Participatory Causal Loop Modelling in the Kempen region

Making a context analysis to develop adaptation pathways for a climate-robust soil and water system in the area surrounding Reusel, The Netherlands

MSc Thesis by Sebastiaan van den Oever

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Abstract

Soil and water systems in elevated sandy soil areas in the Netherlands increasingly face consequences of climatic and socio-economic changes. The research project ‘KLIMAP’ aims at developing adaptation pathways for these areas, to contribute to making the soil and water systems climate-robust. The area surrounding the village of Reusel, in the Province of Noord-Brabant is an area where adaptation pathways are planned to be developed. The first step to develop adaptation pathways is making a context analysis, where objectives for the pathways are defined, problems are framed and the system of interest is delineated. Such a description is lacking for the Reusel case study. Considering argumentations in scientific literature, this context description is best to be made in a participatory exploration. The differences and similarities in stakeholders’ knowledge and perceptions of the problems in the social-ecological system need to be considered. The following research question was posed: *‘What is the perception of stakeholders of leverage points to make the soil- and water system around Reusel climate-robust?’* Causal loop diagrams were made in a participatory way, to answer the research question. Causal loop diagrams (CLDs) are conceptual models, showing the causal links amongst key drivers or variables in a system, affecting the systems’ behaviour or outcomes. Individual CLDs were made during stakeholder interviews, showing the stakeholders’ understanding of the interactions and vulnerabilities in and around the soil- and water system. The diagrams were merged into a ‘shared’ CLD, synthesizing the stakeholders’ viewpoints. The final CLD consists of 3 sub-diagrams, visualizing interactions on farm scale, municipal scale, and catchment scale. The diagrams were analysed to identify leverage points in the system.

A decrease in groundwater quantity was seen as the central problem variable in the system, caused by reinforcing loops in groundwater abstractions for agriculture and industry. Large-scale and intensive agriculture, deeply rooted in a capitalistic system of production maximization and cost price efficiency was perceived as an important cause of degradation of biodiversity and amenity value of the landscape. As the water system in the area is focused on water drainage instead of water retention, it makes the soil- and water system more vulnerable to climate change. In the brook systems, flooding occurs during extreme rainfall events, and nature areas dry out during periods of drought. Based on the investigated vulnerabilities, leverage points for a climate-robust system were identified. Four key categories of leverage points are (1) changes in water system design & management, (2) changes in agricultural practices, (3) an area-oriented approach towards environmental & spatial issues and (4) awareness raising & incentives for sustainable behaviour and adaptation. These leverage points can be considered in the further development of adaptation pathways for the region. Although the leverage points are broadly supported by the involved stakeholders, it should be considered that stakeholders still have various objectives and values related to the soil- and water system, which are within their personal sphere of action and interest.

Although it was not the objective of this research, it turned out that from a conceptual and methodological point of view, causal loop diagrams do have added value in developing adaptation pathways. They help to investigate the ‘mental models’ of involved stakeholders on the system of interest and its problems. In addition, CLDs are a useful tool to discuss which interventions are most effective in a social-ecological system.

Key words: adaptation pathways, participatory causal loop modelling, vulnerability, robustness, social-ecological systems, mental models, leverage points

Samenvatting

Bodem- en watersystemen op de Nederlandse hoge zandgronden krijgen steeds meer te maken met de gevolgen van klimaatverandering en sociaaleconomische veranderingen. Het KLIMAP onderzoeksproject richt zich op het ontwerpen van adaptatiepaden voor deze gebieden, om een bijdrage te leveren aan klimaat-robuuste bodem en watersystemen. Het gebied rondom het dorp Reusel, in de provincie Noord-Brabant, is een gebied waar adaptatiepaden zullen worden samengesteld. De eerste stap in het samenstellen van adaptatiepaden is het maken van een context analyse, waarin doelen voor de paden worden gedefinieerd, problemen worden onderzocht en het 'system of interest' wordt afgebakend. Zo'n beschrijving mist nog voor het casus gebied Reusel. Volgens argumentaties in wetenschappelijke literatuur heeft het toegevoegde waarde om de context analyse te maken middels een participatieve verkenning. In zo'n verkenning is het wenselijk om verschillen en overeenkomsten in de kennis en opvattingen van belanghebbenden over interacties en problemen in het sociaalecologische systeem mee te nemen. Wanneer dit bekend is kunnen ook zogenaamde 'knoppen om aan te draaien' om een robuust systeem te krijgen worden bepaald. In dit onderzoek werd daarom de volgende onderzoeksvraag gesteld: *Wat zijn de opvattingen van belanghebbenden over de knoppen om aan te draaien voor het verkrijgen van een klimaat-robuust bodem en watersysteem rondom Reusel?* Om de onderzoeksvraag te beantwoorden, werden causale diagrammen (engels: causal loop diagrams) opgesteld, middels een participatief proces. 'Individuele' causale diagrammen werden gemaakt tijdens interviews met stakeholders, die de opvattingen van de betreffende stakeholders weergeven over de interacties en problemen in en rondom het bodem- en watersysteem. De individuele diagrammen werden daarna samengevoegd tot een 'gedeeld' causaal diagram, dat de individuele standpunten van stakeholders bij elkaar voegt. Het definitieve causale diagram bestaat uit 3 sub-diagrammen, die interacties op verschillende ruimtelijke schaalniveaus weergeven: boerderij-, gemeentelijke- en stroomgebied schaal. De diagrammen zijn vervolgens geanalyseerd voor het identificeren van de 'knoppen om aan te draaien'.

Een afname in grondwaterkwantiteit werd door belanghebbenden gezien als centrale probleem variabele, veroorzaakt door zichzelf versterkende (vicieuze) cirkels in grondwateronttrekkingen voor landbouw en industrie. Grootschalige- en intensieve landbouw, diep geworteld in een kapitalistisch systeem van productie maximalisatie en kosten efficiëntie, werd gezien als een belangrijke oorzaak van afname in biodiversiteit en belevingswaarde van het landschap. Het watersysteem in het gebied is gericht op water afvoeren, in plaats van water vasthouden, waardoor het bodem- en watersysteem extra kwetsbaar is voor droogte. Tijdens piekbuien komt wateroverlast voor in de beekdalen en tijdens perioden van weinig regenval verdrogen natuurgebieden. Vier hoofdcategorieën met knoppen om aan te draaien, of oplossingsrichtingen zijn: (1) veranderingen in het ontwerp en beheer van het watersysteem, (2) veranderingen in de landbouwpraktijk, (3) een gebiedsgerichte benadering voor milieu- en ruimtelijke problemen en (4) bewustwording en prikkels creëren voor duurzamer consumentengedrag en klimaatadaptatie. Hoewel de 'knoppen om aan te draaien' breed zijn gedragen door de belanghebbenden, moet er rekening mee worden gehouden dat belanghebbenden nog steeds verschillende doelen en waardes hebben als het gaat om het bodem- en watersysteem.

Hoewel het niet de doelstelling was van dit onderzoek, is gebleken dat vanuit conceptueel en methodologisch oogpunt causale diagrammen meerwaarde hebben in het ontwerpen van adaptatiepaden. Ze helpen om de 'mentale modellen' van betrokken belanghebbenden te inventariseren, als het gaat over problemen in een sociaalecologisch systeem. Daarnaast zijn causale diagrammen een nuttig handvat om te bediscussiëren welke interventies het meest effectief zijn in een sociaalecologisch systeem.

Preface

For half a year, I have been engaged in research into climate change adaptation on the elevated sandy soil areas in the Netherlands. Especially due to the broad collaboration of different parties within the KLIMAP project, I had the opportunity to come into contact with many different experts and stakeholders related to the subject of my study. Although the interviews were conducted online due to Covid-19 circumstances, they were interesting and I learned a lot from them. Therefore, I want to thank all respondents I interviewed and the participants of the KLIMAP workshop, for the valuable information you gave me as input for my thesis. During the conversations, it again became apparent that climate change and climate change adaptation is a hot topic in the Netherlands, also in the elevated sandy soil areas. There are already many promising ongoing initiatives contributing to climate change adaption, founded by both governmental and private organizations.

During the process of this thesis, I was supervised by Erik van Slobbe and Raffaele Vignola. A special word of thank goes to you, for the time and effort you have put in supervising me in the past period. We had many interesting and useful conversations, which helped me through the thesis process, step-by-step. Thank you!

In addition to my supervisors, I would like to thank Bas Breman and Ingrid Coninx for the role you fulfilled as contact persons for the KLIMAP project. The moments that I could brainstorm with Bas about my research were very useful and I would like to thank Ingrid for thinking along, co-organizing, and facilitating the KLIMAP workshop.

Lastly, a word of thanks goes to everybody who encouraged me during the thesis process. Thanks to my housemates in Bennekom for the nice coffee breaks and my girlfriend, family, and friends for their mental support.

I hope that for you, as the reader, this thesis provides new useful insights into climate change adaptation and the development of adaptation pathways in natural resource management.

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1. Introduction

In the Netherlands, higher elevated areas with sandy soils increasingly face the consequences of climate change. The areas are called 'elevated sandy soils'. Van de Sandt et al. (2011) write that because of the elevation and soil structure, parts of the areas are not connected to the surface water system of ditches and canals. Besides, the few available watercourses are often designed to discharge water quickly and the speed of infiltration is high because of the soil texture. Therefore, the areas are dependent on precipitation or groundwater for freshwater supply. This causes an increased risk of drought and drought-related damage. The lower elevated parts of these areas, like the stream valleys, have a risk of flooding. This is caused by peak discharges from the higher elevated areas and seepage. As a consequence of climate change, altered precipitation patterns thus pose a threat to agriculture, nature, and built-up areas (Van de Sandt et al., 2011). In addition to climate change, socio-economic changes take place in the elevated sandy soil areas. Land-use changes and a growing population for example lead to an increase in water demand and other challenges, like the transition to circular farming and the energy transition (KLIMAP, 2019).

1.1 Research project background

This thesis research takes place in the context of the KLIMAP research project. Therefore, this project is explained first. KLIMAP is a Dutch research project, focusing on the transition to climate-robust development and management of the elevated sandy soil areas (KLIMAP, 2019). KLIMAP stands for 'Klimaat Adaptatie in de Praktijk', which means: climate adaptation in practice. The project provides tools for adaptation and planning in nature-, agricultural- and urban areas. In a climate-robust soil and water system, freshwater supply, soil and water quality, food security, and biodiversity are guaranteed in the long term (KLIMAP, 2019). Various parties are involved in the project, like universities, knowledge institutes, and waterboards. KLIMAP consists of three working groups. 'Toekomstverkenningen' (future explorations) focuses on models and defining and collecting future scenarios. 'Proeftuinen' (pilot areas) collects data about the effectiveness, costs-benefits, and scale of adaptation measures, by applying and monitoring these measures in 'living labs'. 'Ontwikkelpaden' (development pathways) synthesizes the knowledge of Toekomstverkenningen and Proeftuinen. It does so by developing pathways for adaptation, in collaboration with stakeholders (KLIMAP, 2019).

Adaptation pathways (AP) is a key concept in KLIMAP to collect knowledge and data, start conversations, and design possible future pathways. The future pathways consist of (policy) measures to contribute to climate-robust soil and water systems (KLIMAP, 2019). Adaptation pathways provide a flexible research and planning process, in which pathways with adaptation measures can be developed. The pathways show which measures can be taken over time, considering socio-economic or climatic future uncertainties. The different pathways provide the opportunity to switch from one pathway to another when more is becoming certain about future circumstances (KLIMAP, 2021).

1.2 KLIMAP case study De Reusel

Recently, KLIMAP started conversations to investigate the possibilities for adopting the case study 'De Reusel' to do research. The case study area is located in the southern part of the Province of Brabant. The Reusel is a small river in the area, near the eponymous village Reusel. The area is located in a broader region which is called: 'De Brabantse Kempen'. As sandy soils are characterizing the region, the same challenges as described in the first paragraph of this introduction may apply. More information on the case study area is given in chapter 4.

The immediate cause for considering this area as a case study for KLIMAP is because of an innovative potato farming company in the area, Van den Borne. This is a progressive company, monitoring business processes and innovating based on obtained data in field experiments. Amongst others, the company focuses on circular farming and integrating natural processes with agricultural production. In addition to that, the company experiments with efficient techniques for irrigation. The knowledge and data obtained through (participatory) monitoring and implementing of innovations could be used as input data for the development of adaptation pathways in KLIMAP. However, this data is only useful when the context and objectives of adaptation pathways are clear. Therefore, problems and opportunities for a climate-robust soil and water system should be investigated first, on a local and regional scale. Not only from the perspective of farmers, but also other actors, like the waterboard, municipalities, and the perspective of nature (Breman, Hack, De Graaf, & Ellen, 2020). This is the first step in developing adaptation pathways for the case study.

1.3 Scientific background

When the concept of adaptation pathways is applied to a study area, the first step consists of describing the current situation in the area and investigating or defining (policy) goals and objectives. The problems, vulnerabilities, and water management principles are analysed for the area. This is done for the current situation as well as for the future, using transient (climate) scenarios. Based on the scenarios, points in time are defined, whereafter the existing management in the area is no longer sufficient to meet the objectives (turning points) and measures need to be taken. Those measures are translated into 'adaptation pathways' and processed into a 'roadmap' for adaptation decisions in the (near) future. The pathways can then be implemented, monitored, and evaluated (Haasnoot, Kwakkel, Walker, & ter Maat, 2013).

Adaptation pathways (AP) is a concept that is practically tractable and conceptually appealing. However, in addressing 'wicked problems' AP seems to be limited to consider the multiple stakes, values, and nonlinear interactions between physical, socio-economic, and political factors in the system concerned (Bosomworth, Leith, Harwood, & Wallis, 2017). Bosomworth et al. (2017) describe some challenges which are faced when applying the concept of AP to complicated and nonlinear problem contexts. First, in examples of AP planning, it is often assumed that goals are agreed upon and actions to achieve the goals are largely technical and uncontested. Well established technical system models can be used in such cases, for example to design pathways for flood barriers along a river (Haasnoot, Middelkoop, Offermans, Van Beek, & Van Deursen, 2012). However, when levels of complexity increase and more and complex scales are added, it becomes more difficult to investigate or model how different aspects of the system relate to each other. When the concept is applied to landscape or system scale, multiple stakes, values, and trade-offs exist, which need to be considered. This requires dealing integrally with the various components of a wicked problem. Another challenge is that the definition of adaptation tipping points in wicked problems is not always clear cut. Imagine a case where a tipping point is reached when sea level rises above a defined level. When future scenarios of expected sea-level rise are available, the tipping point can be determined relatively easily. However, when more complexity in the system is acknowledged, possible action trigger points may have multiple (social-political) drivers. In that case, calculating tipping points for the existing management can become difficult and not be traced back to one climatic variable (Werners et al., 2013). Lastly, Bosomworth et al. (2017) mention that AP planning does not always give enough guidance on whether the existing governance and institutional context enable the adaptation pathways to be put into practice.

To overcome these challenges the diverse knowledge, the various views and goals in adaptation planning have to be considered, preferably in a participatory and collaborative way (Bosomworth et al., 2017; Lin et al., 2017). Cradock-Henry, Blackett, et al. (2020) write: *'There are, however, few examples of how to develop and apply adaptation pathways at broader, regional scales, in the context* *of multiple, interacting stressors, using inclusive, participatory approaches'* (p.2). A diagnostic, problem structuring approach can improve the utility of AP in complex problems. Such an approach acknowledges and addresses the underlying drivers of vulnerability, diverse framings, asymmetries in power, and tensions and agreements in knowledge and values. Preferably, the approach is appropriate for co-learning and participatory decision-making (Bosomworth et al., 2017).

1.4 Problem statement

A context description to develop adaptation pathways for the case study around Reusel is lacking. It is not yet known how stakeholders describe the soil- and water system in the area, its problems, and leverage points to obtain a robust system. Leverage points are places to intervene in a (complex) system, as an ecosystem. When a small change is made in one thing, big changes can be the consequence throughout the entire system (Meadows, 1999). Considering what is written about problem structuring in the previous subchapter, this description needs to be made by involving stakeholders in a participatory exploration. In the exploration, the underlying causes of vulnerability need to be investigated as well as the multiple physical-, social-economic- and political interactions within the system of interest. Tensions and agreements in stakeholder knowledge and values on the situation should be considered as well. The system description is needed for the further development of adaptation pathways.

1.5 Report outline

This thesis research report is structured as follows. In chapter 2, the theoretical framework of the study is elaborated, as well as the practical analytical framework. At the end of chapter 2, the research questions are presented. Subsequently, chapter 3 provides the methodology which was used for data collection and analysis. In chapter 4, more information is given on the case study area. Chapter 5 presents the results of the study. Next, a discussion on the concepts, results, and methods of the research is given in chapter 6, as well as recommendations for further research. The conclusion of the research is given in chapter 7.

2. Theoretical framework

This chapter elaborates on the theories and concepts used in the study. Adaptation pathways are explained first, with a focus on the context analysis within the framework. After that, theories of systems thinking and social-ecological systems are explained. Next, the concepts of robustness and vulnerability are defined. Lastly, the concept of system dynamics is explained, as well as causal loop diagrams, the analytical or practical framework of this study.

2.1 Adaptation pathways

Adaptation to changes in climatic, social, environmental, and economic conditions requires a flexible approach. Adaptation is most likely to be successful when a range of actions or strategies are present, which are robust under different possible plausible futures and can be adapted when needed (Bosomworth & Gaillard, 2019). The approach of 'adaptive pathways', or 'adaptation pathways' (AP) is such an approach. It is presented as an approach to planning and decision-making under conditions of uncertainty (Bosomworth et al., 2017). AP helps decision-makers, researchers, and stakeholders in a system to design 'pathways' with sets of measures and strategies that can be taken over time, to adapt to changing conditions.

Most AP planning approaches consist of the following broad categories:

1. Define goals and objectives,
2. Understand the current situation,
3. Analyse possible futures,
4. Develop adaptation pathways,
5. Implement, monitor, evaluate, report & improve (Bosomworth & Gaillard, 2019, p. 2).

Originally, the concept was developed for and used in cases where problems and goals are agreed upon and uncontested. For example, Reeder and Ranger (2011) developed a route map for the Thames Estuary 2100 project. By using 'what-if' situations, they indicated when measures could be implemented. Besides, Haasnoot et al. (2012) and Haasnoot et al. (2013) presented a picture based on the idea of a metro map. In the picture, different 'routes' with measures are presented, leading to different situations, or goals (figure 1). The map shows 'adaptation tipping point's, points in time that policies or objectives might fail or cannot be achieved anymore, because of changing (climatic) conditions. Additional measures are needed after the tipping points, to fulfil the objectives (Haasnoot et al., 2012; Kwadijk et al., 2010). Because of the presence of different pathways, the possibility remains to change to another pathway, depending on the change of conditions over time (Haasnoot et al., 2012).

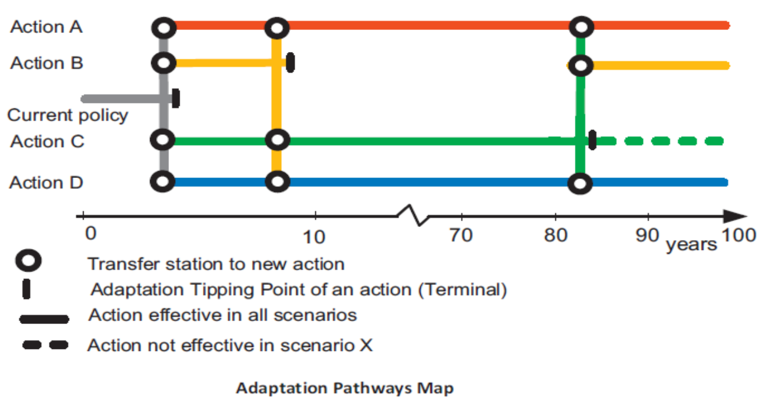


Figure 1 Example of an adaptation pathways map (Haasnoot et al., 2013)

Haasnoot et al. (2013) expanded the AP approach to the Dynamic Adaptive Policy Pathways (DAPP) approach, where adaptation pathways and adaptive policymaking are combined. In this approach, more attention is paid to uncertainties and a monitoring system towards the feasibility of objectives.

The DAPP approach gives more guidance to the policy-making context already, compared to earlier AP examples. However, still, the approach has often been applied to large, well-funded infrastructural projects, with uncontested goals and clearly defined decision-makers. Therefore, Wise et al. (2014) did a call to explore the applicability also in the context of projects where goals, knowledge, decision-makers, means, stakes, and values are less clear and sometimes even conflicting (Bosomworth & Gaillard, 2019). Wise et al. (2014) point out that adaptation pathways for climate change cannot be seen separated from the context in which decision-making takes place. Therefore, not only climatic changes have to be considered, but also changes in the political, cultural, economic, and environmental context. When placing measures to develop pathways for the future, societal transformations have to be considered as well. Otherwise, adaptation measures will have less effect or not lead to the desired result. In that case, there is maladaptation. This means that in developing Adaptation Pathways, existing actions of adaptation should be considered, as well as the entire socio-ecological system in which adaptation takes place(Wise et al., 2014).

As described in the introduction, Bosomworth et al. (2017) also recognize that further AP development is needed in contexts of contested and complex (policy) problems. For example in natural resource management. Therefore, they proposed a diagnostic problem structuring approach to AP planning. Problem structuring is defined as *'a problem diagnosing process that uses multiple problem representations to open-up and broaden problem formulations to better appreciate their systemic complexities and tensions between differing values, knowledge, and disciplines'* (Bosomworth et al., 2017, p. 4).

Context analysis as a first step

Problem structuring as described above is especially takes part in the first step of adaptation pathways development. Bosomworth and Gaillard (2019); Bosomworth, Harwood, Leith, and Wallis (2015); Bosomworth et al. (2017) split up the context analysis in two steps.

1. Defining objectives for AP development. This is a critical step in developing adaptation pathways, as it establishes the boundaries of issues and systems of concern that will be used in the following steps of the process. In an ideal situation, objectives consist of specific and measurable targets relating to the achievement of the goal. This makes evaluation easier.
2. Understanding the current situation. Through understanding the current situation, the problem is framed as well. Insights are provided into the social, economic, and environmental drivers of the problem. The analysis also informs which actions can be taken to reduce the vulnerability of the system towards pressures like climate change. To assess the current situation, different aspects should be considered. The level of agreement about goals among stakeholders, the certainty or uncertainty about the systems, the scale of the problem, the number of stakeholders involved, the urgency of the problem, and possible barriers to adaptation (capacity constraints) (Bosomworth et al., 2015).

After the context analysis is conducted, the development of adaptation pathways is continued by analysing possible futures, developing the adaptation pathways, and implementing, monitoring, and evaluating them afterward (figure 2). These steps are not in the scope of this thesis research.

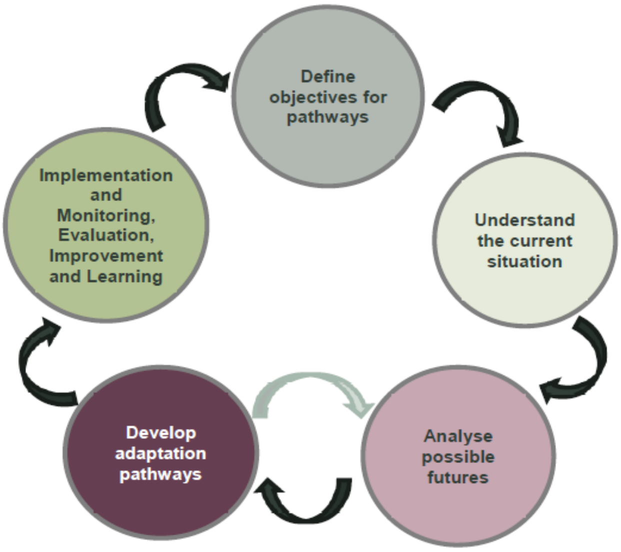


Figure 2 Five stages of an approach to adaptation pathways planning (Bosomworth et al. 2015)

Application in this research

In this research, a clear distinction between the two steps of the context analysis will not be made. I see defining objectives and understanding the current situation as a process that runs simultaneously and cannot be separated from each other. The steps will therefore simply be referred to as 'context analysis'. In this research, the context analysis will consist of making an overview of existing information, involved stakeholders, and investigating how stakeholders define the problem or vulnerabilities. Through doing this, the scale of the problem, the level of agreement among stakeholders, and important components and feedbacks in the socio-ecological system will become clear. If this is defined, leverage points logically follow.

2.2 Social-ecological systems

The previous subchapter described that the societal system with its rules, governance arrangements, and framings on the vulnerabilities should be considered in adaptation pathways development. A theory consistent with this is the theory of Social-ecological systems (SES).

SES are based on the principles of systems thinking. The world around us is becoming more and more complex. Globalization, technological development, climate change, and population growth cause systems to become more interconnected and complex. In an attempt to better understand those systems, look at the roots of their behaviour, and adjust it when necessary, systems thinking is an emerging concept (Arnold & Wade, 2015). It can be defined as *'a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them to produce desired effects. These skills work together as a system.'* (Arnold & Wade, 2015, p. 7).

The word system comes from the Greek 'synhistanai', which means: to place together. Ison (2010) defines a system as: *'an integrated whole distinguished by an observer whose essential properties arise from the relationships between its parts'* (p.22).

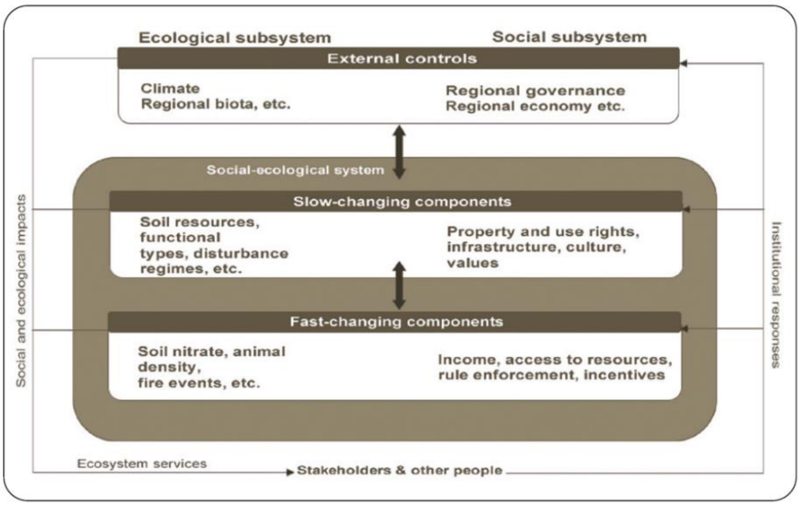


Figure 3 Conceptual model of an integrated social-ecological system (Resilience Alliance, 2010)

Systems thinking is often used in natural resource management (NRM), in particular, to study the interactions between and within the ecological and social system. This approach is therefore called the Social-ecological systems approach. SES are *'systems in which cultural, political, social, economic, ecological, technological and other components interact'* (Resilience Alliance, 2010, p. 6). The theory of SES recognizes that ecosystems are integrated with human society. The SES approach does not focus on a detailed understanding of specific parts of the system, but it takes a holistic view. It tries to understand how components contribute to the dynamics of the entire system (Resilience Alliance, 2010).

A conceptual model of a social-ecological system is visualized in figure 3. External processes or pressures from the outside environment (e.g. climate change) can impact elements of the system. The environment is *'that which is outside the system boundary and which is coupled with, or affects and is affected by the behaviour of the system'* (Ison, 2010, p. 21). Slow-changing components in the system (e.g. groundwater quantity) are impacted by external processes. Next, fast-changing components (e.g. crop yield) are impacted by slow-changing components. The fast-changing components impact people more directly. People respond to the system, through institutional mechanisms. Sometimes 'feedbacks' are triggered, bringing a change in the entire system or having a stabilizing effect. Through feedbacks, systems can self-organize. This makes adaptation possible, to recover or reorganize the system after a disturbance (Resilience Alliance, 2010).

Application in this research

In this thesis, SES will be used as a concept to investigate the context in the first step of adaptation pathways. Components of both the ecological and social systems will be characterized, as well as the boundaries of these systems and interactions between them. It will be investigated as well how external pressures impact the system. Through doing this, the system of interest for the adaptation pathways is investigated. System of interest is a term that is used in research, to avoid confusion with the use of the word 'system'. System of interest is defined as: *'the product of distinguishing a system in a situation, in relation to an articulated purpose, in which an individual or a group has an interest (a stake)'* (Ison, 2010, p. 20).

2.3 Vulnerability and robustness

The main objective of KLIMAP is to contribute to climate robust soil- and water systems (KLIMAP, 2019). When adaptation pathways are developed through a participatory exploration, the exact definition of a robust system depends on the objectives of stakeholders. In that case, stakeholders define what they see as a desirable system state. However, a definition from scientific literature can be given as well. Mens, Klijn, de Bruijn, and van Beek (2011) state that '*system robustness refers to the robustness of a socio-economic and physical system in relation to external disturbances'* (p.3). This means that a system is robust if a specific function of interest keeps existing despite external disturbances. Mens and Haasnoot (2012) make a distinction between the robustness 'of what' and robustness 'for what'.

- Robustness 'of what' refers to the chosen system where robustness applies to. A system can be limited to a physical object, like a flood barrier. However, it can also refer to a social-ecological system, as conceptualized and explained in the previous subchapter. This is the system of interest.
- Robustness 'for what' refers to the types of disturbance(s) and types of change(s). A disturbance occurs external to the system, at a certain frequency. For example an exceptionally long period without precipitation. A disturbance within the system can occur as well. For example an increase in the agricultural area.

To investigate the robustness of a system, information is needed on the reply of a system to disturbances. One of the streams of literature that addresses this is literature on 'vulnerability'. The term vulnerability is used in a wide range of traditions and disciplines. Human geography and ecology especially did conceptualize vulnerability to environmental changes, in social-ecological systems. A broad range of definitions of vulnerability exists in research in environmental science. In all definitions, core elements are present: the exposure of a system to stress, its sensitivity, and its adaptive capacity (Adger, 2006).

- Exposure is *'the nature and degree to which a system experiences environmental or socio-political stress'* (Adger, 2006, p. 3)
- Sensitivity is *'the degree to which a system is modified or affected by disturbances'* (Adger, 2006, p. 3)
- Adaptive capacity is *'the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope.'* (Adger, 2006, p. 3)

Adger (2006) combines these aspects into a definition, which will also be used in this study: *'the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt'* (p.1). When the vulnerability is analysed for a range of disturbances, having different frequencies, it can be considered as the flip side of system robustness (Mens et al., 2011). For example, when the vulnerability to a meteorological drought is low, the robustness of the system is high.

Application in this research

In this research, the concept of vulnerability will be used to investigate how stakeholders perceive vulnerability from a systems perspective. When this is known, leverage points to increase system robustness can be defined.

2.4 Causal loop diagrams

In line with the problem statement, it is desirable to have a holistic understanding of the interactions within and around the social-ecological system and its vulnerabilities. When having this understanding, problems can be analysed as well as predicted outcomes of interventions in the system, concerning side effects, feedbacks, and trade-offs among other objectives (Kelly et al., 2013). Models integrating knowledge across different fields of science are more and more developed, supporting to assess these side-effects, feedbacks, and trade-offs (Kelly et al., 2013). An example is the concept of 'system dynamics' (SD). *'System dynamics is an umbrella term for all approaches aiming to understand the behaviour of complex systems over time. Generally, approaches deal with internal feedback loops and time delays that affect the behaviour of the entire system'* (Kok, 2009, p. 3). SD approaches use feedback loops and stock and flows to represent the behaviour of the system (Kok, 2009).

'Causal loop modelling' is one of the methods of system dynamics. A causal loop diagram (CLD) is a conceptual model, showing causal links amongst key drivers or variables in a system, affecting the system's behaviour or outcomes (Maani, 2013, p. 28). CLDs sometimes are simply called 'system maps' (Lopes & Videira, 2017). A CLD consists of system variables, that are linked to each other, indicating cause-effect relationships (Lopes & Videira, 2017; Maani, 2013). When two variables change in the same direction, the type of relationship between the variables is denoted by a plus (+) sign on the arrow. When they change in opposite direction, it is visualized by a minus (-) sign. When two or more variables are connected in a closed cycle, a feedback loop is formed. This represents a special dynamic pattern in the behaviour of a system. Feedback loops can be reinforcing or balancing. A reinforcing feedback loop represents a self-propelling dynamic, underlying continuous decline or growth patterns. A balancing loop represents a stabilizing pattern and reaching targets (Maani, 2013). An example of a CLD is shown in figure 4.

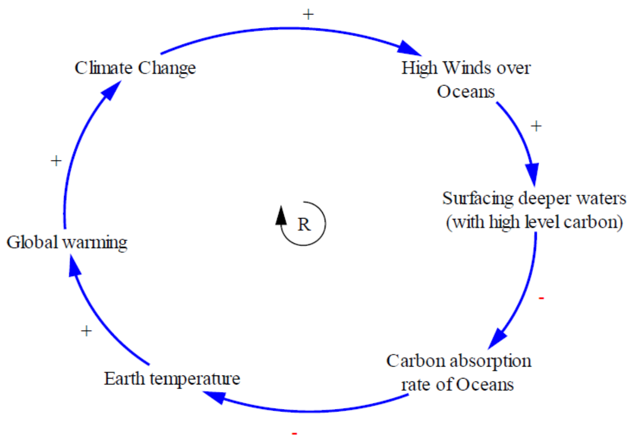


Figure 4 Example of a CLD with reinforcing structure, showing how climate change affects winds over the oceans, in the end increasing Global warming (Maani, 2013)

Construction of causal loop diagrams

The way of creating CLDs differs in the scientific literature. In some cases, researchers construct the CLDs themselves, after literature study and/or in conversations with stakeholders. For example, Sendzimir, Magnuszewski, Balogh, and Vari (2007) use causal loop diagrams to generate a comprehensive understanding of flood problems in the Tisza River Basin. The CLD in that paper is made by the authors, in advance of participatory modelling exercises with stakeholders. The authors visualize the interactions between the water sector and agriculture. This CLD is especially based on historical flood data and literature present opportunities and vulnerabilities regarding floods. The participatory process of constructing CLDs and discussing them is not performed in the paper, it is given as a future opportunity for research. Zare, Elsawah, Bagheri, Nabavi, and Jakeman (2019) apply the concept of CLD in a case of water resource management in Iran. They do not only make conceptual, qualitative diagrams, but also quantify the diagrams afterwards. When formulas are connected to the relations between the variables and the variables are made measurable, the system dynamics can be simulated using simulation software. In the study of Zare et al. (2019), the Driver-Pressure-State-Impact-Response (DPSIR) analytical framework is used for the first problem scoping and -structuring. The DPSIR is framework is filled in by the authors of the paper, based on scientific literature. It is also written that stakeholder input was used for CLD development, but it is not clear how that is done exactly.

The DPSIR framework, developed by the European Environment Agency (European Environment Agency, 2003), contributes to gathering and organizing information in a way that is useful for the conceptualization of causal loop diagrams. According to Gregory, Atkins, Burdon, and Elliott (2013) and Zare et al. (2019), system elements are structured according to the following framework elements.

- Drivers: forces, often human activities, causing pressures on the system
- Pressures: direct causes of changes in the system states
- States: changes in the state of the system
- Impacts: the impact on the environment
- Responses: the human responses to the changes in the system

The DPSIR framework will also be used in this thesis research in initial problem scoping.

In the previous examples, the role of stakeholders in CLD construction seems to be limited, at least a detailed documentation of it misses. However, A CLD can be made by thorough interaction among experts and stakeholders. When this is done, the 'mental models' of the involved stakeholders on the system are investigated. This gives a rich understanding of the system under question. (Barbrook-Johnson & Penn, 2021; Lopes & Videira, 2017). This contributes to sharing knowledge and creating a common understanding of the situation (Zare et al., 2019). This approach is also called 'participatory systems mapping' (PSM) (Barbrook-Johnson & Penn, 2021; Lopes & Videira, 2017). Stakeholder groups are involved in group model-building activities, like workshops. In a workshop, stakeholders can collaboratively construct a causal loop diagram on a problem, with help of facilitators. After a CLD is made, stakeholders can discuss leverage points (Lopes & Videira, 2017).

As described above, CLDs can be made in stakeholder workshops. There are also examples where CLDs are made during individual interviews with stakeholders (Inam, Adamowski, Halbe, & Prasher, 2015; Perrone, Inam, Albano, Adamowski, & Sole, 2020; Sohns, Ford, Adamowski, & Robinson, 2021). This provides several (separate) individual CLDs, which are later merged to a 'shared' CLD by the authors. The shared CLD synthesizes the mental models of the involved stakeholders. The advantage of this approach is that stakeholders are encouraged to openly express their views on the problems their causes. In workshops, 'opposing' groups may be present, which makes it difficult to create an open and neutral discussion. By building the CLD based on individual interviews, it can be guaranteed that the narrative of each involved stakeholder is represented in the merged CLD (Inam et al., 2015).

Application in this research

Five main stages are followed in the papers of Inam et al. (2015), Perrone et al. (2020), and Sohns et al. (2021). (1) Global problem definition, (2) Stakeholder analysis, (3) Interviews with stakeholders and construction of individual CLDs (4) Group CLD build from merging individual CLDs (5) Simplification of the merged CLD. After this, the CLD can be validated with the interviewed stakeholders, for example in a workshop and the CLD can be analysed. This method is roughly followed in this thesis research. The operationalization of the steps is given in chapter 3.

2.5 Research questions

Based on the problem statement and conceptual framework, the following research question is posed:

> *What is the perception of stakeholders of leverage points to make the soil and water system surrounding Reusel climate robust?*

The following sub-questions are raised:

1. What is the system of interest when investigating leverage points to make the soil and water system climate robust?
2. Which actors do have a stake in the system of interest?
3. How do these stakeholders describe the social-ecological system, its interactions, and feedback loops contributing to the problems and vulnerabilities of the system of interest?
4. Based on the perception of stakeholders, what are the leverage points to make the soil and water system climate-robust?

3. Methodology

In this chapter, the overall research design of the study is presented first. Afterward, research methods & data collection are elaborated.

3.1. Research design

The concept of causal loop diagrams (CLD), as introduced in the previous chapter, was the leading methodological concept in this study. Qualitative data was obtained through developing CLDs together with stakeholders. Figure 5 shows the research design. It largely follows the steps taken in the participatory-modelling approach of Inam et al. (2015). First, the system of interest for analysing perceptions on vulnerabilities and robustness of the soil and water system was identified. Actors having a stake in that system followed from that. Next, the identified stakeholders were interviewed and individual CLDs were built during the interviews. The interviews were analysed and the individual CLDs were finalized and digitized. In step 4, the individual interviews were merged into a shared model. In the next step, sub diagrams were identified from the merged model. In step 6 an expert workshop was facilitated, in which the diagrams were analysed and the strengths and weaknesses of the approach of causal loop diagrams were discussed.

3.2 Research methods and data collection

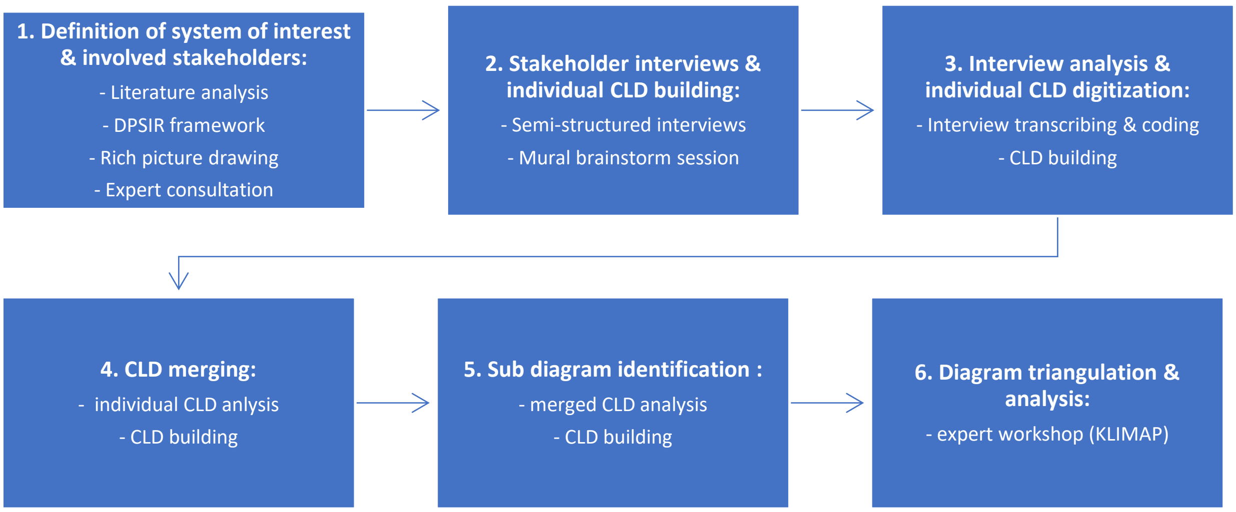


Figure 5 Research design of the study, consisting of 6 steps and corresponding methods

Per research step, as shown in figure 5, the methods and data collection are explained now.

Step 1: Definition of system of interest & involved stakeholders

In step 1 main topics related to climate robustness of the soil- and water system in the case study area were explored, to define the system of interest for the study. Defining this is important, as it provides the boundaries and scale of the social-ecological system to be analysed and the stakeholders involved (Perrone et al., 2020).

Literature analysis was performed in this step, conducted by the researcher. Policy-related documents, descriptions of the soil and water system, objectives for development in the region, problem descriptions, and stress tests were used. Examples of data sources are Waterboard de Dommel, the Province of Brabant, and existing regional research projects, like De Schakelkast. The data from the literature analysis was structured according to the Driver-Pressure-State-Impact-

Response (DPSIR) framework. This framework was explained in chapter 2. After the DPSIR framework was completed, a rich picture was drawn. Rich pictures are *‘visual depictions of the problem situation using drawings and arrows showing the links between key issues’* (Ison, 2010, p. 288). The objective of a rich picture is to capture the main components, viewpoints, and structures of a system, informally. By doing this, an overview of system components, problems, and involved stakeholders is made. A rich picture can become richer over time when more information is added (Reynolds & Holwell, 2010). The rich picture gave a delineation for the system of interest for the study.

Actors having a stake in the system of interest were investigated next, based on the rich picture. The stakeholders were identified, to interview them in step 3. Different stakeholders groups were listed in a table, giving information on their ‘power’, the possibility to impact the situation, and their ‘interest’, their way of being impacted by the situation. This list was discussed with an expert from Waterboard de Dommel, which led to the first list of contacts. Stakeholders from this list were contacted for an interview. In addition, snowball sampling was used during the interviews, to identify more stakeholders. Respondents of the interviews were asked to mention other people having power or interest related to the discussed problems in the soil and water system. 14 Stakeholders were identified and interviewed, their function and organization are given in the results chapter.

In the approach of Inam et al. (2015) four major categories of stakeholder roles concerning their resource issues are used. This is done to investigate which stakeholders are sufficiently available and what type of stakeholders are missing. These categories are: ‘decision makers’, ‘users’, ‘implementers’ and ‘experts’. Although attention has been paid in this study to the stakeholder categories, it was not possible to find an even amount of stakeholders for each category. This is due to time limitations and limitations in the KLIMAP research project. As the KLIMAP project on the case of Reusel is in its initial stage, it is difficult to come into contact with ‘users’ in the field.

Step 2: Stakeholder interviews & individual CLD building

In step 2 individual causal loop diagrams were made, based on the perception of stakeholders.

After the list of stakeholders was established, stakeholders were contacted. Individual interviews were conducted to investigate stakeholders’ views on the vulnerabilities and leverage points for a robust system. While interviewing, an individual causal loop diagram was built together in collaboration with the interviewee, representing his/her mental model on the system.

The interviewees were presented with the purpose and objective of the interview first. After that, the study area as described in chapter 4 was shown. Then, the method of drawing a causal loop diagram was introduced, showing an example. Due to Covid-19 circumstances, the online brainstorm program *Mural* was used to make the individual causal loop diagrams, as interviews had to take place online. In this program, respondents were able to place post-its. Respondents were asked to describe the main problem variable(s) related to the soil- and water system and place that in the middle. After that, the stakeholder was asked to add causes on the left side of this problem variable. Consequences were added on the left side, using the post-its. Next, interviewees had to connect problems, causes, and consequences by using arrows. Polarities of the relations and present feedback loops were indicated as well. Respondents were asked to consider physical, socio-economic, and institutional variables while making the CLD. They were also asked to indicate how current existing policies or measures mitigate the problems and what they see as leverage points to make the soil and water system robust.

An example of a post-it version made during an interview is shown in figure 6. Because of time limitations and a multitude of topics discussed, it was often not possible to entirely ‘complete’ the causal loop diagrams. Variables and phrases of respondents were put into post-its, but connecting them was often not finished. Therefore, the interviews were analysed and the diagrams were completed afterward (step 3). The interviews lasted 1 hour to 1 hour and 15 minutes and were recorded in Microsoft Teams. The interview guide is given in Annex A.

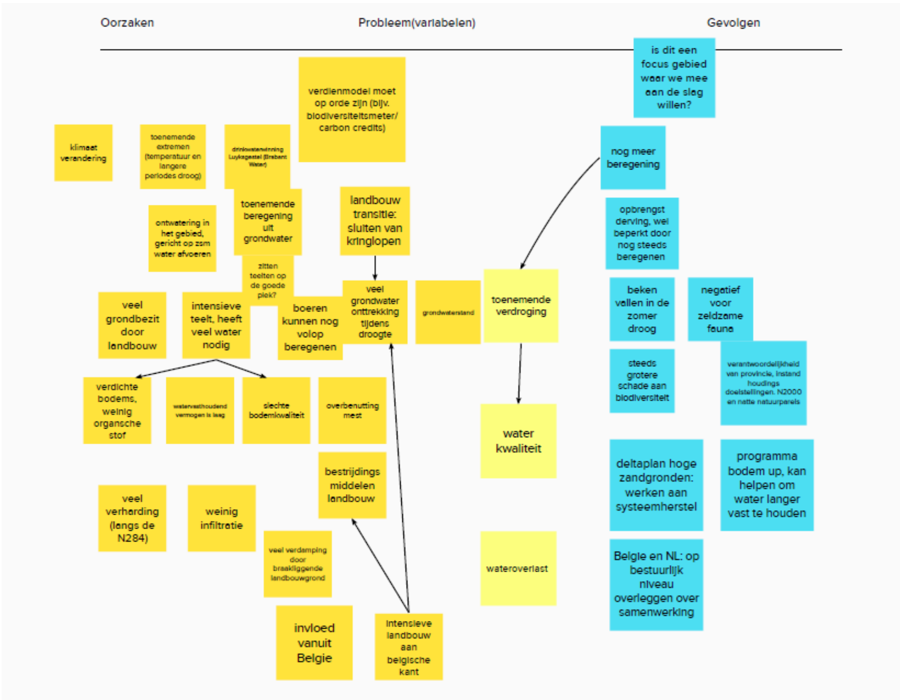


Figure 6 Example of post-it brainstorm for making an individual CLD during an interview

Step 3: Interview analysis and individual CLD digitization

In step 3, the interviews were analysed and the individual CLDs were finished and digitized.

The interviews were transcribed based on the recordings. Next, the interviews were coded in the digital program *Atlas.ti 9*. Coding was done for three reasons:

1. To get an overview of what respondents said about topics, compare this and find differences and similarities in visions of stakeholders. Also, collect the information on mentioned leverage points.
2. Reproduce the individual CLDs. As described in step 2, it was not possible to complete the individual CLDs during the interviews. By coding the interviews it was investigated how the interviewees perceived the relationships between problems, causes, and consequences.
3. Homogenise the language of the individual CLDs. Stakeholders often mentioned the same topics but used different words to explain them. Through coding the interviews, it was possible to find a coherent language. This made it easier to merge the individual CLDs later.

Coding was done in different stages. Eker and Zimmermann (2016) developed a method to guarantee a systematic use of qualitative data in model conceptualization. The first steps of this method were followed:

- Identifying concepts and discovering themes in data. In this step, 'open coding' was performed to understand the main elements of the interviews.

- Categorizing the codes and aggregating themes into variables. Through doing this, a hierarchical coding tree was formed. The coding tree consisted of 20 categories. This process is also known as 'axial coding'.

The next two steps in the method of Eker and Zimmermann (2016) are the following:

- Identifying causal relationships and record these in the coding program.
- Transforming the coding into causal diagrams

Although in this research causal relationships were not specially recorded in the coding program, the steps above were largely followed. To identify a causal relationship, there was looked for indicators such as 'because', 'if….then', etc. While reading through the transcribed interviews and paying attention to these indicators and the earlier made, the individual CLDs were finished and drawn in the digital program *Vensim*.

Step 4: CLD merging

In this step, the individual CLDs were merged into a group CLD, synthesizing the mental models of the interviewed stakeholders.

In the approach of Inam et al. (2015) the most detailed individual CLD is taken as the foundation for model merging. Variables from the other models are added until all variables are included. Meanwhile, controversies, agreement, and differences in the level of detail are documented. In this thesis research, the method of Inam et al. (2015) was not chosen. A wide variety of topics emerged from the individual CLDs, different terminology was used, and a significant amount of differences in the level of detail of the diagrams was present. Using the approach of Inam et al. (2015) would therefore be too time-consuming. Instead, a method described by Ryan, Pepper, and Munoz (2019) was used, known as 'synthesis'. *'Synthesis as a qualitative research approach seeks to develop an understanding of a phenomena by bringing together separate parts of information to create a whole'* (Ryan et al., 2019, p. 8). Synthesis is based on the principle that research findings that are perceived important should be understood within a wider context but in a unified and accessible format. This can be achieved through synthesis. When using synthesis in causal loop diagram- or mental model research, it is assumed that multiple individual models consist of pieces of the entire picture. A holistic picture of this information is made by combining the individual viewpoints towards a whole. To put this into practice in model merging, frequency of occurrence is used first, to find the most frequently used concepts in all CLDs. After that, each individual CLD is analysed to find key concepts, important for the story of that particular CLD (magnitude of occurrence). Those concepts are added to the group CLD. (Ryan et al., 2019).

In this research, the frequency of occurrence of variables in the individual CLDs was counted in Microsoft Excel. After that, the individual CLDs were analysed, to determine the magnitude of occurrence of variables in the diagrams. This was performed during an expert working session, consisting of the supervisors of this thesis research and myself. In this analysis session, the main issue was identified for each CLD. Next, a narrative was made for each CLD, telling the main story or points of attention of each diagram. The spatial scale concerning the view of the respondent on the social-ecological system was identified as well. Lastly, all present feedback loops in the individual CLDs were written down.

After the analysis, a first merged model was made in *Vensim*. This model was based on the present feedback loops in the individual CLDs and the frequently used variables. In a second version of the merged model, variables were added to represent the individual viewpoints of the respondents. The narratives made during the individual CLD analysis were especially useful for this. This second version resulted in a detailed shared causal loop diagram.

Step 5: Sub- diagram identification

As the detailed shared causal loop diagram was too detailed, it was simplified in step 5. This was done to make it clear and communicable. The simplification was based on the identified spatial scales in the individual CLD analysis in step 4. Three different sub-diagrams were extracted from the detailed merged model. Each represented a different spatial scale concerning interactions in the soil and water system. Again, the diagrams were made in *Vensim*.

Step 6: Diagram triangulation & analysis

In step 6, the three sub-diagrams as constructed in step 5 were analysed. Also, a reflection was made on the used concepts and methodology. An expert workshop was organized, consisting of people involved in the KLIMAP research project. The workshop had four objectives:

1. Investigating the opinion of experts on the content of the diagrams, as a way of data triangulation
2. Discussing leverage points for a climate-robust soil and water system, following from the system relations and issues in the diagrams.
3. Investigating expert opinions on the strengths and weaknesses of the used concepts and methods within the development of adaptation pathways.
4. Discussing the opportunities for continuing with the Reusel case study in the KLIMAP project.

An interdisciplinary team of 14 experts was present during the workshop. The group consisted of participants from research institutes (Wageningen Environmental Research, KWR, Stowa), universities (Wageningen University & Research, Radboud University Nijmegen) and Waterboards (De Dommel, Vallei en Veluwe). Further, there was one facilitator for the discussion and I presented the methods and findings of the research. The online workshop lasted 1.5 hours and was facilitated in Microsoft Teams. In addition, *Miro* (Miro.com) was used to structure the discussion. In this online Whiteboard, the participants were able to place post-its in the diagrams for making remarks or asking questions about uncertainties. Besides, participants placed post-its containing their ideas on the usefulness of the concept and methods. After the post-its were put up, there was time to explain them, which led to further discussion.

A recording of the workshop was made in Microsoft Teams. Afterward, the recording was summarised and analysed. Findings from the discussions on the content, leverage points, and methods were processed in the results and discussion of the research. In addition to collecting data for the thesis research, the workshop was also interesting from an organizational point of view. It provides an example of how experts in an interdisciplinary research project can come together, to discuss results and evaluate how a research method can bring together the different working groups within a research project. More thoughts about this are given in the discussion chapter.

4. Case study area

One of the objectives of this study is to investigate how stakeholders define the system of interest when talking about the soil and water system. This means that in the results chapter, a more elaborate description of the case study area will follow, based on stakeholders' perceptions on problems in the soil and water system. However, a rough location and some general information of the study area is given, to have a delineation for the start of the research. As developments and pressures on the soil and water system can be located outside the study area, the area described below is seen as a 'focus area'.

The area is located in the Province of Noord-Brabant in the south of the Netherlands (figure 7). The area is located in a region which is called: 'De Brabantse Kempen'. The study area borders Vlaanderen (Belgium) on the south and west side.

Figure 7 Study area (source: OpenStreetMap)

This study area was chosen for a few reasons. First, the company of v.d. Borne Aardappelen is located in the area, being the 'driving force' behind the Reusel case study in KLIMAP. Next, by experts of the waterboard, this area, especially the southern part, was described as a 'sand head', where the brooks in the area originate. The area is therefore also important for the inundation of water. This makes it interesting to be analysed from a hydrological point of view. Lastly, the study area is proposed as a test case in De Schakelkast. De Schakelkast is a submitted project for the EO Wijers contest (Verhoeven et al., n.d.-a), proposing a multidisciplinary team of system integration experts. The team focuses on economic, social, environmental, and spatial challenges in the Kempen area, using an area-oriented approach. Local (already existing) initiatives are connected and stimulated by the team, to achieve landscape transitions. In De Schakelkast, this area is chosen, because there are several problems regarding water quantity, biodiversity, and the image of the area. At the same time, the entrepreneurial spirit in the area gives opportunities to solve problems (Verhoeven et al., n.d.-b). In this thesis research, information from the Schakelkast is used, as it covers the same spatial area.

History and land use

Three villages Reusel, Bladel, and Hapert are located at the north side of the study area, along the N284. Especially south of Reusel, heather reclamation took place recently, in the ’50s and ’60s of the previous century. During this period, upscaling took place in agriculture and farmers started using artificial fertilizers. Traditionally the soils in this area were poor in terms of nutrients, but the pioneering mentality of the farmers caused the soils to become more fertile. A large-scale and efficient agricultural and livestock farming area arose (van Geel, Krauth, & in 't Zandt, 2020; Verhoeven et al., n.d.-b).

Coniferous forests were planted on the highest parts of the area, south of Reusel and Bladel. The ‘Kroonvensche’ and ‘Peelsche heide’ are located here, with two ‘Natuurpoorten’, places where catering is located and walking- and cycling routes start. The countryside area south of Bladel and Hapert has a more mixed landscape, compared to the area south of Reusel. There is large-scale agriculture and livestock farming as well. However, there are also some more small-scale landscape elements. Examples are estates ‘Ten Vorschel’ and ‘Achterste hoef’. Recreational businesses are located here, like bungalow parks and farmers owning a campsite (Verhoeven et al., n.d.-b).

The nature reserve south of the A67 partly belongs to the study area as well. This is a larger contiguous nature reserve when comparing it to the nature reserves south of Reusel and Bladel. This area largely consists of coniferous forest. However, the ‘Cartierheide’ is also located here, a large heathland area. Some illustrations of the land use are given in figure 8.

Figure 8 Agricultural plot in the area, surrounded by nature (left) and a fen, predominantly surrounded by coniferous forest (right) (van Geel et al., 2020)

Elevation, soil type & hydrology

The southern part of the study area has a high elevation compared to the rest of the area, between 35.5 and 32.5 m – NAP (Bakema, 2020). In terms of the Dutch soil classification system, most parts of the southern area consist of ‘vedpodzolgronden’. These soils consist of fine loamy sand with a humous top layer. Because of the elevation and soil characteristics, the areas are infiltration areas, where the water infiltrates and discharges quickly. The soil type is susceptible to the leaching of phosphate and nitrate (Provincie Noord-Brabant, 2021).

Towards the villages in the north, the elevation gradually decreases, to an elevation between 22.0 and 30.0 m NAP (Provincie Noord-Brabant, 2021). Corresponding to the elevation in the landscape, brooks originate in the south of the area and flow to the north. From West to East, the most important brooks are called: ‘Reusel’, ‘Rouwenbochtloop’, ‘Raamsloop’, ‘Goorloop’ and ‘Dalems Stroompje’. The Goorloop and Dalems Stroompje come together at Hapert and from then on they are called ‘Grote Beerze’. In addition, the Nete originates in the southwest corner of the study area and flows westwards towards Belgium. This brook flows through the ‘Reuselse Moeren’, a peat moor nature area. The stream valleys around the brooks are dominated by 'enkeerdgronden'. This soil type indicates naturally wet conditions, where the infiltrated water from the higher areas reaches the surface as seepage (Possen, 2019). A soil type- and elevation map are given in Annex B.

5. Results

The results of the research are described in this chapter. First, the results of the literature analysis on the system of interest and involved stakeholders are given. Next, the causal loop diagrams are presented and explained. In the next subchapter, the results of the expert triangulation on the diagram content are given. Finally, the leverage points for a climate-robust soil and water system are elaborated.

5.1 System of interest and involved stakeholders

In this subchapter, a delineation for the system of interest for this study is given, as well as an investigation of involved stakeholders. This provides boundaries to the further causal loop diagramming process. It is based on an analysis of study area-specific literature. The analysis takes the perspective of sketching a problem situation in and around the soil- and water system, as by doing so it becomes clear what belongs and does not belong to the system of interest for this study.

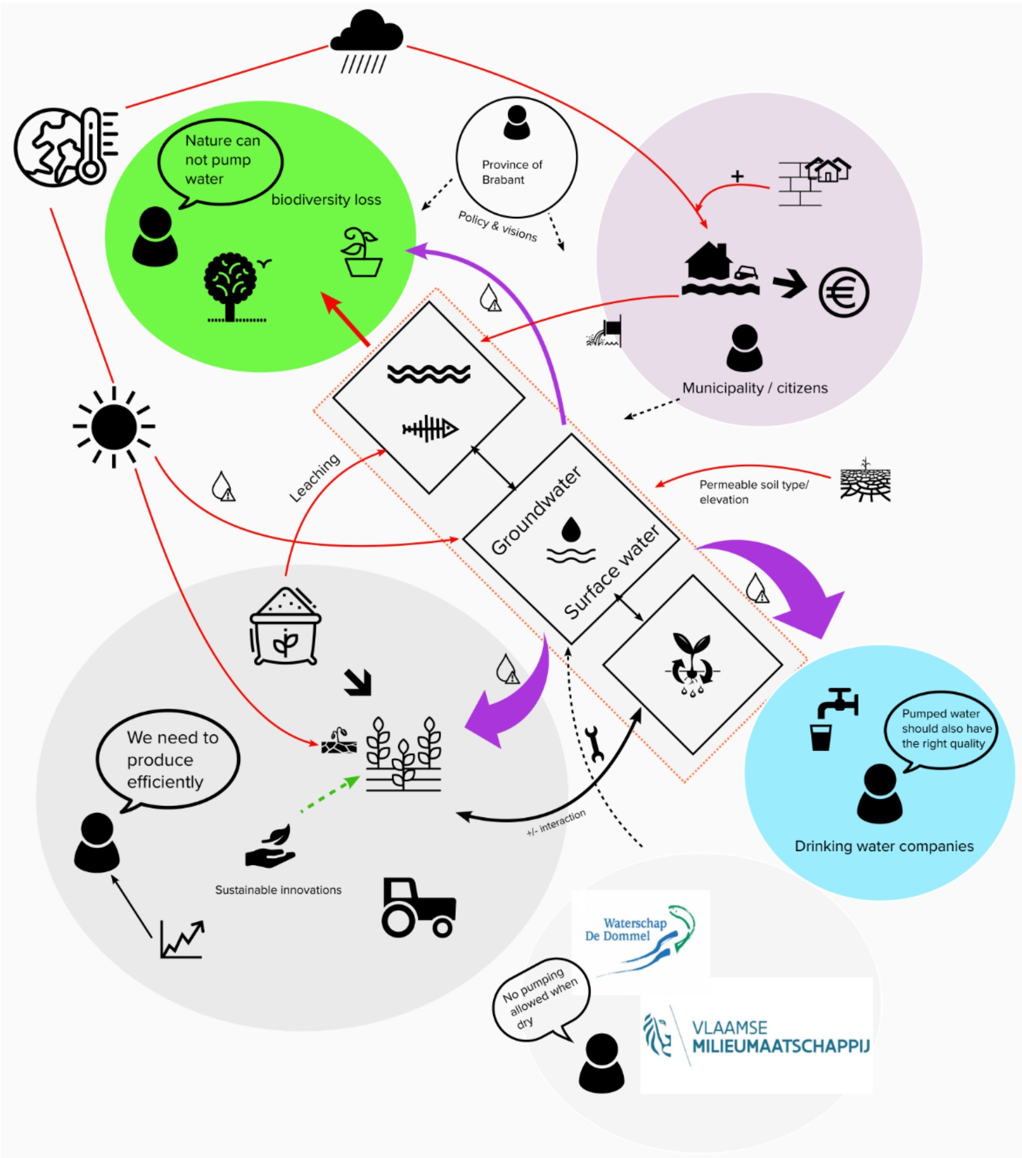


Figure 9 Rich picture, based on literature analysis

The completed DPSIR framework is given in Annex C. Although the DPSIR framework is useful for structuring literature, it gave a rather linear overview of Drivers, Pressures, States, Impacts, and Responses within the system. It was difficult to consider and visualise interactions using this framework. Therefore the rich picture was drawn afterwards, based on the DPSIR framework, to better visualise interactions (figure 9).

The soil and water system is visualised at the centre of the rich picture, in different square boxes. Red arrows show adverse impacts on the soil and water system, often originating from pressures inside or outside the soil and water system. The blue lines show important water flows. Actors having a stake in or impacting the system are visualised in coloured circles surrounding the boxes of the soil- and water system. They are indicated with a pictogram of a person. Further, black dotted arrows show the presence of management, for example, the conduction of policies. The other symbols are self-explanatory, showing further components of the system.

Decreasing water quantity seems to be an important issue in the area. Surface water and shallow groundwater flow towards the brook valleys quickly. This was observed when looking at the ishohypse pattern for the phreatic surface for the study area (Grondwatertools, 2021; Possen, 2019). Large parts of the infiltrated water flow to deeper groundwater (Bakema, 2020; van Geel et al., 2020). Over the past 10 years, a rapid decline in groundwater levels is observed. This became particularly visible during the years 2018-2020 because of the dry summers (Bakema, 2020; TNO Geologische Dienst Nederland, 2021). After winter in spring, groundwater levels are highest and during the growing season, the groundwater decreases and is below the median (Bakema, 2020; Waterschap De Dommel, n.d.). Some data behind the remarks on groundwater is given in Annex D. In addition to low groundwater levels, surface water supply in the higher located areas is hardly possible and there is limited soil moisture and capillary rise (van Geel et al., 2020). The brooks in the area are characterised by fluctuations in discharge, depending on the rainfall patterns. Possen (2019) writes that the brooks Reusel and Raamsloop regularly run dry. During peak rainfall events, flooding can occur. This is especially the case in the brook valleys in the northern part of the study area, around the villages (Veltmaat, 2019).

Water quality may be an issue as well. The surface water and groundwater in the area contain too many nutrients. Nutrient-rich groundwater comes to the surface in the brooks and in nature areas (Possen, 2019). Because of the low water levels and decrease in water quality, it is difficult to comply with the Kader Richtlijn Water (KRW) (Provincie Noord-Brabant, 2017).

Provincie Noord-Brabant (2017) writes that there is debate on the soil quality in the Province of Brabant. Agriculture in the Netherlands is focused on efficiency and cost price minimization. 'Growth' is central in the economic system. The business plans of farmers are impacted by parties who have a stake in the growth model, like suppliers and consumers. This results in applying monocultures, a large amount of livestock, over fertilisation, and the use of large and heavy machinery. This has an impact on the soils in Brabant. Soils are compacted and soil structure is degraded. There is run-off and leaching of fertilizers and crop protection products. In addition, there is a decrease in organic matter content, resulting in a decrease in water buffering capacity, and buffering capacity of fertilizers and minerals (Provincie Noord-Brabant, 2017). Based on this information, the assumption is made that soil quality is an issue in the study area.

Climate change as an external stressor may reveal the vulnerability of the system and reinforces the above-described issues. In the rich picture, this is visualised by the symbols of the warming earth and the sun and raincloud. Average annual temperatures and heatwaves are increasing in The Netherlands. Also, more (extreme) rainfall events are observed. In addition, longer periods of no precipitation occur, especially during spring and summer. Climatic projections predict that these factors will change further in the future (Klein Tank, Beersma, Bessembinder, Van den Hurk, & Lenderink, 2014).

The interaction of the soil and water system with its environment is explained in the next paragraph, through describing the power and interest of stakeholders in the system.

Impact on stakeholder groups

Actors having a stake in or impacting the system are visualised in the picture in the different coloured circles surrounding the boxes of the soil- and water system. In table 1, the power and interest of these stakeholder groups are listed, following from their position in the rich picture. Although the literature suggests that these are the involved stakeholders in the soil and water system, the results of the interviews may reveal that other stakeholders are involved as well.

Table 1 Involved stakeholder (groups) and their power and interest

Stakeholder(s)	Power/possibility to impact situation	Interest/impacted by the situation	Source
Waterboard De Dommel	• Pursue water management policies • Able to invest in the water system (for example brook system restoration) • Able to take measures on (ground) water management • Able to (partly) regulate irrigation/pumping, by irrigation bans and permits	• Responsible for operational (ground)water management • Prefer good collaboration with water users, like farmers • Aim at a preserving water system at the elevated sandy soil areas • Responsible for meeting KRW and flooding guidelines	(Provincie Noord-Brabant, 2017; Stumpe, 2011)
Municipality (Reusel- de Mierden/	• Pursue policy/take measures on urban (ground) water • First point of contact for citizens in the municipality in case of complaints	• Responsibility for (ground) water in the urban area • Responsible for discharge of wastewater and rainwater • Responsibility for good living environment	(Stumpe, 2011)
Province of Brabant	• Regional policy framework and strategic goals (e.g. regional climate adaptation and program soil and water)	• Responsibility for the quality of deep groundwater	(Stumpe, 2011)

Farmers (agriculture / livestock farming)	• Way of cultivation can impact soil quality • Use water for irrigation (so competition) • Can positively impact soil and water quality through sustainable farming initiatives	• Benefit from a fertile soil • Face economic losses when there are water shortages and nuisance because of flooding • Require sufficient groundwater pumping • Must comply with regulations (e.g. around nitrogen deposition)	(Provincie Noord-Brabant, 2017)
Nature organisations (e.g. Brabants Landschap, Staatsbosbeheer, Bosgroepen)	• Little power • Can rely on regulations/law for nature protection	• Nature areas dry out • Biodiversity decreases • Investments often do not have the desired result because of environmental factors and land use	(Baan, Koreman, & Dingemans, 2020)
Vlaamse milieumaatschappij	• Planning of integrated water policy Vlaanderen • Management groundwater and unnavigable waterways Vlaanderen • Measure water quantity/water quality and check drinking water production	• Choices made in the Netherlands regarding water management and planning impact water quantity and quality Vlaanderen (e.g. through connected surface water and groundwater)	(Vlaamse Milieumaatschappij, n.d.)
Drinking water companies	• Major groundwater user • Can invest in sustainable methods for drinking water production	• Benefit from sufficient water quality and quantity	(Veltmaat, 2019)
Citizens	• May have participation through citizen groups	• Experience nuisance and possible damage from flooding • Benefit from a vital nature for recreation	(Veltmaat, 2019)

A list of the stakeholders who were interviewed is given in table 2. Compared to table 1, stakeholders from all identified stakeholder groups were interviewed, except for drinking water companies and citizens.

Table 2 Organization and function of the interviewed stakeholders. In the context of privacy, names cannot be given and details in function description are left away.

Interview/ respondent number	Organisation	Function
1	Waterboard De Dommel	Plan maker
2	Farming company	Farmer
3	Waterboard De Dommel	Ecologist
4	Province of Brabant	Policy advisor Groundwater
5	Architectural firm	Landscape architect
6	Farmer interest organisation (ZLTO)	Advisor
7	Waterboard De Dommel	Policy/program advisor
8	Waterboard De Dommel	Policy/program advisor
9	Municipality of Bladel	Policy advisor
10	Province of Brabant	Policy advisor soil and water
11	Huis vd Brabantse Kempen (regional project organisation)	project leader
12	Bosgroep Zuid (nature management organisation)	Region representative
13	Municipality Reusel-De Mierden	Policy advisor
14	N.A.	Process and project leader area development

5.2 Causal loop diagram development

It is not in the scope of this research to discuss the individual causal loop diagrams (CLDs) separately, as they are synthesized in the merged CLD. The digitized individual CLDs can be found in Annex E. The first two versions of the merged CLD were made through analysis of the individual CLDs and considering the frequency of occurrence of the variables in the individual CLDs (methodology – step 4). The outcomes of this analysis and Excel table with frequencies of occurrence are given in Annex F.

As written in the methodology chapter, the first version of the merged CLD was based on the present loops and frequently occurring variables in the individual CLDs. Variables occurring in 4 or more individual diagrams were add to the merged CLD.This first version of the CLD is shown in Annex G. In the second version of the merged CLD, variables were added to represent the individual viewpoints of the respondents. This resulted in a very detailed diagram. It is given in figure 10 as an illustration. The diagram will not be elaborated, as it is too detailed to be communicated. More explanation on the diagrams will be given in 5.3.

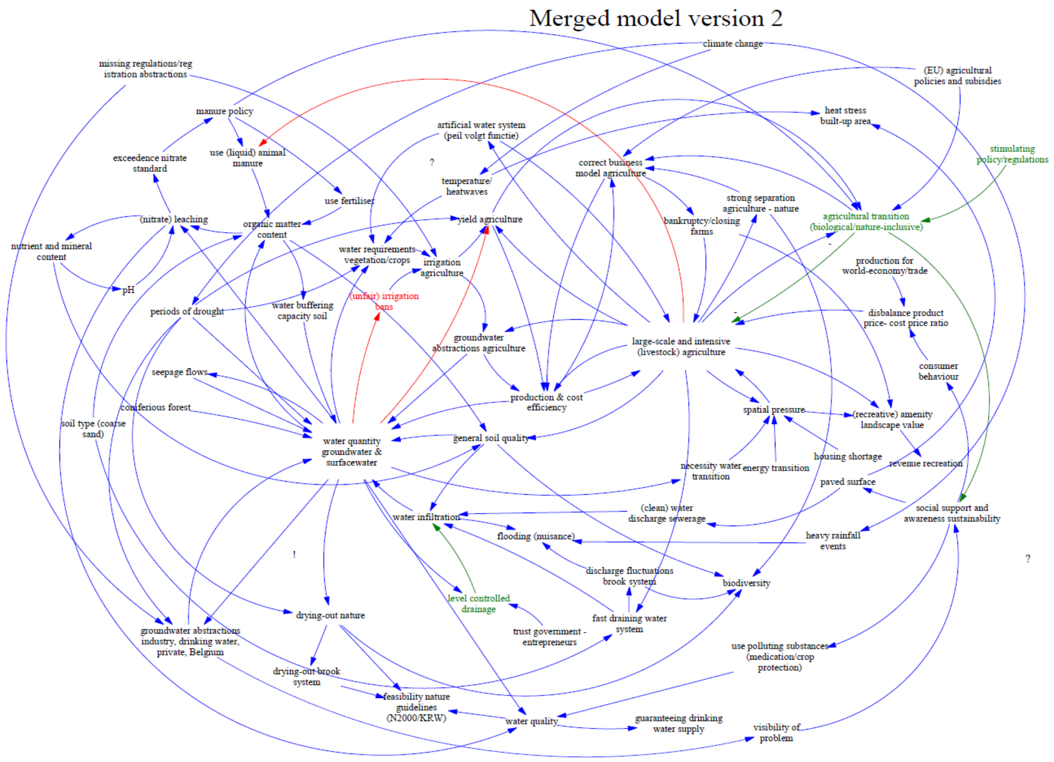


Figure 10 Detailed merged Causal Loop Diagram

5.3 Final causal loop diagrams

Three different spatial scales regarding the soil and water system were present in the individual CLDs. This became clear from the individual CLD analysis Annex F. To simplify the diagram in figure 10, three sub-diagrams were made. Figure 11 shows how the sub-diagrams are relating to each other. The fact that there are three different diagrams does not mean that there is no overlap between the topics dealt with in the diagrams. When topics play at different scales, they are included in more diagrams. The diagrams are shortly introduced below.

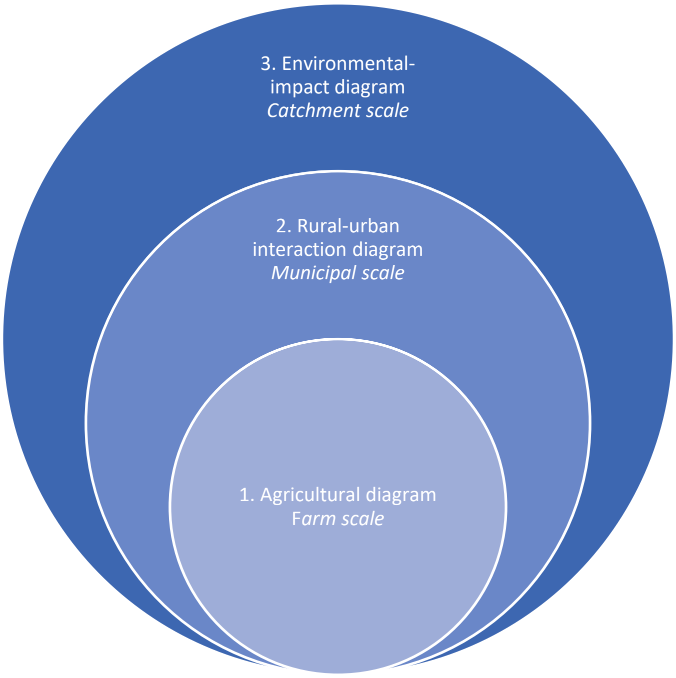


Figure 11 Overview of sub-diagrams and spatial scales

Agricultural diagram, farm-scale: This diagram considers interactions at farm-scale. This view on the system was mainly taken by farmers and farmer representatives (ZLTO). They also considered some outside pressures on the farm. Other groups of stakeholders also mentioned interactions that are covered in this diagram, but they framed these in a broader context (as represented in the following diagrams).

Rural-urban interaction diagram, municipal scale: This diagram focuses on the interaction between urban, or built-up areas and the rural area. Therefore, it is considered as the municipal scale. The agricultural diagram fits within this diagram. This spatial scale of view on the system was especially taken by respondents of the municipality and respondents who are involved in spatial planning and development.

Environmental - impact diagram, catchment scale: This diagram shows the impact of the above-mentioned diagrams on the environment, especially on the water system and nature. This diagram has the largest scale, as in principle it considers an entire catchment. This view on the system was especially taken by respondents from the waterboard and province, nature managers, and ecologists.

The diagrams are presented and explained one by one in the following sub-chapters. Information from the transcribed and coded interviews will be used for this. The diagrams as explained below are based on perceptions of stakeholders only. No argumentation from scientific literature has been added. Numbers are placed in bracket behind part of the sentences, to indicate which respondents/ interviewees mentioned what. The numbers correspond to table 2 in chapter 5.1. The terms 'respondents' and 'interviewees' are both used in the description below, but they mean the same. In the diagrams, bold arrows indicate frequent made relations or often mentioned variables in the individual CLDs. Green indicates already existing mitigation attempts or positive developments. Grey arrows show external drivers and pressures. These affect the system from the outside. Red coloured components indicate conflicting perceptions between the stakeholders. Loops are indicated with a number so that they can be referred to in the explanation.

Agricultural diagram – farm scale

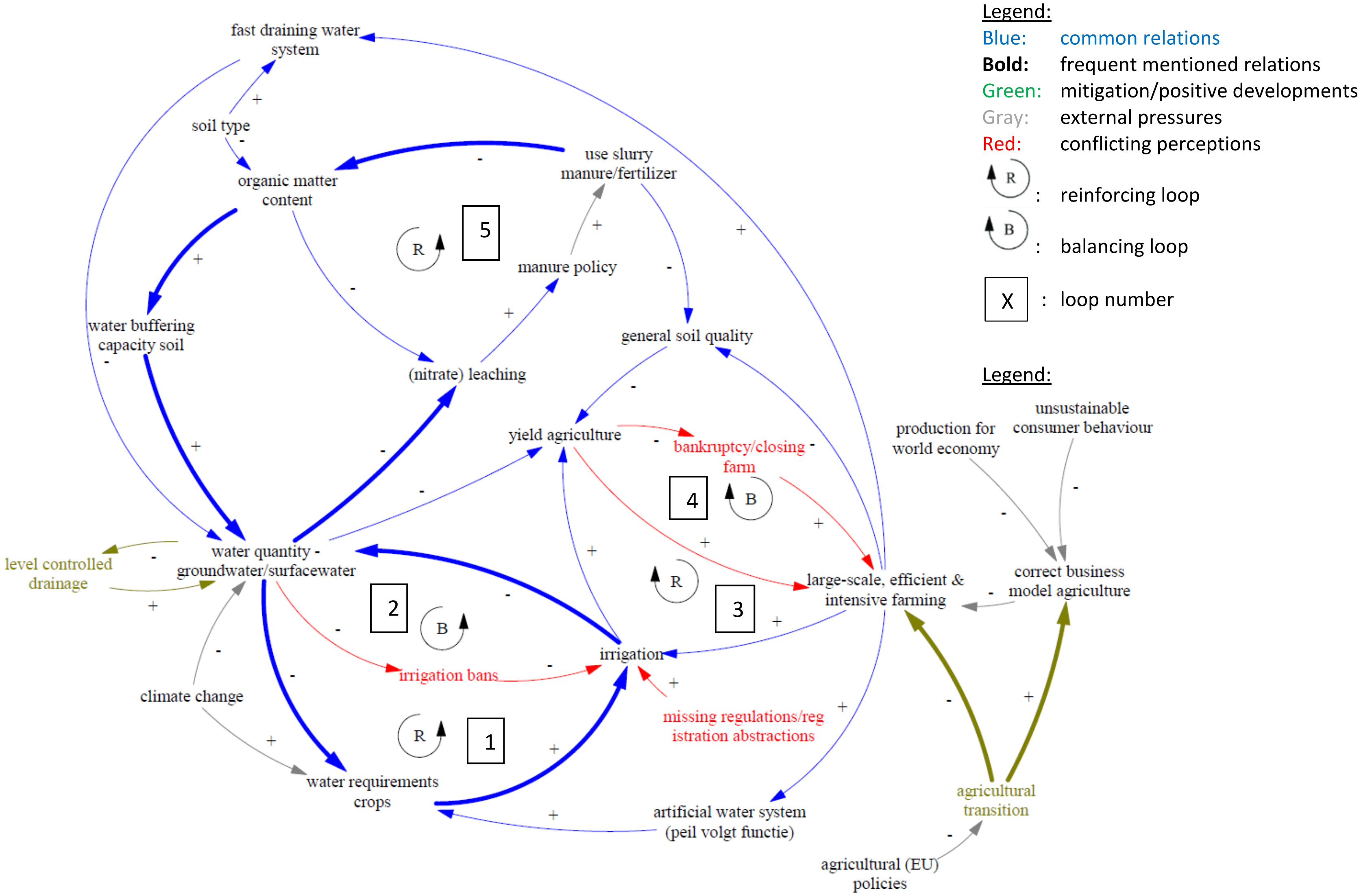


Figure 12 Agricultural diagram, visualizing stakeholders' perceptions on system interactions and problems at farm scale

Diagram explanation

Key factors in the agricultural diagram (figure 12) are ‘water quantity’ and ‘large-scale, efficient & intensive farming’. Water quantity has 5 incoming and 5 outgoing arrows. Large-scale, efficient & intensive farming has 4 incoming and 4 outgoing arrows. Although more loops are visible in the diagram, 5 main loops are explained. The other loops present are largely the same but have minor deviations.

Loop 1 is the water quantity – irrigation loop. A decrease in water quantity, especially groundwater quantity was often mentioned by respondents. 11 respondents mentioned this aspect. Loop 1 shows that more irrigation in agriculture leads to a decrease in water quantity because groundwater abstractions are needed for irrigation. A decrease in water quantity causes the crop water requirements to increase further. In return, this leads to more irrigation. This is a reinforcing loop. Respondents mentioned that this irrigation loop is reinforced because the abstraction of groundwater is relatively easy (3, 4, 7, 8, 10). For irrigation of grassland, there are restrictions (8). However, for other crops, there are fewer regulations. Permits for a groundwater pump can be obtained relatively easily. Next, it is easy to get around the pumping rules, which makes registering all groundwater wells difficult.

Loop 2 shows that respondents also mentioned a balancing loop regarding water quantity. Respondents stress that there are irrigation bans, especially on grassland and that regulations become more strict because of the decreasing water quantity. As the irrigation policy is complex and diverse, loops 1 and 2 are conflicting. Part of the respondents mentioned that there are irrigation bans, part of them did say that the impact of the irrigation bans is negligible.

An often mentioned pressure of the irrigation loop (loop 1) is large-scale & intensive agriculture and livestock farming in the area. This variable occurred in the individual CLD of 9 respondents. Respondents said that the intensive way of agriculture dates back to the land reclamation period in the previous century. During this period, especially south of Reusel, heathland has been reclaimed and the agriculture has been organised according to cost-efficiency. The livestock density in the area is high and in addition, maize and grass are produced on large scale for the livestock (7,8). Next to that, potatoes are produced, especially for fries-producing companies (13). Intensive agriculture does not stand alone. External drivers or pressures, outside the farm scale, are also recognised by respondents. Because of free world trade, agriculture is producing for export a lot. In addition to that, consumer behaviour is unsustainable and people want to buy food for low prices (9,13). This causes that agriculture needs to maximise production while minimizing costs. This causes an unsustainable business model and agriculture to become more and more intensive.

The water quantity problem is reinforced by the fact that the water system in the area is designed for quick drainage of the water. From the past, the water management in the area has been organized according to the principle of ‘water level follows function’. This means that the water management is adapted to the land use in the area and not according to the natural optimal situation. An artificial water system has been developed. Especially for agriculture, ditches were straightened and drainage was constructed. This also has an impact on the farm scale, as the water is drained quickly from the farm. Because of the artificial water system, crops are not always grown in a suitable location. This means that crop location is not adapted to landscape properties. For example, potatoes are grown in higher areas, where water drains quickly. Therefore, this increases the water requirements of the crops. As long as agriculture can irrigate crops, the yield will not decrease. However, at the same time the decrease in water quantity in the area also directly leads to a decrease in yield. The impact of yield on the scale and intensity of agriculture is seen differently by respondents. This is shown below, by explaining loops 3 and 4.

Loop 3 shows that an increase in the yield of agriculture leads to even more large-scale and intensive agriculture. The consequence of this is an increase in irrigation, leading to more yield. This is a reinforcing loop. The explanation behind this is that as long as farmers can get yield, or sell their livestock, there is no incentive to produce more sustainably. Then the agriculture becomes more large-scale again.

Loop 4, however, shows that other respondents recognised a balancing loop regarding the yield of agriculture. Normally, when farms go bankrupt, agriculture becomes more intensive. Often the smaller farms in the area close and the larger farms take over their land. These farms then become more large-scale and start to produce even more intensive and efficient. However, when yield increases, fewer farms have to close or go bankrupt. The scale of farming stays at the same level or decreases and irrigation decreases. A balancing loop occurs.

Loop 5 shows the perception of stakeholders on the decreasing organic matter content in the area. Stakeholders mentioned that by themselves, the sandy soils in the area are sensitive to leaching and have a low organic matter content. Because of that, there is leaching of nitrate towards ground and surface waters. The government of the Netherlands reacts to this by making the policy and regulations for manure more strict (2,5). Therefore, the farmers can only use fertilizer or inject slurry manure during parts of the season. Stakeholders state that as a result of this, organic matter content in the soil further decreases, resulting in more nitrate leaching, et cetera. The organic matter content also impacts the water buffering capacity of the soil, leading to a decrease in groundwater quantity.

Mentioned mitigating interactions

Later in the results chapter, leverage points to make the system robust are given. However, stakeholders already mentioned current mitigation strategies or 'positive' developments having an impact on the farm-scale (visualised in green). Respondents 1,2 and 6 saw level controlled drainage as one of the solutions regarding the water quantity at the farm scale. Level controlled drainage can help to regulate the water level on the plot level, by bringing water into the soil (1). However, as it can also be used as drainage it is difficult to include level control drainage in the regulations of the waterboard. Therefore, it is not yet implemented on a large scale (1,6). The agricultural transition was mentioned by 9 respondents. The view on how the agricultural transition will change the system exactly differs, but it mainly reduces the large-scale and intensive agriculture. Because of the agricultural transition, more attention is paid to nature-inclusive- and biological farming. Other types of crops are grown and crops and meat are produced with larger regard for the environment. Although (European) agricultural policies and the financial system partly restrict the agricultural transition, there are farmers in the area who are already engaged in alternative ways of farming.

Rural-urban interaction diagram – municipal scale

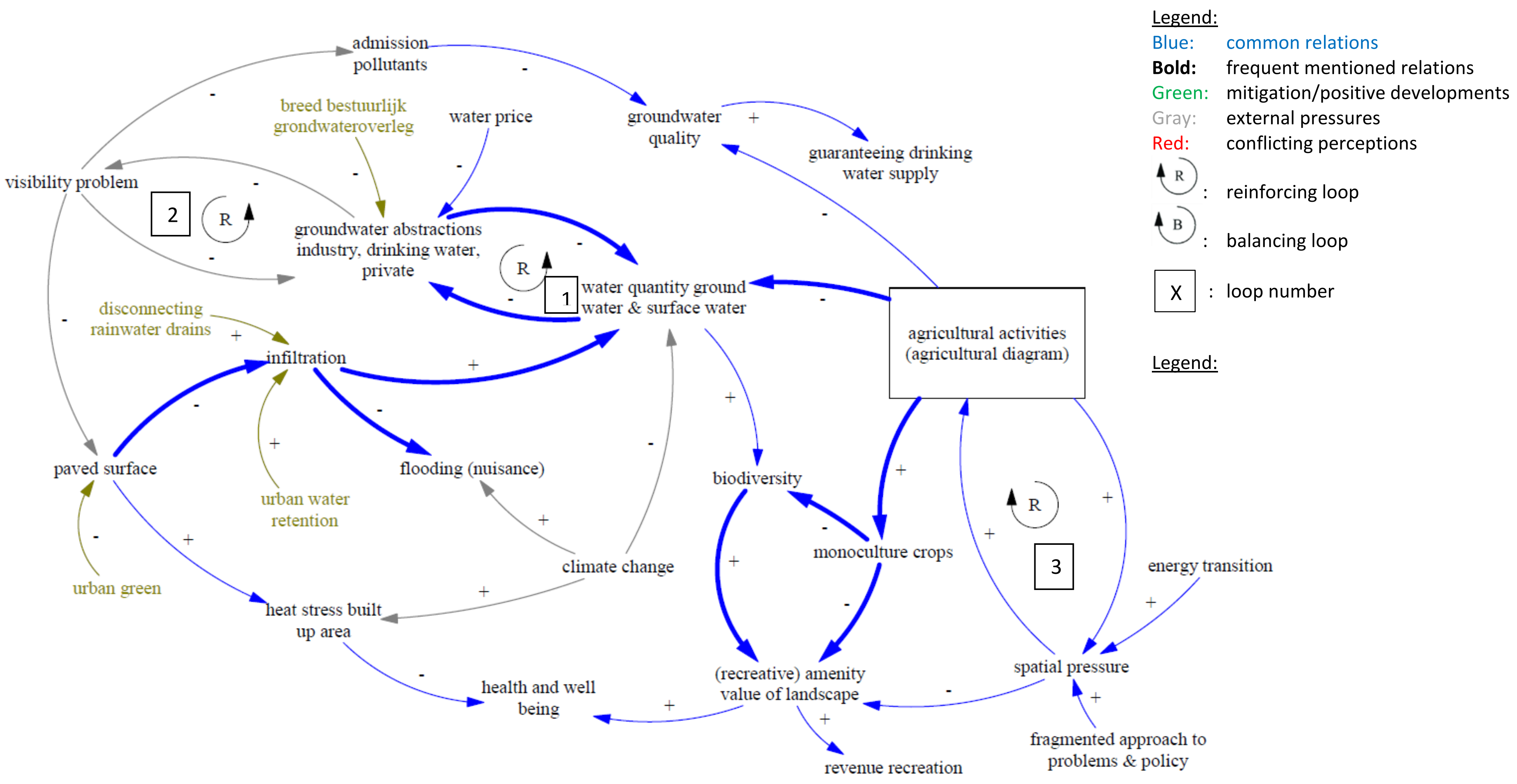


Figure 13 Rural-urban interaction diagram, visualizing stakeholders' perceptions on system interactions and problems at municipal scale

Diagram explanation

The rural-urban interaction diagram (figure 13) shows the interactions between the rural- and built-up area. The rural area here mainly refers to the agricultural area. Therefore, the position of the previous agricultural diagram is visualised using a box. This diagram is here summarised with 'agricultural activities'. Three important loops are visible in the diagram. The other causal relations are linear.

Loop 1 shows that stakeholders perceive groundwater abstractions for industry, drinking water, and private purposes as another cause for the decreasing water quantity, especially for decreasing groundwater levels. However, there was no full agreement on the degree of impact of these abstractions on the groundwater level. Groundwater abstractions for drinking water were mentioned. For example in Flanders (Belgium) and at Luyksgestel, a place southeast of the study area (2,3,8,10,11). In addition, in Belgium, there are groundwater abstractions for industry, as well as in the Netherlands, for example for beer breweries. This water is withdrawn from the deep groundwater. At the surface, this has an impact on the shallow groundwater and surface water as well (8, 10). However, for example, respondent 7 explained that the abstractions at Luyksgestel only have small or no impact on the water system in the area around Reusel. The lack of clarity among the stakeholders is especially caused by the fact that there is not always good documentation on how groundwater flows and how it impacts seepage flows(1). Next to increases in pumping for industry and drinking water, there has been a strong increase in abstractions for private purposes in the past 10 years (8). As the groundwater decreases, more water needs to be pumped up. Therefore, loop 1 is a reinforcing loop.

Loop 2 shows that as long as more and more water is being pumped up for society, there is no visibility of the problem (8). Groundwater levels are not visible and therefore not seen as a problem by society. When the problem is not visible, more water is pumped up. Therefore, this is a reinforcing loop as well.

When problems are not visible and recognised, polluting medicines and industrial substances will still be allowed, reducing the groundwater quality when entering the environment. Groundwater quality is also seen as being decreased by the use of fertilizers and crop protection products in agriculture. As groundwater quality decreases further, the drinking water supply cannot be guaranteed in the long term (4, 14).

Another mentioned problem is the amount of paved surface in the built-up area. Because of the expansion of the urban area (3,8), the infiltration capacity in those areas reduces. For example in Reusel, Bladel and Hapert, there are industrial zones, where large parts of the area are paved. During peak rainfall events, parts of the area get flooded, as the sewer gets overloaded and the water cannot infiltrate (1,7,8,9). Infiltration is also seen as important for water quantity in the area. When infiltration increases, water can infiltrate towards groundwater and increase water quantity (1,2,7,8,9). Climate change reinforces the flooding problems and also the heat stress in the built-up area when there is too much paved surface.

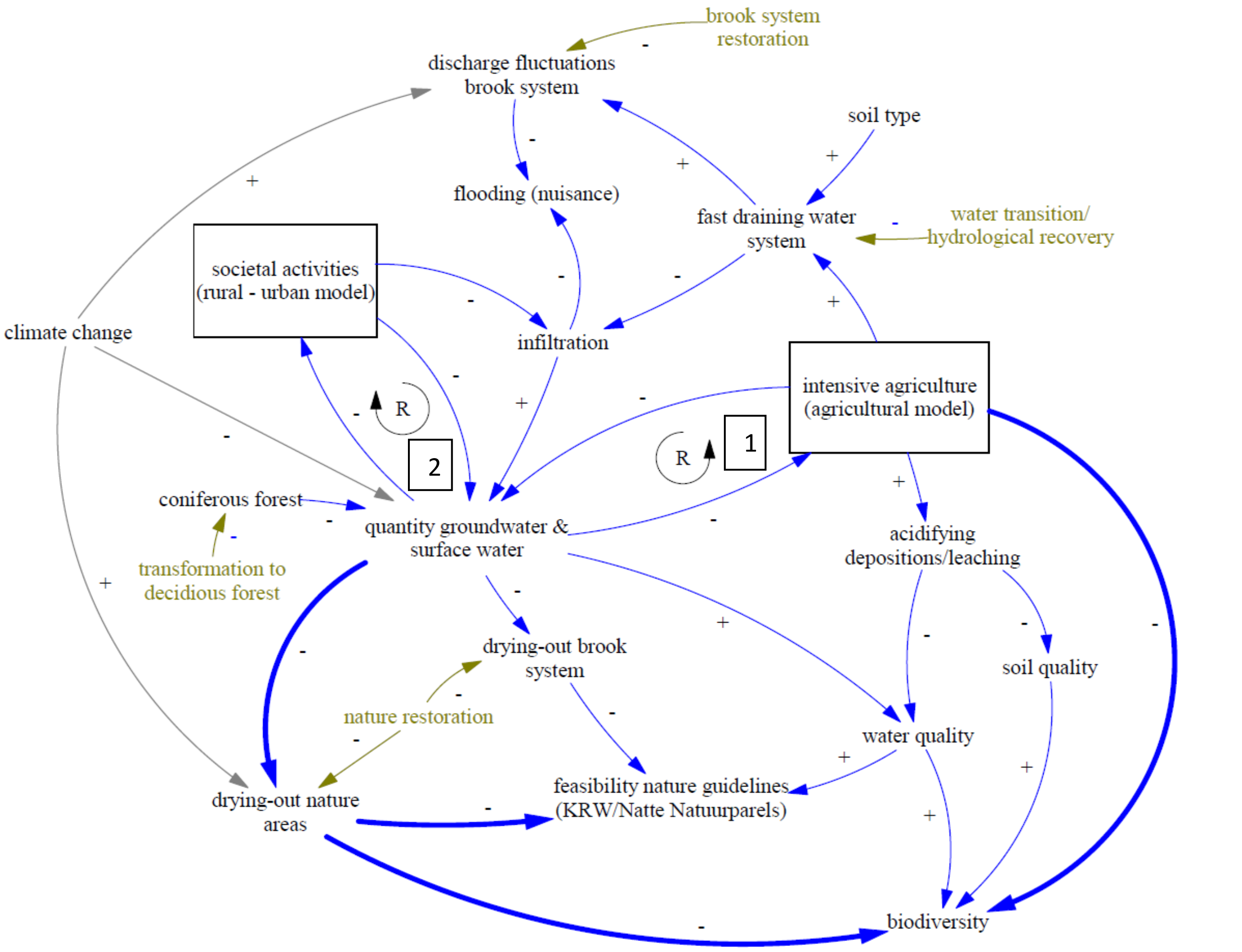
Loop 3 is mentioned by 2 respondents (5,13). Because of the large-scale agriculture in the Netherlands, spatial pressure occurs. At the same time, one respondent (5) also mentioned that when agriculture becomes more extensive during the agricultural transition, more land is needed. This also increases spatial pressure. Because of the spatial pressure, agriculture feels the need to produce more efficiently. This results in a reinforcing loop. Spatial pressure is also increased by other developments and land use functions, like the energy transition and housing shortage. When there is a fragmented approach towards spatial planning, it is difficult to solve the spatial pressure. More spatial pressure harms the (recreative) amenity value of the landscape. This value also decreases because of the large-scale agricultural activities. Monoculture crops lead to a monotonous and close landscape, where interesting landscape elements are missing. This harms the health and wellbeing of the inhabitants of the area, as well as on recreation. On the other hand, when agriculture becomes more nature-inclusive, for example, the landscape value can change, because of more (natural) variation in the landscape.

Mentioned mitigating interactions

Urban water retention, disconnecting rainwater drains, and increasing urban green are seen as ways to mitigate the problems concerning infiltration and paved surface (1,7,10,13). The waterboard, municipalities, and province are working on this already. For example as part of 'Deltaplan Hoge zandgronden', parts of the industry zone 'De Sleutel' are disconnected and water is transported to a wadi outside the industry zone (10). Deltaplan Hoge zandgronden is an implementation program for Climate adaptation in the southern part of the Netherlands. Also, private individuals are encouraged to apply more green in their gardens and disconnect rainwater drains.

Further, respondents mentioned the 'Breed bestuurlijk grondwateroverleg' as having a regulating impact on the groundwater abstractions (4,8). This is a consultation between parties in Brabant about the drought problem and how the groundwater abstractions can be regulated better. For example, the Province of Brabant, waterboards, municipalities, and drinking water companies are involved.

Environmental-impact diagram – catchment scale



Legend:

Blue: common relations

Bold: frequent mentioned relations

Green: mitigation/positive developments

Gray: external pressures

Red: conflicting perceptions

R : reinforcing loop

B : balancing loop

X : loop number

Legend:

Figure 14 Environmental-impact diagram, visualizing stakeholders' perceptions on system interactions and problems at catchment scale

Diagram explanation

In the environmental-impact diagram (figure 14), no new feedback loops occur. Therefore, it is named 'impact diagram', as it especially shows the impact on the environment at the catchment level. The positions of the two foregoing diagrams are visualised in the diagram.

When considering the impact on the environment, or catchment, again stakeholders saw water quantity as the main problem variable. In this diagram, water quantity has 5 incoming and 5 outgoing arrows. **Loop 1** shows the reinforcing impact of large-scale and intensive agriculture on water quantity. This was explained in the agricultural diagram. **Loop 2** shows the reinforcing impact of societal activities on the water quantity. This was explained in the rural-urban-interaction model already. The water quantity in loop 2 is mainly impacted because of groundwater abstractions for drinking water, industry, and private purposes.

Water quantity is not only decreased by societal and agricultural activities. Stakeholders mentioned other causes of a decreasing water quantity in the catchment as well. The forests in the southern part of the study area are mainly monotonous coniferous forests. The forests are located at the highest points in the area, where water should infiltrate. They were planted during the land reclamation period when heathland turned into farmland. In the forests, evaporation is high and water retention is low. Therefore, it harms the water quantity and the seepage system is disturbed by it as well. Further, the agricultural diagram showed that respondents mentioned that the water system in the area is focused on fast drainage. This has an impact on the farm scale. However, fast drainage of water was also mentioned as impacting the water quantity on the catchment scale. Strong discharge fluctuations in the brooks are another consequence of the fast-draining water system(1,3,9,10,12). During peak rainfall events, the brooks cannot cope with the water. This leads to flooding, as also shown in the rural-urban interaction model.

The decrease in water quantity, groundwater, in particular, causes drying-out of nature. This was mentioned by 10 respondents. Other sectors can pump up water, but nature cannot do this(3,8). Therefore, the decreasing groundwater levels especially cause problems in the nature areas. For example the peat moor nature area 'Reuselse Moeren' falls dry. Normally, this area is permanently under water (1,3). At other places in the study area, nature dries up as well. The decrease in water quantity also gives problems in the brook system. Especially during summer, large parts of the brooks fall dry (1,3,10,12). This, while normally the brooks should permanently discharge water(3). The drought in nature areas and the brook system harms biodiversity. The brooks contain rare fauna, that dies (10). North of the study area, the estate 'Landgoed de Utrecht' is located. Some of the brooks in the study area flow towards the estate. The water board had to pump groundwater in the brooks there to keep the fauna alive in the years 2018-2020 (3). The drought also has an impact on biodiversity in the fens and wet heathland areas.

Climate change is seen as an external pressure by the respondents, reinforcing the above-mentioned issues. Because of an increase in average temperature, evaporation increases. In addition, there are long periods of low precipitation, especially during summers. The summers of 2018-2020 are examples of this. The increase in temperature and low precipitation have an impact on water quantity, but also increase drying-out of nature directly. Stakeholders also mentioned that peak rainfall events occur more often. This increases the chance of flooding in the stream valleys.

Both nitrogen and sulphur contribute to acidifying depositions. Nitrogen mainly originates from agriculture. One respondent also mentioned the sulphur depositions, from the previous century as having an impact on the area. The acidifying depositions and decreasing groundwater table lead to oxidating processes in the soil and leaching of nutrients. As described in the description of the study area, the soil type in the area is already prone to leaching and oxidation. This increases the process of leaching even more. Because of these processes, the soil becomes toxic, as the pH decreases(12). This harms soil quality and biodiversity. Stakeholders mentioned that the water quality is impacted as well. Leaching from soils leads to high levels of nutrients in surface water and groundwater. Also, direct nitrate runoff from agricultural plots contributes to this.

The problems regarding water quality and quantity cause that guidelines for nature are difficult to be met. The brooks in the area are part of the 'Kaderrichtlijn Water' (KRW). The KRW gives guidelines for the quality of ground and surface water. It is difficult to meet the guidelines when water quality decreases. 'Natte Natuurparels' also belong to the policy of the KRW. These are wet nature areas, prone to drought (10). The waterboard and province are responsible for the conservation of these areas (7,10). Although there is no nature with N2000 status in the study area, respondents did mention the decrease in the feasibility of N2000 guidelines, province-wide. For example Landgoed de Utrecht is a N2000 area (7).

Mentioned mitigating interactions

Respondents mentioned different ongoing developments to decrease the vulnerability of the catchment. Nature restoration can help to alleviate the problems concerning water quantity, drying-out of nature, and the decrease in biodiversity. Nature restoration for example consists of transforming the coniferous forest to deciduous forest (1,3,12). Although this is not conducted on large scale yet, it is in the ambition map of the Province of Brabant, to obtain more diverse forest areas. Another way of nature restoration is converting nature areas back to heathland. This improves habitat conditions and can therefore increase biodiversity. However, when heathland has to be restored, forests need to be cut. A current limitation for this measure is that cutting forests is not considered positive by society (12).

Further, changes in the water system can help to bring back the water system to its natural conditions. An example is a hydrological recovery, where attention is being paid to restore the seepage system in the area. Seepage flows are essential for nature, so attention has to be paid to the places where water inundates how it flows towards nature areas (7,8,12). This falls within the broader assignment of the water transition, where the waterboards, Province of Noord Brabant, and municipalities are currently working on. Slowly, the focus of water management is changing from water discharge towards water retention. In the area, for example, this is done by removing drainage. Also, the land use (for example crop types) is adapted to the natural conditions of the area and water system (1,4,5,7,8). Brook system restoration was also mentioned as an example of the water transition, which reduces vulnerability towards climate change of the brooks in the area. The straightened streams are made more meandering, with natural banks. For example, this can help to reduce the discharge fluctuations in the brooks. Although the above-mentioned developments are ongoing, respondents mentioned that they have to be implemented and improved much further.

5.4 Triangulation on diagram content

As described in the methodology, a workshop was organised to analyse the presented diagrams and to draw and discuss lessons on the used methodology. An elaborate report of the organised workshop is given in Annex H. In the first part of the workshop, the content of the diagrams was discussed, as a way of data triangulation. The findings of that discussion are given now. The other part of the workshop outcomes (leverage points and discussion on methodology/concepts) are given in 5.6 and the discussion chapter. The participants of the workshop will be referred to as 'the participants'. Sometimes a comparison is made to the opinion of the interviewed stakeholders. These will be referred to as 'the stakeholders'.

After the three sub-diagrams were presented, participants of the workshop were asked to reflect on the content of the diagrams. It was asked whether they recognised the interactions as mentioned by the stakeholders during the interviews. In particular, participants focussed on the agricultural model, as this diagram led to the most discussion. Two parts of the diagram were discussed in particular. A participant from the waterboard mentioned that the regulations around groundwater abstractions and irrigation for agriculture are not as simple as presented in the agricultural diagram. From the diagram, it seems as if there are almost no regulations, but this is more nuanced in reality. Irrigation- and groundwater abstraction bans differ for grassland and other types of crops. In addition, a permit is required to install groundwater pumps. This partly strikes with what the diagram shows and what stakeholders said. Most of the stakeholders mentioned that using groundwater for irrigation is very easy and at low costs. This discussion point during the workshop made clear that the irrigation and groundwater abstraction policy is complicated and more research and nuance are needed to visualise this in a diagram correctly. The discussion also arose on the organic matter content loop (loop 5) in the agricultural diagram. A respondent mentioned that when looking at soil organic matter content maps, the percentage of organic matter content in the area around Reusel is sufficient. This contradicts what is shown in the diagrams, as stakeholders mentioned that organic matter content in the area is too low. In addition, participants of the workshop mentioned that the beneficial impact of organic matter content on the water buffering capacity of the soil is uncertain.

The discussion as described above led to another discussion. Participants of the workshop realised and mentioned that it is not important whether the interactions in the diagram are scientifically correct. As the diagrams are based on perceptions of stakeholders, it shows how they perceive interactions in the soil-and water system. As experts or scientists, you could change the diagrams based on what you perceive to be the right representation of reality. However, the diagrams are especially useful to get more data on how stakeholders' perceptions of the system. This is an important starting point when entering into a dialogue with stakeholders about the climate-robustness of the system.

Concluding, at least it was observed that water quantity is an important problem variable in the perception of stakeholders. This should be at the center of the further development of adaptation pathways. It was remarked that that in addition to the CLDs, more information is needed on the water flows in the area. A water balance, for example in the form of a Sankey diagram, could give a more clear overview of water use. This water balance could then be compared to the mental models (CLDs) of the stakeholders and help in the development of adaptive pathways.

5.5 Leverage points for a robust system

Leverage points for obtaining a climate- robust soil- and water system were discussed both during the stakeholder interviews and the expert workshop. The results are described below.

Leverage points – stakeholders' perception

In the causal loop diagrams, some important current mitigating developments, measures, and policies for the problems were given already. Those were based on presence in the individual CLDs. However, during the interviews, stakeholders were also asked what they see as key leverage points or opportunities to make the soil and water system robust and decrease its vulnerability. The leverage points were divided into five main categories, as shown in figure 15. Most opportunities fell within the category of 'Changes in water system design and management'. 'Changes in agriculture' were recognised as a leverage point as well. The opportunities in the categories of 'Area-oriented approach towards environmental & spatial functions' and 'Awareness raising & incentives for sustainable behaviour and adaptation' are especially on the institutional and policy side of adaptation. Some other separate opportunities were mentioned as well, included in the category 'others'.

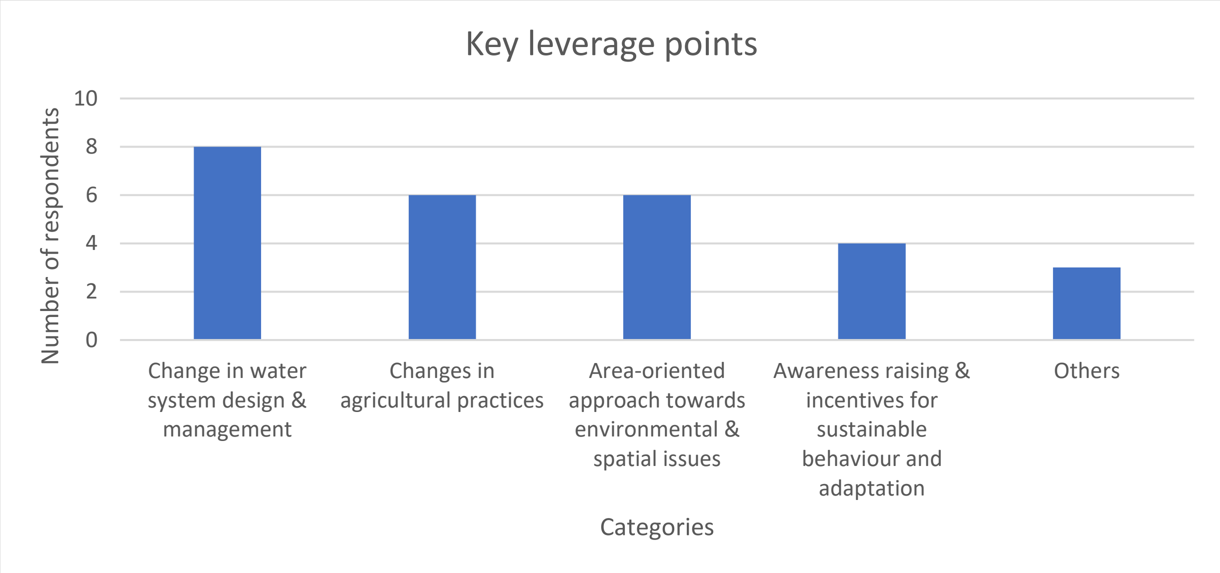


Figure 15 Categories of key leverage points, indicating the number of respondents mentioning opportunities falling within the categories

Table 3 gives an overview of the main mentioned opportunities per category of leverage points. An explanation is added as well, based on the remarks of the stakeholders. Some categories have overlap with other categories. For example, the principle of 'land use function follows water level' (category: changes in water system design & management) needs an integrated or area-oriented approach to be implemented.

Table 3 Main mentioned opportunities per category of leverage points, with explanation

Category	Mentioned opportunities	Remarks of stakeholders
Change in water system design & management	- Management principle of land use function follows water level (functie volgt peil) - Change the fast drainage of the water system - Create a more meshed water system	When soil and water system is robust, other functions can be built on it. Adapt functions to what is possible at the location. Change the fast drainage by retaining water. For example by closing excavated upper water courses and deactivating drainage. Local knowledge is important to achieve these points. Locals know where interventions in the water system are needed.
Changes in agricultural practices	- Switch from intensive to extensive agriculture - Change the agricultural business model - Decrease nitrogen deposition	Through changing the business model, farmers can become responsible for other functions, like energy, water retention, and increasing biodiversity. Extensive agriculture offers opportunities for this. Other crops can be cultivated, which are well-adapted to the area, and drought-resistant. Regional products can be produced through nature-inclusive farming. This can help to reduce the scale of agriculture. As the agriculture in the area is large-scale already, most respondents are

		sceptical towards intensive forms of agriculture. For example towards forms where agricultural production is combined with energy and water production.
Area-oriented approach towards environmental & spatial issues	- Combine land use functions - Cover all objectives in policy/visions - From individual to joint responsibilities	An integrated institutional approach to programs, policy, and implementation is needed, on the landscape level. Necessary to deal with different spatial functions, transitions, and challenges. Province, waterboard, and municipality are jointly responsible. However, an organisation acting on a regional scale (e.g. 'Huis van de Brabantse Kempen') has potency for coordinating, as it can switch between long term and short term perspective. Use local knowledge and motivation to prevent the approach from becoming bureaucratic. Respondents argue that such an area-oriented approach is most promising in solving the issues at stake.
Awareness-raising & incentives for sustainable behaviour and adaptation	- Create (political) support for change - Change consumer behaviour - Financial incentives for reducing pollution and sustainable investments (private and companies)	When there is more public support for changing the system and problems are recognised, this will also lead to political changes (e.g. changes in agricultural policy). In addition, when consumers pay fair prices for their food, farmers can pay more attention to sustainable farming methods. Further, the government can financially stimulate entrepreneurs to do sustainable investments, for example, to reduce pollution or take climate change adaptation measures. When 'frontrunners' are rewarded, others will take over. This also means that large water users or polluters have to pay more tax.
Other	- More natural vegetation in nature areas - Change manure policies and legislation; fertilization according to potential - Create more trust amongst government - farmers	Increasing natural vegetation in the nature reserves decreases the vulnerability of nature to (external) pressures, as it becomes more diversified and adapted to local conditions. For example, deciduous forests require less water than the planted coniferous forests. When animal manure can be applied according to the required amount, the reinforcing loop in organic matter content can be broken through and crops can be produced more efficiently. Trust amongst government and farmers can help to upscale measures in the soil and water system, which now difficult to be implemented within the current system of

		regulations. An example of such a measure is level-controlled drainage

Leverage points – expert perception

While in the stakeholder interviews the perception on leverage points was inventoried, a discussion on leverage points was also organised during the expert workshop. Sometimes, during this workshop discussion, the mentioned opportunities went into the direction of concrete solutions already, instead of discussing leverage points. In contrast to the stakeholder interviews, the discussion with experts was based on the 'final' diagrams. Participants were asked what is at the heart of the problems in the system and what this means for making the soil and water system in the study area climate robust.

From the diagrams, participants concluded that 'water quantity' is the most important problem variable. Therefore, the robustness of the system seems to be dependant on water quantity. A participant then mentioned that the irrigation loop in the agricultural diagram is a central one, connected to the water quantity and caused by intensive agriculture. Therefore, to make the system robust, more attention should be paid to agricultural policy and the agricultural transition. This could break through the reinforcing irrigation loop. For example, when farmers would change their business operations and start to grow other types of crops, this can reduce the crop water requirements. Meanwhile, the agricultural transition contributes to improving the soil quality. However, it was also mentioned that the agriculture in the area around Reusel is still large-scale and focused on efficiency. Therefore there is a long way to go to change this.

On the rural-urban interaction model, it was remarked that only reinforcing loops are visible and no balancing loops. This shows that the system is vulnerable and things are getting out of hand. Respondents mentioned that from that diagram it seems as if 'paved surface' and 'groundwater abstractions' are the main causes of the problems in this diagram. Reducing the amount of paved surface and groundwater abstractions could make the system more robust. As the problem of decreasing groundwater levels and pollution is not always visible, overview and transparency in water use, abstractions and discharge are important. Two participants of the waterboard mentioned that to make changes to the system, it has added value to make use of zoning regarding solution space. This can help to go through a transition, instead of focussing on separate solutions only. To make these zones, it can be identified which measures are needed where dependent on the most urgent problems in a certain area. For example, a distinction is made between areas where drought is the biggest problem and areas of frequent flooding. In this way, zoning can also help to identify the spatial scale on which climate robustness is addressed. The use of zoning fits well in the call more integration in spatial pressure.

Because of time limitations during the workshop, the environmental-impact diagram was not discussed.

6. Discussion

This chapter provides a discussion on the conducted research. First, it is discussed how the used approach of causal loop diagrams can contribute to developing adaptation pathways. After that, the content-based results of the research are discussed. Thirdly, the methodology is discussed and recommendations for further research are given at the end.

6.1 Causal loop diagrams in adaptation pathways

Part of the context analysis in developing adaptation pathways is to understand the current (social-ecological) situation (Bosomworth et al., 2015). As Bosomworth et al. (2017) argued, a diagnostic, problem structuring approach can improve the utility of AP in complex problems. Although it was not the purpose of this thesis research to develop a problem-structuring approach, it turned out that participatory causal loop diagramming has the potential to give substance to the type of approach Bosomworth et al. (2017) aim at. In addition, the conceptual findings of this thesis research fit into two of the learning questions for the adaptation pathways framework, as posed by Werners, Wise, Butler, Totin, and Vincent (2021). The first of those questions read: *'What kind of stakeholder engagement processes promote collaborative learning about climate change, a common agenda for the future, and adaptive and transformational planning?'* The second question is: *'What diagnostic approaches can effectively map root causes of vulnerability and controlling variables, particularly across scales?'* (Werners et al., 2021, p. 8). By elaborating on different strengths of the used causal loop diagrams approach, it is shown how it contributes to filling the above above-mentioned 'knowledge gaps'. The described strengths were also remarked by experts during the KLIMAP workshop, so part of the argumentations is based on findings of that discussion.

First, constructing the causal loop diagrams (CLD) helps to elicit the 'mental models' of stakeholders on the system of interest for adaptation and its vulnerabilities. Mental models are *'cognitive representations of external reality'* (Jones, Ross, Lynam, Perez, & Leitch, 2011, p. 3). By eliciting the mental models, it can be investigated what similarities and differences exist between stakeholders' understanding of the problems in the systems. If large differences exist in stakeholder knowledge, a further conversation could be facilitated, to improve understanding and communication between the stakeholders. In case there is a shared understanding amongst stakeholders on the problem, the decision-making process for adaptation can be improved (Jones et al., 2011; LaMere, Mäntyniemi, Vanhatalo, & Haapasaari, 2020). In this research, it turned out that the mental models of stakeholders diverge in the fact that they have different spatial scales of reference when talking about the soil and water system. Part of the stakeholders framed problems and interactions at farm scale, others considered the municipal scale, or even the catchment scale. For a farmer, it makes sense to consider the problems at the farm scale and to conduct adaptation efforts to alleviate the consequences. However, it does make less sense for a farmer what happens at the catchment scale, for example, the impact on biodiversity. On the other hand, for someone from a waterboard, the catchment scale is his/her system of interest for adaptation. This is an example of differences in mental models and needs to be considered when adaptation pathways are developed, to keep all relevant stakeholders involved and motivated in the process. Involving all relevant stakeholders in the decision-making process on adaptation increases the legitimacy of the process (LaMere et al., 2020).

Second, the participatory approach to making causal loop diagrams helps to collect expert and local knowledge on the system (Jones et al., 2011). This enhances problem-solving, based on synthesized knowledge from a variety of sources (LaMere et al., 2020). In the performed research, knowledge was gathered from experts and stakeholders. This contributed to finding out critical variables regarding the robustness of the soil- and water system. For example, in this case, it turned out that water quantity should be central in the further development of the adaptation pathways. In addition to critical problem variables, the entire understanding of the system was improved, by collecting information on feedbacks and other interactions in the soil- and water system. This can help to address the core causes of vulnerability in adaptation and make a systematic change, instead of only addressing direct causes of vulnerability (Wise et al., 2014). As local and expert knowledge on the system is brought together, making and analysing causal loop diagrams is also a social learning process for both experts and stakeholders (Jones et al., 2011; LaMere et al., 2020). It guides them to improve their understanding of problems and their causes and consequences in the area of interest (Cradock-Henry, Connolly, Blackett, & Lawrence, 2020).

Third, causal loop diagrams can be used as a tool to discuss where in the system measures or policies can be most effective and feasible. This is also argued in other literature on developing system maps (Barbrook-Johnson & Penn, 2021; Cowie et al., 2019; Cradock-Henry, Connolly, et al., 2020; Noble & Walker, 2006; Stave, 2003). In causal loop diagrams, the analysis can be based on the feedbacks in the system (Maani, 2013). It is possible to discuss which reinforcing loops in the system could be weakened or be changed to balancing loops. In addition, an analysis can be done on which feedback loops arise and which are changed when interventions are done, and what it means for the rest of the (social-ecological) system. In this thesis research, this type of analysis was done during the stakeholder interviews and the expert workshop, by investigating leverage points. This information is valuable for the further process of developing the adaptation pathways, as it provides (quantitative) data about the effectiveness of measures in pathways.

The last described strength is based on a suggested idea during the expert workshop discussion. In the conducted thesis research, the causal loop diagrams were based on the current situation and not quantified. However, the approach could also be used to analyse possible futures through scenario planning. Analysing possible futures is also a step in adaption pathways development. In the traditional adaptation pathways approaches, scenarios are composed based on future uncertainties. Using a computational model, it is calculated when adaptation tipping points are reached in the future (Haasnoot et al., 2013). Causal loop diagrams, however, could help to conduct future analysis in a participatory way. Kok (2009) uses the so-called 'Story-and-Simulation approach' to develop scenarios and semi-quantify them. In collaboration with the stakeholders, narrative storylines for the future were made. Narratives in this case mean storylines, for example consisting of the expected impacts of climate change (Cradock-Henry, Connolly, et al., 2020; Kok, 2009). The storylines can be turned into future scenarios, for example on expected land use, or changes in water availability. When the scenarios are quantified, they are used as input for a model. Although Kok (2009) used fuzzy cognitive mapping, which is another type of system dynamics modelling, future scenarios can also be used in causal loop diagrams. The digital program *Vensim* provides opportunities to simulate the causal loop diagrams when formulas are added to the variables (stocks) and connections between the variables (flows). Zare et al. (2019) did such an analysis, by quantifying and running causal loop diagrams. Such an analysis can have added value, as it can complement or replace the traditional computational models used in adaptation pathways, which are often made without stakeholder input.

The last remark in this paragraph is separate from the preceding argument and focuses on the use of the concept of vulnerability in the conducted research. In the methodological framework, the concept of vulnerability has not specifically been operationalised. In the conceptual framework (chapter 2), it was mentioned that vulnerability is composed of exposure, stress, and adaptive capacity. When conducting the research, these separate products of vulnerability have not been considered. Instead, vulnerability has more been used as a synonym for 'problems' in the area and as the flip side of robustness. The specific operationalisation of vulnerability in the framework of causal loop diagrams could be further improved.

6.2 Discussion of results

In this section, the content-based findings of the research will be discussed. The findings are compared to literature and a reflection is made on the meaning of the conducted context analysis and identified leverage points for developing adaptation pathways in the area surrounding Reusel.

Constructed causal loop diagrams

The outcomes of the performed analysis give a rich overview of the stakeholders' values, goals, and knowledge of the soil and water system around Reusel. In addition, the causal loop diagrams give an integrated overview of vulnerabilities in the area, their symptoms, and root causes. Adaptation is most effective when both the symptoms and root causes of vulnerability are addressed (Werners et al., 2021).

Literature comparison

To my best knowledge, a participatory exploration as conducted in this thesis research has not been made for the elevated sandy soil areas in the Netherlands. Therefore, findings will first be compared to literature which applied causal loop diagrams to other areas and problem contexts. Inam et al. (2015) developed causal loop diagrams in a participatory way, to involve stakeholders in building a model for informing decision-making on soil salinity management in a river basin in Pakistan. Their 'merged' model, was divided into various sub-models, addressing the agricultural, social, environmental, and economic components of the system of interest (Inam et al., 2015). Although the sub-diagrams in this thesis research were not made based on these categories, the themes were still present in the causal loop diagrams. This means that it is reasonable to assume that when developing adaption pathways for the area around Reusel, the agricultural, social, environmental and economic components of the system need to be considered. The system of interest is broader than only the physical or ecological aspects of the soil and water system. Werners et al. (2021) confirm this, by mentioning examples of root causes of vulnerabilities that are located in the socio-economic or political system. They mention 'governance misfits', 'political barriers', 'cultural barriers', and 'constrained resources access' as examples of root causes (Werners et al., 2021). In the analysis for the Reusel case study area, for example it turned out that the agricultural transition is restricted by agricultural governmental agricultural policies and cultural barriers, like consumer behaviour. In further development of adaptation pathways for the area around Reusel, it is good to consider these political rules and societal values.

Another similar type of research is the paper of Cradock-Henry, Blackett, et al. (2020). The authors intended to inform regional adaptation planning in Hawke's Bay, in New Zealand. By expert elicitation, taking insights from stakeholders, and system dynamics modelling, an investigation was made of the likely impacts of climate change on regional farming systems. In their analysis, the interactions between elements in the agricultural system were considered, as well as its location in the entire social-ecological system around it. As Cradock-Henry, Blackett, et al. (2020) write, stakeholders, see that there is an impact of climate change on the farm level. For example, a decrease in precipitation leads to drought, limited farm productivity, and pests. Excess precipitation can lead to floods on farm plots. Pressures on freshwater resources were also seen on a regional, or landscape scale. Watercourses have been modified from their natural state, which makes water provision difficult, and water demand in the area increases because of climate change. Such problems were also mentioned by the stakeholders in the Reusel case study area. Moreover, the findings of Cradock-Henry, Blackett, et al. (2020) also show that there are different spatial scales of reference towards environmental problems in the mental models of stakeholders. This was also a finding of the study of Lange, Siebert, and Barkmann (2015). They focussed on different case study areas in Germany, to explore the views of land use stakeholders on sustainable land management in these areas. Involved sectors were: 'agriculture', 'forestry', 'water management' and the 'sector of rural planning and development'. The study showed that stakeholders argue concerning their specific spatial scales. The interviewed stakeholders talked about topics within their sphere of action. The farmers and forestry land managers had a strong local focus, on their working environment. The water managers had a focus on a regional scale (Lange et al., 2015).

The above-mentioned differences were also present in perceptions of stakeholders in the area surrounding Reusel, as some stakeholders especially talked about the farm scale, others on the municipal scale and another group considered the catchment scale. It is therefore important to consider this sphere of action or interest of the stakeholders when developing adaptation options in the region. Discussion and conversation between various stakeholder groups should be encouraged and continued. This is needed to motivate stakeholders to think out of their sphere of action or interest. In addition, the conversation can contribute to guarantee that measures are taken on the local scale align with measures on the regional scale and vice versa.

Central problem variable

The views of stakeholders on the system of interest largely match with the literature analysis which was made in the first step of the thesis research. Soil quality, water quality, and water quantity are the main topics of concern, although water quantity seems to be the main problem variable. The 3 sub-diagrams showed that water quantity amongst others is impacted by climate change and reinforcing loops in groundwater pumping. This has its effect on the entire catchment. During the expert workshop, it was therefore discussed that water quantity, especially groundwater quantity should be central in the further development of the adaptation pathways for this case study. When future explorations are done and adaptation tipping points are defined, these can be based on water quantity. In that case, certainly, the problem variable is widely recognised by the stakeholders.

Soil organic matter content

As written in paragraph 5.5 it is not the question of whether the stakeholders' mental models can be scientifically proven. Therefore, it is not the objective of this study to 'test' the correctness of causal loop diagrams against scientific literature. However, for one aspect a comparison to scientific literature is made now. A decrease in organic matter content was perceived as an important vulnerability of the soil and water system by stakeholders. A lot of discussions arose on this during the expert workshop, as participants of the workshop mentioned that stakeholders are echoing each other on this point, while the argumentations are not scientifically proven. To compare, Wosten, Groenendijk, Veraart, and van der Lugt (2019) confirm that there are worries about a decrease in organic matter content on Dutch agricultural soils among farmers. The right level of organic matter in the soil is a basis for water- and nutrient availability, carbon storage, resistance to pests and diseases, crop production, and the possibility for cultivation with machines. When organic matter content is at the right level, agricultural soils also resist pressures, like drought and extreme precipitation. Surprising, however, is that the soil organic matter content map of Van den Berg et al. (2017) shows that the organic matter content in the study area is between 0.04 – 0.05 kg/kg. This is average compared to the rest of The Netherlands. According to Wosten et al. (2019), for soils where organic matter content is >3%, an increase in organic matter content with 1% will lead to 1mm extra of water available. Given that 31500 kg of 'fresh organic matter' per ha is needed to increase the organic matter content by 1%, it is questionable whether focusing on organic matter content is beneficial from a cost-benefit ratio point of view. In addition, the regulations and restrictions to applying animal manure were seen as a limitation for organic matter content, driving a reinforcing loop. Applying animal manure and compost is effective in the short term, but not in the long term. In the long term, other measures are more effective, especially decreasing the intensity of tillage and guaranteeing a soil cover during winter. The exact effects of the impact of organic matter content on field-, farm- and catchment levels are still being further investigated (Wosten et al., 2019). This, again, shows that perceptions of stakeholders are not automatically in line with the scientific literature. When developing adaptation pathways, stakeholders' perceptions on important problems should be considered, to guarantee that adaptation measures match stakeholders' urgencies and priorities.

Leverage points

Comparison stakeholder- and expert view

Based on the problem- or vulnerability analysis, leverage points in the system were defined. The mentioned leverage points in the expert workshop largely matched with leverage points mentioned by stakeholders during the individual interviews. For example, the experts mentioned a 'policy change in agriculture' as a leverage point. This falls within the category 'changes in agriculture', of table 3 in chapter 5, which means that it corresponds to the stakeholder-based leverage points. Another leverage point or solution direction mentioned by the experts is 'dividing the area into zones regarding solution space'. This leverage point fits in the category of 'area-oriented approach towards environmental & spatial issues'.

Literature illustrations

To put the findings into perspective, table 4 provides literature examples and explanations belonging to the identified leverage point categories. Also, where possible, a literature-based indication is given regarding the expected impact on the soil and water system.

Table 4 Literature illustration and explanation per category of leverage points

Leverage point category	Literature illustration and explanation	Sources
Change in water system design & management	A commonly used approach among the Dutch water boards is the strategy of 'drought steers functions'. The strategy consists of three principles: 1. Conserving and retaining water. Storing part of the excess precipitation in soil and water courses, restore brook systems for more groundwater supply, and construct urban water buffers. 2. Supply of water from larger water bodies (limited). 3. Accept water shortages and adapt, which means that companies/farmers change their management and possibly nature types are changed. Water is the steering factor in spatial planning. In the social-ecological system, this leverage point especially contributes to decreasing water demand and increasing water availability.	(Stowa, 2020)
Changes in agricultural practices	The most effective to address the problems related to large-scale and intensive farming is to not address the symptoms one by one but to reorientate the entire farming system, towards more sustainable agriculture. A broad range of alternative agricultural practices exists, each with its strengths, weaknesses, and effects on the system. Three main alternative agricultural practices in the Netherlands are 'circular farming', 'nature-inclusive farming', and 'organic farming'. When conventional farming systems are	(Rigby & Cáceres, 2001; Runhaar, 2017; Ten Berge, Van Ittersum, Rossing, Van de Ven, &

	changed, ammonia emissions can be reduced, inputs are used more efficiently and agriculture is better integrated with nature conservation, having a positive effect on biodiversity. In the social-ecological system, it can have a positive impact on the entire environment, at a catchment scale. Reinforcing loops related to the negative impacts of agriculture can be changed into balancing loops. Supporting governmental policies and a profitable business model is key to make the transition towards alternative farming approaches.	Schans, 2000; Vrolijk, Reijs, & Dijkshoorn-Dekker, 2020),
Area-oriented approach towards environmental & spatial issues	An area-oriented approach is a broad term. An example of a principle that is often used in such approaches in The Netherlands is the 'Dutch Layers Approach to spatial planning and design'. According to this approach, considerations in spatial planning take into account the characteristics of three present layers: 'Substratum' (physical environment), 'Networks' (infrastructure), and 'Occupation' (land use). The substratum layer transforms slower than the network layer, while the network layer transforms slower than the occupation layer. Therefore, in the order of substratum – networks – occupation, the layers set the priorities and conditions for addressing spatial planning issues on the other layers. Spatial planning provides coherence between the layers. The layered approach is seen as a temporary phenomenon in spatial planning in the Netherlands and its quality is being discussed. However, it is an example of how it could contribute to the soil and water system of Reusel to tackling the environmental problems in an integrated way. The slower components of the system demand priority, as they normally represent important drivers of change in the whole system.	(Hagens, 2006; Stowa, 2020; van Schaick & Klaasen, 2011)
Awareness-raising & incentives for sustainable behaviour and adaptation	The lack of understanding of climate change and its impacts amongst citizens is still a barrier to adaptation. However, all modes of communication play a role in climate change adaptation, by increasing citizens' understanding of climate change and motivating people to participate in the adaptation process. Awareness-raising in the Netherlands is often done on the municipal level. The Dutch government provides communicative tools for awareness-raising towards climate change adaptation, especially to be used by municipalities. Communicative tools for awareness-raising can be embedded in a wider mix of policy instruments. For example, accompanying them by economic or legal policy instruments.	(Biesbroek et al., 2010; Mees, Tijhuis, & Dieperink, 2018)
Others	N.A.	N.A.

Trade-offs and objectives

The suggested categories could be main categories for measures in adaptation pathways. The leverage points are broadly supported by involved stakeholders in this study. However, as Reidsma et al. (2015) write, still trade-offs are inevitable, among the leverage points and practical solutions. This is due to the various values and objectives that stakeholders have. For a farmer, his income might be most important, a nature manager might be most interested in sustaining biodiversity, and a citizen in landscape amenities (Reidsma et al., 2015). This was also observed in this thesis and should be considered when adaptation pathways will be developed. Farmers, for example, especially aim at continuing efficiency in production and creating a better trust relationship with the government, so that other innovative measures can be taken. Stakeholders from the waterboard, on the other hand, especially think that a transition in the water management is the solution. Stakeholders from the municipalities and the ones responsible for spatial development especially aim at an integrated and area-oriented approach towards the spatial issues. They also prefer to raise awareness on climate change among citizens. The concept of causal loop modelling can be further be used in the area to keep conversations going.

6.3 Reflection on the methodology

In this subchapter, the strengths and weaknesses of the used methodology are discussed. The discussion largely follows the order of the steps taken in the thesis research.

Defining system of interest & involved stakeholders

As the first step in the research, the system of interest was defined as well as an identification of stakeholders, based on literature. Overall, it was difficult to find area-specific information. Therefore, some assumptions had to be made. For example, it was assumed that general problems described in a document on soil quality in the Province of Brabant (Provincie Noord-Brabant, 2017) were also applicable to the study area. Making these assumptions was not seen as a significant problem, as the literature analysis was only performed to create a reference for building the causal loop diagrams, not to base the conclusions on.

The DPSIR framework was a useful method to structure the literature study, as it helps to think about key relationships between society and the environment in a simple way (Svarstad, Petersen, Rothman, Siepel, & Wätzold, 2008). The approach can potentially be used in all types of environmental research (Patrício, Elliott, Mazik, Papadopoulou, & Smith, 2016). On the other hand, it was also recognised that the approach does not take into account system dynamics and suggests that causal chains in the system are linear and unidirectional(Gregory et al., 2013; Patrício et al., 2016). Therefore, the DPSIR framework was complemented with a rich picture. The rich picture helped to think about system dynamics concerning the social-ecological system.

Involved stakeholders in the system of interest followed logically from the rich picture. Not all stakeholder groups from the list of identified stakeholders could be interviewed, because of time limitations (e.g. water management Vlaanderen, citizens, and drinking water companies). In addition, when considering the stakeholder roles concerning resource issues, in particular stakeholders involved in 'decision making' and 'implementation' were interviewed. Only one 'user' was interviewed. A user is someone who uses the soil- and water system, or is affected by it (Water Framework Directive, 2003). Probably this does have not have a significant impact on the variables and main problems in the causal loop diagrams, as still a broad range of topics was discussed with the interviewees. However, it may have impacted the way problems were framed. In contrast to experts, decision-makers, and implementers, users are most dependent on the area for their income. As an example, the results showed that interviewees perceived large-scale agriculture as key in the decrease of water quantity. When more farmers ('users') would have been interviewed, they may have framed the impact of large-scale farming more tentatively, or highlight other causes for the decrease in water quality.

To identify stakeholders to involve in CLD building, Inam et al. (2015) use an approach of Elias, Cavana, and Jackson (2002). A brainstorm on marginal stakeholders is made first, by authors and experts, whereafter the stakeholders are categorized based on their roles concerning resource issues: decision makers, users, implementers, and experts. Next, stakeholders are structured based on three relationships: power, legitimacy, and urgency. The last step is placing them in a power vs. interest grid. Through this iterative process, the most important stakeholders are selected. Stakeholder selection in this thesis research was partly based on this approach, but still, it deviates from it. In future research, the approach of Elias et al. (2002) could well be used to improve reliability when selecting stakeholders.

Interviews & individual CLD building

Due to Covid-19 circumstances, the interviews and CLD building with stakeholders took place online. This made it easier to plan interviews and no travel time was needed. The use of post-its in *Mural* helped to structure the conversation. Interviewees had to think explicitly about problems and their causes and consequences. This provided depth to the interviews. The interviewees themselves also recognised this.

As described in the methodology, finishing the CLDs towards 'perfect' diagrams was not possible in the available time for the interviews. Transcribing and coding the interviews afterwards helped to finish and digitize the CLDs. The used language in the individual CLDs was also homogenised through this. Although the interviews have been analysed with great precision (using coding) bias can play a role. In this case, bias means that diagram variables or interactions present in the digitized individual causal loop diagrams were not intended as such by the concerning stakeholder. If more time had been available, the final individual CLDs could have been sent back to the stakeholders for validation.

Model merging and presentation

As Ryan et al. (2019) write, an iterative process of trial and error is key to get to a 'complete' causal loop diagram. However, in studies, like Cradock-Henry, Connolly, et al. (2020) a transparent explanation of how a causal loop diagram was made misses. In that case, a foundation is lacking on which future researchers can base their methodology (Ryan et al., 2019). Transparency and reproducibility are a challenge when building a diagram or model based on individual interviews (Olazabal, Neumann, Foudi, & Chiabai, 2018). A well-documented and transparent process is key in the flexible and multi-purpose approach of building system maps (Barbrook-Johnson & Penn, 2021). Several attempts were done in this thesis research to overcome the above-described weakness. The synthesis approach as suggested by Ryan et al. (2019) was used to merge the diagrams. Documentation of the frequency of occurrence (in excel) and the documentation of the individual model analysis helped to increase transparency in merging the models. Despite this, bias may still play a role. A choice had to be made on which specific arrows were drawn in the merged diagram and which factors were more or less important in the individual diagrams. Also, some assumptions and free choices have been made to simplify the detailed merged diagram towards the sub-diagrams. By all means this highlights the importance of the same researcher constantly being involved in the process i.e. the person conducting the interviews also analyses and merges the models. Validation of the merged diagram with the interviewed stakeholders can also help to improve reliability. For example, Perrone et al. (2020) organised several group sessions with the interviewed stakeholders to investigate whether they agreed with the merged diagrams. During such a meeting, it can be discussed whether stakeholders think their perceptions are represented well in the merged diagram. Also, possible controversies can be discussed. In the case when group meetings are not possible, an online survey could be sent to the participants, where questions are asked about their agreement on the final CLD. Leverage points could be identified as well through such a survey (Lopes & Videira, 2017).

As described earlier, the method of making a merged group model based on individual CLDs is flexible, easy to understand, and cost-effective (Inam et al., 2015; Perrone et al., 2020). In addition, in this thesis research, it turned out that starting the modelling process by making individual diagrams supports stakeholders to openly express their opinions on the system of interest. On the other hand, it turned out that making a merged CLD based on individual CLDs is time-consuming. It takes a lot of effort to finish the individual CLDs, analyse them, homogenise the language and combine them into a merged diagram. In case of limited time, it is questionable whether the added value of starting the process by making individual CLDs outweighs the time it takes to process the individual CLDs into a merged CLD.

Workshop on diagram triangulation and analysis

Unfortunately, it was not possible to bring all interviewed stakeholders together in a group discussion on the model. However, the workshop with experts involved in the KLIMAP project also led to an interesting discussion on the causal loop diagrams and their implications. In literature, such a workshop is also known as a focus group discussion. This is a technique in which a researcher brings together a group of individuals, to discuss a specific topic collect the perceptions of participants on that topic (O. Nyumba, Wilson, Derrick, & Mukherjee, 2018). A group discussion contributes to performing transdisciplinary research. In a transdisciplinary research project like KLIMAP, it is relatively easy and cost-effective to facilitate such a discussion. The participants had different backgrounds and were able to reflect on the causal loop diagrams with their background knowledge. Part of the participants had area-specific knowledge and other participants were specialised in the concept of adaptation pathways. This delivered useful data. For the participants of the workshop, it was a learning process as well. For example, the workshops' participants realised that in climate change adaptation, the stakeholders' perception of the system is at least as important as the 'scientific knowledge on the system.

6.4 Future research

In this subchapter, recommendations are given for future research. At first, the causal loop diagrams could be developed and refined further. More attention can be paid to identifying feedback loops, to better understand the system dynamics. Iteration is important in developing causal loop diagrams (Inam et al., 2015). A system model or causal loop diagram can be seen as finished when the stakeholders are satisfied with the completeness of the diagram and level of detail (Cradock-Henry, Connolly, et al., 2020). Therefore, a validation with stakeholders would be useful as well, for example in a workshop. Next, future research can quantify parts of the developed diagrams and simulate them. This can be done in order to do future explorations to define adaptation tipping points. Definition of future scenarios can be done in collaboration with stakeholders, by making storylines of future developments and quantifying the storylines afterwards. This would provide an integrated model, considering socio-economic and physical aspects related to the soil and water system. Lastly, further investigation could be done into the identified (categories of) leverage points. More scientific evidence needs to be collected, in order to investigate the effectiveness of the leverage points. In addition, research can be done into practical solutions related to the leverage points. A key point when thinking about practical solutions is to investigate how these can be implemented and upscaled, in terms of responsibilities and the usefulness of local knowledge.

7. Conclusion

An explorative analysis was done in this thesis research, in which causal loop diagrams were made based on stakeholders' perceptions. The causal loop diagrams show stakeholders' perceptions on interactions in the social-ecological system, contributing to problems and vulnerabilities in the soil and water system in the area surrounding Reusel. Amongst others, stakeholders from the waterboard, province, municipalities, nature organisations, and farmers were involved in the process. The mental models of the stakeholders on the soil and water system correspond with three different spatial scales: farm-, municipal- and catchment scale.

(Ground) water quantity seems to be the main problem variable in the area. The large-scale and intensive agriculture in the area is an important pressure on the water quantity. Farmers are forced to increase efficiency by 'external' pressures, like the capitalistic economic system and agricultural policies. Stakeholders see a low organic matter content in the area as an important aspect leading to the degradation of the soil. Groundwater abstractions for industry, drinking water, and private purposes also are another cause of the decrease in groundwater. Further, stakeholders perceive that a large amount of paved surface makes the system vulnerable to climate change, leading to flooding or heat stress. Spatial pressure and monocultures in agriculture result in a decrease in the amenity value of the landscape. At the catchment scale, nature areas are vulnerable to climate change, and dry-out because of the decrease in water quantity. The decrease in water- and soil quality is also harmful to biodiversity. This makes that nature guidelines are difficult to be met. As the water system in the area is focused on water drainage instead of water retention, discharge fluctuations in the brook system occur. This can lead to flooding on the one hand, or the brook system drying out on the other side. Hydrological recovery and making the brook system in the area more natural are measures that are currently carried out to alleviate the problems.

Considering the opinion of stakeholders and experts involved in the KLIMAP project, there are 5 key categories of leverage points to make the system climate robust. (1) A 'change in water system design & management' can help to increase water availability and the area and decrease the water demand. This can especially be achieved when more attention is paid to water retention and the land use is adapted to water availability. (2) 'Changes in agricultural practices' can help to reduce the negative impact of large-scale agriculture on the environment. Extensive forms of agriculture could be adopted, like nature-inclusive farming. (3) An 'area-oriented approach towards environmental & spatial issues' can help to deal with the different required transitions and challenges at the landscape scale and through that, reduce spatial pressure. (4) 'Awareness raising & incentives for sustainable behaviour and adaptation' can have the effect that a better business model for sustainable agriculture arises, because of more 'fair prices' being paid for food. In addition, entrepreneurs, as well as citizens, will be more aware of climate adaptation measures they can take, like reducing pavement or water pollution.

The key leverage points can be central aspects when further developing adaptation pathways for the area. Although the leverage points are broadly supported by the involved stakeholders, it should be considered that stakeholders still have various objectives and values related to the soil- and water system. As this study only investigated the current situation, the causal loop diagrams could also be used to do future explorations through conversations with the stakeholders.

Although it was not the objective of this research, it turned out that from a conceptual and methodological point of view causal loop diagrams do have added value in the development of adaptation pathways. Especially in the case of contested and complex adaptation problems, the used participatory exploration can help to investigate the mental models of involved stakeholders on the system of interest. By doing this, tensions and agreements in stakeholders' value and knowledge on the system can be investigated, as well as the root causes of vulnerability. In addition, the causal loop diagrams give guidance in a collaborative learning process of stakeholders and experts to discuss which interventions are most effective in a social-ecological system.

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Annexes

Annex A: Interview guide

Naam respondent	
Datum	
Functie	
Achtergrond	

Voorstellen en introductie thesis

- *Verzoek opname interview*
- *vragen naar privacy rondom gegevensverwerking*

Ik stel voor dat ik eerst mezelf even voorstel en wat vertel over mijn onderzoek. Daarna wat algemene vragen, waarbij u zichzelf ook kunt introduceren.

Momenteel doe ik onderzoek voor mijn master thesis. N.a.v. onderzoeksprogramma KLIMAP (Klimaatadaptatie in de Praktijk). Kent u dit? *(In dit onderzoeksprogramma zijn veel verschillende partijen betrokken en het doel van dit project is om onderzoek te doen en tools aan te leveren voor het (klimaat) robuust maken van het bodem en watersysteem op de hoge zandgronden.)*

Binnen KLIMAP wordt onder andere gewerkt aan casus de Reusel-Bladel, een gebiedje in het zuiden van Brabant, in de Kempen. KLIMAP wil m.b.v. het concept van ontwikkelpaden een zogenaamde 'roadmap' aandragen met oplossingen voor de problemen in het bodem- en watersysteem. Echter is het daarvoor wel belangrijk om context te weten en de opgaven helder te krijgen.

Ik ben geïnteresseerd in hoe belanghebbenden en betrokkenen de huidige bodem- en watersysteem ervaren en beschrijven, met knelpunten t.a.v. bodem en water en kansen voor een robuust bodem en watersysteem. Ik neem mee fysieke systeemaspecten (bijv. watertekort door hoge ligging) maar ook sociaaleconomische (drinkwateronttrekkingen) of institutionele ontwikkelingen (eventueel druk van buitenaf). Door met verschillende betrokkenen vanuit een breed perspectief naar het systeem te kijken hoop ik zo een beter beeld te krijgen van de opgaven en van de mogelijke knoppen om het systeem robuuster te maken.

Als onderzoeksgebied houd ik grofweg de strook van Reusel – Bladel aan en dan richting het zuiden, tot aan de grens met Vlaanderen (*uitleg bij kaartje, zie bijlage)*. Maar deze afbakening zit niet in de beton gegoten. U kunt dus ook factoren noemen die net buiten het gebied liggen maar wel van belangrijke invloed zijn.

Algemene vragen:

Ik stel eerst wat algemene vragen, en daarna een soort werksessie ervan maken en d.m.v. post-its de structuur van het systeem en probleem weer te geven.

1. Zou u om te beginnen zichzelf even kunnen introduceren? Uw naam, functie?

2. Wat is uw betrokkenheid bij het gebied?

3. Op welke manier is het bodem- en watersysteem op u / uw werk van invloed?

4. Hoe zou u het gebied omschrijven?

Bouwen van Causaal Diagram

In mijn onderzoek werk ik met causale diagrammen. Modellen waarin je goed een probleem kan structureren en dynamiek van systeem en verschillende relaties op een overzichtelijke manier in beeld kunt brengen (*Voorbeelden laten zien en uitleg geven, zie bijlage).* Tijdens dit interview wil ik graag met u een opstapje maken. Ik doe dat met alle respondenten die ik interview, dat leg ik dan naast elkaar.

5. Gezien vanuit uw rol/betrokkenheid bij het gebied, wat zou u als belangrijkste problemen of probleemvariabelen neerzetten in het midden (mbv post-it)?

6. Wat zijn de oorzaken hiervan, hoe verhouden die zich tot elkaar, kunt u dat ook aangeven?

7. Wat zijn volgens u de belangrijkste consequenties van de opgave/het probleem?

8. Welke belanghebbenden zijn nog meer betrokken en hoe ziet u hun rol in dit plaatje?

9. Welke 'feedback loops zijn volgens u aanwezig in dit overzicht'?

10. Waar ligt volgens u de kern van het probleem?

11. Waar zitten volgens u de belangrijkste 'knoppen om aan te draaien' om deze opgaven het hoofd te bieden? (wie is daarbij aan zet? Op wat voor schaal? Etc.)

Afronding

12. Denkt u dat dit een zinvolle begrenzing is van het casusgebied of heeft u daar een ander idee bij? Wellicht denkt u dat gezien de genoemde problemen de focus anders zou moeten liggen?

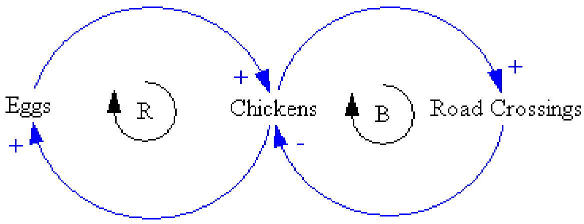
13. Zijn er nog onderwerpen die niet ter sprake gekomen zijn, die u graag mee wilt geven?

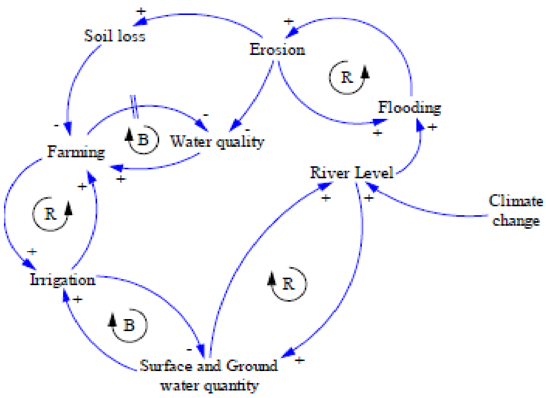
14. Heeft u nog suggesties voor andere respondenten?

- *Deelnemer hartelijk danken voor interview en uitleggen vervolg*

Bijlagen Interview guide (tijdens het interview gepresenteerd in MURAL)

Studiegebied (Bron: OpenStreetMap)





Voorbeelden van causale diagrammen (Bron: https://metasd.com/2010/04/are-causal-loop-diagrams-useful/ and

Annex B: Soil type & elevation study area

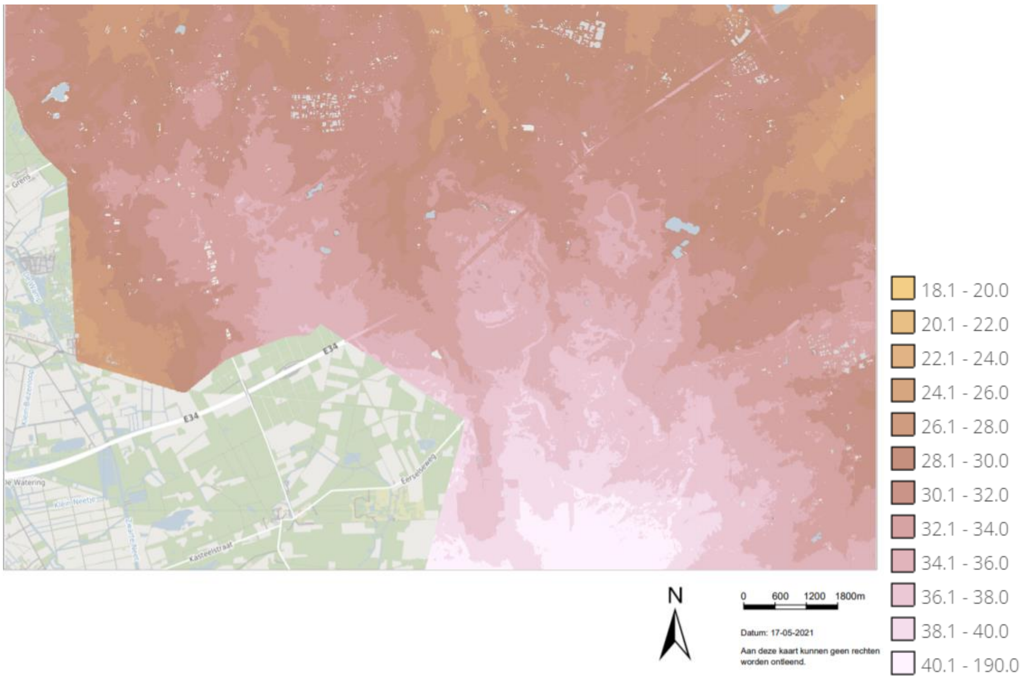


Figure 16 Study area elevation map, AHN 2 (Kaartbank Brabant, 2021)

Figure 17 Study area soil type map (Kaartbank Brabant, 2021).

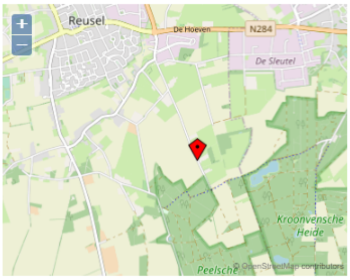
An extensive legend of the map is given on: https://kaartbank.brabant.nl/viewer/app/Kaartbank

Annex C: Completed DPSIR overview

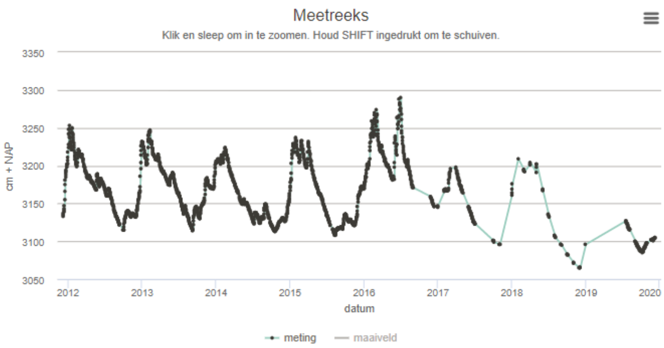
Drivers	Soil type; Wet nature areas; Geology; Hydrology, water system focused at discharging; Climate (change); Large-scale, efficient agriculture; Land use not adapted to system; Fertilization/manure use agriculture; Drinking water production
Pressures	• Temperature changes: - Increase in mean temperature - Mild winters - Hot summers, more heatwaves • Precipitation changes: - Increase in winter - More frequent and intense rainfall events in summer - More dry years/precipitation deficit • Rapid drainage towards buil-up area • Parts of area drained strongly because of soil type/elevation -> water percolates to deeper groundwater • Limited soil moisture content • Leaching/runoff of nutrients and pesticides • nitrogen deposition • Reusel and Raamsloop have strong draining effect on area • Increase in irrigation volume/groundwater abstraction by: - Agriculture - Industry - Drinking water sector • High use of fertilizers/manure
State (changes)	▪ Low water levels Reusel/Raamsloop /smaller water courses ▪ Decreasing groundwater levels: - Especially at end summer and autumn ▪ Frequent floodings, Reusel Raamsloop overflow its banks ▪ Poor water quality: - Higher temperatures - Algae blooms - Nitrate/phosphate/pesticides ▪ Degraded soil: - Compacted - Decrease soil organic matter - Decreasing soil moisture content ▪ Desiccation of nature ▪ Declining species diversity in nature and meadow landscape
Impacts	➢ Floodings/damage in built-up area ➢ Need for expensive investments in watersystem ➢ KRW difficult to achieve ➢ Irrigation ban and precipitation deficit -> harvest damage ➢ Harvest damage/pests because of water abundance ➢ Fertilizer standard exceeded ➢ Soil quality further decreases ➢ Decrease in biodiversity ➢ Nature development goals can hardly be achieved (N2000) ➢ Increased risk of wildfires ➢ Undesired results of investments in nature development ➢ Competition for water division ➢ Decreasing quality swimming water, spread of diseases ➢ Drinking water sources at risk
Responses	Rules/legislation: - Europe: KRW (kaderrichtlijn water) - Waterboard: irrigation policy Policy/visions: - National: Beleidstafel droogte - Province: Vision climate adaptation Brabant - Province: Strategy vital soil Brabant - Water transition Waterboard Local plans/measures/initiatives: - Approach 'Natte natuurparels' - Stream valley restoration - 'Natuurakker' - Measures by vd Borne: precision irrigaion/collect soil and crop data/improve carbon content soil

Figure 18 Completed DPSIR framework, based on literature

Annex D: Groundwater data



Filters in peilbuis		Bovenkant filter cm + NAP	Onderkant filter cm + NAP
◉	Filter 001	2727	2627



Eigenschappen meetreeks voor analyse periode	
Startdatum analyse periode	09-12-2011
Einddatum analyse periode	09-12-2019
Aantal waarnemingen	1941
Gemiddelde	3168.6
Standaard deviatie	41.1
Minumum	3065
10-percentiel	3119.0
50-percentiel (mediaan)	3169.0
90-percentiel	3222.0
Maximum	3290

Figure 19 Groundwater levels over the past 10 years, for monitoring well location B57A0025, south of Reusel (Grondwatertools, 2021)

In figure 19, a decreasing groundwater trend is especially visible during the period 2018-2020.

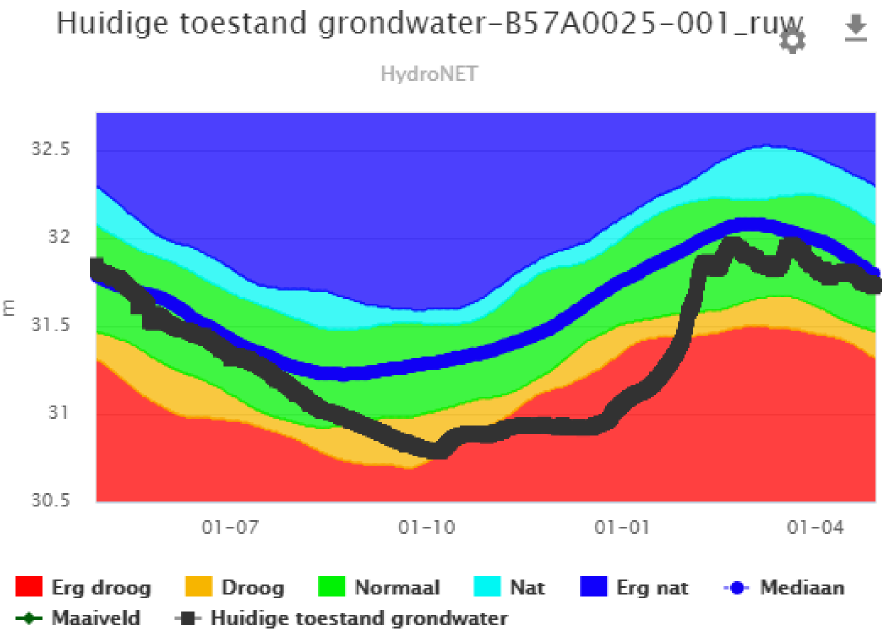
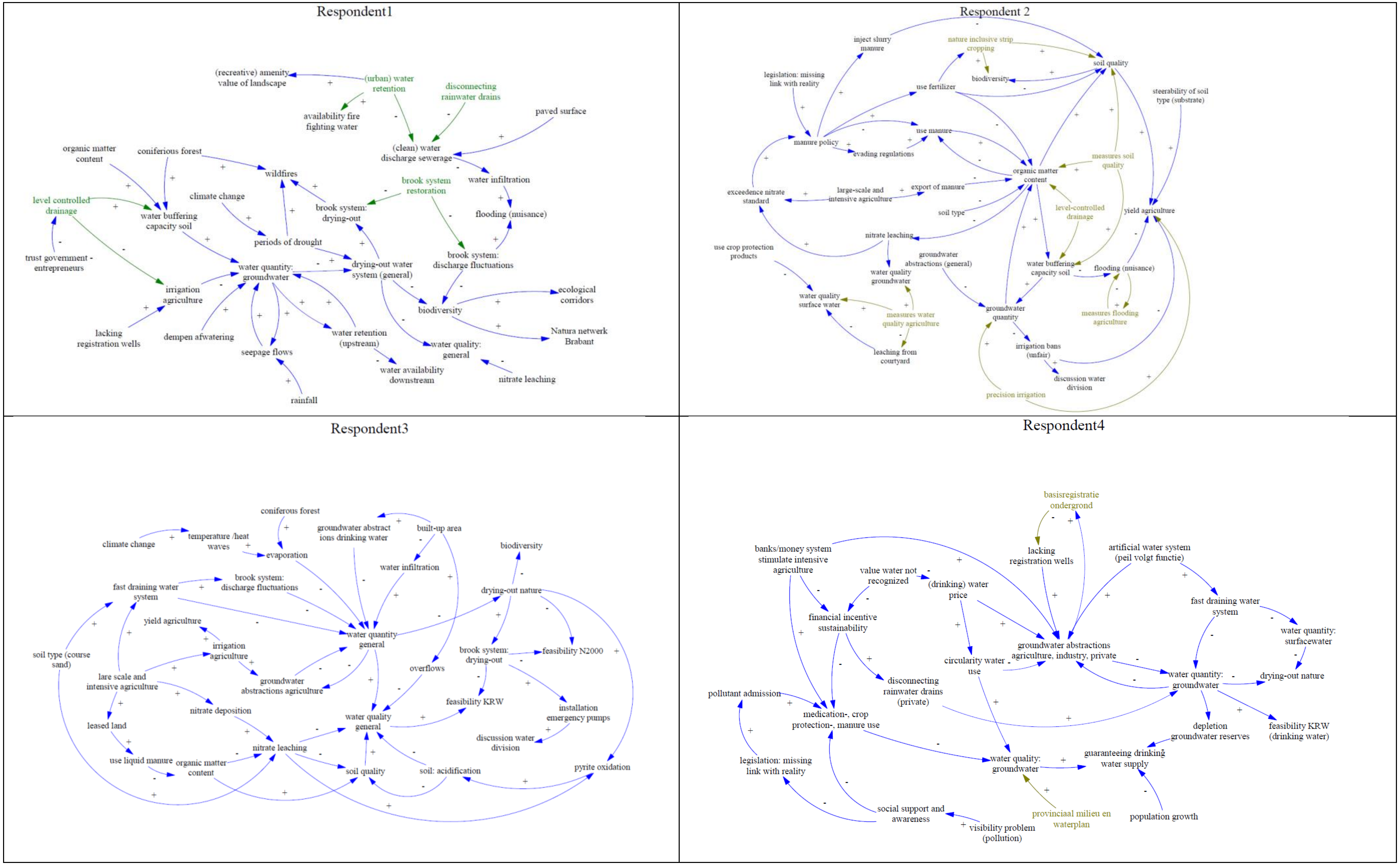
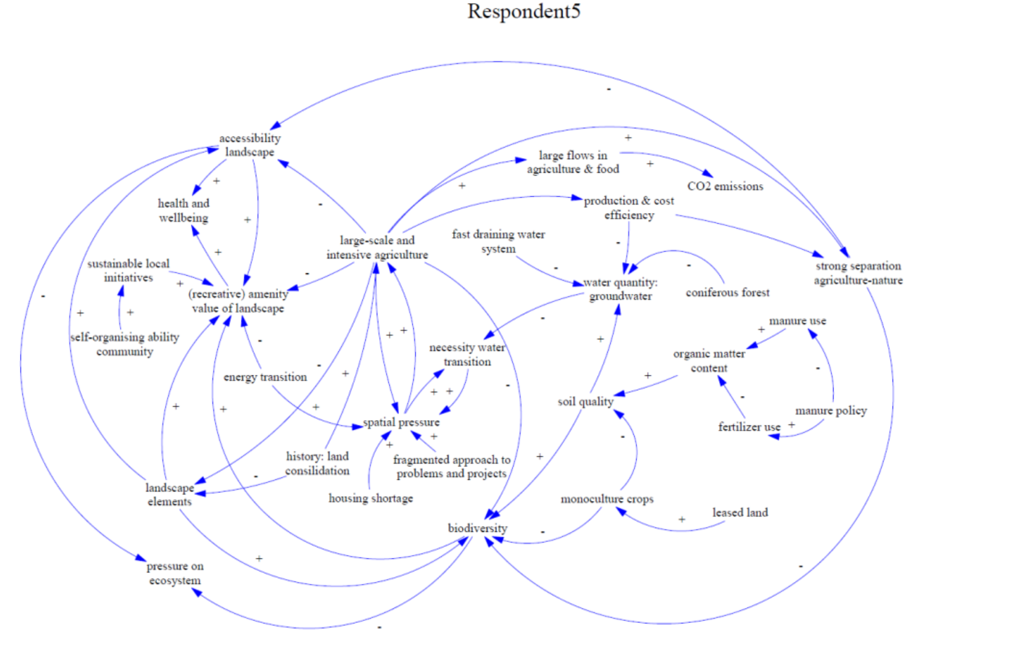


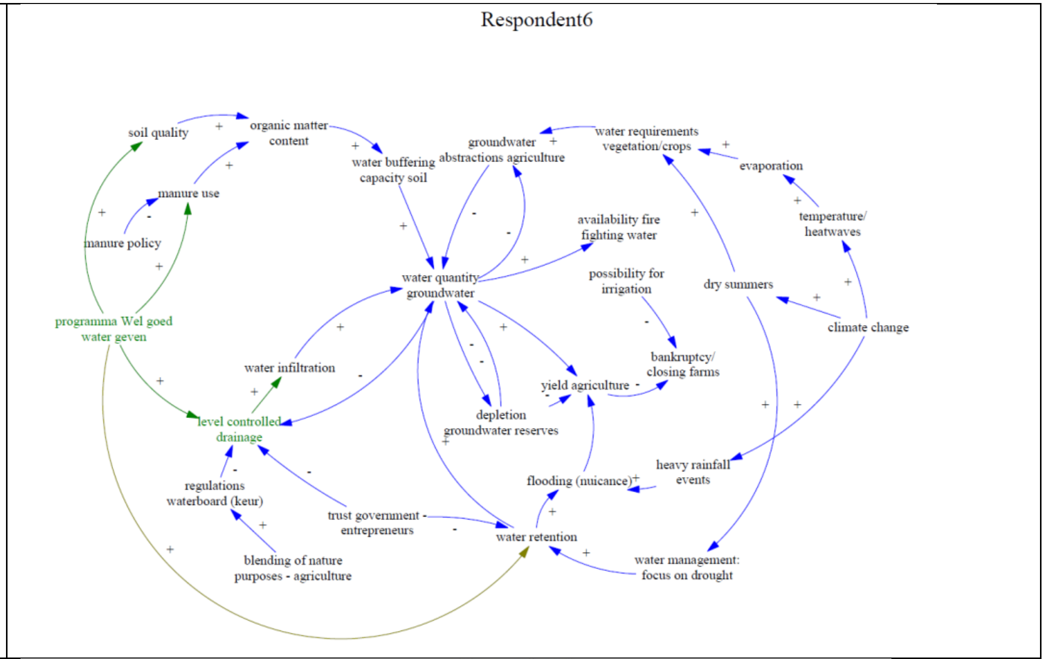
Figure 20 Groundwater level for monitoring well location B57A0025, over the period of May 2020 – May 2021 (Waterschap De Dommel, n.d.)

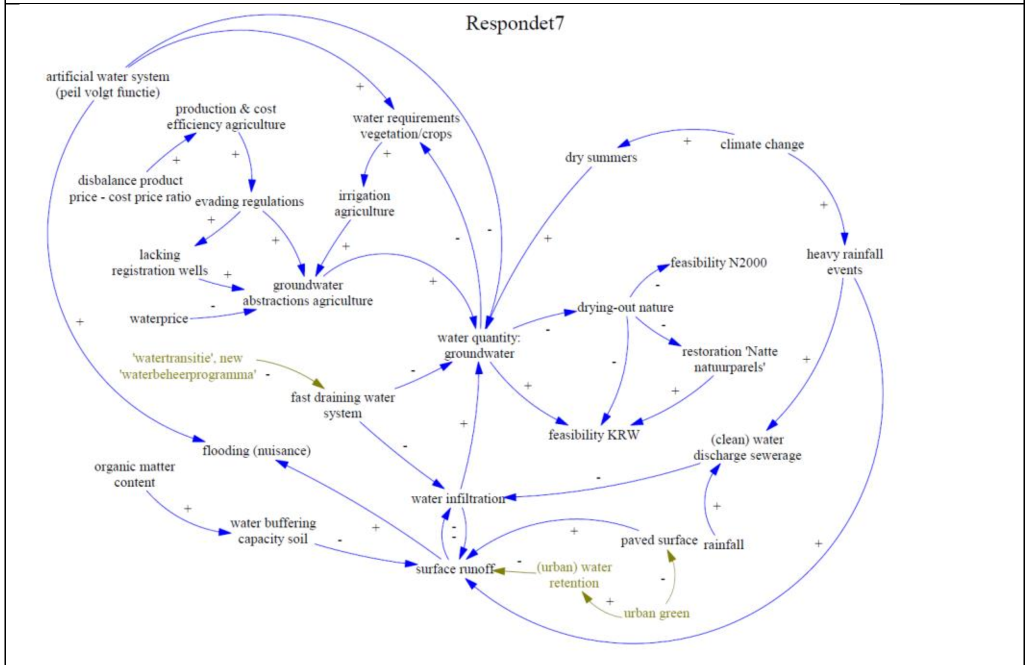
The black line in figure 20 shows the groundwater trend and shows that especially during the second part of 2020 the groundwater level was below the median.

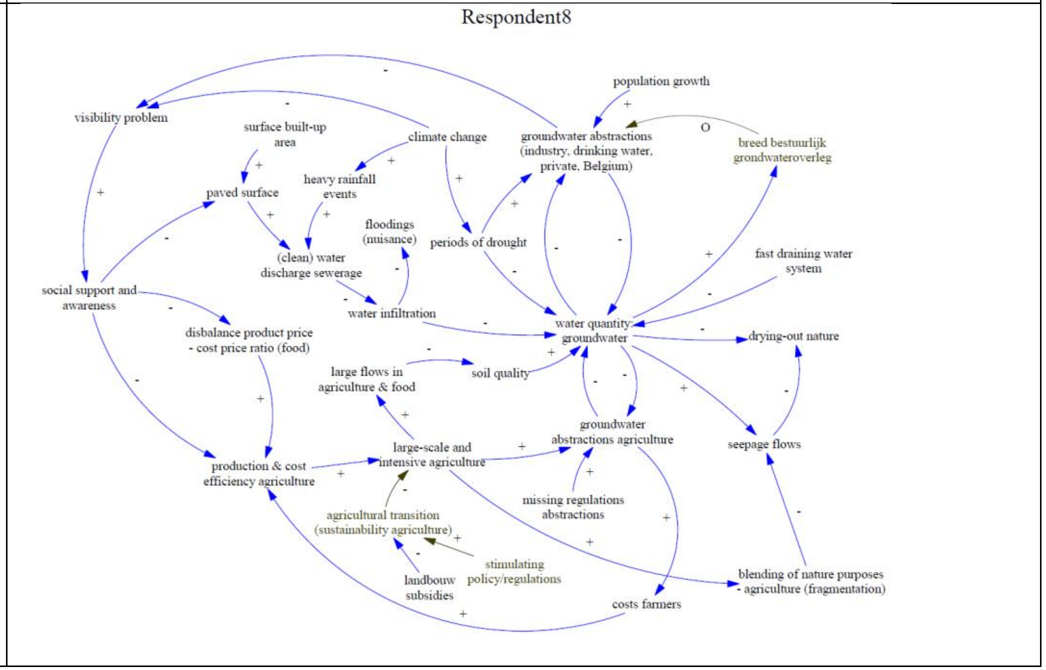
Annex E: Individual causal loop diagrams

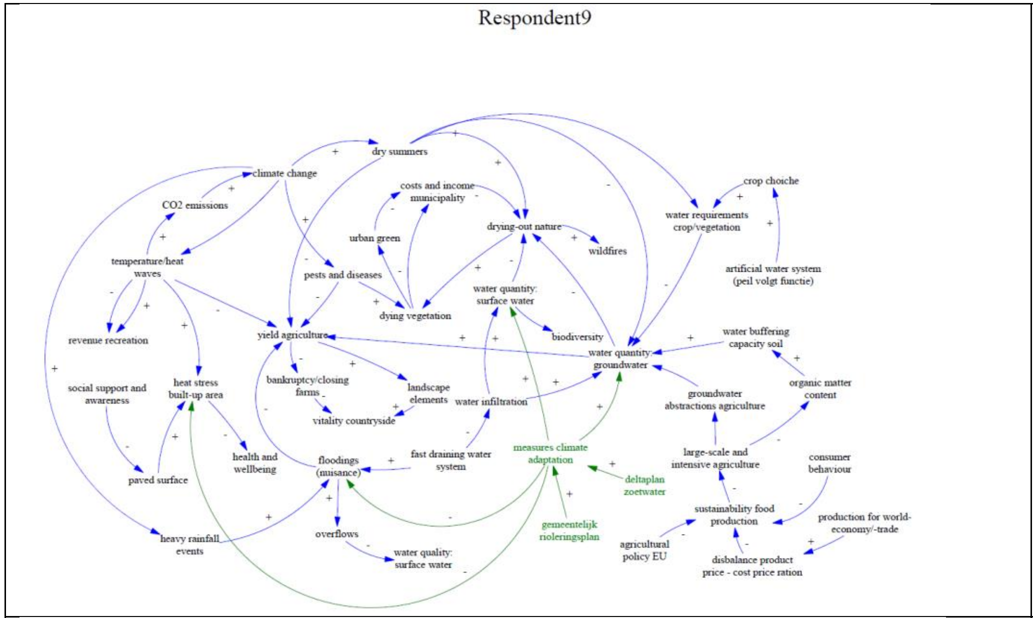


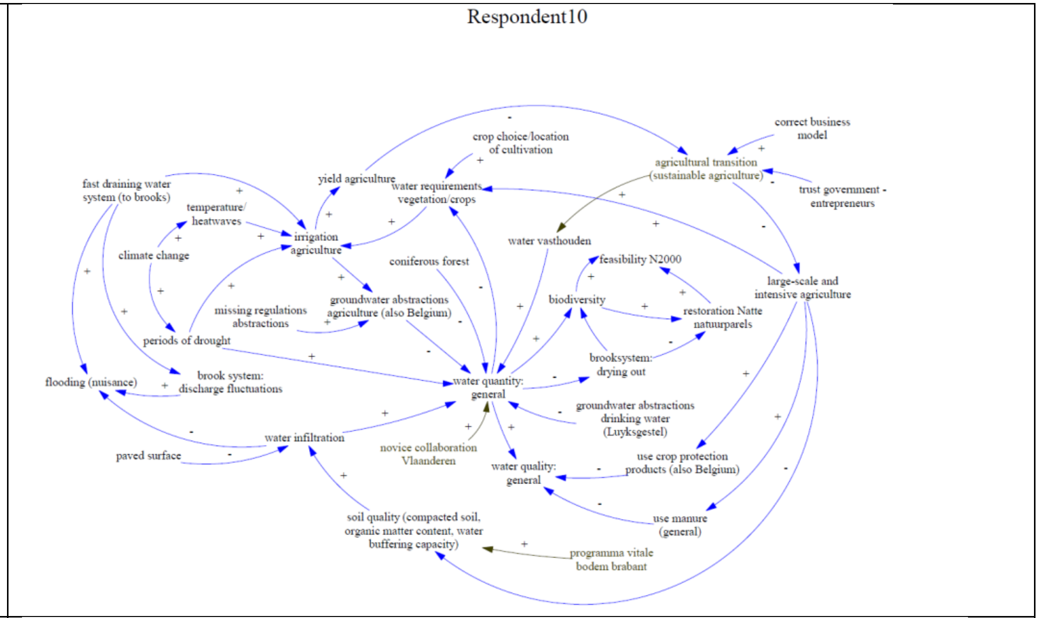

Respondent5
accessibility landscape
health and wellbeing
sustainable local initiatives
(recreative) amenity value of landscape
self-organising ability community
large-scale and intensive agriculture
large flows in agriculture & food
CO2 emissions
production & cost efficiency
fast draining water system
water quantity: groundwater
coniferous forest
strong separation agriculture-nature
necessity water transition
energy transition
spatial pressure
fragmented approach to problems and projects
history: land consilidation
housing shortage
landscape elements
organic matter content
manure use
manure policy
fertilizer use
soil quality
monoculture crops
leased land
biodiversity
pressure on ecosystem

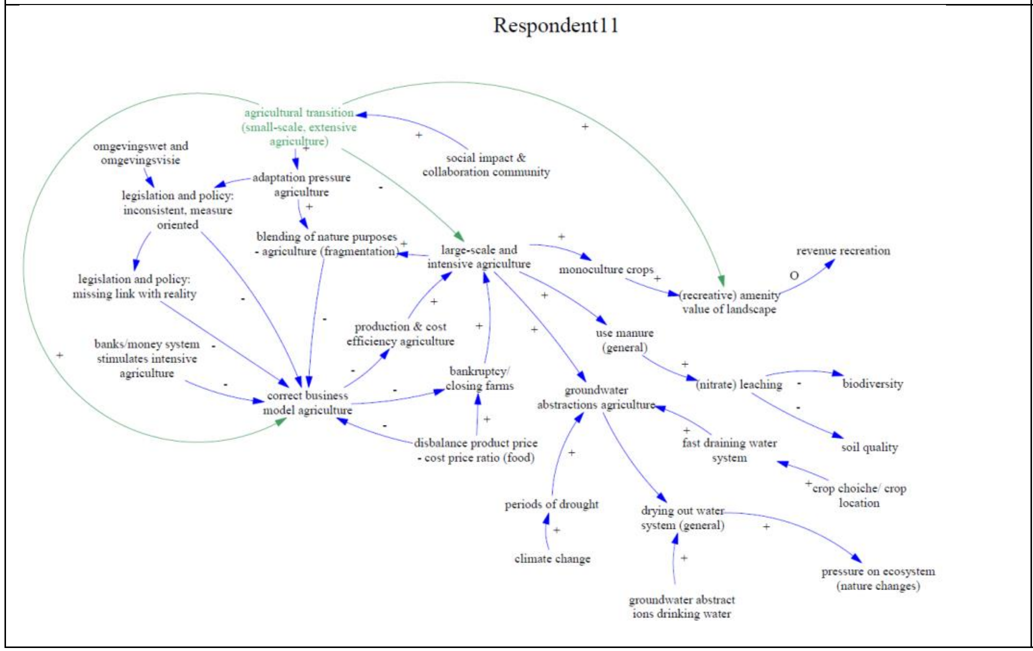

Respondent6
soil quality
organic matter content
manure use
manure policy
water buffering capacity soil
groundwater abstractions agriculture
water requirements vegetation/crops
evaporation
temperature/ heatwaves
availability fire fighting water
possibility for irrigation
water quantity groundwater
dry summers
climate change
programma Wel goed water geven
water infiltration
bankruptcy/ closing farms
yield agriculture
level controlled drainage
depletion groundwater reserves
regulations waterboard (keur)
flooding (nuicance)
heavy rainfall events
trust government entrepreneurs
water retention
blending of nature purposes - agriculture
water management: focus on drought

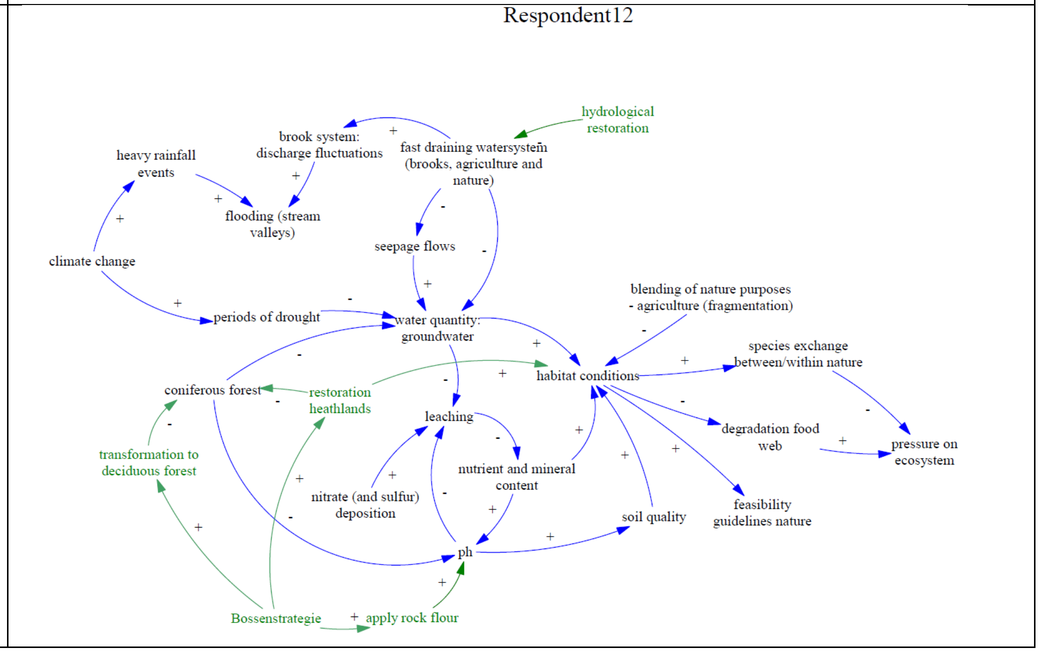

Respondet7
artificial water system (peil volgt functie)
production & cost efficiency agriculture
water requirements vegetation/crops
disbalance product price - cost price ratio
evading regulations
irrigation agriculture
dry summers
climate change
lacking registration wells
groundwater abstractions agriculture
feasibility N2000
heavy rainfall events
waterprice
drying-out nature
water quantity: groundwater
restoration 'Natte natuurparels'
'watertransitie', new 'waterbeheerprogramma'
fast draining water system
feasibility KRW
flooding (nuisance)
(clean) water discharge sewerage
organic matter content
water infiltration
water buffering capacity soil
paved surface
rainfall
surface runoff
(urban) water retention
urban green

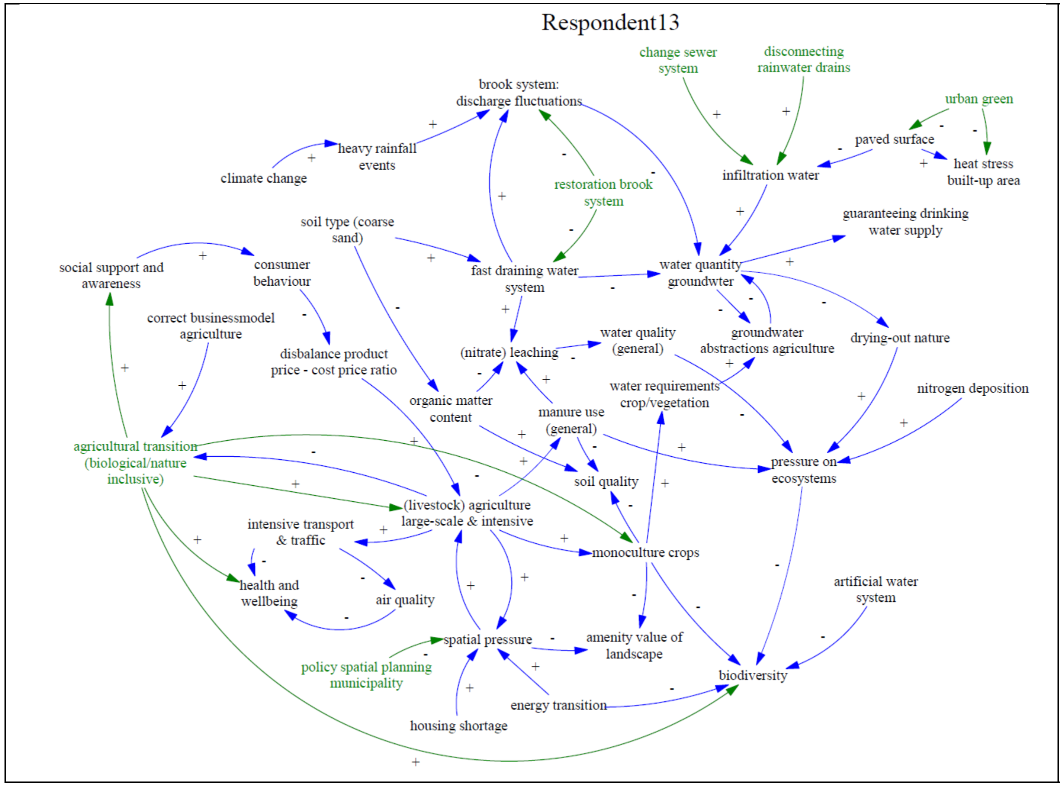

Respondent8
population growth
visibility problem
surface built-up area
climate change
groundwater abstractions (industry, drinking water, private, Belgium)
breed bestuurlijk grondwateroverleg
paved surface
heavy rainfall events
floodings (nuisance)
periods of drought
(clean) water discharge sewerage
fast draining water system
social support and awareness
water infiltration
water quantity groundwater
drying-out nature
disbalance product price - cost price ratio (food)
large flows in agriculture & food
soil quality
groundwater abstractions agriculture
seepage flows
production & cost efficiency agriculture
large-scale and intensive agriculture
agricultural transition (sustainability agriculture)
missing regulations abstractions
stimulating policy/regulations
landbouw subsidies
blending of nature purposes - agriculture (fragmentation)
costs farmers

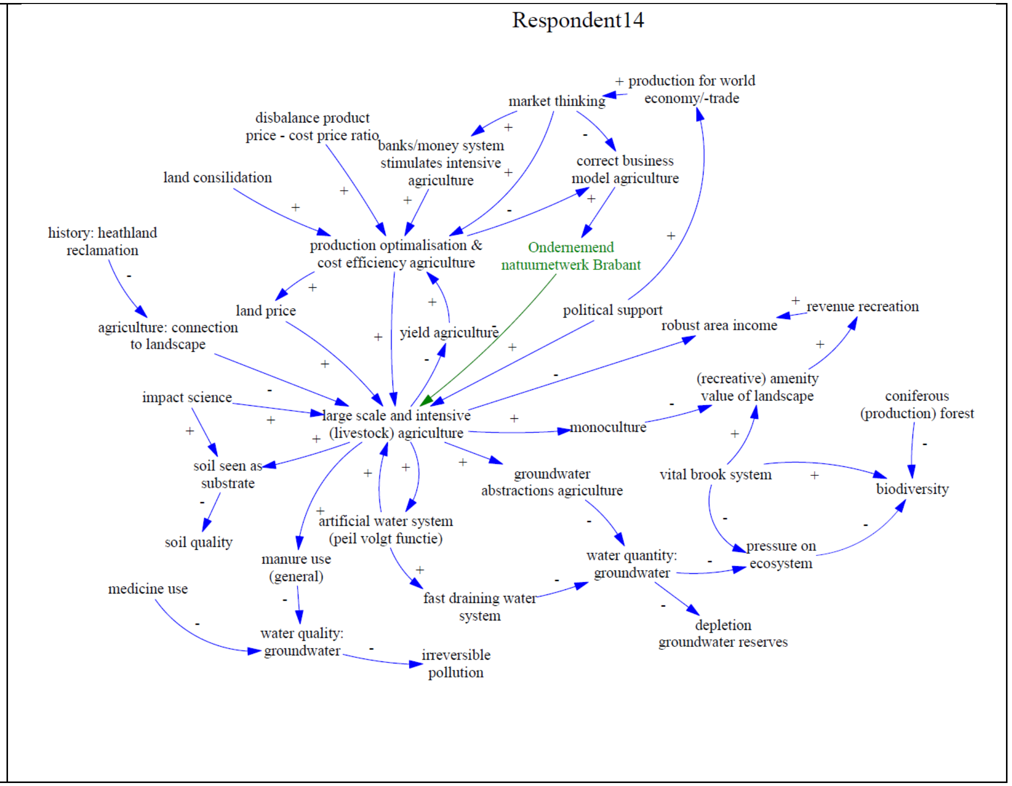

Respondent9
dry summers
climate change
CO2 emissions
costs and income municipality
crop choiche
urban green
drying-out nature
water requirements crop/vegetation
wildfires
temperature/heat waves
pests and diseases
artificial water system (peil volgt functie)
water quantity: surface water
dying vegetation
revenue recreation
yield agriculture
biodiversity
water buffering capacity soil
water quantity: groundwater
social support and awareness
heat stress built-up area
bankruptcy/closing farms
landscape elements
water infiltration
groundwater abstractions agriculture
organic matter content
vitality countryside
health and wellbeing
floodings (nuisance)
fast draining water system
measures climate adaptation
large-scale and intensive agriculture
consumer behaviour
paved surface
deltaplan zoetwater
overflows
gemeentelijk rioleringsplan
sustainability food production
production for world-economy/-trade
heavy rainfall events
water quality: surface water
agricultural policy EU
disbalance product price - cost price ration


Respondent10
correct business model
crop choice/location of cultivation
agricultural transition (sustainable agriculture)
trust government - entrepreneurs
fast draining water system (to brooks)
yield agriculture
water requirements vegetation/crops
temperature/heatwaves
irrigation agriculture
water vasthouden
climate change
coniferous forest
feasibility N2000
large-scale and intensive agriculture
missing regulations abstractions
groundwater abstractions agriculture (also Belgium)
biodiversity
restoration Natte natuurparels
periods of drought
brooksystem: drying out
flooding (nuisance)
brook system: discharge fluctuations
water quantity: general
groundwater abstractions drinking water (Luyksgestel)
water infiltration
novice collaboration Vlaanderen
paved surface
water quality: general
use crop protection products (also Belgium)
soil quality (compacted soil, organic matter content, water buffering capacity)
use manure (general)
programma vitale bodem brabant


Respondent11
agricultural transition (small-scale, extensive agriculture)
omgevingswet and omgevingsvisie
social impact & collaboration community
adaptation pressure agriculture
legislation and policy: inconsistent, measure oriented
blending of nature purposes - agriculture (fragmentation)
large-scale and intensive agriculture
revenue recreation
monoculture crops
legislation and policy: missing link with reality
(recreative) amenity value of landscape
production & cost efficiency agriculture
use manure (general)
banks/money system stimulates intensive agriculture
bankruptcy/closing farms
(nitrate) leaching
biodiversity
correct business model agriculture
groundwater abstractions agriculture
soil quality
disbalance product price - cost price ratio (food)
fast draining water system
crop choiche/ crop location
periods of drought
drying out water system (general)
climate change
pressure on ecosystem (nature changes)
groundwater abstractions drinking water


Respondent12
hydrological restoration
brook system: discharge fluctuations
fast draining watersystem (brooks, agriculture and nature)
heavy rainfall events
flooding (stream valleys)
seepage flows
climate change
blending of nature purposes - agriculture (fragmentation)
periods of drought
water quantity: groundwater
species exchange between/within nature
coniferous forest
restoration heathlands
habitat conditions
leaching
degradation food web
pressure on ecosystem
transformation to deciduous forest
nutrient and mineral content
nitrate (and sulfur) deposition
soil quality
feasibility guidelines nature
ph
Bossenstrategie
apply rock flour


Respondent13
change sewer system
disconnecting rainwater drains
urban green
brook system: discharge fluctuations
heavy rainfall events
climate change
paved surface
heat stress built-up area
infiltration water
restoration brook system
guaranteeing drinking water supply
soil type (coarse sand)
social support and awareness
consumer behaviour
fast draining water system
water quantity groundwter
correct businessmodel agriculture
disbalance product price - cost price ratio
(nitrate) leaching
water quality (general)
groundwater abstractions agriculture
drying-out nature
organic matter content
manure use (general)
water requirements crop/vegetation
nitrogen deposition
agricultural transition (biological/nature inclusive)
soil quality
pressure on ecosystems
(livestock) agriculture large-scale & intensive
intensive transport & traffic
monoculture crops
health and wellbeing
air quality
artificial water system
spatial pressure
amenity value of landscape
policy spatial planning municipality
biodiversity
energy transition
housing shortage


Respondent14
production for world economy/-trade
market thinking
disbalance product price - cost price ratio
banks/money system stimulates intensive agriculture
correct business model agriculture
land consilidation
history: heathland reclamation
production optimalisation & cost efficiency agriculture
Ondernemend natuurnetwerk Brabant
land price
yield agriculture
political support
revenue recreation
robust area income
agriculture: connection to landscape
impact science
large scale and intensive (livestock) agriculture
(recreative) amenity value of landscape
coniferous (production) forest
monoculture
soil seen as substrate
groundwater abstractions agriculture
vital brook system
biodiversity
soil quality
artificial water system (peil volgt functie)
manure use (general)
water quantity: groundwater
pressure on ecosystem
medicine use
fast draining water system
depletion groundwater reserves
water quality: groundwater
irreversible pollution

Annex F: Individual CLD analysis and frequency of occurrence

Table 5 Table showing findings of individual CLD analysis

Respon-dent nr.	Main issue	Narrative	Scale/level	Key concepts	Present loops
1	Pressures cause problems with interactions in the water system	Groundwater quality decreases and seepage flows are disturbed. Amongst others, this is caused by climate change, a low organic matter content and irrigation for agriculture. Through vulnerability of the brook system, the water system dries up, leading to biodiversity decrease. Discharge fluctuations in the brook system sometimes lead to flooding. The problems are more and more being addressed by taking measures in the water system, like water retention and brook system restoration	Catchment		(1)water quantity groundwater -> water retention (upstream) (2)water quantity groundwater -> seepage flows
2	Government legislation and policies reinforce soil degradation	Sandy soils have a high change of nitrate leaching. However, this can be prevented using manure, because then the organic matter content increases. As there is a lot of nitrate leaching in the area already the manure policy of government is becoming stronger and stronger. Fertilizer has to be used and amount of permitted animal manure reduces further. This leads to ongoing soil degradation and worsening of the problem. Groundwater quantity decreases as the water buffering capacity of the soil is low because of the low organic matter content. This leads to unfair irrigation bans and lower yields for agriculture. Nature inclusive strip cropping can have a positive impact, but this is hardly possible due to regulations	Farm level	organic matter content; water buffering capacity soil; use fertilizer; use (animal) manure; nitrate leaching; manure policy; groundwater quantity	(1)organic matter content -> use manure (2) organic matter content -> water buffering capacity soil -> groundwater quantity (3) organic matter content -> nitrate leaching -> exceedance nitrate standard -> manure policy -> use manure OR use fertilizer (4) organic matter content -> nitrate leaching -> exceedance nitrate standard -> manure policy -> evading regulations -> use manure
3	Agricultural practices impact nature	The large scale and intensive agricultural practices negatively influence water quantity, water quality and soil quality. As a consequence, nature degrades, because it dries out. Nature guidelines, like KRW and N2000 cannot be met and the brook system degrades. The problem is reinforced by climate change and physical area characteristics, like coniferous (water demanding) forest and the course sand as soil type.	Catchment *(farming-nature interactions)*		(1)water quantity general -> groundwater abstractions agriculture more possible loops in the agricultural practices
4	Groundwater depletion and pollution	As the value of water is not recognised enough and problems concerning groundwater are not visible, an incentive is lacking to use polluting substances and water in a sustainable way. This causes a declining groundwater quantity and quality. As a	Provincial scale		(1)groundwater abstractions agriculture, industry, private -> water quantity groundwater

		result, nature dries out and guaranteeing drinking water supply becomes a challenge on the long term. Policy and programs like the ‘provinciaal milieu en waterplan’ and ‘basisregistratie ondergrond’ are currently having a problem-solving impact on this.			(2)groundwater abstractions agriculture, industry, private -> ‘basisregistratie ondergrond -> lacking registration wells
5	Decreasing landscape value of countryside	Value of landscape is at risk. Agriculture intensifies, leading to production & cost efficiency. This impacts water quantity, and gives more spatial pressure. (on water and soils) Agriculture further intensifies because of this spatial pressure. This impacts biodiversity, through an ever becoming more strong separation between agriculture and nature. (recreative) Value of the landscape decreases because intensive agriculture leads to a monotonous landscape, with a low amount of landscape elements and accessibility decreases.	Landscape scale/region al *(regional)*	large-scale and intensive agriculture; production & cost efficiency; water quantity groundwater; biodiversity; spatial pressure; amenity value of landscape	(1)large-scale and intensive agriculture -> spatial pressure (2)large-scale and intensive agriculture -> production & cost efficiency -> groundwater quantity -> necessity water transition -> spatial pressure
6	Climate change & adaptation in farming	Groundwater quantity decreases because of two (main) reasons: (1) Climate change, causing that groundwater abstractions agriculture increase. (2) soil quality is low, because of the manure policy (organic matter). Therefore, soil cannot buffer water. This has an impact on yield of farmers. The problem could be solved by level controlled drainage (part of programm 'Wel goed water geven'), but application is difficult because of regulations of the waterboard and a lack of trust in the entrepreneurs (farmers)	Farm level *(impact of climate change on farm level)*	Water quantity groundwater; Level controlled drainage; Climate change; Yield agriculture; regulations waterboard; trust government – entrepreneurs;	(1)level controlled drainage -> water quantity groundwater -> level controlled drainage (2)water quantity groundwater -> groundwater abstractions agriculture
7	Groundwater availability	Agriculture has become too efficient and large scale. That impacts groundwater quantity, as they can still pump up groundwater relatively easy. The water system has become artificial, lost its resilience (peil volgt functie). Paved surface (industry, built-up area) causes flooding on one hand and increasing problem with groundwater quantity on other hand (low infiltration capacity). Decreasing water quantity is a problem for nature (drying-out, guidelines cannot be achieved). Can be solved by decreasing the fast discharge of water system	Catchment	water quantity groundwater; water requirements crops; irrigation agriculture; groundwater abstractions agriculture; artificial system	(1)water infiltration -> surface runoff -> water infiltration (2)water quantity groundwater -> water requirements vegetation/crops -> irrigation agriculture -> groundwater abstractions agriculture
8	Groundwater abstractions cause decrease in	Intensive and large scale agriculture leads to a decrease in groundwater quantity, because of groundwater abstraction. This has come about, because there is not enough social	??		(1) water quantity: groundwater abstractions agriculture

	groundwater quantity	support and awareness, leading to a disbalance in prices, which forces agriculture to be efficient. The problem is exacerbated by climate change, which is not seen as a problem. This causes that more water is pumped up, also for industry, drinking water and for industry in Belgium. Because of the lack of social support and awareness, built-up area is mainly paved, which prevents the water from infiltration Breed Bestuurlijk Grondwateroverleg is bringing a change in the amount of groundwater abstractions, but this impact is still small and unclear			(2) groundwater abstractions (industry, drinking water, private, Belgium) -> water quantity groundwater (3) groundwater abstractions (industry, drinking water, private, Belgium) -> water quantity groundwater -> breed bestuurlijk grondwater overleg (4)groundwater quantity -> groundwater abstractions (industry, drinking water, private, Belgium) -> visibility problem -> social support and awareness -> paved surface -> (clean) water discharge sewerage -> water infiltration (5) groundwater abstractions agriculture -> costs farmers -> production & cost efficiency agriculture -> large-scale and intensive agriculture -> (6) groundwater abstractions agriculture -> costs farmers -> production & cost efficiency agriculture -> large-scale and intensive agriculture -> large flows in agriculture and food -> soil quality -> groundwater quantity -> (7) groundwater quantity -> groundwater abstractions (industry, drinking water, private, Belgium) -> visibility problem -> social support and awareness -> disbalance product-price-cost price ratio -> production & cost efficiency agriculture -> large-scale and intensive agriculture -> groundwater abstractions agriculture -> not clear to what extent this loop is correct, not shown in merged model
9	Disbalance in nexus urban – agriculture – nature - water	- Climate change causes problems with health and well-being of people in built-up areas, because of heat stress, and problems with floodings during heavy rainfall events - Further, both climate change and the (world) economy influence agriculture in such a way that it is intensive and artificial. This causes problems with water quantity and closing farms, which is bad for the vitality of the countryside.	Urban-farmland boundary (municipality)		(1)drying-out nature -> dying vegetation -> (urban green) -> cost and income municipality -> drying out nature (2) climate change -> temperature/heat waves -> CO2 emissions

		- Nature degrades because of diminishing groundwater quantity and climate change. This problem is reinforced, because municipality use the income from nature area for further nature restoration - Climate adaptation measures (e.g. deltaplan zoetwater) help to solve the problems			
10	Water availability	Water quantity is decreasing. At first, because of climate changes leads to higher temperature and more periods of drought. This causes agriculture to pump up more water. In addition, agriculture is large scale and intensive. The fact that agriculture can still pump up water causes that agriculture becomes more large scale, as there is no incentive for an agricultural transition. This leads to a bad soil quality as well, so that water cannot infiltrate easily. The fast draining brook system reinforces the problem, causing water to flow away easily. This all has impact on nature.	Catchment		(1)drying-out water system -> water requirements crops -> irrigation agriculture -> groundwater abstractions agriculture (2)drying out water system -> water requirements vegetation/crops -> irrigation agriculture -> yield agriculture -> agricultural transition -> water retention (3)drying out water system -> water requirements crops -> irrigation agriculture -> yield agriculture -> agricultural transition -> large-scale and intensive agriculture -> soil quality -> water infiltration (4)large scale and intensive agriculture -> water requirements vegetation/crops -> irrigation agriculture -> yield agriculture -> agricultural transition
11	Missing correct business model for agriculture	A correct business model for agriculture is lacking. This is mainly caused by adaptation pressure, leading to inconsistent and measure oriented policy and legislation for agriculture. Also the economic system has its share in this. As a consequence, agriculture in the area becomes more large-scale. This impacts the value of the landscape and also has a negative impact on the environment, like soil quality, biodiversity and groundwater quantity. On the other hand, in parts of the area, especially south of Bladel, more small-scale, extensive farming occurs. This has a positive impact on the area.	Landscape/ regional		(1)large-scale and intensive agriculture -> strong separation agriculture-nature -> correct business model agriculture -> production & cost efficiency agriculture OR (2)bankruptcy/closing farms
12	Soil degradation causes nature degradation	Because of nitrate and sulfur deposition, nutrients and minerals in the soil leach. The soil becomes toxic and pH decreases. This is a vicious cycle. Leaching is reinforced by a decreasing groundwater table, because of climate change and a fast draining water system. Habitat conditions changes as a consequence of decreasing groundwater and soil quality, which gives pressure on the ecosystem. The Bosgroep takes several	Catchment?? Nature		(1)(nitrate)leaching -> nutrient and mineral content -> ph

		measures to solve these problems. Especially applying rock flour is efficient. However, this is not so much done in the area yet.			
13	disbalance in nexus urban – agriculture – nature – water	agriculture and livestock farming is intensive. Lack of social support and awareness leads to consumer behaviour which stimulates the intensive agriculture. Intensive agriculture, climate change, a fast draining water system and paved surface in built-up area causes decreasing water levels and availability. This gives pressure on ecosystems. Spatial pressure is created because of housing shortage, the energy transition and intensive agriculture. This has a negative impact on the landscape value and the health and wellbeing of inhabitants of the area The agricultural transition is bringing a change in these problems. Brook restoration and changing the urban water system can change the fast drainage and infiltration of water	Urban-farmland boundary (municipal)		(1)water quantity groundwater -> groundwater abstractions agriculture (2) (livestock) agriculture large scale & intensive -> spatial pressure (3)(livestock) agriculture large scale & intensive -> agricultural transition (4) -> (livestock) agriculture large scale & intensive -> agricultural transition -> social support and awareness -> consumer behaviour -> disbalance product price – cost price ratio
14	Impact of market thinking on agriculture	Because of world trade and market thinking, agriculture has become large scale and intensive. This results in a vicious loop. As a consequence, water quality and quantity decreases, and a pressure on ecosystems and landscape value and -income	Catchment – global??		(1)production optimalisation & cost efficiency agriculture -> large scale and intensive (livestock) agriculture -> yield agriculture (2) production optimalisation & cost efficiency agriculture -> land price ->large scale and intensive (livestock) agriculture -> yield agriculture (3) production optimalisation & cost efficiency agriculture-> correct business model agriculture -> ondernemend natuurnetwerk Brabant -> large scale and intensive (livestock) agriculture -> yield agriculture (4)large-scale and intensive (livestock) agriculture -> artificial water system (peil volgt functie)

Table 6 Table showing frequency of occurence of variables in individual CLDs (variables including once are not included)

	Respondent nr:														**Frequency of occurrence:**
CLD variables/components	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
water quantity: groundwater	1	1	0	1	1	1	1	1	1	0	0	1	1	1	11
fast draining water system	0	0	1	1	1	0	1	1	1	1	1	1	1	1	11
soil quality	0	1	1	0	1	1	0	1	0	1	1	1	1	1	10
climate change	1	0	1	0	0	1	1	1	1	1	1	1	1	0	10
groundwater abstractions agriculture	0	0	1	1	0	1	1	1	1	1	1	0	1	1	10
large-scale and intensive (livestock) agriculture	0	1	1	0	1	0	0	1	1	1	1	0	1	1	9
organic matter content	1	1	1	0	1	1	1	0	1	1	0	0	1	0	9
biodiversity	1	1	1	0	1	0	0	0	1	1	1	0	1	1	9
water infiltration	1	0	1	0	0	1	1	1	1	1	0	0	1	0	8
periods of drought	1	0	0	0	0	1	1	1	1	1	1	1	0	0	8
flooding (nuisance)	1	1	0	0	0	1	1	1	1	1	0	1	0	0	8
yield agriculture	0	1	1	0	0	1	0	0	1	1	0	0	0	1	6
water buffering capacity soil	1	1	0	0	0	1	1	0	1	1	0	0	0	0	6
heavy rainfall events	0	0	0	0	0	1	1	1	1	0	0	1	1	0	6
coniferous forest	1	0	1	0	1	0	0	0	0	1	0	1	0	1	6
drying-out nature	0	0	1	1	0	0	1	1	1	0	0	0	1	0	6
paved surface	1	0	0	0	0	0	1	1	1	1	0	0	1	0	6
disbalance product price - cost price ratio (food)	0	0	0	0	0	0	1	1	1	0	1	0	1	1	6
production & cost efficiency agriculture	0	0	0	0	1	0	1	1	0	0	1	0	0	1	5
agricultural transition (biological/nature-inclusive/extensive)	0	1	0	0	0	0	0	1	0	1	1	0	1	0	5
nitrate leaching	1	1	1	0	0	0	0	0	0	0	1	0	1	0	5
pressure on ecosystem	0	0	0	0	1	0	0	0	0	0	1	1	1	1	5
artificial water system (peil volgt functie)	0	0	0	1	0	0	1	0	1	0	0	0	1	1	5
brook system: discharge fluctuations	1	0	1	0	0	0	0	0	0	1	0	1	1	0	5
(recreative) amenity value of landscape	1	0	0	0	1	0	0	0	0	0	1	0	1	1	5
water requirements vegetation/crops	0	0	0	0	0	1	1	0	1	1	0	0	1	0	5
use manure (general)	0	0	0	0	0	0	0	0	0	1	1	0	1	1	4

use manure	0	1	0	1	1	1	0	0	0	0	0	0	0	0	4
irrigation agriculture	1	0	1	0	0	0	1	0	0	1	0	0	0	0	4
monoculture crops	0	0	0	0	1	0	0	0	0	0	1	0	1	1	4
water quality: general	1	0	1	0	0	0	0	0	0	1	0	0	1	0	4
temperature/heat waves	0	0	1	0	0	1	0	0	1	1	0	0	0	0	4
groundwater abstractions drinking water	0	0	1	0	0	0	0	1	0	1	1	0	0	0	4
social support and awareness	0	0	0	1	0	0	0	1	1	0	0	0	1	0	4
correct business model (agriculture)	0	0	0	0	0	0	0	0	0	1	1	0	1	1	4
use crop protection products	0	1	0	1	0	0	0	0	0	1	0	0	0	0	3
bankruptcy/ closing farms	0	0	0	0	0	1	0	0	1	0	1	0	0	0	3
crop choiche/location of cultivation	0	0	0	0	0	0	0	0	1	1	1	0	0	0	3
level controlled drainage	1	1	0	0	0	1	0	0	0	0	0	0	0	0	3
soil type	0	1	1	0	0	0	0	0	0	0	0	0	1	0	3
water quality: groundwater	0	1	0	1	0	0	0	0	0	0	0	0	0	1	3
nitrogen deposition	0	0	1	0	0	0	0	0	0	0	0	1	1	0	3
depletion groundwater reserves	0	0	0	1	0	1	0	0	0	0	0	0	0	1	3
(urban) water retention	1	0	0	0	0	1	1	0	0	0	0	0	0	0	3
seepage flows	1	0	0	0	0	0	0	1	0	0	0	1	0	0	3
brook system: drying- out	1	0	1	0	0	0	0	0	0	1	0	0	0	0	3
disconnecting rainwater drains	1	0	0	1	0	0	0	0	0	0	0	0	1	0	3
urban green	0	0	0	0	0	0	1	0	1	0	0	0	1	0	3
(clean) water discharge sewerage	1	0	0	0	0	0	1	1	0	0	0	0	0	0	3
health and wellbeing	0	0	0	0	1	0	0	0	1	0	0	0	1	0	3
trust government - entrepreneurs	1	0	0	0	0	1	0	0	0	1	0	0	0	0	3
banks/money system stimulates intensive agriculture	0	0	0	1	0	0	0	0	0	0	1	0	0	1	3
manure policy	0	1	0	0	1	1	0	0	0	0	0	0	0	0	3
legislation & policy: missing link with reality	0	1	0	1	0	0	0	0	0	0	1	0	0	0	3
feasibility N2000	0	0	1	0	0	0	1	0	0	1	0	0	0	0	3
lacking registration wells	1	0	0	1	0	0	1	0	0	0	0	0	0	0	3
blending of nature purposes - agriculture (fragmentation)	0	0	0	0	0	1	0	1	0	0	0	1	0	0	3
revenue recreation	0	0	0	0	0	0	0	0	1	0	1	0	0	1	3

inject slurry manure	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
use fertilizer	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2
leased land	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2
large flows in agriculture & food	0	0	0	0	1	0	0	1	0	0	0	0	0	0	2
steerability of soil type (seen as substrate)	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
water quality: surface water	0	1	0	0	0	0	0	0	1	0	0	0	0	0	2
evaporation	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2
CO2 emissions	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2
rainfall	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2
restoration 'Natte natuurparels'	0	0	0	0	0	0	1	0	0	1	0	0	0	0	2
wildfires	1	0	0	0	0	0	0	0	1	0	0	0	0	0	2
(ondernemend) Natura netwerk Brabant	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2
groundwater abstractions industry	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
groundwater abstractions private	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
water quantity: general	0	0	1	0	0	0	0	0	0	1	0	0	0	0	2
water quantity: surface water	0	0	0	1	0	0	0	0	1	0	0	0	0	0	2
drying-out water system (general)	1	0	0	0	0	0	0	0	0	0	1	0	0	0	2
brook system restoration	1	0	0	0	0	0	0	0	0	0	0	0	1	0	2
surface built-up area	0	0	1	0	0	0	0	1	0	0	0	0	0	0	2
overflows	0	0	1	0	0	0	0	0	1	0	0	0	0	0	2
heat stress built-up area	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2
(political) discussion water division	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
population growth	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
medication use	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2
visibility problem (pollution)	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2
social impact & collaboration community	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
consumer behaviour	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2
landscape elements	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2
(drinking) waterprice	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2
production for world economy/- trade	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2
evading regulations	0	1	0	0	0	0	1	0	0	0	0	0	0	0	2
missing regulations abstractions	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2
feasibility KRW	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2

strong separation agriculture-nature	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
spatial pressure	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2
history: land consilidation	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2
enery transition	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2
housing shortage	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2
guaranteeing drinking water supply	0	0	0	1	0	0	0	0	0	0	0	0	1	0	2

Annex G: First version of merged causal loop diagram

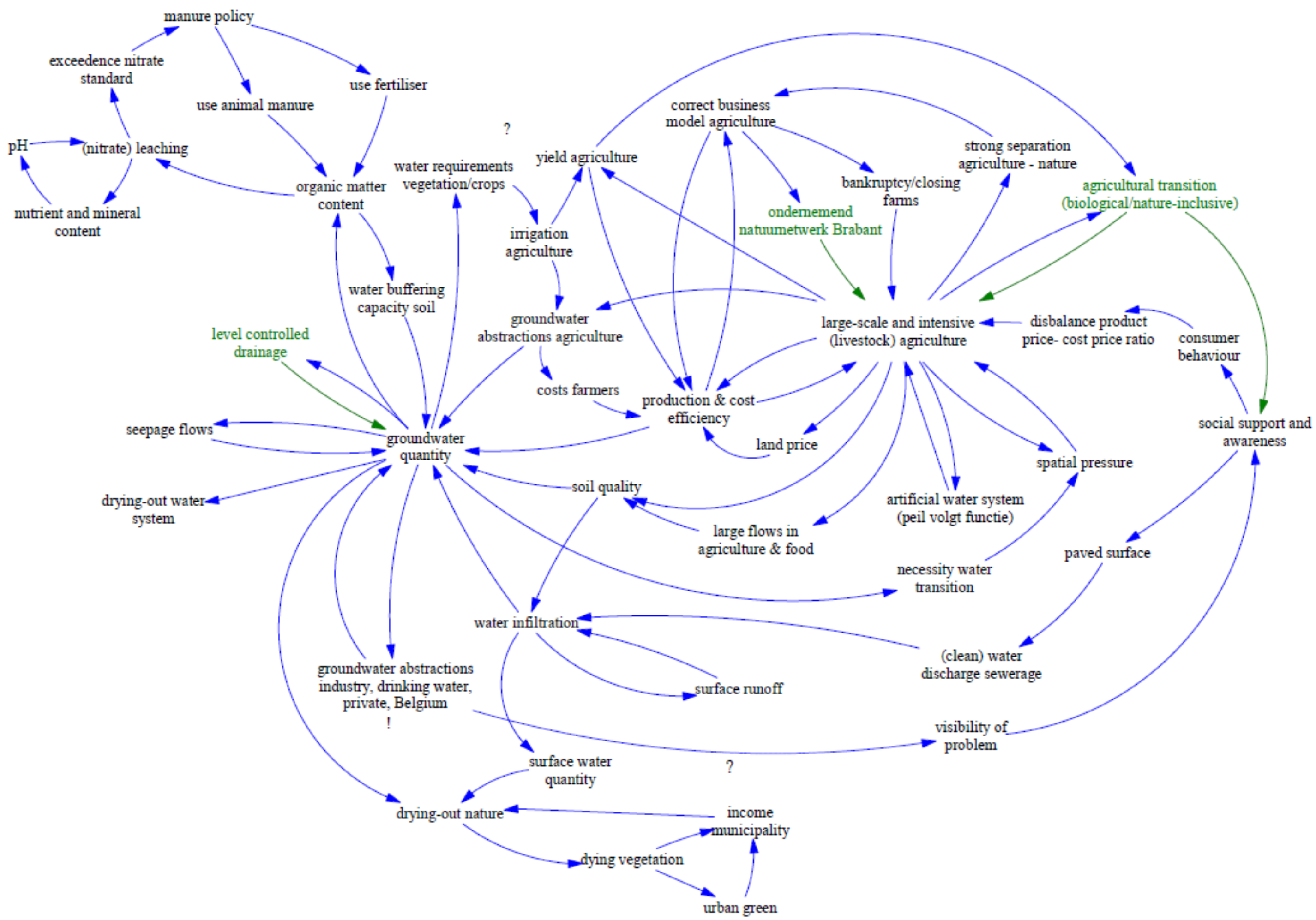


Figure 21 Merged Causal Loop Diagram version 1

Annex H: Summary KLIMAP expert workshop

Datum: 15-04-2021
Tijd: 12:30

Presentatie onderzoeksprobleem, onderzoeksvraag, methode en voorlopige bevindingen

Vragenrondje

- Nog even een keer benaderd dat dit perceptie is van de stakeholders
- Kleine discussie over het irrigatieverhaal. Het irrigatie en onttrekkingsbeleid is erg ingewikkeld. Deelnemer van het waterschap gaf aan dat onttrekkingen niet vrij zijn. Maar dat er tegelijkertijd ook een verschil zit tussen grasland en akkerland. Hier zijn de meningen dus nog over verdeeld en het is lastig weer te geven in deze causal diagram.

Discussie: Klopt beschrijving die respondenten hebben gemaakt met beeld van deelnemers/werkelijkheid?

- Deelnemer meldt dat als je op kaart organische stof gehalte bij Reusel opzoekt het gewoon ligt op gebied met hoog percentage organische stof gehalte. Dat het ook vanuit water kwantiteit niets toevoegt als je meer organische stof toevoegt. Dus klopt die opvatting wel?
- Er is geen meting die het bevestigt, iedereen praat elkaar na -> dikkere pijlen
- Maar in zo'n diagram kijk je naar hoe mensen het zien
- Dit is niet zozeer bedoeld om de kwantiteit van de gegevens weer te geven, maar knoppen vinden om aan te draaien.
- Je kunt dit gebruiken voor communicatie en voor inzicht: wat hangt waarmee samen.

➔ En waar wil je verder investeren als het gaat om feitenverzameling/onderzoek? Op basis van deze diagrams

- Ook interessant: wat wordt niet genoemd, wat zie je niet? Wat wordt over het hoofd gezien?
- Kan je aangeven hoe onzeker een relatie is?

Discussie in MIRO: komt beeld overeen met wat we in KLIMAP gebruiken?

- Het gaat er niet zozeer om of het klopt of niet, maar het gaat erom hoe mensen er tegenaan kijken. Als je met mensen in gesprek gaat over klimaatrobuustheid etc, moet je realiseren dat dat hun visie is. Dit is een stukje van het systeem.
- Dit is uitgangspunt als je in gesprek gaat met de streek. Het geeft vorm aan hoe je het gesprek aan gaat.
- Het is dan een instrument in de communicatie.
- Reusel: Welke maatregelen passen in de casus? Gezien het wereldbeeld dat we zelf hebben (feiten?) en het wereldbeeld dat er is in het gebied. Het moet uiteindelijk ook wel overeenkomen.
- Casus Reusel: kwantiteit grondwater is een belangrijke. Wordt heel erg teruggevoerd op bodemvruchtbaarheid en organische stof.
- Deelnemer: Irrigatie staat centraal en de grootschalige veeteelt. Dan zouden we binnen KLIMAP veel meer moeten besteden aan beleid van landbouw. Het rechter deel is voor een groot deel beleidsgericht.

- Waterbehoefte gewas: zit ook een grote potentiele loop in. Voor oplossing. Bedrijfsvoering van de agrariër, andere soort gewassen. Wat levert dat op?
- Landbouw zit heel erg op sturen. Zorg maar dat er meer water is, des noods pomp je het terug. Dat is een andere kijk dan het waterschap, een tegenstelling.
- Landbouwtransitie kan grote kentering in systeem teweeg brengen.
- Ondertussen in het gebied wil de landbouw veel, veel veel, dus dan is er nog een lange weg te gaan
- Je kunt niet verwachten dat mensen buiten hun eigen grenzen gaan treden. De 3 diagrammen hebben interactie met elkaar. Je zou willen dat iedereen met elkaar integreert, maar dat heb je zomaar niet voor elkaar. Dus dé oplossing kan je niet van een bepaalde sector verwachten.
- Hoe kan je de 3 diagrammen nog beter aan elkaar matchen?

Volgende model: stedelijk landelijk model

- Er zijn eigenlijk alleen maar reinforcing loops. Dat betekent dat de boel uit de hand loopt. De perceptie is dat het niet goed gaat.
- Knoppen om aan te draaien in dit diagram: grondwateronttrekkingen, verhard oppervlak
- Klimaatbestendig: waar hebben we het dan over? Technisch/maatschappelijk
- Hier wordt de communicatiekant inzichtelijk, hoe zien de mensen hun werkelijkheid. En ook de technische kant. Die discussie moet je aangaan.
- Kijk naar zonering. Wat heeft waar waardevoorkeur en wat voor maatregelen wil je nemen? Bijv… hooggelegen gebieden waar je afhankelijk bent van water en de lager gelegen gebieden waar je wateroverlast hebt. Hoe groot is je oplossingsruimte? Hoe groot maak je het systeem waarbinnen je klimaatbestendig iets wilt doen?
- Discussie: gewoon maar water oppompen, of moeten we veel meer vasthouden?

Gebruik methode in KLIMAP

- Diagram bruikbaar in het veranderen van het systeem, ook richting de toekomst?
- Nuttig om grootste risico's t.a.v. klimaatrobuustheid te identificeren. Belangrijkste risico is begin van ontwikkelpaden traject. Waterkwantiteit moet in het midden staan bij verder denken over ontwikkelpaden -> dus probleemanalyse.
- Scenario planning en CLD kan mooie combinatie zijn. Identificeer aantal risico factoren en grote impact, als je die in matrix uit zet, kan je ze koppelen aan bestaande diagrammen. Andere relaties worden dan zichtbaar. Dan weet je welke scenario's je kunt onderscheiden en hoe je er toe kan komen. Bijv. scenario's als het gaat om landbouw. Toekomstperspectieven voor regio.
- Wetenschappelijke feiten leggen t.o.v. de percepties
- Diagram gebruiken om vraaggericht de goede data boven tafel te krijgen. Binnen klimap is het een rode draad: match of mismatch tussen onderzoekers en mensen uit de praktijk. Vaak nog licht daartussen. Dit diagram gebruiken om te laten zien: er zit nog ligt tussen hoe mensen tegen de wereld aankijken.
- Als je gebiedsgerichte aanpak wil, moet je over grenzen heen, en de communicatie aangaan. Daar zijn nog nauwelijks instrumenten voor. Het diagram moet dan nog herzien, maar het herzien heeft z'n functie.
- Methode: je kunt het wat makkelijker maken door direct te starten tijdens een workshop met zo'n diagram. Kan tijd sparen. Vervolgens het ook leggen naast participatieve monitoring.

- Naar mate je het meer doet kan je archetypen gaan identificeren. Je kunt dan sneller zulk soort diagrammen maken

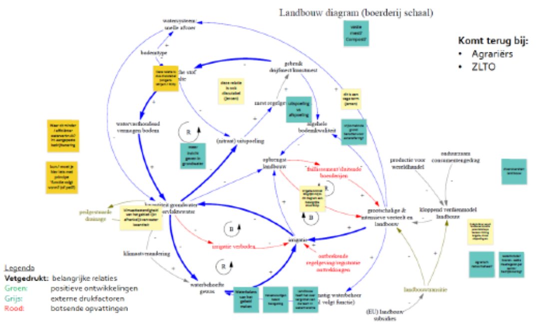
Losse post-its

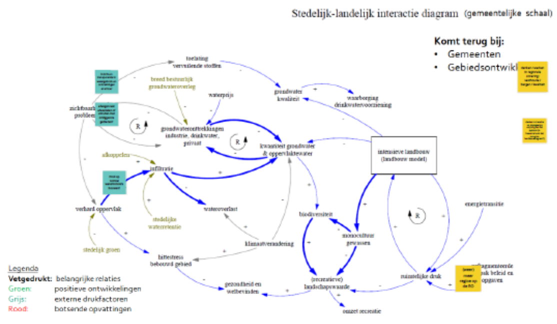
- Leggen naast Sankey diagram: objectieve waterstromen naast perceptie

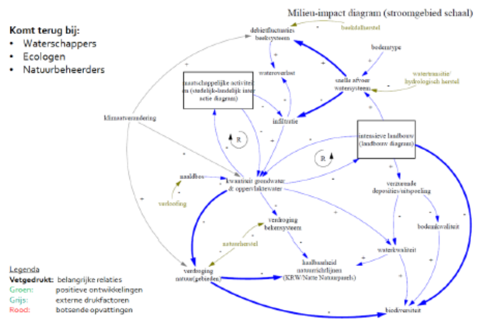
Hoe verder in de casus?

- Aan de hand van de diagrammen het gesprek aan gaan, leggen naast sankey diagrammen. Dan kijken waar we in stap 2 uitkomen, met de toekomstverkenningen.
- Naast participatieve monitoring, etc., ga ook een gesprek aan, hoe kijk je aan tegen de wereld? (eventueel in een collectieve sessie bij elkaar gaan zitten)
- In zo'n gesprek moet wel een stukje objectiviteit zitten. Bijv.: dit is waar we mee te maken hebben vanuit klimaatverandering.
- Let ook op mensen die het al toepassen en die anderen enthousiast kunnen maken. Sluit ook aan bij opschaling. Wellicht uitersten bij elkaar brengen? Bijv. intensieve precisielandbouw en natuurinclusieve landbouw.

A copy of the Miro whiteboard is given on the next page

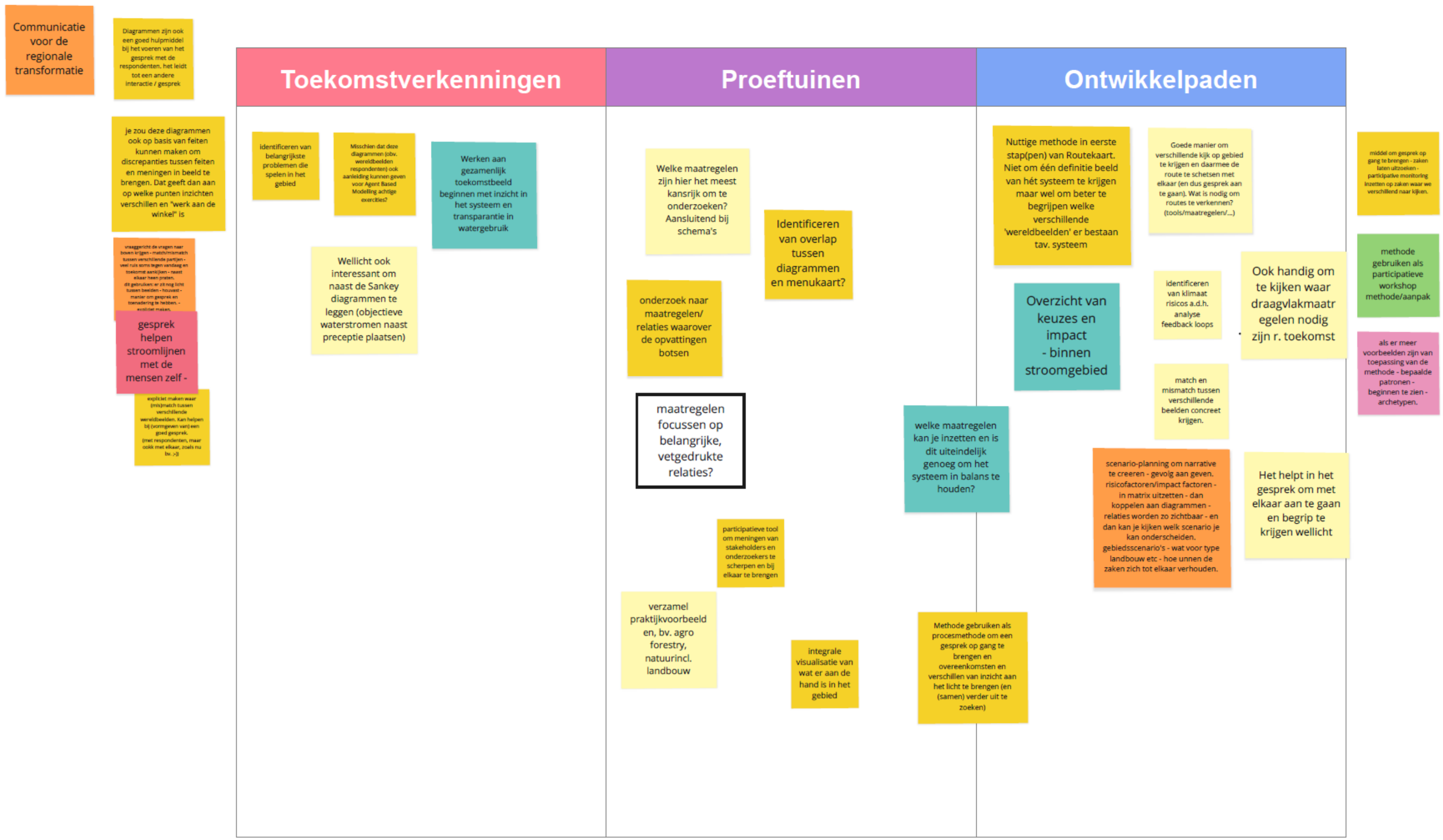






Hoe zou je de resultaten kunnen gebruiken?

- Waar ligt de focus van het system?
- Als je naar het model kijkt, welke vragen zou dit model dan kunnen oplossen of aanpakken?
- Waar raken de onderwerpen elkaar?
- Waar kan je ingrijpen om Reusel klimaatbestendig te maken?



Communicatie voor de regionale transformatie
Diagrammen zijn ook een goed hulpmiddel bij het voeren van het gesprek met de respondenten. het leidt tot een andere interactie / gesprek
je zou deze diagrammen ook op basis van feiten kunnen maken om discrepanties tussen feiten en meningen in beeld te brengen. Dat geeft dan aan op welke punten inzichten verschillen en "werk aan de winkel" is
vraaggericht de vragen naar boven krijgen - match/mismatch tussen verschillende partijen - veel ruis soms tegen vandaag en toekomst aankijken - naast elkaar heen praten. dit gebruiken: er zit nog licht tussen beelden - houvast - manier om gesprek en toenadering te hebben. - expliciet maken.
gesprek helpen stroomlijnen met de mensen zelf -
expliciet maken waar (mis)match tussen verschillende wereldbeelden. Kan helpen bij (vormgeven van) een goed gesprek. (met respondenten, maar ookk met elkaar, zoals nu bv. ;-))
Toekomstverkenningen
identificeren van belangrijkste problemen die spelen in het gebied
Misschien dat deze diagrammen (obv. wereldbeelden respondenten) ook aanleiding kunnen geven voor Agent Based Modelling achtige exercities?
Werken aan gezamenlijk toekomstbeeld beginnen met inzicht in het systeem en transparantie in watergebruik
Wellicht ook interessant om naast de Sankey diagrammen te leggen (objectieve waterstromen naast preceptie plaatsen)
Proeftuinen
Welke maatregelen zijn hier het meest kansrijk om te onderzoeken? Aansluitend bij schema's
Identificeren van overlap tussen diagrammen en menukaart?
onderzoek naar maatregelen/ relaties waarover de opvattingen botsen
maatregelen focussen op belangrijke, vetgedrukte relaties?
participatieve tool om meningen van stakeholders en onderzoekers te scherpen en bij elkaar te brengen
verzamel praktijkvoorbeelden, bv. agro forestry, natuurincl. landbouw
integrale visualisatie van wat er aan de hand is in het gebied
welke maatregelen kan je inzetten en is dit uiteindelijk genoeg om het systeem in balans te houden?
Methode gebruiken als procesmethode om een gesprek op gang te brengen en overeenkomsten en verschillen van inzicht aan het licht te brengen (en (samen) verder uit te zoeken)
Ontwikkelpaden
Nuttige methode in eerste stap(pen) van Routekaart. Niet om één definitie beeld van hét systeem te krijgen maar wel om beter te begrijpen welke verschillende 'wereldbeelden' er bestaan tav. systeem
Goede manier om verschillende kijk op gebied te krijgen en daarmee de route te schetsen met elkaar (en dus gesprek aan te gaan). Wat is nodig om routes te verkennen? (tools/maatregelen/...)
Overzicht van keuzes en impact - binnen stroomgebied
identificeren van klimaat risicos a.d.h. analyse feedback loops
Ook handig om te kijken waar draagvlakmaatregelen nodig zijn r. toekomst
match en mismatch tussen verschillende beelden concreet krijgen.
scenario-planning om narrative te creeren - gevolg aan geven. risicofactoren/impact factoren - in matrix uitzetten - dan koppelen aan diagrammen - relaties worden zo zichtbaar - en dan kan je kijken welk scenario je kan onderscheiden. gebiedsscenario's - wat voor type landbouw etc - hoe unnen de zaken zich tot elkaar verhouden.
Het helpt in het gesprek om met elkaar aan te gaan en begrip te krijgen wellicht
middel om gesprek op gang te brengen - zaken laten uitzoeken - participatieve monitoring inzetten op zaken waar we verschillend naar kijken.
methode gebruiken als participatieve workshop methode/aanpak
als er meer voorbeelden zijn van toepassing van de methode - bepaalde patronen - beginnen te zien - archetypen.