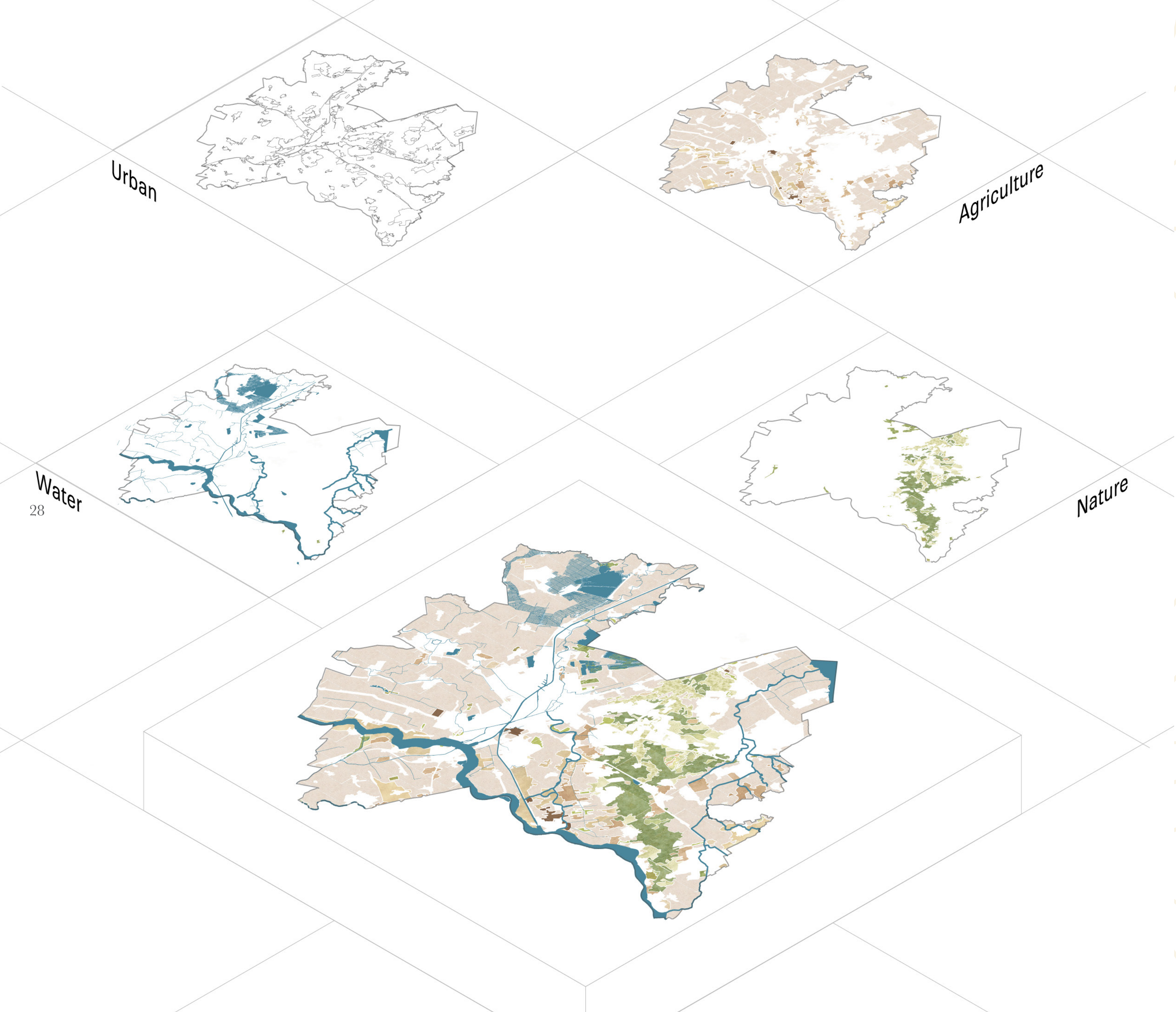
Focus area

[Fig.1.12] Focus area of the research

Focus area

This research focuses on the rural areas within the Province of Utrecht (see figure 1.12). In this research, rural areas are defined as the geographical areas that are located outside cities and towns. Nature and parks are also not included.

Additionally, emphasis is placed on the drinking water quality from groundwater abstractions, as approximately 60% of drinking water in Utrecht is sourced from groundwater. All groundwater abstractions are depicted in the map, but a focus lays on the groundwater abstractions in the defined rural areas. These groundwater abstractions are depicted in a different color.



[Fig.1.13]: Axonometry of the landscape of the province of Utrecht
Source: Own image

1.3 Problem statement and research question

Problem statement

The quality of groundwater in the province of Utrecht is under pressure which could have significant implications for drinking water quality in the future. The decline in water quality is primarily due to current agricultural practices and further urbanization. At the same time, the rural areas in the Province of Utrecht face significant spatial challenges arising from both urbanization and the need for sustainable agricultural practices. The province of Utrecht is set to become one of the the fastest-growing provinces in the Netherlands in the coming years, and it is clear that agricultural sustainability in the province of Utrecht must be achieved. Various plans exist for urbanization, agriculture, and water quality, but a clear, integrated future vision with corresponding action perspectives to safeguard drinking water quality are lacking. The province of Utrecht wishes to gain more insight into future scenarios and available considerations for rural areas to safeguard drinking water and simultaneously urbanize and redevelop the agricultural sector. The goal is identifying integrated solutions that can ensure the protection of the groundwater quality at groundwater abstractions, for public drinking water.

Research question

Based on the problem statement, the following main research question is formulated:

"How could the groundwater quality at groundwater abstractions for public drinking water, in the rural areas of the province of Utrecht be spatially safeguarded by 2050, by applying integrated solutions for groundwater quality, agriculture and as well as urbanization?"

The next chapter elaborates on how this main research question will be answered.

Objectives

- To give insight in the possible considerations of safeguarding groundwater quality, used for drinking water in the Province of Utrecht;
- To provide the Province of Utrecht research-based argumentations for specific spatial choices;
- To create an integrated future perspective for the rural areas in the Province of Utrecht regarding groundwater quality, used for drinking water.

2. Approach

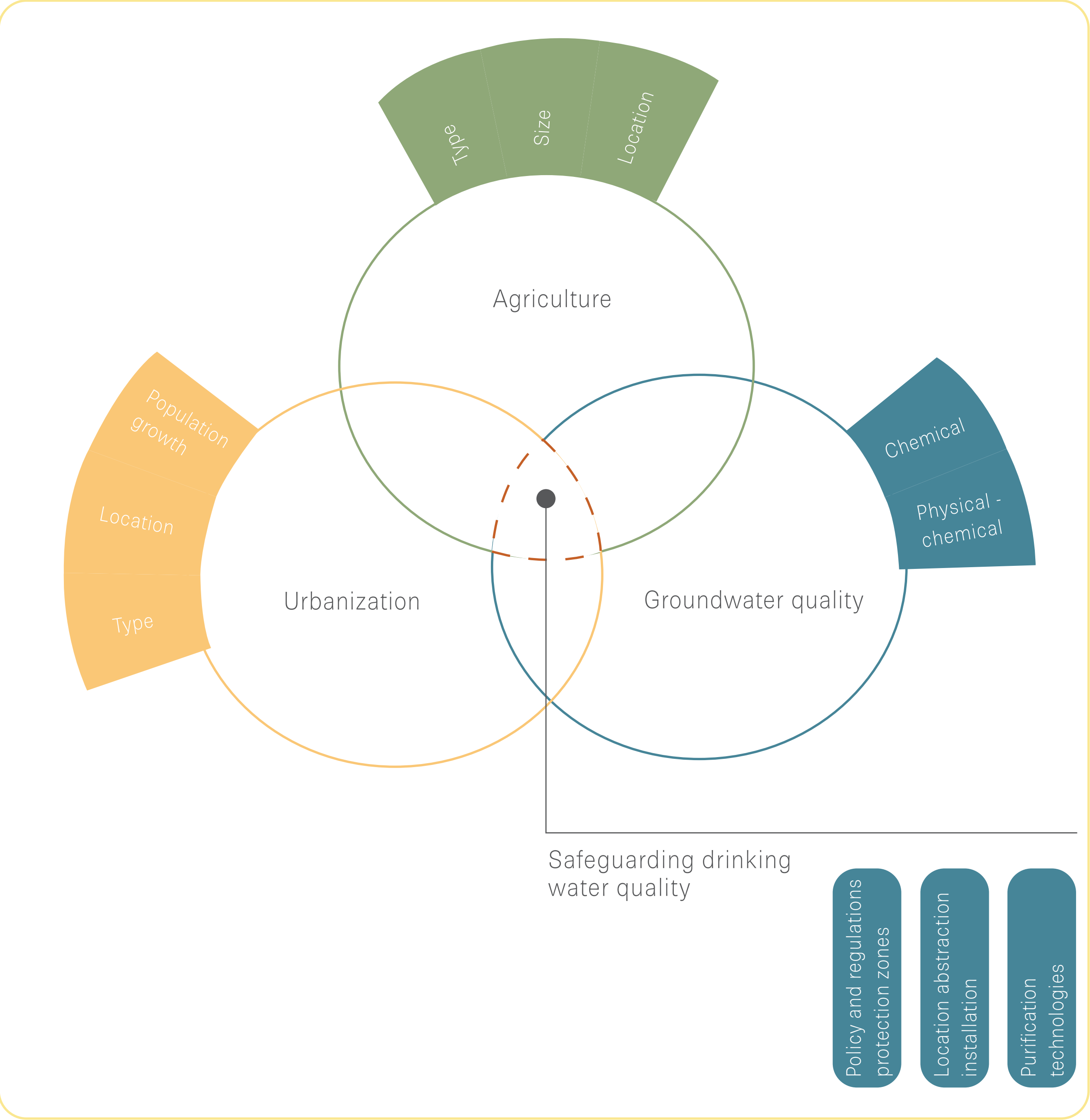
2.1 Conceptual framework

This research explores integrated solutions between groundwater quality, agriculture, and urbanization to safeguard drinking water quality in the focus area. The three components—groundwater quality, agriculture, and urbanization—are brought together in the conceptual framework. Where these components intersect lies the potential for an integrated solution to secure drinking water quality. Each component is associated with several variables, which have emerged as the most critical through an initial systemic analysis of the issue. The research focuses specifically on these variables.

Definition of urbanization

According to the European Environment Agency, “Urbanization is the increase in the proportion of people living in towns and cities” (European Environment Agency, 2025). The process of urbanization includes several components, such as the physical expansion of cities, like housing, industries and infrastructure, but also economic development and a change in lifestyle and culture. In this research, not all components of urbanization will be taken into account. **Only the physical expansion of housing and industrial/commercial area is considered in this study.** Other urbanization-related components, such as spatial claims for the purpose of the energy transition and/or climate adaptation, are not included.

Spatial boundary of research: rural areas



[Fig.14]: Conceptual framework
Source: Own image

2.2 Methodology

To address the main research question, a total of seven sub-questions have been formulated. A multi-method approach is used, meaning that multiple methods are used to answer these sub-questions. The image on the next page illustrates which methods are used to address each sub-question, along with the corresponding outcomes. These are divided into the phases: understand, specify, explore, and plan. The used methods are described on the following page.

On page 34-35, a methodological framework is presented, showing the interrelation between the sub-questions and the results. This framework is also divided into the four phases (understand, specify, explore and plan).

Additionally, the timeline on page 36-37 provides an overview of when these sub-questions will be answered.

Explanation of pattern language

During the use of the research, pattern language will be used as a method to answer a sub-question. However, it is necessary to define a pattern and a pattern language.

The concept of a pattern language is in 1977 developed by architect Alexander Christopher and his colleagues. It helps to tackle the complexity of a variety of systems, under which designing cities and landscapes (Salingaros, 2000). A pattern is a repeatable design principle that provides a solution to recurring problems. The pattern describes the problem and the solution at the same time. Patterns consist of a hypothesis, the theory that supports this hypothesis, and a practical solution or application, often illustrated with a sketch or example (Rooij & van Dorst, 2020).

Patterns together form a pattern language. They work together to design complex systems and are a clear communication tool for presenting solutions. Each pattern is linked to one or more patterns and patterns can be created in different scales (Salingaros, 2000).

Because of the nature of a pattern language to help tackling problems in a complex system, it is also useful for creating integrated solutions. Therefore, this method is used as a design tool in this research.

Research question

"How could the groundwater quality at groundwater abstractions for public drinking water, in the rural areas of the province of Utrecht be spatially safeguarded by 2050, by applying integrated solutions for groundwater quality, agriculture and as well as urbanization?"

- Literature research
- Policy document research
- QGIS data analysis
- Conversations - intern
- Interviews
- Field work
- Flow analysis
- Pattern language
- Scenario building
- Workshop

Sub-questions

Phase		Sub-questions	Aim	Methods	Result
Understand	SQ1	How is the safeguarding of groundwater quality used for public drinking water organized spatially and administratively in the province of Utrecht, and how has this evolved over time?	*Understanding the spatial and governance components of ensuring drinking water quality in the region, with time dimension.*		*Analytical maps* *Timeline* *Stakeholder overview*
Understand	SQ2	A. How and where do agriculture and urbanization affect the groundwater quality in the rural areas of the province of Utrecht, and what are the consequences for drinking water quality?	*Understanding how agriculture and urbanization impact the drinking water system, and identifying which other factors influence groundwater quality.*		*Analytical maps* *Systemic section(s)*
Understand	SQ2	B. Are there other (external) factors that influence groundwater quality in the rural areas of the province of Utrecht, and what are the consequences for drinking water quality?			
Identify	SQ3	What spatial trends and policies exist for urbanization and agriculture in the province of Utrecht, and how do they affect the rural areas and interact with each other?	*Identifying existing and future issues, potential considerations within the system, and their impact on the rural areas*		*Base of storylnes for scenarios*
Identify	SQ4	What are the bottlenecks and challenges for safeguarding groundwater quality used for public drinking water in the rural areas of the province of Utrecht, looking at the trends, policies and influences of urbanization and agriculture on water quality?	*Identifying key barriers and challenges for safeguarding drinking water regarding agriculture, urbanization and groundwater quality.*		*Overview bottlenecks and challenges*
Explore	SQ5	Which solutions and alternatives could be used to safeguard groundwater quality used for public drinking water and which considerations are possible between agriculture, urbanization and water quality?	*Exploring potential integrated solutions between agriculture, urbanization, and groundwater quality, as well as alternatives to safeguard drinking water quality.*		*Overview possible solutions and considerations* *Pattern language*
Explore	SQ6	Which future scenarios are possible to safeguard groundwater quality used for public drinking water in the rural aeas in the province of Utrecht, where integrated solutions are used for water quality, agriculture and urbanization?	*Developing feasible future scenarios and corresponding policy recommendations.*		*Future scenarios*
Plan	SQ7	Which development strategies, including relevant stakeholders, are possible and in line with the scenarios and which interventions fit within the relevant time context?	*Exploring potential interventions for integrated solutions between agriculture, urbanization, and groundwater quality, and alternatives to safeguard drinking water quality.*		*Strategies*

Methods

Literature research

For sub-questions 1 through 5, a literature review is conducted. The literature review forms the scientific foundation of this study. It involves reviewing scientific reports, articles, and books relevant to each sub-question. Literature is sourced using Google Scholar, the TU Delft library, and websites of research institutions and governmental organizations.

Policy document research

To answer sub-questions 1, 3, and 4, policy research is conducted. This primarily focuses on provincial policies related to groundwater quality, urbanization, and agriculture, as well as policies from water authorities. Additionally, national and international policies on these three themes are examined at a high level. For this policy research, documents are sourced from the websites of governmental bodies and the European Union.

Interviews

Sub-questions 3, 4, and 5 are partially answered through interviews. These interviews are conducted either in person or online. In sub-question 1, the key stakeholders are identified, forming the basis for the selection of the interview list. Recruitment of participants will primarily rely on the internal network.

QGIS data analysis

Open data in QGIS and internal data from the Province of Utrecht are analyzed and used to assess the area. This information provides a better understanding of the region and is utilized for creating base maps.

Conversations - intern

During the research, an internship is carried out within the Province of Utrecht as a graduate trainee. During this period, conversations are held with professionals about groundwater, agriculture, and urbanization. These discussions take place throughout the research period and serve as a significant source of knowledge for all sub-questions. This method is particularly important for quickly gaining an understanding of the situation at the start of the research and for building a network with other actors who are crucial for the study (e.g., for interviews).

Fieldwork

To gain insight into the production of drinking water, a visit is made to one of the drinking water production sites within the focus area. During the research it will become clear which areas need integrated solutions the most. These areas will be visited to get a better understanding of the landscape, agricultural practices and other important features.

Pattern language

Pattern language is used as a method to create solutions for different scales and create different designs. It forms a basis for the workshop, but is adjustable during the use of it. New patterns could be created if necessary.

Scenario building

Sub-question 6 is answered through the scenario building. These scenarios are developed based on trend and policy analyses. The variables for each theme (groundwater quality, urbanization, and agriculture) are incorporated into the scenarios, forming specific narratives. An overview of the characteristics of these narratives is created following the trend and policy analyses. The scenarios depict potential future outcomes for groundwater quality, agriculture, and urbanization, serving as a starting point for developing a strategy or strategies to safeguard drinking water quality.

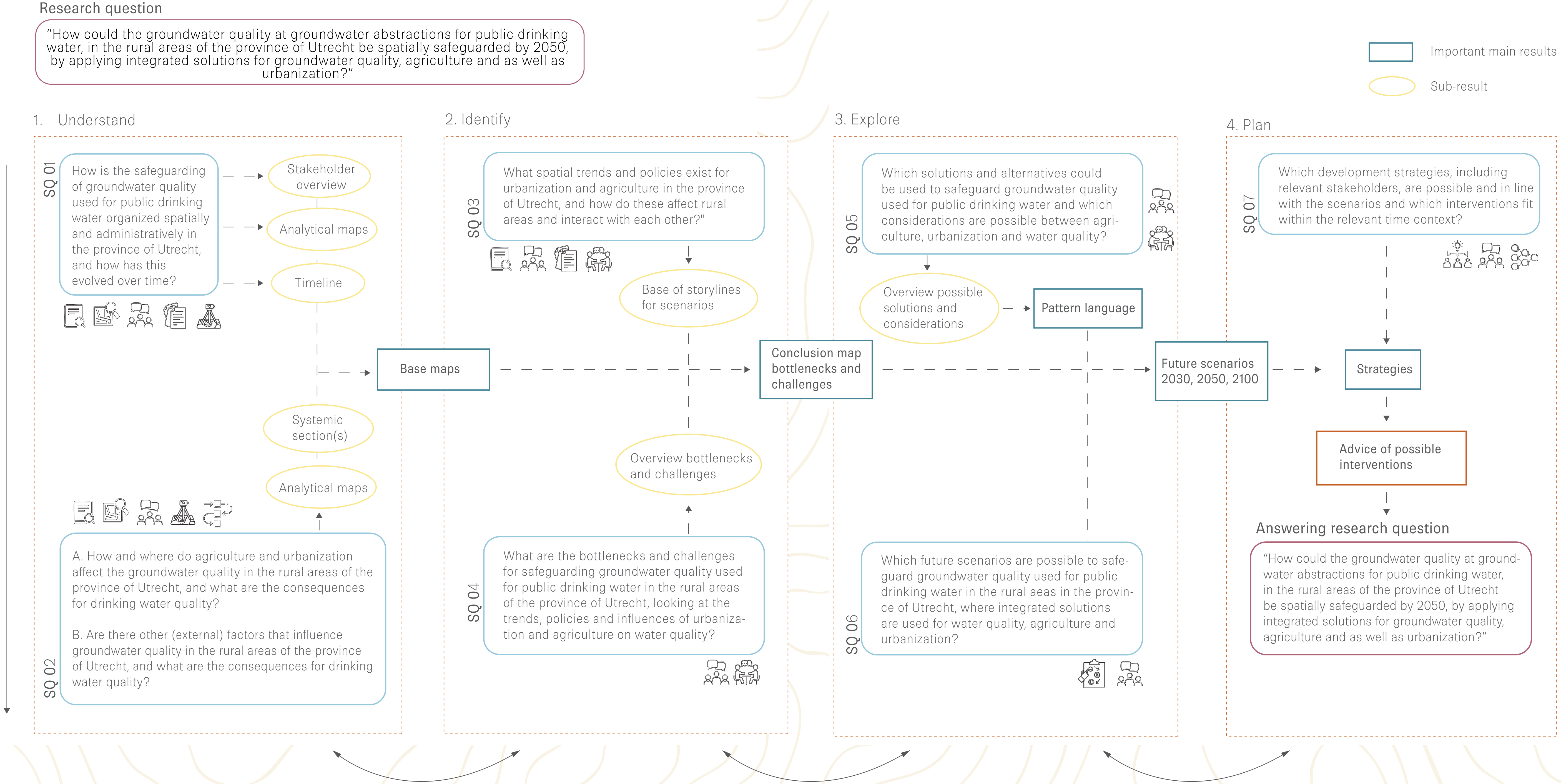
Flow analysis

The various impacts of urbanization and agriculture on groundwater quality are analyzed using a flow analysis. To develop integrated solutions, it is essential to approach the problem from a systemic perspective.

Workshop

After the scenarios have been developed, a workshop is organized for internal staff, professionals, and interview participants. During this workshop, the pattern language method is used to design one or more strategies in response to the scenarios. The participants are required to collaborate to achieve this. The outcome of the workshop is one or more strategies that can then be further elaborated.

Methodological framework



3. Groundwater systems

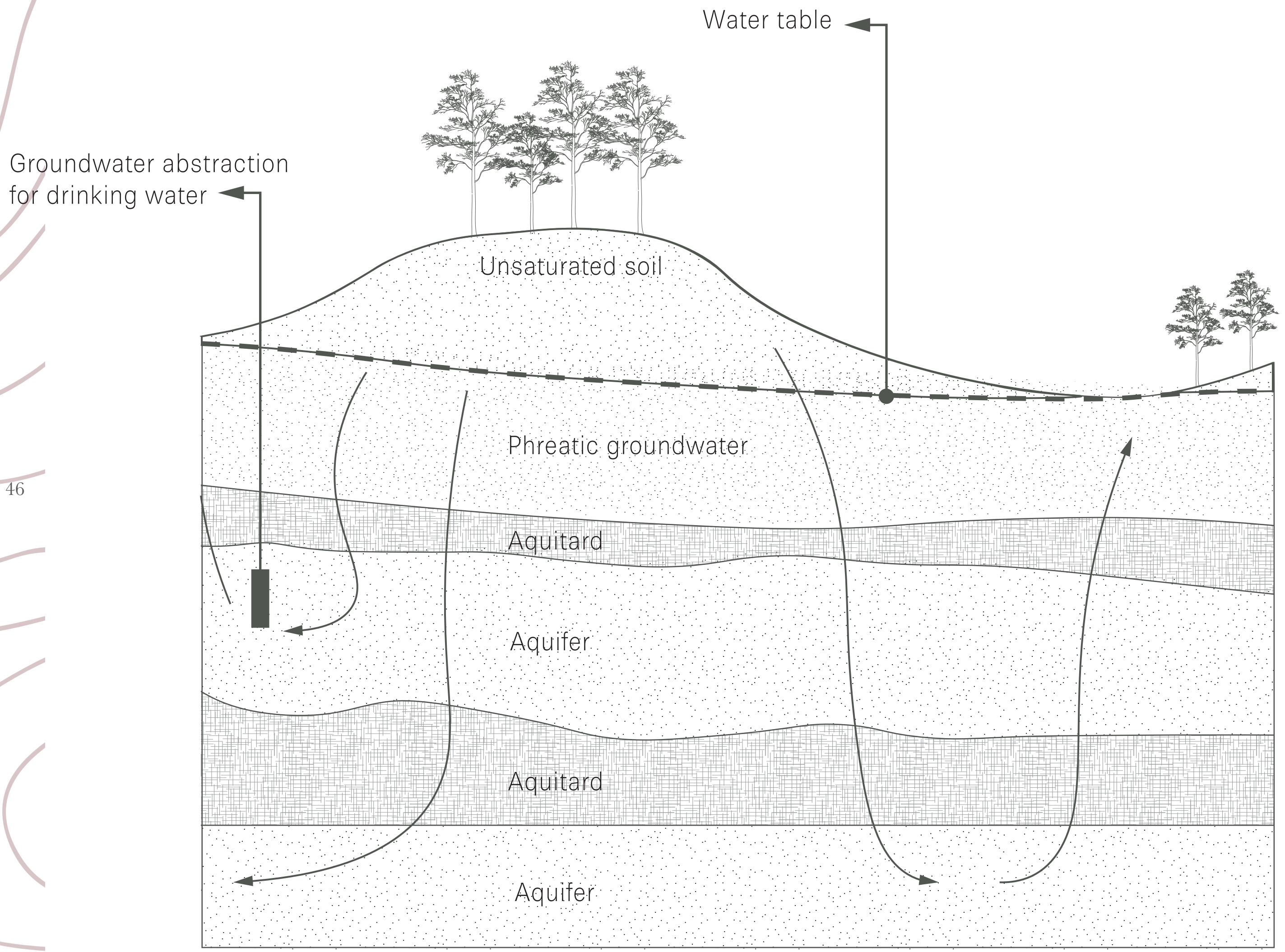
3.1 Explanation of groundwater systems

To understand the state of groundwater quality and why poor quality poses a problem, it is first essential to comprehend the structure of a groundwater system in general, as well as the groundwater systems in the focus area.

The importance of groundwater

Groundwater serves various functions for both nature and humans, both directly and indirectly. For terrestrial, groundwater-dependent ecosystems, groundwater discharge and high groundwater levels with good water quality are essential conditions. For humans, groundwater is crucial for the production of drinking water, watering livestock, and as a water source for agriculture and other important direct uses like industry. Additionally, groundwater creates conditions for specific activities in the soil, such as certain types of agriculture and the prevention of land subsidence through maintaining specific groundwater levels. In this research, the direct function of groundwater for drinking water production is addressed, while the other functions are considered in exploring integrated solutions (D. Hendriks et al., 2023)

Aquifers and soil structure



[Fig.3.1]: Explanation of aquifers and soil structure
Source: Own image

Soil structure

The soil is composed of layers, consisting of an alternation between well-permeable layers, such as sand and gravel, and poorly permeable layers, such as clay, loam, or bedrock. Water flows easily through the permeable layers but very poorly through the impermeable layers. While water can flow through poorly permeable layers, it does so very slowly (D. Hendriks et al., 2023).

From the soil surface, the water content increases, allowing a distinction to be made between an unsaturated and a saturated zone. In the unsaturated zone, the space is partially filled with air and partially with water. This is important for root development and thus constitutes a key zone for vegetation (Vernes, 2013). The well-permeable layers are referred to as "aquifers". The uppermost aquifer is called the phreatic groundwater. The water table is the water level that the groundwater would reach if a well were dug and is also known as the 'phreatic surface' (Vernes, 2013).

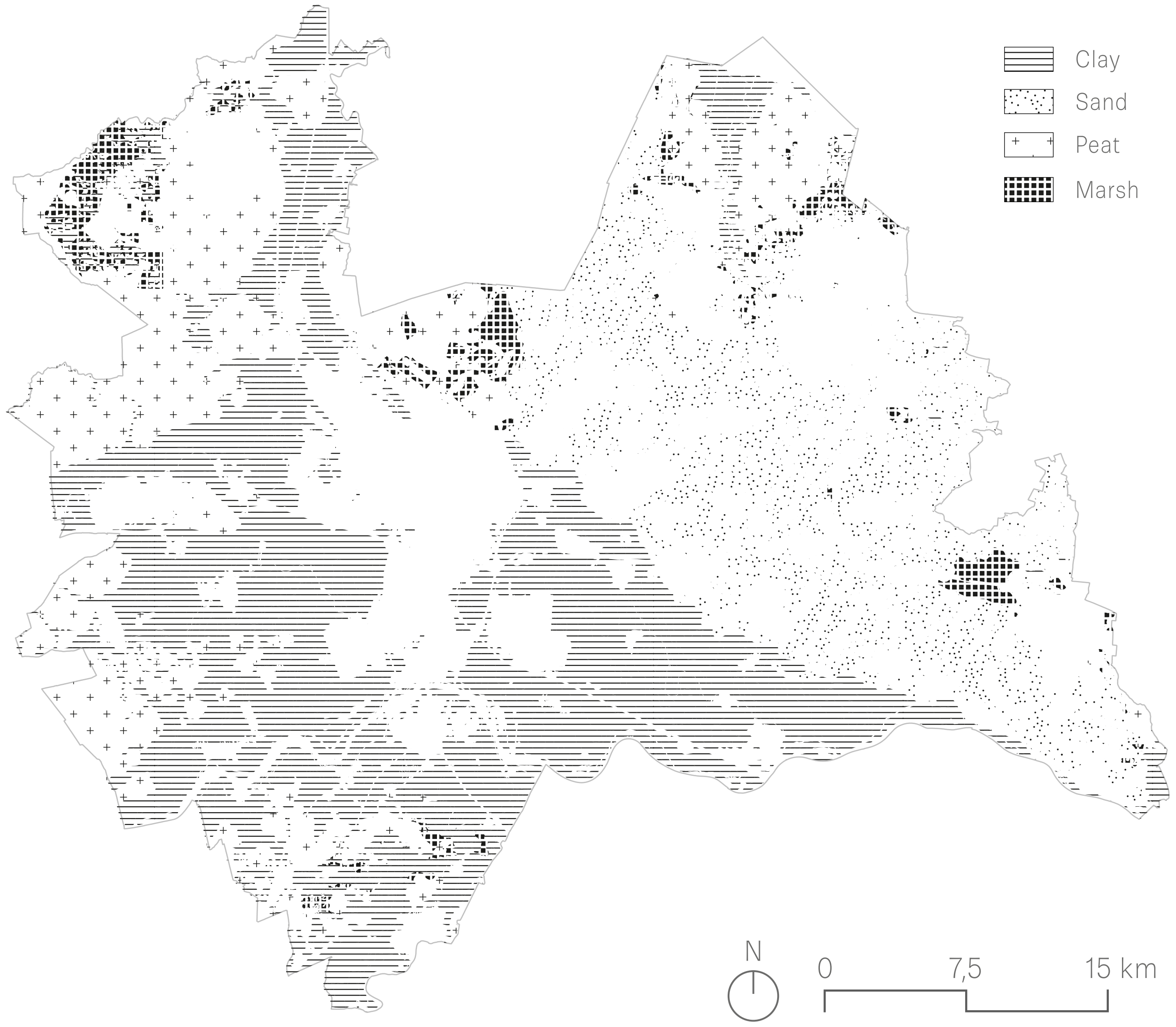
Soil structure and pollution

The soil structure is closely connected to the response to pollution. In sand layers, groundwater generally flows faster than in other soil types, resulting in less natural removal of pollutants in sandy soils (Paulissen et al., 2007). One of the three barriers that slow down or reduce the spread of contaminants is the presence of clay layers in the soil, primarily in the vertical direction (Verweij et al., 2022).

Soil structure in Utrecht

The right-hand page presents the general soil structure of the province of Utrecht. It clearly illustrates the variation in soil types, with the Utrechtse Heuvelrug prominently visible through the sand layer located in the eastern part of the province. In the western region, clay and peat are predominant. Additionally, in several locations, marsh soils can be observed.

Soil structure in the province of Utrecht



[Fig.3.2]: Soil structure in the province of Utrecht
Source: Own image

Groundwater flows

The natural flow of groundwater goes as follows:

Rainwater and surface water infiltrate in higher elevated infiltration zones. Infiltration zones are areas where water flows downward . The water moves from shallower to deeper aquifers. In the lower seepage areas, water flows in the opposite direction—from deeper to shallower aquifers—and subsequently reaches the surface. This process is influenced by the composition of the soil and differences in soil pressure. When the groundwater level is lower than the surface water level, infiltration occurs. Water from the deeper aquifers serves as an important source for stream discharge (D. Hendriks et al., 2023). This is specifically the case for Dutch groundwater-systems.

Various changes in the landscape over the past centuries have altered groundwater flows, compared to its natural state. For instance, polders and canals have been constructed, and intensive drainage has been implemented to facilitate functions such as agriculture and habitation. This has affected the groundwater level, resulting in a change of groundwater flows. Additionally, groundwater abstraction for drinking water, agriculture, and industry has impacted the natural flow of groundwater (Van Den Brink & Van Der Aa, 2003).

Types of groundwater systems

Groundwater systems and networks occur on various spatial and temporal scales (Van Den Brink & Van Der Aa, 2003). The following systems can be distinguished:

Local systems: These are relatively small systems where infiltration and exfiltration areas are adjacent to each other (Van Den Brink & Van Der Aa, 2003). The maximum depth at which groundwater flows is shallow, and the residence time is relatively short, lasting at most a few decades (D. Hendriks et al., 2023).

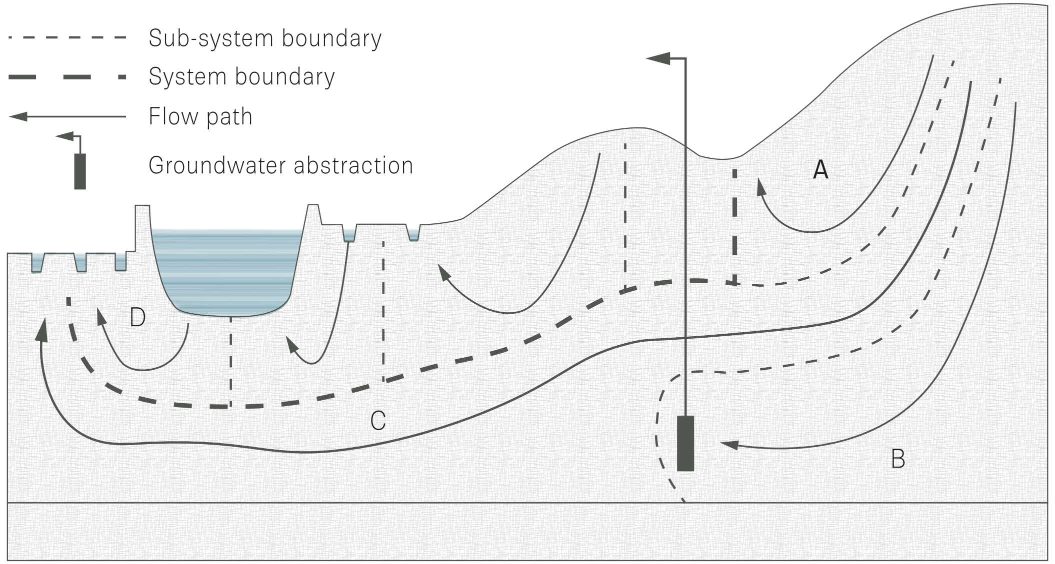
Intermediate systems: These systems are relatively shallow (up to approximately 50 meters below the surface) and include at least one local system between the infiltration and exfiltration areas (Van Den Brink & Van Der Aa, 2003). Residence times range from several decades to hundreds of years (D. Hendriks et al., 2023).

Regional systems: These systems feature a high-elevation infiltration area and a low-elevation exfiltration area, corresponding to topographic highs and lows (Van Den Brink & Van Der Aa, 2003). Travel times can range from decades to thousands of years. This type of system extends to considerable depths. An example of a regional system is the Utrechtse Heuvelrug, located within the province of Utrecht (D. Hendriks et al., 2023).

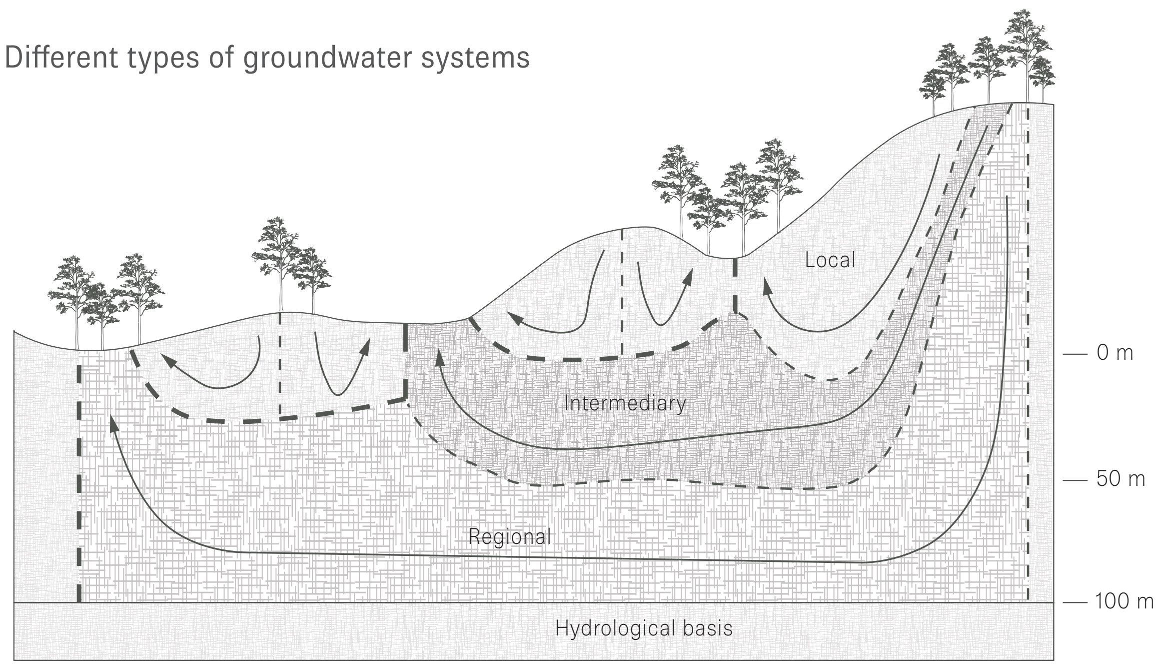
Right, first image: [Fig.3.3] Schematic representation of groundwater flows in A: a natural situation, with groundwater flows from an infiltration area to a natural lower point; B: Groundwater surrounding a groundwater abstraction point, C & D: Groundwater flows around (constructed) waterways and polders
Source: Image re-designed, based on source: (Stuurman and Griffioen, 2003)

Right, second image: [Fig.3.4] Schematic respresentation of local, intermediary and regional groundwatersystems
Source: Image re-designed, based on source: (Stuurman and Griffioen, 2003)

Groundwater flows in different situations



Different types of groundwater systems



In addition to this tripartite classification, there are also micro and supraregional groundwater systems:

Micro systems: These systems involve shallow water flow on a parcel scale, from the central part of a parcel to the nearest ditch or trench (D. Hendriks et al., 2023). The residence time within these systems is in the order of days or weeks.

Supra regional systems: These systems span, on the other hand, multiple watersheds and are even larger than regional groundwater systems. In these systems, the infiltration area is located in a topographically high region, while the exfiltration area is in a large, low-lying area. Groundwater within these systems resides at great depths (>100 meters below the surface), and the residence time is extremely long, exceeding 1,000 years (Van Den Brink & Van Der Aa, 2003).

Groundwater quality

Groundwater is a slow system. Groundwater in deeper aquifers could be millennia old. In addition to its slow movement, water can also spread over great distances (Van Den Brink & Van Der Aa, 2003). Groundwater quality is largely determined by the infiltrating water—rainwater, river water, or seawater. The composition of the soil also influences groundwater quality, as it determines which substances precipitate from the groundwater and which elements from the sediment dissolve into the groundwater. Furthermore, the transport time and transport route also affect groundwater quality (Verweij et al., 2022).

Along with infiltrating water, anthropogenic substances, such as pesticides and pharmaceutical residues, can also be carried along. These substances can penetrate deeper aquifers and spread over long distances. In this way, contamination in one location can, through the groundwater system, impact another location. The influence of human activities on the chemical quality of groundwater is referred to as groundwater pollution and is a current issue in the Netherlands and the province of Utrecht (Swartjes et al., 2022). This could also impact drinking water quality, as such contamination may also be present in the aquifer of the groundwater abstraction site. This is already happening in drinking water abstractions in the focus area, where drinking water organizations have to do extra purifying (Gathered during internship, 2025). A more detailed description of the different effects on groundwater quality is given in the next chap-

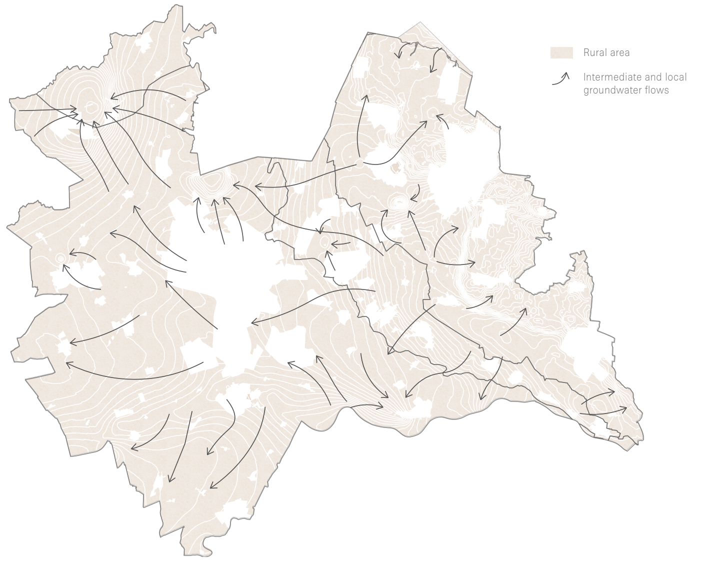
Groundwater flows in Utrecht

Now that the mechanisms of groundwater flows and different types of groundwater systems have been established, the functioning of groundwater systems in the province of Utrecht can also be examined.

Figure 3.7 illustrates the regional groundwater flow, showing that rainwater infiltrates in the higher-elevated Utrechtse Heuvelrug. From this elevated area, the groundwater flows towards the lower-lying regions in the east and west, eventually reaching the rivers and, ultimately, the sea.

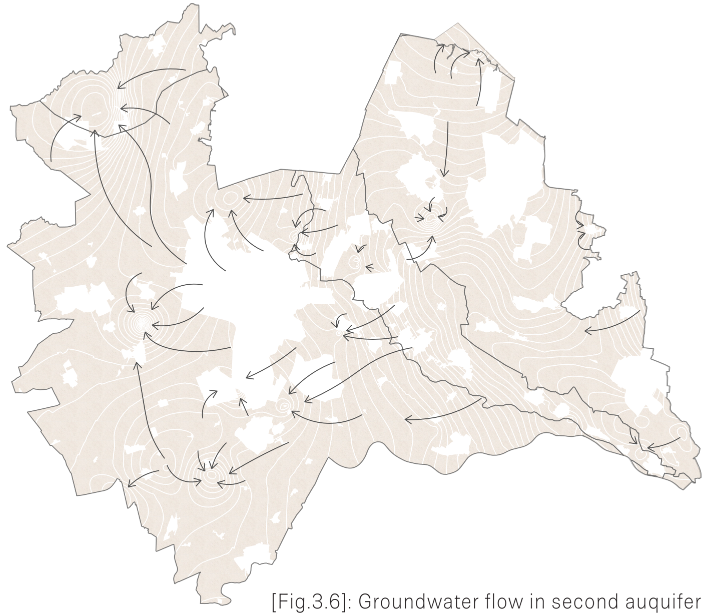
As previously established, groundwater flows vary depending on the depth of the soil layers. Figure 3.5 presents the groundwater flow in the first aquifer, which differs from figure 3.6, where the flow in the second aquifer is depicted. Both figures illustrate the discharge of groundwater from the Utrechtse Heuvelrug towards east and west. However, the groundwater moves towards specific locations within the region where it is abstracted for drinking water purposes. Groundwater abstractions often influence groundwater flows, which is clearly visible in these figures. At abstraction sites, groundwater is withdrawn, creating a new flow direction towards these points. The specific locations of drinking water abstractions and a detailed explanation of the drinking water system will be provided in the following chapter.

Groundwater flow in first aquifer



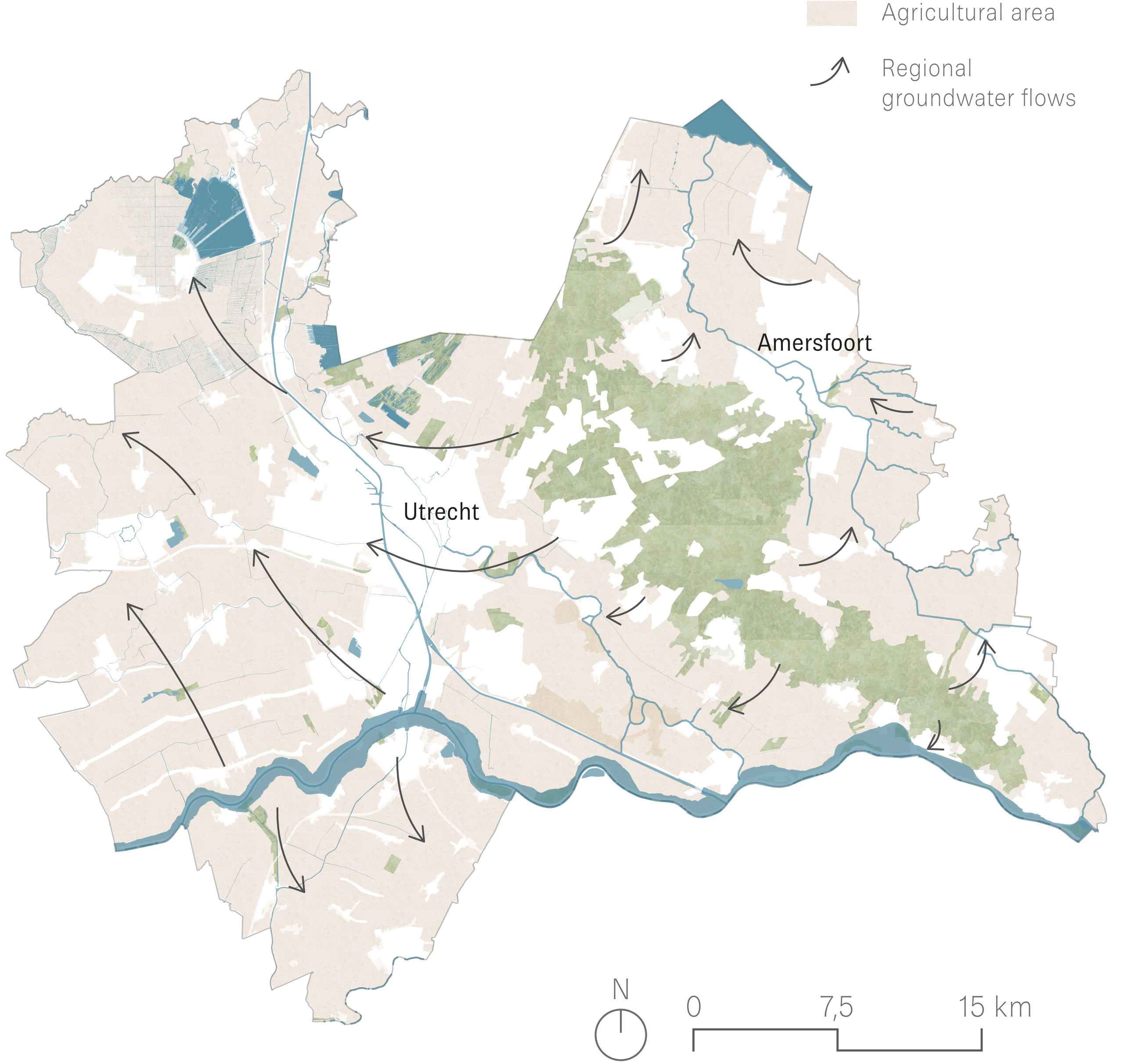
[Fig.3.5]: Groundwater flow in first auquifer
Source: Own image

Groundwater flow in second aquifer



[Fig.3.6]: Groundwater flow in second auquifer
Source: Own image

Regional groundwater flows



[Fig.3.7]: Regional groundwater flows
Source: Own image

3.2 European Water Framework Directive

To understand how the groundwater quality is measured, it is necessary to know how the groundwater quality is assessed according to the European Water Framework.

European Water Framework Directive

The Water Framework Directive (WFD) is a European directive that sets standards and requirements for the quality of groundwater and surface water (Informatiepunt Leefomgeving, 2025).

The Water Framework Directive (WFD) stipulates that by 2015, all groundwater bodies must be in good condition, with an extension until 2027. The “good status” of groundwater is defined in the WFD as “the condition in which both the quantitative and chemical status are at least good.” What constitutes a good quantitative and chemical status is further specified in the WFD (Landelijke Werkgroep Grondwater, 2019).

The WFD ensures an integrated approach to water management, respecting the integrity of whole ecosystems, including by regulating individual pollutants and setting corresponding regulatory standards. It is based on a river basin district approach to make sure that neighbouring countries cooperate to manage the rivers and other bodies of water they share (see figure 20) (European Commission, 2025).

The WFD includes five environmental objectives for groundwater:

1) Preventing or limiting the input of pollutants into groundwater;

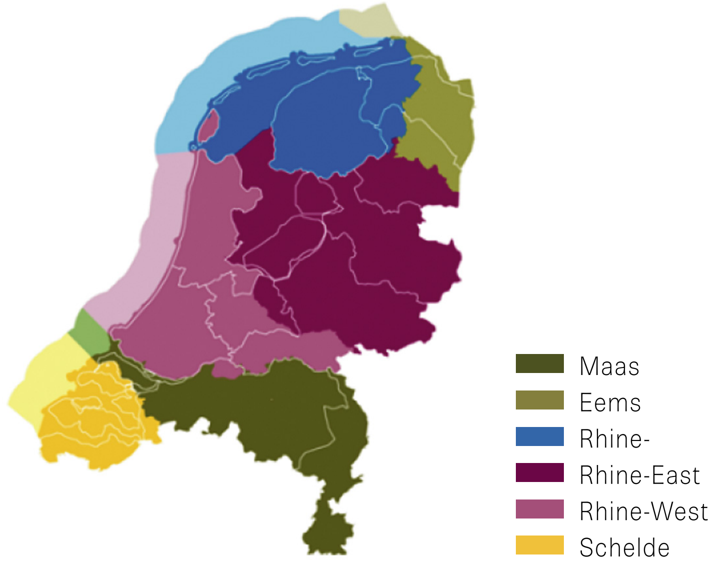
2)Preventing the deterioration of the status of all groundwater bodies;

3) Achieving and maintaining “good status” in groundwater bodies;

4)Reversing significant and sustained upward trends in concentrations of pollutants caused by human activity;

5)Achieving the objectives for protected areas. (Ambient and RHDHV, 2024)

Stream areas in the Netherlands



[Fig.3.8]: Stream areas, divided according to the European Wa
Framework Directive. The province of Utrecht has two differe
stream areas: Rhine-East and Rhine-West.
Source: (De Rijksoverheid, 2021)

Dutch implementation of WFD

In the Netherlands, the Water Framework Directive (WFD) is interpreted and implemented as follows:

- The Environmental Planning Act (Omgevingswet) stipulates that the regional water programs of the provinces implement the WFD and the Groundwater Directive;

- In the water management programs of the water boards, the regional water programs are taken into account, with regard to European water regulations;

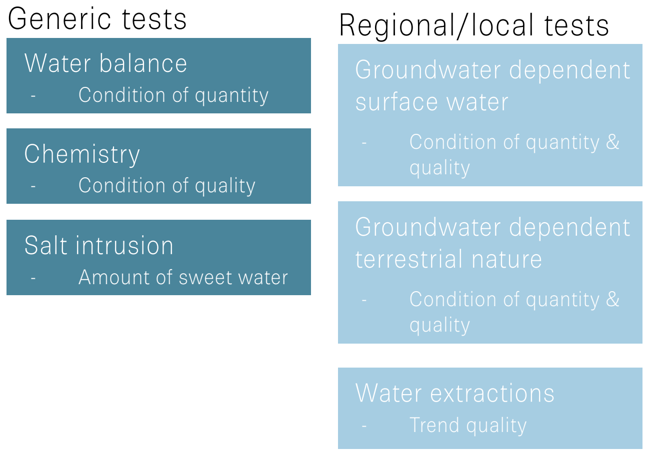
- The national government establishes river basin management plans. (Ambient and RHDHV, 2024)

The Netherlands has provided its own interpretation of the goals of the Water Framework Directive (WFD). The assessment of this has been translated into the protocol “Condition and Trend Assessment of Groundwater Bodies under the WFD.” This protocol provides guidelines for groundwater managers, provinces, and water boards, allowing the quantitative and chemical condition of groundwater bodies to be assessed in a consistent manner. This includes the determination of trends and the assessment of area-specific functions within a groundwater body (Landelijke Werkgroep Grondwater, 2019).

An important point to note is that the determination of trends does not affect the condition assessment itself but is necessary for the so-called “at-risk” determination. For the drinking water test, however, this trend determination is crucial for the condition assessment.

The condition of groundwater quality is measured using six tests: three general tests, applicable across the entire groundwater body, and three location-specific tests where groundwater-dependent functions are present within the groundwater body. The basic judgment on the condition of the groundwater body is considered good if none of the three general tests yield a negative (insufficient) result (Landelijke Werkgroep Grondwater, 2019).

Tests of the WFD for groundwater bodies



[Fig.3.9]: The 6 tests of the WFD
Source: Own image, based on: Landelijke Werkgroep Grondwater, 2019)

Generic Tests:

1) Water Balance Test: The water balance test is part of the characterization and assesses whether groundwater resources are being depleted due to extractions. Long-term changes in groundwater levels are analyzed.

2) Chemical Condition and Trend Assessment: This test evaluates substances with European established standards, such as pesticides and nitrates, or those with nationally set threshold values (chloride, cadmium, lead, phosphate, nickel, and arsenic).

3) Intrusion Test: This test examines salinization due to the intrusion of saltwater into the groundwater.

Regional/Local Tests:

1) Groundwater-Dependent Surface Waters: This test investigates whether the WFD surface water goals are not being met due to insufficient groundwater recharge or the influx of pollutants from the groundwater.

2) Groundwater-Dependent Terrestrial Ecosystems: This test assesses whether there is significant damage to terrestrial ecosystems caused by low groundwater levels, groundwater contamination, or insufficient groundwater supply.

3) Groundwater Extractions for Human Consumption: For groundwater extraction points used for drinking water, this test checks for rising trends in threshold substances and EU-regulated substances in the raw water quality. The condition is deemed insufficient if such trends are observed.

The Netherlands has already received two extensions for meeting the WFD targets (Slagter et al., 2024). In 2024, a mid-term evaluation was conducted to assess whether the goals for 2027 will be achieved with the current measures being implemented (Ambient and RHDHV, 2024).

For surface water, 80% of the water bodies meet the set targets. However, the situation is more complicated for groundwater. According to the assessment of the Water Framework Directive (WFD), only 4 groundwater bodies do not meet the established standards (meaning the other 19 groundwater bodies do). However, this gives a skewed picture, as protected areas, including those for drinking water abstraction, have not been included. Furthermore, substances such as PFAS, pharmaceutical residues, and industrial discharges are not included in the WFD tests. If tests for these areas were also included, only 4 groundwater bodies would be considered in good condition. Increasingly, various substances are being found that are not covered by the WFD tests (Slagter et al., 2024).

With this information, it has become evident how the results of groundwater quality should be interpreted. It also provides a foundation for analyzing the groundwater quality of the focus area and the influences on it."

4. Drinking- and groundwater quality in Utrecht

Understand

SQ1 How is the safeguarding of groundwater quality used for public drinking water organized spatially and administratively in the province of Utrecht, and how has this evolved over time?

A. How and where do agriculture and urbanization affect the groundwater quality in the rural areas of the province of Utrecht, and what are the consequences for drinking water quality?

SQ2 B. Are there other (external) factors that influence groundwater quality in the rural areas of the province of Utrecht, and what are the consequences for drinking water quality?

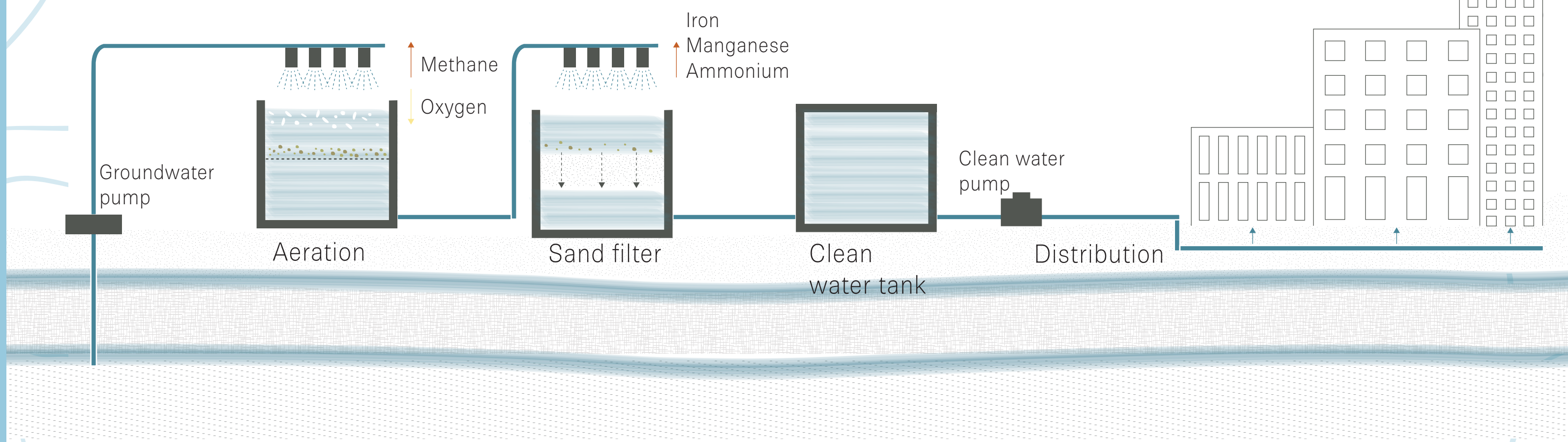
4.1 Production of drinking water

Approximately 60% of the drinking water in the province of Utrecht is made from groundwater. This is facilitated by 29 extraction sites, which collectively draw up to 110 million cubic meters of groundwater annually for drinking water production. The remaining 40% of drinking water is derived from surface water, sourced from two extraction sites that together supply up to 70 million cubic meters per year. In total, this amounts to approximately 180 million cubic meters of drinking water annually (Tuit et al., 2024). This study focuses specifically on drinking water produced from groundwater, with particular attention given to the purification processes involved in groundwater treatment.

Groundwater is one of the purest forms of water, as it is naturally filtered through soil layers, such as sand and clay, which act as a natural filtration system. This process is often referred to as "Filter Zero." The groundwater is located tens to hundreds of meters deep in the soil. Once extracted, it is transported via pipelines to a drinking water production facility. The abstracted water is commonly referred to as "raw water" (Bedrijfinbeeld, 2012).

Upon arrival at the drinking water production facility, additional purification steps are required to remove residual contaminants. The purification process varies between production facilities due to differences in soil composition and contamination from human, animal, and plant sources at each location (Vitens, 2025b). For this reason, this section outlines the general steps involved in drinking water production, without delving into the specific characteristics of each abstraction site in the region.

General filtering process of groundwater



[Fig. 4.1]: Filtering process of groundwater to drinking water
Source: own image

1 Aeration

During this step, the groundwater is exposed to oxygen. This technique facilitates the removal of gases such as carbon monoxide and methane, while also causing the oxidation of metals. For example, methane is present as a dissolved gas in the extracted groundwater (Meerkerk & Siegers, 2022). Since the water has remained underground for an extended period, it may have absorbed an excess of minerals. Metals such as iron, for instance, "rust" into small flakes during the aeration process, making them easy to filter out of the water (Vitens, 2025b).

2 Sand filtration

Filtration involves the use of sand filters to remove unwanted substances from the water. For extraction sites that are more influenced by surface activities, the water is further treated with an activated carbon filter to remove color, odor, and taste compounds (Vitens, 2025). Additionally, iron, manganese, and ammonium are filtered out of the water during this process (Bedrijfinbeeld, 2012).

3 Extra filtering

The water is sometimes subjected to post-filtration or softening. This step is not always necessary and depends on the quality of the groundwater sources. In many extraction sites, the groundwater is clean and requires only aeration and iron removal. However, in some cases, the water undergoes additional aeration or requires a more precise filter to remove so-called "metal flakes" from the water (Vitens, 2025b).

4 Storage and distribution

After completing these steps, the water is stored in a "clean water" tank until it is distributed to customers.

Residual streams

During the process, four residual streams are generated as a by-product. These residual streams include materials such as iron and manganese sludge, filtered particles, humic acids and methane. The management and disposal of these residual streams are important aspects of the production process to minimize environmental impact. These residual streams are utilized in various ways. For instance, methane can be harnessed to generate energy, while humic acids are used as a substitute for fertilizers.

4.2 The history of drinking water quality

The production of drinking water has a rich history and is closely linked to overall water quality. The way of drinking water quality is ensured today has been shaped by policies, spatial-landscape and technological developments. This section provides a brief history of the development of drinking water quality assurance.

1200 - 1600

Many cities were located along a river or had a river flowing through them. Throughout the Netherlands, surface water was a good and clean source of drinking water, especially fast-flowing rivers. Until around the year 1600, canals were usable as clean drinking water. Cities situated on sandier soils used not only surface water, but also groundwater for drinking water. Households had their own drinking water wells, but municipal authorities also provided public wells that were accessible to everyone (Van Dam, 2021)

1600 - 1800

During this period, urbanization increased, and canals in many cities wered used as open sewers. This was influenced by political and economic power dynamics. A notable example is the city of Leiden, which, like many other cities, faced rapid population growth. The Leiden city council directed developers to construct more houses and abolished the requirement to build cesspits. Instead, so-called 'secreegoten' (wastewater channels) wered introduced, allowing waste to be discharged direcly into the canals.

In addition to household waste, industrial activities further worsened the situation. Although authorities attempted to concentrate industries in specific areas, this policy was not always effectively enforced. New types of businesses emerged, using acidic and corrosive substances, and their industrial waste discharges were tolerated by the city government. Higher-quality water was imported and sold within the city, but poor residents could not afford it and frequently fell ill, sometimes with fatal consequences.

Beyond these causes of increased water pollution, two spatial factors also contributed to the further decline in water quality. First, the natural flow of rivers was disrupted due to ongoing land reclamation around cities, which also significantly altered local and regional groundwater flows (Paulissen et al., 2007). As the land surrounding cities subsided due to reclamation, the natural flow of rivers stagnated. Additionally, the expansion of canal networks negatively affected water flow speed - the longer the canal, the greater the resistance the incoming water encountered (Van Dam, 2021).

1800 - 1900

In 1851, an Amsterdam resident named Jacob van Lennep managed to persuade a group of wealthy English investors to fund a plan to transport clean dune water from Heemstede to Amsterdam. He received permission from the king to establish the Amsterdamsche Duinwater Maatschappij (Amsterdam Dune Water Company). Engineer Christiaan Vaillant developed the pipelne that enabled the transport of dune water from Heemstede to Amsterdam. From December 12, 1853, Amsterdam residents could purchase clean drinking water for 1 cent per bucket (Waternet, 2025).

1900 - 2000

The 20th century started with the Housing Act of 1901, which made it mandatory to install flush toilets in homes. By 1938, all cities with more than 50,000 inhabitants had an integrated flushing system, and the construction of sewer systems steadily increased, along with the development of wastewater treatment plants.

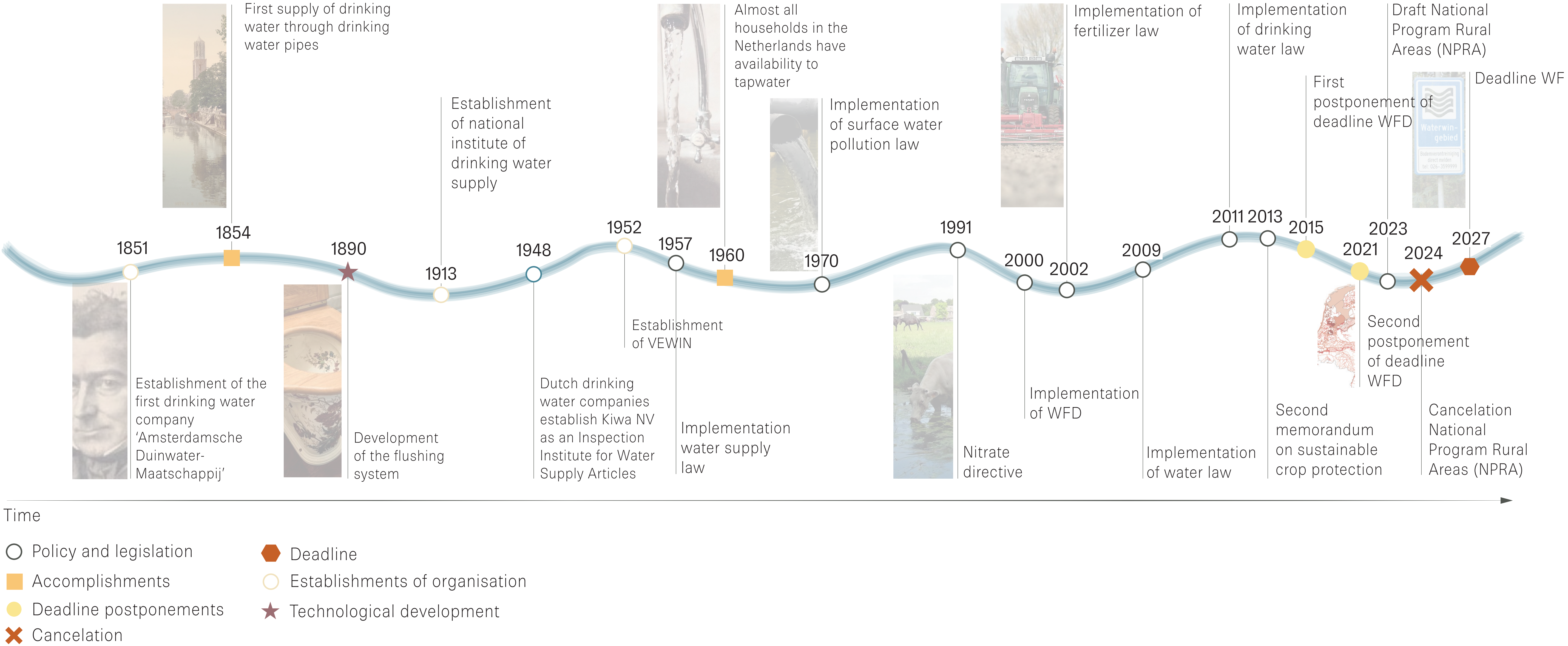
Additionally, after many earlier attempts starting in 1903, a law was introduced in 1970 to combat surface watter pollution: The Surface Water Pollution Act. This law aimed to establish sufficient purification capacity to ensure that the burden on surface water would not exceed its self-cleaning ability (Havekes, 2021)

2000 - 2025

The 21st century also started with a new directive on water quality: the Water Framework Directive in 2000 (Informatiepunt Leefomgeving, 2025). Wat the European level, there were many concerns about water quality, prompting countries to collaborate in drafting this directive. The directive required all countries to achieve good water quality by 2015, with a possible extension until 2017. So far, the Netherlands has postponed the deadline multiple times, meaning its water quality still does not meet the directive's standards (Slagter et al., 2024).

To address, among other things, the water quality comprehensively in rural areas, the National Rural Area Program was established in 2024. One of its goal was to improve water quality. However, this program has since been canceled, and there is currently no new plan to tackle these issues in an integrated manner (Geerts, 2024).

Timeline of (drinking) water quality



4.3 Spatial dimension

Drinking water quality is spatially safeguarded through different forms of legislation. There are different groundwater protection zones present in the Province of Utrecht, which secure safe drinking water. These are the following:

Water abstraction areas

In these areas the groundwater gets abstracted. The border of these protected areas is a 60-day zone, where the groundwater needs 60 days to move to the abstraction wells. There are only water abstraction activities allowed - everything else is prohibited. However, there are some exceptions.

Groundwater protection areas

These areas surround the aforementioned water abstraction areas. These zones have a 25-year zone as a border, where the groundwater needs 25 years to move to the abstraction wells.

The abstraction points with these kinds of areas are mostly relatively shallow abstractions, with little or no protective clay layers. This means it can easily be contaminated by ground level activities. There are extra rules regarding activities. Environmentally harmful companies and some other activities are prohibited.

Drilling-free zones

These zones also surround water abstraction areas and have a 25-year zone. There are 19 abstraction zones which are protected by a drilling-free zone. These abstractions have one or more contiguous poorly permeable clay layers and are therefore less prone to ground level activities. The rules in this zone apply to drilling, to protect the clay layers. Below a certain depth, drilling is not allowed: the depth limits.

100-years zone

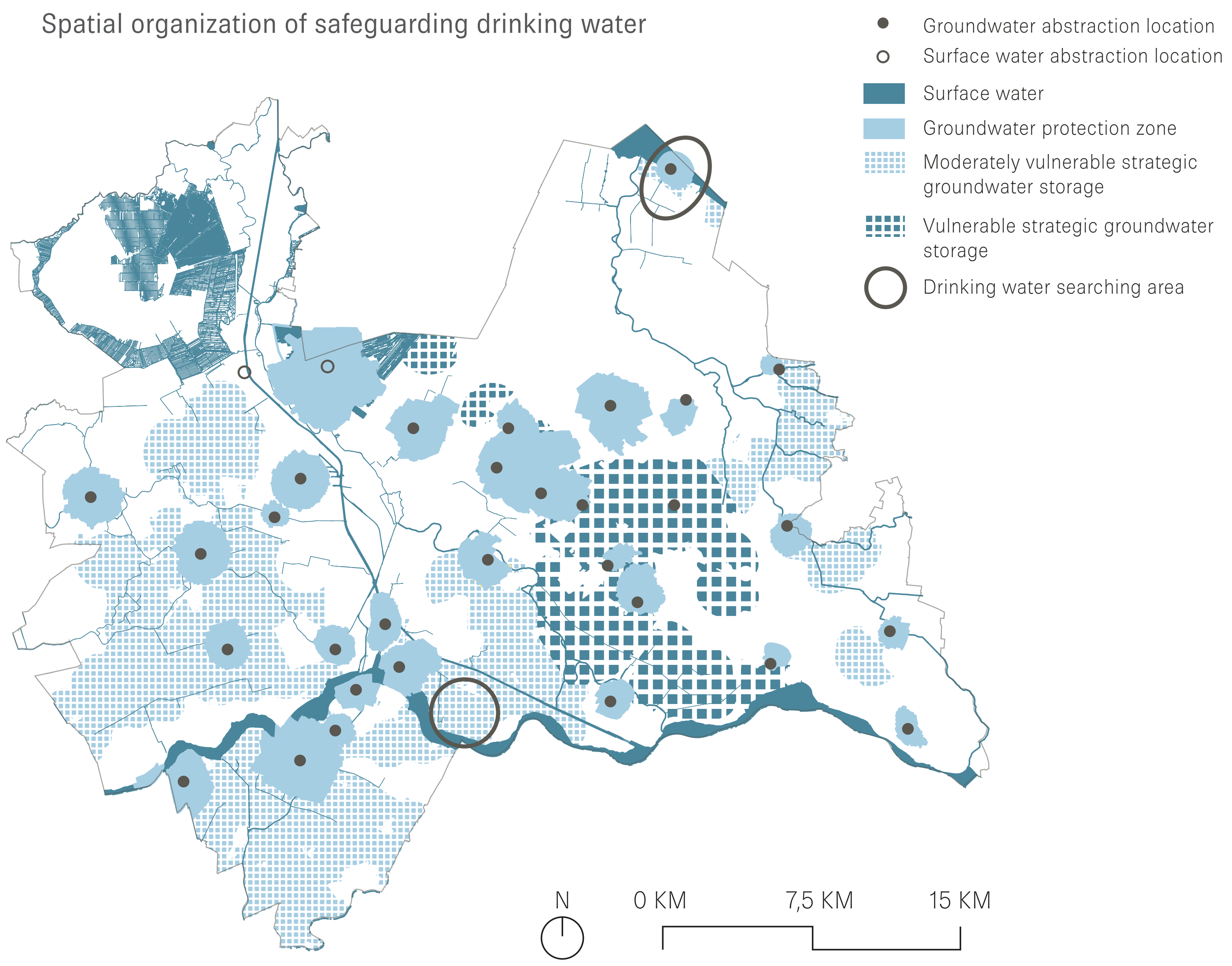
These zones surround a groundwater protection area and have a 100-years zone (groundwater needs 100 years to move to an extraction point). Not every groundwater protection zone has a 100-years zone. There are no specific rules, but there is a 'duty of care'.

Protection zones surface water abstraction

Drinking water abstractions of surface water are prone to contaminants from air and water. With this protection zone, surface water and land 100 m on both sides of the bank are protected from calamities, contaminated discharges and spatial development with high risks.

Moderately vulnerable and vulnerable strategic groundwater storages

These designated storages secure future water availability for groundwater abstraction to create drinking water. There are no specific rules, but there is a 'duty of care' (Provincie Utrecht, 2024c).



[Fig.4.5]: Spatial dimension of drinking water in the Province of Utrecht

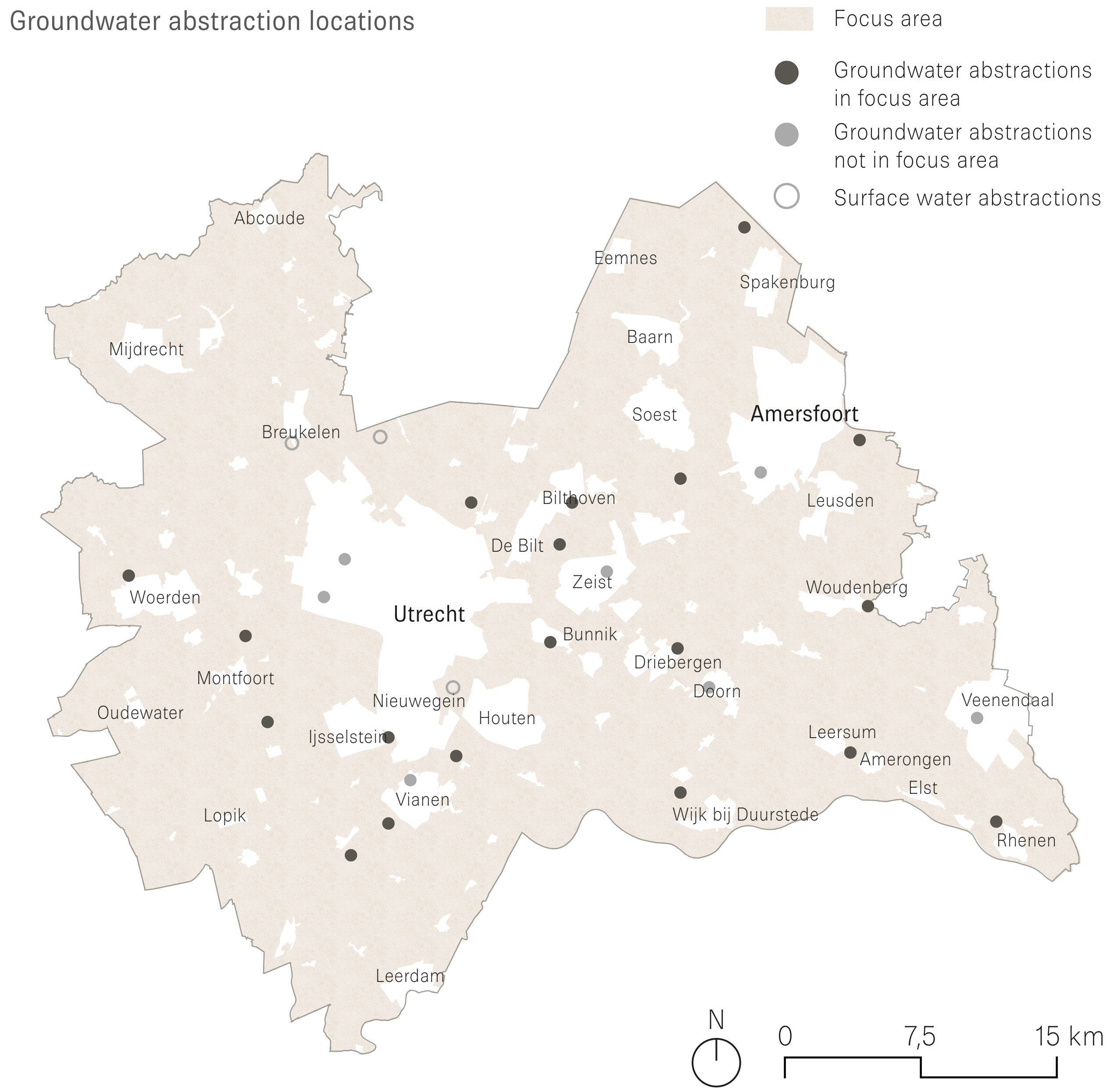
4.4 Groundwater abstractions in the rural areas

As previously indicated in this report, this study focuses on the rural areas of the province of Utrecht. Consequently, only groundwater abstractions located in rural areas are considered. This means that a total of 19 abstractions are examined.

Each abstraction is unique, facing distinct challenges. In some cases, additional purification steps are applied beyond the basic steps outlined in Section 2.1. The following page provides a concise overview of the abstractions, including general information such as the amount of abstracted water and the purification processes. The reported abstraction amount represents the permitted capacity, which is the maximum allowable amount of abstraction. However, actual abstraction amounts may vary, occasionally falling below or exceeding this limit.

As can be seen in the figure, significant volumes of water are abstracted in Linschoten, Beerschoten, and Lexmond. Moreover, the abstractions in Soestduinen and Groenekan are highly vulnerable. The abstractions in Beerschoten, Bilthoven, Blokland, Rhenen, Driebergen, Bunnik, and Woerden are considered (moderately) vulnerable. The vulnerability of these abstractions is determined by the presence or absence of one or more confining clay layers, as mentioned before in chapter 3. The vulnerability of these abstractions is determined by the presence or absence of one or more confining clay layers, as mentioned before in chapter 3. Such clay layers provide a protective barrier against surface contamination. The absence of these layers increases the susceptibility of the abstractions to such contaminants.

The operational viability of abstractions in the southeastern part of Utrecht remains a key concern for Vitens. Currently, a groundwater abstraction site in Doorn is being decommissioned due to its age and, more importantly, its high vulnerability to surface contaminatio (Vitens, 2025a).



[Fig.4.6]: Drinking water abstractions in the rural area of the province of Utrecht

Nieuwegein
2,5 mln m3 per year — 2nd aquifer

Purification: Softening, aeration and sand filtration

Woerden
3,0 mln m3 per year — 1st & 2nd aquifer

Purification: Softening, aeration, cascade areation, sand filtration, post-filtration, active coal, UV-desinfection

Linschoten
10,0 mln m3 per year — 2nd & 3rd aquifer

Purification: Aeration and sand filtration

Blokland (not yet operational)
3,25 mln m3 per year — 3rd & 4th aquifer

Purification: Aeration and sand filtration (in Linschoten)

Lexmond
12,0 mln m3 per year — 2nd and 3rd aquifer

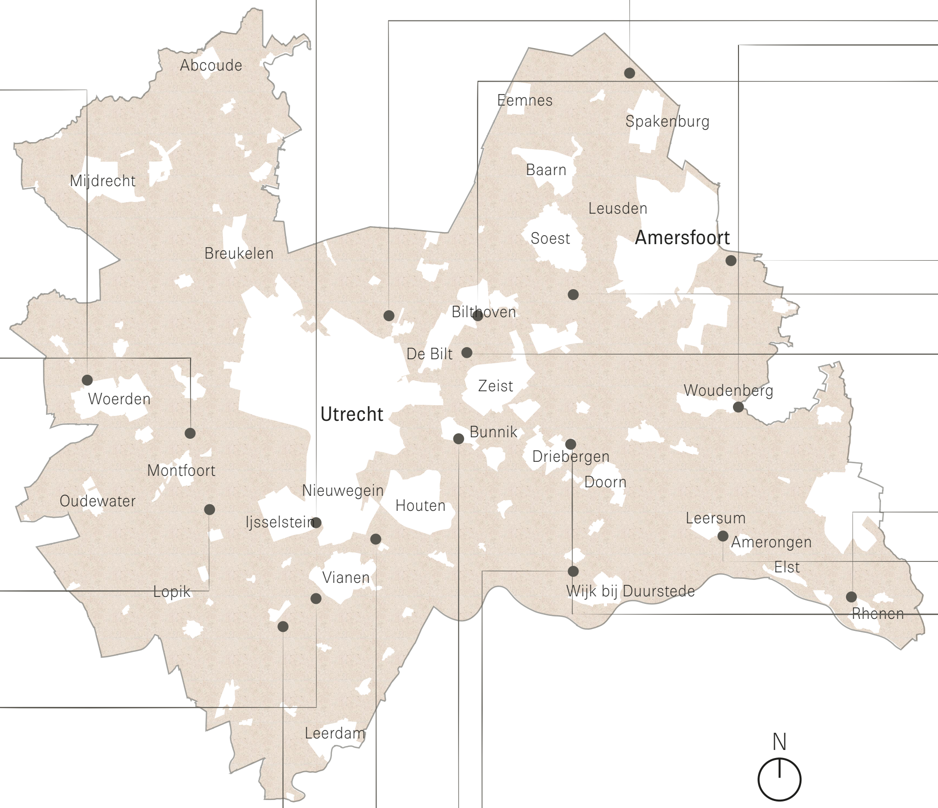
Purification: Softening, aeration, sand filtration, extra filtration, active coal, UV-desinfection

Vianen Panoven
0,8 mln m3 per year — 2nd aquifer

Purification: Softening, aeration, sand filtration, active coal (in Lexmond)

Tull en 't Waal
6,0 mln m3 per year — 3rd, 4th & 5th aquifer

Purification: Softening, aeration and sand filtration



Bunnik
3,5 mln m3 per year — 2nd aquifer

Purification: Aeration and sand filtration

Cothen
3,0 mln m3 per year — 2nd & 3rd aquifer

Purification: Softening, aeration and sand filtration

Eempolder
5,0 mln m3 per year — 3rd aquifer

Purification: Aeration and sand filtration

Bilthoven
2,0 mln m3 per year — 2nd & 3rd aquifer

Purification: Cascade aeration and Akdolit filtration

Beerschoten
8,0 mln m3 per year — 2nd & 3rd aquifer

Purification: Aeration and sand filtration

Driebergen
0,9 mln m3 per year — 1st & 2nd aquifer

Purification: Aeration and sand filtration

Woudenberg
3,4 mln m3 per year — 3rd aquifer

Purification: Aeration and sand filtration

Groenekan
7,5 mln m3 per year — 2nd aquifer

Purification: Aeration and sand filtration

Soestduinen
9,0 mln m3 per year — Phreatic

Purification: Aeration

Amersfoort Koedijkerweg
1,5 mln m3 per year — 3rd aquifer

Purification: Aeration and sand filtration

Leersum
0,8 mln m3 per year — Phreatic

Purification: Aeration, marble filtration and lime pellets

Rhenen
2,0 mln m3 per year — 3rd, 4th & 5th aquifer

Purification: Aeration and sand filtration

Legend
- Water abstraction area
- Groundwater protection zone
- 100 years zone
- Drilling-free zone
- Focus area
- Groundwater abstractions in focus area
- Abstraction is vulnerable
- Abstraction is very vulnerable

4.5 Stakeholders

Various stakeholders are involved in ensuring safe drinking water quality. This section provides a brief overview of the key stakeholders who are directly and indirectly responsible for ensuring good drinking water quality.

Water management structure

Table 4.1 provides an overview of the water management structure in the Province of Utrecht. There is significant fragmentation in responsibilities within this structure, necessitating good collaboration between the stakeholders. There is no single entity with overall responsibility for all water related matters (Province of Utrecht, 2023). For instance, drinking water companies are responsible for producing clean drinking water. However, drinking water in the province of Utrecht is mainly made of groundwater and the provincial government is accountable for good groundwater quality. These responsiblities are closely interconnected. Additionally, the operational domains of waterboards and drinking water companies extend beyond provincial boundaries, further complicating the system.

European Union	Creating guidelines: - Water Framework Directive (WFD) - Bathing Water Directive - Urban Wastewater Directive - Floods Directive - Drinking Water Directive - Groundwater Directive
Ministry of Infrastructure and Water	- Legislation in the field of water management (aligned with European regulations) - National policies and guidelines
Dutch Directorate-General for Public Works and Water Management (Rijkswaterstaat)	- Management of major waterways, such as the Nederrijn/Lek and the Amsterdam-Rhine Canal - Water quality of national waters
Province of Utrecht	- Management of provincial waterways, such as the Eem and Merwede Canal - Allocation of water functions - Safeguarding water interests for groundwater and surface waters - Protection of groundwater quality - Translation of national policy to regional levels - Permits for large-scale groundwater abstractions - Supervision of designated swimming locations
Waterboards	- Flood defenses - Water quality management (wastewater treatment, permitting of discharges into surface waters) - Water quantity management (water level regulation, permitting of groundwater and surface water abstraction) - Management and maintenance of regional waters - Management of regional waterways - Control of muskrat populations
Municipalities	- Collection and transport of wastewater to treatment facilities via sewer systems - Collection and processing of rainwater to prevent flooding - Prevention of structural groundwater nuisance - Management and maintenance of urban surface waters, such as ponds, streams, and lakes - Climate-proofing urban areas - Management of local and urban waterways
Drinking water companies	- Production and distribution of drinking water

[Table 4.1]: Water management structure
Source: Based on (Staat van Utrecht, 2023)

Water management in Utrecht

In the province of Utrecht, there are four waterboards and two drinking water companies present (see figure 4.7). The waterboard Stichtse Rijnlanden is the largest waterboard in the region, while the drinking water company Vitens is located over almost the whole of the province. The provincial government collaborates closely with these parties to ensure drinking water quality.

Status of waterboards

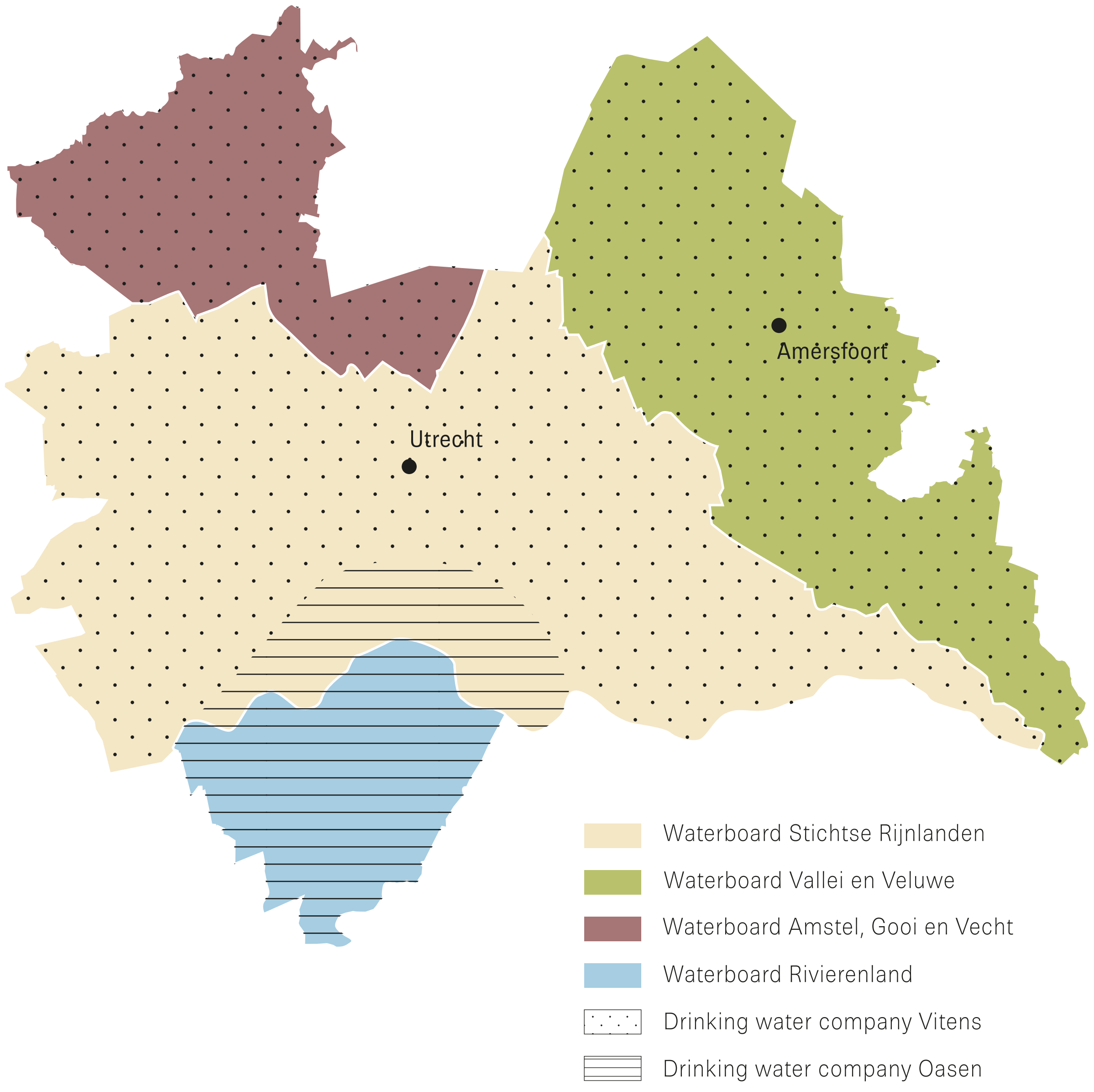
Water boards in the Netherlands have a historical origin dating back to the late Middle Ages. To cultivate land and establish settlements, drainage was essential. Until the late Middle Ages, local villagers managed water control themselves. However, this gradually changed as landownership shifted from villagers to large landowners (Staat van Utrecht, 2023).

The construction of dikes and water drainage systems required structured consultations between parties with diverse interests. Additionally, there was growing awareness that water management extended beyond individual villages. This led to the formation of cooperative organizations aimed at creating an effective water management system. These early collaborations marked the establishment of the first water boards. Their role was not only in execution but also in decision-making, making water boards the oldest democratic governing bodies in the Netherlands (Staat van Utrecht, 2023).

The Stichtse Rijnlanden Water Board was founded in 1255 and is the oldest water board in the Netherlands (Unie van Waterschappen, 2025). Water boards operate parallel to provincial governments but have a functional administration rather than a general administrative structure like provinces. The governing body of a water board includes two designated seats for the agricultural sector and two for nature conservation organizations, ensuring that these stakeholders' interests are embedded in water management (Staat van Utrecht, 2023).

Due to their close connection to local stakeholders and their interests, water boards are essential partners for the province of Utrecht. Given that this research focuses on the relationship between land use, and groundwater- and drinking water quality, engaging with water boards is crucial for identifying potential solutions.

Division of waterboards and drinking water companies



[Fig.4.7]: Division of the different waterboards and drinking water companies in the province of Utrecht
Source: Own image

4.6 Groundwater quality in Utrecht

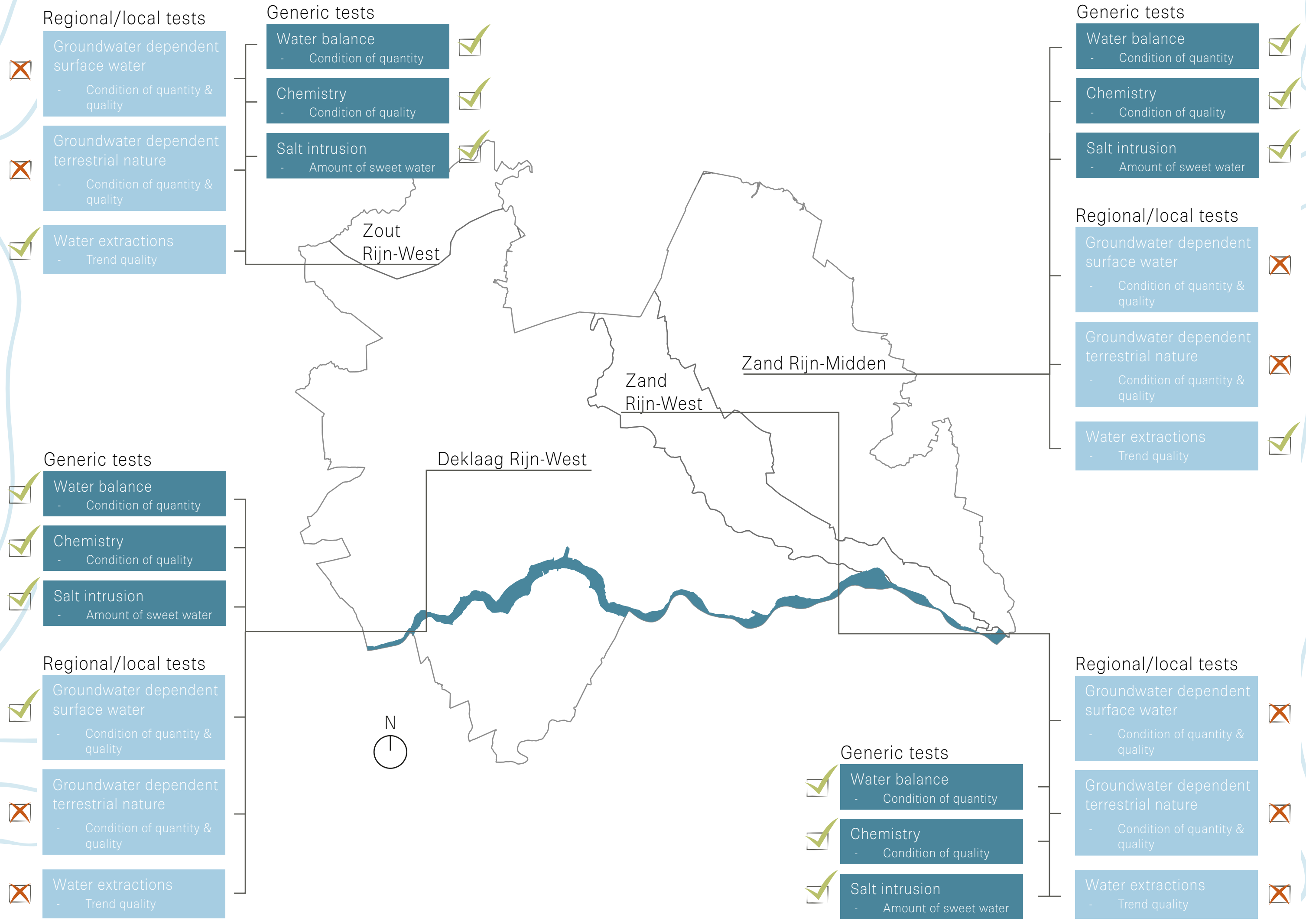
Condition of groundwater bodies

According to the Water Framework Directive (WFD), both groundwater quantity and quality must be in good condition by 2027. In 2024, a mid-term evaluation was conducted to determine whether progress toward achieving these goals is on track. This mid-term evaluation is a national assessment and not specific to the province of Utrecht. However, a comprehensive overview of the current situation regarding groundwater quantity and quality in relation to the WFD goals is provided (Ambient and RHDHV, 2024).

The province contains three groundwater bodies: Deklaag Rijn-West, Zand Rijn-West, and Zand Rijn-Midden. The groundwater quality for each groundwater body has been evaluated, providing an overview of the current situation. Each groundwater body crosses provincial boundaries and therefore the quality is also influenced by activities outside the province of Utrecht.

The evaluation makes it clear that there is still a challenge regarding water quality for human consumption. The characterization (based on the area dossiers) shows that for half of the groundwater abstraction sites, there remains a need to improve water quality (Ambient and RHDHV, 2024).

Condition of groundwater bodies in the province of Utrecht



[Fig.4.8]: Condition of different groundwater bodies in the province of Utrecht
Source: Own image

Condition of groundwater

The condition of shallow and deep groundwater in the province of Utrecht is assessed, among other methods, through the Provincial Groundwater Quality Monitoring Network (PMG). In 2024, approximately 100 monitoring wells were sampled across the province. The monitoring network was analyzed for three types of substance groups:

1. Nutrients, metals and salts;
2. Pesticides, and;
3. PFAS

Additionally, the substance groups pharmaceuticals and industrial substances (emerging contaminants) were analyzed. However, these groups were only investigated within the Water Framework Directive (WFD) monitoring network (17 wells at two depth levels), as these substances had already been mapped in 2021.

To provide a comprehensive overview of groundwater quality, the key conclusions for each substance group are presented separately. This is further divided into phreatic groundwater and deeper groundwater.

Nutrients, metals and salts

For this substance group, no concerning developments have been observed compared to previous monitoring rounds in past years (Vissers, 2024) However, several substances exceed the threshold values in both deep and shallow groundwater. These substances include aluminium, calcium, chloride, potassium, magnesium, manganese, sodium, nickel, nitrate, nitrite and zinc. in most cases, these exceedances occur only once or twice. However, calcium and manganese exceed the threshold values at multiple locations.

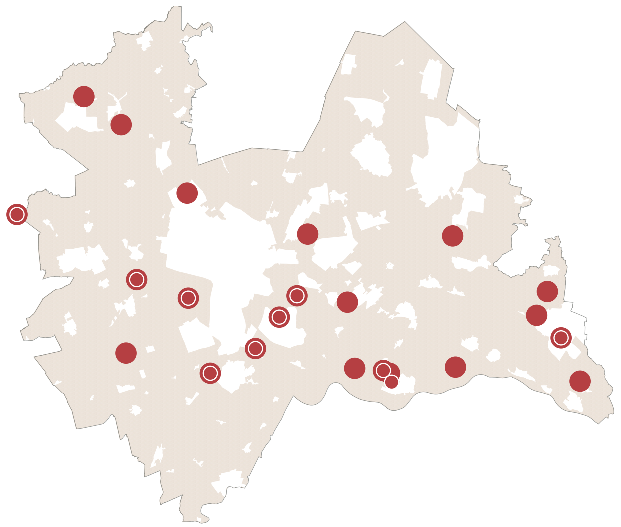
High calcium concentrations in water influence water hardness but generally do not pose a direct threat to human, animal, or environmental health. Its presence is primarily of natural origin (Vissers, 2023).

Chloride levels exceed the threshold at four measurement points in the western part of the province. However, these exceedances occur in peatland areas, where the elevated values have a natural origin due to the influence of brackish groundwater and peat oxidation (Vissers, 2023).

Additionally, potassium exceedances have been observed at four measurement points located in the sandy soils of the southeastern part of the province. These high concentrations are attributed to agricultural fertilization (Vissers, 2023).

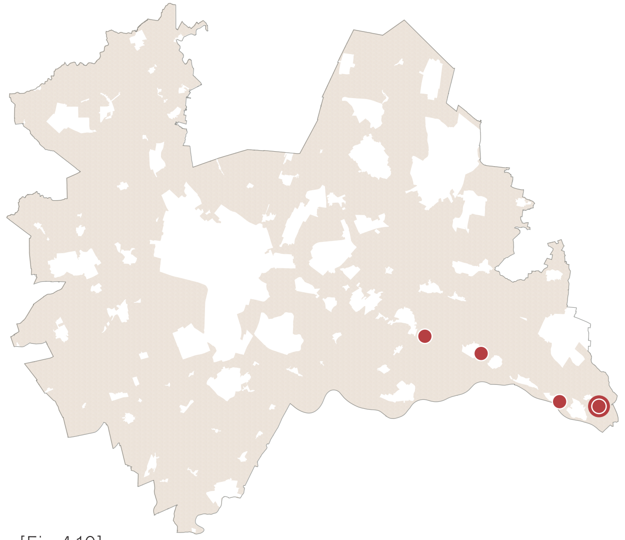
Concentration in deep filter
Concentration in shallow filter

Exceedance of calcium



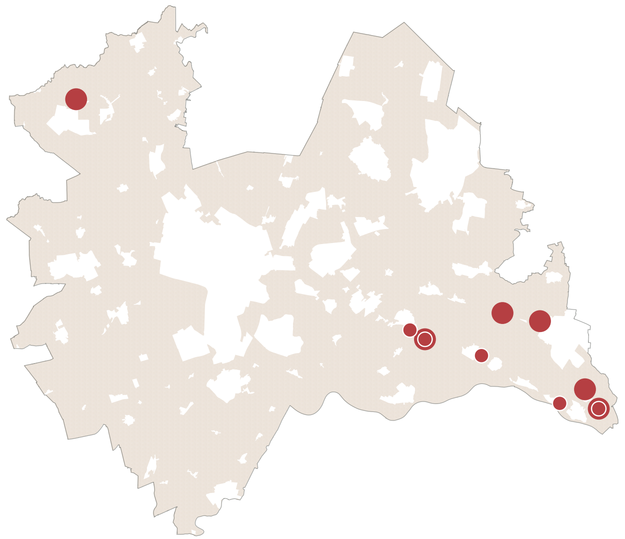
[Fig.4.9]
Source: Own image based on (Vissers, 2024)

Exceedance of nitrate



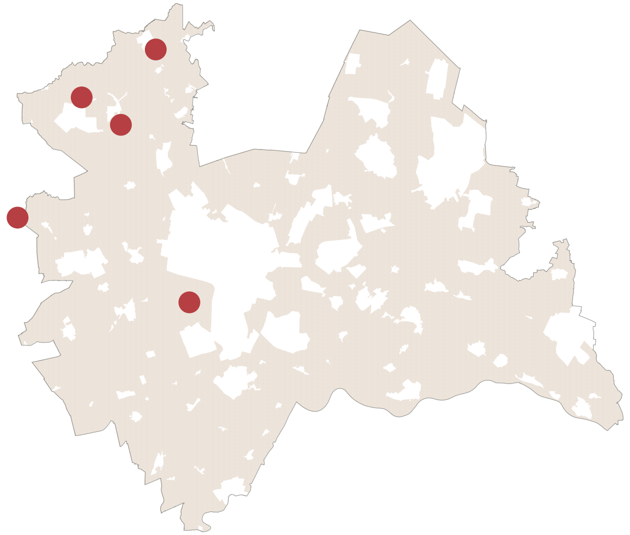
[Fig.4.10]
Source: Own image based on (Vissers, 2024)

Exceedance of potassium



[Fig.4.11]
Source: Own image based on (Vissers, 2024)

Exceedance of chloride



[Fig.4.12]
Source: Own image based on (Vissers, 2024)

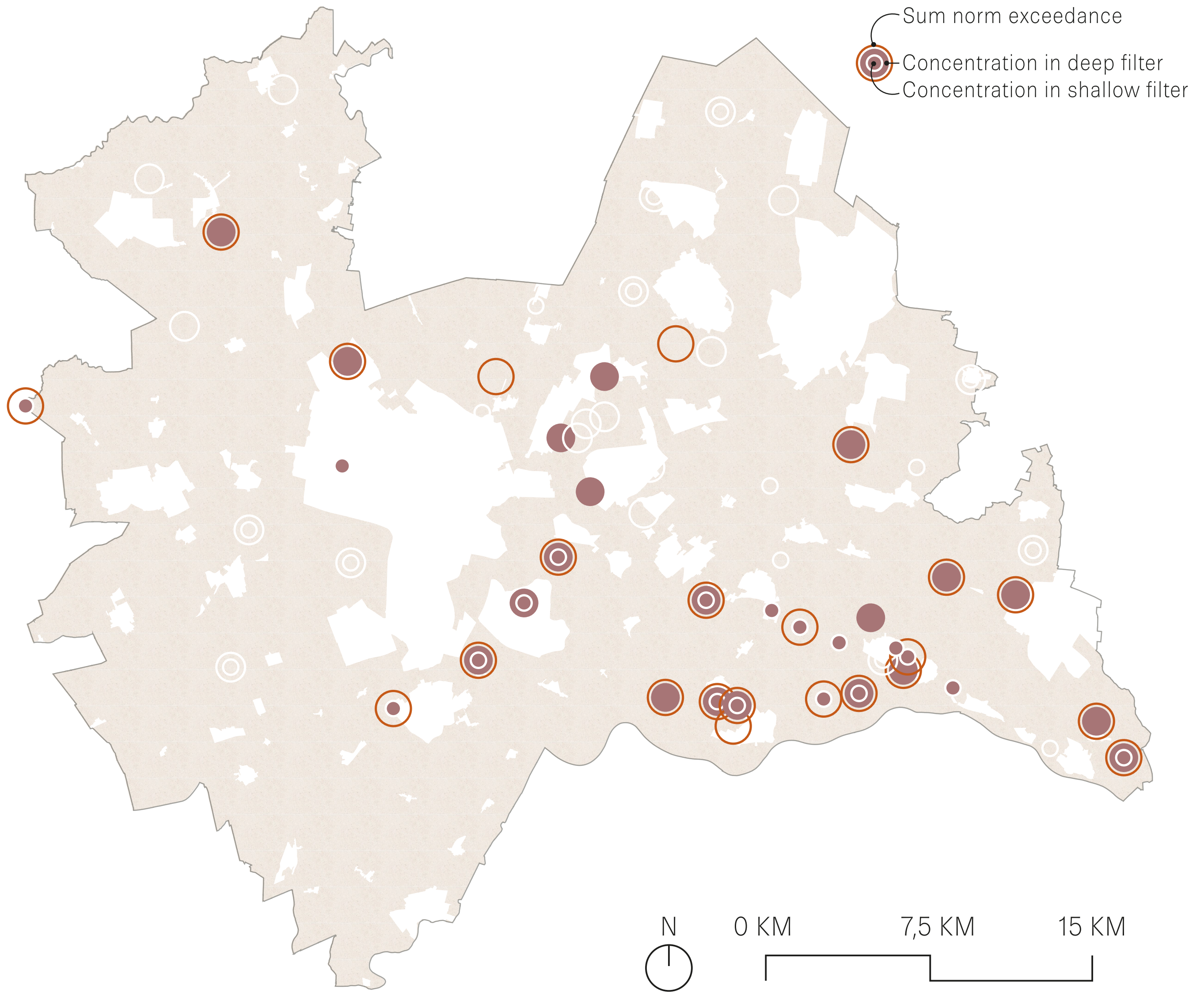
Pesticides

Of all monitoring filters in the province, 71% contained one or more of these types of substances above the reporting threshold in measurements taken in 2024. In 15% of the monitoring filters, one or more of these substances exceeded the legal threshold values of 0.1 µg/l or 1 µg/l (Vissers, 2024). In orchards, fungicides, herbicides, and insecticides are applied, resulting in the detection of multiple substances in nearly all samples - often at grasslands, pesticide resideus are frequently found above the permitted concentration levels (Vissers, 2023).

These findings also include substances that have long been banned, but continue to appear in groundwater with similar frequency. Such compounds are known to degrade very slowly and persist in the environment for extended periods (Vissers, 2024).

Overall, the situation regarding pesticide use appears to be improving, as declining trends can be observed for many types of substances. "*However, the overall pattern of widespread occurrence in groundwater remains unchanged. This is partly due to the inclusion of newly identified or previously unmonitored substances in the analysis, many of which are now frequently detected* " (Vissers, 2023). Figure 4.13 illustrates that exceedances are primarily concentrated in the southeastern part of the province. In this region, concentrations exceeding the Water Framework Directive (WFD) standards are found in both deep and shallow filters, along with violations of the sum standard (i.e., the combined concentration of multiple pesticides).

Exceedance of pesticides



[Fig. 4.13]: Amount of pesticides in the province of Utrecht
Source: Own image, based on (Vissers, 2024)

PFAS

Measurements from 2023 and 2024 indicate an increasing diffuse load to PFAS substances across the entire province. Much remains unknown about the pathways and distribution mechanisms of PFAS substances (Vissers, 2023). No specific source or cause has been identified for the elevated concentrations (Visser, 2024).

The primary substances within the PFAS group are PFOA and PFBA, with PFOA concentrations frequently exceeding drinking water standards. High concentrations are often found in roadside verges. In addition, newly emerging substances are being detected, such as trifluoroacetic acid (TFA). This compound is predominantly found in areas used for arable farming and orchards, suggesting a possible link to the use of pesticides (Vissers, 2023).

Recent reporting suggests that PFAS concentrations in deep groundwater are expected to increase in the future (Vissers, 2024).

Medicines

Pharmaceutical residues have been detected in several locations within the province, but are generally not classified as the most problematic substances. The distribution of these substances is closely linked to areas with significant surface water influence (Vissers, 2024).

4.4 Influences on groundwater quality

Difficulties in allocating influences

Groundwater quality is influenced by a wide range of factors. Chapter 3 explains the groundwater system of the province of Utrecht, highlighting its complex groundwater flow paths. Identifying the sources of contamination is particularly challenging due to the presence of tilted clay layers, which can cause groundwater to flow in multiple directions. Additionally, substances that emerge at the surface may be several decades old, and in many cases, the exact origin of a contaminant remains unknown.

Currently, the province is conducting research on the movement of contaminants on a local scale. However, on a larger scale, it is difficult to determine the precise behavior of contaminants in the subsurface. Another complicating factor is that each type of substance has distinct properties, which influences how it interacts with the soil.

Based on this information, it becomes evident that directly linking land use to specific types of contamination is challenging. Nevertheless, groundwater flow paths can be used as a basis for a rough estimation of potential contaminant movement. This approach is employed in this section to map the relationship between land use and contamination flows (Gathered during internship, February 10 2025).

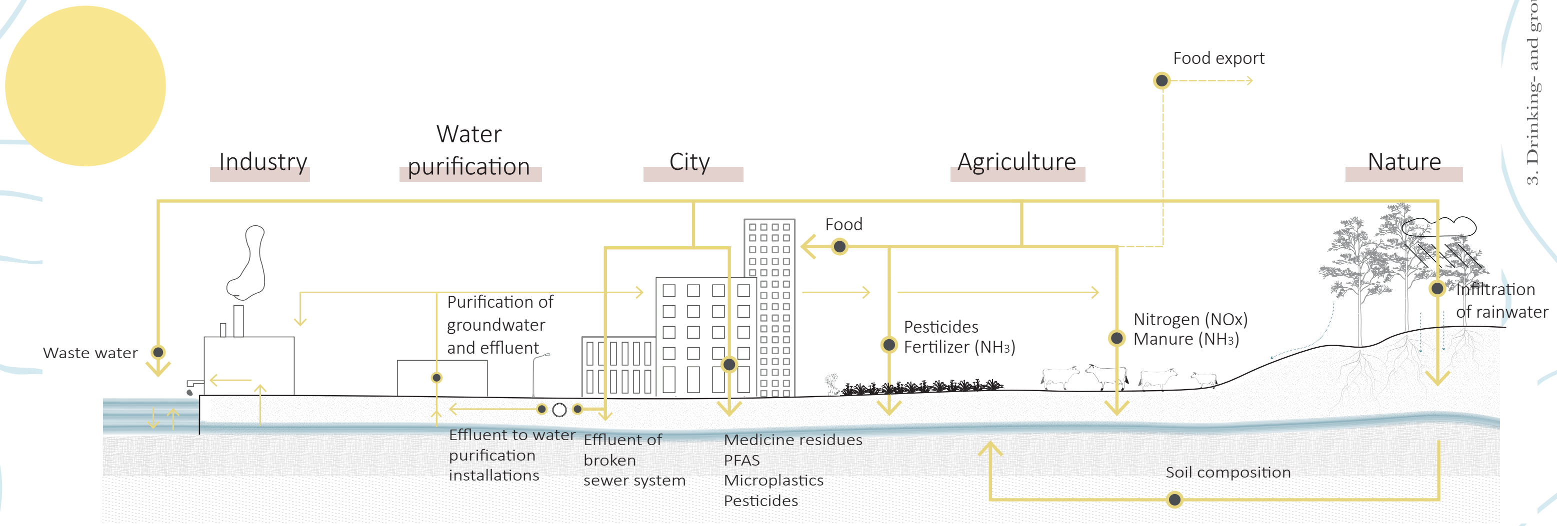
Right: [Fig.4.14] Systemic section of different pollutants leaking in groundwater
Source:Own image

Urbanization and groundwater quality

Urbanization can have a considerable impact on groundwater quality. The expansion of hard surfaces—such as buildings, roads, and pavements—reduces the amount of rainwater that can naturally seep into the ground. This limits the replenishment of groundwater supplies and leads to greater surface runoff. Such runoff often contains contaminants, including heavy metals, oils, and excess nutrients, which can infiltrate the subsurface.

In addition, the dense infrastructure associated with urban areas increases the likelihood of leaks from sewer systems, industrial operations, and polluted sites, contributing to localized groundwater contamination (Khatri et al., 2014).

Different effects of urbanization on groundwater quality



Agriculture and groundwater quality

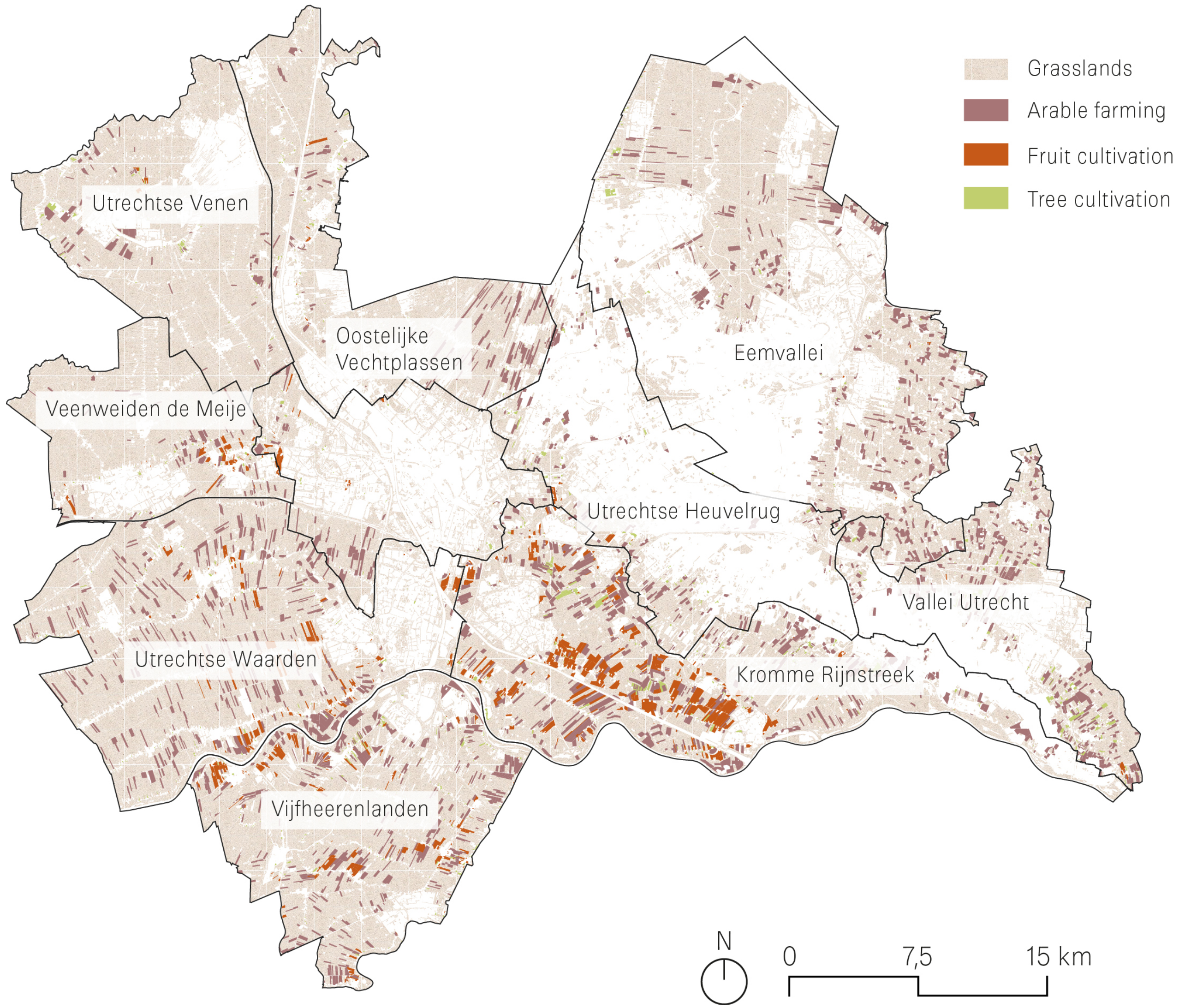
As previously mentioned in this report, agriculture could sometimes have a negative impact on groundwater quality. However, different types of agriculture affect groundwater quality in varying ways and to different degrees of intensity. To distinguish these effects in the province of Utrecht, the distribution of the type of agriculture is analyzed. Figure 4.15 illustrates this distribution.

In the province of Utrecht, 45% of agricultural activity is specialized in dairy farming, while 30% is dedicated to other grazing livestock. Livestock farming thus constitutes a significant portion of agricultural land use in rural areas, characterizing the province as a grazing livestock region. Intensive livestock farming is primarily found in the eastern part of the province (Provincie Utrecht, 2024b)

Approximately 7% of agricultural enterprises in Utrecht specialize in fruit cultivation (horticulture), which is mainly concentrated in the Kromme Rijn region. Arable farming is relatively scarce in the province (Provincie Utrecht, 2024b). While it is somewhat dispersed across the region, it is more concentrated in the southwestern and eastern parts of the province.

Pollutants that result from farming and cattle breeding are comprised of nutrients, sediments, pathogens, pesticides, metals and salts (Khatri & Tyagi, 2014b). The following sections provide an overview of the different types of agriculture and their effects on groundwater and drinking water quality.

Distribution of different forms of agriculture



[Fig.4.15] Distribution of different forms of agriculture
Source:Own image

Livestock farming

Livestock farming refers to the practice of raising animals for the production of goods derived from them. In the province of Utrecht, this sector is the most prominent and is reflected in land-use, which is predominantly grassland.

Nutrient leaching and run-off

Livestock farming has a predominantly negative impact on groundwater quality due to nutrient surpluses - mainly nitrogen and phosphorus. These surpluses result from leaching and surface run-off. Runoff refers to the emission pathway in which water flows over the surface of the land into adjacent ditches or streams. Leaching, by contrast, involves water percolating through the soil and entering surface water through the groundwater or subsurface drainage systems (Schipper et al., 2022).

A surplus of nutrients deteriorates biological water quality and, according to VEWIN, poses an increasing threat to drinking water sources. The emission of nitrogen into soil and water is largely concentrated in the dairy sector, with the majority of emissions attributed to milk production. The dairy industry accounts for 39% of the total nitrogen surplus in agricultural soils (Koops et al., 2024).

Excessive nutrient leaching from agricultural land to shallow groundwater is particularly prevalent in sandy and loess soils (Vewin, 2024b). This is due to the high permeabiility of such soils, allowing water to drain rapidly. It is important to note, however, that grassland is generally less susceptible to nitrate leachin compared to arable land (Van den Hout et al., 2023).

Crop protetion for livestock feed

Livestock farming depends on the cultivation of feed crops (arable farming), which typically involves the use of fertilizers and pesticides. One common feed crop is silage maize. The effects of arable farming on groundwater quality are discussed in more detail in the corresponding section. According to STOWA, herbicides used in maize cultivation contribute most significantly to groundwater contamination (Kruijne et al., 2020).

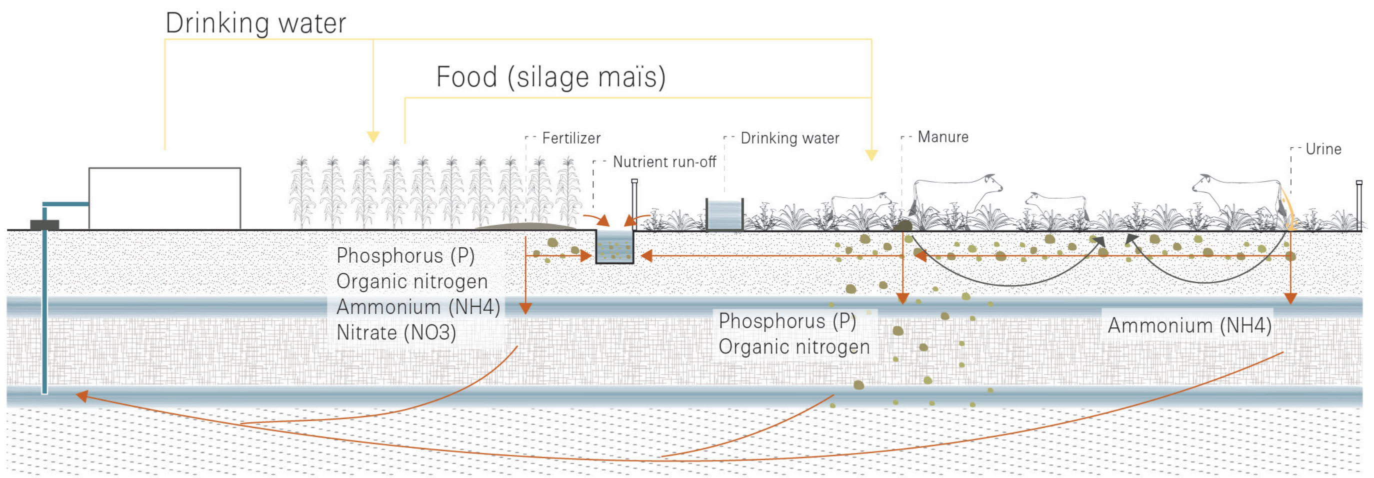
Water use

As noted earlier, groundwater quantity is directly linked to its quality. In livestock farming, both tap water and groundwater are used for watering livestock. Additionally, irrigation is practiced on dairy farms, especially on the higher sandy soils (Van der Meer, 2023). "Irrigation involves the abstraction of surface or groundwater, which is then applied to agricultural crops using irrigation systems" (De Louw et al., 2024). When used intensively, irrigation can negatively affect the hydrological system and other water uses (De Louw et al., 2024). Research from Wageningen University & Research shows that in 2021, approximately 50% of total water use in agriculture was attributable to livestock farming (van der Meer, 2023).

A longer supply chain

In general, the livestock production chain is longer, as animals require both grazing land and cultivated feed crops. This means that the effects on groundwater quality are more varied, and livestock farming typically requires more space than other agricultural sectors.

Different effects of livestock on groundwater quality



Arable farming

Arable farming is defined as: "Land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than fice years)" (European Environment Agency, 2025a).

Crop protection

In arable farming, pesticides are used to protect crops from pests and diseases. These substances can enter the soil and surface water through various pathways. These so-called emission routes can be divided into two types: diffuse sources and point sources. Point sources have a specific, identifiable location, which allows the pollution to be traced back to a particular cause or activity. Iin contrast, diffuse sources lack a clearly identifiable location, making it difficult to pinpoint the exact acitivity or cause (Havekes et al., 2021). Among the diffuse sources, leaching is an emission pathway that degrades groundwater quality. In the case of point sources, acitivites such as filling the sprayer, spillage, malfunctioning equipment, and the discharge of washing and wastewater have a negative impact on groundwater quality (Wenneker et al., 20212).

In arable farming, crop protection products are used relatively intensively, particularly in potato cultivation. In 2020, 45% of the total use of pesticides was attributed to seed, consumption and starch potatoes. "In addition, pesticides are widely applied in ornamental horticulture and other arable crops, including sugar beet and seed onions (Koops et al.., 2024).

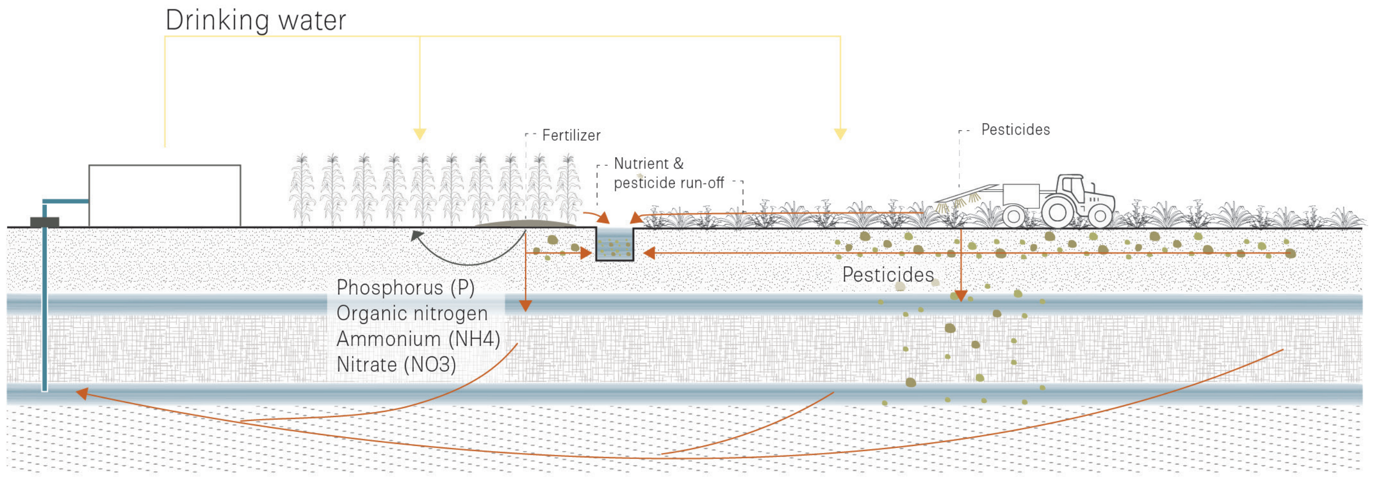
Nutrient leaching and run-off

Nutrient surpluses also occur in arable farming, with leaching to groundwater being one of the associated processes. To optimize crop growth, livestock manure, synthetic fertilizers, and organic amendments such as compost are used (WUR, 2024). In particular, potato cultivation is associated with a nitrogen surplus in the soil (Koops et al., 2024). The negative effects of nutrient surpluses have already been discussed in the section on livestock farming.

Water use

In recent years, irrigation has increasingly been employed by arable farmers to mitigate drought damage and improce the efficiency of nutrient uptake (WUR, 2024). Groundwater is predominantly used for irrigation purposes (Van der Meer, 2023). As previously mentioned, increased irrigation may negatively impact the water system and other water-related functions.

Different effects of arable farming on groundwater quality



Tree cultivation

Tree cultivation is defined as: "Land primarily used for the cultivation of trees (including conifers and spruces) and shrubs, where the height of the plants is not a determining factor" (Kadaster, 2025a).

Crop protection

Pesticides are also used intensively in tree cultivation. However, compared to the previously mentioned crops—such as seed, table, and starch potatoes, apples, pears, silage maize, onions, and several other crops—the use in tree nurseries is relatively limited.

Water usage

Finally, irrigation is also used in the tree nursery sector, primarily to prevent damage caused by night frost.

Fruit cultivation

Fruit cultivation is a form of horticulture focused on the production of fruit. As mentioned earlier, 7% of all agricultural enterprises in the province of Utrecht are specialized in fruit cultivation.

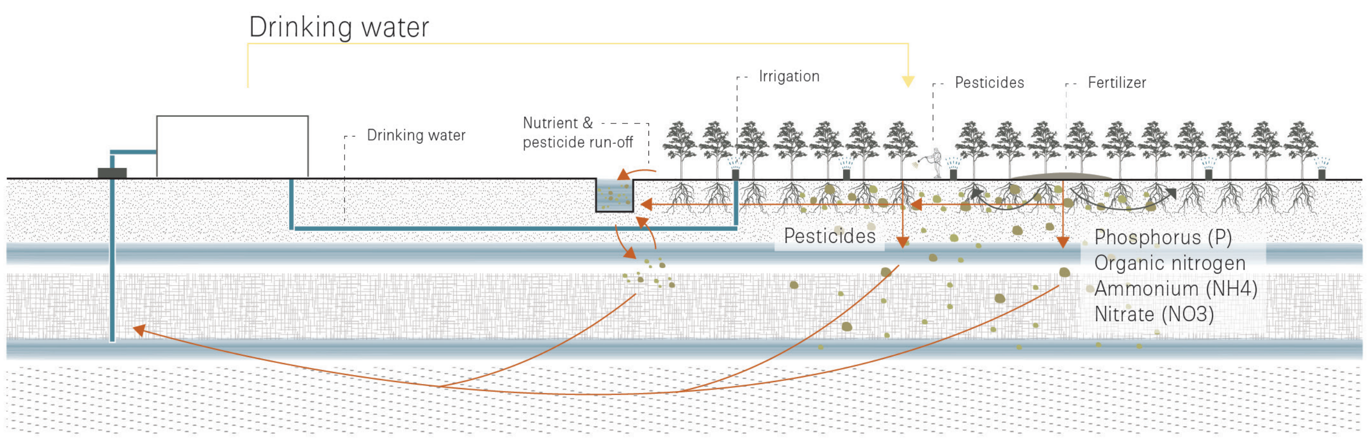
Crop protection

Pesticides are also used in fruit cultivation to protect crops against pests and diseases. According to Statistics Netherlands (CBS), apples and pears are among the most frequently treated fruit crops in the Netherlands (CBS, 2022). Fruit trees and strawberries also receive relatively high levels of pesticide application on average (Natuur & Milieu, 2024). In areas where these types of crops are grown, it can therefore be assumed that pesticide use is relatively higher than in areas where such crops are absent. In the province of Utrecht, pesticide use—particularly from orchards (fruit cultivation)—has been identified as a significant concern (Vissers, 2023).

Water usage

Irrigation is also widely used in fruit cultivation, primarily to prevent damage from night frost and to support the establishment of crops—that is, to help young plants take root. Groundwater is the main source of water used for irrigation of crops (Van Der Meer, 2023). As mentioned earlier, an increase in irrigation can have negative effects on the water system and on other land-use functions.

Different effects of fruit and tree cultivation on groundwater quality

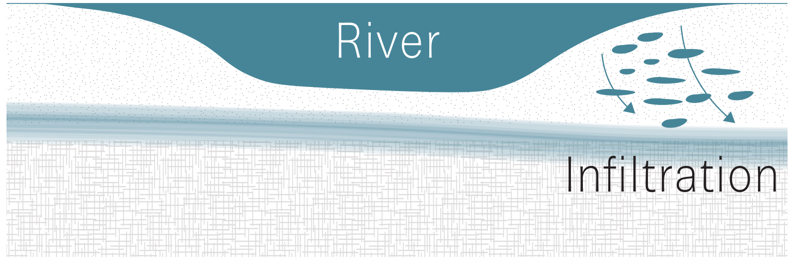


Influence of surface water

Surface water also influences groundwater quality. However, the specific ways in which groundwater quality is affected in the province of Utrecht remain unclear. To gain better insight into this, a study has recently been initiated by the province of Utrecht (Gathered during internship, March 10, 2025).

In general, rainwater infiltrates into the soil, after which the groundwater flows towards rivers and eventually discharges into the sea. However, in certain locations, water infiltrates from riverbanks into the subsurface - a proces known as bank filtration. This can occur naturally or be articifically induced. When infiltration is sustained by groundwater abstraction, the situation is considered artificical (Berliner Wasserbetriebe, 2020). The exact locations where bank filtration occurs in the province of Utrecht are not yet fully known. To addres this, the province has developed so-called regional groundwater dossiers. These dossiers provide information for eacht groundwater abstraction site, including potential risks to the abstraction. They also indicate the influence of surface water and whether bank filtration is present (Engel & Jensen, 2021).

Bank filtration



[Fig.4.15] Bank filtration
Source: Own image

4.5 Sub-conclusion

This chapter adresses the first two sub-questions. For each sub-question, the main conclusions are briefly outlined. On the enxt page, a conclusion map of this chapter is depicted.

SQ1: How is the safeguarding of drinking water quality organized spatially and administratively in the province of Utrecht, and how has this evolved over time?

Production of drinking water has shifted from an individual to a more public responsibility

In the Middle Ages, the population was individually responsible for securing drinking water, which ultimately led to significant public health issues due to deteriorating water quality. Over time, the protection of overall water quality - and specifically drinking water quality - gradually became a public responsibility. Through the implementation of laws and regulations, this protection has steadily improved. Today, responsibilites within water management are somewhat fragmented across various governmental bodies.

Groundwater quality around groundwater abstractions are spatially safeguarded in several ways

The province protects groundwater quality through the designation of groundwater protection zones, drilling-free zones, surface water protection zones, and 100-year zones. In addition certain areas have been designated as strategic groundwater reserves, intented for future groundwater abstraction (for future generations). The applicability of specific zones for water abstraction depends, among other factors, on the geological composition of the subsurface.

More than half of the groundwater asbtractions are vulnerable to pollution in the province of Utrecht

The regional case files have revealed the composition of the soil surrounding the abstraction sites. These analysis show that a protective clay layer is often not consistently present across the entire area, which increases the vulnerability of the groundwater to contamination due to easier infiltration of pollutants.

SQ2 A. How and where do agriculture and urbanization affect the groundwater quality in the rural areas of the Province of Utrecht, and what are the consequences for drinking water quality?

Pollution and water quality is location specific - it needs an area-oriented approach;

Groundwater quality varies significantly across the province, and there is no single solution to adress the wide range of contaminants. A tailored, area-specific approach is required, as the issue cannot be resolved solely at the regional level.

Pesticides and PFAS constitute the most significant concern in the province of Utrecht

It has become evident that the majority of shallow and deep monitoring filters detect the presence of pesticides and PFAS. Exceedances of pesticide thresholds are primarily observed in the southeastern part of the province. In contrast, nutrient surplus represents a relatively smaller issue within the province of Utrecht. Additionally, PFAS-substances are diffusely distributed throughout the province and have no identifiable source or cause.

Linking land-use directly to specific types of contamination is difficult

It is relatively difficult to directly link land use to specific contaminants. This is primarily due to the uncertainty regarding how substances have migrated through the groundwater system, which is influenced by the complexity of different types of groundwater flows.

Within arable farming and fruit- and tree cultivation, pesticides are the most significant concern

Within arable farming and fruit cultivation, the highest pesticide usage is typically associated with the production of apples, pears, and potatoes. As a result, this type of land use tends to have a relatively high negative impact on groundwater quality.

In Livestock, nutrient surpluses and water usage are the most significant concern

In general, the livestock production chain is more complex, resulting in a wider variety of effects on groundwater quality. Both grassland and arable land used in livestock farming involve nutrient application, making nutrien surplus a relatively more significant issue in livestock farming compared to other types of agriculture.

Contaminants mostly concentrate in the southwest of the province of Utrecht

When considering all contaminants collectively, it becomes evident that they are primarily concentrated in the southwestern part of the province, including pesticides, PFAS, and nutrients.

SQ2 B. Are there other (external) factors that influence groundwater quality in the rural areas of the Province of Utrecht, and what are the consequences for drinking water quality?

Quality and quantity are closely linked

It has become clear that groundwater quality and quantity cannot be considered seperately, as they are strongly interdependent. Therefore, when seeking integrated solutions, it is essential to also consider groundwater quantity.

Infiltrating surface water can affect groundwater quality

The regional case files have revealed that surface water can sometimes influence groundwater quality near drinkinig water abstraction sites through the process of bank filtration. This may negatively impact groundwater quality, as contamintants present in the surface water can infiltrate into the subsurface, a process that is further affected by land use in the vicinity of the riverbanks.

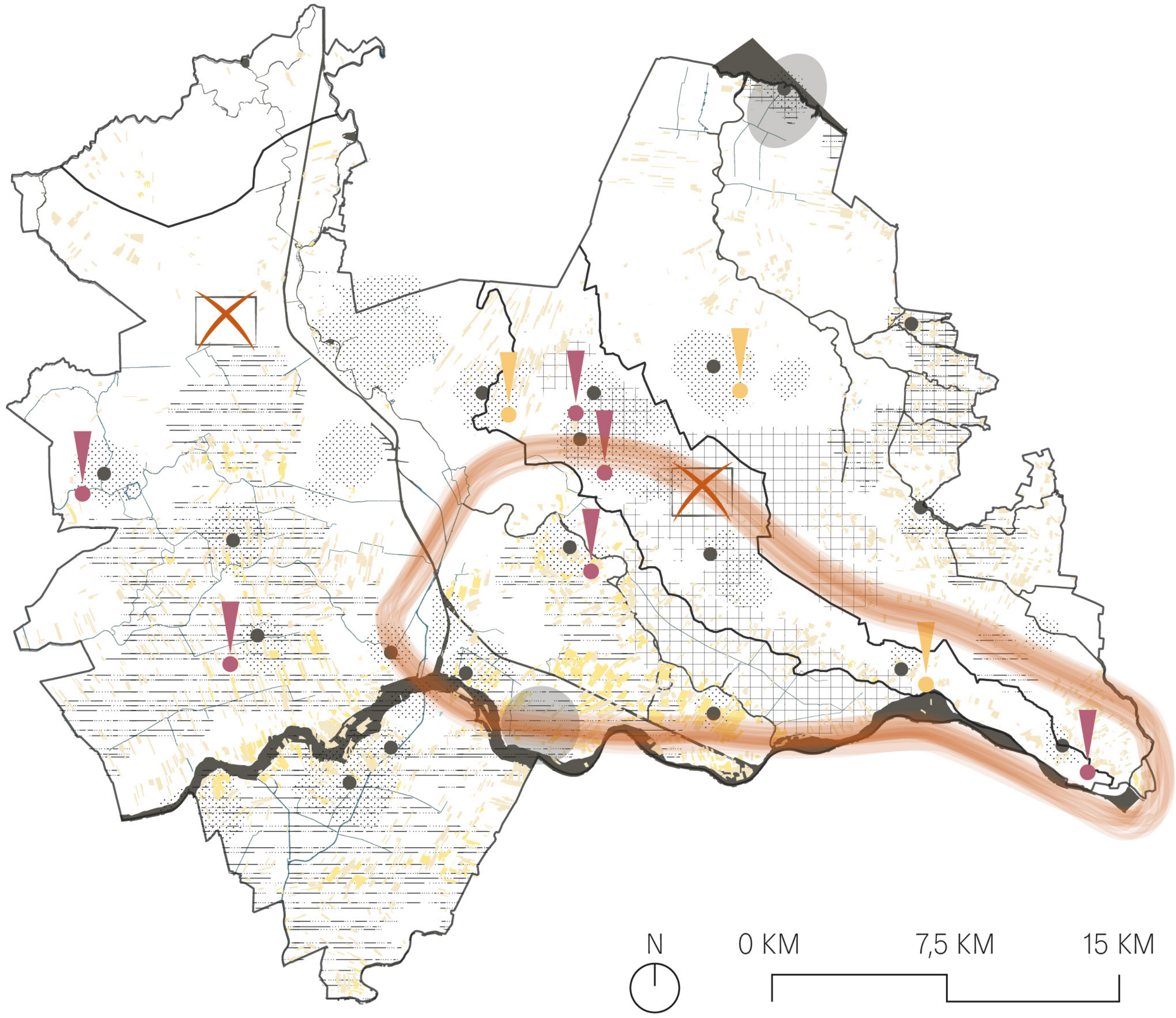
- Groundwater abstraction location
- Surface water abstraction location
- Surface water
- Groundwater protection zone
- Vulnerable strategic groundwater storage
- Drinking water searching area
- Vulnerable drinking water abstractions
- Very vulnerable drinking water abstractions

- Fruit cultivation
- Arable farming
- Tree cultivation

- Condition of groundwater body insufficient

- Most exceendance of pesticides and nutrients

Conclusion map



5.Spatial trends and policies

Identify

SQ3

What spatial trends and policies exist for urbanization and agriculture in the province of Utrecht, and how do they affect the rural areas and each other?

This chapter examines the trends and policies related to urbanization and agriculture. This analysis is based on policy research, discussions with colleagues from the province of Utrecht, and interviews. The effects on rural areas are made clear through these trends and policies. This information then serves as the foundation for developing potential scenarios, which are further explained and elaborated upon Chapter 6.

4.1 Trends and policies agriculture

Trends

There are several trends within the agricultural sector, which are related to water quality. By means of literature study and interviews, different trends are distinguished. These trends are elaborated below.

Upscaling and intensification of agricultural enterprises

1

Over the past 11 years, the number of agricultural enterprises in the province of Utrecht has decreased by 23% (Connecting Agri & Food, 2023). Simultaneuously, the number of animals per farm has increased, as has the number of large-scale farms. This reflects a national trend, indicating that upscaling and intensification have taken place (Connecting Agri & Food, 2023; (Berkhout et al., 2023).

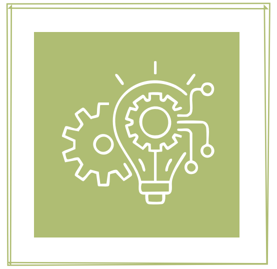
Transition livestock to other forms of agriculture

2

This trend is primarily a result of the decline in the number of dairy farmers. As their numbers decrease, may permanent grasslands are disappearing. Additionally, there was previously a so-called grassland requirement, which allowed farmers to apply for derogation if they met the 80% rule, meaning that 80% of their land had to be grassland. This requirement is no longer in effect, making it possible to convert permanent grassland into other crops. The Waterboard Vallei and Veluwe indicates that these grasslands are now being converted into arable farming, bulb cultivation, and other crop production. As discussed in the previous chapter, these types of agriculture have a negative impact on water quality, primarily due to pesticide use (Waterboard Vallei and Veluwe, 2025).

Focus on innovation

3



In agriculture, there is a growing emphasis on the use and development of innovative techniques. These include methods such as precision farming, vertical cultivation, computer-controlled horticulture, and other advanced technologies (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019).

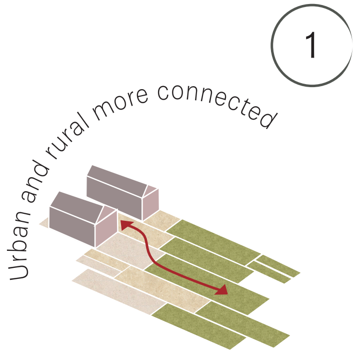
Policies

Vision agriculture

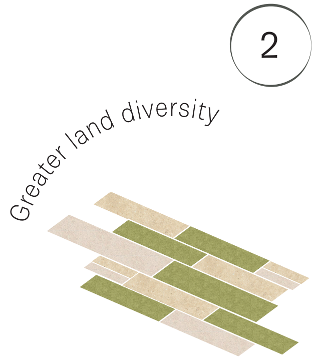
Currently, the province of Utrecht is in the process of revising its agricultural vision. In this vision, the province acknowledges the necessity of an agricultural transition, aiming to establish a sustainable food system that ensures both a viable income model for farmers and greater appreciation for food. A key factor identified in this transition is consumer behavior. Through its agricultural vision, among other initiatives, the province seeks to promote more sustainable dietary habits and fosters a resilient and profitable agricultural sector. This vision outlines a long-term objective for 2050 and serves as a foundational component of the broader environmental vision (Provincie Utrecht, 2024b).

The envisioned future outlined in this document consists of multiple components, which have been summarized in several visual representations (see right page).

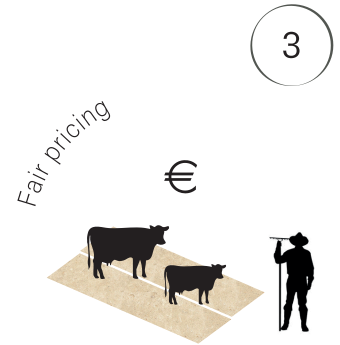
Summary focal points of agricultural vision



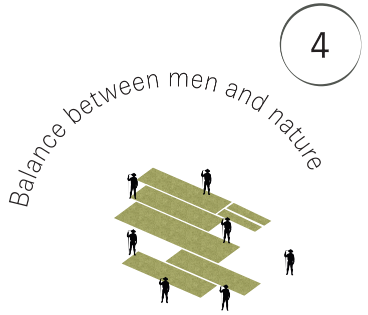
- Residents are strongly involved with the origin of their food
- Lively rural communities



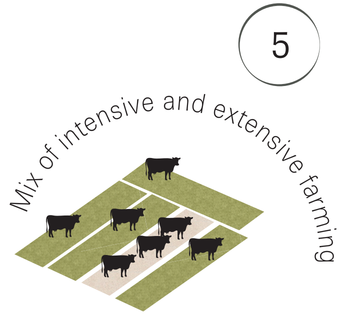
- Agriculture still biggest land-use
- More diversity in types of agriculture
- Focus on new types of crops
- Shift from production for animal feed to human food



- External costs (environmental an societal) are included in the pric
- Equivalent chains
- Society pays for green-blue services
- Enhancing services to create a good business model



- Focus on nature-inclusive agriculture
- Usage of pesticides is reduced to the maximum
- Agroforestry as an important connecter between agriculture and nature
- Good soil care



- Extensive farming around nature parks and vulnerable areas
- Intensive farming within the norms

Utrecht Programme Rural Areas (UPLG)

In addition to its vision, the Utrecht Programme for Rural Areas (UPLG) serves as a key policy document outlining the future of agriculture. Although the National Programme for Rural Areas (NPLG) has been discontinued, the province of Utrecht continues to implement its own programme for rural development. This programme adopts a region-specific approach as a continuation of the NPLG. The UPLG aims to address all rural challenges in an integrated manner.

Within the UPLG, the rural areas of the province of Utrecht are divided into five distinct subregions:

- The Peat Area of Groene Hart
- The Peat Area of Eemland
- Utrechtse Heuvelrug
- The Gelderse Valley
- Kromme Rijn Region

Each subregion faces unique challenges, and the UPLG outlines specific development trajectories tailored to each area.

Peat Areas: Groene Hart and Eemland

The peat areas face the greatest challenges and is therefore designated as a priority region within the UPLG. The development trajectory for the peat area in 2050 focuses on reducing CO_2 emissions while promoting sustainable agriculture and nature conservation. Consistent with the broader vision, the emphasis is on extensive, nature-inclusive circular agriculture. Additionally, water levels will be raised, and efforts will be directed towards ecological restoration and the creation of a rich green-blue infrastructure.

Utrechtse Heuvelrug

This region plays a crucial role in maintaining a sustainable water system. The UPLG's development strategy for Utrechtse Heuvelrug focuses on restoring the water system and natural ecosystems. Key measures include prolonging water retention, rehabilitating drought-sensitive habitats, restoring groundwater discharge, and revitalizing forests and nature reserves. On the slopes of the Heuvelrug, a process of 'hydrological disentanglement' is being implemented.

Gelderse Valley

The development trajectory for the Gelderse Valley envisions a diverse landscape where agriculture, nature, and urban areas coexist harmoniously. Here, agriculture is transitioning towards nature-inclusive circular farming, with an increased focus on other services (multifunctional agriculture). Sustainability is further enhanced through innovation and diversification, while recreational green corridors facilitate easy access to the surrounding countryside. Additionally, the urban areas around Amersfoort and Veenendaal have expanded significantly. At the same time, water quality has improved, streams have been restored, and water retention capacity has been increased.

Kromme Rijn Region

This region is highly fertile and serves as an important recreational area for nearby urban centers. The primary objective is to enhance green infrastructure and improve accessibility. Short food supply chains have been expanded, fostering stronger connections between urban and rural areas (Provincie Utrecht, 2023a).

4.2 Trends and policies urbanization

Trends

There are several trends within the urbanization, which are related to water quality. By means of literature study and interviews, different trends are distinguished. These trends are elaborated below.

Population growth

1

According to projections by the CBS, the province of Urecht is expected to be one of the three fastest-growing provinces in the Netherlands. Currently, the province has a population of approximately 1,370,000, but this number is projected to increase to nearly 1,464,200 by 2050 (Staat van Utrecht, 2025). This population growth is partly driven by an incrase in average life expectancy and migration (Stoeldraijer et al., 2022).

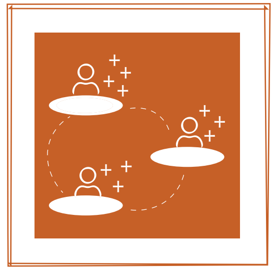
Growth in single-person households

2

In addition to population growth, projections by the PBL and CBS also indicate a shift in household composition. Between 2022 and 2035, PBL and CBS anticipate an increase in the number of households across all COROP-regions, with more than 10% growth observed in half of these regions. After 2035, the growth in the number of households, as well as overall population growth, is expected to slow down (Planbureau voor de Leefomgeving & Centraal Bureau voor de Statistiek, 2022)

Majority of municipalities in Utrecht expected to grow until 2050

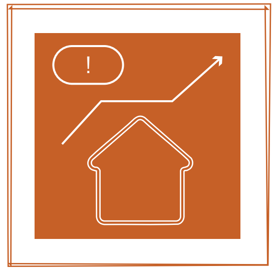
3



The majority of municipalities in the province of Utrecht are projected to experience population growth. The city of Utrecht is expected to see the most significant increase, followed by the municipalities of Bunnik and Vianen. In contrast, a small number of municipalities - such as Lopik and Montfoort - are expected to face population decline (Staat van Utrecht, 2025).

High demand in housing

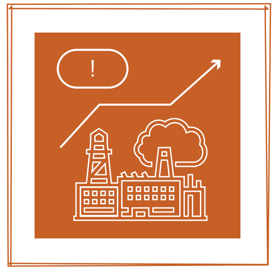
4



By 2040, approximately 165,000 new homes must be built in the province of Utrecht. While a significant portion of this housing development can take place within existing urban and village areas, the province anticipates that one or more large-scale residential developments will be necessary in the future (Provincie Utrecht, 2021).

High demand for industrial land - emerging shortage

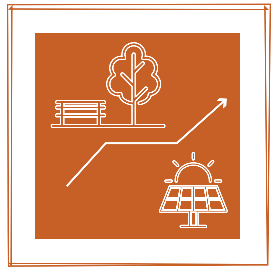
5



The demand for industrial land is higher than previously anticipated. "Stronger employment growth and transitions related to the circular economy, energy and climate are the main drivers of this increase." (De Kort et al., 2023). In the province of Utrecht, the estimated need for industrial land expansion amounts to approximately 100 to 240 net hectares by 2030. An additional 85 to nearly 190 hectares is expected to be needed between 2030 and 2040. The greatest demand comes from regular business operations (SMes) in sectors such as trade, installation, repair, and contruction (up to environmental category 3). In addition, there is significant demand from large-scale logistics and heavier industries (environmental category 4) (De Kort et al., 2023).

Increasing additional spatial demands

6



In addition to residential development and industrial areas, other emerging spatial demands also fall under urbanization. For example, space is required to accomodate the energy transition and climate adaptation (De Kort et al.,2023). This includes the need to allocate land for, for example, solar parks and water storage.

Spatial vision

For urban development, the province has established a set of fundamental principles in its spatial vision. These principles are as follows:

- Expand within existing urban and village areas as much as possible, particularly near key transport hubs;
- Expand within other urban areas;
- Link potential new large-scale developments to high-quality public transport at (existing or new) hubs along major infrastructure corridors.

The province faces a high demand not only for housing but also for additional employment locations. The designated hubs for integrated residential and employment development are: Woerden, Maarssen, Breukelen, Utrecht Zuilen, Utrecht Overvecht, Amersfoort-Schothorst, Amersfoort Vathorst, Veenendaal Centrum, Veenendaal – De Klomp, Bunnik, Houten, Nieuwegein City, and Driebergen-Zeist (Provincie Utrecht, 2021).

This section provides a brief overview of the province's policy on both residential development and employment locations.

Housing

Given the high demand for housing, the province has adopted a new approach: a joint regional programming system. In this system, the province collaborates with municipalities at a regional level to determine which residential locations can be developed and within what scope (both quantitatively and qualitatively). Municipalities have the initiative to propose housing development sites, while the Provincial Council establishes the framework within which these developments can take place (Provincie Utrecht, 2021).

Locations for working

ICT, business services, and financial services are key sectors for the economy of Utrecht. These functions can be effectively integrated with other urban activities. The province focuses on so-called "interaction environments": well-connected urban locations with a strong provision of amenities.

In addition to these sectors, specific business parks are required for industries such as manufacturing and logistics. For these specialized business parks, the province primarily aims at restructuring, revitalizing, and, where necessary, repositioning existing business areas in urban regions to optimize space utilization. The demand for business parks in the province is estimated at 212 hectares by 2030. However, the province remains cautious about developing new, unplanned business parks. Instead, it is open to facilitating the expansion of existing local businesses.

The planning of business locations follows the same regional programming system as that used for residential developments (Provincie Utrecht, 2021).

Urbanization locations

In the spatial vision, potential locations for large-scale, integrated developments have been identified (see Figure 4.2). Some of these developments also consider expansion areas (Provincie Utrecht, 2021)

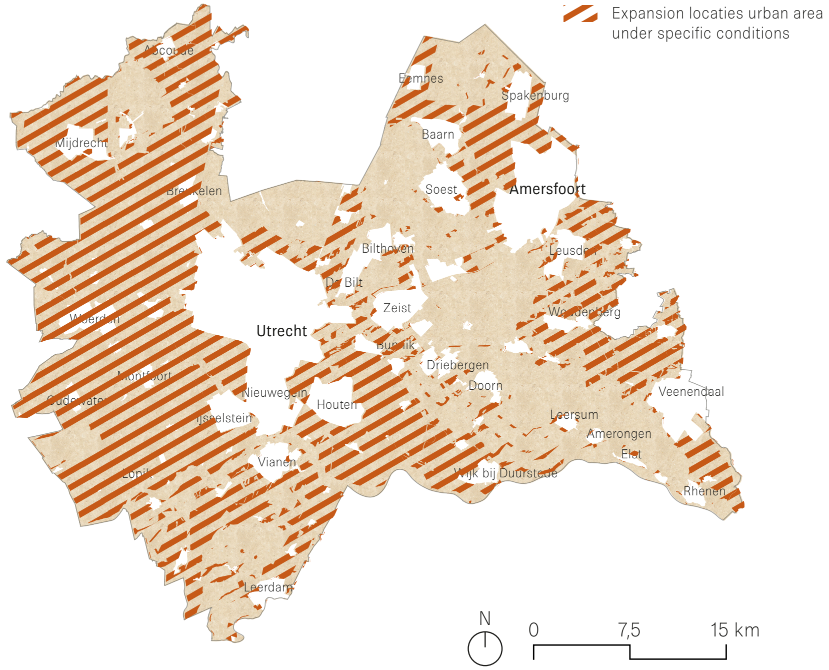
The province of Utrecht has no concrete urbanization plans beyond 2040. However, decisions for the future—such as infrastructure and accessibility—must already be made (Gathered during internship, February 26 2025).

Housing and employment program

The regional programming mentioned in the spatial vision has been further elaborated in the Housing and Employment Program. This program provides a clear overview of all urban development plans per municipality. Figure 5.1 also illustrates which developments are already underway and which plans have been designed for realization in the coming years.

The largest housing developments planned until 2030 are located in Mijdrecht, the municipality of Amersfoort, and Odijk (Bunnik) (Provincie Utrecht, 2023b).

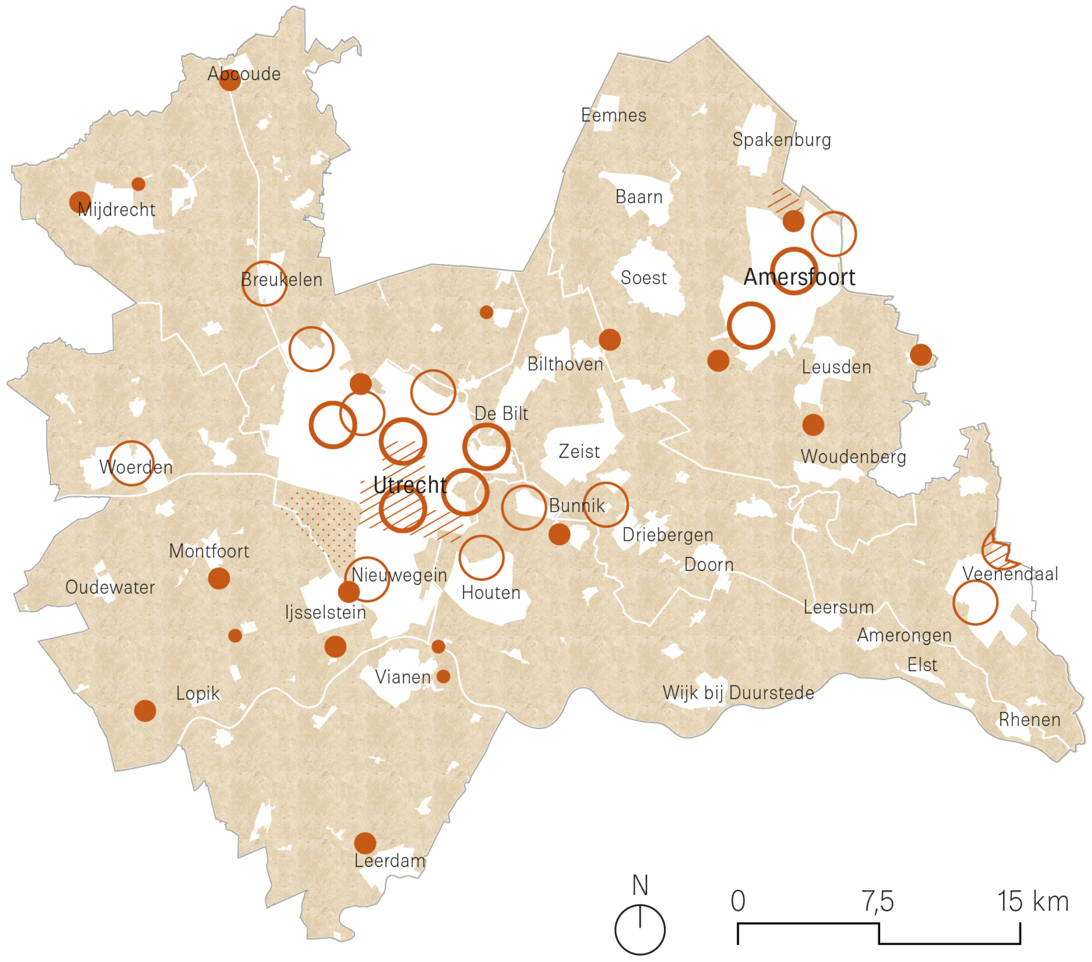
Possible expansion locations for small urban development



Left: [Fig.5.1]: Possbile expansion locations for small urban development - under 50 dwellings
Source: Own image, based on: (Provincie Utrecht, 2023b)

Right: [Fig.5.2]: Urban developments in the province of Utrecht
Source: Own image, based on: (Provincie Utrecht, 2023b)

Urban developments in the province of Utrecht



Focus area - rural areas

Search direction large scale integral development living-working-accessibility

Long-term search direction large scale integral development living-working-accessibility

Designed location for housing - according to provincial programme 2023

Priority location for large scale integral development living and working around node

Potential location for large scale integral development living and working around node

Designed location for commercial/industrial zone - according to provincial programme 2023

4.4 Sub-conclusion

This chapter addresses the third research question. The main conclusions are briefly outlined below.

SQ3: What spatial trends and policies exist for urbanization and agriculture in the Province of Utrecht, and how do they affect the rural areas and each other?

Two agricultural trends potentially impacting groundwater quality negatively

Within the agricultural sector, two notable trends may negatively affect groundwater quality. Firstly, there is a transition from grassland to arable land and fruit cultivation. Secondly, an increasing number of new pesticides are being detected. Both developments pose a threat to the quality of groundwater resources.

Diverging agricultural developments: intensification vs. ecological practices

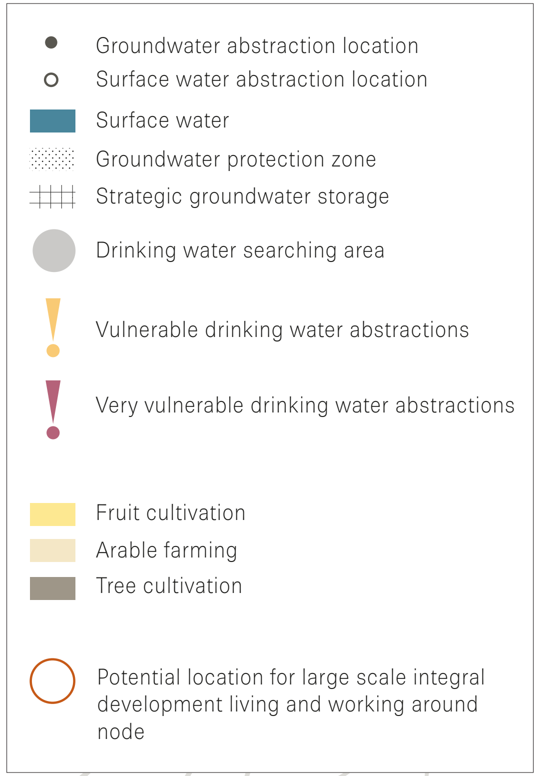
Two distinct trajectories are emerging within agriculture: on the one hand, a trend towards upscaling and intensification; on the other hand, a shift towards more ecological and small-scale farming practices.

Utrecht's agricultural policy focuses on organic and nature-inclusive farming

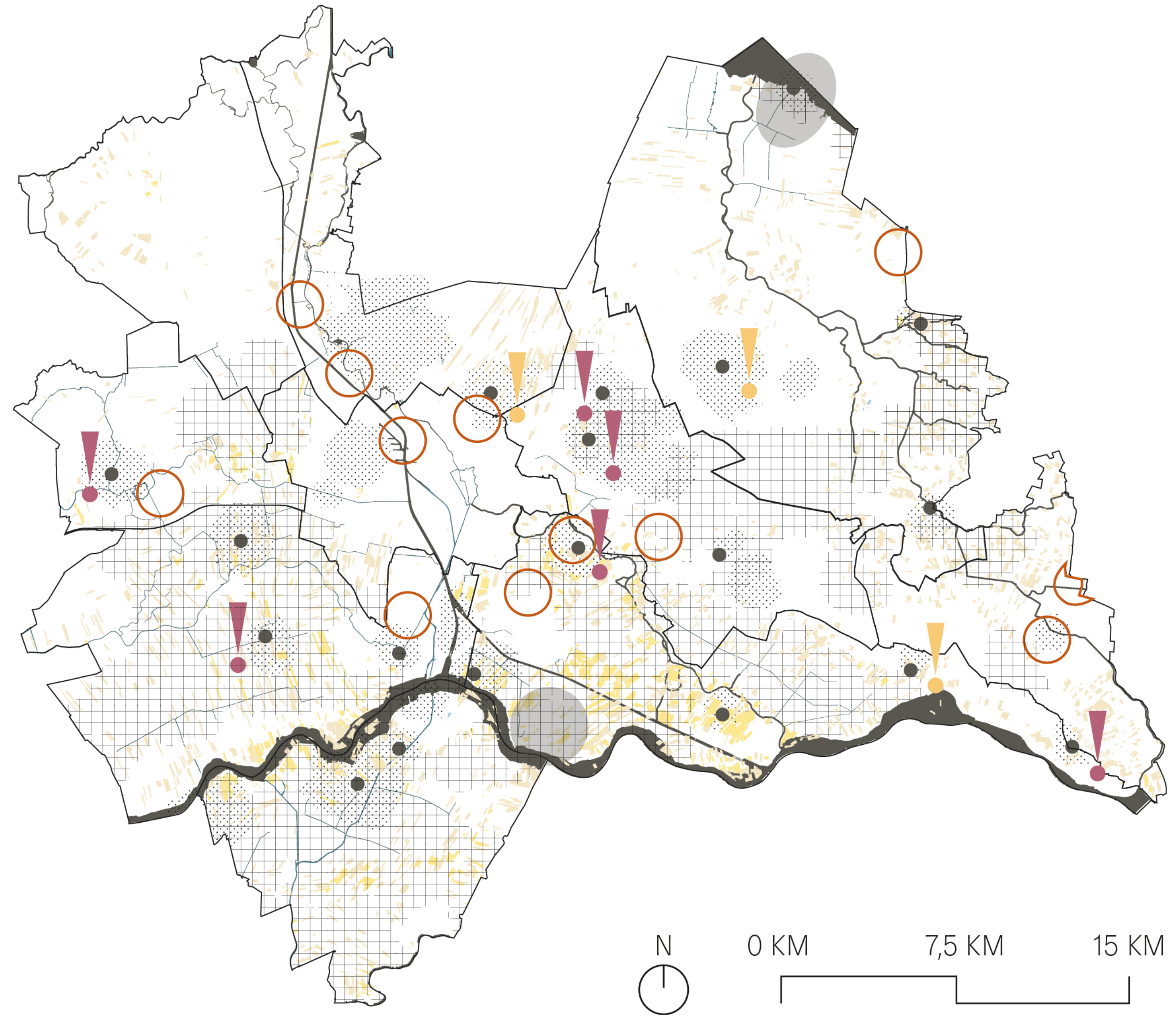
The provincial agricultural policy of Utrecht strongly emphasizes organic and nature-inclusive farming, promoting the use of short supply chains as part of a sustainable food system.

Large-scale development sites of housing and industry required in rural areas

Provincial policy states that at least two large-scale development sites for residential and commercial/industrial use are necessary to meet current and future demands. These developments are expected to take place in rural reas, indicating a growing influence of urbanization in these rural areas. It is not ruled out that additional locations for urban expansion will be needed in the distant future. This would reduve the availability of land for agriculture.



Conclusion map



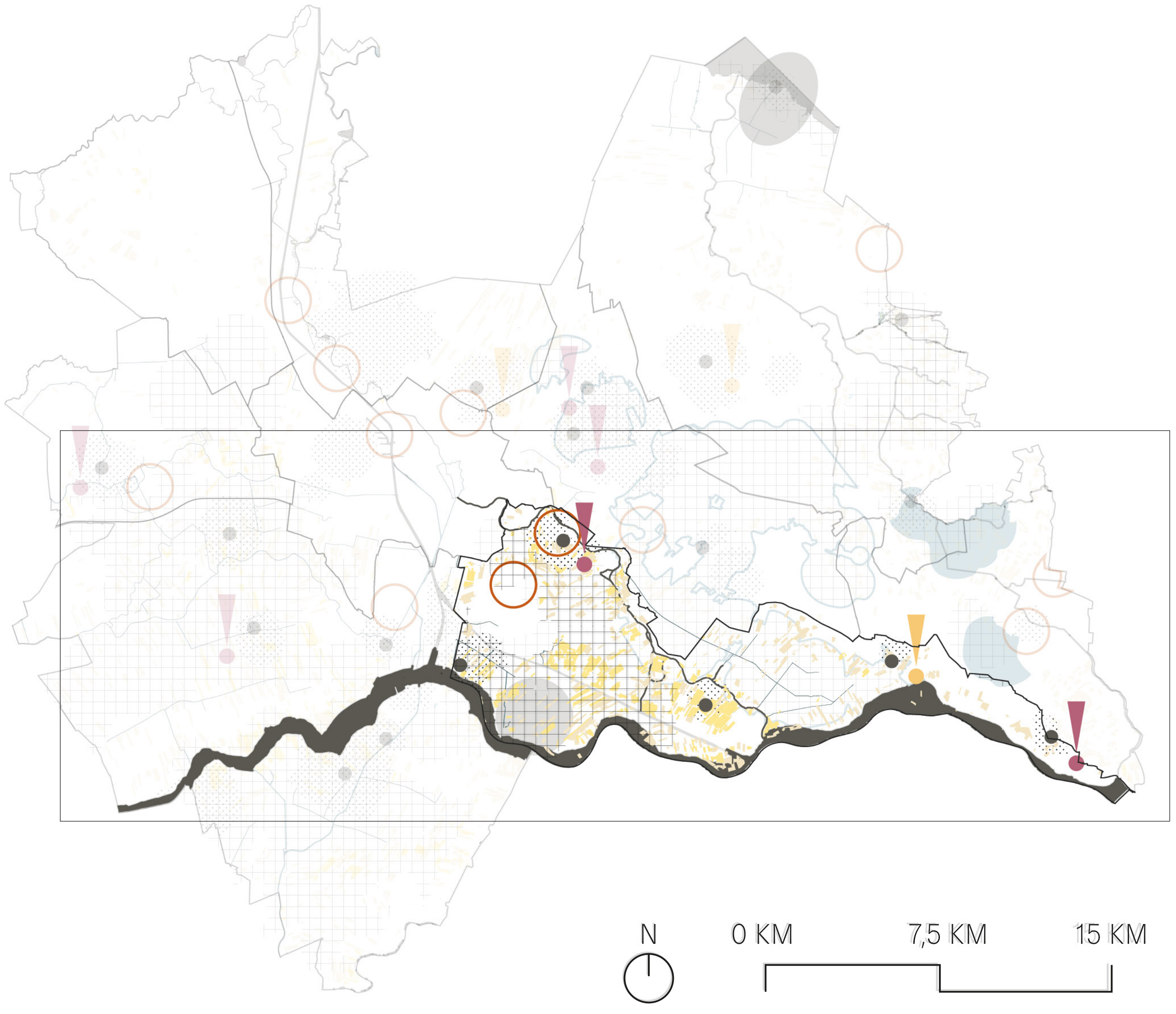
[Fig.4.4]: Conclusion map
Source: Own image

Focus area: Kromme Rijnstreek

An analysis of the landscape

The Kromme Rijnstreek has emerged from the analysis as the most dynamic area for further investigation. This chapter presents the regional analysis of this area, providing a brief overview of its history and spatial (main)structures. This analysis serves as the foundation for identifying and elaborating on the region-specific challenges and issues.

0.1 Choice of focus area



- Groundwater abstraction location
- Surface water abstraction location
- Surface water
- Groundwater protection zone
- Strategic groundwater storage
- Drinking water searching area
- Vulnerable drinking water abstractions
- Very vulnerable drinking water abstractions
- Fruit cultivation
- Arable farming
- Tree cultivation
- Potential location for large scale integral development living and working around node

Kromme Rijnstreek

Based on the area analysis and the exploration of trends and policies, the Kromme Rijnstreek has been selected as the focus area. This region contains five drinking water abstraction sites, three of which are (highly) vulnerable. Additionally, a designated drinking water search area is located in the southwest of the region, which also includes part of the future strategic groundwater reserve. The urbanization challenge in this area is significant as well: Houten and Bunnik have been designated in policy as urbanization locations where large-scale integralted developments for housing and eployment are planned. Finally, the region exhibits a great diversity of agricultural types, with fruit cultivation playing a relatively large role compared to other rural areas in the province of Utrecht. These factors together make it a dynamic and compelling area for further study.

0.2 Spatial characteristics

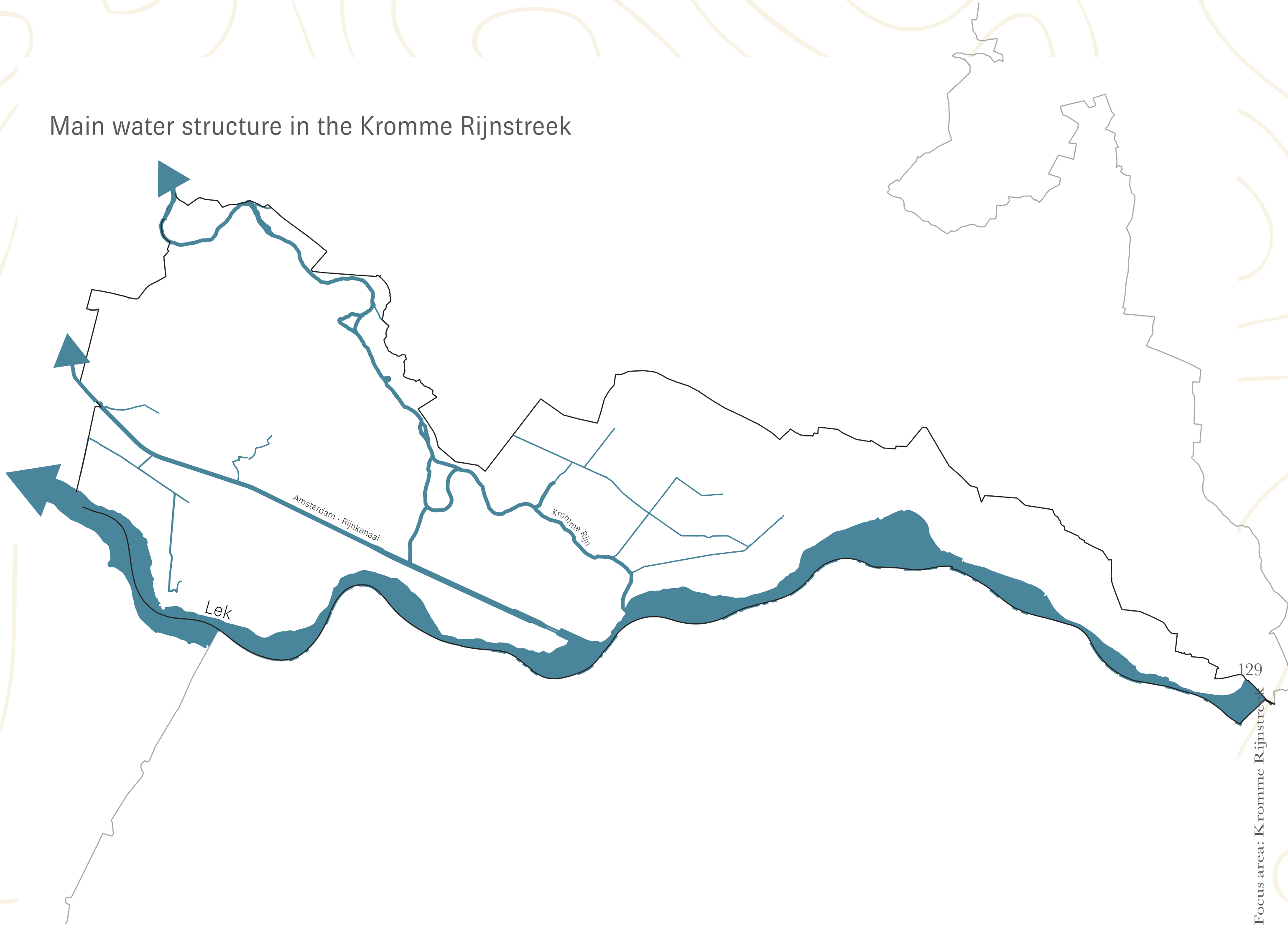
As previously demonstrated, the Kromme Rijn region is characterized by a rich historical background. This history has significantly influenced the spatial organization of the area, as has become clear in the previous paragraph. To gain a deeper understanding of the region, this section provides an analysis of its spatial structures. These structures are first examined at the regional level, followed by a brief discussion of the various subareas within the region.

Water

The Kromme Rijnstreek is bordered to the south by the river the Lek, to the northeast by the slopes of the Utrechtse Heuvelrug, and to the norhwest by the city of Utrecht. The Amsterdam-Rijnkanaal cuts through the western part of the region, while the Kromme Rijn river meanders towards the northern border. The Langbroek basin is clearly recognizable by its rectilinear ditch patterns. South of the Amsterdam-Rijnkanaal, a similarly regular structure is also visible. In contrast, this structured pattern is entirely absent in the eastern part of the region, where sandy soils dominate.

Water structure in the Kromme Rijnstreek

Main water structure in the Kromme Rijnstreek



The Kromme Rijnstreek is closely connected to the Utrechtse Heuvelrug: water that infiltrates into the Heuvelrug resurfaces along its flanks in the Kromme Rijnstreek as seepage. As a result, these two landscapes cannot be considered in isolation. Decisions regarding water quality in the Utrechtse Heuvelrug have a significant impact on the water quality wihin the Kromme Rijnstreek.

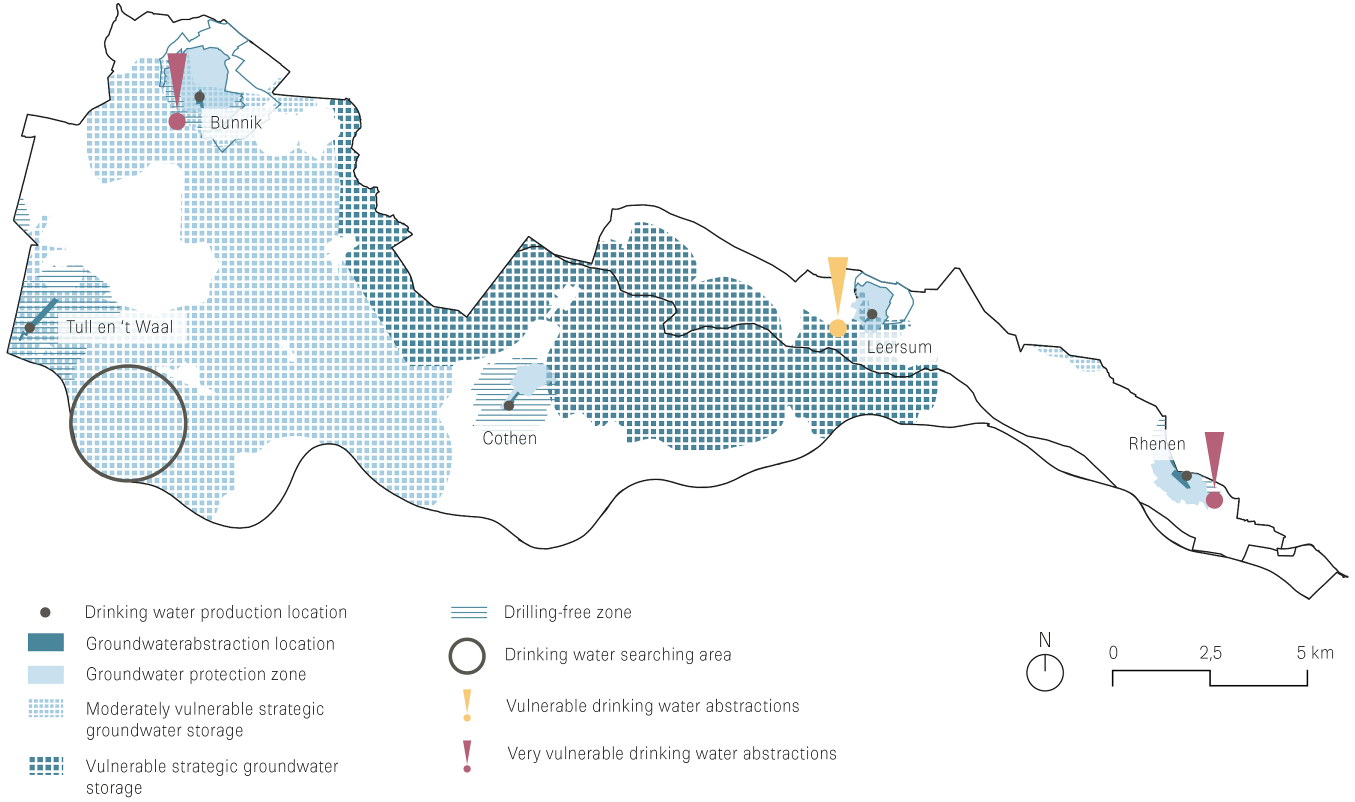
Infrastructure

Accessibility to the region's motorway network is concentrated in the northwest, above the city of Houten. There are two pairs of provincial roads (N-roads) that connect the smaller towns and villages and also serve as crossing points over the river the Lek. However, these roads are not interconnected. Crossings over the Lek via N-roads are available at Wijk bij Duurstede and Rhenen.

In addition to the road network, a railway runs through the region, extending southward via Houten and eastward via Bunnik.

The region's accessibility clearly illustrates that urban development is primarily concentrated in the northwest, while the remainder of the area is characterized by a predominantly rural landscape.

Spatial structure of groundwater abstractions and protection zones



Main infrastructure in the Kromme Rijnstreek

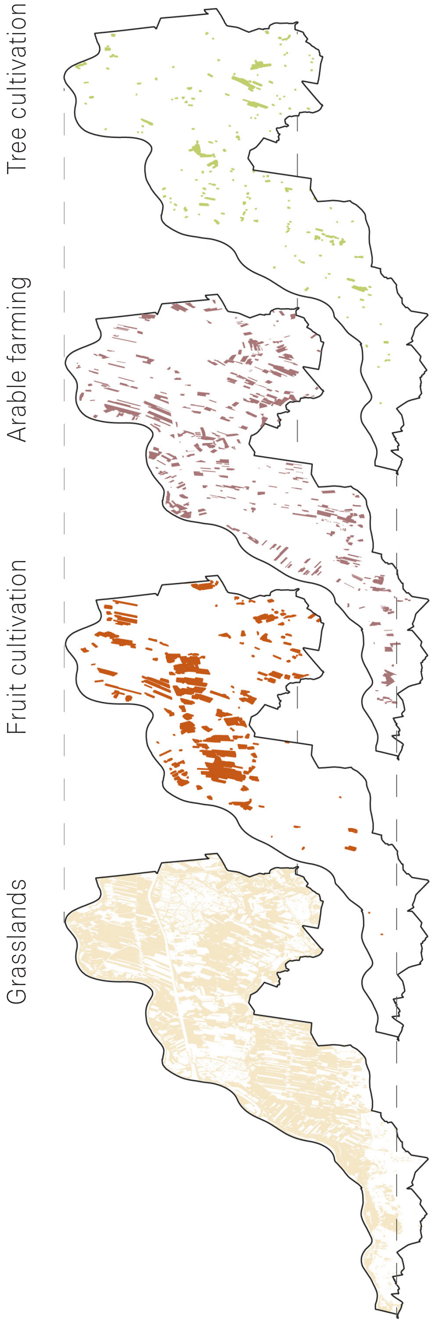
Urban structure

The Kromme Rijnstreek exhibits a diverse urban structure, which reflects the considerable variation in its landscape. As the accessibility analysis has also demonstrated, urbanization is primarily concentrated in the northwestern part of the region. Throughout the area, various forms of ribbon development can be observed, while in the eastern part, several smaller villages allign along a provincial road. The ribbon development runs parallel to both the Kromme Rijn and the river the Lek.

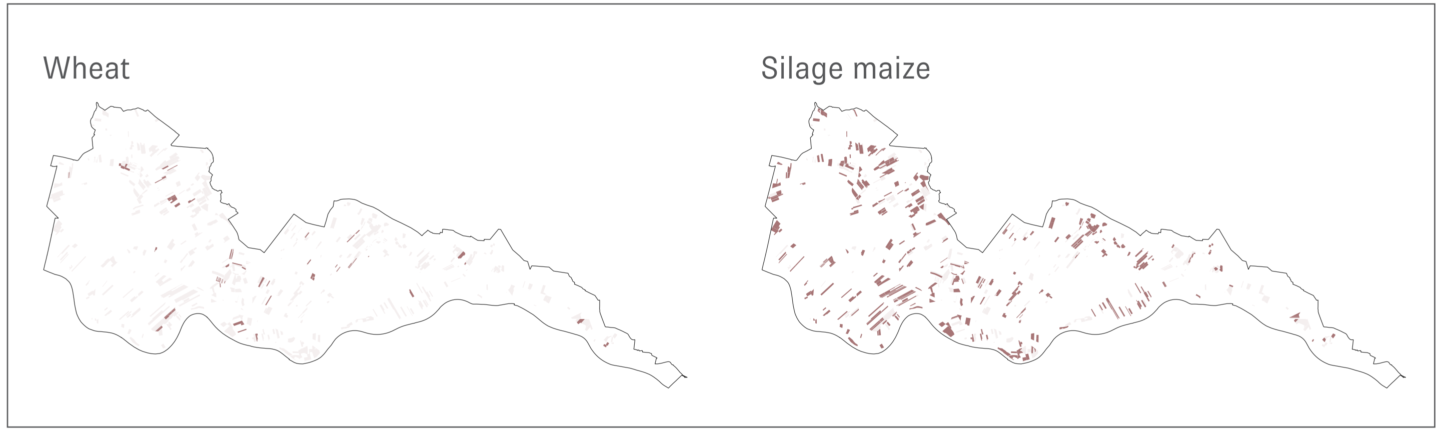
Urban structure

Agriculture

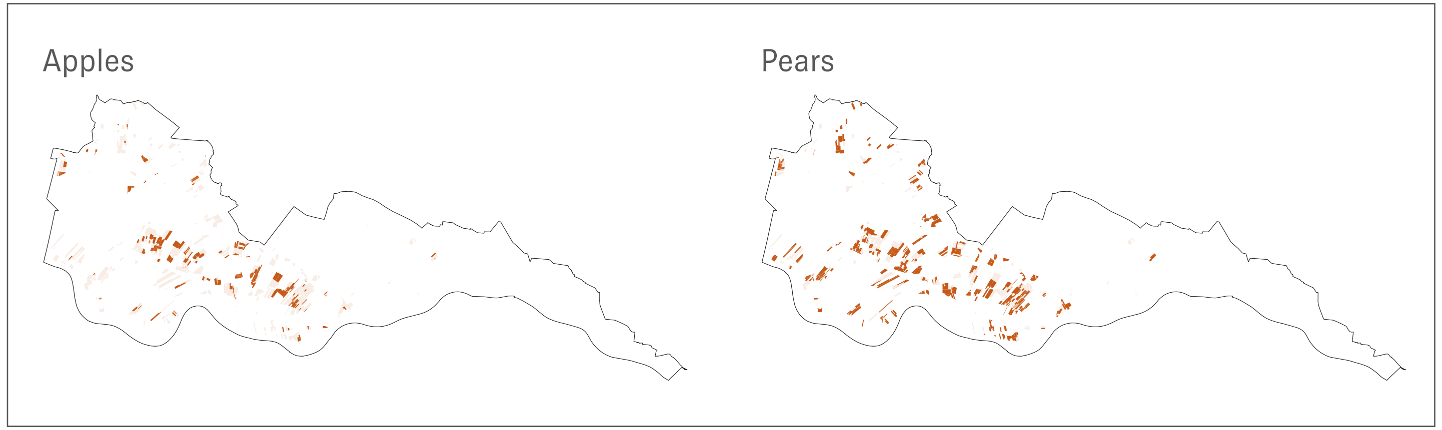
The Kromme Rijnstreek exhibits a wide variety of agricultural activities. It has the highest proportion of fruit cultivation (20%) compared to other subregions of the province of Utrecht. Arable and horticulture farms account for 18% of the agricultural land, while the remaining land primarily consists of dairy farms with permanent grassland (Provincie Utrecht, 2024d). For each type of agriculture, an analysis was conducted to determine which to crops constitute the largest share of total land use within the category. This approach helps to assess the impact on drinking- and groundwater quality.



Arable farming



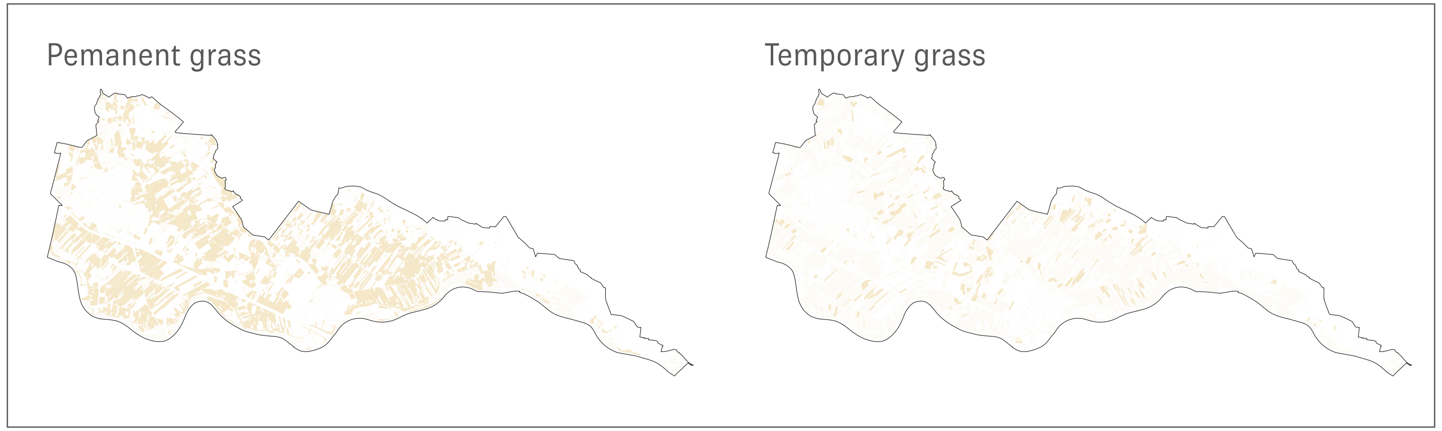
Fruit cultivation



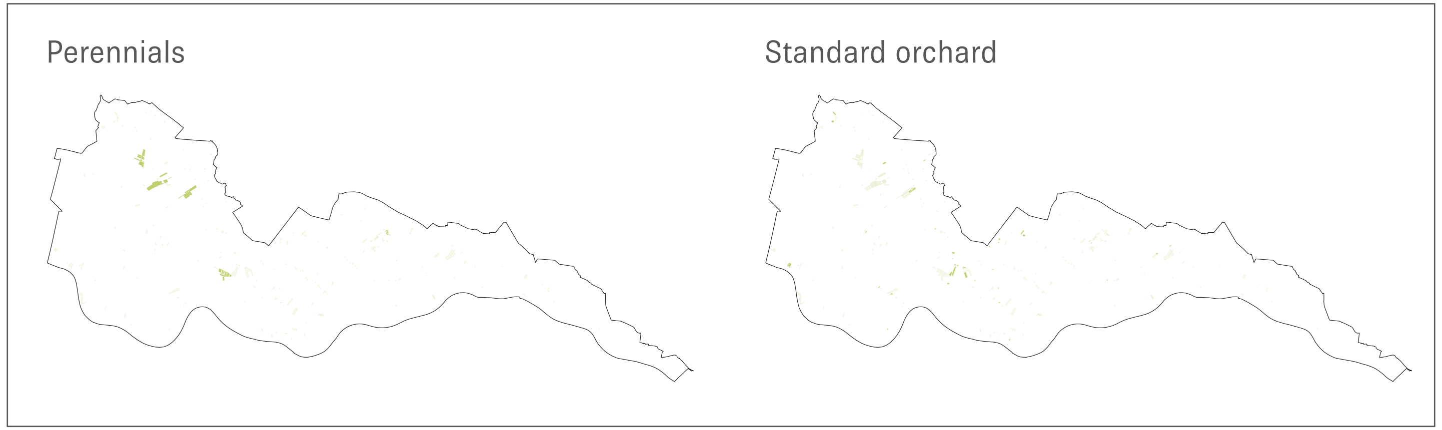
Arable farming
The largest share of arable farming in the Kromme Rijnstreek consists of silage maize, which is primarily used for livestock feed production. Additionally, wheat is cultivated in the area. Both crops require relatively low amounts of pesticide application (CBS, 2022). This land-use is spread over the whole region.

Fruit cultivation
Fruit cultivation in the Kromme Rijnstreek is clustered in the west of the region. Apples and pears consist of the largest share of this land-use. Apple and pear cultivation are in the top list of most pesticide use (CBS, 2022). This type of cultivation therefore has relatively a big negative impact on groundwater quality.

Livestock



Tree cultivation



Livestock
Permanent grassland is predominant in the Kromme Rijnstreek, although temporary grassland is distributed throughout the area. Permanent grassland is primarily used for dairy farming, and relatively few pesticides are applies to grassland (see Chapter 4).

Tree cultivation
Tree cultivation is not strongly respresented in the region.

In conclusion, arable farming in the Kromme Rijnstreek involves relatively low pesticide use across a significant portion of the agricultural land.

0.3 Land-use and drinking water

Bunnik

3,5 mln
m3 per year

2nd
aquifer

!

Purification: Aeration and sand filtration

Characteristics

This drinking water abstraction site is located southwest of the village of Bunnik, at the transition between the Utrechtse Heuvelrug in the north and low-lying polder areas in the south. The licensed abstraction capacity is 3.5 million m3 per year, and the site supplies drinking water primarily to the municipalities of Bunnik and Houten. Data from previous years show that the volume of raw water abstracted has consistently remained below the maximum licensed capacity. The raw water is abstracted from the second aquifer and treated through a two-step process: aeration and sand filtration. In 2017, pellet softening was added to reduce water hardness (Engel et al., 2021).

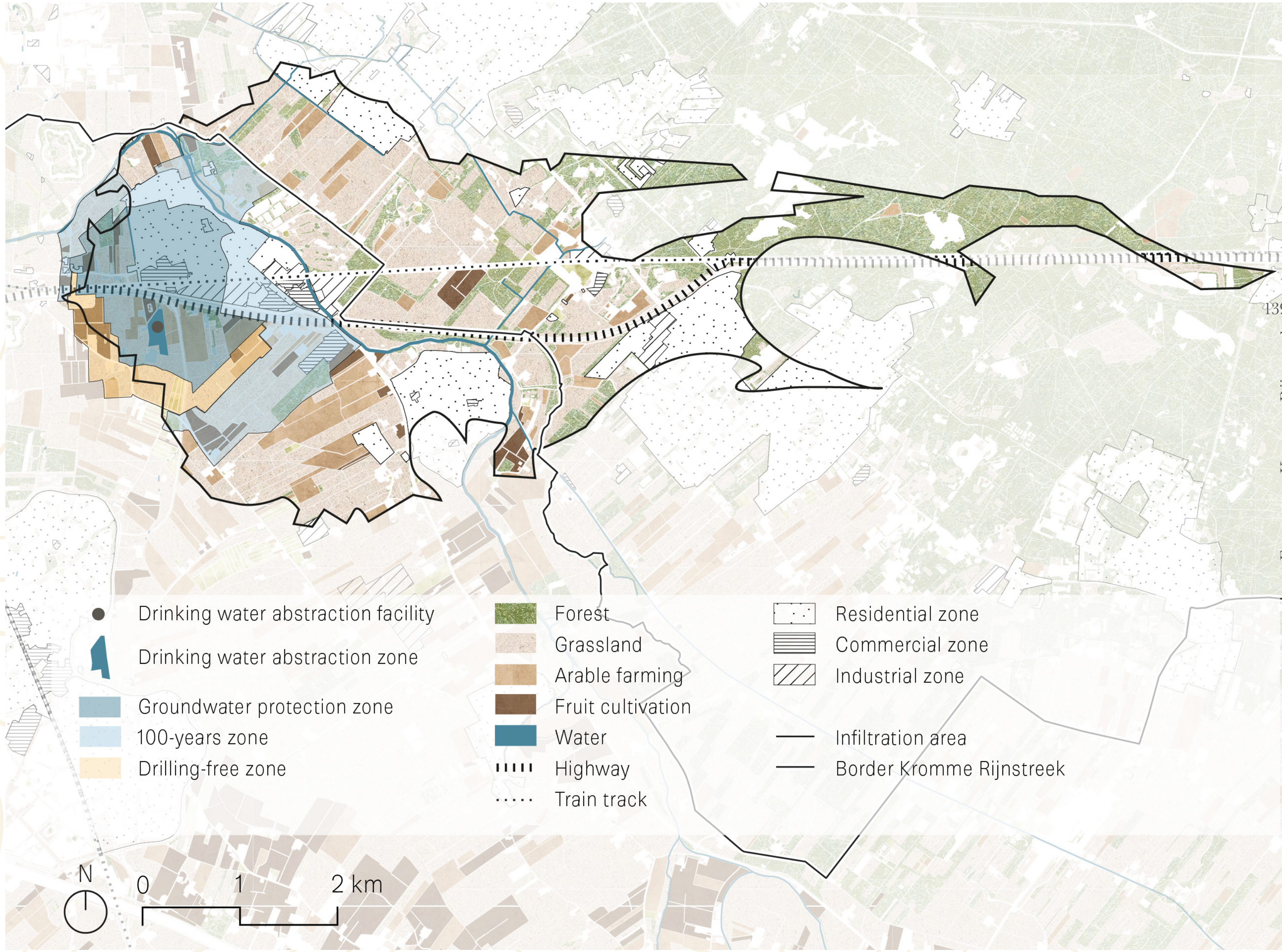
Vulnerability of abstraction

The area file indicates that only 27% of the total infiltration area for this groundwater abstraction is protected by supplementary regulations. This implies that a significant portion of the abstracted groundwater is not protected in the long term, making groundwater protection a regional concern. Consequently, risks to groundwater should be carefully considered in the context of new spatial or infrastructural developments.

Although relatively thick clay layers are present around the site, fractures are found wihin these layers. Furthermore, these clay layers are not regionally continuous, which, in combination with the large size of the catchment area, makes the abstraction site vulnerable to contamination (Engel et al., 2021).

Land-use

The figure below shows land use within the infiltration area. Compared to other drinking water abstraction sites, the infiltration area is relatively large and exhibits diverse land use. The predominant land use types include grassland, forest, and residential area. Additionally, both a motorway and a railway lin run through the infiltration area. Groundwater flows in a southwest direction, originating from the Utrechtse Heuvelrug.



Tull en ' t Waal

6,0 mln
m3 per year

3rd, 4th & 5th
aquifer

Purification: Softening, aeration and sand filtration

Characteristics

The groundwater abstraction site is located southwest of the city of Houten, at the transition between the subregions of the Kromme Rijnstreek and the Vijfheerenlanden. The permitted capacity for this abstraction is 6.0 million liters per year, and it generally supplies drinking water to the municipalities of Uterch, Nieuwegein, and Houten. Data from previous years indicate that the volume of raw water abstracted has consistently remained below the maximum licensed capacity. The raw water is abstracted from the second and third aquifer layers and treated through a three-step process: anaerobic softening, plate aeration, and dual-media sand filtration. (Engel et al., 2021).

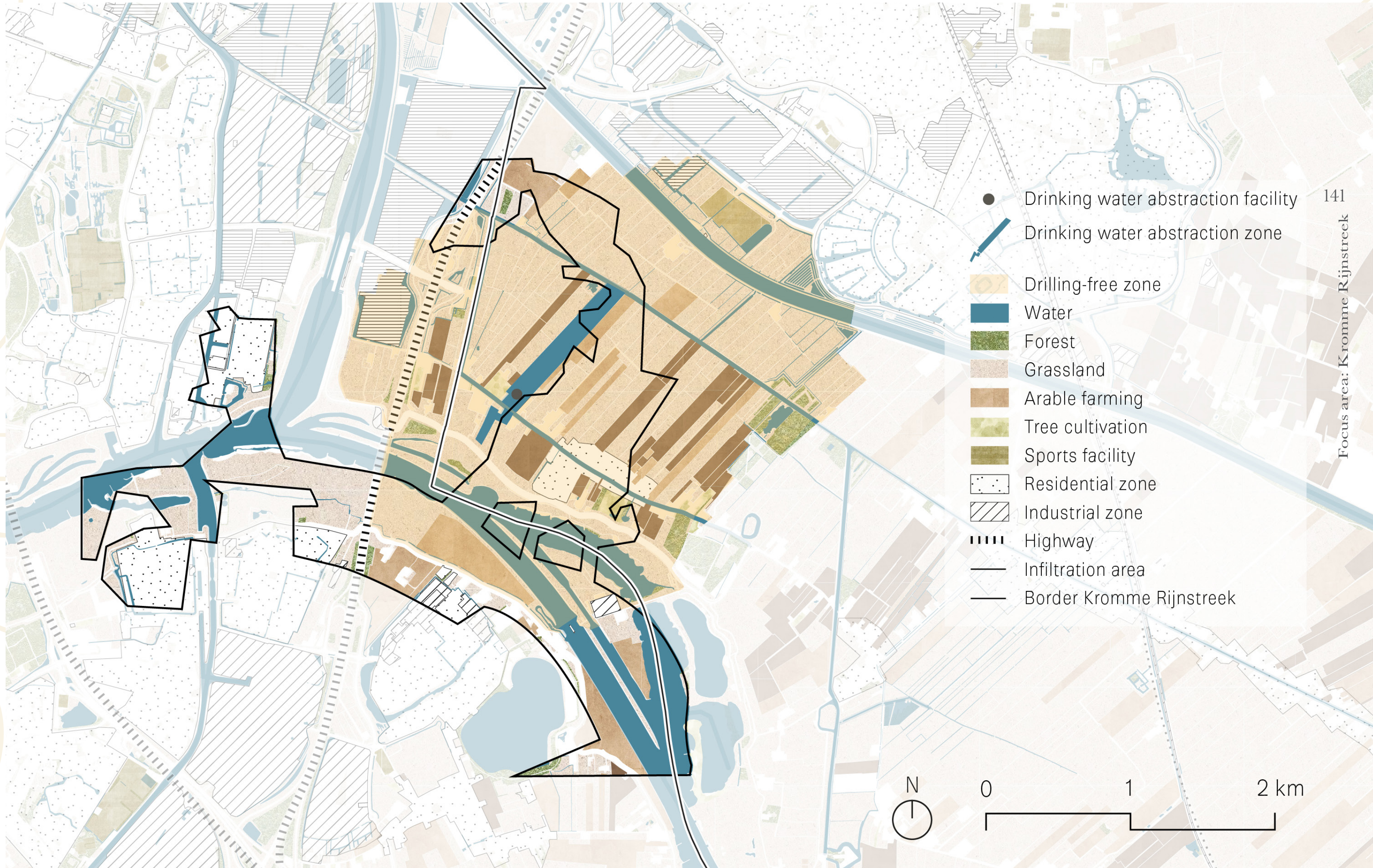
Vulnerability of abstraction

The Lek and a small area north of it constitute the main recharge zone for this groundwater abstraction site, as water infiltrates into the subsurface. The regional dossier notes that the Lekkanaal may also contribute to the abstraction in the future (west of the bdrilling-free zone). Although officially classified as a groundwater abstraction, the site exhibits significant bank fitration from surface water. Several Lek-related contaminants hae been detected at the abstraction site (Engel et al., 2021).

Due to the protective characteristics of the subsurface layers, the abstraction has been classified as not vulnerable. However, part of the abstracted water is less than 100 years old, suggesting some potential influence from the overlying aquifer systems (Engel et al., 2021).

Land-use

The figure below shows the land use within the infiltration area. Within the drilling-free zone, the area is predominantly characterized by grassland, with some areas used for fruit cultivation and arable farming. The A27 highway also passes through this drilling-free zone. In the southern and western parts of the infiltration area, residential area is also present.



Cothen

3,0 mln
m3 per year

2nd & 3rd
aquifer

Purification: Softening, aeration and sand filtration

Characteristics

This drinking water abstraction site is located between the villages of Wijk bij Duurstede and COthen, near the northern boundary of the Kromme Rijnstreek. The licensed abstraction capacity is 3.0 million m3 per year, and the site supplies drinking water to the municipality of Wijk bij Duurstede. Data from previous years show that the volume of raw water abstracted has consisently remained well below the maximum licensed capacity. The primary reason for this is insufficient pipeline capacity to distribute the full licensed volume. The raw water is abstracted from the second and third aquifers and is treated in a three-step process: softening, aeration, and sand filtration (Engel et al., 2021)

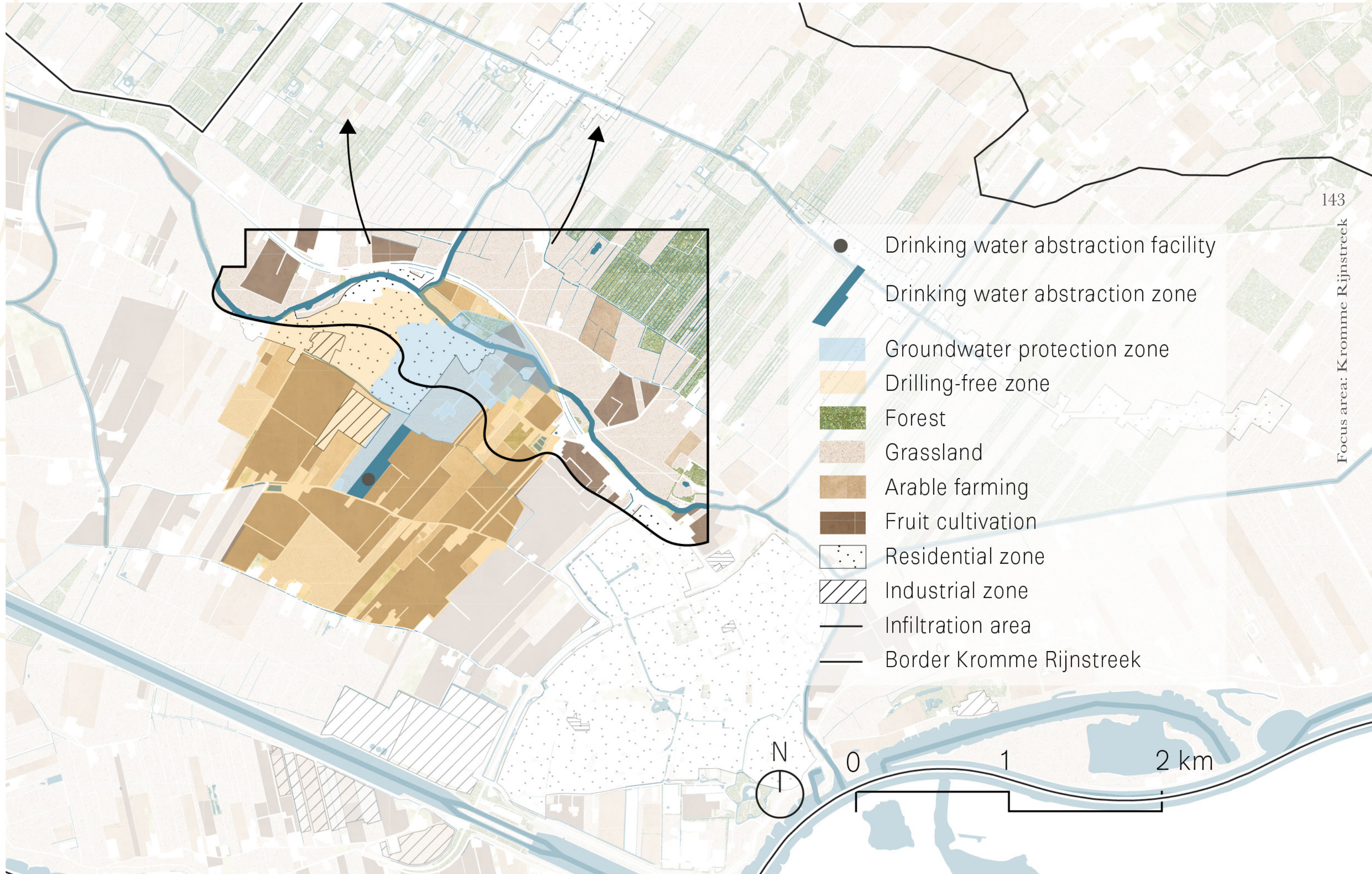
Vulnerability of abstraction

The water abstracted from the second aquifer is relatively well protected by an overlying clay layer, which serves as a protective barrier. As a result, the abstraction site is classified as not vulnerable.

Additionally, figure ... shows that a small portion of the catchment area falls within a designated groundwater protection zone. This implies that a significant portion of the abstracted groundwater is not protected in the long term, making groundwater protection a regional concern. Consequently, risks to groundwater should be carefully considered in the context of new spatial or infrastructural developments (Engel et al., 2021).

Land-use

The figure below illustrates land use within the catchment area and the drilling-free zone. The infiltration area is located to north of the abstraction site and consists largely of grassland and arable land. The arable land is primarily used for tree cultivation and fruit cultivation. The provincial road N229 runs along the northern edge of the drilling-free zone and through the infiltration area. Several enterprises classified under environmental risk categories are located within the protection zones. These sites are subject to risk-based regulatory oversight. The industrial area located in close proximity to the abstraction site represents the highest potential risk in the area.



Leersum

0,8 mln
m3 per year

Phreatic

!

Purification: Aeration, marble filtration and lime pellets

Characteristics

The drinking water abstraction site in Leersum is located between Leersum and Amerongen, along the Utrechtse Heuvelrug, near the northern boundary of the Kromme Rijnstreek. The licensed abstraction capacity is 0.8 million m3 per year and the site supplies drinking water primarily to the municipalities of Rhenen and Utrechtse Heuvelrug.

The raw water is abstracted from the phreatic aquifer and treated through a three-step process: aeration, marble filtration, and pellet softening (Engel et al., 2021).

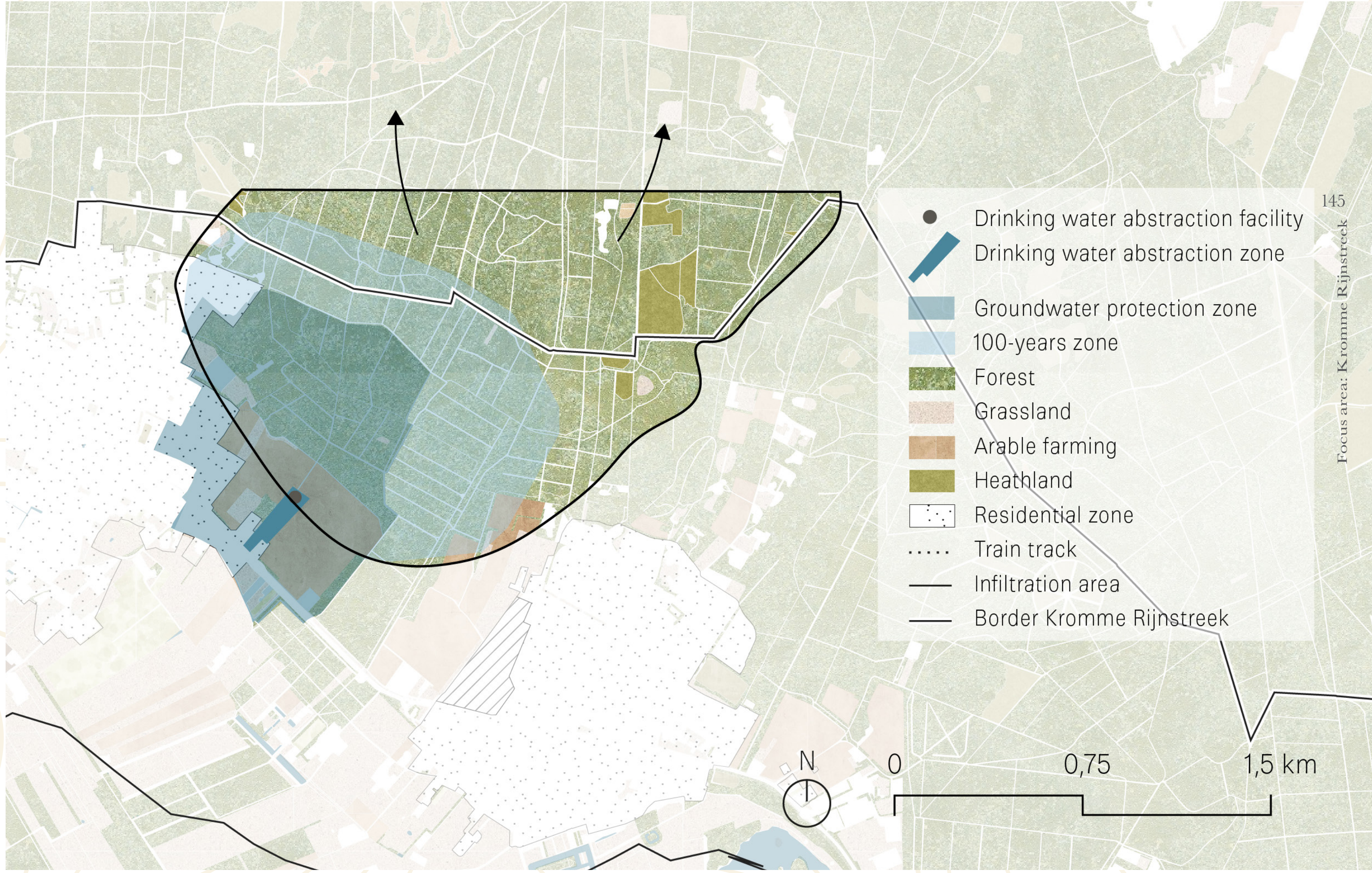
Vulnerability of abstraction

Approximetaly half of the infiltration area is protected by a designated groundwater protection zone. This implies that the remaining portion of the area is not subject to additional regulatory protection, even though a substantial share of the future abstracted water is expected to originate from this unprotected area. The infiltration area extends further northward, but its exact boundaries are uncertain. However, the relevance of the more northern parts is considered low due to the long groundwater travel time, which exceeds 500 years.

In the shallow subsurface, confining layers are locally absent, which has led to the classification of the site as highly vulnerable.

Land-use

The figure below shows the land use within the infiltration area. The majority of the area is covered by forest. In addition, there are several patches of arable land, primarily located near the abstraction site itself. This arable land presents the greatest risk to the abstraction, mainly due to the increased vulnerability of the soil in these locations compared to other parts of the infiltration area. Besides the forest areas and agricultural land, there is also a small zone of residential area and a limited section of industrial land.



Rhenen

2,0 mln
m3 per year

3rd, 4th & 5th
aquifer

!

Purification: Aeration and sand filtration

Characteristics

This drinking water abstraction site is located northwest of the city Rhenen. While the abstraction site itself lies just within the Kromme Rijnstreek, the water abstraction area, groundwater protection zone, and drilling-free zone extend across both the Kromme Rijnstreek and the Utrechtse Heuvelrug. The licensed abstraction capacity is 2.0 million m3 per year, and the site supplies drinking water to the municipality of Rhenen. Data from previous years show that the volume of raw water abstracted has consistently remained well below the maximum licensed capacity.

The raw water is abstracted from the third, fourth and fifth aquifers and is trated using a two-step process: plate aeration and marble filtration (Engel et al., 2021).

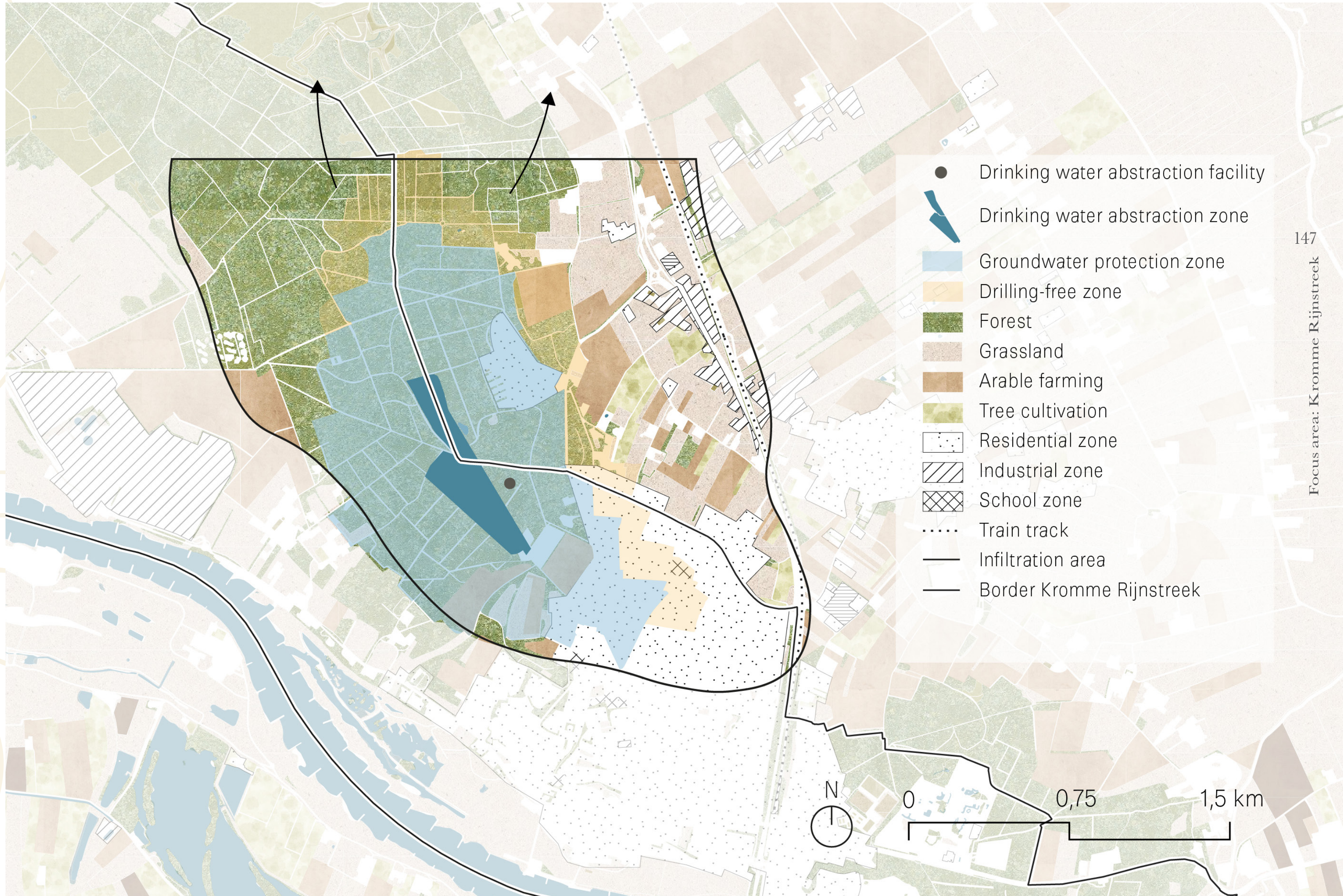
Vulnerability of abstraction

Approximately half of the infiltration area is protected by a designated groundwater protection zone. This implies that the remaining portion of the area is not subject to additional legal or regulatory safeguards, even though a significant share of the future abstracted water is expected to originate from this unprotected zone. The infiltration area extends further northward, although its exact shape is not clearly defined. However, the relevance of the more northern section is considered low due to a groundwater travel time exceeding 500 years.

The site has limited natural subsurface protection and is therefore classified as vulnerable.

Land-use

The figure below shows land use within the infiltration area. The majority of the area is forest. In the eastern part of the infiltration area, there is arable land and fruit cultivation, along with several commercial enterprises. To the southeast of the abstraction site lies a residential area of the city of Rhenen. Within the groundwater protection zone, the allotment garden complex presents the most significant risk to the drinking water abstraction.



6.Interplay of agriculture, urbanization and groundwater quality

Identify

SQ4

What are the bottlenecks and challenges for safeguarding groundwater quality used for public drinking water in the rural areas of the province of Utrecht, looking at the trends, policies and influences of urbanization and agriculture on water quality?

This chapter discusses the challenges and bottlenecks related to safeguarding groundwater quality for the purpose of ensuring drinking water quality. First, the main challenges identified in the research are presented. These challenges are then linked to various bottlenecks. Finally, the chapter briefly adresses the specific challenges and bottlenecks within the Kromme Rijn region.

6.1 Generic challenges

With a clear understanding of how the drinkng water production system in the province of Utrecht is organized, along with relevant trends and policies concerning agriculture, urbanization, and groundwater quality, an inventory has been made of the most pressing challenges facing rural areas in the province. Based on insights gathered from literature an conversations and interviews with both internal and external professionals, three major challenges have been broadly identified (see below).

1 Maintain a good drinking water quality

This challenge is closely related to the focus of the research question: improving drinking water quality. Specifically, this challenge concerns the purification of drinking water - the output of the process.

2 Improve groundwater quality

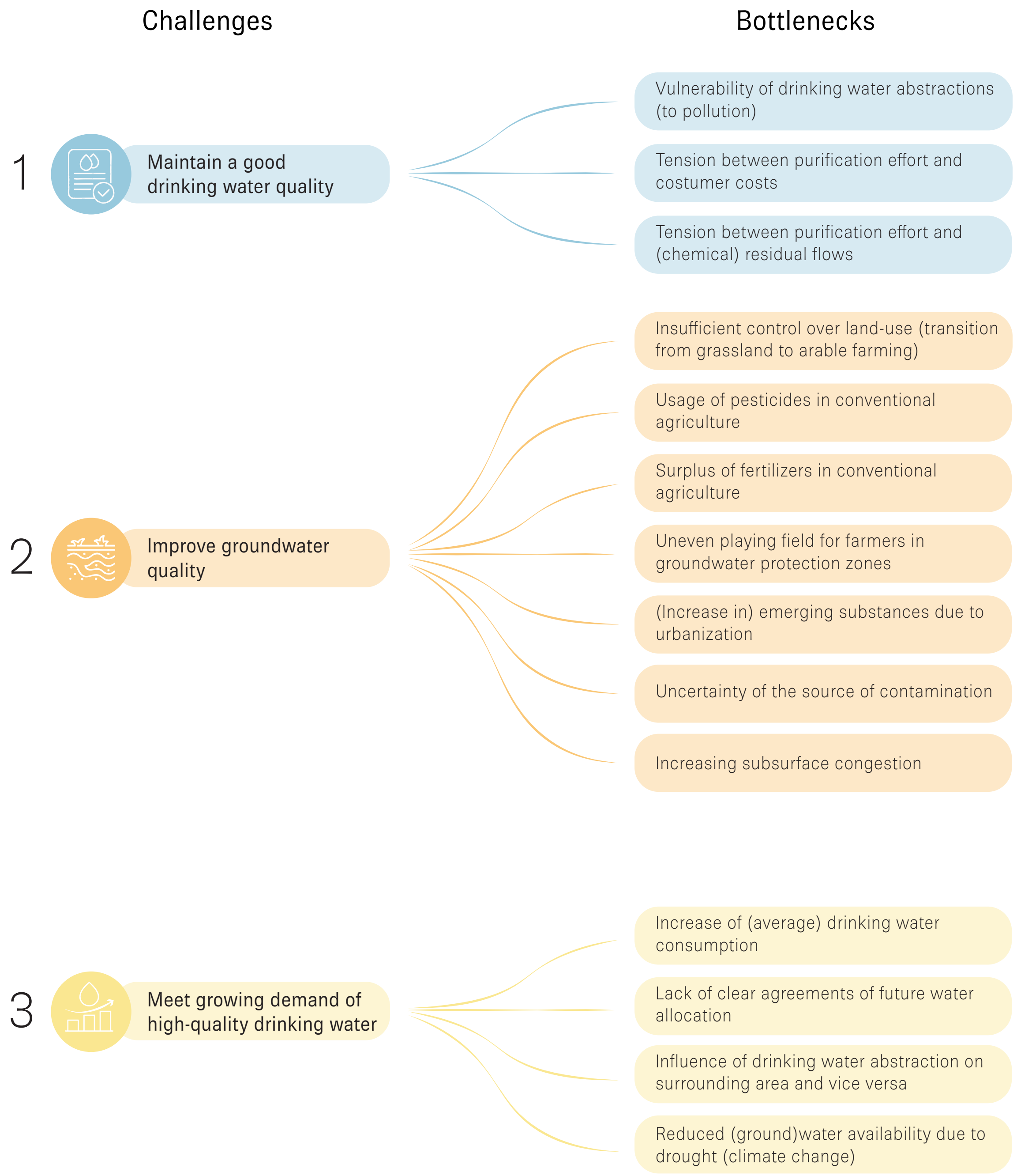
Both the literature and interviews highlight the need to improve groundwater quality, in order to safeguard drinking water quality. This challenge is therefore closely linked to the overall goal of ensuring high drinking water quality. The focus of this challenge is to minimize and/or eliminate the negative impacts on groundwater quality as much as possible.

3 Meet growing demand of high-quality drinking water

Water quality is closely linked to water quantity, as supported by much of the literature and interviews. This challenge focuses on ensuring a balance between water quantity and water quality, while also considering the spatial planning of various functions.

6.2 Generic bottlenecks

Within the three challenges, corresponding bottlenecks have been identified. At times, these bottlenecks transcend a single challenge and are also part of another challenge. These challenges and bottlenecks are generic to the rural areas of the province of Utrecht. The bottlenecks will be further elaborated on the following pages. The next paragraph dives deeper into the specific bottlenecks of the area Kromme Rijnstreek.



1 Maintain a good drinking water quality

Vulnerability of drinking water abstractions (to pollution)

As mentioned before in this report, the location of drinking water abstraction grew historically, while not paying good attention of the suitability of the location (Jansen, 2024). This means many locations are vulnerable to pollution, due to, for example, sandy soils. In sand layers, groundwater generally flows faster than in other soil types, resulting in less natural removal of pollutants in sandy soils (Paulissen et al., 2007). Due to this vulnerability, the abstraction is more prone to possible pollution and more risks are present.

Tension between purification effort and costumer costs

In multiple interviews, it has been indicated that there is a tension between purification effort and costumer costs (Gathered during internship, February 26, 2025). Generally, it is possible to intensively purify water. However, a price increase (or decrease) must be well substantiated and cannot be implemented arbitrarily. Additionally, drinking water companies are not permitted to generate excessive profits, which makes it more challenging to invest in future developments. They must adhere to the so-called *Weighted Average Cost of Capital*. a regulation through which the government protects consumers from excessively high costs. At the same time, drinking water companies also bear a shared responbility for public health (Drinkwaterplatform, 2024).

Tension between purification effort and (chemical) residual flows

This issue partly revolves around the ethical question of whether it is socially responsible to purify water in an extremely intensive manner. Such purification requires significant financial and energy resources, and the process itself generates (chemical) residual streams, such as highly saline waste streams. Multiple interviews have identified these residual streams as a bottleneck (Gathered during internship, February 26, 2025). For some of these residual streams, no effective treatment solutions have yet been developed .Currently, various studies are being conducted to explore new methods for processing these residual streams and creating high-value applitcations for them (KWR Water Research Institute, 2019; KWR Water Research Institute, 2022; Drinkwaterplatform, 2023). However, these efforts are still in their early stages.

2 Improve groundwater quality

Insufficient control over land-use (transition from grassland to arable farming)

Due to the abolition of the derogation, many livestock farmers are going bankrupt. As a result, other wealthy farmers or property developers are purchasing this land, leading to a change in land use. A common trend is the conversion of permanent grassland into arable farming. However, in arable farming, more pesticides are used, which directly poses a risk to groundwater quality. The authorities do no have the resources or the speed of action necessary to immediately purchase the released land to prevent this change in land use (Gathered during internship, March 5, 2025).

Surplus of fertilizers and (use of) pesticides in conventional agriculture

The impact of agriculture on (ground)water quality is highlighted in nearly all interviews (Gathered during internship, March 5, 2025). Data from the province of Utrecht also indicate that not only are substances found exceeding regulatory limits, but more importantly, a combination of many different substances is often detected together (Vissers, 2024).

Due to its negative impact on groundwater quality, the surplus and excessive use of pesticides present a significant challenge in addressing this issue. The use of pesticides also raises an ethical question regarding their societal responsibility. Furthermore, discussions on this topic frequently revolve around legislation. Multiple interviewees emphasize that there is currently no clear and comprehensive (European and national) uniform legislation to ban the use of certain pesticides (Gathered during internship, February 26 2025).

Additionally, an interviewee from Pré Sustainability points out that the continuous emergence of new crop protection products is another major challenge. Legislation is often slow and unable to adapt quickly to such developments (Gathered during internship, March 5, 2025).

Uneven playing field for farmers in groundwater protection zones

In groundwater protection areas, different regulations apply compared to areas outside these zones. Additionally, regulatory differences exist between provinces. As a result, farmers operating within groundwater protection areas and in certain provinces face more restrictions than those outside these areas, creating an uneven playing field. This disparity is evident in pesticide usage, for instance, and also in the expiration of derogations, which occured significantly earlier in groundwater protection areas than in other regions. A concern raised by Vitens is that these groundwater protection areas are now being explicitly designated on maps to impose restrictive regulations. Consequently, the location of certain farmers negatively impacts them compared to their counterparts elsewhere (Vitens, 2025c)

Lack of a viable revenue model for groundwater-friendly agriculture

In multiple interviews, it has been indicated that a viable revenue model for groundwater-friendly agriculture is lacking (Gathered during internship, March 5 2025), The high price of land places significant pressure on agricultural operations, requiring land to be highly profitable to maintain a positive financial balance. Due to the loss of derogation, retiring dairy farmers lease their land to arable farmers or transition to arable farming themselves, as it is far more profitable (Vitens, 2025c)

For example, waterboard Vallei & Veluwe has experimented with sustainable soil management in collaboration with farmers. However, the loss of derogation has rendered many of these initiatives financially unviable (Gathered during internship, February 26, 2025). Similarly, one interviewee states that establishing a viable revenue model remains one of the biggest challenges (Gathered during internship, March 24 2025). Vitens emphasizes that farmers are not receiving adequate support in transitioning to more sustainable agricultural practices that minimally impact water quality (Gathered during internship, March 5 2025)

Uncertainty of the source of contamination

The groundwater is a slow system, and contamination can spread over several kilometers. As a result, the origin of the contamination is often unknown, making it difficult to address the exact source. Additionally, historical pollution is also a concern, in which case the original source can no longer be addressed.

(Increase in) Emerging contaminants due to urbanization

Literature indicates that urban functions directly impact groundwater quality and, consequently, drinking water quality. Not only do current urban activities negatively affect groundwater, but historical pollution also plays a role (Vitens, 2025c) In recent years, an increasing number of emerging contaminants have been detected, particularly in surface water. Due to the limited knowledge about these substances, assessing their risks and tracing their sources remains challenging (Drinkwaterplatform, 2022). The growth of urbanization leads to an increase in emerging contaminants in groundwater and drinking water sources. This presents a significant bottleneck in efforts to improve groundwater quality.

Increasing subsurface congestion

The growing use of underground space creates an extra challenge to safeguard groundwater and drinkwater quality. For instance, the expansion of district heating networks near drinking water pipelines raises concerns about potential warming of the water within these pipes, which could affect its quality (Gathered during internship, February 26 2025).

Moreover, the impact of heat from these networks on contaminants in the subsurface remains uncertain. Temperature influences chemical equilibria and the kinetics of (bio) chemical processes in groundwater, which can accelerate or slow down the dissolution and precipitation of minerals, the binding of substances, and the degradation of contaminants (Schout & Bloemdendal, 2022). A potential risk is that previously immobilized contaminants may become active again and/or start mitigating through the subsurface.

3 Meet growing demand of high-quality drinking water

Increase in (average) drinking water consumption

In recent years, average drinking water consumption has been increasing, partly due to dry summers (Baggelaar et al., 2022). Consequently, the demand for high-quality drinking water has grown, which in turn affects both the numer and scale of groundwater abstractions. Groundwater systems are not inherently capable of accomodating this cumulative demand.

Lack of clear agreements on future water allocation

Currently, a strategy has been developed by drinking water companies and the province of Utrecht to meet future drinking water demands (Vitens & Provincie Utrecht, 2018). As the cumulative demand continues to grow, clear agreements on the allocation of drinking water are necessary. However, such agreements ave not yet been clearly established (De Hoog & Bol, 2025).

Influence of drinking water abstraction on surrounding area and vice versa

The extent of groundwater abstraction directly influences spatial planning as increased pumping expands the affected area. This necessitates risk assessments for groundwater quality and the establishment of designated protection areas. Land in the province is used for a wide range of functions, or must be allocated for emerging priorities such as the energy transition. According to Vitens, integrating current and future land use into policy while ensuring an optimal distribution of resources is highly challenging (Gathered during internship, February 26 2025). Due to increasing spatial pressures, developing new drinking water abstraction sites has become increasingly difficult.

Reduced (ground)water availability due to drought (climate change)

Due to climate change, conditions, are becoming drier, leading to reduced groundwater recharge during the summer. In general, a smaller volume of groundwater results in relatively higher concentrations of contaminants. Water quality and water quantity are closelt interconnected, and increasing drought also poses challenges for water quality. It is essential to carefully asses how a balance can be achieved between water uality and water quantity (Gathered during internship, February 26 2025).

6.3 Bottlenecks Kromme Rijnstreek

In addition to the general bottlenecks, area-specific bottlenecks can also be identified in the Kromme Rijnstreek. Based on the previous chapter, the characteristics of the area - particularly in terms of landscape and drinking water - have been outlined. For each challenge, this section briefly discusses the specific bottlenecks present in the region and their respective locations.

1 Maintain a good drinking water quality

Within the Kromme Rijnstreek, three out of five groundwater abstraction sites are (highly) vulnerable to contamination. This makes it relatively more difficult to maintain good drinking water qualiy at these abstraction locations.

2 Improve groundwater quality

The Kromme Rijnstreek has the highest concentration of fruit cultivation, a sector generally associated with high pesticide usage. As outlined in the previous chapter, apples and pears constitute the largest share of land use within this sector. Earlier in this study, it was noted that apples and pears are among the most intensively sprayed crops. Therefore, the presence of these crops represents a signifcant bottleneck in efforts to improve groundwater quality in the Kromme Rijnstreek.

In addition, two large-scale development sites have been designated near Houten and Odijk. These developments place further pressure on groundwater quality, as they may contribute to an increased presence of emerging contaminants in the area and less space for infiltration.

3 Meet growing demand of high-quality drinking water

In the Kromme Rijn region, two large-scale residential and commercial development sites have been designated, increasing pressure on available space. As a result, there is limited room for establishing new drinking water production sites or expanding existing ones.

6.4 Sub-conclusion

This chapter addresses the fourth research question. The main conclusions are briefly outlined below.

SQ4: What are the challenges and bottlenecks for safeguarding the drinking water quality in the rural areas of the province of Utrecht, looking at the trends, policies and influences of urbanization and agriculture on groundwater quality?

Three generic challenges could be distinguished

These challenges are: maintaining good drinking water quality, improving groundwater quality, and meeting a growing demand for high-quality drinking water.

Ethical questions around purification effort are an important bottleneck

It has become evident that additional purification efforts raise ethical questions, concerning both the costs of treatment and the handling of residual waste streams.

The most bottlenecks are within the second challenge - improving the groundwater quality

Within this challenge, many of the key bottlenecks are found in the agricultural sector.

Within the Kromme Rijnstreek, vulnerability of three groundwater abstractions are a bottleneck

In the Kromme Rijn region, three out of five groundwater abstractions have been designated as vulnerable, which poses a significant challenge to ensuring good drinking water quality.

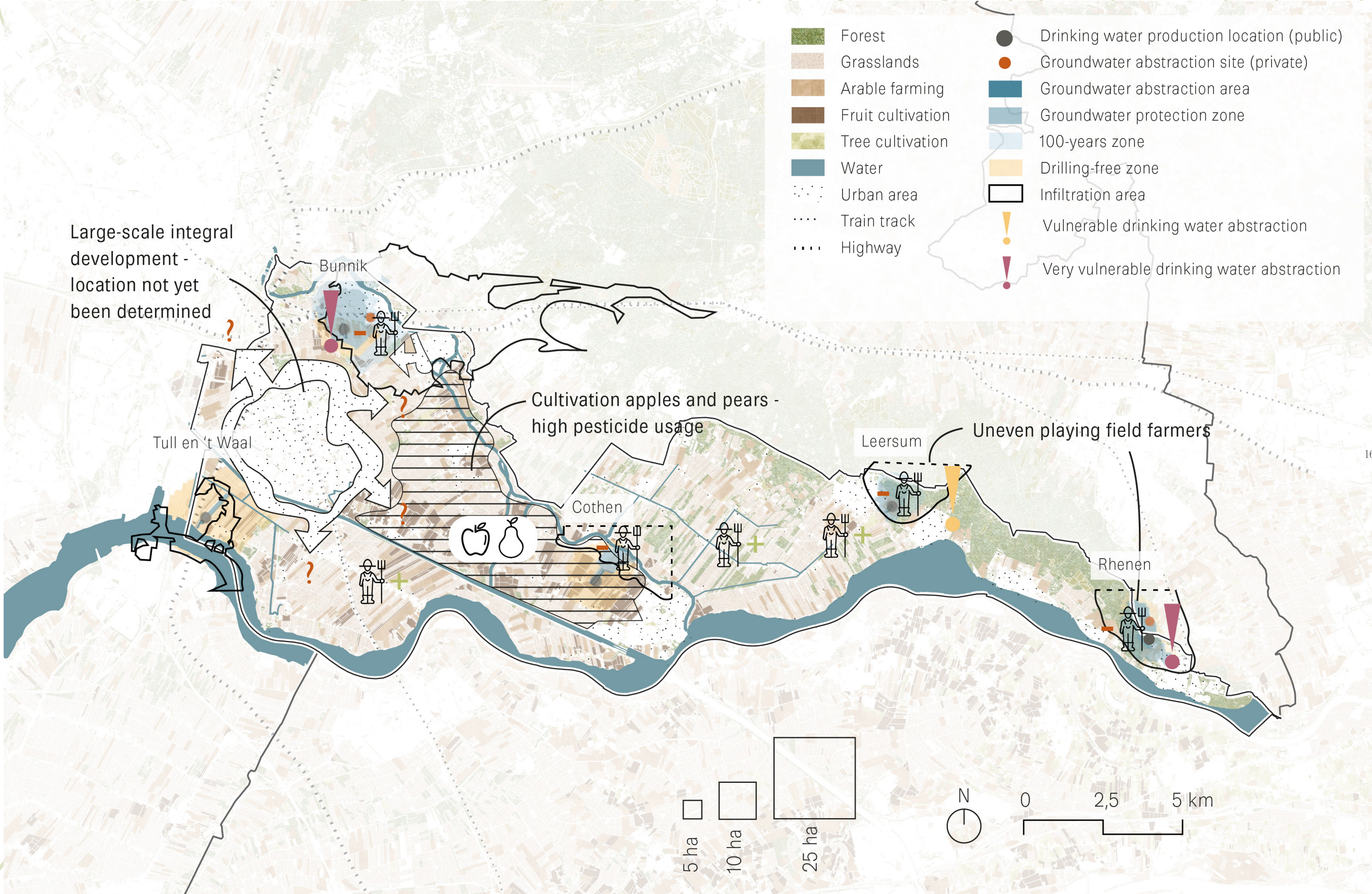
Within the Kromme Rijnstreek, it is a challenge to improve groundwater quality in combination with two large-scale urban developments

In the Kromme Rijn region, two large-scale integrated urban developments are planned, which may present an obstacle to improving groundwater quality.

Within the Kromme Rijnstreek, high amount of fruit and arable farming pose a threat to groundwater quality

The Kromme Rijn region has a relatively high presence of fruit cultivation and arable farming, which may pose a challenge to improving groundwater quality.

Conclusion map



7. Future perspectives

Explore

SQ5

Which solutions and alternatives could be used to safeguard groundwater quality used for public drinking water and which considerations are possible between agriculture, urbanization and water quality?

SQ6

Which future scenarios are possible to safeguard groundwater quality used for public drinking water in the rural aeas in the province of Utrecht, where integrated solutions are used for water quality, agriculture and urbanization?

This chapter explores possible solutions and alternatives to safeguard groundwater quality used for public drinking water. It also highlights the considerations between agriculture, urbanization and groundwater quality. The solutions are presented using the pattern language approach (Note: a more detailed explanation of the pattern language can be found in the pattern book).

Subsequently, four scenarios have been developed based on the analyzed trends and policies (Chapter 4). For each scenario, a design was developed for the case study area of the Kromme Rijn region, using the pattern language approach. To gather additional input for these designs, a workshop was organized involving both internal and external professionals from the province of Utrecht. This input is comparde to the author's design, with a focus on the chosen solutions and spatial decisions. Subsequently, two final designs are presented. These are hybrid designs that combine elements from both the author's and the workshop participants' designs. These final designs are for the scenarios 1 and 4 (least extreme and most extreme).

7.1 Pattern language

Introduction

In this research, the concept of a pattern language is applied to create integrated solutions between groundwater, agriculture and urbanization.

The concept of a pattern language is in 1977 developed by architect Alexander Christopher and his colleagues. It helps to tackle the complexity of a variety of systems, under which designing cities and landscapes (Salingaros, 2000). A pattern is a repeatable design principle that provides a solution to recurring problems. The pattern describes the problem and the solution at the same time. Patterns consist of a hypothesis, the theory that supports this hypothesis, and a practical solution or application, often illustrated with a sketch or example (Rooij & van Dorst, 2020).

Patterns together form a pattern language. They work together to design complex systems and are a clear communication tool for presenting solutions. Each pattern is linked to one or more patterns and patterns can be created in different scales (Salingaros, 2000).

Because of the nature of a pattern language to help tackling problems in a complex system, it is also useful for creating integrated solutions. Therefore, this method is used as a design tool in this research.

Organization of the patterns

The pattern language is divided into three categories: technical patterns, organizational patterns, and spatial patterns.

Technical patterns:
These patterns involve the appliction or improvement of existing and emerging technologies within domains of water, agriculture, or urban development. An example is the implementation of new surface water purification techniques. In some cases, technical patterns may overlap with spatial patterns.

Organizational patterns:
These patterns are organizational in nature. While they do not directly result in spatial interventions, they support the realization of such interventions. An example is the provision of subsidies for biological farming.

Spatial patterns:
These patterns focus specifically on the (re) allocation of land and/or the introduction of specific spatial interventions. An example is the implementation of agroforestry.

T Technical

O Organizational

S Spatial

Substantiation of the patterns

The patterns are developed through literature research, interviews, and brainstorming sessions. These interviews and brainstorming sessions were conducted with professionals both within and outside the province of Utrecht. During the sessions, participants were asked to propose solutions for the different bottlenecks that were identified in the research. The solutions were then placed into a conceptual framework to clarify the relevant topics for which the solution applies: agriculture, urbanization, groundwater quality, or a combination of two or more.

AGRICULTURE A

URBANIZATION U

GROUNDWAER QUALITY G

DRINKING WATER QUALITY D

Rules of the language - workshop

In this study, the patterns were applied in a design workshop. During the workshop, various professionals from within and outside the province of Utrecht collaboratively used the pattern language to develop a design. There was also a test-workshop organized with students from the Urbanism track, who were familiar with the pattern language method. By employing the pattern language, the participants responded to the four scenarios previously developed.

To facilitate the use of the pattern language, a set of rules and a game sequence were created. These elements were intended to make the pattern language accessible to participants from different domains. Additionally, the structured sequence supported the initiation and progression of the discussion. More information about these rules and sequence can be found in the pattern book. The following page presents the design of the patterns used in the workshop, including the components they comprise. Important note: the patterns for the workshop are made in Dutch, since the participants of the workshop all spoke Dutch.

A detailed explanation of the patterns can be found in the pattern book.

Example of pattern used in the workshop

Title

Pattern code

R1

ALLEEN BIOLOGISCHE LANDBOUW TOEGESTAAN IN GRONDWATER-BESCHERMINGSGEBIEDEN

Category

Ruimtelijke oplossing

Picture

Explanation

Bij biologische landbouw worden geen pesticiden gebruikt en dit komt ten goede aan de (grond)waterkwaliteit.

Practical implication

Concrete acties

- Regels stellen in de provinciale omgevingsverordening;
- Pachtgronden gebruiken;
- Optioneel: Financiële steun aan agrariërs voor transitie naar biologisch.

Most important stakeholders

Stakeholders

- Provincie Utrecht
- Agrariërs
- Ministerie van LVVN

Scale

Lokaal · Stad · Regionaal · Interregionaal

Term (time)

Kort

Relevance to

L G

Important considerations

Belangrijke afwegingen

- Keuze maken in certificaten and keurmerken;
- Planschadeprocedures;
- Effectiviteit van de maatregel - identificeer effecten buiten grondwaterbeschermingsgebieden

Spatial consequences

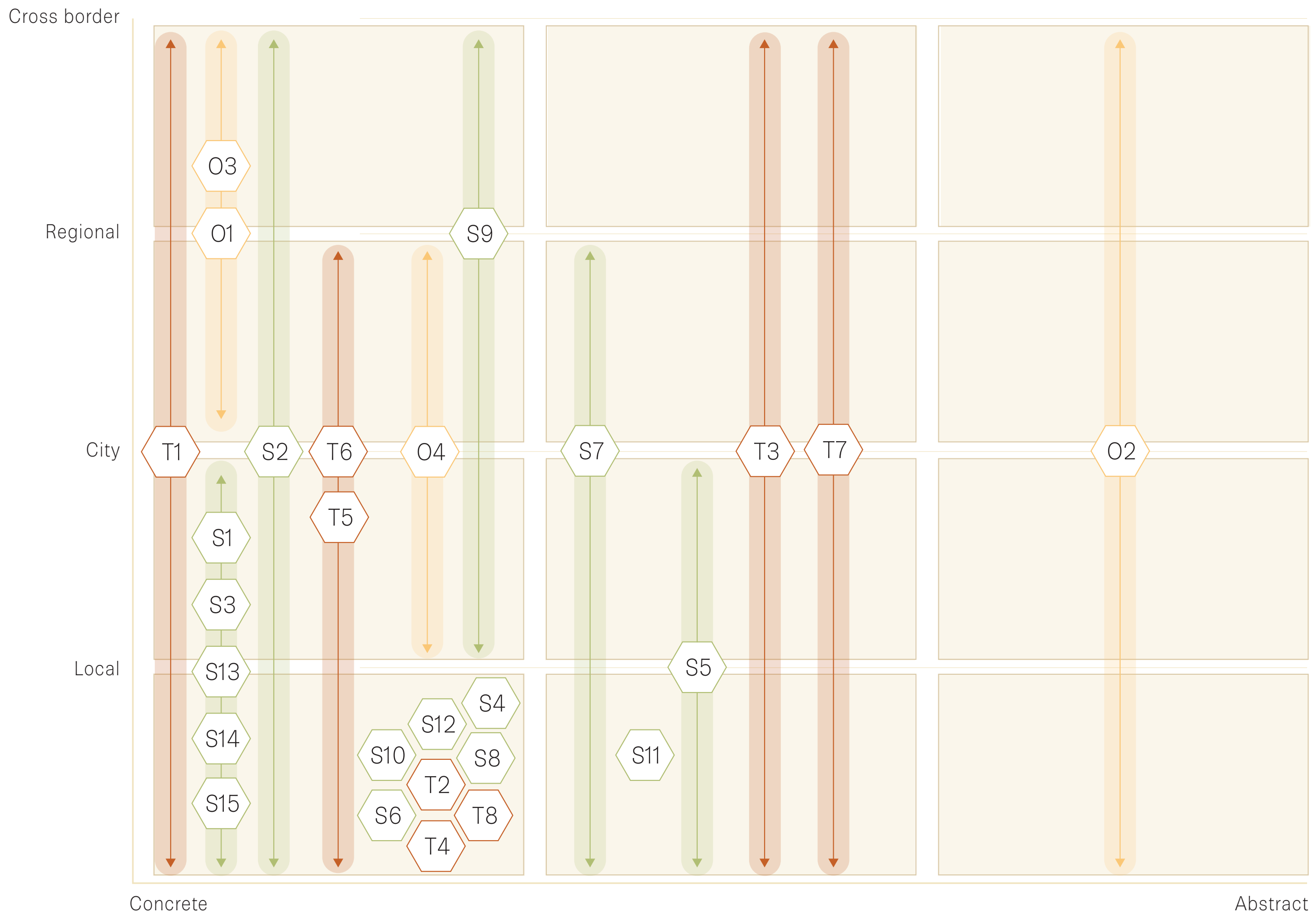
Ruimtelijke gevolgen

- Fruitteelt: minder fruitteelt (moelijker om biologisch te telen) of verplaatsen uit grondwaterbeschermingsgebied;
- Akkerbouw: ander soort akkerbouw, mogelijk ook minder

Pattern matrix

The diversity of the patterns is ensured by positioning the patterns along the dimensions of scale and abstraction (see adjacent figure). This visualization shows that several patterns can be applied at multiple scales. Furthermore, the pattern language predominantly contains many concrete patterns. In particular, the technical patterns demonstrate applicability across various scales.

Pattern matrix



Assessment framework

In chapter 6, three main challenges are identified, where several bottlenecks are present within these challenges. To evaluate the solutions both individually and in relation to each other, an assessment framework has been developed. This framework clarifies the impact of each solution on the identified bottlenecks, categorizing the effects as positive, neutral, or negative. The impact assessment is based on the current situation and the potential effect of each solution on this context.

In the development of a strategy, this assessment framework can be utilized to guide decision-making. It provides insight into the collective impact of a set of solutions on the various challenges, facilitating a more informed and balanced approach.

Impact

Impact	
Positive	+
Neutral	●
Negative	-

	Vulnerability of drinking water abstractions (to pollution)	Tension between purification effort and costumer costs	Tension between purification effort and (chemical) residual flows	Insufficient control over land-use (transition from grassland to arable farming	Usage of pesticides in conventional agriculture	Surplus of fertilizers in conventional agriculture	Uneven playing field for farmers in groundwater protection zones	(Increase in) emerging substances due to urbanization	Uncertainty of the source of contamination	Increasing subsurface congestion	Increase of (average) drinking water usage	Lack of clear agreements of future water allocation	Influence of drinking water abstraction on surrounding area and vice versa	Reduced (ground)water availability due to drought (climate change)
T1: Develop new drinking water abstractions	+	●	+/●	●	●	●	-	●	●	-	●	●	-	-
T2: Focus on new purification techniques - drinking water	+	+	+	●	●	●	●	●	●	●	●	●	+/●	●
T3: Focus on new purification techniques - surface water	●	+	+	●	●	●	●	+	●	●	●	●	●	●
T4: Precision agriculture	●	●	●	●	+	+	+/●	●	●	●	+	●	●	●
T5: Sustainable abstraction techniques	+/●/-	+/●	+/●	●	●	●	+/●/-	●	●	●	●	●	+/●/-	+/●
T6: Eleborate amount of observation wells groundwater quality	●	●	●	●	●	●	●	●	+	●	●	●	●	●
T7: Water purification before discharge	●	●	●	●	●	●	●	+	●	●	●	●	●	●
T8: Downscaling drinking water abstraction	+/●	●	●	●	●	●	+	●	●	+	-	●	+	+
O1: Stimulation - subsidy scheme for conversion to biological farming	●	●	●	+	+	+	+	●	●	●	●	●	+	●
O2: Collaboration in circular water management	●	+	+	●	●	●	●	●	●	●	+	+	●	+
O3: Stimulation - financial support for innovation in precision agriculture	●	●	●	+	+/●	+/●	+	●	●	●	+	●	●	+
O4: Acquiring land and leasing it to farmers	●	●	●	+	●	●	+/●	●	●	●	●	●	+	●
S1: Only biological agriculture in groundwater protection areas	●	●	●	+	+	+	-	●	●	●	●	●	+	●
S2: Only biological agriculture in infiltration areas	●	●	●	+	+	+	-	●	●	●	●	●	+	●
S3: Sweet water storage in rural land	●	●	●	●	●	●	●	●	●	●	●	●	●	+
S4: Natural water filtering	●	●	+	●	●	●	●	+	●	●	●	●	+	●
S5: Focus on services	●	●	●	●	+	+	+/-	-	●	●/-	+/●/-	●	+/●/-	●
S6: Remediation of soil	●													
S7: Land consolidation	+/●	●	●	+	+/●	+/●	+/●	●	●	+/●	+/●	●	●	●
S8: Expropriation	+/●	●	●	+	+/●	+/●	+/●	●	●	+/●	+/●	●	●	●
S9: Recreational awareness route	●	●	●	●	●	●	●	●	●	●	●	●	●	●
S10: Agroforestry	●	●	●	●	●	+	●	●	●	●	●/-	●	●	+
S11: Groundwater friendly cultivation	●	●	●	●	+	+	●	●	●	●	●	●	●	+/●
S12: No high-category industry allowed	●	●	●	●	●	●	●	+	●	●	●	●	●	●
S13: Bufferzones	●	●	●	●	●	+	●	●	●	●	●	●	●	+
S14: Only abstractions for public drinking water allowed	●	●	●	●	●	●	●	●	●	+	+/●	+	●	+
S15: Expand groundwater protection zone	+	●	●	●	+	+	-	+	●	●	●	●	●/-	●

7.2 Scenarios

Explanation of the scenarios

Based on the analyzed trends and policies, four scenarios have been developed: drinking water landscape, urban landscape, production landscape en landscape under pressure. All scenarios represent a combination of trends and policies and serve as the foundation for formulating a future strategy.

Variables in the scenarios

The first variable used in the scenarios concerns the demand for residential and industrial areas. The analyzed trends reveal both population growth and an increase in the number of single-person households. These trends jointly contribute to a growing demand for housing. Additionally, a looming shortage of industrial and commercial space has become apparent. These developments have been combined into a single variable along the y-axis, representing urbanization.

The x-axis reflects a spectrum from extensive to intensive agriculture. Provincial policy in Utrecht promotes both biological and nature-inclusive farming as well as precision agriculture. Thus, efforts are aimed at both extensification and technological innovation. This dual approach allows for exploring the contrasts between these two extremes.

Guiding trends

Two guiding trends have been extended across all scenarios:

- The upscaling of agricultural enterprises;
- The transition from grassland to arable land and fruit cultivation

Scenario structure

Each scenario is structured around three thematic challenges: urbanization, agriculture and water. These are explained in three corresponding sections. A synthesis of these challenges follows, highlighting the key considerations for each scenario. While the key considerations are consistent across all scenarios, their relatively priority will differ. The priority order is listed at the end of each scenario.

Use of numbers and quantities

A selection of numbers/quantities was used to define the challenges presented in the scenarios.

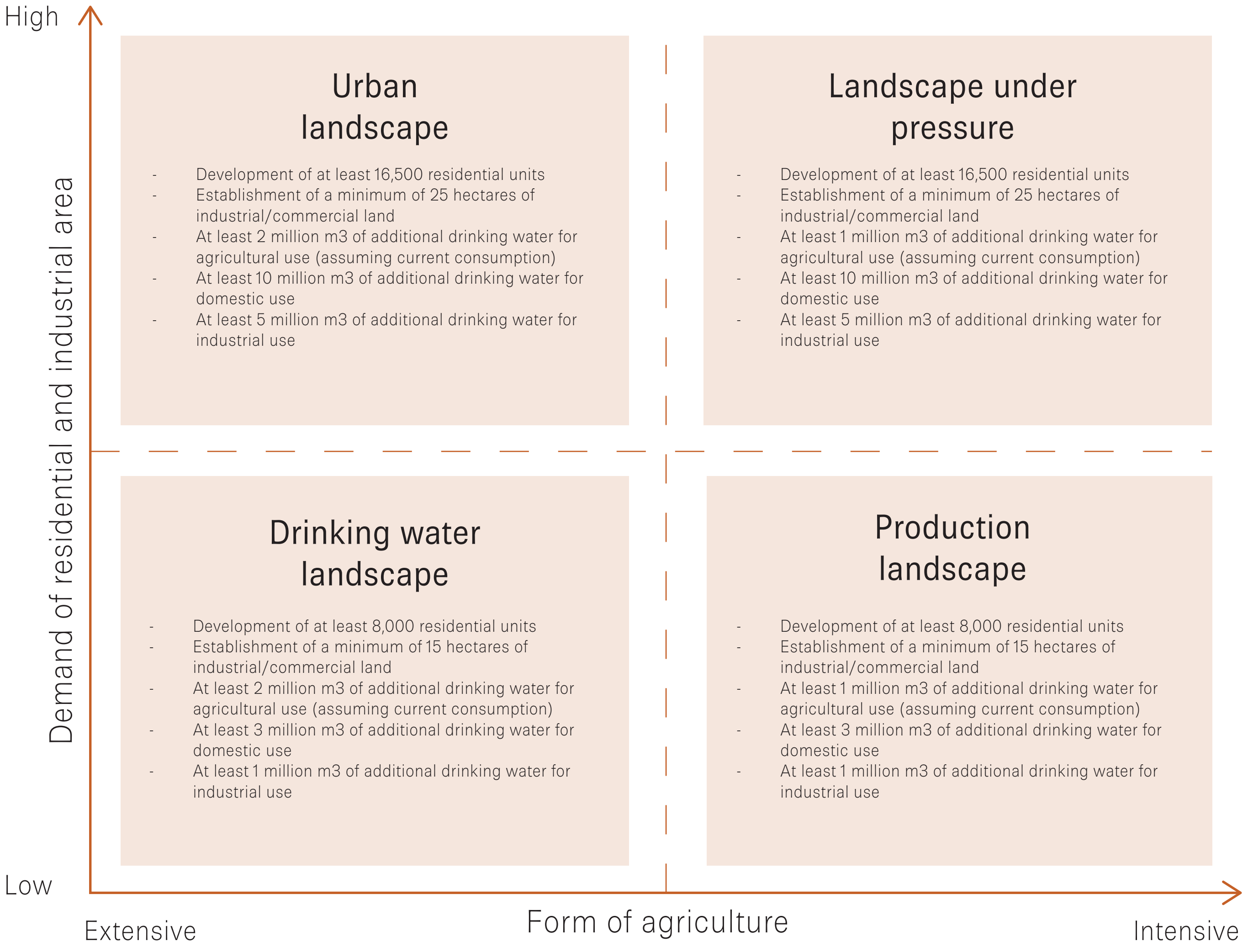
To quantify the housing challenge, the 2023 "Living and Working" program was used, which provides an overview of the number of housing units required under current conditions in cities and villages in the Kromme Rijnstreek. This estimate was then proportionally compared to the total of housing units needed in the province of Utrecht, to derive an estimate for the required hectares of industrial/commercial land.

In collaboration with professionals from the Province of Utrecht, an estimated number of housing units needed was developed for the high urbanization scenarios. The corresponding percentage (the estimate) was then applied to estimate the required hectares of industrial/commercial land.

Additionally, estimates of water usage were included in the scenarios. These figures were also developed in collaboration with professionals from the province of Utrecht through a rough approximation.

On the next page, the four different scenarios are depicted in a matrix.

The four scenarios



Input workshop for scenarios

As described above, the pattern language was applied in a workshop setting. In this workshop, the scenarios served as the starting point for the participants. Using the pattern language, participants responded to the various scenarios. Three scenarios were explored during the workshop: Urban Landscape, Production Landscape, and Landscape Under Pressure. For each scenario, one group developed a design, using the pattern language.

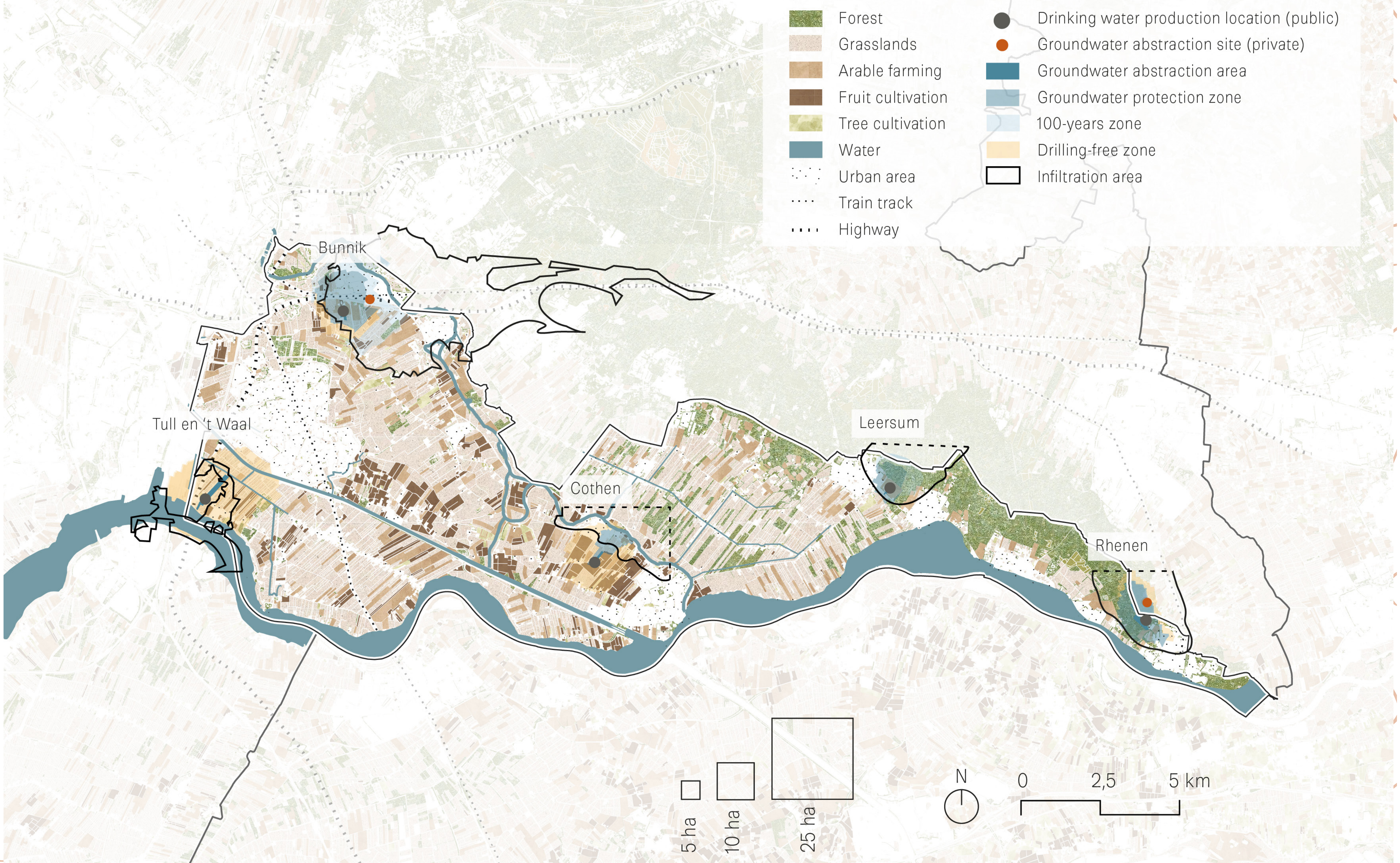
The following pages provide a detailed explanation of each scenario. This is followed by the author's own design, after which the participants' designs from the workshop are presented. A comparison between these two designs is then made. **After all three scenarios have been addressed, two new designs are introduced. These are hybrid designs that combine elements from both the author's and the workshop participants' designs. These final designs are for the scenarios 1 and 4 (least extreme and most extreme). These scenarios are chosen, because these scenarios differ the most from each other. This highlights the difference of the chosen solutions and the spatial impact.**

Scenario 1 was not included in the workshop. The reason for this is that the challenges in this scenario are the lowest. One of the objectives of the workshop was to identify the key solutions and considerations between groundwater quality, agriculture, and urbanization. In a scenario with relatively low demands, fewer tough decisions need to be made. Additionally, the number of participants allowed for the formation of three groups with a sufficient number of members each.

Therefore, only the author's design is presented for scenario 1, and no comparative analysis is provided.

On the next page, the current situation is depicted. The following pages provide a detailed explanation of each scenario, including the designs.

Current situation



Scenario 1: Drinking water landscape

Urbanization challenge

In this scenario, population growth in the province of Utrecht is in line with projections, and the province is expected to have a population of 1.4 million by 2050. By 2050, an additional 170,000 housing units must be constructed, along with 300 hectares of industrial land in the province of Utrecht. In the Kromme Rijnstreek specifically, at least 8,000 housing units must be developed, along with a minimum of 15 hectares of industrial land.

Agricultural challenge

In the Kromme Rijnstreek, 60% of grassland has been converted to extensive arable farming and/or fruit cultivation. Many agricultural enterprises have undergone scale enlargement, although both permanent and temporary grasslands still represent a substantial share of the agricultural area. Demand for organic products has increased, and short supply chains have become more prevalent within the region.

Although arable farming and fruit cultivation generally involve substantial use of pesticides, their use is more limiited in extensive agriculture. Nonetheless, overall (ground)water quality has slightly deteriorated, primarily due to the introduction of new type of pesticides, the purification methods for which are still unclear to Vitens. These contaminants are also present - albeit in lower concentrations - in the shallow groundwater, which has necessitated significantly more purification at several drinking water abstraction sites that rely on shallow sources.

Water consumption

The conversion of grasslands to extensive arable farming and fruit cultivation has led to a modest increase in water consumption. However, the implemenation of extensive farming practices has promoted natural soil recovery, enhancing water retention compared to intensive farming. Consequently, if agricultural water use remains constant, an additional 15 million m3 of drinking water per year will be required in the province of Utrecht. Specifically, in the Kromme Rijnstreek, a least 2 million m3 of additional drinking water must be produced annually to meet agricultural needs.

Moreover, average water consumption has remained stable at 129 liters per person per day. Previously, water use had increased due to increasingly dry summers, but has since declined as a result of water-saving initiatives implemented by the province of Utrecht. This leads to an additional annual demand of 15 million m3 of drinking water for domestic use in the province of Utrecht. In the Kromme Rijnstreek, at least 3 million m3 of additional drinking water must be secured annually for domestic use.

Finally, the industrial sector is also expected to require more (drinking)water. In the Kromme Rijnstreek, industrial water demand will increase by at least 1 million m3 annually.

In total, The Kromme Rijnstreek will require an additional 6 million m3 of drinking water per year.

Summary

- Development of at least 8,000 residential units
- Establishment of a minimum of 15 hectares of industrial/commercial land
- At least 2 million m3 of additional drinking water for agricultural use (assuming current consumption)
- At least 3 million m3 of additional drinking water for domestic use
- At least 1 million m3 of additional drinking water for industrial use

Key considerations

1. How should the impacts of arable farming and fruit cultivation on groundwater quality be addressed?

2. Should the focus be on protecting existing drinking water sources, investing in technical solutions, or adopting a hybrid appraoch - or perhaps an entirely different strategy?

3. Where will urban development take place, and how will this interact with existing drinking water resources? To what extend is the Kromme Rijnstreek expected to absorb the urbanization challenge?

4. How could the risks associated with urbanization be mitigated? Or should these risks be accepted?

5. Should the additional drinking water demand in the Kromme Rijnstreek be met locally?

Order of priority

3 2 4 1 5

Principles of the design - own design

- Urbanization around existing urban centers;

- Realising new groundwater abstraction for drinking water production in drinking water searching area;

- Focus on geographical distribution of groundwater abstraction for drinking water supply;

- Protecting groundwater abstractions by restricting land use within the infiltration areas to agroforestry and biological agriculture;

- Focusing on maximizing water infiltration on Utrechtse Heuvelrug and inland;

- Focus on ecosystems services in agriculture;

- Promoting groundwater friendly agriculture throughout the entire region.

Applied patterns

T1 T5 T8

O1

R2 R3 R5 R10 R11

Ground- and drinking water

- New groundwater abstraction
- New surface water abstraction
- Increase drinking water production
- Expand groundwater protection zone
- Sweet water storage in rural land
- Only abstractions for drinking water allowed
- Geographical diversification of groundwater abstractions
- Focus on new purification techniques - drinking water
- Natural water filtering
- Water purification before discharge
- Elaborate amount of observation wells groundwater quality
- Drinking water production location (public)
- Drinking water production location (private)
- Water abstraction area
- Groundwater protection zone
- 100-years zone
- Drilling-free zone
- Infiltration zone

Agriculture

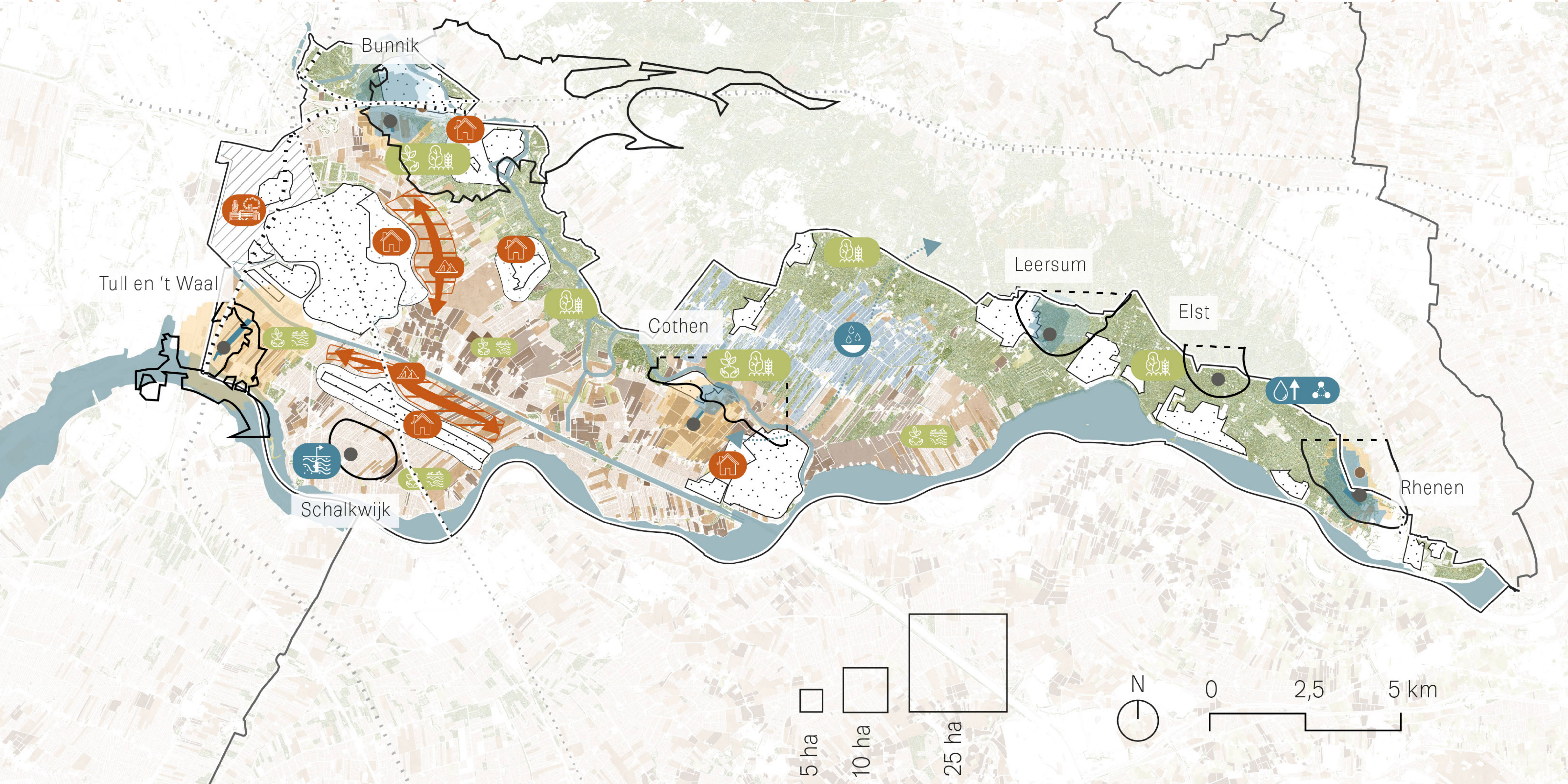
- Biological agriculture
- Groundwater friendly agriculture
- Agroforestry
- Precision agriculture
- Land consolidation
- Grasslands
- Arable land
- Fruit cultivation
- Tree cultivation

Landscape

- Bufferzone
- Forest
- Water
- Train track
- Highway

Urbanization

- Low-density housing
- High-density housing
- Industrial zone
- Recreational functions
- Train station
- Recreational awareness route
- Residential area
- Industrial area


Bunnik
Tull en 't Waal
Cothen
Leersum
Elst
Rhenen
Schalkwijk
5 ha
10 ha
25 ha
N
0
2,5
5 km

Scenario 2: Urban landscape

Urbanization challenge

In this scenario, population growth in the province of Utrecht has significantly exceeded previous projections. By 2050, the province is expected to have **approximetaly 1.8 million inhabitants** (rather than the previously estimated 1.4 million). As a result, the urbanization challenge has intensified: by 2050, an additional **350,000 housing** units must be constructed, **along with 500 hectares of industrial land** in the province of Utrecht. In the Kromme Rijnstreek specifically, **at least 16,500 housing units must be developed, along with a minimum of 25 hectares of industrial land.**

Agricultural challenge

In the Kromme Rijnstreek, 60% of grassland has been converted to extensive arable farming and/ or fruit cultivation. Many agricultural enterprises have undergone scale enlargement, although both permanent and temporary grasslands still represent a substantial share of the agricultural area. Demand for organic products has increased, and short supply chains have become more prevalent within the region.

Although arable farming and fruit cultivation generally involve substantial use of pesticides, their use is more limiited in extensive agriculture. Nonetheless, overall (ground)water quality has slightly deteriorated, primarily due to the introduction of new type of pesticides, the purification methods for which are still unclear to Vitens. These contaminants are also present - albeit in lower concentrations - in the shallow groundwater, which has necessitated significantly more purification at several drinking water abstraction sites that rely on shallow sources.

Water consumption

The conversion of grasslands to extensive arable farming and fruit cultivation has led to a modest increase in water consumption. However, the implemenation of extensive farming practices has promoted natural soil recovery, enhancing water retention compared to intensive farming. Consequently, **if agricultural water use remains constant,** an additional 15 million m3 of drinking water per year will be required in the province of Utrecht. **Specifically, in the Kromme Rijnstreek, a least 2 million m3 of additional drinking water must be produced annually to meet agricultural needs.**

Furthermore, climate change has caused average per capita water consumption to rise **to 150 liters per day**, largely due to increasingly dry summers. This has led to an additional demand of **85 million m3** of drinking water per year for domestic use in the province. **Of this, at least 10 million m3 must be provided annually in the Kromme Rijnstreek.**

Finally, the industrial sector is also expected to require more (drinking)water. In the Kromme Rijnstreek, industrial water demand will increase by at least 5 million m3 annually.

In total, The Kromme Rijnstreek will require an additional 17 million m3 of drinking water per year.

Summary

- Development of at least 16,500 residential units
- Establishment of a minimum of 25 hectares of industrial/commercial land
- At least 2 million m3 of additional drinking water for agricultural use (assuming current consumption)
- At least 10 million m3 of additional drinking water for domestic use
- At least 5 million m3 of additional drinking water for industrial use

Key considerations

1. How should the impacts of arable farming and fruit cultivation on groundwater quality be addressed?

2. Should the focus be on protecting existing drinking water sources, investing in technical solutions, or adopting a hybrid approach - or perhaps an entirely different strategy?

3. Where will urban development take place, and how will this interact with existing drinking water resources? To what extend is the Kromme Rijnstreek expected to absorb the urbanization challenge?

4. How could the risks associated with urbanization be mitigated? Or should these risks be accepted?

5. Should the additional drinking water demand in the Kromme Rijnstreek be met locally?

Order of priority

3	4	5	2	1

Principles of the design - own design

- Urbanization around public transport hubs and on sandy soils;

- Increasing drinking water production from non-vulnerable groundwater abstractions;

- Realising new surface water abstraction for drinking water production at the Lek;

- Focus on prevention and extra purifcation techniques at groundwater abstraction Bunnik;

- Protecting groundwater abstractions at Utrechtse Heuvelrug (Leersum and Rhenen) by restricting land use within the infiltration areas to agroforestry and biological agriculture;

- "Central Park" as natural environment with natural filtering and bufferzones. Focus on biological agriculture and ecological services from farmers;

- Enhancing public awareness among residents and visitors through a recreational awareness route;

- Holding companies accountable for their own water treatment and emphaszing circular water management.

Applied patterns

T1 T2 T6 T7

O1 O2

S2 S4 S5 S9 S10 S11 S13

Ground- and drinking water

- New groundwater abstraction
- New surface water abstraction
- Increase drinking water production
- Expand groundwater protection zone
- Sweet water storage in rural land
- Only abstractions for drinking water allowed
- Geographical diversification of groundwater abstractions
- Focus on new purification techniques - drinking water
- Natural water filtering
- Water purification before discharge
- Elaborate amount of observation wells groundwater quality
- Drinking water production location (public)
- Drinking water production location (private)
- Water abstraction area
- Groundwater protection zone
- 100-years zone
- Drilling-free zone
- Infiltration zone

Agriculture

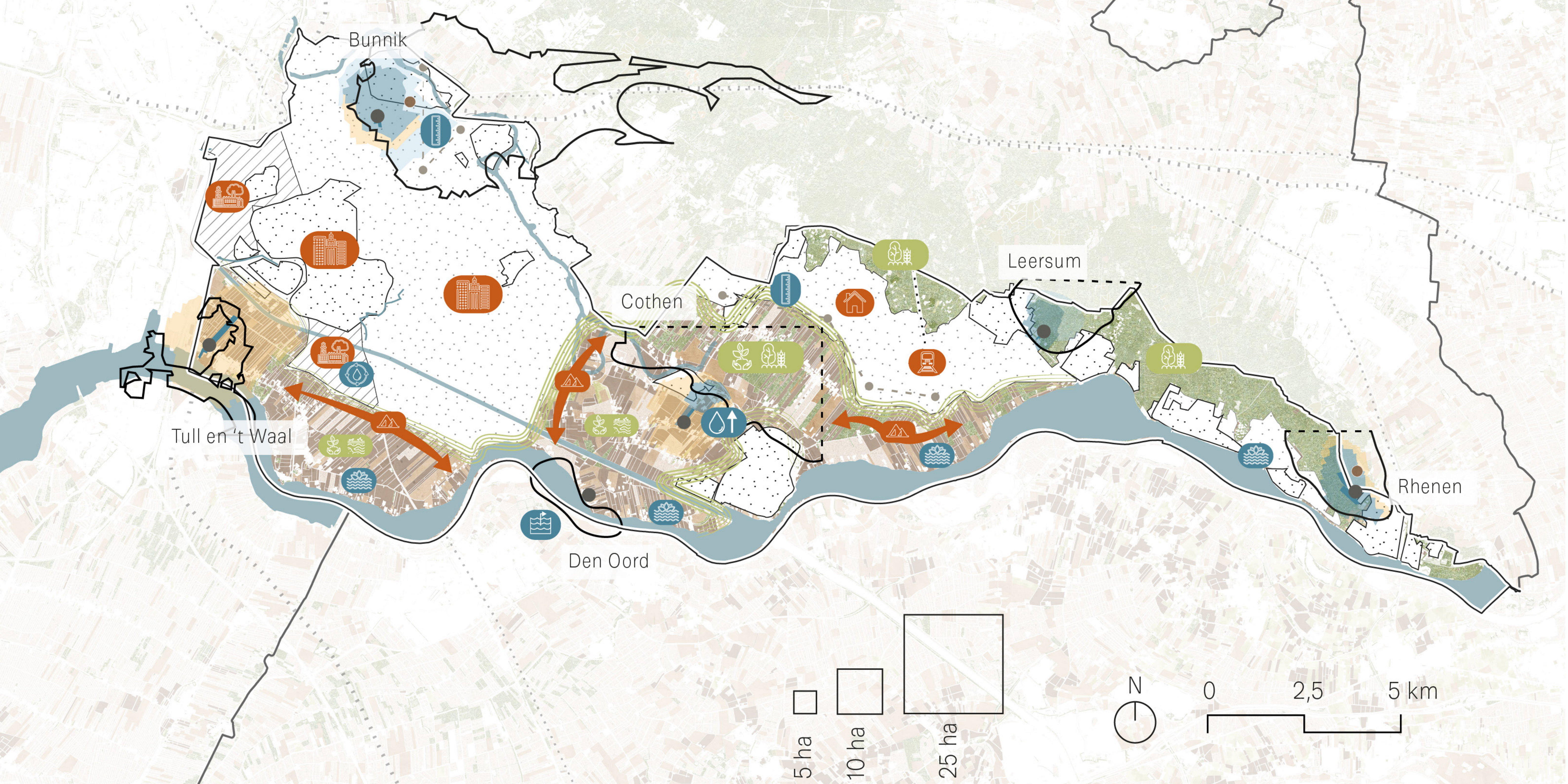
- Biological agriculture
- Groundwater friendly agriculture
- Agroforestry
- Precision agriculture
- Land consolidation
- Grasslands
- Arable land
- Fruit cultivation
- Tree cultivation

Landscape

- Bufferzone
- Forest
- Water
- Train track
- Highway

Urbanization

- Low-density housing
- High-density housing
- Industrial zone
- Recreational functions
- Train station
- Recreational awareness route
- Residential area
- Industrial area



Bunnik
Cothen
Leersum
Tull en 't Waal
Den Oord
Rhenen
5 ha
10 ha
25 ha
N
0
2,5
5 km

Principles of the design - group design workshop

- Effective spatial zoning;

- Centralized drinking water source – establishment of a new surface water extraction site near Schalkwijk;

- Urban development Houten and Wijk bij Duurstede;

- Circular and sustainable development;

- Biological fruit cultivation and urban agriculture;

- Extra industry along Amsterdam-Rijnkanaal;

- Kromme Rijn and flank areas of Utrechtse Heuvelrug as natural bufferzones;

- Addition of estates along the Kromme Rijn;

- Focus on clean surface water management.

Applied patterns

T1 T2 T4 New

O1 O2

R2 R3 R13 R14 R16


Trein
Snelweg
Bunnik
Leersum
Tull en 't Waal
Cothen
Rhenen
CIRCULAIR
BEWUST
NATURA 2000
INZETTEN op schoon opp water
5 ha
10 ha
25 ha
N
0
2,5
5 km

Differences and similarities - own design and group design

Design

There are several similarities and differences between the individual design and the group design:

- The urbanization locations are (almost) the same. Both designs chose to focus urban development east of Houten and southwards along the Amsterdam-Rijnkanaal. In the group design, however, urbanization is only present near Leersum, while in the individual design, it extends along the entire Utrechtse Heuvelrug. It should be noted that the group indicated they did not fully meet the urbanization targets as described in the scenario.

- The location of new industrial areas differs between the two designs. In the group design, the new industrial area is situated east of Wijk bij Duurstede, near the Amsterdam-Rijn Kanaal and the Lek. In contrast, the individual design places new industrial development east of Houten. However, this area intersects with the Nieuwe Hollandse Waterlinie, which is why the group chose not to situate industrial development there.

Chosen patterns

The table below highlights which patterns were selected both by the group during the workshop and in the individual design. A total of six patterns were chosen in the same way. The selected patterns are:

S2 - Biological agriculture in groundwater protection zones
S3 - Sweet water storage in rural area
S13 - Bufferzones
S14 - Only abstractions for drinking water allowed)
S15 - Expand groundwater protection zone
T1 - Develop new drinking water abstraction
T2 - Focus on new purification techniques - drinking water
T4 - Precision agriculture
O1 - Stimulation: subsidy scheme for conversion to biological farming
O2 - Collaboration in circular water management

New pattern - Conscious water use in urban areas (safe and healthy circular water use)

Corresponding patterns

Not chosen patterns

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	T1	T2	T3	T4	T5	T6	T7	T8	O1	O2	O3	O4
Group 2	○	⊗	⊗	○	○	○	○	○	○	○	○	○	⊗	⊗	⊗	⊗	⊗	○	⊗	○	○	○	○	⊗	⊗	○	○
Personal	○	⊗	○	⊗	⊗	○	○	○	⊗	⊗	⊗	○	⊗	○	○	⊗	⊗	○	○	○	⊗	⊗	○	⊗	⊗	○	○

There are some important caveats when comparing the individual design with the group design. In the individual design, no maximum number of patterns was considered, whereas in the workshop, a limit of ten patterns was applied. This allowed the author's design to respond more comprehensively to the challenges posed in the scenario, while the workshop designs lack several important solutions. Despite this difference, several noteworthy observations emerge from the comparison:

- In the group design, there is a strong emphasis on regulation through the selection of S14 (only abstractions for drinking water allowed) and S15 (expand groundwater protection zone). These patterns were not selected in the individual design.

- The individual design instead emphasizes a self-purifying landscape. For example, S4 (natural water filtering) was selected, and agricultural sustainability was promoted through S2 (biological agriculture in groundwater protection zones), S10 (agroforestry), and S11 (groundwater-friendly cultivation). While the group design also focused on biological farming, it additionally emphasized innovation by selecting T4 (precision agriculture).

- The group design includes freshwater storage in rural areas near Schalkwijk (S3). Although this pattern was not selected in the individual design, it is indeed relevant in scenarios where a significant increase in drinking water production is required.

- The group created a new pattern focusing on circular water use in urban areas. In doing so, they aimed to reduce the increased demand for drinking water. This type of solution was not yet included in the pattern book, nor was it applied in the individual design.

Input for final design

First and foremost, it has become clear that more than ten patterns are needed for the design in this scenario. The following points will be incorporated into a final design:

- The implementation of freshwater storage in rural areas (Schalkwijk) in response to a significantly increased demand for drinking water;

- The use of solutions focused more explicitly on circular water management (new pattern) to address a significantly increased drinking water demand;

- The application of both regulatory and spatial measures;

- The consideration of the cultural-historical value of the Nieuwe Hollandse Waterlinie in selecting locations for urban development (including both housing and industry);

Scenario 3: Productive landscape

Urbanization challenge

In this scenario, population growth in the province of Utrecht is in line with projections, and the province is expected to have a population of 1.4 million by 2050. By 2050, an additional **170,000 housing** units must be constructed, **along with 300 hectares of industrial land** in the province of Utrecht. In the Kromme Rijnstreek specifically, **at least 8,000 housing units must be developed, along with a minimum of 15 hectares of industrial land.**

Agricultural challenge

In the Kromme Rijnstreek, 80% of grassland has been converted to extensive arable farming and/or fruit cultivation. Permanent grassland has become the exception rather than the rule, and many farms have undergone significant upscaling. This development is partly due to persistently low demand for organic products.

Arable farming and fruit cultivation in the region typically involve substantial use of pesticides, which has led to a marked deterioration in overall (ground)water quality. Moreover, the agricultural transformation has introduced an increasing number of new pesticides, for which Vitens has not yet identified effective purification methods. These contaminants are also present in the shallow groundwater, necessitating considerably more intensive treatment at several drinking water abstraction sites that depend on this shallow groundwater. There is a substantial risk that these pollutants will move into deeper aquifers on a large scale, posing a serious threat to the long term viability of groundwater resources for drinking water supply.

Water consumption

Water consumption in the agricultural sector has increased due to the transition toward arable farming and/or fruit cultivation. As a result, if current levels of agricultural water use persist, an additional **30 million m3 of drinking water per year** will be required in the province of Utrecht. Specifically, in the Kromme Rijnstreek, **at least 1 million m3 of additional drinking water must be produced annually to meet agricultural demand.**

Moreover, average water consumption has remained stable at **129 liters per person per day.** Previously, water use had increased due to increasingly dry summers, but has since declined as a result of water-saving initiatives implemented by the province of Utrecht. This leads to an additional annual **demand of 15 million m3** of drinking water for domestic use in the province of Utrecht. **In the** Kromme Rijnstreek, **at least 3 million m3 of additional drinking water must be secured annually for domestic use.**

Finally, the industrial sector is also expected to require more (drinking)water. In the Kromme Rijnstreek, industrial water demand will increase by at least 1 million m3 annually.

In total, The Kromme Rijnstreek will require an additional 5 million m3 of drinking water per year.

Summary

- Development of at least 8,000 residential units
- Establishment of a minimum of 15 hectares of industrial/commercial land
- At least 1 million m3 of additional drinking water for agricultural use (assuming current consumption)
- At least 3 million m3 of additional drinking water for domestic use
- At least 1 million m3 of additional drinking water for industrial use

Key considerations

1. How should the impacts of arable farming and fruit cultivation on groundwater quality be addressed?

2. Should the focus be on protecting existing drinking water sources, investing in technical solutions, or adopting a hybrid approach - or perhaps an entirely different strategy?

3. Where will urban development take place, and how will this interact with existing drinking water resources? To what extend is the Kromme Rijnstreek expected to absorb the urbanization challenge?

4. How could the risks associated with urbanization be mitigated? Or should these risks be accepted?

5. Should the additional drinking water demand in the Kromme Rijnstreek be met locally?

Order of priority

1	2	3	4	5

Principles of the design - own design

- Urbanization around public transport hubs - compact city;

- Focusing on maximizing water infiltration on Utrechtse Heuvelrug - UH as strong drinking water supply area;

- Focus on geographical distribution of groundwater abstraction for drinking water supply at Utrechtse Heuvelrug;

- Realising new surface water abstraction for drinking water production at the Lek;

- Focus on prevention and extra purifcation techniques at groundwater abstraction Bunnik;

- Enlarging groundwater protection zones;

- Grasslands in infiltration areas, fruit and tree cultivation and arable farming outside infiltration areas through the use of land consolidation;

- Focus on precision agriculture.

Applied patterns

T2 T4 T5 T6

O3 O4

S3 S4 S7 S13 S15

Ground- and drinking water

- New groundwater abstraction
- New surface water abstraction
- Increase drinking water production
- Expand groundwater protection zone
- Sweet water storage in rural land
- Only abstractions for drinking water allowed
- Geographical diversification of groundwater abstractions
- Focus on new purification techniques - drinking water
- Natural water filtering
- Water purification before discharge
- Elaborate amount of observation wells groundwater quality
- Drinking water production location (public)
- Drinking water production location (private)
- Water abstraction area
- Groundwater protection zone
- 100-years zone
- Drilling-free zone
- Infiltration zone

Agriculture

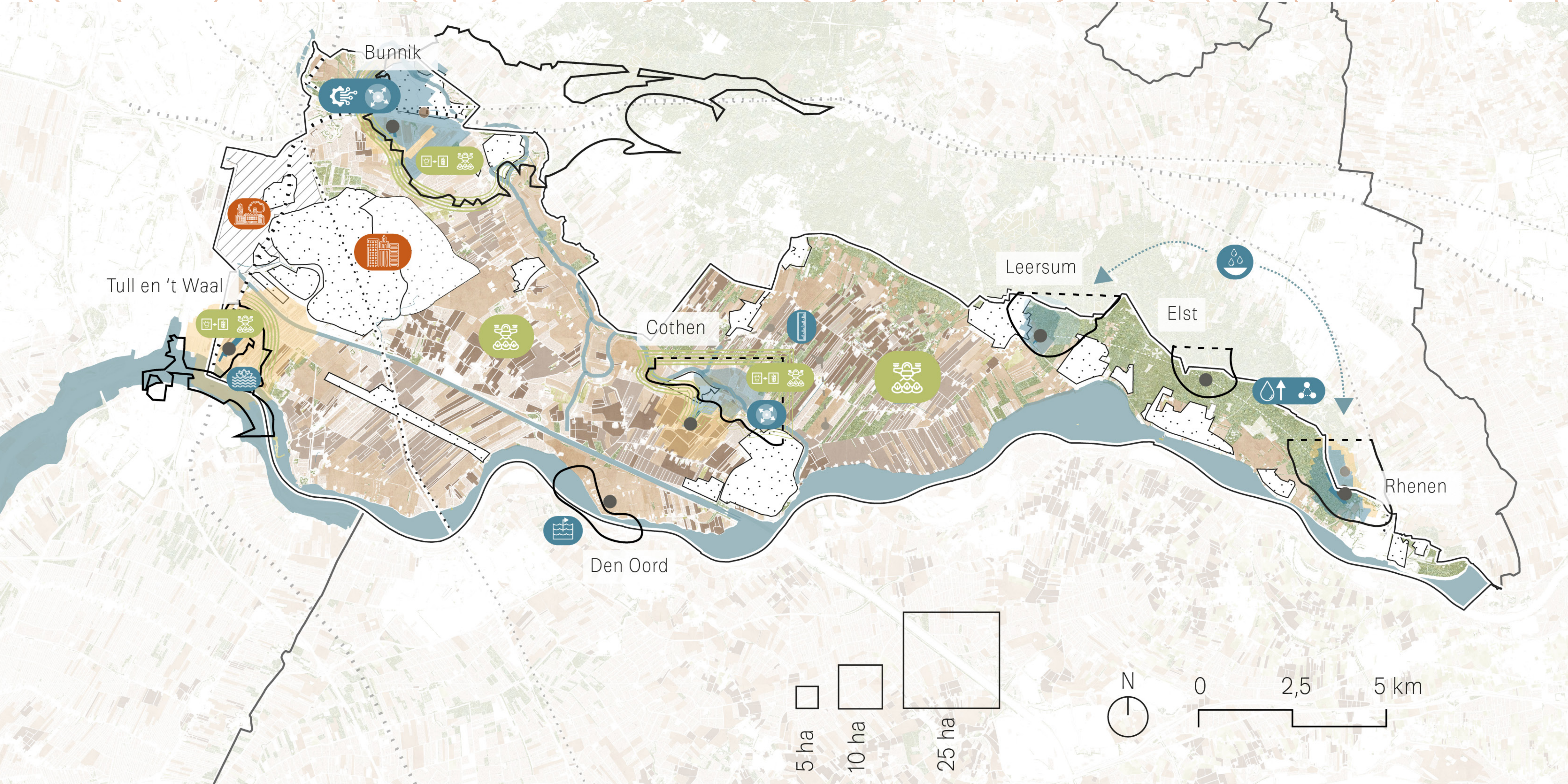
- Biological agriculture
- Groundwater friendly agriculture
- Agroforestry
- Precision agriculture
- Land consolidation
- Grasslands
- Arable land
- Fruit cultivation
- Tree cultivation

Landscape

- Bufferzone
- Forest
- Water
- Train track
- Highway

Urbanization

- Low-density housing
- High-density housing
- Industrial zone
- Recreational functions
- Train station
- Recreational awareness route
- Residential area
- Industrial area



Bunnik
Tull en 't Waal
Cothen
Leersum
Elst
Rhenen
Den Oord
5 ha
10 ha
25 ha
N
0
2,5
5 km

Principles of the design - group design workshop

- Concentrating the housing development task (Odijk City);

- Partially adopting an extensive building approach – adding a street to each town and village;

- Innovation and water reuse:
    - Water battery
    - Greywater systems in residential development
    - Technical water purification for industrial use
    - Water supply from the Kromme Rijn to agricultural areas;

- Expansion of existing groundwater abstraction sites.

Applied patterns

T4 T6 T7 New

O2

S1 S3 S4 S7 S11


Bos
Grasland
Akkerbouw
Fruitteelt
Boomkwekerij
Water
Stedelijk gebied
Trein
Snelweg
Drinkwaterproductielocatie (publiek)
Grondwateronttrekking (privaat)
Waterwingebied
Grondwaterbeschermingsgebied
100-jaars zone
Boringsvrije zone
Intrekgebied
Bunnik
Tull en 't Waal
Cothen
Leersum
Bestaand sted. geb.
Uitbreiding
bos
Grondwater-landbouw
Fruitteeltkern
Akkerbouw mozaïk
Agroforestry
Veelteelt + recreatie
5 ha
10 ha
25 ha
N
0
2,5
5 km

Differences and similarities - own design and group design

Design

There are several similarities and differences between the individual design and the group design:

- Both the individual design and the group design opted for a compact approach to addressing the housing development task. In the individual design, this was realized east of Houten, whereas the group design located it near Odijk, combined with a more extensive form of urbanization by adding development to each village in the region.

- In both designs, the industrial area is situated north of Houten. Notably, in the group design, this was combined with the addition of forest and recreational facilities.

- The group design demonstrates a strong focus on zoning different types of agriculture. In contrast, the individual design pays less attention to this aspect, resulting in a less clear allocation of specific agricultural types across the area.

Chosen patterns

The table below highlights which patterns were selected both by the group during the workshop and in the individual design. A total of five patterns were chosen in the same way. The selected patterns are:

S1 -Only biological agriculture in infiltration zones
S3 - Sweet water storage in rural area
S4 - Natural water filtering
S7 - Land consolidation
S11 - Groundwater friendly cultivation
T4 - Precision agriculture
T6 - Elaborate amount of observation wells groundwater quality
T7 - Water purifcation before discharge
O2 - Collaboration in circular water management

New pattern - Increase production of current abstraction

There are some important caveats when comparing the individual design with the group design. In the individual design, no maximum number of patterns was considered, whereas in the workshop, a limit of ten patterns was applied. This allowed the author's design to respond more comprehensively to the challenges posed in the scenario, while the workshop designs lack several important solutions. Despite this difference, several noteworthy observations emerge from the comparison:

- Although this scenario emphasizes intensive agriculture, the group chose S1 (only biological agriculture in infiltration zones). They also selected groundwater-friendly crops (S11) and would have included agroforestry (S10) if the maximum number of cards had not been reached. Agroforestry is, however, still visible in the spatial design. None of these solutions were selected in the individual design.

- The individual design proposed the establishment of a new drinking water extraction site to achieve a more distributed spatial layout while slightly increasing production. In contrast, the group design focused on increasing production at existing extraction sites.

- Notably, the group selected T7 (water purification before discharge), despite the scenario's focus on intensive agriculture and low urbanization pressure. They also opted for O2 (collaboration in circular water management), which was chosen in the individual design only in scenarios with high urbanization pressure.

Corresponding patterns   Not chosen patterns

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	T1	T2	T3	T4	T5	T6	T7	T8	O1	O2	O3	O4
Group 3	X	○	X	X	○	○	X	○	○	○	X	○	○	○	○	○	○	○	X	○	X	X	○	○	X	○	○
Personal	○	○	X	X	○	○	X	○	○	○	○	○	X	○	X	○	○	○	X	X	X	○	○	○	○	X	X

Input for final design

First and foremost, it has become clear that more than ten patterns are needed for the design in this scenario. The following points will be incorporated into a final design:

- Implementing types of agriculture in locations where they are most suitable (based on soil characteristics);

- Considering the use of S11 (groundwater-friendly crops) and S10 (agroforestry) within this scenario;

- Increasing production at existing water abstraction sites rather than establishing a new groundwater abstraction site;

- Expanding villages in a more extensive manner to reduce pressure on large-scale urban development near Houten.

Scenario 4: Landscape under pressure

Urbanization challenge

In this scenario, population growth in the province of Utrecht has significantly exceeded previous projections. By 2050, the province is expected to have **approximetaly 1.8 million inhabitants** (rather than the previously estimated 1.4 million). As a result, the urbanization challenge has intensified: by 2050, an additional **350,000 housing** units must be constructed, **along with 500 hectares of industrial land** in the province of Utrecht. In the Kromme Rijnstreek specifically, **at least 16,500 housing units must be developed, along with a minimum of 25 hectares of industrial land.**

Agricultural challenge

In the Kromme Rijnstreek, 80% of grassland has been converted to extensive arable farming and/or fruit cultivation. Permanent grassland has become the exception rather than the rule, and many farms have undergone significant upscaling. This development is partly due to persistently low demand for organic products.

Arable farming and fruit cultivation in the region typically involve substantial use of pesticides, which has led to a marked deterioration in overall (ground)water quality. Moreover, the agricultural transformation has introduced an increasing number of new pesticides, for which Vitens has not yet identified effective purification methods. These contaminants are also present in the shallow groundwater, necessitating considerably more intensive treatment at several drinking water abstraction sites that depend on this shallow groundwater. There is a substantial risk that these pollutants will move into deeper aquifers on a large scale, posing a serious threat to the long=term viability of groundwater resources for drinking water supply.

Water consumption

Water consumption in the agricultural sector has increased due to the transition toward arable farming and/or fruit cultivation. As a result, if current levels of agricultural water use persist, an additional **30 million m3 of drinking water per year** will be required in the province of Utrecht. Specifically, in the Kromme Rijnstreek, **at least 1 million m3 of additional drinking water must be produced annually to meet agricultural demand.**

Furthermore, climate change has caused average per capita water consumption to rise **to 150 liters per day**, largely due to increasingly dry summers. This has led to an additional demand of **85 million m3** of drinking water per year for domestic use in the province. **Of this, at least 10 million m3 must be provided annually in the Kromme Rijnstreek.**

Finally, the industrial sector is also expected to require more (drinking)water. In the Kromme Rijnstreek, industrial water demand will increase by at least 5 million m3 annually.

In total, The Kromme Rijnstreek will require an additional 16 million m3 of drinking water per year.

Summary

- Development of at least 16,500 residential units
- Establishment of a minimum of 25 hectares of industrial/commercial land
- At least 1 million m3 of additional drinking water for agricultural use (assuming current consumption)
- At least 10 million m3 of additional drinking water for domestic use
- At least 5 million m3 of additional drinking water for industrial use

Key considerations

1. How should the impacts of arable farming and fruit cultivation on groundwater quality be addressed?

2. Should the focus be on protecting existing drinking water sources, investing in technical solutions, or adopting a hybrid approach - or perhaps an entirely different strategy?

3. Where will urban development take place, and how will this interact with existing drinking water resources? To what extend is the Kromme Rijnstreek expected to absorb the urbanization challenge?

4. How could the risks associated with urbanization be mitigated? Or should these risks be accepted?

5. Should the additional drinking water demand in the Kromme Rijnstreek be met locally?

Order of priority

2	3	5	4	1

Principles of the design - own design

- Urbanization around public transport hubs and on sandy soils;

- Focusing on maximizing water infiltration on Utrechtse Heuvelrug - UH as strong drinking water supply area;

- Realising new surface water abstraction for drinking water production at the Lek;

- Focusing on prevention and extra purifcation techniques at groundwater abstractions Bunnik and Cothen;

- Allowing only groundwater abstractions for public drinking water in infiltration areas in Bunnik and Rhenen;

- Enlarging groundwater protection zones;

- Grasslands in infiltration areas, fruit and tree cultivation and arable farming outside infiltration areas through the use of land consolidation;

- Focus on precision agriculture;

- Groundwaterfriendly agriculture in infiltration areas.

Applied patterns

T1 T2 T4 T5 T6 T7

O2 O3 O4

S3 S4 S6 S7 S13 S14 S15

Ground- and drinking water

- New groundwater abstraction
- New surface water abstraction
- Increase drinking water production
- Expand groundwater protection zone
- Sweet water storage in rural land
- Only abstractions for drinking water allowed
- Geographical diversification of groundwater abstractions
- Focus on new purification techniques - drinking water
- Natural water filtering
- Water purification before discharge
- Elaborate amount of observation wells groundwater quality
- Drinking water production location (public)
- Drinking water production location (private)
- Water abstraction area
- Groundwater protection zone
- 100-years zone
- Drilling-free zone
- Infiltration zone

Agriculture

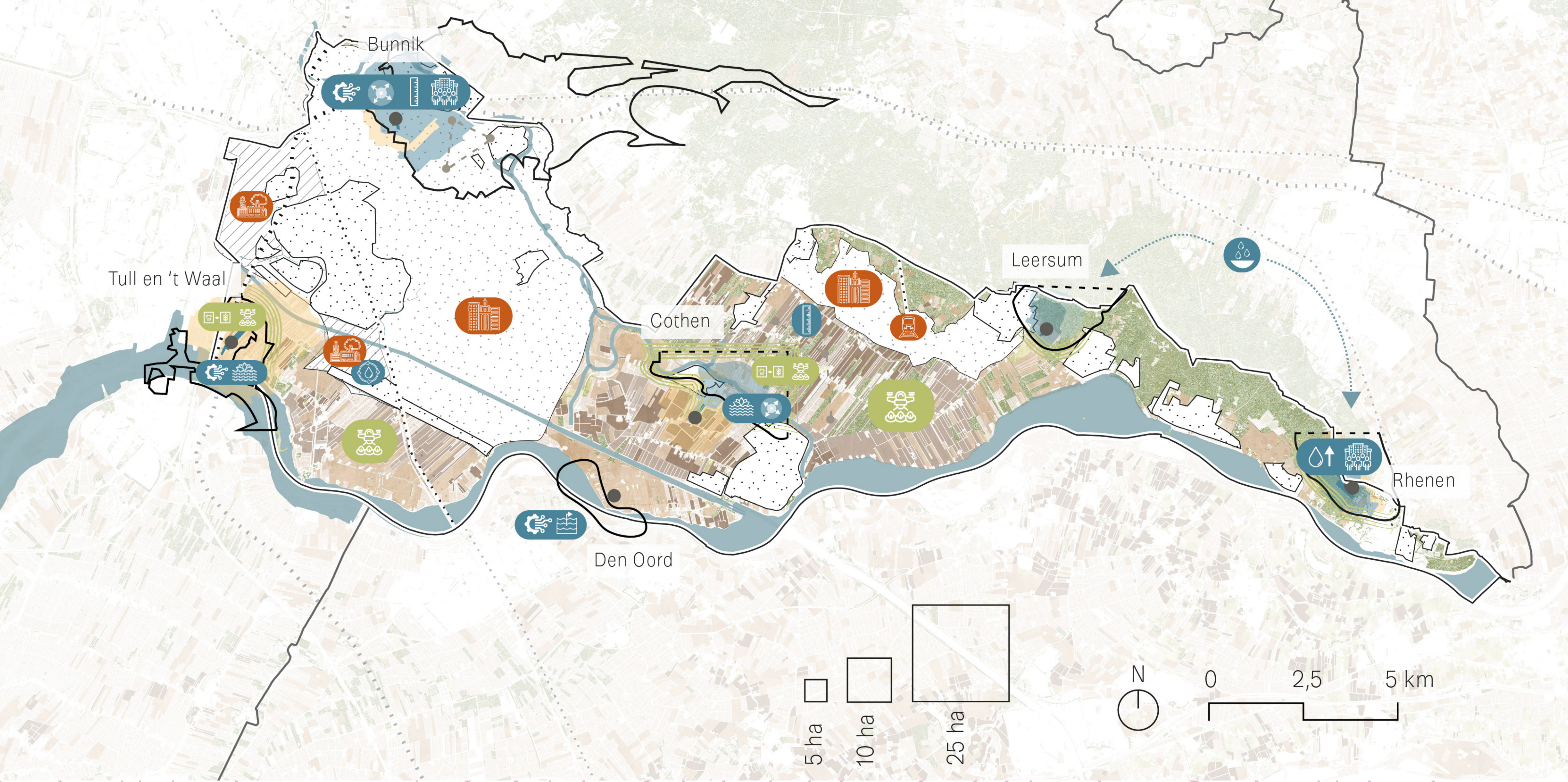
- Biological agriculture
- Groundwater friendly agriculture
- Agroforestry
- Precision agriculture
- Land consolidation
- Grasslands
- Arable land
- Fruit cultivation
- Tree cultivation

Landscape

- Bufferzone
- Forest
- Water
- Train track
- Highway

Urbanization

- Low-density housing
- High-density housing
- Industrial zone
- Recreational functions
- Train station
- Recreational awareness route
- Residential area
- Industrial area



Bunnik
Tull en 't Waal
Cothen
Leersum
Den Oord
Rhenen
5 ha
10 ha
25 ha
N
0
2,5
5 km

Principles of the design - group design workshop

- Urban development (in red) is concentrated along the Utrechtse Heuvelrug, aligning with existing settlements on the ridge, and located along the water infiltration zone (in blue;

- High-density urban development between Bunnik and Houten is envisioned as the 'Houten Metropolis';

- Subsurface water storage is conceptualized as a 'water battery' beneath the Utrechtse Heuvelrug;

- The Nederrijn and Lek rivers are utilized as sources to supply water to the region;

- Bank filtration is planned near the island of Schalkwijk;

- A stacked configuration of business parks is promoted to minimize land use (in hectares), incorporating modern technologies; to be realized above Tull en 't Waal;

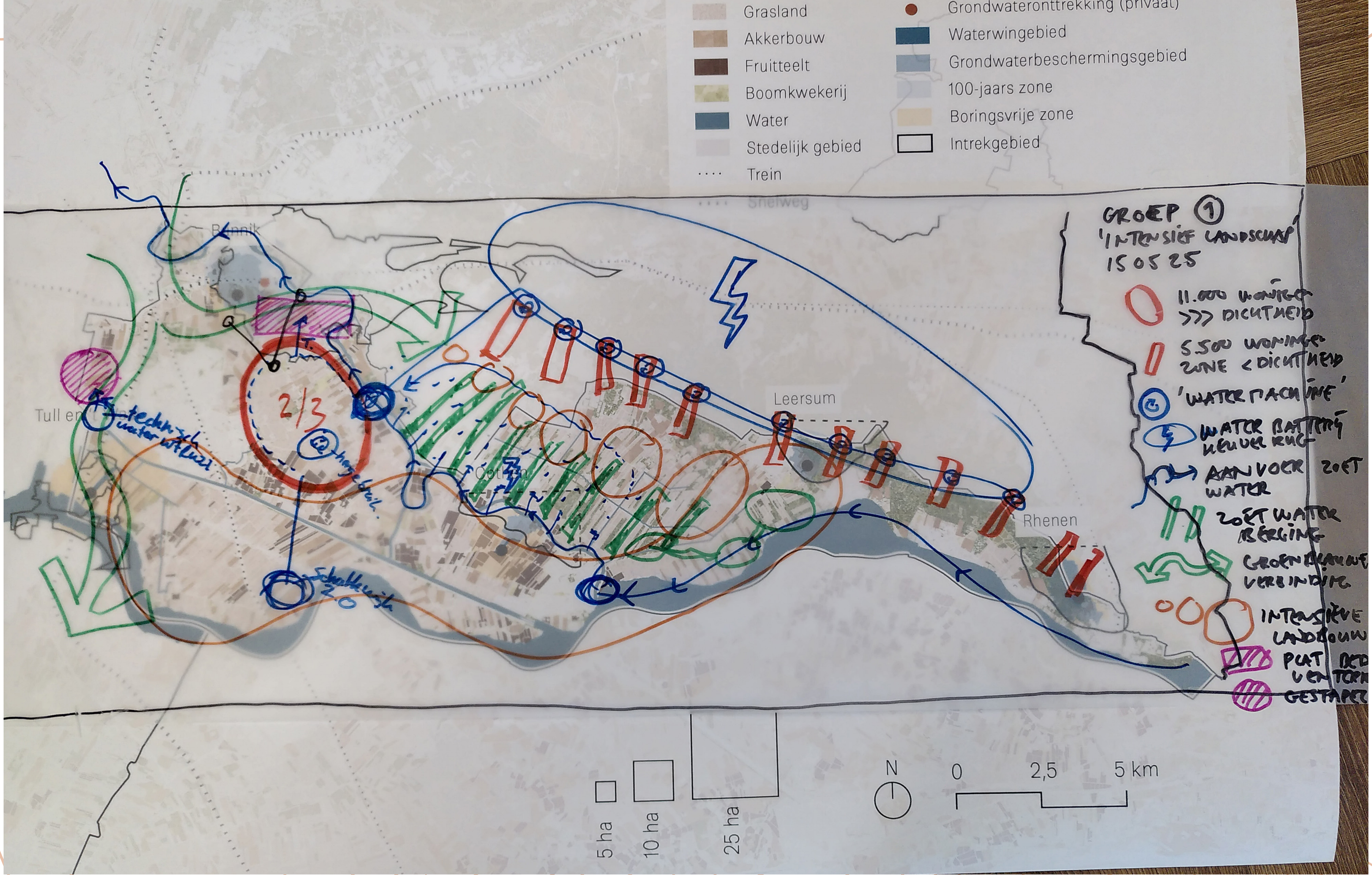
- Intensive agriculture remains present in the region;

- Innovation and water reuse are emphasized across sectors: spatially through the water battery; in residential areas via greywater systems; in industry through advanced water purification technologies; and in agriculture through water supply from the Kromme Rijn.

Applied patterns

T1 T2 T7 New

S3 S6 S8 S9 S11 S13


Grasland
Akkerbouw
Fruitteelt
Boomkwekerij
Water
Stedelijk gebied
Trein
Grondwateronttrekking (privaat)
Waterwingebied
Grondwaterbeschermingsgebied
100-jaars zone
Boringsvrije zone
Intrekgebied
Leersum
Rhenen
GROEP 1
'INTENSIEF LANDSCHAP'
15 05 25
11.000 WONINGEN
>>> DICHTHEID
'WATERMACHINE'
AANVOER ZOET WATER
ZOET WATER BERGING
INTENSIEVE LANDBOUW
2/3
5 ha
10 ha
25 ha
N
0
2,5
5 km

Differences and similarities - own design and group design

Design

There are several similarities and differences between the individual design and the group design:

- The urbanization locations are (almost) the same. Both designs chose to focus urban development east of Houten and along the flank of the Utrechtse Heuvelrug.

- Part of the newly planned industrial area was designed in the same location in both designs: west of Houten. However, in the group design, this area is smaller near Houten, and an additional industrial zone was developed north of Odijk. This decision was made to protect the cultural-historical value of the Nieuwe Hollandse Waterlinie. Furthermore, the group design emphasizes a highly urbanized, innovative industrial area, which was not particularly designed in the individual design.

Chosen patterns

The table below highlights which patterns were selected both by the group during the workshop and in the individual design. A total of five patterns were chosen in the same way. The selected patterns are:

S3 - Sweet water storage in rural area
S6 - Soil remediation
S8 - Expropriation
S9 - Recreational awareness route
S11 - Groundwater friendly cultivation
S13 - Bufferzones
T1 - Develop new drinking water abstraction
T2 - Focus on new purification techniques - drinking water
T7 - Water purifcation before discharge

New pattern - Building water-efficient and water-recycling residential buildings

There are some important caveats when comparing the individual design with the group design. In the individual design, no maximum number of patterns was considered, whereas in the workshop, a limit of ten patterns was applied. This allowed the author's design to respond more comprehensively to the challenges posed in the scenario, while the workshop designs lack several important solutions. Despite this difference, several noteworthy observations emerge from the comparison:

Corresponding patterns   Not chosen patterns

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Group 1	○	○	⊗	○	○	⊗	○	⊗	⊗	○	⊗	○	⊗	○	○
Personal	○	○	⊗	⊗	○	⊗	⊗	○	○	○	○	○	⊗	⊗	⊗

	T1	T2	T3	T4	T5	T6	T7	T8	O1	O2	O3	O4
Group 1	⊗	⊗	○	○	○	○	⊗	○	○	○	○	○
Personal	⊗	⊗	○	⊗	⊗	⊗	⊗	○	○	⊗	⊗	⊗

- It is noteworthy that the group design clearly emphasizes spatial distribution of groundwater abstraction sites along the Utrechtse Heuvelrug, even though this strategy was not associated with the use of pattern T5 (geographical diversification of drinking water production locations). This approach, however, aligns with the strategy used in the individual design.

- Through the selection of S8 (expropriation) and T7 (water purification before discharge), the group placed emphasis on regulatory measures as well as on increasing the responsibility of companies themselves. The group noted that hard choices had to be made.

- No organizational solutions were selected in the group design, whereas almost all organizational solutions were included in the individual design. One possible explanation for this difference is the maximum number of cards allowed during the workshop.

- Both the group and individual designs include freshwater storage in rural areas (S3). In the individual design, this was implemented on the Utrechtse Heuvelrug, while in the group design it was placed in the Langbroekerwetering. This is particularly interesting, as the latter location was used in scenario 1 of the individual design. The group design made this possible by opting for very high-density development, which freed up relatively more space for freshwater storage.

- Remarkably, in this scenario, the group design includes S9 (recreational awareness route). The group considered this a more important solution than other available options, highlighting the importance they placed on raising public awareness about drinking water sources.

Input for final design

First and foremost, it has become clear that more than ten patterns are needed for the design in this scenario. The following points will be incorporated into a final design:

- The use of solutions focused more explicitly on circular water management (new pattern) to address a significantly increased drinking water demand;

- The implementation of freshwater storage in rural areas (Langbroek) in response to a significantly increased demand for drinking water;

- Implementing solutions to raise awareness among residents and users of the area within this scenario.

Differences and similarities - between groups

Design

There are several similarities and differences between the individual design and the group design:

- In all groups, the urbanization task has been (partially) implemented in the area between Houten and Odijk. Two groups have opted to concentrate a significant portion of this urban development with high density to the east of Houten. Additionally, each scenario includes urban expansion along the edges of the Utrechtse Heuvelrug.

- Two groups opted for the implementation of a large water battery, but these were realized in different locations within the region (Schalkwijk vs. Langbroek).

- The newly planned industrial zone has been implemented in a different location in each group.

Chosen patterns

The table below highlights which patterns were selected by two or all groups during the workshop. There is one solution that was selected by all groups. In addition, seven solutions were chosen by two groups. The corresponding patterns are as follows:

S3 - Sweet water storage in rural area (1,2,3)
S11 - Groundwater friendly cultivation (1,3)
S13 - Bufferzones (1,2)
T1 - Develop new drinking water abstraction (1,2)
T2 - Focus on new purification techniques - drinking water (1,2)
T4 - Precision agriculture (2,3)
T7 - Water purifcation before discharge (1,3)
O2 - Collaboration in circular water management (2,3)

Corresponding patterns

Not chosen patterns

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
Group 1	○	○	⊗	○	○	⊗	○	⊗	⊗	○	⊗	○	⊗	○	○
Group 2	○	⊗	⊗	○	○	○	○	○	○	○	○	○	⊗	⊗	⊗
Group 3	⊗	○	⊗	⊗	○	○	⊗	○	○	○	⊗	○	○	○	○
	S	S	S M	S	S M	S	S M	S M	S	S M	S M	S M	S M	S M	S

	T1	T2	T3	T4	T5	T6	T7	T8	O1	O2	O3	O4
Group 1	⊗	⊗	○	○	○	○	⊗	○	○	○	○	○
Group 2	⊗	⊗	○	⊗	○	○	○	○	⊗	⊗	○	○
Group 3	○	○	○	⊗	○	⊗	⊗	○	○	⊗	○	○
	M L	M	M	S M	M	S	S M	S M	S M	S M	S M	S M

Several noteworthy observations emerge from the comparison between the groups:

- Each group selected S3 and two groups included a 'water battery' in their scenario. This indicates that S3 represents a key solution across all scenarios.

- In the scenarios with a high degree of urbanization, both T1 and T2 are selected. The selection of T2 by both groups may reflect the increased complexity and diversity of risks associated with more intensive urban development.

- In the high-urbanization scenarios, S13 was selected. Notably, group 3 also intended to choose S13, but was constrained by the maximum number of cards allowed. This indicates that S13 can be considered an important solution across all scenarios.

- In the scenarios with intensive agriculture, S11 was selected. This suggests that it is considered one of the most effective solutions in the context of intensive farming.

- In groups 2 and 3 (scenarios 2 and 3), S10 was selected as an additional solution, had there not been a limit on the number of cards. This suggests that agroforestry is not considered the primary solution, but is still regarded as one of the important measures. In the individual design, however, S10 was explicitly identified as a key solution.

- Notably, T4 was selected in groups 2 and 3 (scenarios 2 and 3), reflecting the contrast between intensive and extensive farming practices. Group 1 also identified this solution as a supplementary measure. This suggests that T4 is regarded as a relatively significant intervention.

- In the scenarios with intensive agriculture, T7 was selected. This is notable because the solution focuses on increased responsibility of industrial companies for water treatment. It became apparent that group 3 was not aware that this solution applied exclusively to industrial companies. Therefore, no definitive conclusion can be drawn regarding this solution.

- Finally, groups 2 and 3 selected O2.. Since these scenarios are opposites of each other, it is possible that this represents a generic solution, not specific to any particular scenario.

- During the workshop, the solutions S10, S12, T5, O3, and O4 were not selected. However, S10, S12, O3, and O4 were chosen as additional solutions when exceeding the maximum number of allowed cards was permitted.

Furthermore, T5 was unintentionally applied by group 1 but was not explicitly selected. Thus, only S5 (focus on recreational services) and T8 (downscaling drinking water abstraction) remain.

Final design - scenario I

- Urbanization (housing) around existing urban centers;

- Develop extra industrial zone at Houten-West (around existing industrial zone);

- Realising sweet water storage at Langbroek and Schalkwijk. Sweet water storage at Langbroek is being pumped up to the Utrechtse Heuvelrug to infiltrate;

- Realising new groundwater abstraction for drinking water production in Elst;

- Focus on geographical distribution of groundwater abstraction for drinking water supply at Utrechtse Heuvelrug;

- Protecting groundwater abstractions by restricting land use within the infiltration areas to agroforestry and biological agriculture;

- Strenghten nature-network by implementing agroforestry and reforestation along the flanks of the Utrechtse Heuvelrug;

- Increase drinking water production at Cothen and Tull en 't Waal

- Focus on ecosystems services in agriculture and recreational services along near Houten and Schalkwijk;

- Promoting groundwater friendly agriculture throughout the entire region;

- Strenghten the Nieuwe Hollandse Waterlinie
- reforestation at Houten-North.

Ground- and drinking water

New groundwater abstraction
New surface water abstraction
Increase drinking water production
Expand groundwater protection zone
Sweet water storage in rural land
Only abstractions for drinking water allowed
Geographical diversification of groundwater abstractions
Focus on new purification techniques - drinking water
Natural water filtering
Water purification before discharge
Elaborate amount of observation wells groundwater quality
Drinking water production location (public)
Drinking water production location (private)
Water abstraction area
Groundwater protection zone
100-years zone
Drilling-free zone
Infiltration zone

Agriculture

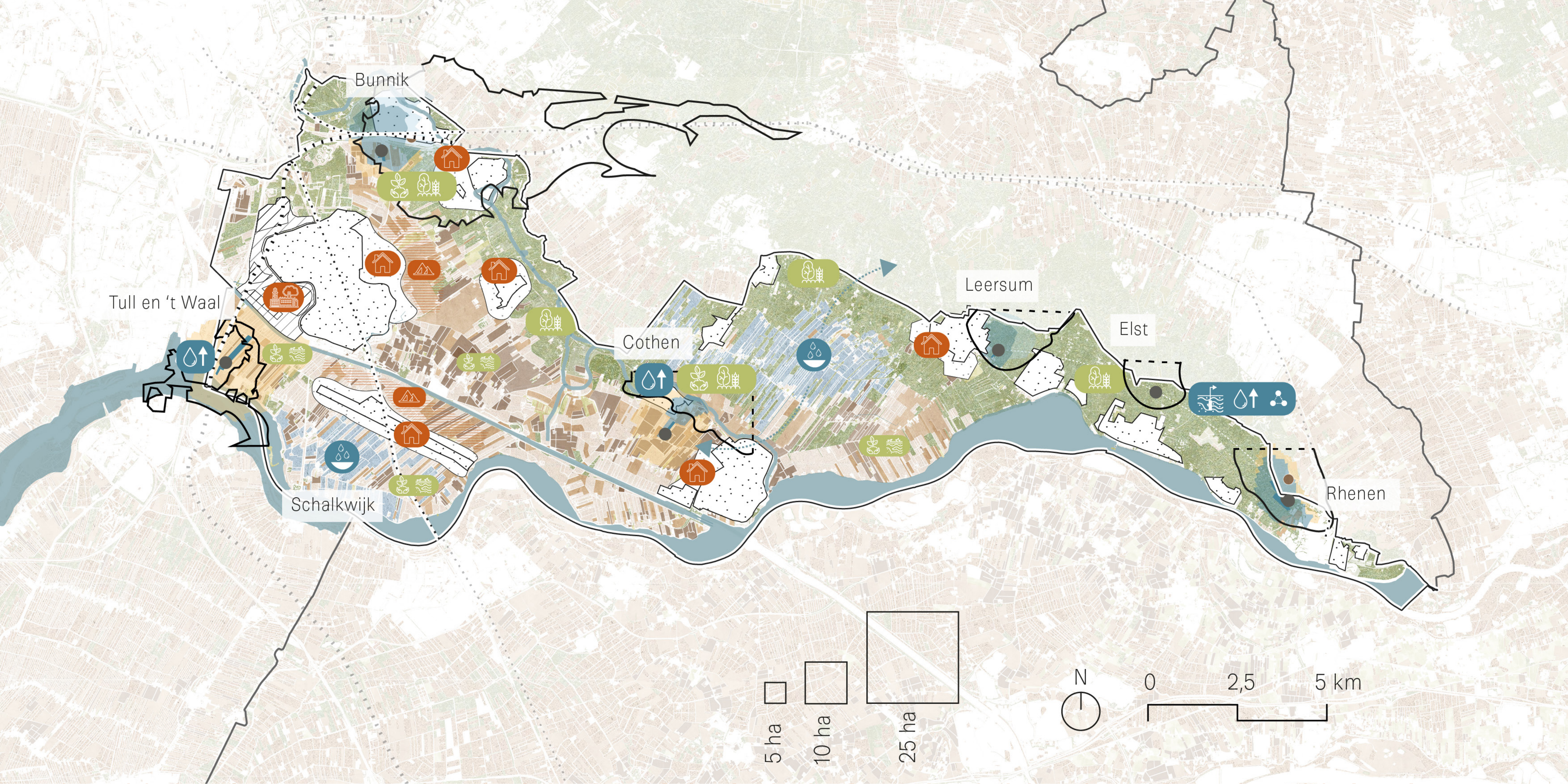
Biological agriculture
Groundwater friendly agriculture
Agroforestry
Precision agriculture
Land consolidation
Grasslands
Arable land
Fruit cultivation
Tree cultivation

Landscape

Bufferzone
Forest
Water
Train track
Highway

Urbanization

Low-density housing
High-density housing
Industrial zone
Recreational functions
Train station
Recreational awareness route
Residential area
Industrial area


Bunnik
Tull en 't Waal
Cothen
Leersum
Elst
Schalkwijk
Rhenen
5 ha
10 ha
25 ha
N
0
2,5
5 km

Final design - scenario 4

- (High-density) Urbanization around public transport hubs and on sandy soils - housing;

- Developing extra industrial zone at Houten-West (around existing industrial zone) and create new industrial zone at Den Oord;

- Focusing on maximizing water infiltration on Utrechtse Heuvelrug - UH as strong drinking water supply area;

- Realising sweet water storage Schalkwijk. Bank filtration is planned near the island of Schalkwijk.

- Realising new surface water abstraction for drinking water production at Schalkwijk;

- Realising new groundwater abstraction for drinking water production in Elst;

- Focusing on geographical distribution of groundwater abstraction for drinking water supply at Utrechtse Heuvelrug;

- Focusing on prevention and extra purifcation techniques at groundwater abstractions Bunnik and Tull en ‘t Waal;

- Focusing on innovation in water purification techniques - demanding water purification before discharge at industrial zones;

- Allowing only groundwater abstractions for public drinking water in infiltration areas in Bunnik and Rhenen;

- Enlarging groundwater protection zones;

- Grasslands in infiltration areas, fruit and tree cultivation and arable farming outside infiltration areas through the use of land consolidation;

- Only allowing precision agriculture and groundwater friendly agriculture in infiltration areas.

- Implementing agroforestry along the flanks of the Utrechtse Heuvelrug;

- Zoning fruit cultivation and arable farming where it is best suited - fruit cultivation between Wijk bij Duurstede and Houten and arable farming between Cothen and the Utrechtse Heuvelrug;

- Elaborate amount of observation wells at newly urbanized area in infiltration area of Bunnik and along the infitlration area of Cothen.

Ground- and drinking water

- New groundwater abstraction
- New surface water abstraction
- Increase drinking water production
- Expand groundwater protection zone
- Sweet water storage in rural land
- Only abstractions for drinking water allowed
- Geographical diversification of groundwater abstractions
- Focus on new purification techniques - drinking water
- Natural water filtering
- Water purification before discharge
- Elaborate amount of observation wells groundwater quality
- Drinking water production location (public)
- Drinking water production location (private)
- Water abstraction area
- Groundwater protection zone
- 100-years zone
- Drilling-free zone
- Infiltration zone

Agriculture

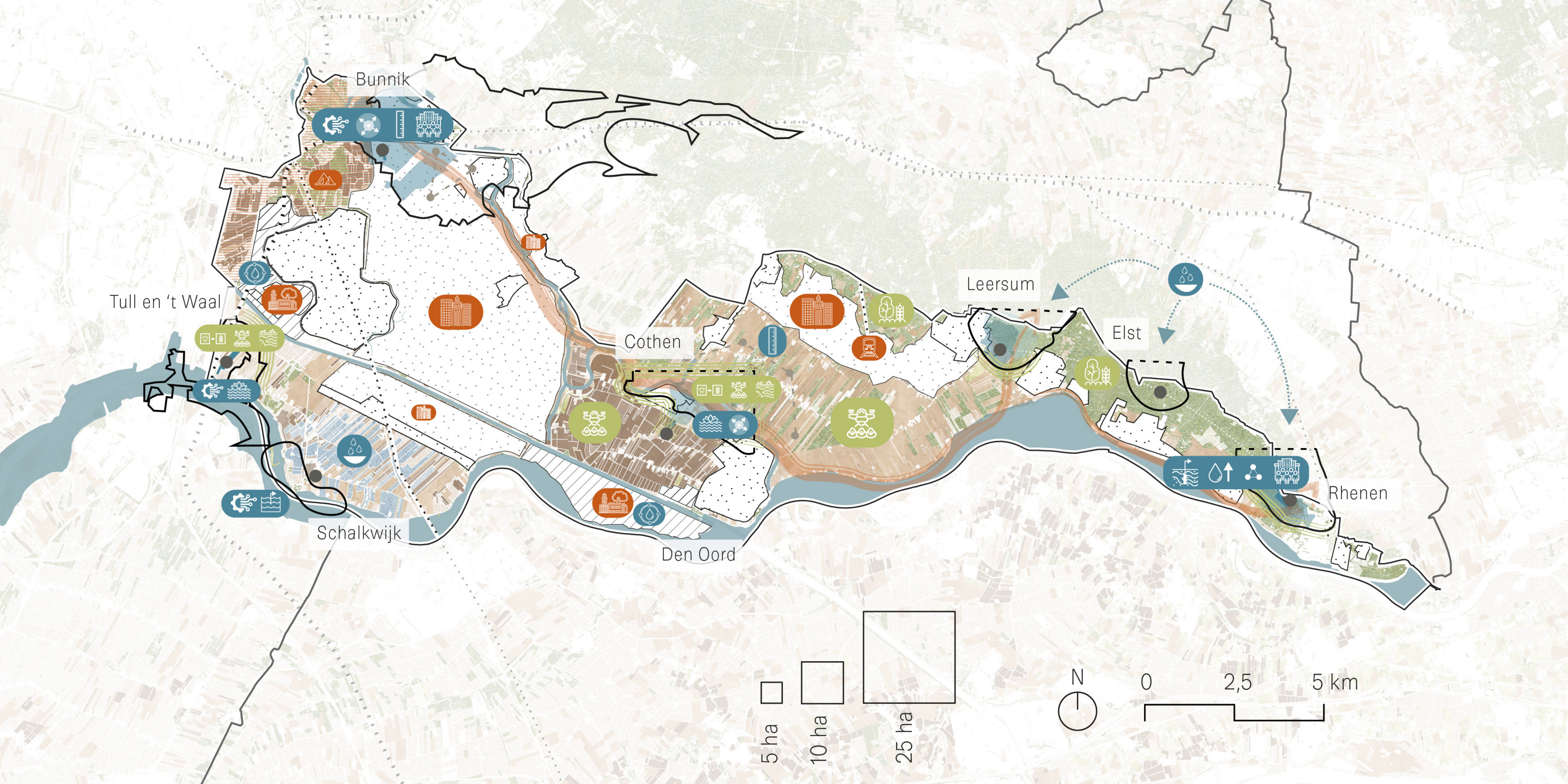
- Biological agriculture
- Groundwater friendly agriculture
- Agroforestry
- Precision agriculture
- Land consolidation
- Grasslands
- Arable land
- Fruit cultivation
- Tree cultivation

Landscape

- Bufferzone
- Forest
- Water
- Train track
- Highway

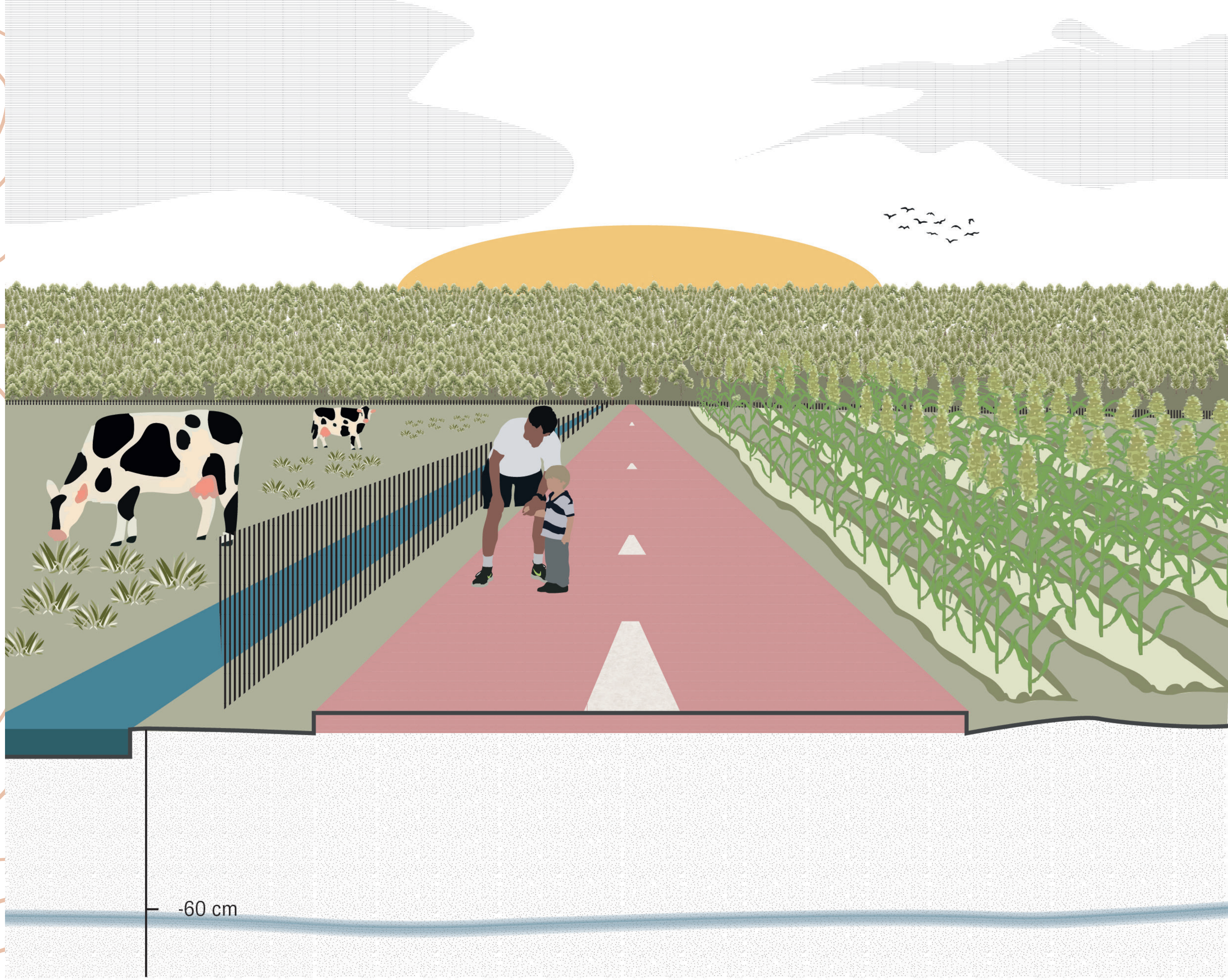
Urbanization

- Low-density housing
- High-density housing
- Industrial zone
- Recreational functions
- Train station
- Recreational awareness route
- Residential area
- Industrial area


Bunnik
Tull en 't Waal
Schalkwijk
Cothen
Den Oord
Leersum
Elst
Rhenen
5 ha
10 ha
25 ha
N
0
2,5
5 km

In the current situation, grassland dominates the landscape in Langbroek, alongside patches of forest and a small area of arable land.

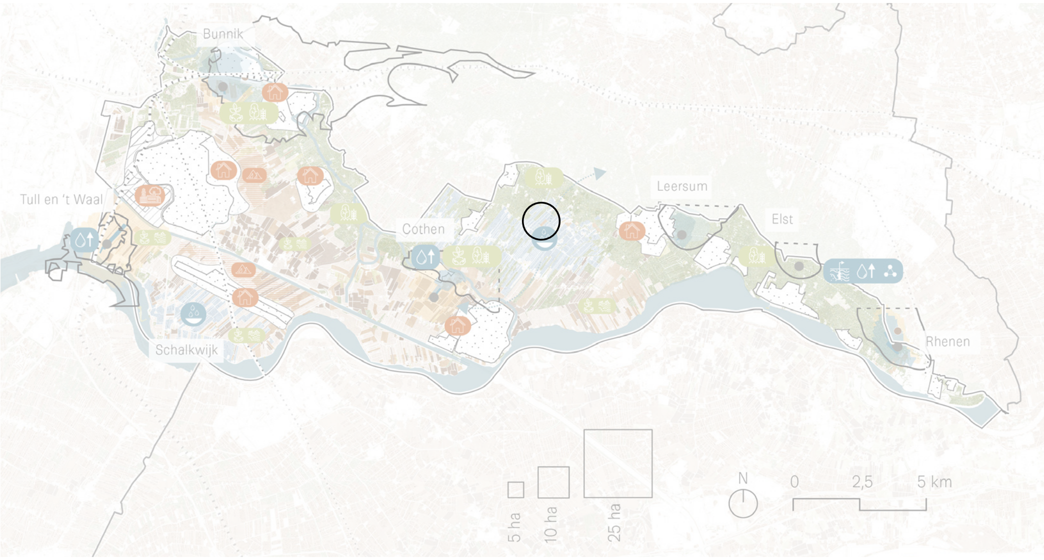
Location

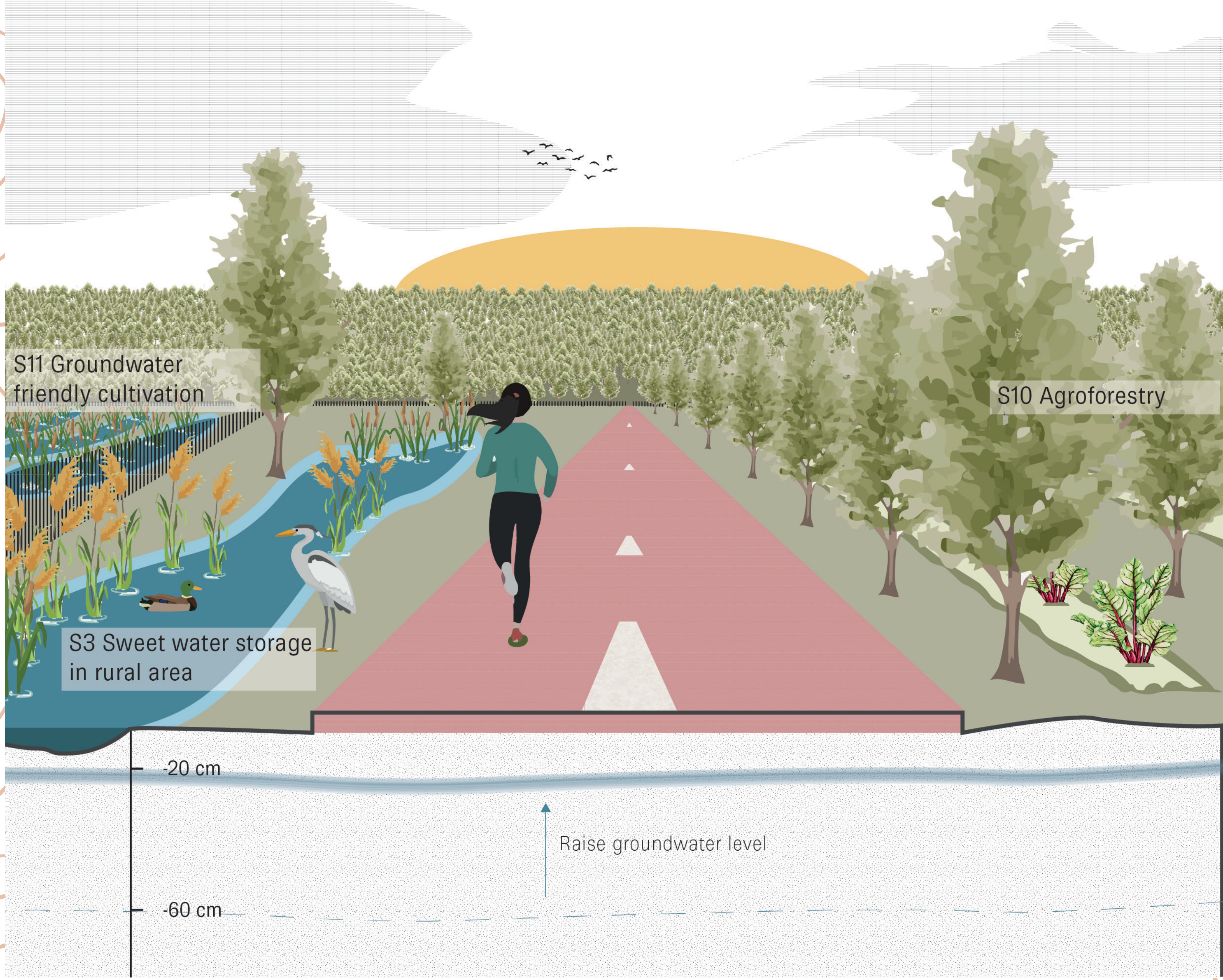


LANGBROEK- CURRENT SITUATION

In scenario 1, Langbroek has been transformed into a large freshwater storage area, which is subsequently used for infiltration on the Utrechtse Heuvelrug. This water landscape includes groundwater friendly agriculture, and agroforestry is the predominant form of agriculture at the transition zone toward the Utrechtse Heuvelrug.

Location

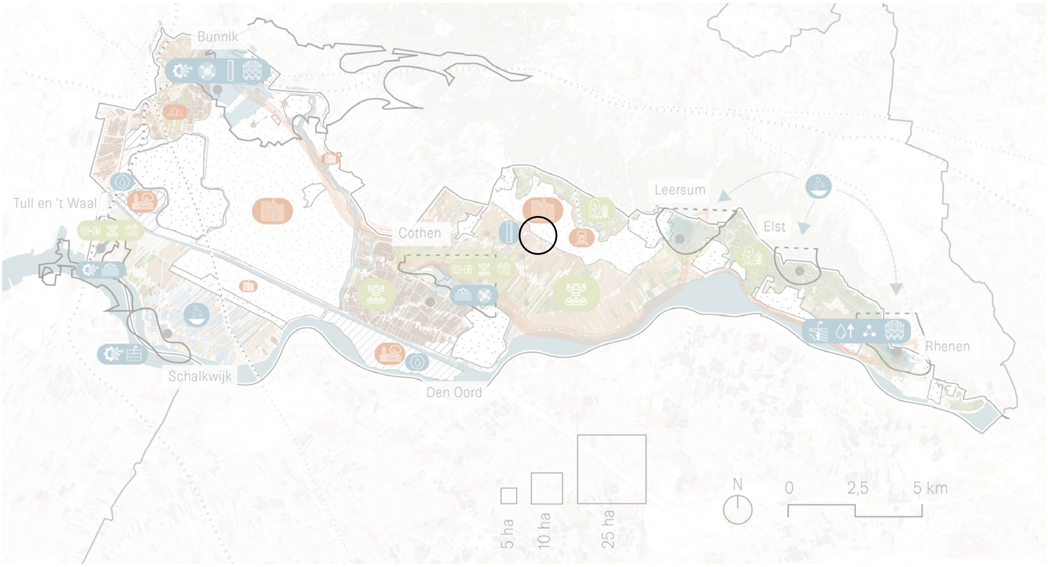


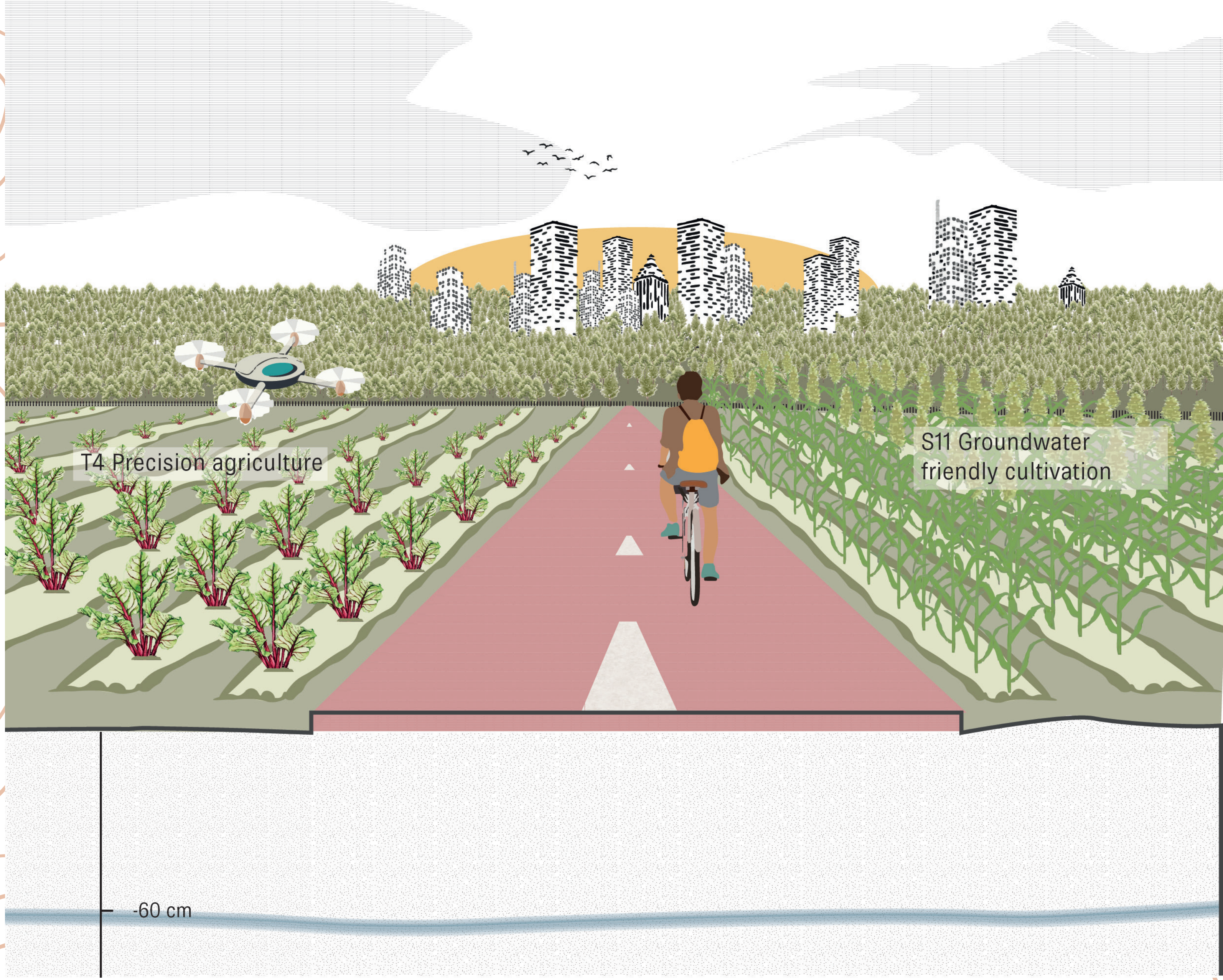


LANGBROEK- SCENARIO 1

In scenario 4, the area surrounding Langbroek has been transformed into intensive arable land, where groundwater friendly agriculture and precision agriculture dominate the landscape. The high-density urbanization on the Utrechtse Heuvelrug is visible from Langbroek.

Location

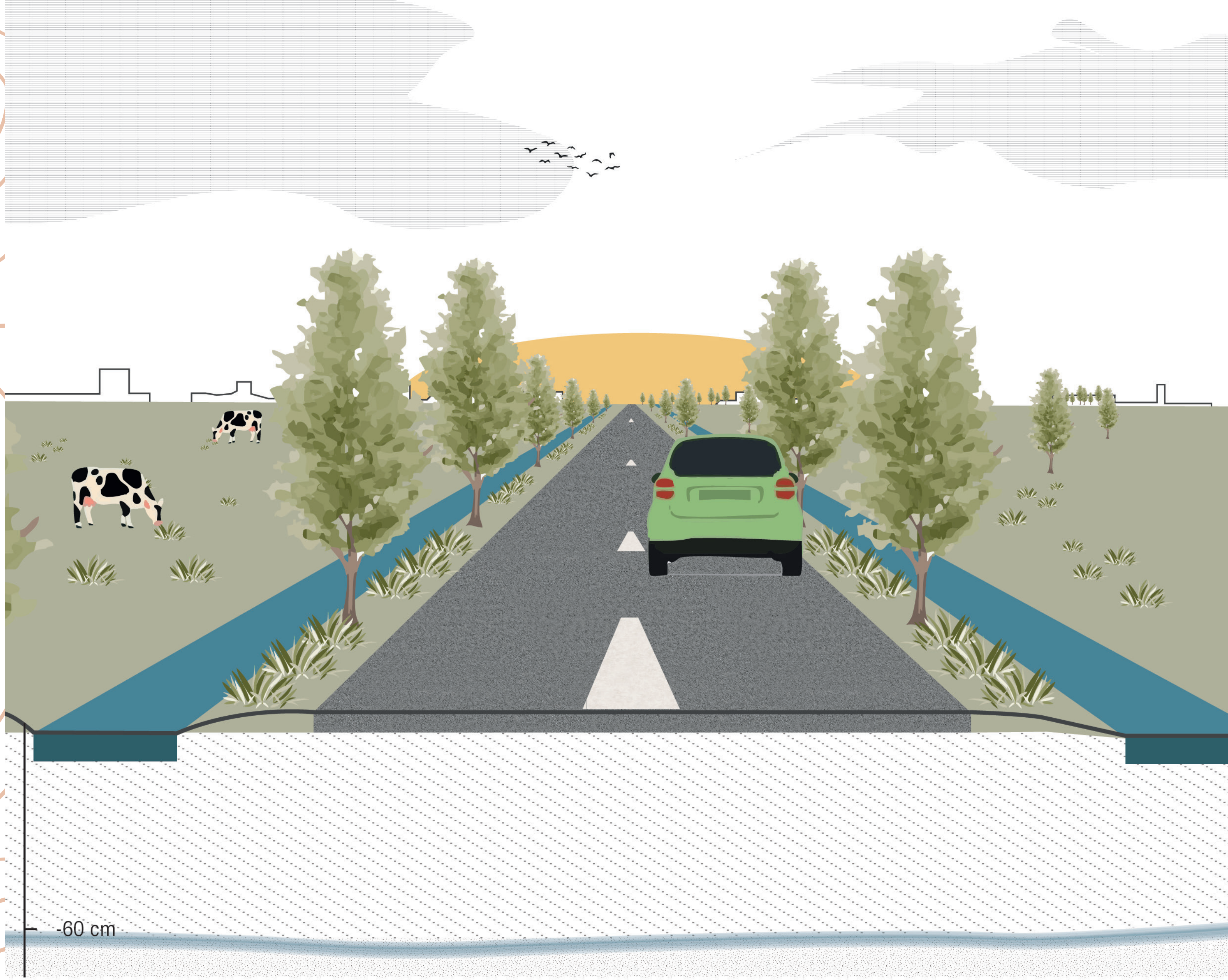




LANGBROEK- SCENARIO 4

In scenario 1, low-density housing has been added near Odijk, and biological farming dominates the landscape in the infiltration areas. In addition, many farmers have (partially) shifted toward providing recreational services, which are primarily located on the edges of towns and villages.

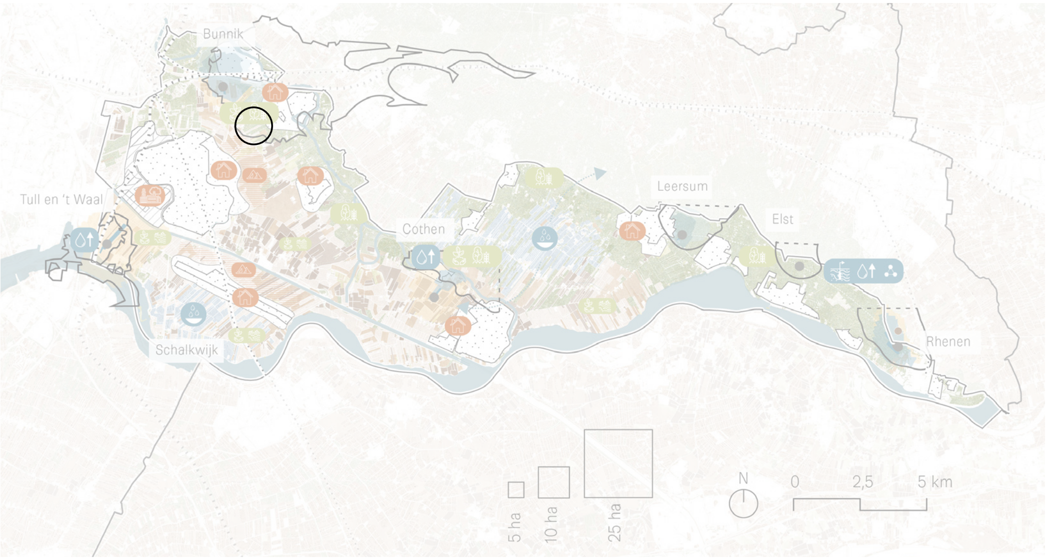
Location

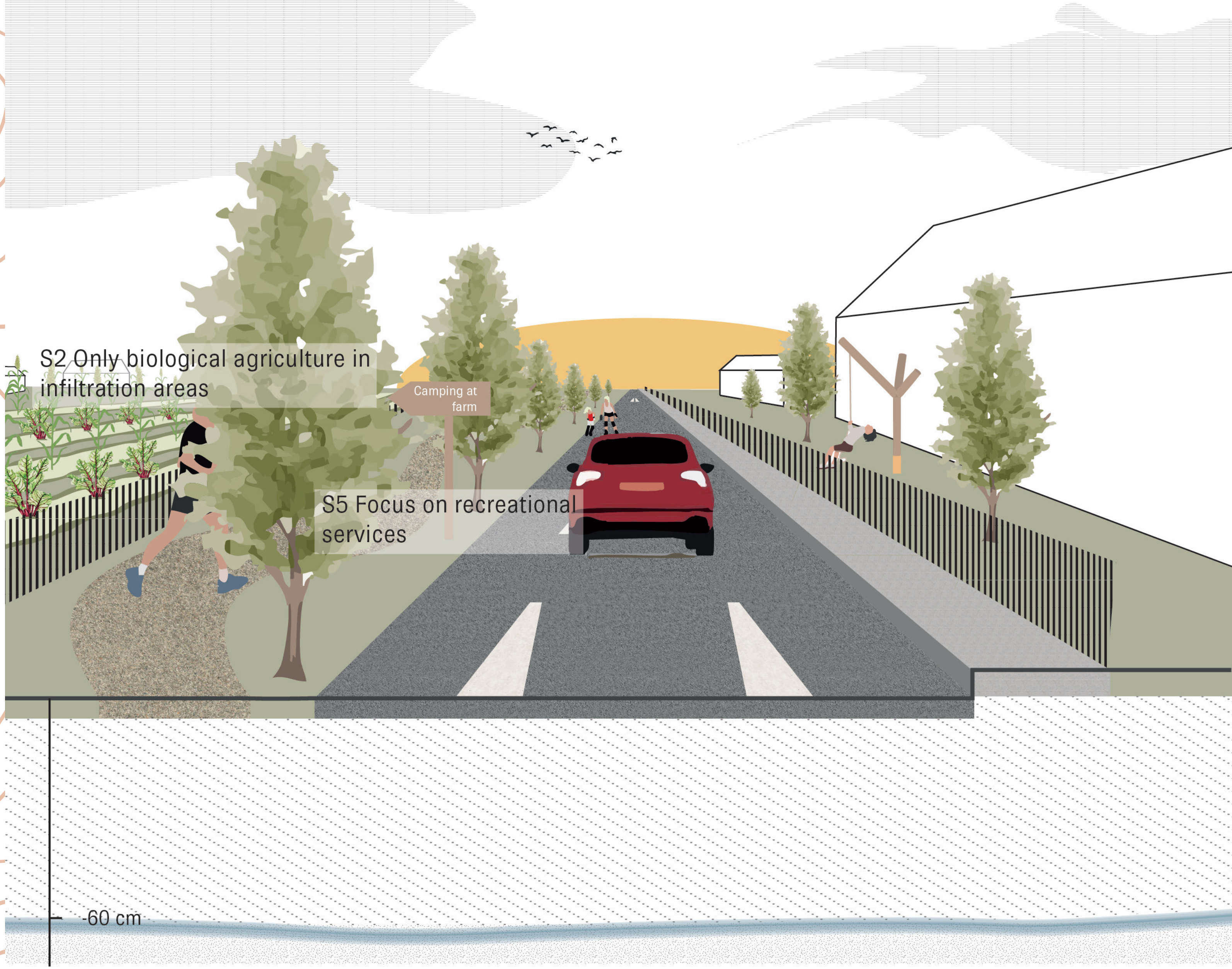


HOUTEN - BUNNIK - CURRENT SITUATION

In scenario 1, low-density housing has been added near Odijk, and biological farming dominates the landscape in the infiltration areas. In addition, many farmers have (partially) shifted toward providing recreational services, which are primarily located on the edges of towns and villages.

Location

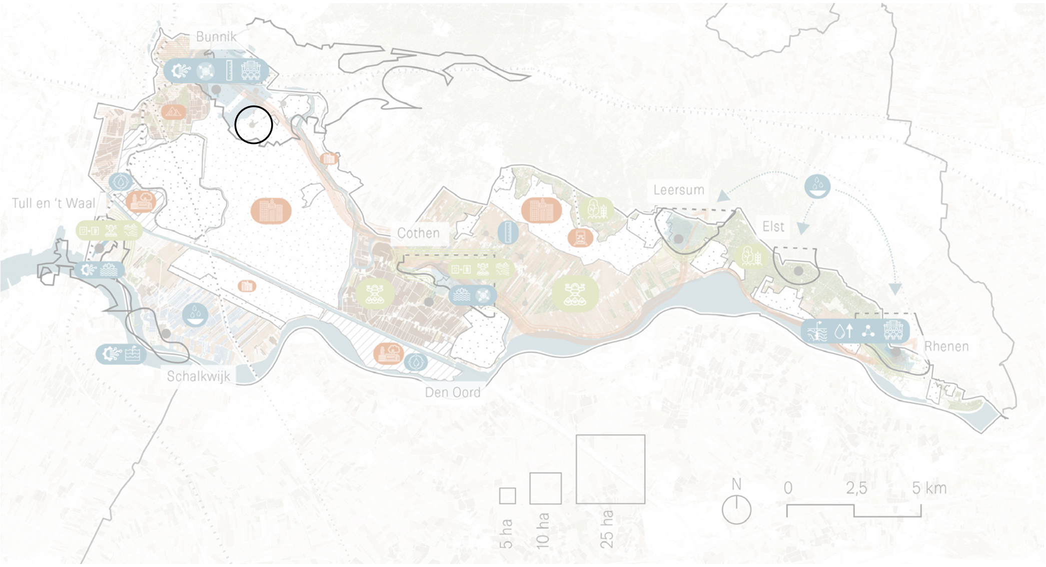


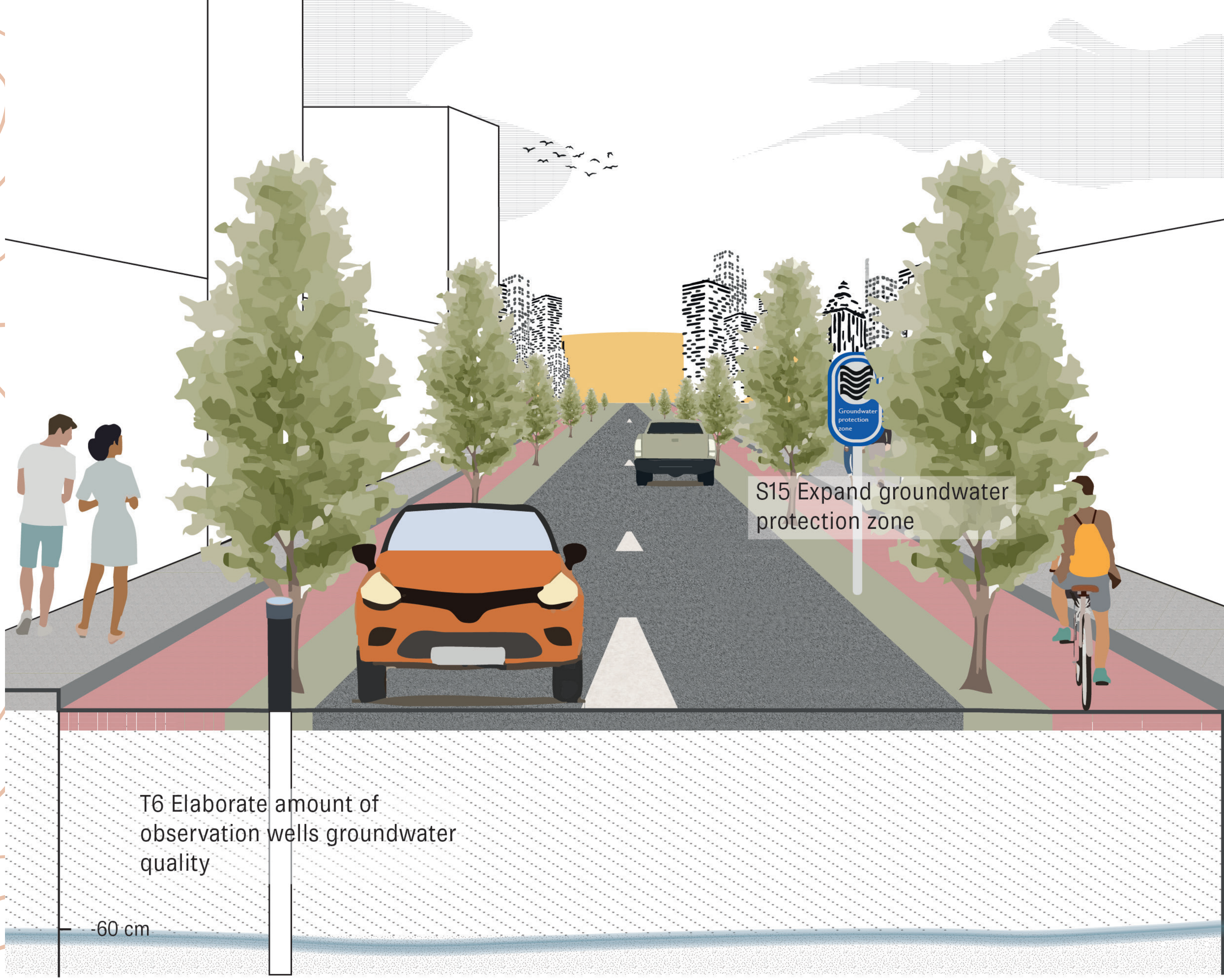


HOUTEN - BUNNIK - SCENARIO 1

In scenario 4, the area between Houten and Odijk has become fully urbanized with high-density development due to the high degree of urbanization. To protect groundwater quality in the Bunnik infiltration area as much as possible, the groundwater protection zone has been expanded (S15). These zones are physically marked in the landscape with groundwater protection zone signs. In addition, more monitoring points have been installed to measure groundwater quality, enabling earlier identification and localization of risks associated with urbanization.

Location





HOUTEN - BUNNIK - SCENARIO 4

6.3 Sub-conclusion

This chapter addresses the 5th and the 6th research questions. The main conclusions are briefly outlined below.

SQ5: Which solutions and alternatives could be used to safeguard the drinking water quality and which considerations are possible between agriculture, urbanization and water quality?

Solutions in subdivision of technical, organizational and spatial solutions

It has become evident that three distinct types of solutions can be identified. These solutions are linked to the previously identified bottlenecks and may have both positive and negative impacts across multiple challenges. Through the application of an assessment framework, these solutions can be deployed in an integrated manner.

Stimulation vs regulation

The scenarios reveal a clear trade-off between stimulating certain types of land use and regulating them. It has become evident that hard decisions need to be made in the most extreme scenario (scenario 4) and this leads to more regulating solutions. In contrast, scenario 1 is characterized by more stimulating solutions.

Surface water abstraction vs groundwater abstraction

In each scenario, considerations were made regarding the necessity and type of additional drinking water abstraction. Particularly in highly urbanized scenarios, the development of surface water abstraction is essential to meet required production capacity.

The use of the Utrechtse Heuvelrug

Each scenario includes a consideration of how the Utrechtse Heuvelrug could be utilized for drinking water supply. This mainly concerns the volume of abstraction and strategies to minimize negative effects related to increased production. Also in the workshop, the use of the Utrechtse Heuvelrug was highlighted in each group. Enhanced infiltration is identified as a key solution in this context.

Sweet water storage is a key-solution in all scenarios

The research identified sweet water storage in rural areas as a key solution. Additionally, buffer zones, groundwater friendly agriculture, agroforestry, and collaboration in circular water management emerged as important solutions for safeguarding groundwater quality. Sweet water storage at Schalkwijk and Langbroek are the most logical and suitable locations for realizing sweet water storage.

Building water-recycling houses is an important solution within a high urbanization scenario

During the workshop, two separate groups independently arrived at the same innovative solution: the construction of water-recycling housing. This convergence suggests that, although absent from the current Pattern Language, the solution is essential within the context of these scenarios.

SQ6: Which future scenarios are possible to safeguard the drinking water quality in the rural landscapes in the province of Utrecht, where integrated solutions are used for water quality, agriculture and urbanization?

Four scenarios could be classified

Based on the trend analysis, four distinct scenarios have been developed, with urbanization represented on the y-axis and agriculture on the x-axis.

Drinking water landscape: In this scenario characterized by low urbanization and extensive agriculture, the focus lies on a purifying landscape that supports drinking water production. There is ample space for water storage, and groundwater abstraction is spatially distributed across the region.

Urban landscape: This scenario combines high urbanization with extensive agriculture. The focus is on the maximum protection of the purifying landscape, alongside compact urban development near public transport hubs and lower-density development on the sandy uplands.

Production landscape: In this scenario of intensive agriculture and low urbanization, innovation in the agricultural sector is central. Precision agriculture is dominant. Preventive and nature-based measures are also emphasized to safeguard groundwater abstractions. The Utrechtse Heuvelrug serves as an important clean source for drinking water, supplemented by surface water abstraction.

Landscape under pressure: This final scenario combines both intensive agriculture and high urbanization. Innovation in both the agricultural and industrial sectors is key. Urban development is as compact as possible, while groundwater abstraction zones are protected through regulatory and nature-based measures. The Utrechtse Heuvelrug remains a vital clean water source, supported by additional surface water abstraction.

8. Strategic pathways

Plan

SQ7

Which development strategies, including relevant stakeholders, are possible and in line with the scenarios and which interventions fit within the relevant time context?

This chapter presents potential development phasing strategies for the previously described scenarios. First, the results of the workshop are analyzed, with a comparison made between the three groups. Subsequently, an indicative phasing is presented for scenario 1 and scenario 4.

8.1 Phasing - Analysis workshop

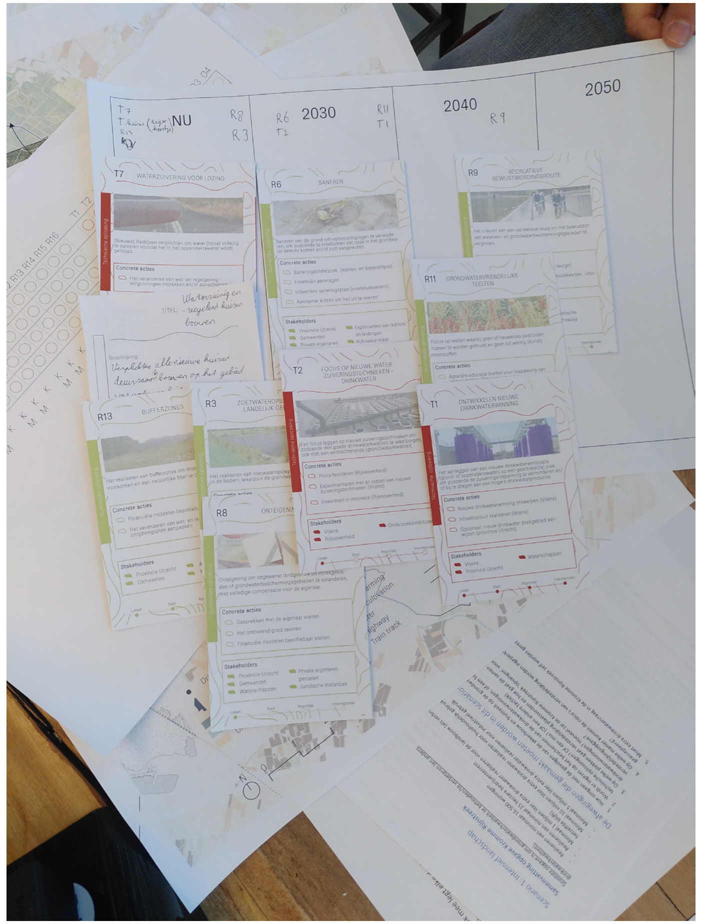
During the workshop, participants were instructed to map out the selected solutions over time. This was done using the format shown below (see Figure 8.1). The participants placed the solutions within this table.

NU	2030	2040	2050

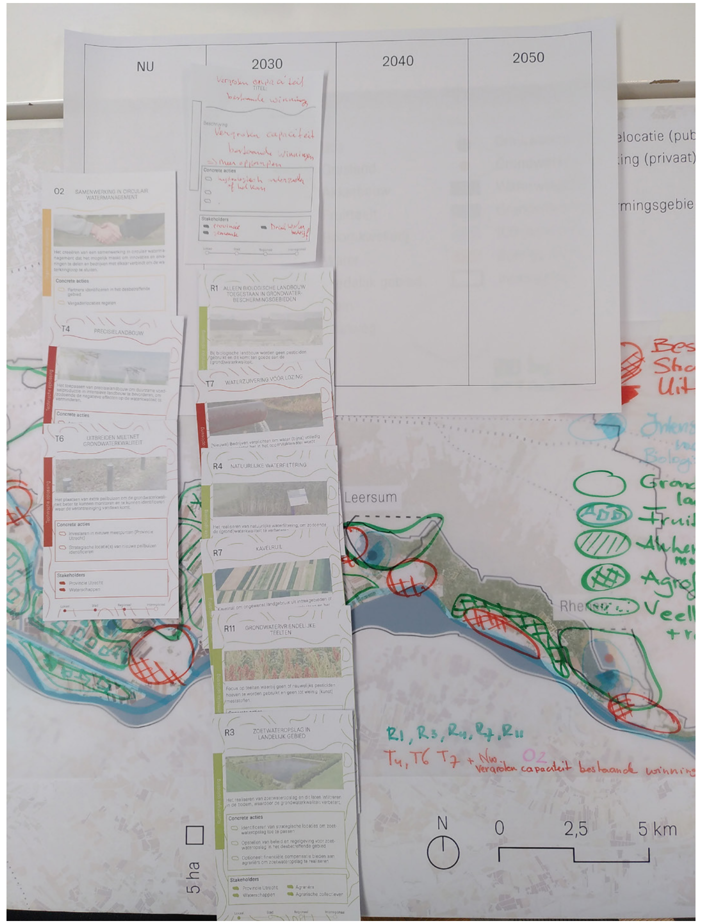
[Table 8.1]: Phasing format

The following pages contain images of the outcomes of this assignment for each group. These outcomes were subsequently organized into two tables (see Table 8.1 and Table 8.2). Table 8.1 presents a comparison of all proposed solutions, whereas Table 8.2 includes only the shared solutions. These comparisons served as the basis for developing a phased approach for scenario 1 and scenario 4.

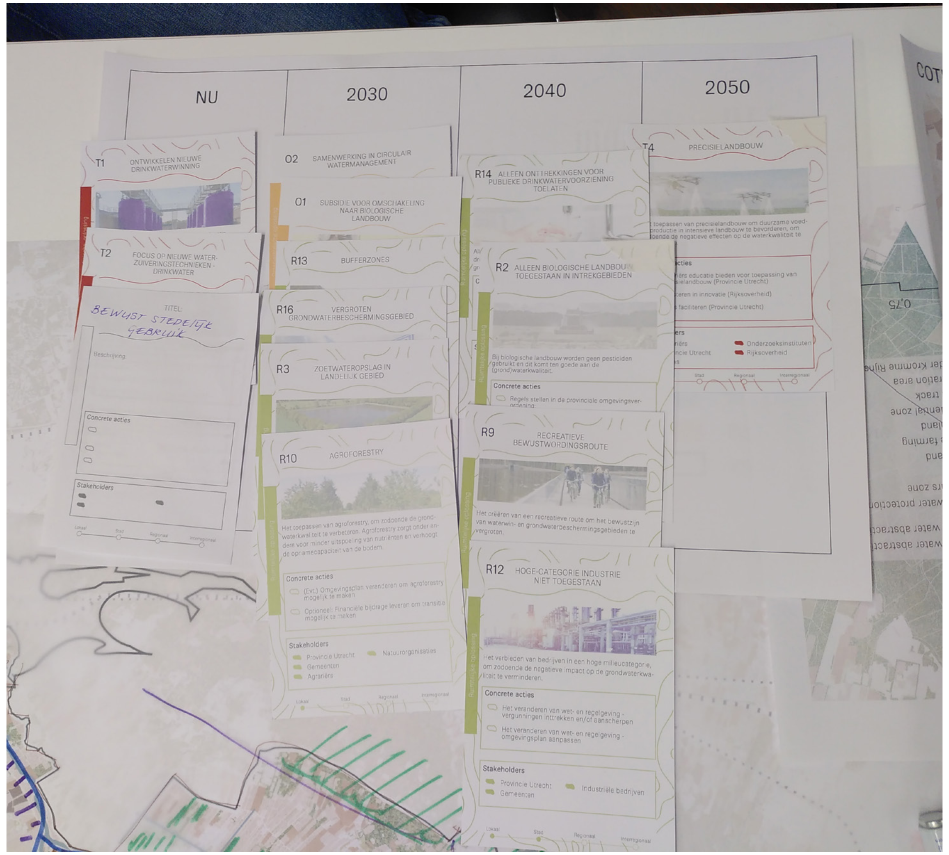
Group 1 - phasing



Group 3 - phasing



Group 2 - phasing



Comparison all patterns

When comparing the solutions proposed by each group, the following observations can be made:

- Group 2 distributed their solutions widely across the timeline. Group 1 placed their cards between the present and 2030, while group 3 predominantly placed theirs in 2030.

- Only one card was placed in 2050: T4 (precision agriculture).

	NOW	2030	2040	2050
Group 1	S3, S8, S13, T7, Own pattern	S6, S11, T1, T2	S9	
Group 2	T1, T2, Own pattern	S3, S10, S13, S16, O1, O2	S2, S9, S12, S14	T4
Group 3	T4, T6, O2	S1, S3, S4, S7, S11, T7, Own pattern		

Comparison common patterns

When comparing the solutions proposed by each group, the following observations can be made:

- S3 (sweet water storage in rural area) is placed in 2030 by two groups, while group 1 positions it in the present. A possible explanation is that group 1 faced the largest water challenge and therefore aimed to secure sweet water as soon as possible;

- The implementation of a new drinking water abstraction site and the application of new purification technologies are scheduled at different times by group 1 and group 2. Group 1 places these in 2030, whereas group 2 schedules them for the present.

- It is noteworthy that group 1 first prioritizes the realization of bufferzones (S13) and sweet water storage (S3), followed by the development of a new drinking water abstraction (T1) and a focus on new purification techniques (T2), while group 2 approaches this sequences in the exact opposite order. One possible explanation is that, in the most extreme scenario (group 1), immediate space must be allocated for bufferzones, which is closely linked to the realization of sweet water storage. This interpretation is supported by the fact that group 2 also placed sweet water storage and bufferzones within the same time frame.

- There is consensus between group 1 and group 3 regarding the implementation of S11 (groundwater friendly agriculture) by 2030.

- There is a significant difference in the implementation timeline of T4 (precision agriculture) between group 2 and group 3. Group 2 was later asked why they scheduled T4 for 2050. They indicated that the card was placed primarily as a long-term objective, rather than an immediately actionable measure. In contrast, group 3 placed T4 (precision agriculture) in the present.

- Both group 1 and group 2 placed S9 (recreational awareness route) in 2040, indicating a consensus on its implementation timeline.

	NOW	2030	2040	2050
Group 1	S3, S13, T7	S11, T1, T2	S9	
Group 2	T1, T2	S3, S13, O2	S9,	T4
Group 3	T4, O2	S3, S11, T7		

Input for phasing

The following points will be incorporated into a final design:

- In the most extreme scenario, sweet water storage is one of the first measures to be implemented. In less severe scenarios, this may be postponed until 2030;

- Sweet water storage could be developed concurrently with bufferzones. The more extreme the scenario, the earlier this combination needs to be realized;

- The development of a new drinking water source and the focus on new purification technologies can take place between the present and early 2030s in scenarios with high urbanization;

- In a scenario characterized by intensive agriculture, the implementation of groundwater friendly agriculture could begin around 2030;

- Precision agriculture (T4) may be positioned as a long-term objective, but in an intensive agricultural scenario, it could also serve as an initial measure;

- In scenarios involving high urbanization, S9 (recreational awareness route) may be developed around 2040.

8.2 Phasing - Scenario 1

Based on the timeline analysis of the workshop, a phasing has been developed for scenario 1 (see next page). Please note: this phasing is indicative.

Most important actions

This scenario focuses on the development of freshwater storage in Langbroek, in combination with the implementation of biological agriculture and agroforestry. The development of freshwater storage in Langbroek is accompanied by a transition towards wet cultivation, an increase in drinking water production in Cothen, and the establishment of a new drinking water production site on the Utrechtse Heuvelrug.

To enable this development in Langbroek, innovation in wet cultivation is required, allowing farmers to generate alternative sources of income. Biological agriculture will be mandatory in infiltration areas by 2040, and this transition can be supported through the introduction of a subsidy scheme aimed at promoting biological farming.

Substantiation of phases

The phasing in this scenario is structured in such a way that, by 2040, the agricultural landscape has largely been transformed into a groundwater-friendly system.

From 2040 onwards, the natural landscape will be further enhanced through additional afforestation north of Houten and along the flanks of the Utrechtse Heuvelrug. The afforestation north of Houten will be integrated with the expansion of the industrial area.

By 2045, biological agriculture will have become the standard, and farmers will serve as key partners for the province and drinking water companies. In addition to biological farming, groundwater-friendly crops and agroforestry will dominate the landscape of the Kromme Rijnstreek.

Urban development in this scenario progresses gradually; due to the relatively limited demand, this approach is feasible. The increase in drinking water production in Tull en 't Waal and Cothen will supply the new housing developments in Houten-East with drinking water. This increase is made possible through the development of freshwater storage in both Langbroek and Schalkwijk. The later-developed drinking water production site on the Utrechtse Heuvelrug will support existing facilities, providing greater flexibility and contributing to the supply for additional housing developments in areas such as Werkhoven and Wijk bij Duurstede.

Key stakeholders

Farmers

The focus in this scenario lies on the transition of agriculture towards a groundwater-friendly system and the creation of a self-purifying landscape. Farmers play a central role in enabling this transition through the adoption of biological agriculture, groundwater-friendly crops, and agroforestry. In this scenario, farmers are key partners in safeguarding groundwater quality.

Nature organizations

Nature conservation organizations are also important stakeholders within this scenario. The implementation of agroforestry, sweet water storage, and reforestation requires their collaboration and expertise.

Agricultural collectives

Farmer collectives play a key role in the implementation of groundwater friendly agriculture, the transition toward recreational services, and the deployment of sweet water storage. In the shift toward more groundwater friendly agriculture, these intermediary organizations are crucial for the effective organization of rural areas and for ensuring accountability in the use of subsidies.

Vitens

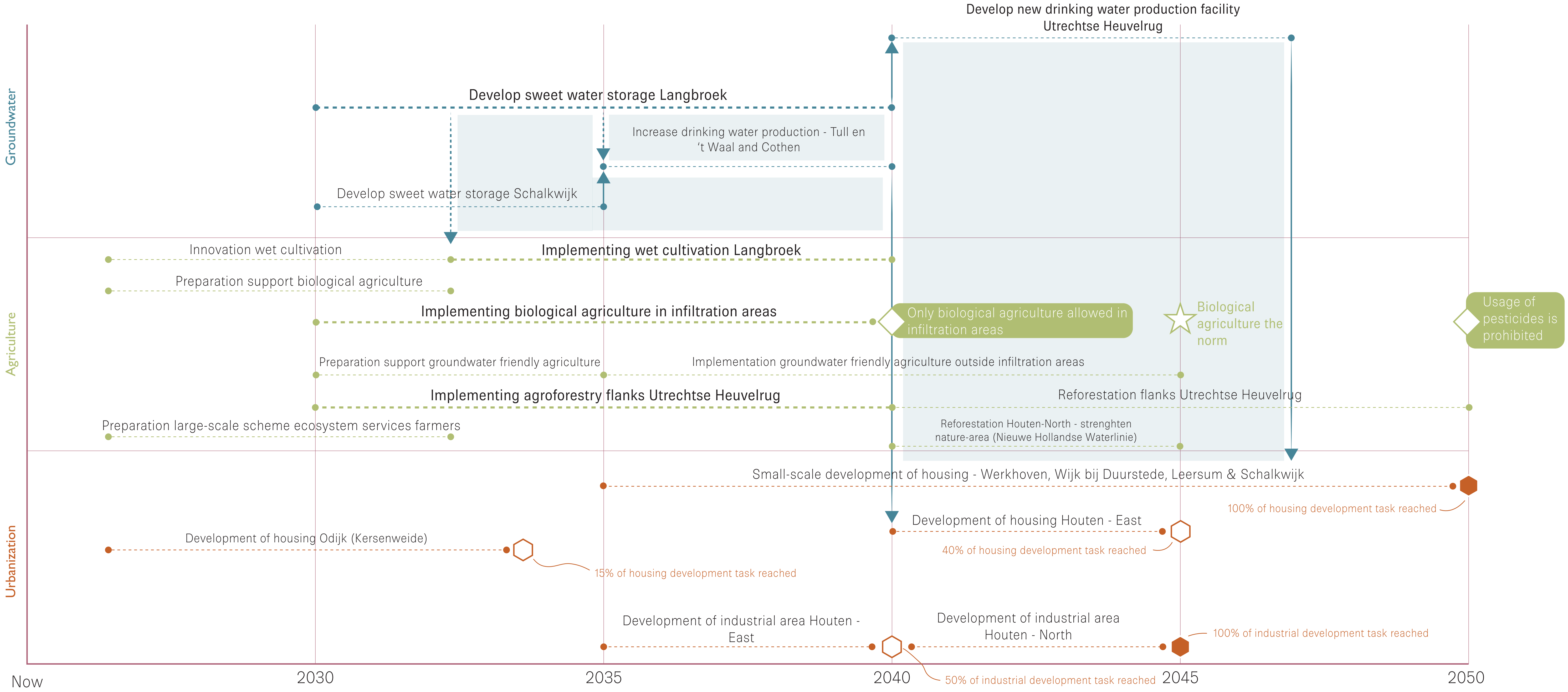
Vitens is an important partner in the development of new drinking water abstraction sites. In addition, Vitens can play a supportive role in promoting more sustainable agriculture, for example by co-financing the transition to biological farming.

Province of Utrecht

In this scenario, the Province of Utrecht primarily assumes a facilitating and stimulating role: defining desired developments within groundwater infiltration areas and supporting farmers in their transition are the province's key responsibilities.

Waterboards

In this scenario, water boards play a crucial role in supporting the implementation of groundwater-friendly agriculture and in realizing freshwater storage in Schalkwijk and Langbroek.


Groundwater
Agriculture
Urbanization
Develop new drinking water production facility Utrechtse Heuvelrug
Develop sweet water storage Langbroek
Increase drinking water production - Tull en 't Waal and Cothen
Develop sweet water storage Schalkwijk
Innovation wet cultivation
Implementing wet cultivation Langbroek
Preparation support biological agriculture
Implementing biological agriculture in infiltration areas
Only biological agriculture allowed in infiltration areas
Biological agriculture the norm
Usage of pesticides is prohibited
Preparation support groundwater friendly agriculture
Implementation groundwater friendly agriculture outside infiltration areas
Implementing agroforestry flanks Utrechtse Heuvelrug
Reforestation flanks Utrechtse Heuvelrug
Preparation large-scale scheme ecosystem services farmers
Reforestation Houten-North - strenghten nature-area (Nieuwe Hollandse Waterlinie)
Small-scale development of housing - Werkhoven, Wijk bij Duurstede, Leersum & Schalkwijk
100% of housing development task reached
Development of housing Houten - East
40% of housing development task reached
Development of housing Odijk (Kersenweide)
15% of housing development task reached
Development of industrial area Houten - East
Development of industrial area Houten - North
100% of industrial development task reached
50% of industrial development task reached
Now
2030
2035
2040
2045
2050

8.3 Phasing - Scenario 4

Based on the timeline analysis of the workshop, a phasing has been developed for scenario 1 (see next page). Please note: this phasing is indicative.

Most important actions

In this scenario, the focus lies on a large-scale redistribution of agricultural land through land consolidation and/or expropriation, as well as the development of sweet water storage areas near Schalkwijk and the Utrechtse Heuvelrug. Two new drinking water production sites will be established: a surface water abstraction facility near Schalkwijk and a groundwater abstraction site near Elst.

Within agriculture, precision agriculture and groundwater friendly agriculture are key solutions in the redistribution of agricultural zones. To support this transition, it is necessary to invest in innovation within the agricultural sector, specifically targeting these themes. Innovation in water purification technologies is also crucial within this scenario.

Substantiation of phases

In this scenario, the development of sweet water storage begins immediately, while a larg-scale redistribution of agricultural land takes place within the next decade, between 2030 and 2040. The largest residential development projects are expected to be completed by 2045.

Starting in 2030, a new surface water abstraction facility will be developed in Schalkwijk, with completion planned for 2040. Simultaneously, sweet water storage will be developed in Schalkwijk between 2030 and 2035. The new surface water abstraction in Schalkwijk will support the increasing drinking water demand driven by large-scale housing development in Houten-East. A groundwater abstraction site will be developed in Elst on the Utrechtse Heuvelrug. Projects to establish sweet water storage in this area are already underway, thus, development starts immediately and is expected to be completed between 2040 and 2045.

The redistribution of agricultural land begins in 2030 and is planned over a tean-year period. During this decade, groundwater infiltration areas will be restructured to include groundwater friendly agriculture, grasslands, precision agriculture and bufferzones. Preperations to support the adoption of precision agriculture and groundwater friendly agriculture begin now. By 2040, only groundwater friendly agriculture will be permitted in infiltration areas, and by 2050, precision agriculture will be the standard.

From 2030 onward, a subsidy scheme for innovation in purification technologies will be launched. This provides companies with a ten-year transition period to prepare for the implementation of the 2040 regulation "Water purification before discharge," under which industries will only be permitted to discharge fully purified water. By 2045, groundwater abstraction for public drinking water purposes will be allowed exclusively in Bunnik and Rhenen.

The large-scale housing development in Houten-East begins in 2035. From that point on, the construction of water-efficient and circular housing will be mandatory. Prior to 2035, the province will support innovation to assist companies in meeting these new building requirements. Before the start of large-scale development in Houten-East, the groundwater quality monitoring network will be expanded to allow for earlier detection of potential risks related to urban expansion. A similar expansion of the monitoring network will take place in Langbroek before new housing is built on the Utrechtse Heuvelrug.

Lastly, between 2030 and 2035, an additional protective zone will be established around the water abstraction sites in Bunnik and Cothen. In Bunnik, this measure aims to mitigate risks associated with large-scale urbanization, while in Cothen, it aims to address the risks of intensified agriculture, as Langbroek is expected to transition into intensive arable land.

Key stakeholders

Farmers
This scenario places a strong emphasis on the large-scale redistribution of agricultural land, making farmers key stakeholders in achieving this objective. Furthermore, farmers are expected to adapt their agricultural practices by transitioning to precision farming and groundwater-friendly crops. This shift is essential for protecting groundwater quality.

Research institutes
In this scenario, research institutes are key stakeholders in driving rapid innovation, particularly in areas such as new water purification technologies, precision agriculture, and groundwater-friendly agriculture.

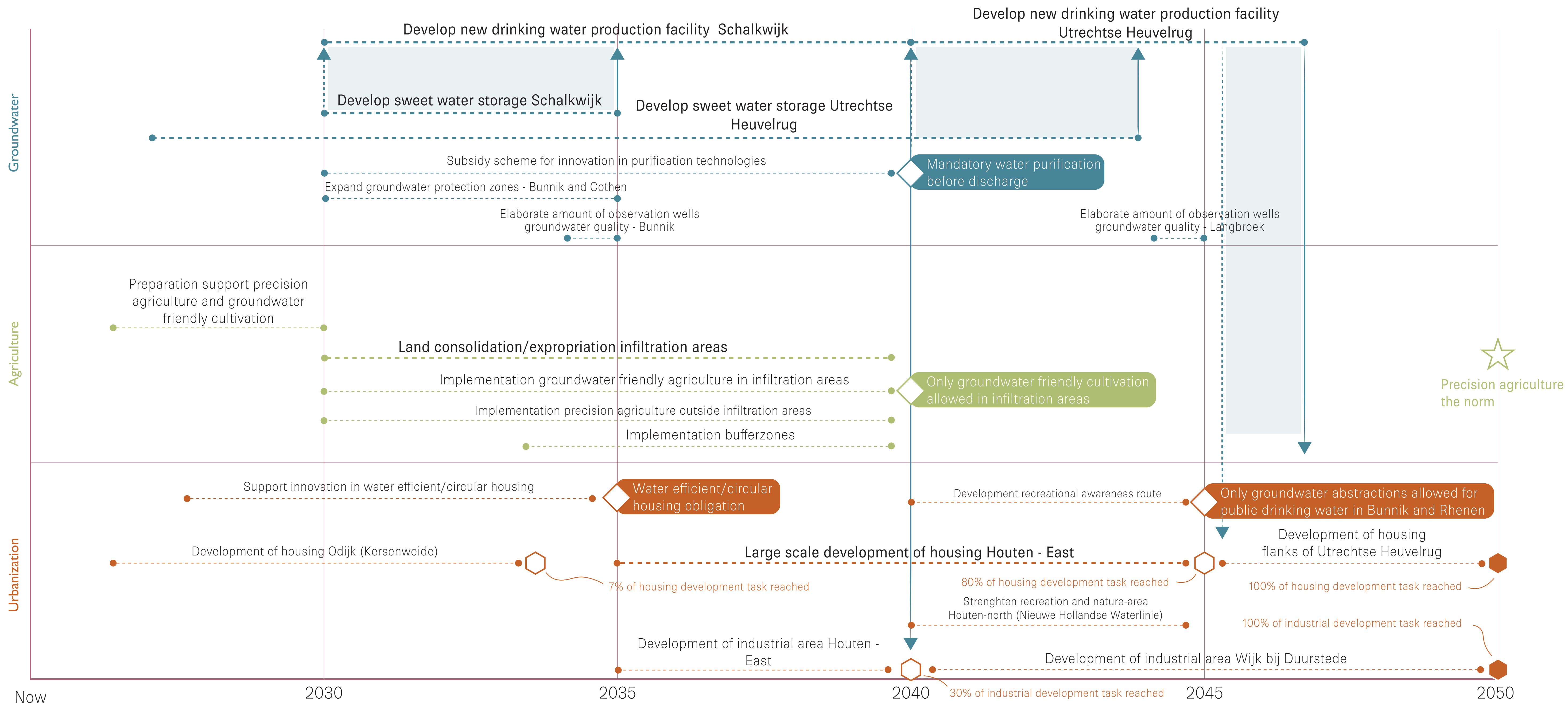
Industrial companies
Due to the substantial demand for industrial land, industrial companies are important stakeholders in this scenario. The area designated for industrial development increases significantly, which has a direct impact on groundwater quality. The regulations “water purification before discharge” and “only groundwater abstractions allowed for public drinking water” directly affect the operations of these companies.

Vitens
Vitens is an important partner in the development of new drinking water abstraction sites. In addition, Vitens can play a supportive role in promoting more sustainable agriculture, for example by co-financing the transition to precision agriculture.

Real estate developers
Due to the significant housing development challenge, real estate developers are crucial stakeholders in this scenario. Water-efficient and circular construction plays a central role and is primarily implemented by this stakeholder group. This is an important measure to reduce average (drinking) water consumption and, in doing so, to protect groundwater resources.

Province of Utrecht
In this scenario, the province of Utrecht assumes a more regulatory role compared to scenario 1. The province can facilitate land consolidation or, if necessary, expropriate plots to achieve the desired land distribution at a regional scale. In addition, the province designates new protection zones, among other measures, to safeguard groundwater resources.

Waterboards
In this scenario, water boards play a crucial role in supporting the implementation of groundwater-friendly agriculture and in realizing freshwater storage in Schalkwijk.


Groundwater
Agriculture
Urbanization
Develop new drinking water production facility Schalkwijk
Develop new drinking water production facility
Utrechtse Heuvelrug
Develop sweet water storage Schalkwijk
Develop sweet water storage Utrechtse
Heuvelrug
Subsidy scheme for innovation in purification technologies
Mandatory water purification
before discharge
Expand groundwater protection zones - Bunnik and Cothen
Elaborate amount of observation wells
groundwater quality - Bunnik
Elaborate amount of observation wells
groundwater quality - Langbroek
Preparation support precision
agriculture and groundwater
friendly cultivation
Land consolidation/expropriation infiltration areas
Implementation groundwater friendly agriculture in infiltration areas
Only groundwater friendly cultivation
allowed in infiltration areas
Implementation precision agriculture outside infiltration areas
Implementation bufferzones
Precision agriculture
the norm
Support innovation in water efficient/circular housing
Water efficient/circular
housing obligation
Development recreational awareness route
Only groundwater abstractions allowed for
public drinking water in Bunnik and Rhenen
Development of housing Odijk (Kersenweide)
Large scale development of housing Houten - East
Development of housing
flanks of Utrechtse Heuvelrug
7% of housing development task reached
80% of housing development task reached
100% of housing development task reached
Strenghten recreation and nature-area
Houten-north (Nieuwe Hollandse Waterlinie)
100% of industrial development task reached
Development of industrial area Houten -
East
Development of industrial area Wijk bij Duurstede
30% of industrial development task reached
Now
2030
2035
2040
2045
2050

8.4 Sub-conclusion

This chapter addresses the 7th research question. The main conclusions are briefly outlined below.

SQ7: Which development strategies, including relevant stakeholders, are possible and in line with the scenarios and which interventions fit within the relevant time context?
between agriculture, urbanization and water quality?

Sweet water storage could be implemented as one of the first solutions in every scenario

The workshop made evident that, in every scenario, participants placed this solution either in the present or by 2030.

Developing sweet water storage in Schalwijk in 2030 is a solution for the further elaborated scenarios (scenario 1 and 4)

This solution can be implemented in both scenarios and can be considered a no-regret measure.

The most important timezone is between now and 2040

In each group, most solutions were placed within the timeframe between the present and 2040 This indicates that the major landscape transition is expected to occur within this period. It also suggests that preparations for this transition must begin immediately in order to make it feasible.

In the least extreme scenario, farmers, nature organizations and agricultural collectives are the most important stakeholders

The focus in this scenario lies on the transition of agriculture towards a groundwater-friendly system and the creation of a self-purifying landscape. In this transition, key-stakeholders are farmers, nature organizations and agricultural collectives.

In the most extreme scenario, farmers, research institutes, industrial companies and real estate developers are the most important stakeholders

In the scenario that centers on a large-scale redistribution of agricultural land combined with a high degree of innovation, farmers, research institutes, industrial companies, and real estate developers are key stakeholders.

Farmers are key-stakeholders in all scenarios

In both the most and the least extreme scenarios, farmers have emerged as key stakeholders. In both cases, a transition in agricultural practices will be required (groundwater friendly agriculture, precision agriculture, biological agriculture).

9. Conclusion and recommendations

This chapter answers the main research question:

“How could the groundwater quality at groundwater abstractions for public drinking water, in the rural areas of the province of Utrecht be spatially safeguarded by 2050, by applying integrated solutions for groundwater quality, agriculture and as well as urbanization?”

The conclusions to the sub-questions have been discussed in the previous chapters. At the end of each chapter, a sub-conclusion was presented for the corresponding sub-question. Firstly, the conclusions will be discussed. After this, recommendations are written for the province of Utrecht.

9.1 Conclusion

A combination of spatial, technical and organizational solutions is always necessary to protect groundwater quality

The study has clearly demonstrated that safeguarding groundwater quality requires a combination of spatial, technical, and organizational solutions. The number of solutions increase as pressure on the landscape intensifies. All scenarios include solutions from all three categories and a composition is needed to provide a solution for as many bottlenecks as possible.

Many solutions are both concrete and locally applicable

The pattern language developed in the study includes a relatively high number of solutions that are both concrete and locally implementable. Examples include natural water filtering and the application of precision agriculture. This indicates that local stakeholders can play a key role in safeguarding groundwater quality near abstraction sites.

Sweet water storage is a key-solution in all scenarios

The research identified sweet water storage in rural areas as a key solution. In the Kromme Rijnstreek, sweet water storage at Schalkwijk and Langbroek are the most logical and suitable locations for realizing sweet water storage. This solution can be implemented in all future scenarios and can be considered a no-regret measure. It could also be implemented as one of the first solutions in the phasing.

Groundwater friendly agriculture, agroforestry, bufferzones and collaboration in circular water management emerged as important solutions for safeguarding groundwater quality

These solutions have emerged across multiple scenarios as key measures to help safeguard groundwater quality used for drinking water purposes.

Low urbanization and extensive agriculture - Leveraging the landscape's self-purifying and water storage capacity

If there is a shift toward more extensive forms of agriculture and a relatively low urbanization rate, opportunities arise to capitalize on the landscape's inherent self-purifying capacity. Solutions proposed within these future scenarios include the promotion of biological farming, the implementation of agroforestry, large-scale freshwater storage, and a slight increase in drinking water production from existing groundwater abstractions. Key stakeholders in these future scenarios include farmers, nature conservation organizations, waterboards, agricultural collectives, and drinking water companies.

High urbanization and intensive agriculture- Focusing on innovation and prevention

If agricultural intensification and upscaling persist, the focus will need to shift toward innovation and prevention. Precision agriculture and groundwater friendly agriculture are key solutions in this context, along with land consolidation to exchange land use within groundwater protection zones. The goal is to mitigate risks to groundwater quality as much as possible within these designated zones. These solutions can be complemented with preventive measures such as increasing public awareness and expanding groundwater monitoring networks.

The number of technical solutions increases in line with spatial pressure. In highly urbanized scenarios, greater emphasis must also be placed on the responsibility of industrial actors for their own water treatment, as well as on making conscious choices about land-use functions that rely on groundwater abstraction to safeguard groundwater availability. Farmers, research institutes, industrial companies, drinking water companies, waterboards and real estate developers are important stakeholders within scenarios characterized by high urbanization and intensive agriculture.

Risk mitigation through land-use adaptation within infiltration areas - reconsidering abstraction sites with large infiltration areas

Within all scenarios, not only the groundwater protection areas were considered, but mainly also the infiltration areas. These areas are typically larger and lack comprehensive regulatory protection. The study shows that groundwater quality is more easily safeguarded at abstraction sites with relatively small infiltration areas. In scenarios with intensive agriculture, land-use adjustment through land exchange proved more feasible in these smaller infiltration zones. However, under high spatial pressure, it becomes difficult to eliminate all risks within infiltration areas, necessitating a stronger emphasis on preventive measures.

Opening new surface water abstractions is essential in three scenarios - groundwater abstraction alone is insufficient

In the explored scenarios, new surface water abstractions were introduced to meet drinking water demand. This indicates that groundwater abstraction alone would not be sufficient in these cases. As a result, increasing the capacity of groundwater abstraction and/or expanding the number of abstraction points is not a viable strategy.

The province's role differs across future scenarios

The province holds responsibility for groundwater quality and can fulfill this responsibility in various ways. In scenarios with low population growth and extensive agriculture, a stimulating role - such as through the povision of subsidies - appears most appropriate. As spatial pressure increases, the province is more likely to take on a facilitating and regulatory role. Measures in these future scenarios may range from banning non-public groundwater abstractions in specific areas to enabling collaborative circular water management frameworks.

9.2 Recommendations

Reconsidering groundwater abstractions with large infiltration area

The study has shown that especially in scenarios combining high urbanization with intensive land use, protecting the infiltration areas of groundwater abstractions becomes increasingly complex. A key insight is that the larger the infiltration area, the more difficult it becomes to regulate and control potential sources of contamination. In light of continued urbanization, a critical discussion must be initiated about the extend to which pollution risks are considered acceptable and the long-term viability of such abstractions.

Show not only what the province opposes, but what it actively supports - a stimulating and facilitating role is needed to reduce the uneven playing field among farmers

Groundwater protection is currently characterized mainly by restrictions and regulations. This has created an uneven playing field for farmers operating within groundwater protection zones. The provincial approach has so far focused predominantly on what is not allowed, reflecting a strongly regulatory stance. However, there is significant innovative capacity within the agricultural sector, offering potential for a more stimulating and motivational policy approach. The province has an opportunity to communicate a clear and positive vision for land use within protection zones - one that supports farmers and encourages sustainable practices rather than merely enforcing limitations.

Develop strategies for continued urbanization and increasing drinking water demand - design-based research is needed

The province, together with its partners, has formulated a drinking water strategy and initiated a program aimed at raising awareness of drinking water sources. Nevertheless, current trends indicate increasing drinking water consumption and ongoing population growth. It remains uncertain whether the awarenes programm will be effective or how climate change and other external developments will unfold. In three out of four scenarios examined in this study, additional surface water abstraction was necessary to meet future drinking wter demand. It is therefore recommended to explore alternative strategies under varying scenarios, especially those in which trends deviate from current policy expectations. Moreover, it is essential to engage in spatial design research to understand how such strategies can be spatially impolemented, and to anticipate the need for difficult decisions concerning the allocation and prioritization of drinking water resources.

Make use of the pattern language method (the card game)

Utilize the Pattern Language method (the card game) and organize more frequent internal workshops where this method is applied. This approach encourages content-driven dialogue and could contribute to more integrated planning processes.

10. Reflection

Introduction

This chapter presents a reflection on the graduation research, guided by seven reflection questions. These questions address the research process, the chosen methodology, the connection to the master track, the scientific and societal relevance of the study, its transferability, the interaction between research and design, and my own role as an urbanist. The chapter concludes with a personal reflection.

Relation between graduation topic and master track

What is the relation between your graduation project topic, your master track (A, U, BT, LA, MBE), and your master programme (MSc AUBS)?

The question how groundwater quality at abstraction sites for public drinking water supply could be spatially safeguarded, is central to this research. Aligning with the content of the Urbanism Track, my research is a combination of spatial planning, landscape planning, engineering and urban design.

This study was conducted within the studio "Metropolitan Ecologies of Places" (MEP) of the Urbanism Track, where systems and design thinking are the central themes. Groundwater systems are a vital component of landscapes and must be incorporated into spatial development (WUR, 2023). The pressure on space in the Netherlands is continuously increasing, which also impacts natural systems, including groundwater. Especially when dealing with water systems, it is essential to take a systemic approach and view the processes in their entirety (College van Rijksadviseurs, 2023). In this research, I tried to look systemically to the impacts on groundwater quality at abstraction sites and create integrated solutions between groundwater, urbanization and groundwater. Because of its systemic nature and integrality, my research has a clear link with both the studio topic, as well as the broader Urbanism Track and master programme.

Societal, scientific and professional relevance

How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?

Societal relevance - This topic has much societal relevance and is currently a discussed topic (news articles, reports and research). As mentioned before, groundwater is a vital source of drinking water in the Netherlands. The Province of Utrecht is even almost completely dependent on groundwater to produce drinking water. It is therefore necessary for the whole of the Netherlands to get insight into the possibilities of (re) arranging space/functions to protect and improve the groundwater quality. In this way, the drinking water quality can be assured, which is vital for all processes in the Netherlands. With this research, I contribute to solutions for this societal issue.

Scientific relevance - In general, there are few integrated studies that take groundwater and drinking water as guiding principles. This research attempts to adopt this approach, thereby contributing to a different and innovative perspective on spatial planning. In this way, I contribute to the body of knowledge in the scientific field of the spatial organization of groundwater and drinking water.
Professional relevance - This study not only represents possibilities for a potential design of the landscape within specific trends, but also aims to provide the province of Utrecht with scientifically substantiated considerations

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Professional relevance - This study not only represents possibilities for a potential design of the landscape within specific trends, but also aims to provide the province of Utrecht with scientifically substantiated considerations for the revision of the environmental vision. Water and soil as guiding principles is a new concept within the government, and the province of Utrecht is actively working on implementing this in all plans for the environment (Provincie Utrecht, 2022). With this study, I tried to put these principles in practice with the pattern language and show how a spatial design could look like. This is done by creating scenario maps. The insights from this research can subsequently be used by the province to reassess and refine its environmental vision and in this way I contributed to the professional field.

Ethical aspects – Within this study, several ethical issues were addressed and each proposed design introduces distinct ethical concerns – such as a change in Dutch cultural landscapes, the distribution of (drinking)water between functions, using strict laws which impacts current business models to safeguard groundwater quality, and more. There are two main ethical concerns that occurred most frequently – the fair distribution of (drinking) water and justice for farmers.

Drinking water is a basic necessity for people and nature. During the research, it became evident that attention also had to be given to the quantity of water and its distribution across various functions. This issue of distribution led to questions about which functions were truly essential. It sparks much discussion, and it became clear that these difficult decisions are ones that no one, including myself, wants to make. Decisions regarding the allocation of (drinking) water affect the basic needs of humans, animals, and plants, and as such, represent highly ethically charged choices.
Justice for farmers is also a very important ethical consideration, but is not the focus in this research. There is already a lot of disagreement about the future of the farmers in the Netherlands and how they operate. A

(re)design of the rural area in the Province of Utrecht has many consequences for the farmers – such as the need to develop new business models when demanding biological agriculture in an area. Through the section 'important considerations' in the developed pattern language, these considerations are slightly highlighted. However, I did not explore in depth the economic and emotional effects on farmers of the proposed design.

Methodology and approach

How do you assess the value of your way of working (your approach, your used methods, used methodology)?

My approach and methodology are characterized by a high degree of concreteness and practical orientation. Rather than employing overarching theoretical concepts, existing systems were analysed and subsequently addressed through practical solutions – the pattern language. I did not base my work on abstract concepts – such as circularity - my focus was more on specific components of the system, like toxic substances, groundwater quality, et cetera.

Defining - In this study, the definition of urbanization was limited to the physical expansion of residential and industrial/ commercial areas. However, urbanization encompasses many more components than these two, each with additional consequences for groundwater quality - for example: space for the energy transition. These other components should indeed be considered in realistic planning processes. This was not done in this research, which is a limitation.
I also found the task of framing the definition of urbanization challenging, and it repeatedly emerged as a "bump on the road". As a result, it became more difficult to quantify the effects of urbanization on groundwater quality. The difficult traceability and the multitude of substances arising from urbanization further complicated the issue. This was more straightforward in the case of agriculture, where the effects could be divided into

various types of farming. The outcome is a more general overview of pollutants related to urbanization, in contrast to the more specific overview for agriculture.
Additionally, the focus of this study was solely on groundwater abstractions within the province of Utrecht. However, in the development of the scenarios, the option was made available to consider other forms of drinking water provision. This provided an opportunity to look beyond the scope and offer a broader view of an alternative course of action.

Multi-method approach – Various methods were employed in this study to address the research questions, including literature review, interviews, and a workshop. The literature review served as a solid foundation for building knowledge about groundwater systems. Conducting interviews and organizing brainstorming sessions with colleagues within the provincial government provided a broad perspective on the research problem, as the participants came from diverse domains. However, it became evident that there was significant overlap between these two methods (interviews and brainstorming sessions), and the preparation for both was relatively time-consuming. In future research, it may be better to choose one of the two methods in order to reduce the time spent on preparation.

The use of the pattern language method for generating solutions mainly contributed to achieving integration within the proposed solutions. The solutions could be linked to the various challenges and bottlenecks identified in this research, which contributed to a structured approach. The pattern language is also intended to function as a clear communication tool (Salingaros, 2000). This was confirmed during the workshop, where participants indicated that the patterns were easy to understand and facilitated discussion around the design process.

The workshop proved to be a crucial method for reaching well-substantiated conclusions. Due to its significance, the organization of the workshop gradually became a central theme in the process of the research, evolving from a means to obtain results into a goal in itself. As a result, I allocated less time to other research activities and ultimately lacked sufficient time for writing the final report.

The (test)workshops themselves proved to be effective methods for achieving a well-thought-out design. Because multiple professionals approached the same problem from different perspectives, the resulting designs included ideas that I, as a researcher, would not have initially considered. The workshops significantly contributed to the exploration of various design options and simultaneously supported the development and refinement of (new) solutions.

Relation between research and design

How did your research influence your design/ recommendations and how did the design/recommendations influence your research?

Several challenges and bottlenecks were identified during the research and subsequently linked to the pattern language. Using this pattern language, the design was developed. The design is therefore directly connected to the research findings of the study. Additionally, the pattern language itself is grounded in theoretical foundations.

At the same time, the design process also influenced the research. During the design phase, new potential solutions emerged, which were then incorporated into the pattern language. This required returning to the research phase in order to investigate and substantiate these new solutions. This iterative process occurred with several patterns, meaning that the design influenced the research multiple times.

Transferability

How do you assess the value of the transferability of your project results?

Since many of the identified trends in urbanization and agriculture occur at a national scale, the principles underlying the scenarios could be applied to other regions in the Netherlands. However, quantitative data – such as the number of required housing units and the demand for drinking water – would need to be adapted to the specific characteristics of each region.

The pattern language developed in this study could be applied to other regions in and outside the Netherlands, where groundwater is the primary source of drinking water and where the landscape and climate are similar to those of the case study area – the Kromme Rijnstreek. This area includes a variation of sandy soils from the Utrechtse Heuvelrug and more clay and peat-dominated areas in the rest of the region. The pattern language includes solutions tailored to these specific landscapes and corresponding land uses. The applicability of this research is more limited in regions where surface water is the main source of drinking water and where groundwater quality issues differ – such as in areas facing challenges like saltwater intrusion

Professional work environment

How did working in a professional environment (at the province of Utrecht) influence your research process and outcomes?

The opportunity to conduct an internship at the province of Utrecht during this research influenced both the research process and its outcomes in multiple ways.

Firstly, the broad structure of the province and the wide range of domains (domains of water, agriculture and urbanization) allowed me to acquire extensive knowledge and speak with a large number of professionals. This significantly supported a faster and more thorough understanding of the research problem. In addition, I had easier access to key documents relevant to my analysis, which accelerated the analytical phase of the project. I also benefited from improved access to professionals outside the province, such as drinking water company Vitens. This was made possible through the networks of colleagues within the province, which in turn facilitated and expedited the interview process – particularly the arrangements for conducting the interviews.

At the same time, conducting the internship also meant that I chose to write recommendations specifically for the province of Utrecht. This created a certain set of expectations regarding the content of the research. For instance, while I aimed to explore the extremes within the scenario development, the province preferred more realistic and implementable scenarios. This created a tension in the process. The final result reflects a compromise: more scenarios were developed than initially planned, including at least one that represents a more realistic outcome.

Professional growth

How did the research process change you as an Urbanist?

At the start of this research, I had limited knowledge of water-related topics and had not yet worked on any projects where water played a central role. Throughout the research process, it became increasingly clear to me how water systems are inextricably linked to the built environment and its quality. I not only gained deeper knowledge of groundwater systems and drinking water production, but I also developed a better understanding of how land use in the area can significantly impact another. I have come to realize that system thinking is a highly important and valuable skill to develop, and I will carry this skill forward in my role as an urbanist. Especially now, as it becomes more crucial than ever to address spatial challenges in an integrated and interdisciplinary manner.

Personal reflection

Finally, I would like to conclude with a personal reflection on my graduation research. First and foremost, I have learned a great deal during my internship at the province of Utrecht. My colleagues in the Water team taught me a lot of (technical) knowledge, which significantly enhanced the quality of the research and my understanding of the issue at hand. Participating in meetings and working groups allowed me to feel part of the team and helped make the issue come alive for me. At the same time, this immersion also required me to constantly reflect on my role as an Urbanist. Due to the technical point of view of the team, I sometimes lost my view as an Urbanist – a more broad perspective of the issue. It was highly educational to learn about the different thinking and working approaches of these professionals. The knowledge I have gained, especially the technical expertise from the Water team, will be invaluable for the continuation of my career as an Urbanist.

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