Ensuring Climate-Resilient Groundwater Levels Year-Round: A Framework to Propose Groundwater Norms and Measures to Mitigate Drought

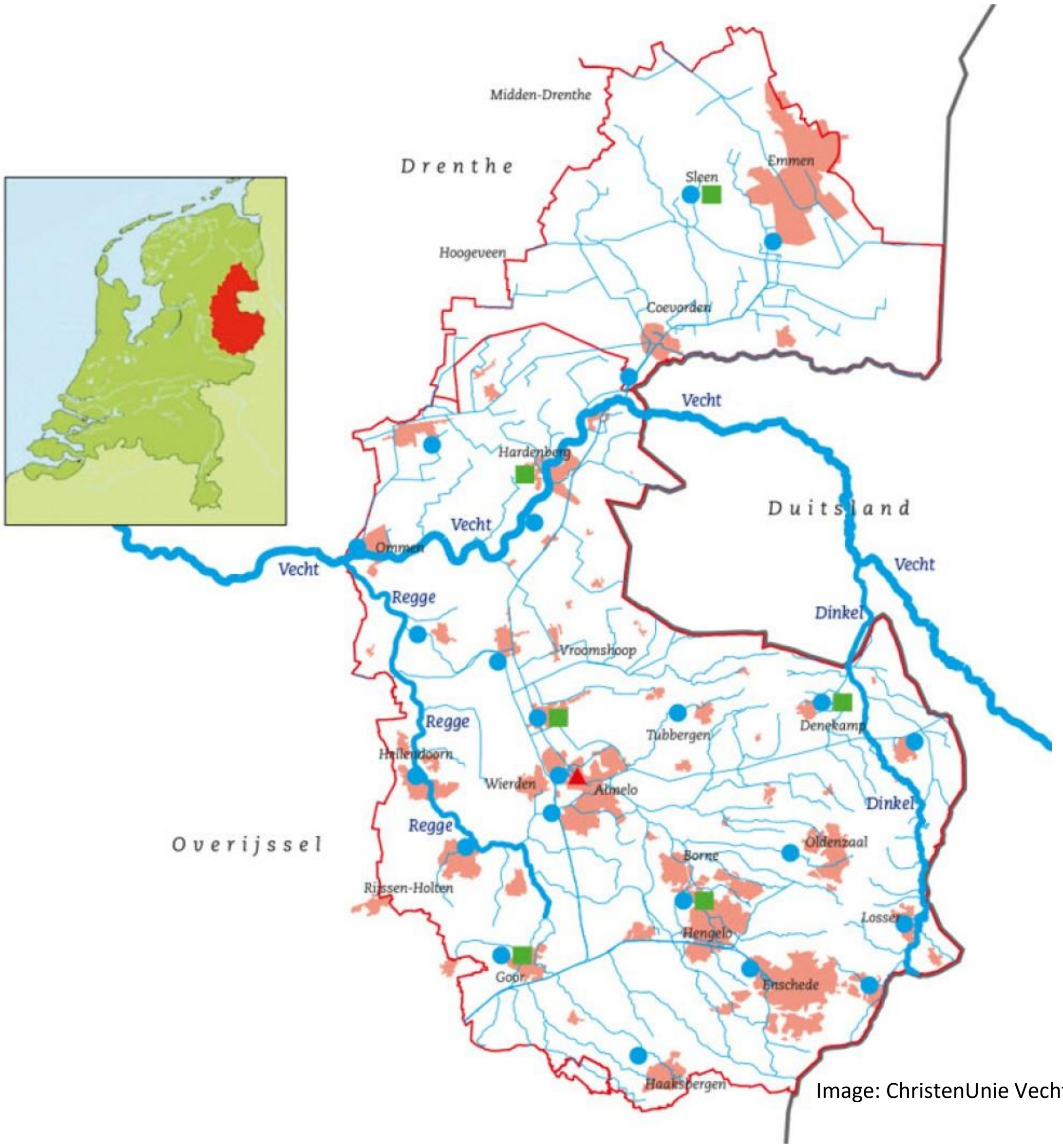

Image: ChristenUnie Vechtstromen

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WATERSCHAP vechtstromen

Preface

In front of you lies the Bachelor thesis “Ensuring Climate-Resilient Groundwater Levels Year-Round: A Framework to Propose Groundwater Norms and Measures”, which I carried out at Waterschap Vechtstromen in Almelo. This thesis has been written to finalize the graduation requirements of the bachelor’s program in Civil Engineering at the University of Twente.

This study aims to create a framework which standardises the process of choosing the best suitable measures and norms for groundwater management in the Netherlands. The framework evaluates three specific land use types to determine a top five for the best suitable measures and norms, for that specific land use type. Following from these top fives a combined assessment will take place, leading to an advice to ensure climate-resilient groundwater levels all year round and mitigate the impact of droughts on the groundwater supply.

Looking back, I can say that I have learned a lot about groundwater management in the Netherlands during the ten weeks of my internship at Waterschap Vechtstromen. However, the experience of doing research by myself for the first time was a rather tough but meaningful and instructive experience. It could be frustrating when things do not work out well or do not go as planned. Fortunately, I had great guidance throughout the entire process thanks to my supervisors. Therefore, I would like to thank my external supervisor Jeroen van der Scheer (Waterschap Vechstromen) for sharing his enthusiasm, expertise and network of colleagues which made it possible to have discussions on the topic of groundwater management, to host an expert session with hydrologists and environment managers, and to interview colleagues of external waterboards as well. Furthermore, I want to thank my supervisor from the university Lara Wöhler for the critical feedback and positive guidance throughout the process.

Lastly, thank you my reader: I hope you enjoy reading my thesis.

Arend de Bart
Enschede, July 15, 2024

Abstract

Climate change negatively affects the environment, resulting in more frequent and more intense extreme weather events such as droughts. Throughout the years the main focus in Dutch water management was to prevent flooding, by applying specified norms and measures to mitigate water nuisance as much as possible as described by law. However, as the impacts of the droughts become more severe over time, such as in the year 2018, it becomes clear that there is a huge gap in drought mitigation in water management in the Netherlands.

This study investigates the possibility of standardizing groundwater management in the Netherlands related to drought by constructing a framework that will guide norms and measures to mitigate drought-related effects and ensure climate-resilient groundwater levels all year round. To be able to construct such a framework several methods are used. Based on literature research and interviews the current state of groundwater management could be described and the necessary steps of establishing a framework could be discovered.

This research is performed in three steps. The literature faces in which the current state of water management standards has been investigated. Several measures and norms have been chosen and constructed that could act as instruments to mitigate the effects of drought on groundwater levels. Additionally, requirements of specific land uses have been investigated based on literature and interviews.

The second phase was to develop a structure to propose a set of norms and measures, based on the first phase. In this structure, six steps will be taken: determination of land use type, determination of requirements of each land use type, selection of standards for assessment including norms and measures, the assessment of the norms and measures, the combined assessment to find the best measures and norms and the final advise.

The third and final phase was evaluating the framework and the selected measures and norms constructed in the second phase during an expert session. The outcomes of the expert session helped to develop advice for the waterboard on how to mitigate the effects of drought on groundwater levels in a climate-resilient way.

Keywords: Groundwater framework, Norms, Measures, Groundwater management, Climate-resilience, Drought mitigation

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1. Introduction

1.1 Context

Global climate change

Global climate change refers to long-term shifts in the average state of the climate or its variability, lasting for several decades or more. These changes include shifts in average weather conditions, such as global temperature increases, and the frequency of extreme weather events like droughts, heat waves, floods, and storms. Climate change can occur naturally due to factors like changes in the sun's energy or Earth's orbital cycles. However, it can also result from human activities, such as the release of greenhouse gases, sulphate aerosols, and carbon dioxide into the atmosphere, or through changes in land use. These human-induced factors play a significant role in the current trends of climate change, impacting ecosystems and human societies worldwide (Adedeji et al., 2014; Green et al., 2011).

Short-term effects of Global climate change

Short-term effects of Global climate change imply that due to increased CO_2 in the atmosphere, leads to an increased photosynthesis process in plants (Cassia et al., 2018), the procedure by which plants can transfer CO_2, water and minerals into oxygen and energy-rich compounds (Brittannica, 2024). However, due to increased O_3 levels in the atmosphere, the important source of energy for plants to perform photosynthesis is blocked, which is sunlight (Cassia et al., 2018). Additionally, the rise in CO_2 levels will contribute to an increased average global temperature and unexpected variations in rainfall will occur more frequently leading to more frequent extreme weather events such as heat waves, flooding events and droughts (Cassia et al., 2018).

Local effects of climate change

The effects can lead to major financial impacts on different sectors on a small scale. Droughts are specifically relevant to the agricultural sector e.g. Where plants will grow less effectively, or entire crop harvests fail due to high temperatures and lack of precipitation (Coderoni & Pagliacci, 2023). Besides that, due to the effects of climate change heat islands will occur in urban areas. The result is that temperatures in cities will increase significantly over time (McCarthy et al., 2010). This would increase urban water demand by 80% by 2050, putting more stress on groundwater management(Flörke et al., 2018).

1.2 Problem Description

In the management area of Vechtstromen, the increasing occurrence of extreme weather events due to climate change poses a significant challenge. Increased temperatures and greater variation in weather patterns can significantly impact groundwater levels (Coderoni & Pagliacci, 2023; McCarthy et al., 2010). Higher temperatures lead to more evaporation from soil and water surfaces, causing more groundwater to be lost to the atmosphere(Konapala et al., 2020). Climate change can result in more frequent and severe droughts, limiting precipitation needed to refill groundwater reservoirs. Additionally, intense but infrequent rainfall events lead to greater surface runoff, decreasing groundwater recharge (Konapala et al., 2020; Ran et al., 2012).

While plans are in place to address water nuisances, there is a notable absence of established norms regarding drought management within the waterboard. The current focus on monitoring, storing, and processing surface and groundwater, as well as retention in other water bodies, underscores the critical need to incorporate groundwater explicitly into hydrological designs with emphasis on the integration of flooding and droughts resilient to climate change (Mens et al., 2022; Monincx et al., 2024b).

Currently, there are no existing norms that provide guidelines to mitigate the effects of droughts on groundwater levels. With the increasing effects of climate change on the evaporation and runoff due to extreme and unpredictable weather events, the call for guidance and drought management gets louder every day. Besides that, based on research on the extreme dry year of 2018 it was found that European ground-based measures for spatially continuously monitoring drought impacts on forest growth and mortality as a consequence of climate change are very limited (Schuldt et al., 2020). The results of the extremely dry year of 2018 show the urgency of robust concrete management and norms for using groundwater to mitigate environmental effects. These effects were also prone in the east of the Netherlands, in the Vechtstromen management area (de Lenne & Worm, 2019).

Within Waterboard Vechtstromen a special project team has been set up to establish norms to mitigate the impact of drought on groundwater. Despite ongoing efforts within the project team to explore this integration, this research addresses the critical knowledge gap regarding groundwater management norms and measures within the context of the Poelsbeek and Loodiep catchment areas. By investigating the integration of groundwater into the water system and clarifying the lack of clear norms for managing groundwater levels, this study aims to advance scientific understanding and contribute to enhancing the resilience and sustainability of water management practices.

1.3 Study Areas

The study area on which the research will be focussing consists of two catchment areas within the domain of the waterboard Vechtstromen: Loodiep and Poelsbeek, as can be seen in Figure 1 below.

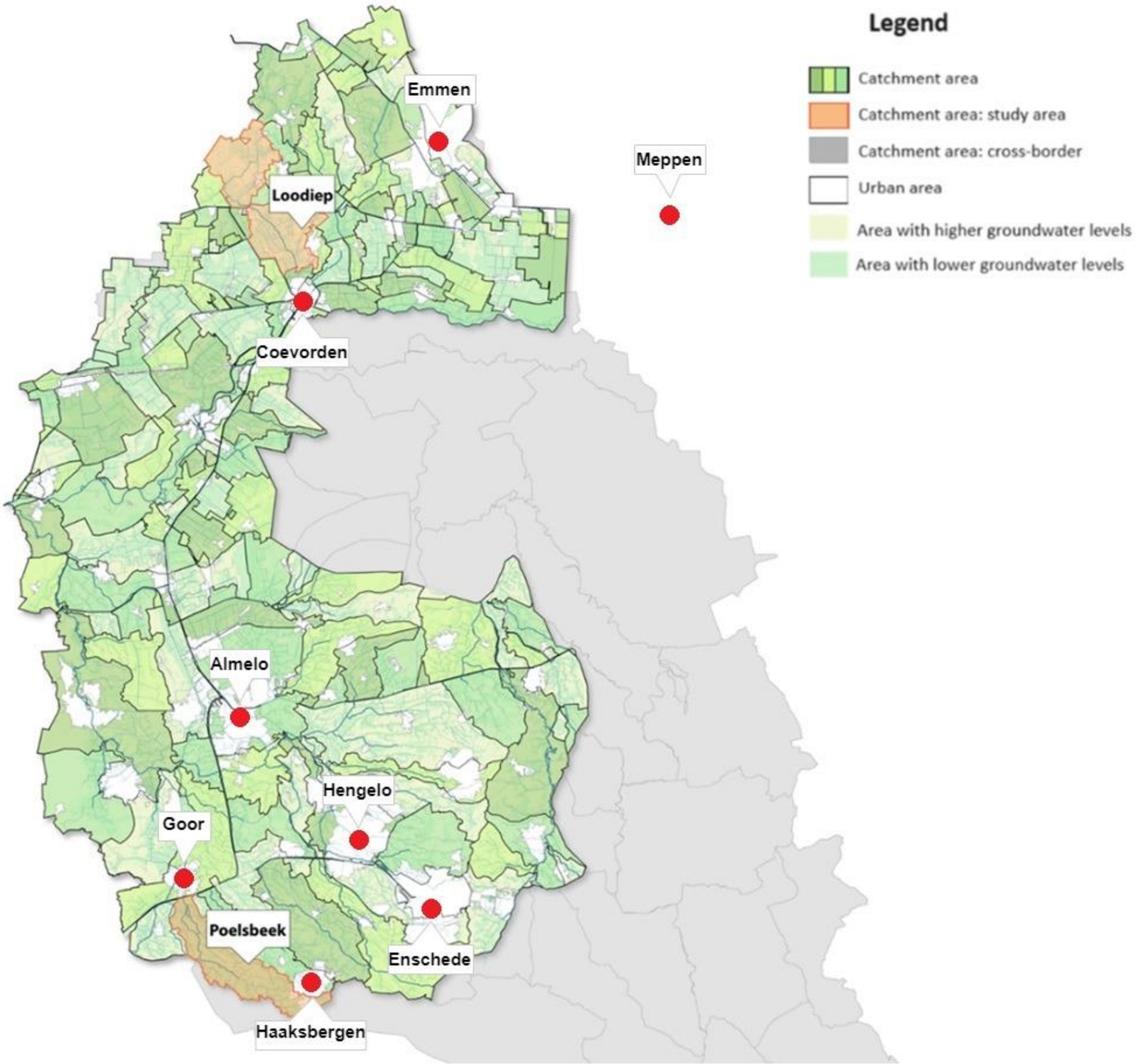

Figure 1: Catchment areas within the study area and their surroundings (Monincx et al., 2024b)

The main water supply in the Vechtstromen management area through watercourses can be seen in Figure 2 below.

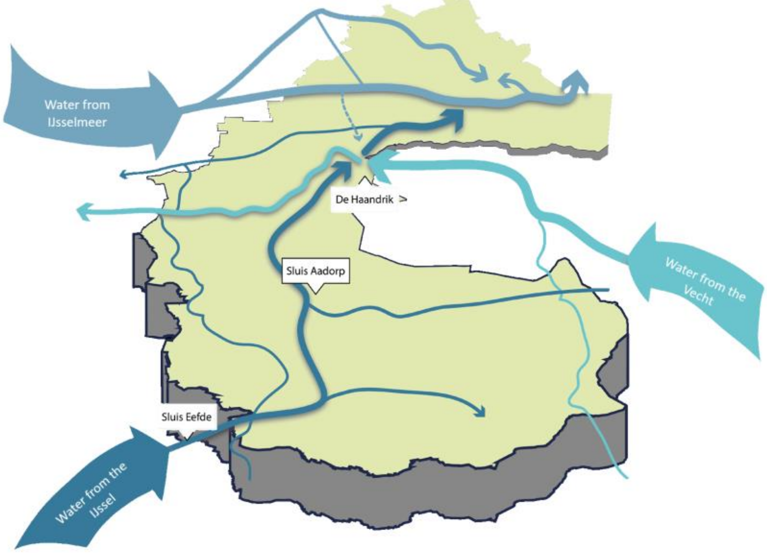

Figure 2 The water supply through the main watercourses in the Vechtstromen management area

Poelsbeek Catchment Area

The catchment area of the Poelsbeek is located west of Haaksbergen. Nearly all surface area of the catchment area is assigned to agricultural fields. Besides that, there is a small forest area in the northern part and some urban areas located in the north-east as well as an area neighbouring the city of Haaksbergen in the southeast, as can be seen in Figure 3 below.

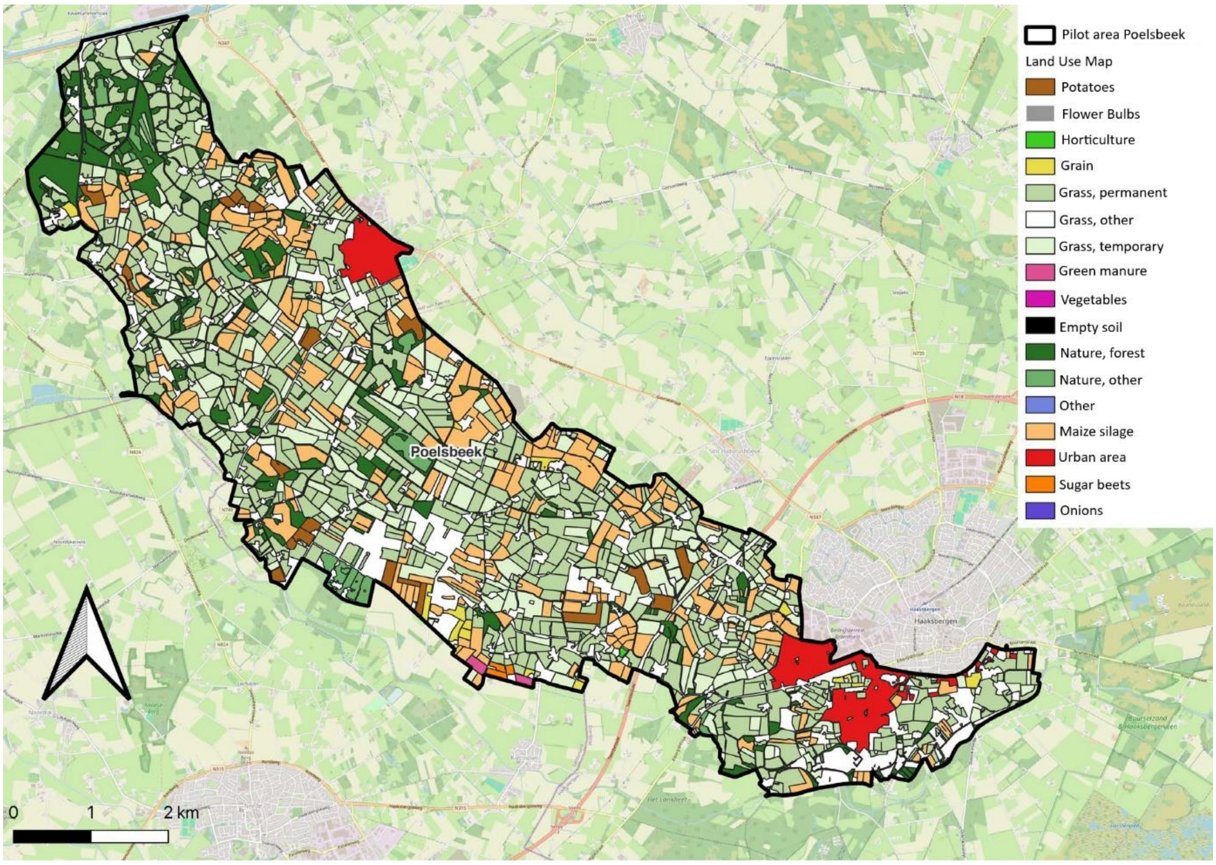

Figure 3 Land Use Map of Poelsbeek Catchment Area

The regulated stream flows into the Twentekanaal near Goor. The catchment area relies solely on precipitation for its water supply. Groundwater extraction occurs mainly for agriculture but for some industrial purposes in and around Haaksbergen.

During the summer, groundwater levels drop below the level of the streambed, causing periods of non-flow in the stream. The low groundwater levels lead to drought problems for agriculture (resulting in drought damage of up to 30%) and for nature, especially in the upland areas (Monincx et al., 2024a). The average rainfall deficit during the growing season ranges from 50 to 75 mm. Due to climate change, this deficit is expected to increase to 125-150 mm (Monincx, et al., 2024). Improved cultivation methods and crop breeding are projected to increase production and consequently evaporation in the future. The average rainfall deficit during the growing season is expected to increase to 200-225 mm by 2050. This represents an increase of 150 to 200% compared to the present (1991-2020)(Monincx et al., 2024a).

Loodiep Catchment Area

The catchment area of the Loodiep extends from the city of Meppen to Coevorden. And just like the Poelsbeek catchment area, the Loodiep catchment area consists mainly of farmland of distinct types. Besides that, there is a large nature area in the Northwest of the catchment area, consisting of "de Mepperhooilanden" and "Boswachterij Gees", which are visible below in Figure 4.

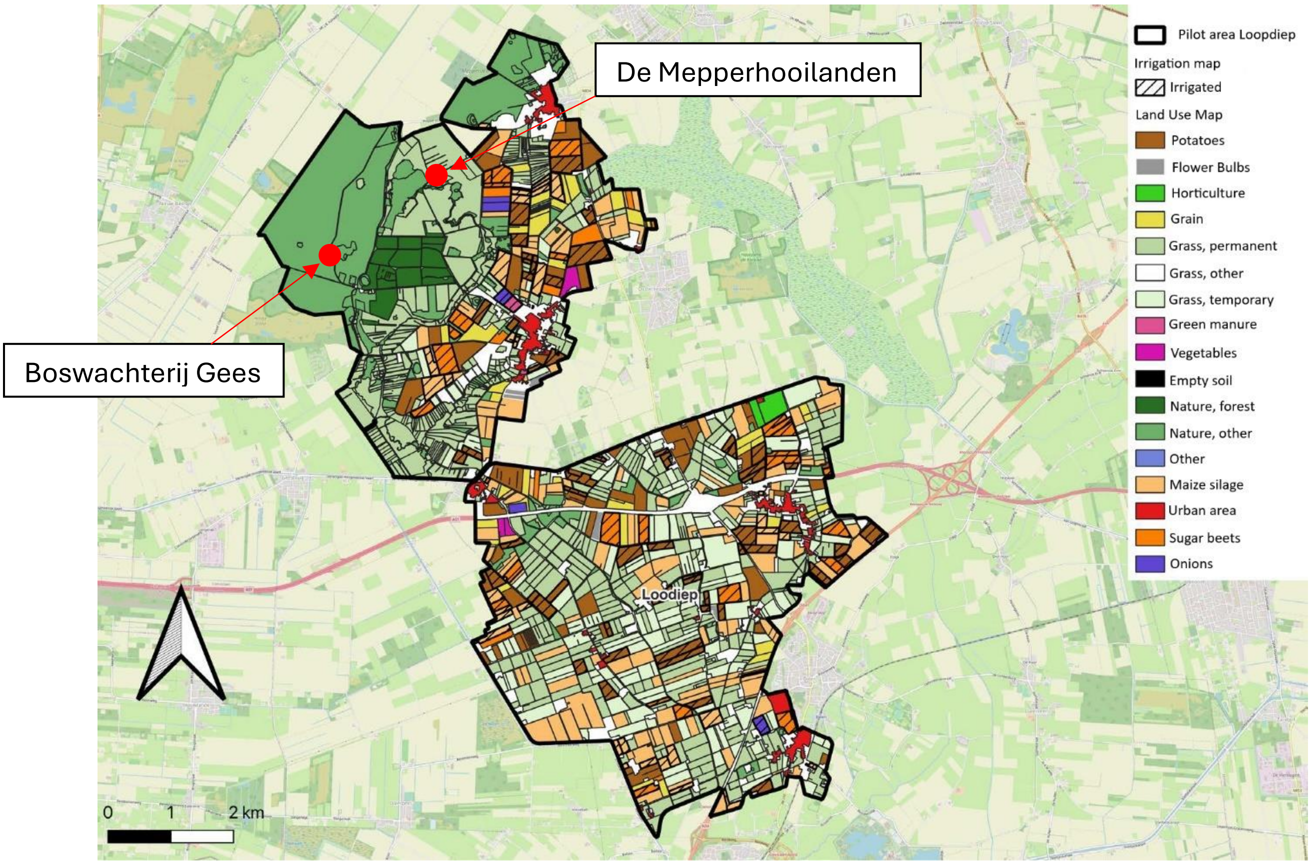

Figure 4 Land Use Map of Loodiep Catchment Area

In the northern part, an area of drained agricultural land feeds the Geeserstroom, which then flows into the Loodiep. The stream passes under the Verlengde Hoogeveense Vaart canal through a siphon. Water can be supplied from this canal, originating from the Ijsselmeer, in a southerly direction. The stream flows freely into the Coevorden-Zwinderen canal. Compared to the Poelsbeek study area, the Loodiep is not entirely dependent on precipitation under the current climate conditions, as water supply is possible from the Geeserstroom. During summer, water demand is determined by water level management and irrigation. There is little flow and thus little movement. The upper part of the Loodiep does not provide water for the southern part during the summer period. Water supply to the southern part occurs via inlet from the canal. The main consumers of the groundwater in this area are the agricultural sector.

In the summer half-year, the potential rainfall deficit is 40 mm in the current situation at rainfall station Hoogeveen. Due to climate change and the autonomous development of agriculture, this deficit will increase to approximately 200 mm (Monincx, et al., 2024). The main challenges for 2050 in this area are therefore water availability and water quality. The water supply capacity from the canal and Ijsselmeer is under pressure in the long term due to climate change. This is caused by lower Rhine discharge in the summer, increased water demand, and balancing interests in water distribution. This results in shortages in agriculture, nature, and the stream's water level and flow.
The inlet water is cleaner and has lower pollutant levels. This is positive in current situations where water supply is possible. However, if water availability for supply decreases due to climate change, this may pose an additional challenge for the water quality of the Loodiep (Monincx et al., 2024a).

1.4 Research Objective

Following the problem statement, the main research objective is to investigate and develop a framework which will lead to robust strategies for integrating groundwater management norms and measures to limit the impact of drought. This framework is a guideline to establish climate-resilient hydrological recommendations for Waterschap Vechtstromen evaluated for the Poelsbeek and Loodiep catchment areas. By dissecting this main objective into tangible sub-objectives, the following sub-objectives will be considered in this research:

1. Assess the current state of groundwater management norms within the Netherlands.
2. Evaluate existing norms, measures and strategies for addressing water nuisance and their effectiveness in mitigating flood risks within the catchment areas.
3. Investigate the specific groundwater level challenges and limitations in the context of climate change-induced extreme weather events.
4. Propose norms to mitigate drought effects on groundwater effectively.
5. Identify the best possible measures and norms for Urban areas, Agricultural land and nature based on their bottlenecks and demands.

1.5 Research Questions

Main Question

"How to standardise proposing norms and measures in a water management advise to guarantee sufficient groundwater levels throughout the year and ensure sustainable water management in the face of climate change?"

Sub Questions

1. What is a groundwater norm?
2. What is the effect of climate change on groundwater levels?
3. What groundwater-dependent land use types can be found in an area and what are the requirements related to groundwater?
4. What norms and measures are effective in providing desired groundwater levels and limiting the impact of low groundwater levels on the environment?
5. How can norms and measures effectively be selected for increasing groundwater levels in an area?
6. What are important criteria to assess the best suitable measures or groundwater norms and how to score the criteria?

2. Literature Review

2.1 Definition Descriptions

Drought

In their paper "Understanding the Drought Phenomenon: The Role of Definitions," Donald A. Wilhite and Michael H. Glantz explore the complexity of defining drought (White & Glantz, 1985). They mention that drought lacks a universally accepted definition since it is a phenomenon that occurs on different levels. This statement is confirmed by later studies into the definition of drought in 2014 by Benjamin Lloyd-Hughs in his work "The impracticity of a universal drought definition". It is found that for most practical purposes, drought is unquantifiable in the universal sense (Lloyd-Hughes, 2014). Instead, definitions of drought vary based on disciplinary perspectives, geographical contexts, and specific applications. Wilhite and Glantz identify four key types of drought definitions, each focusing on different impacts and criteria:

1. **Meteorological Drought** is defined by a lack of precipitation over a period, usually compared to the historical average for a specific region. The duration and intensity of this precipitation shortage are critical factors.
2. **Agricultural Drought** is about the impact of reduced rainfall on crop production and soil moisture levels. It typically focuses on periods when moisture shortages affect plant growth and yield.
3. **Hydrological Drought** is about the effects of precipitation deficits on water supply, including streamflow, reservoir and lake levels, and groundwater levels. It often occurs more slowly than meteorological droughts due to the lag in the hydrological cycle.
4. **Socioeconomic Drought** looks at the impact of drought conditions on human activities and economic systems. It considers factors like water demand exceeding supply and the resultant financial losses and societal effects.

In the scope of this research, all types of droughts will be considered as all types of droughts come with their potential issues and ways to harm the surrounding environment.

Groundwater and surface water

In the Dutch Environmental Act, groundwater is defined according to European water directives as 'water located beneath the surface in the saturated zone, in direct contact with the soil or subsoil (Informatiepunt Leefomgeving, 2024; Omgevingswet Artikel 1.1, 2024).'

However, according to this act, only the water in the saturated zone is considered groundwater, as targeted by the Kaderrichtlijn Water (Water Framework Directive) and the "Grondwaterrichtlijn" (Groundwater Directive) accordingly. This differs from the Water Act, which included all water in the soil as groundwater. The Water Framework Directive explicitly excludes soil moisture in the unsaturated zone from the definition of groundwater (Informatiepunt Leefomgeving, 2024).

To distinguish the difference between groundwater, on which this research is focussed, and surface water it is important to define surface water as well. The Environmental Act defines surface water as the cohesive body of water freely occurring at the earth's surface, with the substances contained therein, as well as the associated soil, banks, and, as expressly designated under law, drier bank areas, as well as flora and fauna (Omgevingswet Artikel 1.1, 2024).

Climate Resilience
Climate resilience refers to the capacity to prepare for, recover from, and adapt to the effects of climate change. This concept includes the ability to deal with more frequent and severe weather events, prolonged droughts, ocean warming, acidification, and other related impacts (Center for Climate and Energy Solutions, 2019). Additionally, resilience is associated with thinking systems, in which the systems require adaptation so the impact of climate change can be minimized (Subiyanto et al., 2020).

Climate resilience is a critical aspect of climate action plans. It involves efforts at multiple levels, from individual assets to entire neighbourhoods, to mitigate the effects of climate change. The aim is not only to protect people and property, but also involves generating economic activity, creating jobs, and driving prosperity (Center for Climate and Energy Solutions, 2019).

Groundwater Norm
A norm includes a specific allowed occurrence probability for a system or measure to fail every once in a specified period, which will be assessed later on in the section 2.2. Currently, groundwater norms concerning drought mitigation do not exist. However, it is possible to define a groundwater norm based on the definition of a water nuisance norm.

A water nuisance norm prescribes the duty of care that the waterboard has in preventing or limiting water nuisance due to inundation from surface water caused by heavy precipitation once in a specified timeframe. This prescription provides clarity for citizens and businesses regarding the risk and responsibility for protecting their properties, buildings, and movable goods (Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat, n.d.).

Therefore, a groundwater norm covers the duty and care of a water board in preventing or limiting the decrease in groundwater levels due to the effects of drought and climate change and includes a probability of a measure or system being allowed to fail once in a specified period.

Water Management Framework
The definition of a framework describes a structured set of guidelines, principles, or concepts used to address complex issues, guide decision-making, and achieve objectives. It serves as a systematic plan that outlines processes, methodologies, or approaches for understanding and managing a particular problem or system (Cambridge Dictionary, n.d.).

Frameworks provide a foundation for organizing information, setting standards, and ensuring consistency in implementation. They can be applied in various fields such as project management, software development, policy making, and academic research to facilitate comprehensive analysis and effective solutions.

In the scope of this thesis, a water management framework will be constructed and therefore contribute to creating advice and policies to tackle groundwater-related issues related to droughts caused by climate change.

2.2 Existing Strategies and Measures for Groundwater Management

Flood risk norms are essential for addressing regional water inundation concerns. By the National Water Management Agreement (2009), water boards have committed to assessing their areas for flood risks, utilizing nationally established benchmark values. These norms, enshrined in provincial water ordinances, gauge the acceptable frequency of surface water overflow events, as can be seen in Table 1 below.

Table 1 Risk norms for regional water nuisance (Waterschap Vechtstromen, 2015)

Usage of land	Accepted occurrence probability	Ground level criterion*
Grassland	1:10 years	5%
Cropland	1:25 years	1%
High-quality agriculture and horticulture	1:50 years	1%
Greenhouse horticulture	1:50 years	1%
Urban area	1:100 years	0%

**Ground level criterion: the percentage of land that is allowed to be flooded by surface water*

Additionally, Vechtstromen implements a unique standard for stream valleys, allowing yearly inundation, reflected in the regional flood risk mapping. Disparities in norm mapping among water boards, both nationally and within the area of sub-catchment Rijn-Oost (covering the area of the waterboards Vechtstromen, Reest en Wieden, Rijn en IJssel en Groot Salland), are attributed to diverse methodologies and the allowance for deviations from national standards (Waterschap Vechtstromen, 2015). To address exceedance issues, water boards conduct periodic evaluations against these norms. After evaluation water management strategies are adjusted by changes in the water system, including climate shifts and land use alterations (Waterschap Vechtstromen, 2015).

Furthermore, it is aimed at finding fitting solutions for areas encountering challenges, highlighting collaboration with stakeholders to develop effective measures. Spatial planning integrates water considerations through tools like the 'water test' and 'retention compensation' to ensure adequate water space in municipal zoning plans (Waterschap Vechtstromen, 2015). Proactive distribution of flood risk information improves community awareness and highlights shared responsibilities in water management practices.

The concept of creating norms for water nuisance will also be applied to writing norms for dealing with droughts. This approach will provide clear guidelines for the waterboard and other responsible parties, such as the province, specifying the acceptable degree of failure for a measure or system within a set timeframe, to the potential damage to the surrounding environment.

3. Methodology

3.1 Research Design

To advise effective groundwater norms and measures for sustainable water management, ensuring year-round groundwater sufficiency and resilience to climate change, a framework is constructed as illustrated in Figure 5 below. In the construction phase of the framework, inspiration was taken from the framework from (Lichtenberg et al., 2020) in which they focus on pairing the best suitable measures to a specific region. The framework was then adjusted by the outcomes of interviews, which transcriptions can be found in the appendix 8.A, and several meetings with experts in the field of hydrology and groundwater management.

The framework distinguishes between three types of land use: Urban, Agricultural and Nature. Each type of land use comes with unique properties and specific requirements, which include the area's needs and potential issues. The next step is to identify these corresponding needs and potential issues for each land use type, which will be shown in the section 4.1. Subsequently, following the framework, various water management measures and failure acceptance norms will be proposed to mitigate the impact of these requirements within each specific area. These measures and norms have been established based on literature research, meetings with hydrologists in Waterschap Vechtstromen, and interviews with experts of Waterschap Vallei and Veluwe and Waterschap Drents Overijsselse Delta. The final measures and norms that will be assessed are covered in the results in the section 4.2. To evaluate the feasibility and usefulness of the proposed measures and norms, a Multi-Criteria Analysis (MCA) will be conducted.

The MCA will identify the top five best-scoring norms and measures for each land use. Additional details on how the MCA will be carried out are provided in the expert session section 3.2. If any of the best measures or norms overlap, they will be accepted. If there are more than five different optimal solutions, an extra assessment will be conducted to find the best solutions for the combined land use types. This assessment will focus on a specific pilot area with designated land coverage for each type of land use, based on the requirements of the larger area. In cases of potential conflicting measures or norms, a reassessment will be necessary to determine the most suitable solution. This might involve implementing the next best solution identified in the earlier MCA or modifying the measure or norm to align with the area's requirements.

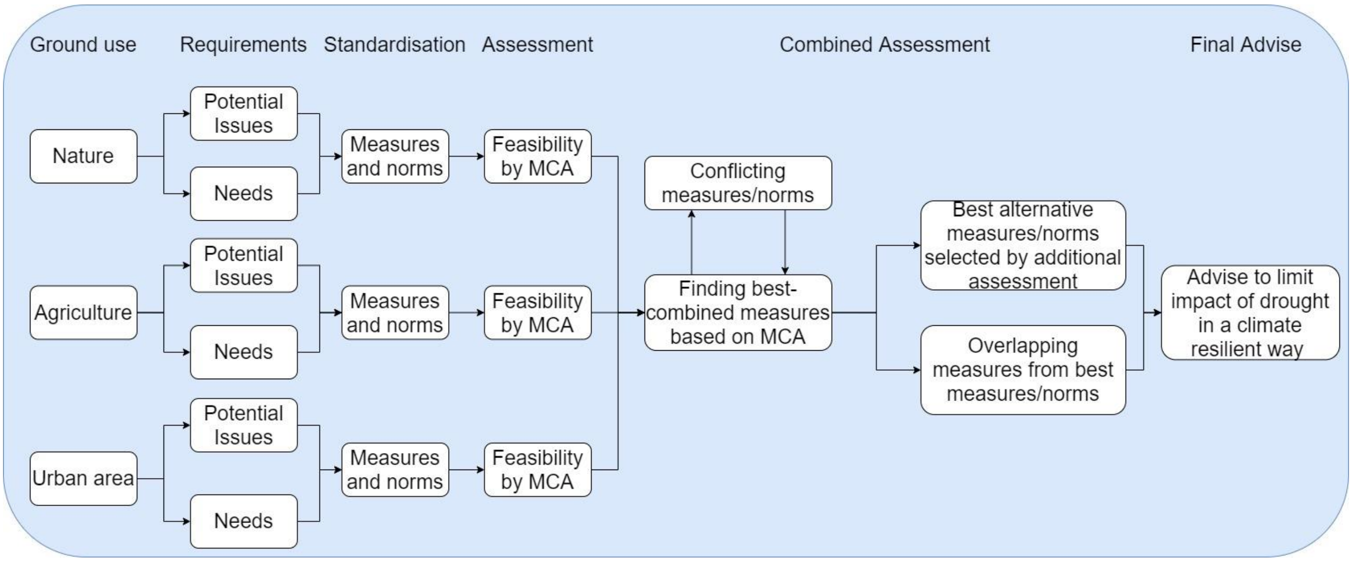

Figure 5 Groundwater management framework to mitigate drought impacts

3.2 Research Methods

Literature

By examining existing research, journals, and governmental publications, essential information could be gained for assessing and maintaining groundwater levels, setting up frameworks, and understanding the impact of groundwater-related issues caused by droughts due to climate change. Analysis of relevant literature on groundwater standardization, measures and norms helped to address sub-questions 1-4 and 6.

Regarding the implantation of the framework, literature research is of great importance too. It helped provide information about the requirements of the distinguished land use types. Additionally, it offered optional measures that are proven effective in mitigating the effects of drought and maintaining groundwater levels at a desired height. Based on the norms for water nuisance found in literature, groundwater norms to mitigate drought could be established. Relevant criteria for assessing and prioritising these measures and norms were also found in the literature.

The literature was mainly gathered via Google Scholar and the main keywords used were:

- Effects of climate change on groundwater (locally/globally)
- Effects of drought on groundwater (locally/globally)
- Definition of norms/groundwater norms
- Groundwater measures
- Global climate change effects on weather patterns
- Water management in the Netherlands/east of the Netherlands

Other relevant documents were shared internally in Waterschap Vechstromen or searched for on governmental websites such as rijkswaterstaat.nl with keywords:

- Kaderrichtlijn water
- Waterplan
- Normen
- Waterwet
- Omgevingswet

Semi-structured Interviews

Interviews with hydrologists who are specialised experts in groundwater management from Waterschap Vallei and Veluwe and Waterschap Rijn & Ijssel helped answer all sub-questions. These interviews offered firsthand knowledge and experiences related to effective measures and norms to maintain desired groundwater levels, determination of requirements of land use types and the development of a framework for proposing the best fitting measures and norms to ensure climate-resilient water levels all year round.

By interviewing hydrologists from external waterboards, the current challenges, developments and opportunities in managing surface and groundwater could be distinguished. The reason for interviewing external waterboards was to gain insight into new challenges or opportunities in mitigating drought, in a different area similar to the Vechstromen management area. Covering the designed framework during the interviews also helped further shape the framework, based on the knowledge and expertise of the hydrologists.

It was chosen to use semi-structured interviews to be able to ask specific questions and walk through the interview smoothly. The transcriptions of the interviews can be found in the appendix 8.A.

Expert Session on Case Study about Pilot Areas:
To provide the best suitable measures and norms in the advice for the waterboard to improve groundwater management, an expert session with hydrologists and environment managers will be held internally at Waterschap Vechstromen. By doing so sub-question 4 could be answered.

In this expert session, a presentation was held showing the proposed framework from the section 3.1 and providing background information on the pilot areas. The main aim of the expert session was to use the expertise of professionals to select the best measures and norms to limit the impact of droughts on groundwater levels and the potential harm these lower levels will do to the environment. Next to that feedback can be provided to improve the framework.

This selection process has been done by filling out a multi-criteria analysis (MCA). For this MCA, criteria have been determined based on criteria mentioned in the MCA of Lichtenberg et al., 2020 and outcomes of interviews. Selected criteria are shown in Table 2, a complete table can be found in the appendix B-2, B-3, B-5 and B-6. To create an easy to repeat and feasible assessment it was chosen to only implement seven criteria.

Table 2 MCA table for one measure/norm

	Criterium	Measure/Norm
Groundwater-system criteria	Effect on the land use type	
	Water Storage Capacity and Infiltration	
	Likelihood of Stakeholder Cooperation	
	Environmental Impact	
	Effect on Groundwater	
	Manageability and Maintenance Feasibility	
	Cost efficiency	
Sum of the scores		

In the MCA, each measure or norm will receive a score from 1-5 for a set of criteria. The measure "Promoting Rainwater Harvesting" is weighed against the criterium "Water Storage Capacity and Infiltration" as an example and can be seen in Table 3 below. A score from 1-5 is assigned and the reasoning behind such a score can be seen as well. Further elaboration on the scoring scale of the rest of the criteria can be found in the appendix B-1 and B-4. The resulting five highest scoring measures and norms will then be implemented in the advice for the waterboard.

Table 3 Elaboration on the scores of the criteria "Effect on land use type"

Criterium	Scale of scores based on impact
	Promoting Rainwater Harvesting
Water Storage Capacity and Infiltration	1. No improvement or degradation in groundwater storage and infiltration capacity 2. Minor improvement in groundwater storage and infiltration capacity 3. Moderate improvement in groundwater storage and infiltration capacity 4. Improvement in groundwater storage and infiltration capacity 5. **Heavy improvement in groundwater storage and infiltration capacity**

4. Results and analysis

4.1 Requirements: Needs and Potential Issues

The first step in the proposed framework is to determine the requirements of each land use type. These requirements have been split into Needs and Potential Issues. The main needs of an area include in what way they require groundwater to flourish or grow and the spatial demands that could be affected by measures to maintain a desired groundwater level in each of the land use types, and can be seen in Table 4 below.

Table 4 Groundwater-related needs for different land use types

Urban area	Agricultural area	Nature
- Sufficient groundwater levels to supply drinking water - Sufficient groundwater levels to nourish vegetation - Sufficient water drainage - Sufficient area to build new houses and infrastructure	- Sufficient groundwater levels for irrigation - Sufficient water discharge - Sufficient groundwater levels to nourish natural vegetation - Sufficient farmland	- Sufficient groundwater levels to nourish vegetation and fauna - Sufficient living space for flora and fauna

The potential issues are effects that occur as a result of certain measures to maintain a desired groundwater level in each of the land use types and can be seen in Table 5 below.

Table 5 Groundwater-related potential issues for different land use types

Urban area	Agricultural area	Nature
- Lower groundwater levels due to groundwater drainage for newly built-up areas (to create a stable building foundation, crawling spaces etc.) - Groundwater depletion in the surrounding environment (Water flows from high to low) - Land depletion leading to sinkholes or subsidence of roads and buildings - Precipitation infiltration is hindered due to the large amount of paved surface	- Groundwater levels depending on precipitation - Groundwater levels depend on water supply from rivers/channels/ditches - Groundwater levels depend on water drainage from rivers/channels/ditches - Ploughing decreases precipitation infiltration in the soil - Lower workability/accessibility of land due to higher groundwater levels to increase groundwater storage/supply - Decline of farm space to grow crops - Harvest failure	- Large groundwater storage, but takes a long time to refill when empty - Groundwater levels depending on precipitation - Groundwater levels depend on water supply from rivers/channels/ditches - Groundwater levels depend on water drainage from rivers/channels/ditches - Groundwater levels way beyond ground level, thus bad groundwater accessibility - Decline of nature area

4.2 Standardisation: Measures and Norms

The second step in the framework to determine are the ways how to satisfy the needs and mitigate the impact of potential issues from the previous step. Therefore, a list of potential measures and norms have been created that could have a positive impact on ensuring climate-resilient groundwater levels year-round in a specific type of land use.

Measures

Leading from the literature and interviews with hydrologists from Waterschap Vallei en Veluwe and Waterschap Drents Overijsselse Delta, Table 6 shows optional measures which could be selected for the waterboard to maintain or increase groundwater levels to the desired level. The measures will be assessed in a multi-criteria analysis during an expert session with internal hydrologists and environment managers of Waterschap Vechtstromen. The results, which will be shown in the section 4.3, will identify the best solutions for advising the waterboard on ensuring sufficient groundwater levels. In appendix C further elaboration on the selection of the measures can be found.

Table 6 Groundwater measures

Measures	Aim
Promoting rainwater harvesting	Limit surface water runoff and increase groundwater storage
Water purification installation earlier in the water system	To limit groundwater usage for drinking water purification purposes and discharge less surface water to downstream areas
Reducing water drainage	Limit surface water runoff and increase groundwater storage
Water level-controlled drainage	Automated water level control based on specific demands of the region
Restricting new urban construction in marshy areas	Less groundwater discharge locally resulting in less groundwater depletion in surrounding areas (water flows from higher levels to lower) -> Less ground depletion as a result of less groundwater depletion
Undeepening and widening water channels	Decreasing surface water runoff and limits the amount of groundwater that evaporates during summer. Also, more room for vegetation in water channels
Promoting perennial crops	Less disturbance of the soil by ploughing -> increase in precipitation infiltration. Also, fewer fertilisers are necessary -> good for the environment
Deploying multiple/new weirs	To control groundwater levels in the area and discharge groundwater when necessary

Norms

Leading from the literature and interviews with hydrologists from Waterschap Vallei en Veluwe and Waterschap Drents Overijsselse Delta, Table 7 shows optional norms which could be selected for the waterboard to limit the harm to the environment and the land users of a specific region. The norms will be assessed in a multi-criteria analysis during an expert session with internal hydrologists and environment managers of Waterschap Vechtstromen. The results, which will be shown in the section 4.3, will identify the best solutions for advising the waterboard on ensuring sufficient groundwater levels. In appendix C further elaboration on the selection of the measures can be found.

Table 7 Groundwater norms

Norms	Aim
- Ditches and streams are allowed to dry up for 1 week 1:10 years	- To prevent the bed from drying out too often, causing harm to nature thriving in the ditch or stream and stopping the distribution of water throughout the region
- Ditches and streams are allowed to dry up for 1 week 1:25 years	- To prevent the bed from drying out too often, causing lots of harm to nature thriving in the ditch or stream and stopping the distribution of water throughout the region
- Ditches and streams are allowed to dry up for 1 week 1:50 years	- To prevent the bed from drying out too often, causing severe and irreversible harm to nature thriving in the ditch or stream and stopping the distribution of water throughout the region
- Groundwater level lowers by 30cm below GLG*[1] in summer 1:10 years	- To prevent a recurring low groundwater level that causes harm to the environment
- Groundwater level lowers by 30cm below GLG*[1] in summer 1:25 years	- To prevent a recurring low groundwater level that causes serious harm to the environment
- Groundwater level lowers by 30cm below GLG*[1] in summer 1:50 years	- To prevent a recurring low groundwater level that causes irreversible and severe harm to the environment
- Groundwater level lowers by 30cm below GVG*[2] in Winter 1:10 years	- To prevent a lack of groundwater supply in the growing season/summer
- Groundwater level lowers by 30cm below GVG*[2] in winter 1:25 years	- To prevent a lack of groundwater supply in the growing season in areas depending on groundwater
- Groundwater level lowers by 30cm below GVG*[2] in winter 1:50 years	- To prevent a lack of groundwater supply in the growing season in areas heavily depending on groundwater

[1]GLG (Gemiddeld Laagste Grondwaterstand) is the average lowest groundwater level in a specific area of a specific period

[2]GVG (Gemiddeld Laagste Voorjaarsstand) is the average lowest groundwater level in spring/just before the growing season

4.3 Assessment: Multi-Criteria Analysis Expert Session

The third step is the assessment of the potential norms and measures in an MCA. In this research, the MCA is conducted during an expert session internally at Waterschap Vechtstromen with seven experts in hydrology and area management. After completion of filling out the scores of all measures during the expert session, which can be found in the appendix D, the following measures and norms scored best:

Table 8 Best scoring measures for each Land Use

Urban area	Score	Agricultural area	Score	Nature	Score
1. Restricting new urban construction in marshy areas	24	1. Promoting rainwater harvesting	26	1. Undeepening and widening water channels	14
2. Undeepening and widening water channels	24	2. Deploying multiple/new weirs	26	2. Restricting new urban construction in marshy areas	13
3. Promoting rainwater harvesting	24	3. Groundwater level-controlled drainage	26	3. Reducing water drainage	11
4. Reducing water drainage	21	4. Reducing water drainage	24	4. Promoting rainwater harvesting	10
5. Groundwater-level-controlled drainage	20	5. Restricting new urban construction in marshy areas	24	5. Deploying multiple/new weirs	9

Table 9 Best scoring norms for each Land Use

Urban area	Score	Agricultural area	Score	Nature	Score
1. Groundwater level lowers by 30cm below GLG in summer 1:10	24	1. Groundwater level lowers by 30cm below GLG in summer 1:10	26	1. Groundwater level lowers by 30cm below GLG in summer 1:50	14
2. Groundwater level lowers by 30cm below GLG in summer 1:25	24	2. Groundwater level lowers by 30cm below GLG in summer 1:50	26	2. Groundwater level lowers by 30cm below GVG in winter 1:50	13
3. Groundwater level lowers by 30cm below GLG in summer 1:50	24	3. Groundwater level lowers by 30cm below GLG in summer 1:25	26	3. Groundwater level lowers by 30cm below GLG in summer 1:25	11
4. Ditches and streams are allowed to dry up for 1 week 1:50	21	4. Groundwater level lowers by 30cm below GVG in winter 1:10	24	4. Groundwater level lowers by 30cm below GVG in winter 1:25	10
5. Ditches and streams are allowed to dry up for 1 week 1:25	20	5. Groundwater level lowers by 30cm below GVG in winter 1:25	24	5. Groundwater level lowers by 30cm below GLG in summer 1:10	9

4.4 Combined Assessment: Finding the Best Combination of Measures and Norms for a Pilot Area

The fourth step in the framework is to find the best-suited measures and norms from the previous step for a greater area. In this thesis, two pilot areas will be assessed within the management area of Waterschap Vechtstromen: "Het Loodiep" and "De Poelsbeek".

Overlapping measures from best measures/norms

As can be seen in Table 10 below, three measures are included in the top five for all categories. These two measures will be automatically included in the final advice to the waterboard. Three measures are included in only two out of the three categories. To determine the remainder of the best suitable measures for the advice, reassessment will be necessary based on the demands of a specific pilot area.

Table 10 Frequency an optional measure gets into the top five of the 3 Land use types

Measure	Top-5 frequency
Restricting new urban construction in marshy areas	3
Promoting rainwater harvesting	3
Reducing water drainage	3
Undeepening and widening water channels	2
Groundwater-level-controlled drainage	2
Deploying multiple/new weirs	2

As can be seen in Table 11 below, three norms are included in the top five for all categories. In the final advice to the waterboard, these three norms will automatically be included. One norm makes it in the top five of two land use types and four norms make it to the top five in only one of the three land use types. To determine the remainder of the best suitable norms for the advice, reassessment will be necessary based on the demands of a specific pilot area.

Table 11 Frequency an optional norm gets into the top five of the 3 Land use types

Norm	Top-5 frequency
Groundwater level lowers by 30cm below GLG in summer 1:10 years	3
Groundwater level lowers by 30cm below GLG in summer 1:25 years	3
Groundwater level lowers by 30cm below GLG in summer 1:50 years	3
Groundwater level lowers by 30cm below GVG in winter 1:25 years	2
Ditches and streams are allowed to dry up for 1 week 1:50 years	1
Ditches and streams are allowed to dry up for 1 week 1:25 years	1
Groundwater level lowers by 30cm below GVG in winter 1:10 years	1
Groundwater level lowers by 30cm below GVG in winter 1:50 years	1

Best alternative measures/norms selected by additional assessment

As mentioned above, two measures and three norms will be automatically implemented in the final advice. To determine the best measures and norms for the pilot areas, the specific requirements and features of the pilot areas need to be determined. The findings of this analysis can be found in Table 12 for the Poelsbeek region and Table 13 for the Loodiep region on the next page. Based on these requirements, it is determined which measures and norms have clear priority over other measures and norms in a specific area. These requirements have been established based on the field research performed by Monincx et al., 2024b, 2024a.

Table 12 Requirements for Pilot Area: "De Poelsbeek"

Needs	Potential Issues
- Sufficient groundwater levels to nourish natural vegetation - Sufficient groundwater levels for irrigation - Sufficient space for nature - Sufficient groundwater levels for nourishing vegetation in urban areas - Sufficient drinking water - Sufficient space for agriculture - Sufficient space for urbanisation around Haaksbergen - Groundwater supply depending on precipitation - No Natura 2000 zones - Discharge of at least 30-40L/s to distribute water sufficiently throughout the Poelsbeek area - Weirs need to pump groundwater to satisfy discharge boundary values	- The Poelsbeek streambed falls dry (when GLG decreases 30-50cm below Poelsbeek streambed during summer)-> Local irrigation leads to damage to nature and agriculture - Irreversible damage to natural vegetation, especially on higher grounds - In summer when groundwater levels decrease below GLG the Poelsbeek area does not distribute any water - Expected precipitation shortage in the summer of 2050 of 200-225mm (3-4x the current shortage of 50-75mm) - Due to the pumping of the weirs, groundwater supply decreases drastically during summer - Groundwater depletion due to urbanisation - Land depletion due to groundwater depletion

Table 13 Requirements for Pilot Area: "Het Loodiep"

Needs	Potential Issues
- Sufficient groundwater levels to nourish natural vegetation - Sufficient groundwater levels for irrigation (10% of the Loodiep surface area needs irrigation) - Sufficient space for nature - Small urban demand (small amount of urban area in the Loodiep area) - Sufficient drinking water - Sufficient space for agriculture - Groundwater supply in summer depending on precipitation - Hoogeveense Vaart supplies the Loodiep region with water - Loodiep needs to sufficiently discharge into the Coevorden-Zwinderen Kanaal	- 18% of the area surface consists of NNN-nature zones (Natuurnetwerk Nederland) which are harmed by drought - In summer, the Hoogeveense Vaart is not water supplying due to low Ijsselmeer water levels - Through lateral groundwater flows, groundwater flows into and out of the area (No water balance is possible, so it is unknown whether there is groundwater seepage or discharge) - Through the west side of the Loodiep area groundwater seepage is assumed to occur - Groundwater seepage occurs from the Boswachterij Gees/Mepperhooilanden to agricultural land - Expected precipitation shortage in the summer of 2050 of 190-200mm (5x the current shortage of 41mm)

The additional assessment revealed that the main focus in both pilot areas is on agricultural and natural regions. In the Loodiep area, there is minimal urban development, leading to the selection of two measures and two norms that primarily benefit agricultural and natural areas. Nevertheless, the Poelsbeek area includes urban regions around Haaksbergen, indicating attention to potential urban issues is necessary. Therefore, one additional measure and one norm have been selected to address urban area concerns, alongside one measure and one norm focusing on agriculture and nature in the Poelsbeek area.

After this additional assessment, the following measures and norms are recommended to ensure sufficient groundwater levels and limit the impact of lower groundwater levels on the users of the land and the land itself:

Table 14 Top-5 Measures to be implemented in the final advice for Pilot Area: "De Poelsbeek"

Measure
Restricting new urban construction in marshy areas
Promoting rainwater harvesting
Reducing water drainage
Groundwater-level-controlled drainage *[3]
Deploying multiple/new weirs *[4]

Table 15 Top-5 Norms to be implemented in the final advice for Pilot Area: "De Poelsbeek"

Norm
Groundwater level lowers by 30cm below GLG in summer 1:10 years
Groundwater level lowers by 30cm below GLG in summer 1:25 years
Groundwater level lowers by 30cm below GLG in summer 1:50 years
Groundwater level lowers by 30cm below GVG in winter 1:25 years *[5]
Ditches and streams are allowed to dry up for 1 week 1:50 years*[6]

Table 16 Top-5 Measures to be implemented in the final advice for Pilot Area: "Het Loodiep"

Measure
Restricting new urban construction in marshy areas
Promoting rainwater harvesting
Reducing water drainage
Undeepening and widening water channels*[4]
Groundwater-level-controlled drainage*[4]

Table 17 Top-5 Norms to be implemented in the final advice for Pilot Area: "Het Loodiep"

Norm
Groundwater level lowers by 30cm below GLG in summer 1:10 years
Groundwater level lowers by 30cm below GLG in summer 1:25 years
Groundwater level lowers by 30cm below GLG in summer 1:50 years
Groundwater level lowers by 30cm below GVG in winter 1:25 years*[6]
Groundwater level lowers by 30cm below GVG in winter 1:50 years*[6]

*[3] = measure scoring relatively higher for the urban areas
*[4] = measure scoring relatively higher for the agricultural/nature areas
*[5] = norm scoring relatively higher for the agricultural/nature areas
*[6] = norm scoring relatively higher for the urban areas

5. Discussion

5.1 Limitations of the Findings

Results during the expert session

The expert session provided relevant information in distinguishing valuable measures and norms. However, there were some limiting factors. The general remark was that it was difficult to score the measures and norms based on the criteria that they had to be weighed against. There were two main reasons for this difficulty. The first reason was that the criteria were more relevant to the measures than the norms. For future improvement, a separate list of criteria with corresponding scoring scales could be constructed. The second reason was that sometimes a high score implied a negative effect and sometimes the higher score indicated a very positive effect of a measure to a certain criterium, which confused the scoring.

Other than these difficulties, there was the fact that it was sometimes hard for me as a host to get to know all the reasoning behind all the scores since seven experts were participating in the session, and it was not possible to thoroughly discuss their outcomes during the session, due to lack of time.

Lastly, it was very useful to benefit from the experts' knowledge and experience in the field of water management. However, for a reliable scientific result the data poule was way too small. To get reliable input, a larger group of results would be better since the results showed major differences in the total scores for the measures in the natural area compared to the urban and agricultural areas.

Selection and interpretation of measures and norms

Creating a top five for both the norms and measures might imply that the other measures and norms have a negative effect on drought mitigation, which might not be the case for all measures and norms. This could be the case due to the limited number of measures and norms that were assessed in this research. The selection of eight measures and nine norms might also confuse since it might indicate that these proposed measures and norms are the only optional standards that can be implemented in groundwater management to mitigate the effects of drought.

The research also only focuses on the positive effects of measures and excludes conflicts between measures. As an example, by discharging less groundwater from an area there will be more water available in times of drought. However, this also increases the groundwater level to a point that potential peak discharges could result in unwanted and harmful floodings, outweighing the positive effect the measure could initially have.

5.2 Future Research Directions

Assigning groundwater level intervals for different land use types throughout the year

The Loodiep and Poelsbeek areas consist of regions suited for agriculture, urban development, and nature zones. Determining an optimal groundwater level to meet the specific needs of these areas could help in selecting the best measures to maintain this level for each type of land use. This optimal groundwater level should include an upper boundary indicating the maximum allowable groundwater level and a lower boundary indicating the minimum allowable groundwater level, as illustrated in Figure 6. These boundaries indicate the levels beyond which the land might be at risk of flooding or becoming too dry. Based on these boundaries, an optimal groundwater level curve can be constructed, as visualised in Figure 7. This curve helps visualize the thresholds, ensuring the land remains safe and functional, and guides the implementation of appropriate water management strategies.

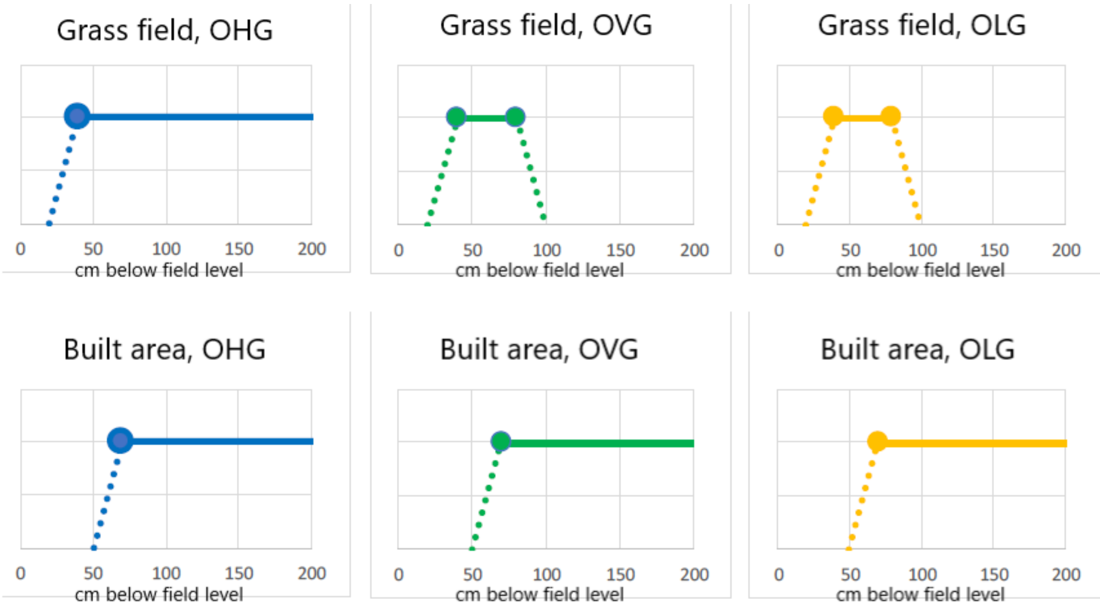

Figure 6: Optimal groundwater levels throughout different seasons (van der Scheer, 2024)
OHG stands for "Optimaal hoogste grondwaterstand" (highest optimal groundwater level)
OVG stands for "Optimaal Voorjaars Grondwaterstand" (optimal groundwater level during spring)
OLG stands for "Optimaal Laagste Grondwaterstand" (optimal lowest groundwater level)

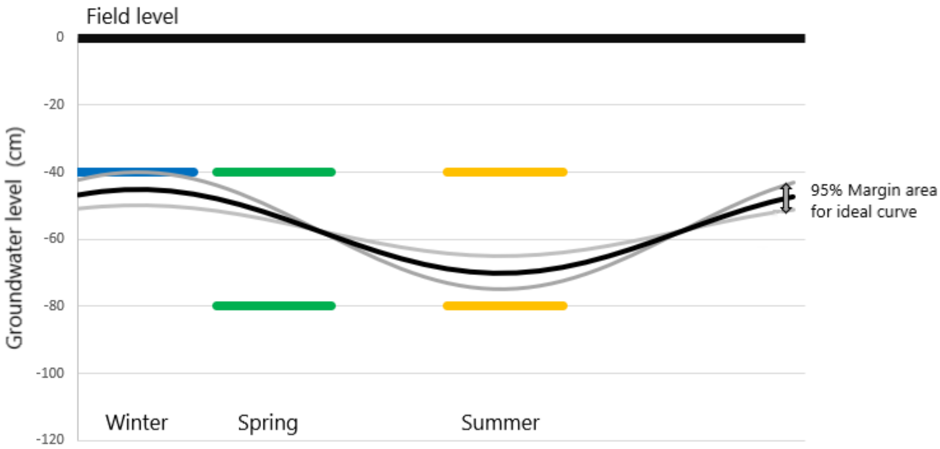

Figure 7: Ideal year-round groundwater level curve for a certain area (van der Scheer, 2024)

Implementing groundwater quality into the framework

This research has solely focused on the impacts of droughts, resulting from climate change, on the quantitative levels of groundwater. However, to ensure climate resilience and sustainability, groundwater quality also plays a crucial role. Therefore, the effects of climate change on groundwater quality should be assessed accordingly. Additionally, this aspect of water quality could be incorporated into the framework to ensure sufficient groundwater levels year-round to be able to find the best measures and norms to propose to a waterboard to ensure sufficient groundwater levels of high quality.

6. Conclusion and Recommendations

6.1 Conclusion

In this research, it is investigated how a framework could be established to propose groundwater norms or measures to guarantee sufficient groundwater levels throughout the year and ensure sustainable water management in the face of climate change. By going step by step through the designed framework a list of the best scoring measures and norms can be determined for any type of area consisting of Agricultural, Nature and Urban areas. To advise a waterboard on how to act to maintain a desired groundwater level to limit the impact of drought in that specific area.
This has been done by answering the six sub-questions.

The first sub-question that needed to be answered was: *What is a groundwater norm?*
A groundwater norm covers the duty and care of a water board in preventing or limiting the decrease in groundwater levels due to the effects of drought and climate change and includes a probability of a measure or system being allowed to fail once in a specified period.

The second question was: *What is the effect of climate change on groundwater levels?*
According to literature groundwater levels will significantly decrease over time due to increased temperatures leading to more evaporation of groundwater and fluctuations in precipitation leading to less and inconsistencies in groundwater supply, as a result of climate change. In the Poelsbeek and Loodiep catchment areas, the precipitation shortage will even increase 4-5 times during the summer in the coming 30 years compared to the current situation. Since these regions are heavily reliant on precipitation as a form of (ground)water supply, the groundwater levels will decrease heavily.

The third question was: *What groundwater-dependent land use types can be found in an area and what are the requirements related to groundwater?*
The main types of land use in an area consist of urban, agricultural and nature areas. Each of these areas comes with its priorities and criteria. For the urban area, it is mainly of great importance that… For the agricultural land, it is mainly important that there is sufficient groundwater to be able to irrigate the crops during the growing season. In nature areas it is important that water channels remain flowing with water to limit the damage to the ecosystems and supply the region with water to nourish the vegetation present in the area.

The last three questions could be answered accordingly: *What norms and measures are effective in providing desired groundwater levels and limiting the impact of low groundwater levels on the environment? 5. How can norms and measures effectively be selected for increasing groundwater levels in an area? 6. What are important criteria to assess the best suitable measures or groundwater norms and how to score the criteria?*
In the Netherlands, norms are currently guiding groundwater to deal with water nuisance as proposed by the National Water Management Agreement in 2009. In this research, inspiration has been drawn from these norms to construct several norms to deal with groundwater shortage and prevent it. Next to that, effective measures have been selected to positively influence the groundwater supply capacity and levels. By accurately assessing these measures and norms through multi-criteria-analysis in which the measures and norms are weighed on specific criteria the best suitable measures and norms for a pilot area could be established.

Following the assessments in the framework, the recommended measures and norms should provide sufficient protection against the increasing effects on groundwater levels caused by drought due to climate change. The conclusion is that the proposed framework could help the waterboard to standardise the process of selecting suitable measures and norms to ensure climate-resilient groundwater levels year-round. Nevertheless, for the framework to be more useful to the waterboard, it should be extended concerning the number of measures and norms that should be assessed.

6.2 Recommendations

Leading from the results of the MCA in the expert session and additional assessment following the steps in the designed framework in Figure 5, the following measures and norms are recommended to be implemented into the new strategies for ensuring sufficient and climate-resilient groundwater levels year-round:

In the **Poelsbeek** catchment area, restricting new urban construction in marshy areas to prevent local groundwater discharge is recommended. This measure prevents depletion of groundwater and ground-level depletion in surrounding environments. Secondly, promoting rainwater harvesting and limiting groundwater drainage to reduce surface runoff, enhance groundwater storage, and raise public awareness about drought issues. Lastly, installing multiple new weirs to change groundwater levels and facilitate controlled discharge when needed, alongside implementing automated groundwater level-controlled drainage systems.

Next to that it should be aimed at that groundwater levels will not get lower than 30cm below GLG in summer 1:10 years, 1:25 years and 1:50 years, depending on the potential harm it could do to the land use type in the area. Also, groundwater levels should not reach below 30cm under GVG in winter 1:25 years, to make sure that the damage it could do due to a lack of water in the growing season is limited. Lastly, ditches and streams should not dry out for one week once every 50 years to limit the potential harm they could do to all life around the water channels.

Recommendations for the **Loodiep** catchment area are similar since it is a very similar area to the Poelsbeek catchment area. Therefore, the majority of the measures will be the same as for the recommended measures for the Poelsbeek catchment area. However, due to the higher presence of urban areas in the area there are differences. Instead of the measure to implement more new weirs in the area it is chosen to recommend undeepening and widening the existing water channels to decrease surface- and groundwater runoff and limit the amount of groundwater that evaporates during summer. This measure also assures more room for vegetation in water channels.

Next to that, the norms that will be suggested to the Loodiep catchment area will also be very similar to the Poelsbeek catchment area. The groundwater levels should not get lower than 30cm below GLG in summer 1:10 years, 1:25 years and 1:50 years. Additionally, groundwater levels should not reach below 30cm under GVG in winter 1:25 years and 1:50 years, to make sure that the damage it could do due to a lack of water in the growing season is limited.

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8. Appendices

A. Interview Transcripts

A-1 Interview with Hydrologist of Waterschap Vallei and Veluwe

Introduction:

1. **Can you briefly introduce yourself and explain your role within the water board?**

Hydrologist specialized in groundwater with surface water and policy advisor at the Vallei en Veluwe water board.

Following from a brief show of the framework:

2. **Do you think that the water board takes sufficient account of groundwater in policy, design, implementation and management?**

Dry summers are getting more attention.

Currently experiencing two extremes on both sides due to an extremely dry summer with an extremely wet winter, which shows the groundwater network is very slow in response. As a result, the system is squeezing. 1x drained, the water can no longer be returned.

Small waterways were almost always dry during dry periods and were not maintained for years, because there was no need for them. But that has to change now.

More needs to be retained, but some places are getting too wet, so small waterways need to be used more.

Taking more into account each feature, what is too wet and what is too dry for each type of land use.

Theme 1: Requirements

3. **Does the water board have a groundwater task in urban areas?**

   In principle, the task lies with the municipality.
   Silly not to be looked at by the water board.
   Municipal officials often do not have the time, knowledge and resources to draw up adequate measures, so the water board must play a supporting role in this.

4. **How do these requirements differ from those in agricultural areas and nature reserves?**

   The area around Veluwe where seepage water rises is sensitive to desiccation due to climate change. Also, from the point of view of drinking water companies.

5. **To what extent is the water board responsible for maintaining groundwater levels within urban areas?**

   See 3

6. **Can you give specific examples of situations where groundwater levels have become problematically low in each of these three area types and what the consequences have been?**

   Divide the area into 2 areas: No water supplies possible -> a lot of droughts -> everything that lives in it dies, such as fish species and plant species
   In other areas, water supply is possible, if IJssel water is low, it is not possible to pump more, an extra pump has also been installed for that.
   Sometimes, in extreme cases, it is simply not possible to supply water from the IJssel.
   Agriculture is not allowed to irrigate because groundwater levels are too low > crop yield decreases
   Groundwater-dependent areas will be dried up, especially nature in locations where seepage rises.
   Trees in the Veluwe are not affected by this, they have a protection mechanism that adapts to drought, and they also use water other than groundwater.

7. **At what times of the year do you consider the risk of problems with low groundwater levels to be greatest? Why is this?**
   Saves per area, the Veluwe has a large stock, slowly empties towards the environment. In 2018 an extremely dry year, but due to the Veluwe, the impact was quite small.
   2019 also quite dry but still no problem
   2020 was relatively a bit wetter but caused more problems due to a dried-out reservoir.
   Veluwe is a large reservoir, draining slowly, but also filling up slowly. So, several dry years have a major effect on groundwater levels.
   But most drought damage will occur more at the end of the summer.
8. **What changes in groundwater levels do you expect as a result of climate change? (in cm and per season?)**
   On the Veluwe, on the other hand, it will rain more throughout the year. Groundwater will actually increase as a result, as winters are getting wetter, and the capacity is very large. In winter, vegetation will also use little of this water, so a lot of water is stored.
   Where there are more waterways and the groundwater is closer to ground level, there will be more groundwater subsidence. So, in places where a lot of water is drained, the area will become drier and in the Veluwe where very little water is drained, the area will become wetter.

9. **Different priorities apply within each type of land use, the aim of the framework will be to compile an integrated advice for standardizing and standardizing groundwater in a specific area. Is it possible to make a standardised assessment for a combination of multiple functions and how can the water board best weigh conflicting functions against each other?**
   Take a good look at what the priorities are -> What cannot go wrong? ->That's the trade-off.
   If you want to pursue something, other functions must be hindered by it.
   If a nature reserve is so special that the environment and the functions that are located there are subordinate to the nature reserve, then of course you have to focus on that.
   If you want to optimally design an area for one land use or just a little bit of everything, you can also run into problems.
   Then you have to perform a certain multi-criteria analysis to find out what is more important compared to something else.
   Looking at where the irreversible damage is greatest, such as in nature or potato harvesting vs. grassland.

Theme 2: Measures

10. **What measures has the water board currently implemented to prevent groundwater levels from falling too low in urban areas? How do these measures differ from those in agricultural areas and Natura 2000 sites? How effective have these measures proven so far?**
    Filling in or digging waterways, making waterways shallow is also very effective.
    The correct soil height indicates how long a particular waterway can and may continue to drain water.
    The width indicates how large the drainage capacity must be to prevent nuisance.
    These are, in particular, the measures that the water board can take to control discharge through the water board.
11. **Does the water board have sufficient power and resources to meet groundwater targets?**
    -
12. **What new measures or adjustments are being considered to improve current strategies?**
    In the past, aerducts that were built there had to be narrow to save space and deep to allow water to drain quickly.
    So now we have to go back to wider and shallower waterways.

The growing season starts in April, when evaporation begins, so there is no longer any need for groundwater drainage and waterways can run dry.
All the small ditches that are supposed to drain surplus water will no longer be needed after April. This may even be desirable

In addition, retain water as much as possible where it falls.
If we can prevent a discharge peak in large so-called A-waterways by storing water, less discharge capacity is needed. This creates more space, more vegetation can be allowed, and less maintenance of the waterway is required, which can make the water system more robust. This may not be a direct measure to prevent drought, but it will at least make the water system more climate-robust and will indirectly be able to combat drought.

Theme 3: Standardisation

(To what extent is the water board responsible for managing groundwater levels within urban areas?)

13. Can you explain what standards for groundwater levels might look like?

For national policy, rural areas may be flooded once every 10 years and once every hundred years for urban areas. This is for flooding
There is nothing for drought but what is the drought damage in a certain area, you want to minimize this. Standards could be established on this basis.
It also needs to be looked at area-specific, because in areas such as the Veluwe, the groundwater level is meters below ground level. In that case, raising or lowering the groundwater level has hardly any impact.

Closure

14. What do you think are the most important steps that need to be taken to ensure the futureproofing of groundwater management in relation to climate change?

Healthy soil is very important. As a result, moisture balance improves. The agricultural areas have been completely milked with fertilizers, pesticides, etc. to achieve as much yield as possible.
As a result, the soil life has been destroyed.
Soil is partly abiotic in but also large living part, we have lost sight of maintaining this.
By creating a healthier soil, you will have better infiltration -> retain more moisture -> less peak runoff and less outflow nutrients -> so drought survives much better.

Many crops are annuals, not very sustainable. Everything is cleared and ploughed, it would be better to invest in perennial crops that build on what has been invested in previous years. By doing so, you create an ecosystem in itself, where a healthier soil is created that can also retain more water. This would be very good to explore as a water board and think about how this can possibly be stimulated among farmers. For example, by providing certain subsidies or allowing irrigation during certain drier periods.

A-2 Interview with Hydrologist of Waterschap Drents Overijsselse Delta 1

Introduction:

1. Can you briefly introduce yourself and explain your role within the water board?

Policy advisor water quantity since 2016 at the WDOD water board, previously worked at Royal Haskoning as a project hydrologist.

Following a brief show of the framework:

Water and soil system should be more controlling -> For example no potato cultivation in stream valleys

New framework could be -> what groundwater regime can we offer naturally in the form of stream valleys etc. and from there what is a logical distribution.

On constructing norms: Indicate once every 10 years e.g. the groundwater level is so much below ground level once in the summer -> Agriculture can assess damage and risk itself -> Estimate the amount of irrigation themselves and when and keep track of what is allowed

From surface water, it is easier to indicate till when water can be supplied, in the summer 60-70% of the region is water supplied -> clarity for the user about groundwater availability and then what you can and may do with surface water

Norms/standards can provide guidelines and quantifiable, ambitions of the water board become visible

2. **Do you think that the water board takes sufficient account of groundwater in policy, design, implementation and management?**

The ambition could be higher. Groundwater is taken into account in all components though

Theme 1: Requirements

3. **Does the water board have a groundwater task in urban areas?**

The municipality has a duty of care. As soon as the surface water system runs through the urban area, the groundwater system is affected. Together with the municipality, we look for the best solution

Sometimes this means that the water board looks at the surface water system, or the municipality itself to the groundwater system within the area.

Tricky to find a bottleneck for the urban area.

If the water board were responsible, would not deal with public areas, public green spaces, citizens' own plots.

Direct relationship: the moment a municipality decides that drainage must be installed, the water board may experience hindrance. By extraction of groundwater from the environment. This is important to coordinate, especially with new construction plans.

If you have a new built area in an agricultural area -> less agricultural area-> lower groundwater levels are desired for crawl spaces e.g. -> more drainage to keep crawl spaces, etc., dry. Therefore, care not to drain too much groundwater than intended. In addition, more pavement so that surface water/precipitation is drained away faster and cannot penetrate the ground. Means less water reserves for times of drought

What specific challenges do urbanisation and surface paving pose for groundwater management?

See question 3

4. **How do these requirements differ from those in agricultural areas and nature reserves?**

   Urban areas have lower groundwater levels, provided they are built at ground level.
   Extra drainage compared to agriculture and nature reserve

5. **To what extent is the water board responsible for maintaining groundwater levels within urban areas?**

   See three

6. **Can you give specific examples of situations where groundwater levels have become problematically low in each of these three area types and what the consequences have been?**

Nature not problematic low, often relatively wet

Stream valleys are optimized for agriculture in the 60s and 70s:

Whereas previously the wet soils were, the deepening of these valleys has caused the groundwater level to drop enormously - > effect on local places but also on the edges of the stream valleys, which extract groundwater from surroundings.

Urban area in former stream valleys the same takes place:

In an urban area, a district to the east of Meppel, in an old stream valley, a lot of expansion has taken place, where a much lower level has been used, so that a lot of groundwater has to be pumped out. And as a result, extra groundwater is extracted from the region. However, it did not necessarily cause subsidence due to good pile foundations. However, there is regional subsidence, which means that a lot of maintenance has to take place on, for example, the roads.

7. **At what times of the year do you consider the risk of problems with low groundwater levels to be greatest? Why is this?**
   In the summer. That depends on what nature and agriculture need in terms of groundwater levels. Farmers want to be able to access the land in the spring, so it should not be too wet. Evaporation then causes the groundwater level to drop further.
   In winter, the groundwater level is less of a problem for crops and less evaporation, so less of a problem with groundwater drought in winter compared to summer.
8. **What changes in groundwater levels do you expect as a result of climate change? (in cm and per season?)**
   Climate change causes the GHG s (average highest groundwater level) to rise in the lateral moraines in winter, and in the lower areas excess water is easily drained. At the bottom of lateral moraines, the groundwater level is actually higher due to better infiltration, such as on the edge of the Sallandse Heuvelrug. In the rest of the area this will be lower than 10-30cm.

9. **Different priorities apply within each type of land use, the aim of the framework will be to compile an integrated advice for standardizing and standardizing groundwater in a specific area. Is it possible to make a standardised assessment for a combination of multiple functions and how can the water board best weigh conflicting functions against each other?**

Describe this for all functions is optimal, this is less optimal but possible, this is undesirable.

A certain groundwater regime with functions on the one hand and then weigh them against certain groundwater types and based on that, see what is optimal for types of land use. Then make a decision based on the largest amount of land use. Similar to asset management.

If this level is reached, it is no longer acceptable, but in other positions it is already more problematic.

Theme 2: Measures

10. **What measures has the water board currently implemented to prevent groundwater levels from falling too low in urban areas?**
    Encourage municipalities to disconnect from sewage, but let it infiltrate rainwater in urban areas -> (you do not want to have clean rainwater directly in purification -> less supply is needed as well

11. **How do these measures differ from those in agricultural areas and Natura 2000 sites?**
    New extra weirs, weirs extra adjusted
    In Natura 2000, the system may be shifted
    The waterboard has more power here, which means more possibilities for the waterboard

12. **How effective have these measures proven so far?**
    Task to operate the functions in the best possible way. The water board can flood agricultural land, but it is not ideal and undesirable for farmers. Hopes have been placed on provincial plans but are focused on many fronts and obstruct possible measures making this a very difficult package.

13. **Does the water board have sufficient power and resources to meet groundwater targets?**
    The water board has a lot of power and should in principle be allowed to flood a piece of agricultural land, formally speaking. A consideration is made for the large area. The board is not likely to opt for such a measure, but the water board does have policy room to make these kinds of considerations. Has more policy space than the board wants to and perhaps even dares to take.

14. **What new measures or adjustments are being considered to improve current strategies?**

    20 years ago, the Groot Salland Water Board set up a major process to widen waterways and make them shallower for the benefit of KRW (Kaderrichtlijn water) and to prevent over-dewatering.
    A lot of land for purchased, and land to exchange that is located along a waterway.
    Management area can already be supplied with water for 60-70 per cent. To satisfy this, a deepening has been reversed. Deepening and widening is a good solution for places where an extra supply of water is not possible, such as: high-lying sandy soils.

    Pilot: Part of the waterway turned into a rift-like layer, the part behind it could drain sufficiently and the farmer benefits because he gets more land at his disposal. More needs to be done! Adjust at the top of the system so that less water is drained, and more is retained.

    In addition, for irrigation from groundwater, groundwater level boundary measuring tools are installed.
    Within the region, a withdrawal ceiling is being considered, possibly based on an average groundwater recharge, one year is drier than the other, and if you look ahead you can possibly use part of the average groundwater supply for irrigation. Also, for industry, for example. Regulation can be done based on permits but can mainly be done with general rules.

    Drinking water extraction is often located in high areas, not effective, but has to go to places where the water is drained. Tens of percents, 60-70 percent, are drained from the rainwater. Then the moraine can be left alone in the winter. When that drained water is no longer there in the summer, only then groundwater is drained from moraines.
    This means that in stream valleys and moraines, relatively higher groundwater levels should also be maintained in winter.

15. **Are there any innovative or experimental techniques that are currently being tested to better manage groundwater levels?**

Specifically, agriculture and ploughing new land every year and growing new crops. Experiments are being carried out with only ploughing locations where sowing is carried out, so that the entire land does not have to be ploughed, which promotes infiltration. In addition, the bearing capacity of the soil improves, so that the groundwater level does not have to be lowered.
Together with the province DWA, subsidies from water quality -> water quantity now linked to it-> in theory, this scheme could be used to create perennial crops or a more effective method of ploughing, as they ensure less drainage of rainwater, better soil infiltration and relatively higher groundwater levels can be maintained.
Farmers may have to incur fewer costs, so it may not be necessary.

Theme 3: Standardisation

It just depends on how you deal with it and how you define it, do you want it to be indicative or to indicate a certain ambition. Everyone is wary of potential settlements based on norms. But it is useful to give a kind of stability. With nuisance standards, it helps to explicitly indicate what needs to be improved. Also at the administrative level, at the moment the water board does not "have to" do anything based on drought.

(To what extent is the water board responsible for managing groundwater levels within urban areas?)

16. **Can you explain what standards for groundwater levels might look like?**
    See explanation of the framework

17. **What would you see as the most important priority for the water board in terms of groundwater management in relation to drought and climate change?**
    Redesign the water system so that the functions can adapt to it. Everything is geared towards drainage, so adjustments have to be made to retain water. And from there, it can then be looked at how the groundwater use should/can be adjusted

A-3 Interview with Hydrologist of Waterschap Drents Overijsselse Delta 2

This interview was automatically transcripted through the transcription function of Microsoft Teams, the audio of the interview was not recorded and therefore a well-written transcription of the interview was not possible.

B. Additional Data Tables

B-1 Table 18 Criteria to Establish Climate-Resilient Groundwater System (English version)

Criterium	Explanation	Scale of scores based on impact
1. Effect on the land use type	The extent to which damage can be mitigated for the particular soil type and its users	1. Extensive and unrestorable damage is done to the soil and its users 2 Significant damage to the soil and its users 3 Moderate damage to the soil and its users 4 Minor damage to the soil and its users 5 Minimal or no damage to the soil and its users
2. Water Storage Capacity and Infiltration	The level of improvement of groundwater storage and infiltration capacity of the soil	1 No improvement or degradation in groundwater storage and infiltration capacity 2 Minor improvement in groundwater storage and infiltration capacity 3 Moderate improvement in groundwater storage and infiltration capacity 4 Improvement in groundwater storage and infiltration capacity 5 Heavy improvement in groundwater storage and infiltration capacity
3. Feasibility of Stakeholder Cooperation	The extent of stakeholder cooperation in participating in the implementation of measures	1 No cooperation 2 Limited cooperation 3 Sufficient cooperation 4 Strong cooperation 5 Outstanding cooperation
4. Climate resilience	The effectiveness of the measure in addressing the impacts of changing weather patterns due to climate change	1 Ineffective/counterproductive in dealing with changing weather effects 2 Minimally effective in dealing with changing weather effects 3 Moderately effective in dealing with changing weather effects 4 Effective in dealing with changing weather effects 5 Highly effective in dealing with changing weather effects
5. Effect on Ground-water levels	The measure's effectiveness in increasing or maintaining groundwater levels at the desired level	1 Ineffective/counterproductive in increasing or maintaining groundwater levels at the desired level 2 Minimally effective in increasing or maintaining groundwater levels at the desired level 3 Moderately effective in increasing or maintaining groundwater levels at the desired level 4 Effective in increasing or maintaining groundwater levels at the desired level 5 Highly effective in increasing or maintaining groundwater levels at the desired level
6. Manageability and Mainte-nance Feasibility	The extent to which the measure will necessitate maintenance and operational oversight	1 Requires extensive and continuous maintenance and operation 2 Requires significant maintenance and operation efforts 3 Requires a moderate amount of maintenance and operation 4 Requires manageable levels of maintenance and operation 5 Requires minimal maintenance and is highly manageable
7. Cost-efficiency	The degree to which the measure will be beneficial in terms of estimated costs, considering benefits in non-monetary value	1 Provides negligible or no benefits relative to its costs 2 Offers limited benefits relative to its costs 3 Offers balanced benefits relative to its costs 4 Offers considerable benefits relative to its costs 5 Provides substantial benefits relative to its costs

B-2 Table 19 MCA Measures (English version)

		Optional Measures							
		Promoting rainwater harvesting	Water purification installation earlier in the water system	Reducing water drainage	Water level-controlled drainage	Restricting new urban construction in marshy areas	Undeepening and widening water channels	Promoting perennial crops	Deploying multiple/new weirs
Groundwater-system criteria	Effect on the ground type								
	Water Storage Capacity and Infiltration								
	Feasibility of Stakeholder Cooperation								
	Environmental Impact								
	Effect on Groundwater								
	Manageability and Maintenance Feasibility								
	Cost efficiency								
Sum of the scores									

B-3 Table 20 MCA Norms (English version)

		Optional Measures								
		Ditches and streams are allowed to dry up for 1 week 1:10	**Ditches and streams are allowed to dry up for 1 week 1:25**	**Ditches and streams are allowed to dry up for 1 week 1:50**	**Groundwater level lowers by 30cm below GLG in summer 1:10**	**Groundwater level lowers by 30cm below GLG in summer 1:25**	**Groundwater level lowers by 30cm below GLG in summer 1:50**	**Groundwater level lowers by 30cm below GVG in Winter 1:10**	**Groundwater level lowers by 30cm GVG in winter 1:25**	**Groundwater level lowers by 30cm GVG in winter 1:50**
Groundwater-system criteria	Effect on the ground type									
	Water Storage Capacity and Infiltration									
	Feasibility of Stakeholder Cooperation									
	Environmental Impact									
	Effect on Groundwater									
	Manageability and Maintenance Feasibility									
	Cost efficiency									
Sum of the scores										

B-4 Table 21 Criteria to Establish Climate-Resilient Groundwater system (Dutch version)

Criterium	Omschrijving	Score schaal gebaseerd op de impact
1. Effect op het type grondgebruik	De mate waarin schade kan worden verminderd voor het specifieke grondgebruik en de gebruikers ervan	1. Uitgebreide en onherstelbare schade wordt toegebracht aan de bodem en voor de gebruikers ervan 2. Aanzienlijke schade aan de bodem en voor de gebruikers ervan 3. Matige schade aan de bodem en voor de gebruikers ervan 4. Geringe schade aan de bodem en voor de gebruikers ervan 5. Minimale of geen schade aan de bodem en voor de gebruikers ervan
2. Wateropslag-capaciteit en infiltratie	Het niveau van verbetering van de grondwateropslag- en infiltratiecapaciteit van de bodem	1. Geen verbetering in de opslagcapaciteit van grondwater en infiltratiecapaciteit 2. Geringe verbetering in de opslagcapaciteit van grondwater en infiltratiecapaciteit 3. Matige verbetering in de opslagcapaciteit van grondwater en infiltratiecapaciteit 4. Verbetering in de opslagcapaciteit van grondwater en infiltratiecapaciteit 5. Aanzienlijke verbetering in de opslagcapaciteit van grondwater en infiltratiecapaciteit
3. Haalbaarheid van samenwerking met stakeholders	De mate van samenwerking van belanghebbenden bij het uitvoeren van maatregelen	1. Geen samenwerking 2. Beperkte samenwerking 3. Voldoende samenwerking 4. Sterke samenwerking 5. Uitstekende samenwerking
4. Klimaat bestendigheid	De effectiviteit van de maatregel in het aanpakken van de gevolgen van veranderende weerspatronen als gevolg van klimaatverandering	1. Niet effectief bij het omgaan met veranderende weereffecten 2. Minimaal effectief bij het omgaan met veranderende weereffecten 3. Matig effectief bij het omgaan met veranderende weereffecten 4. Effectief bij het omgaan met veranderende weereffecten 5. Zeer effectief bij het omgaan met veranderende weereffecten
5. Effect op grondwaterpeil	De effectiviteit van de maatregel in het verhogen of handhaven van grondwaterstanden op het gewenste niveau	1. Niet effectief bij het verhogen of handhaven van grondwaterstanden op het gewenste niveau 2. Minimaal effectief bij het verhogen of handhaven van grondwaterstanden op het gewenste niveau 3. Matig effectief bij het verhogen of handhaven van grondwaterstanden op het gewenste niveau 4. Effectief bij het verhogen of handhaven van grondwaterstanden op het gewenste niveau 5. Zeer effectief bij het verhogen of handhaven van grondwaterstanden op het gewenste niveau
6. Mate van operationaliteit en vereist onderhoud	De mate waarin de maatregel onderhoud en operationeel toezicht vereist	1. Vereist uitgebreid en continu onderhoud en operationeel beheer 2. Vereist aanzienlijke inspanningen voor onderhoud en operationeel beheer 3. Vereist een gematigde hoeveelheid onderhoud en operationeel beheer 4. Vereist beheersbare niveaus van onderhoud en operationeel beheer 5. Vereist minimaal onderhoud en is zeer beheersbaar
7. Kosten efficiëntie	De mate waarin de maatregel voordelig zal zijn qua geschatte kosten, rekening houdend met voordelen in niet-monetaire waarde	1. Biedt verwaarloosbare of geen voordelen ten opzichte van de kosten 2. Biedt beperkte voordelen ten opzichte van de kosten 3. Biedt gebalanceerde voordelen ten opzichte van de kosten 4. Biedt meer voordelen ten opzichte van de kosten 5. Biedt aanzienlijk meer voordelen ten opzichte van de kosten

B-5 Table 22 MCA Maatregelen (Dutch version)

		Optionele Maatregelen							
		Promoten van opvangen regenwater	**Waterzuivering eerder in watersysteem**	**Minder water afvoeren**	**Peilgestuurd drainage**	**Beperken van nieuwbouw in drassige gebieden**	**Watergangen verbreden en ontdiepen**	**Promoten van meerjaarse gewassen**	**Inzet van meerdere stuwen**
Grondwater-systeem criteria	Effect op het type grondgebruik								
	Wateropslag-capaciteit en infiltratie								
	Haalbaarheid van samenwerking met stakeholders								
	Klimaat bestendigheid								
	Effect op grondwaterpeil								
	Mate van operationaliteit en vereist onderhoud								
	Kosten efficiëntie								
Som van de scores									

B-6 Table 23 MCA Normen (Dutch version)

		Optional Measures								
		Sloten en beken mogen droogvallen voor een week 1:10	**Sloten en beken mogen droogvallen voor een week 1:25**	**Sloten en beken mogen droogvallen voor een week 1:50**	**Grondwater level zakt met 30cm onder GLG in de zomer 1:10**	**Grondwater level zakt met 30cm onder GLG in de zomer 1:25**	**Grondwater level zakt met 30cm onder GLG in de zomer 1:50**	**Grondwater level zakt met 30cm onder GVG in de winter 1:10**	**Grondwater level zakt met 30cm onder GVG in de winter 1:25**	**Grondwater level zakt met 30cm onder GVG in de winter 1:50**
Groundwater-system criteria	Effect op het type grondgebruik									
	Wateropslag-capaciteit en infiltratie									
	Haalbaarheid van samenwerking met stakeholders									
	Klimaat bestendigheid									
	Effect op grondwaterpeil									
	Mate van operationaliteit en vereist onderhoud									
	Kosten efficiëntie									
Sum of the scores										

C. Elaboration on establishing norms and measures

Norms:

Water nuisance norms were the main inspiration for constructing new norms that could act as guidelines for the waterboard to limit the effect of drought on the groundwater levels. Where water nuisance norms prescribe the allowed frequency of occurrence of flooding of specific land use types as prescribed in section 2.2.

Therefore, it is chosen to determine allowed occurrence frequencies for which groundwater levels decrease below an average groundwater level in a specific season for agricultural land, urban areas and nature zones. This idea was welcomed by the opinion of the hydrologists during the interviews as can be seen in the appendix A.

In the end, nine norms were selected that could contribute to mitigating drought impacts across one or multiple land use types, ensuring the assessment in an MCA can determine the most suitable measures for the final advice for an area that includes multiple land use types with different priorities. The final norms therefore became:

1. **Ditches and streams are allowed to dry up for 1 week**

Since ditches and streams are used for discharging water from an area, it is beneficial to a region's groundwater levels when they fall dry, as less water will evaporate from the area. However, this also impacts nature, which is unwanted as this lack of water will negatively affect all aquatic life. To determine the best allowed frequency occurrence three difference intervals will be assessed: once every 10 years, once every 25 years and once every 50 years.

2. **Groundwater level lowers by 30cm below GLG in Summer**

According to experts in the interviews, the most vulnerable season for low groundwater levels and the seasons in which the groundwater levels will drop the most is the summer. Therefore, it is chosen to evaluate three occurrence frequencies at which the groundwater level is allowed to drop by 30 cm below the average lowest groundwater level during the summer period. The value is set at 30 cm as an example, backed by the current precipitation shortage of around 40cm as mentioned in the literature and the expert in the interview A-2 mentioned problematic groundwater level drops of around 30 cm occurred in their management area currently.

3. **Groundwater level lowers by 30cm below GVG in Winter**

According to experts in the interviews, the most important season for storing groundwater and refilling large groundwater reservoirs is before the growing season in the Winter/start of spring. Therefore, it is chosen to evaluate three occurrence frequencies at which the groundwater level is allowed to drop by 30 cm below the average highest groundwater level during the winter period. Thus, meaning that there is to little groundwater reserve to deal with the water demand of the agricultural sector in the growing season combined with the increased amount of evaporation that come with higher temperatures during summer. The value is set at 30 cm as an example, just like the boundary value during the summer period.

Measures

As there exist many measures in water management proven to be effective, it is only possible to select a few measures to be assessed in the framework. The procedure for selecting measures begins with a review of the literature to identify effective strategies from existing research and case studies. This literature review provided an understanding of water management measures during droughts across various land use types, highlighting proven strategies and innovative solutions.

Simultaneously, insights from interviews with hydrologists contribute firsthand knowledge and perspectives on local water management challenges and needs. Following this, outcomes from collaborative meetings further refined the selection process. Through brainstorming sessions and discussions, the potential use of different measures was evaluated.

In the end, eight measures were selected that could contribute to mitigating drought impacts across one or multiple land use types, ensuring the assessment in an MCA can determine the most suitable measures for the final advice for an area that includes multiple land use types with different priorities. The final measures therefore became:

1. **Promoting rainwater harvesting**

By promoting rainwater harvesting, less rainwater will be discharged from the area. This water will not be stored in the ground, which could be very useful during periods of drought. Additionally, from a water quality point of view, it is beneficial to store as much rainwater as possible, as it is a clean source of water which is unwanted in water purification plants. It is also a very cheap measure, as it does not require large constructions or expensive tools.

2. **Water purification installation earlier in the water system**

During droughts, natural water sources like rivers and reservoirs often experience reduced flow and water levels. Purifying water earlier in the system allows for more reliable access to treated water, ensuring continuity of supply even when surface water availability is limited. This measure was also welcomed by the outcomes of the interview of which transcription can be found in A-2.

3. **Reducing water drainage**

Less drainage of water results in less groundwater level decrease, and more water will be stored in the groundwater reservoirs to deal with dry periods. Less drainage also means more water stays within the soil profile leading to more stability of the soil preventing sinkholes or ground depletion.

4. **Water level-controlled drainage**

By fixing a groundwater level at a certain region, undesired groundwater level decrease can be prevented. Only the groundwater excess will be discharged. It is a very easy-to-control mechanism which unfortunately is rather expensive.

5. **Restricting new urban construction in marshy areas**

For the construction of new urban areas, lower groundwater levels are desired to make the ground sturdy to work on and form a stable foundation for the houses. To prevent pile rot, steady groundwater levels are desired, mainly in areas which have wooden piles as foundations. However when these newly built areas are planned to be built on soils that are marsh-like, meaning that the groundwater levels are just below field level or even at field level, a lot of groundwater drainage has to take place according to the outcomes of the interview A-2. Not only will this require preliminary drainage, during the operation phase low groundwater levels in the urban areas are desired to be able to access crawling spaces. Besides that, due this drainage of land, the groundwater of surrounding areas will flow towards the urban area, leading to more groundwater discharge and depletion of surrounding land. This depletion also affects infrastructure as depletion will damage roads asking for more road maintenance, which results in high maintenance costs and hinder of traffic flow.

6. **Undeepening and widening water channels**

By undeepening and widening water channels groundwater and surface water discharge from an area will be reduced, especially after peak precipitation. Next to that, the increased ground level limits the amount of groundwater that evaporates during summer. This widening of the channel also provides an option to implement more vegetation improving the groundwater storage capacity and infiltration of the soil. This measure is built up out of two measures, the undeepening and the widening part of the channel. Since the measures are individually very relevant and are often combined in practise, it is chosen to use the combination of undeepening to limit the number of measures that need to be assessed in the MCA.

7. **Promoting perennial crops**

Following the brainstorm mentioned in the transcription in A-1, promoting perennial crops for mitigating drought could be a very good measure. Perennial crops have multiple advantages. They require less water for the establishment, they provide better precipitation infiltration and hold groundwater limiting the evaporation of the groundwater.

Next to that, by reducing soil disturbance and runoff, perennial crops contribute to improved water and soil quality in rivers and the land itself. As less below-the-ground biotic life will be disturbed and the amount of nutritional soil will flush away decreases, which could otherwise pollute the water in which it gets discharged.

8. **Deploying multiple/new weirs**

Weirs can regulate and control water flow in rivers and streams, ensuring consistent water supply downstream during droughts. This can be realised by maintaining the minimum required flow levels necessary to support aquatic ecosystems in an area. Additionally, reservoirs can be created by using weirs to store water for drier periods.

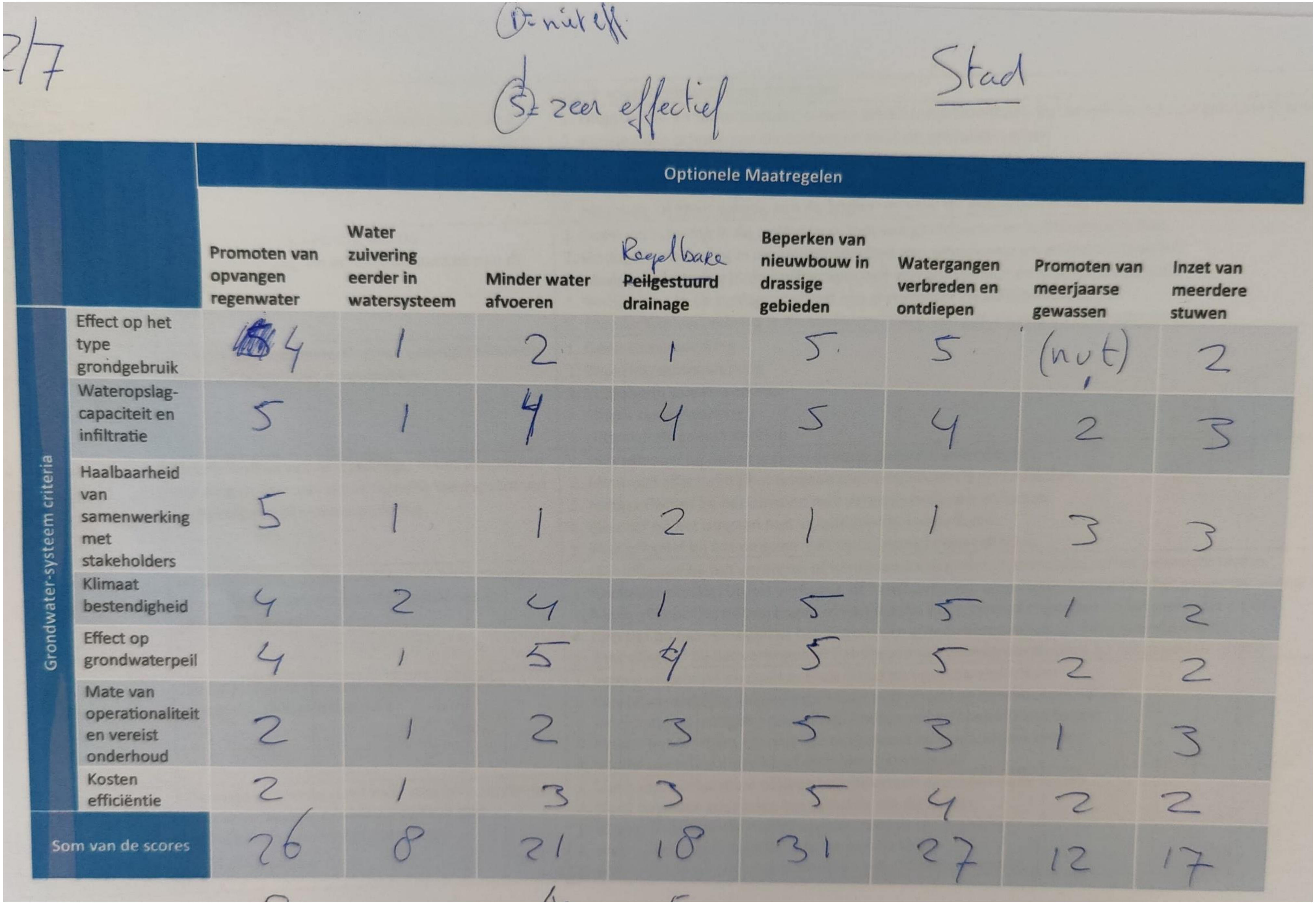
D. Results of Expert Session

2/7

Stad → hydrologisch effecten *GHG

beoordeling: Groundwater-system criteria	Optionale Normen								
	Sloten en beken mogen droogvallen voor een week 1:10	Sloten en beken mogen droogvallen voor een week 1:25	Sloten en beken mogen droogvallen voor een week 1:50	Grondwater level zakt met 30cm onder GLG in de zomer 1:10	Grondwater level zakt met 30cm onder GLG in de zomer 1:25	Grondwater level zakt met 30cm onder GLG in de zomer 1:50	Grondwater level zakt met 30cm onder GLG in de winter 1:10	Grondwater level zakt met 30cm onder GLG in de winter 1:25	Grondwater level zakt met 30cm onder GLG in de winter 1:50
Effect op het type grondgebruik	3	4	5	2	2	2	5	5	5
Wateropslag-capaciteit en infiltratie	2	2	2	3	3	3	3	3	3
Haalbaarheid van samenwerking met stakeholders	3	3	3	4	4	4	2	2	2
Klimaat bestendigheid	3	3	3	5	5	5	1	1	1
Effect op grondwaterpeil	3	3	3	5	5	5	1	1	1
Mate van operationaliteit en vereist onderhoud	4	4	4	2	2	2	1	1	1
Kosten efficiëntie	1	1	1	3	3	3	5	5	5
Sum of the scores	19	20	21	24	24	24	18	18	18

Figure 8 MCA results from expert session on the topic Urban area norms



Grondwater-systeem criteria	Optionele Maatregelen: Promoten van opvangen regenwater	Water zuivering eerder in watersysteem	Minder water afvoeren	Regelbare ~~Peilgestuurd~~ drainage	Beperken van nieuwbouw in drassige gebieden	Watergangen verbreden en ontdiepen	Promoten van meerjaarse gewassen	Inzet van meerdere stuwen
Effect op het type grondgebruik	4	1	2	1	5	5	(n.v.t)	2
Wateropslag-capaciteit en infiltratie	5	1	4	4	5	4	2	3
Haalbaarheid van samenwerking met stakeholders	5	1	1	2	1	1	3	3
Klimaat bestendigheid	4	2	4	1	5	5	1	2
Effect op grondwaterpeil	4	1	5	4	5	5	2	2
Mate van operationaliteit en vereist onderhoud	2	1	2	3	5	3	1	3
Kosten efficiëntie	2	1	3	3	5	4	2	2
Som van de scores	26	8	21	18	31	27	12	17

Figure 9 MCA results from expert session on the topic Urban area measures

Landbouw

GVG → voorjaarsmoment

Groundwater-system criteria	Optionale Normen								
	Sloten en beken mogen droogvallen voor een week 1:10	Sloten en beken mogen droogvallen voor een week 1:25	Sloten en beken mogen droogvallen voor een week 1:50	Grondwater level zakt met 30cm onder GLG in de zomer 1:10	Grondwater level zakt met 30cm onder GLG in de zomer 1:25	Grondwater level zakt met 30cm onder GLG in de zomer 1:50	Grondwater level zakt met 30cm onder ~~GLG~~ in de winter 1:10	Grondwater level zakt met 30cm onder ~~GLG~~ in de winter 1:25	Grondwater level zakt met 30cm onder ~~GLG~~ in de winter 1:50
Effect op het type grondgebruik	5	5	5	2	3	4	2	4	5
Wateropslag-capaciteit en infiltratie	1	1	1	5	4	3	5	4	3
Haalbaarheid van samenwerking met stakeholders	1	1	1	3	4	5	1	1	1
Klimaat bestendigheid	1	1	1	5	4	3	5	4	3
Effect op grondwaterpeil	1	1	1	5	4	3	5	4	3
Mate van operationaliteit en vereist onderhoud	5	5	5	5 *	5 *	5 *	5 *	5 *	5 *
Kosten efficiëntie	1	1	1	1	2	3	1	2	3
Sum of the scores	15	15	15	26	21	26	24	24	23

* onbeheersbaar

Figure 10 MCA results from expert session on the topic Agricultural area norms

Landbouw functie

Grondwater-systeem criteria	Promoten van opvangen regenwater	Water zuivering eerder in watersysteem	Minder water afvoeren	Peilgestuurd drainage	Beperken van nieuwbouw in drassige gebieden	Watergangen verbreden en ontdiepen	Promoten van meerjaarse gewassen	Inzet van meerdere stuwen
	Optionele Maatregelen							
Effect op het type grondgebruik	5 ++	5	5	5 +	5	4	5	5 ++
Wateropslag-capaciteit en infiltratie	5	1 n.v.t	4	5	1	4	3	4
Haalbaarheid van samenwerking met stakeholders	3	1	2	5	3	2	1	4
Klimaat bestendigheid	4	2	4	5	5	4	3	5
Effect op grondwaterpeil	5	1	5	3	5	5	2	4
Mate van operationaliteit en vereist onderhoud	4	1	~~2~~ 3	3	5	2	5	3
Kosten efficiëntie	3	1	3	2	4	3	2	4
Som van de scores	29	12	26	28	25	24	21	29

Figure 11 MCA results from expert session on the topic Agricultural area measures

Natuur

	Optionale Normen								
	Sloten en beken mogen droogvallen voor een week 1:10	Sloten en beken mogen droogvallen voor een week 1:25	Sloten en beken mogen droogvallen voor een week 1:50	Grondwater level zakt met 30cm onder GLG in de zomer 1:10	Grondwater level zakt met 30cm onder GLG in de zomer 1:25	Grondwater level zakt met 30cm onder GLG in de zomer 1:50	Grondwater level zakt met 30cm onder GLG in de GLG winter 1:10	Grondwater level zakt met 30cm onder GLG in de GLG winter 1:25	Grondwater level zakt met 30cm onder GLG in de GLG winter 1:50
Groundwater-system criteria									
Effect op het type grondgebruik				~~[illegible]~~ 2	~~[illegible]~~ 3	~~[illegible]~~ 4	1	2	3
Wateropslag-capaciteit en infiltratie									
Haalbaarheid van samenwerking met stakeholders									
Klimaat bestendigheid				3	~~3~~ 4	5	3	4	5
Effect op grondwaterpeil				3	4	5	3	4	5
Mate van operationaliteit en vereist onderhoud									
Kosten efficiëntie									
Sum of the scores									

Figure 12 MCA results from expert session on the topic Nature area norms

NATUUR

Grondwater-systeem criteria	Promoten van opvangen regenwater	Water zuivering eerder in watersysteem	Minder water afvoeren	Peilgestuurd drainage	Beperken van nieuwbouw in drassige gebieden	Watergangen verbreden en ontdiepen	Promoten van meerjaarse gewassen	Inzet van meerdere stuwen
	Optionele Maatregelen							
Effect op het type grondgebruik	5	5	5	5	5	5	5	5
Wateropslag-capaciteit en infiltratie						5	3	4
Haalbaarheid van samenwerking met stakeholders	3	2	3	4	1	3	2	4
Klimaat bestendigheid	4	~~4~~ 3	5	3	5	5	4	3
Effect op grondwaterpeil	4	1	5	4	5	5	2	3
Mate van operationaliteit en vereist onderhoud	3	1	3	2	5	~~3~~ 4	5	2
Kosten efficiëntie	4	2	3	2	3	4	2	3
Som van de scores								

Figure 13 MCA results from expert session on the topic Nature area measures