Onto sustainable water management in the Wageningse Eng

WATER ACE

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ACT project 3.066: Towards sustainable water management on the Wageningse Eng

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Executive summary

Water availability in the Wageningse Eng will become increasingly unpredictable due to the changing climate. Stakeholders on the Wageningse Eng are therefore aiming to increase the sustainability regarding their management of water resources in the area. The purpose of this project is to provide the water users in the Wageningse Eng with information on current trends in the water system and give user groups an overview of measures aimed at increasing the sustainability of their water use. For this reason, data on precipitation, evaporation and groundwater levels was analysed and trends in the data were evaluated. Next to this, a thorough exploration of possible measures was conducted and these measures were further specified to practical measures that match the user groups and possibilities in the Wageningse Eng. As a final step, a decision tree was created to make the measures clear to the water users and instigate discussions about what measures to take in what cases. The data analysis showed clear seasonal differences in the precipitation deficits and excesses. Trends in evaporation show a significant increase, predominantly in the summer and spring. Trends in other environmental parameters were not significant. The selected measures for the Wageningse Eng were proposed in the following four categories: measures on awareness and insights, measures on efficient water use, measures on retaining rainwater and measures on groundwater recharge. The created decision tree follows these categories and expands on these categories by providing a pathway to sustainable water management and make the measures as tangible and clear as possible for the user groups within the Wageningse Eng. The advice to the commissioner is to provide this decision tree to the water users within the Wageningse Eng, but further research could focus on moving from this choice of a measure to actual implementation.

Table of Contents

Abbreviations

ETpot	=	potential evapotranspiration
ETref	=	reference evaporation
e.g.	=	exampli gratia (for example)
etc.	=	et cetera
GW	=	groundwater
i.e.	=	id est (that is)
LGN	=	landelijk grondgebruiksbestand Nederland
LOESS	=	locally estimated scatter smoothing line
KNMI	=	Koninklijk Nederlands Meteorologisch Instituut
MCA	=	multi-criteria analysis
n.d.	=	no date
P	=	precipitation
PED	=	precipitation excess / deficit
SPEI	=	standardized precipitation evapotranspiration index
WUR	=	Wageningen University & Research

List of figures, tables etc.

List of figures

List of tables

1. Introduction

1.1 Problem introduction

Water is an almost universal requirement for life as we know it. Humans are mainly made up of water and require water to live and thrive, in addition to a plethora of other uses (Chaplin, 2001). Consequently, how to conceive, manage and distribute water has been of human concern since the dawn of time. Many small and big scale disputes have at their origin opposing interests of different water users, known as water conflict (Tulloch, 2009). Managing water sources is a challenging task as every water source has its unique hydrological, ecological, economic and socio-political context. To make matters more complicated, climate change is contributing towards the decrease in water stability, notably through longer droughts, more intense periods of rain and shorter periods of rain in general (Trenberth et al., 2014; IPCC, 2022). The scale at which water is managed, can vary from local, micro scale management at the level of a community to between different countries or continents even on a macro scale.

Within the Dutch region of Gelderland exists an ancient landscape of particular ecological, cultural and historical interest known as the Wageningse Eng where different stakeholders face the issue of how to manage the water resources in the area. The Wageningse Eng Foundation, seeking to preserve and where possible strengthen the natural, scenic and cultural-historical values of the Wageningse Eng, contains representatives of relevant stakeholder groups in order to facilitate the management of the area (Stichting Wageningse Eng, n.d.-d). Examples of such stakeholder groups are water users, the water board and the municipality of Wageningen. Many different water users are present and can be grouped into categories based on their occupation on the Eng. Examples of such user groups are farmers, animal keepers, allotment gardeners and residents (H. Savenije & M. Renkema, personal communication, 30 March 2023). For a more detailed water user- and stakeholder analysis, see chapter 3. Although there are no official rules or regulations set by the Wageningse Eng Foundation itself, water users do have to comply with water use restrictions during periods of drought set by the Water Board Vallei and Veluwe (Stichting Wageningse Eng, n.d.-c; Kenniscentrum InfoMil, n.d.).

Water users in the Wageningse Eng are mainly dependent on groundwater and water from the grid or tap, whilst there is enough yearly precipitation to cover the water needs of the area (Diallo et al., 2022). This situation is far from perfect; much precipitation is wasted and therefore external tap and grid water must be brought into the local system. Increasing the efficient utilization of precipitation within the Eng would help develop a more robust and self-sufficient water system, as the supply of tap and grid water for non-domestic purposes becomes increasingly unpredictable with climate change. Therefore, a more sustainable and resilient water management system must be developed. However, so far, water users in the Wageningse Eng have expressed difficulty in finding a sustainable water management solution. Because of the multiple land uses and associated user groups with their own practices, opinions, needs and knowledge, there is no one-size-fits all solution possible regarding measures. Also, certain measures that would be perfect for one user group, might not apply to the contexts or needs of other user groups or even cause adverse impacts. Although the implementation process is outside the scope of this research, it is important to acknowledge the dilemmas accompanying measures.

1.2 The Wageningse Eng Foundation and the WUR Science Shop

Troubled by the sustainable water management issue, the Wageningse Eng Foundation reached out to Wageningen University & Research (WUR) Science Shop, an organization with the purpose of assisting non-profit groups in finding answers to their issues with academic research, thereby linking science and society. In the case of this project, the WUR Science Shop aims to supply academically backed recommendations for resolving the Wageningse Eng Foundation's dilemmas; i.e., establishing a socially and environmentally sustainable way to manage the water resources in the area (Wageningen University and Research, 2023).

Previous research facilitated by the Science Shop investigated both the quantity and the quality of the water within the system and into the water usage of allotment farmers in the Eng (Diallo et al., 2022; V. Bennink, personal communication, 31 March 2023). This specific ACT project, carried out by Water'Ace, will delve deeper into the water management aspects, specifically looking at what measures can be taken to increase the sustainability of the water use in the Wageningse Eng area. The provided advice and solutions aimed to contribute to sustainable water management within the Wageningse Eng can be used by the WUR Science Shop as input in further stages where measures for sustainable water management are implemented (V. Bennink, personal communication, 31 March, 2023).

Although this project focuses exclusively on the Wageningse Eng, using water in a sustainable way is a more universal challenge. Moreover, due to climate change both temperature and precipitation patterns are changing globally, affecting (local) water availability. If periods of droughts and extreme precipitation become more abundant in the future (KNMI, 2021), sustainable water management will only become more important. Therefore, the outcomes of this local project can be used as an example for similar cases in comparable areas, such as the edges the Veluwe.

1.3 Sustainable water management

Sustainable water use and management has become one of the core challenges faced worldwide (OECD, 2023; Sachs et al., 2022; Nixon et al., 2000; UN-Water, n.d.; FAO, 2018). Due to its importance, much has been written about sustainable water use and many interpretations exist. Because of this multitude of interpretations, it is necessary to define what sustainable water usage/management specifically entails for the Wageningse Eng. Based on input from both the commissioner, the report from the previous ACT group and literature search, the following criteria should be met in order for water use to be considered sustainable:

1. The amount of water that is consumed by users in the Wageningse Eng does not negatively affect the area itself nor the areas it is connected to in both the present and the future.
2. The costs of water use are minimized in regard to initial investments and fixed/recurring costs (e.g., energy costs of a pump or costs of maintenance).
3. Water access is distributed in an equitable and non-discriminatory way amongst all water users.
4. The water system within the Wageningse Eng is the main source of water, with the exception of tap or grid water for residential use.

Adapted from: (OECD, 2023; Sachs et al., 2022; Nixon et al., 2000; Diallo et al., 2022; Purvis, Mao & Robinson, 2019; UN-Water, n.d.; FAO, 2018; V. Bennink, personal communication, 31 March 2023).

This definition is partly based on the three sustainability pillars of the United Nations; environmental sustainability (related to criteria 1), economic sustainability (related to criteria 2) and social sustainability (related to criteria 3) (Purvis, Mao & Robinson, 2019). Furthermore, the unnecessary amounts of tap and grid water that are currently being consumed, should be reduced to minimize the dependency of the area on an external water source. Instead, focusing on groundwater and especially precipitation could enhance the robustness of the system and prevent water going to waste.

1.4 Project delineation

In Figure 1 the spatial layout of the Wageningse Eng, as considered in the Vision is shown. The total area of the Wageningse Eng based on this spatial layout is approximately 205 ha. The Wageningse Eng itself is located on a slope between the Veluwe and the lower Binnenveld. The delineation is chosen in this way as the measures will be evaluated locally within the Wageningse Eng. Groundwater in the phreatic aquifer, measured here in the first soil layers of the Boxtel Formation and/or the iced-pushed ridge deposits, in the Wageningse Eng is generally flowing from north-east to the south-west towards the Nederrijn (Figure A1.1 in Appendix I). The feasible local groundwater measures evaluated in this report will mainly focus on the phreatic aquifer. For this research the considered depth of the system is set at around -80m below NAP, at the Wageningse Eng this means a thickness of the phreatic aquifer of around 100 m (Figure A1.2 in Appendix I).

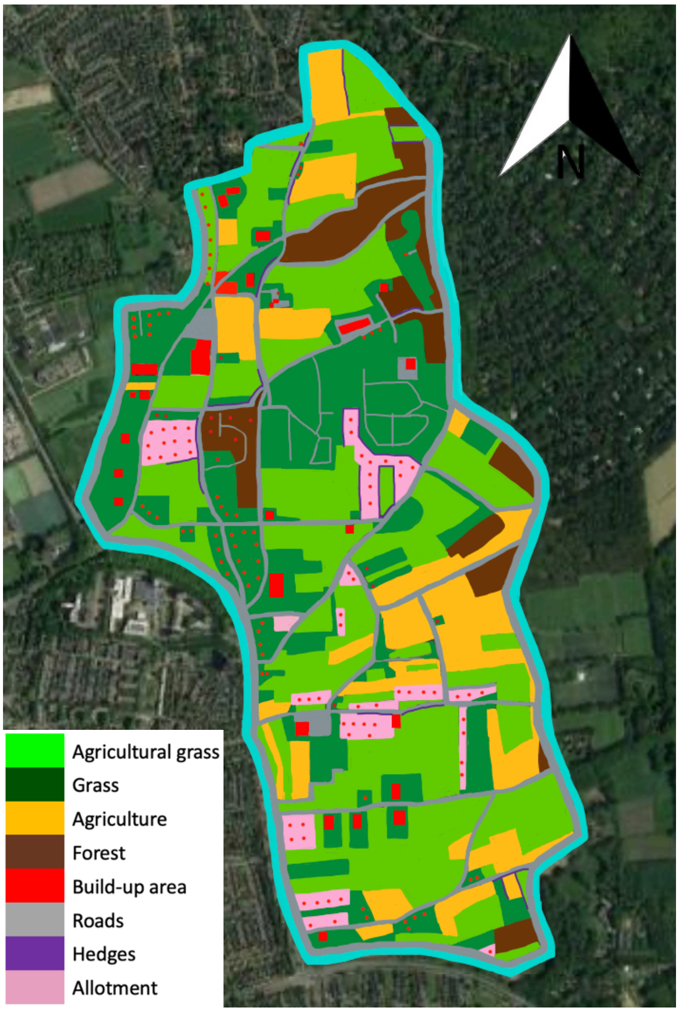

Figure 1: Map of different land uses drawn in polygons based on information from LGN2020, satellite images obtained from Google Maps and field visits.

Within the Wageningse Eng different land uses types are present. The fractions of land use types within the Wageningse Eng as a whole are obtained using the using the Landelijk Grondgebruik Nederland 2020 (LGN2020) dataset (available via the Geodesk of Wageningen University). This dataset has a resolution of 5 x 5 m with 48 different land use types. The land uses within the Wageningse Eng (26 different types) were reduced to 9 different classes, which are indicated in Table 1. The two main types of land use are agricultural grassland (used by animal keepers for letting their animals graze or for the production of hay (37.49%) and grass within primary and secondary build up areas (e.g., sport fields, recreational grass fields (23.79%). Less present land use types are agriculture (12.42%), allotment gardens (8%), roads (8.08%) and forest (7.5%). The smallest types of land uses are build-up areas (1.87%) and hedges (0.77%). Almost every land use type facilitates multiple activities. For instance, agricultural lands host both 'ordinary' cultivation of crops but also a vineyard. To the build-up lands belong both residential homes, farms, shelter locations for animals and sheds.

*Table 1: Land uses of the Wageningse Eng. *The percentage of allotment gardens was taken from (Diallo et al., 2022), the other data was modified from the LGN 2020 dataset.*

Land use type	Percentage of area (%)
Agricultural grass	37.49
Grass (mainly grass in primary and secondary build up areas. E.g: parks, sport fields and other recreation gras fields)	23.79
Agriculture (predominantly maize and grain crops but this class also includes the classified "other agricultural crops")	12.42
Forest (in the Eng predominantly deciduous forest)	7.50
Build-up area	1.87
Roads	8.08
Hedges (high and low shrub vegetation)	0.77
Allotment*	8.00
Remaining	0.06

Another important consideration for the Wageningse Eng is its archaeological value. The Wageningen Municipality has defined almost the entirety of the area as a zone with high archaeological expectations. This means that a permit is needed for disturbing the soil when it is disturbed for areas larger than 250m² and/or deeper than 30cm (Gemeente Wageningen, 2020a).

At last, it should be noted that this research will focus on what is already happening at the moment in de Wageningse Eng and therefore the focus is on the current trends in water system of the Wageningse Eng. Mainly due to time constraints, climate scenarios, such as the KNMI'14-klimaatscenario's, will not be considered and therefore the current trends will not be a guarantee for the climate in the future.

1.5 Integrative project purpose and research questions

The main issues that stakeholders in the Wageningse Eng area and the Science Shop face are related to both a lack of insights on trends regarding precipitation, evaporation and groundwater and a lack of knowledge on what possible measures can be taken to improve the sustainability of the water system. The specific knowledge gap addressed by this project is:

The lacking insight on current trends in the water system and what specific measures can be taken by different stakeholders to improve sustainable water management in the Wageningse Eng.

These insights are required to pave the way to a future where there are no problems related to sustainable water usage withing the Wageningse Eng. The knowledge gap differs widely within stakeholders, and measures for increasing sustainability will rarely be workable for all stakeholders. Moreover, not all stakeholders agree on the need for a sustainable water system, possibly caused by a lack of knowledge. On top of that, not all stakeholders consume water. As stated above, in this case, there exists no one-size-fits-all solution. Therefore, it is essential to look into measures for each stakeholder group on how they can, if needed, improve the sustainability of their water usage, while

keeping current trends in mind. Based on the knowledge gap defined above, the goal of this project is to:
Provide stakeholders in the Wageningse Eng and the WUR Science Shop with information on current trends in the water system and provide user groups with an overview of measures aimed at increasing the sustainability of their water use.

Main research question:

What measures can different user groups take to make water management in the Wageningse Eng more sustainable, taking into account current trends in the water system?

Which has been divided into the following sub-questions:

Who are the main water users and stakeholders in the Wageningse Eng?
What are the current trends in precipitation, evaporation, ground-water and droughts in the Wageningse Eng?
Which sustainable water management measures are available for the Wageningse Eng?
What measures are most suitable for the water users in the Wageningse Eng?

2. Methodology

In this chapter the methods used to answer the different sub-questions will be discussed.

2.1 Stakeholders and water users

For the analysis on stakeholders and water users, data was collected via multiple methods:

- Website of the Wageningse Eng Foundation
  On the website, the organizational structure of the foundation is explained. Furthermore, the website contains a map showcasing where several water users, such as the picking gardens, are located. (Stichting Wageningse Eng, n.d.-a; Stichting Wageningse Eng, n.d.-b; Stichting Wageningse Eng, n.d.-c).
- Meeting with representatives of the Wageningse Eng on 30 March 2023
  During the first meeting with two representatives of the Wageningse Eng, we walked around the area. This provided an overview of the different types of water users. Furthermore, the draft list of users and stakeholders was discussed with the representatives to see if everyone that needed to be included, was actually included (H. Savenije & M. Renkema, personal communication, 30 March 2023).
- Input from the commissioner
  During multiple weekly meetings with Viola, the positions of stakeholders on the matrix was discussed.
- Report from the previous ACT group
  Elements of the report from the previous ACT group (Diallo et al., 2022), were used to create a first, general overview of all stakeholders (including water users). This first overview was adjusted and improved by using the data collected through the other methods.

The structure of the stakeholder and water users chapter is based on the 'Step 2 – Project specific problem definition and stakeholders' chapter of the proposal writing document of ACT (Vrielink et al., 2022). This also goes for the power-interest matrix.

2.2 Trend- and data analysis

Meteorological variables were analysed to map the current hydrological situation within the Wageningse Eng. To this end, long term historical data was used. Daily precipitation (P) and reference evaporation (ETref) data, from 1987 and onwards, were acquired from the Royal Netherlands Meteorological Institute (KNMI) weather station at Deelen, which is located roughly 15 kilometres from the Wageningse Eng. Historical groundwater levels in the Wageningse Eng were acquired from (Grondwaterstanden in Beeld, n.d.). The data on groundwater levels are available between 1972 and 2020.

Data analysis

Based upon this data, two additional variables (or drought indices) were calculated: the precipitation excess / deficit (PED; this is P-ETref), and the standardized precipitation evapotranspiration index (SPEI). The SPEI was originally introduced by Vicente-Serrano et al. (2010). To calculate the SPEI the difference between P and potential evapotranspiration (ETpot) is required. Calculating the ETpot itself is complicated and different simplified methods for this aim have been developed. In this project the ETref is taken immediately as ETpot (which effectively means that the PED is used to calculate the SPEI). This PED was calculated for monthly sums of P and ETref and can be seen as a monthly measure of water excess / deficit in the system. The SPEI can subsequently be calculated over different number of months. For a seasonal SPEI, the PED used as input would have to be summed over a season, i.e. 3 past months (which is denoted as SPEI-3). The season are defined according to (KNMI - Achtergrondinformatie klimaatdashboard, n.d.), which means December to February, March to May, June to August and September to November. The yearly SPEI is denoted as SPEI-12, with the PED summed over the past calendar year. Both the seasonal SPEI (SPEI-3) and the yearly SPEI (SPEI-12) were taken in the same way as indicated in (KNMI - Achtergrondinformatie klimaatdashboard, n.d.). The SPEI package in R is used to calculate the SPEI (Beguería & Vicente-Serrano, 2023). A more negative (positive) SPEI can be interpretated as a period with drier (wetter) conditions.

As part of the data analysis, the differences in PED in different seasons and the growing season were evaluated. Assessing these differences gives a clear indication of when it is most efficient to store water and in which seasons the stored water is needed again. During periods of precipitation deficits, it can be evaluated how long droughts in general took and what the magnitude of the deficit over this dry period was. Calculating these drought durations and intensities (based on the PED) gives a more tangible feature for water users in the Wageningse Eng to take into account when implementing a water use measure.

Trend analysis

Part of the data analysis was to check whether trends are present withing these drought indices and the measured meteorological data. Since this requires long term historical data, the data sources described above (the weather station at Deelen and (Grondwaterstanden in beeld, n.d.)) have been used. Earlier studies on the area used data measured closer to the Eng. For example, the study by (Diallo et al., 2022) used meteorological data measured at the Veenkampen between 2010 and 2021. However, a longer time span is preferred for the trend analysis. The study by (Welling, 2022) used data measured at the Haarweg between 1954 and 2000, after 2000 this data series stops, so it cannot be used to analyse the current hydrological situation at the Wageningse Eng. The monthly accumulations of P and ETref from the Veenkampen weather station differ only slightly from the data of the weather station at Deelen (Figures A2.1 and A2.2 in Appendix II). Therefore, the data from the Deelen weather station is assumed valid to use in this research on the Wageningse Eng.

For the trend analysis, both a linear line and a locally estimated scatter smoothing line (LOESS) were fitted to the data. This LOESS line visualizes the trends more smoothly instead of just a straight linear line. The trendlines were fitted to monthly, yearly and seasonal data of the variables: P, ETref, groundwater (GW), PED and the SPEI. In order to be able to fit a linear line to the data, it was first determined whether the data was normally distributed. The normality was checked visually by using a histogram and a quantile-quantile plot. In addition to this, a Shapiro-Wilk test was conducted (here values of $p \leq 0.05$ indicate a non-normally distributed dataset).

After checking for normality, a linear line was fitted to the data. For normally distributed data, linear regression is used. Furthermore, the significance of the trend (p-value) and the goodness of fit (i.e. how well the line fits the data; R^2) were also calculated. For non-normally distributed data, the Sen's slope estimator is used to obtain the slope and thus magnitude of the trend. In comparison to linear regression, the Sen's slope has the advantages that it can deal better with gross data series errors and outliers and can deal with non-normally distributed data (Aswad et al., 2020). To get the offset for the fitted Sen's slope line, the method as described in (Rousseeuw & Leroy, 2005) was used. For this fitted line, the significance of the trend (p-value according to the Mann-Kendall test (McLeod, 2022; Panda & Sahu, 2019)) and the goodness of fit (i.e. how well the line fits the data; R^2) were also calculated.

Taking into account and getting more insights on these trends is an important first step for water users in the area if they want to become more sustainable in their water use. The current trends will provide water users and other stakeholders with insights on how the hydrological situation of the Eng is changing and (partially) explain why it is important to undertake measures. This has the potential to enhance investment among water users. The other reason for a trend analysis, is that the trends could provide information which is needed to evaluate the selected measures. E.g., if precipitation shows a strong downward trend, measures aiming to retain precipitation might be less optimal for the future, assuming the found trends will continue in the future.

2.3 Exploring possible measures

To identify possible measures for the Wageningse Eng, a thorough exploration of possible measures was conducted. This exploration consisted of the following steps:

- **Brainstorm session with stakeholders on 06/04/2023**

A session was held with stakeholder representatives from the Wageningse Eng foundation. This was also the first time Water'Ace met most of the stakeholders. Different stakeholders could give their view on the current state of the Wageningse Eng and discuss measures they already had in mind.

- **Analysis of previously held interviews in the Eng**

Another ACT project was done on mapping the water use in the Wageningse Eng. Several interviews were conducted during this project and suggestion for measures were made by various interviewees. The results from these interviews were analysed and all suggested measures were taken into account.

- **Meetings with experts and stakeholders (Jos van Dam, Municipality)**

A meeting was held with two representatives from the Wageningen Municipality. During this meeting, the municipality's view on both the Wageningse Eng and sustainable water management were discussed. Another meeting was held with an expert on soil science and agriculture; Jos van Dam. Possible directions of solutions and their relevance for the Wageningse Eng were discussed.

- **Explorative literature search**

Additionally, an explorative search for measures was done in scientific and grey literature. This search was focused on search terms such as: r*ainwater retention, water use efficiency, saving water and collecting rainwater*.

All measures found were assembled into a long list. This list contains all ideas that were gathered and provides the source(s) where they were gathered from. All suggested measures were explored and elaborated upon with both a short explanation and supporting literate whenever possible. Finally, all measures were divided into four categories. Each category contains measures with a specific aim. These categories are based on the definitions made for the water system and sustainable water use as discussed in the introduction, and as discussed with the commissioner and representatives of the Wageningse Eng Foundation. This resulted in the following four categories:

1. **Insight and awareness**

Measures in this category aim to increase the awareness of the problem, to increase and support knowledge on the water system and to provide insights on the amounts of water used within the Eng.

2. **Efficient water use**

Measures in this category aim to promote more efficient water use in the Eng. They focus on providing suggestions and showcasing technologies that can be used by water users to more efficiently use their water. The end-goal of these measures is to decrease the water needs in the Eng.

3. **Rainwater retention**

Measures in this category aim to collect rainwater and retain it for use in the dryer spring and summer periods. These measures are focused on keeping water directly available for water users instead of letting it infiltrate into the groundwater system.

4. **Groundwater recharge**

Measures in this category aim to replenish groundwater levels in water system of the Wageningse Eng. These measures are focused on creating new infiltration pathways from paved surfaces and buildings, as well as increasing the amount of water that can infiltrate to the groundwater in agricultural areas.

2.4 Refining measures

To evaluate what measures are most suitable for the water users in the Wageningse Eng, they need to be made more specific for the area. This was done by narrowing down the number of measures based on specific steps and concretely working out the measures left after this process. Measures in this category aimsMeasures in category 1 aim at increasing the awareness of the problem amongst water users, and giving insight into the water system, water use and information about sustainable water use.
justification:
Justification:
justification:

Justification:
Several steps were taken to narrow down the longlist of measures into a more coherent and worked out shortlist of measures. These steps are as follows:

1. The sandy soils and gently undulating hillslopes that represent the area are not suitable for all measures. Those that do not fit with the environmental conditions on the Eng were excluded.
2. Sightlines and the open character of the landscape are very important for the Eng, and measures need to fit within these landscape characteristics (Gemeente Wageningen, 2020b). Measures that evolved extensive tree planting or creating large buildings were excluded.
3. Sufficient data or insights need(s) to be available on measures or characteristics of the area that these measures depend on. Measures based on spatial characteristics like small scale soil variations were excluded, as this data was not available and could not be gathered within the timeframe of this project.
4. A significant number of measures was related to increasing organic matter content in the soil, and soil management in general. All of these have been combined into a single overarching measure called 'soil management'.
5. Multiple measures were related to types of crops or plants being used. These measures have been combined into a single overarching measure called 'crop management'.
6. A number of measures were related to irrigation types and – strategies. These were combined into a single overarching measure called 'irrigation management'.
7. Some measure pairs were inherently similar and could be implemented very closely together on the Eng. These measure pairs were therefore combined into single measures.

The remaining measures were summed into a measure shortlist. The measures on this shortlist were discussed in an interactive session with water users. During this session, the measures were shortly explained to the attendees. After each measure's explanation, the attendees were asked to fill in two questions for the measure:

- To what extent are you able to implement this measure?
- To what extent do you think this measure (aesthetically) fit in the Eng?

Some time was reserved for filling in these questions, both on a grading scale of 0-10 and in a text box. After the questions were filled in, there was room for a central discussion surrounding the measure. The questions and measure explanations were formatted on paper, and this document can be found in appendix III . These inputs were used to further delineate the measures and relate them more concretely to the Eng and its water users.

The measures on the shortlist were worked out in detail. For each measure, implementation examples for the Eng were given. Calculations on the saved or infiltrated water volumes were conducted where possible, as well as a calculation of the costs in euros and/or area taken up by it. The timeline and scale regarding possible implementation of the measures was elaborated upon.

Finally, the measures from the shortlist were integrated into a central structure. This structure has the shape of a decision tree, where readers/viewers are taken on a tour through each of the four categories of measures via a series of questions about their water use. In this decision tree, the measures are visually scored for four criteria:

Impact on the water system

Summarizes the effect measures can possibly have on the water system. Measures were scored on a scale of 1-5 based on the following factors:

- What are the dominant trends in the area and how a measure is impacted by these trends.
- How much water can be stored with the measure
- How much water can be saved with the measure
- How much water can be infiltrated with the measure
- What is the spatial scale of the measure

Implementation time

Gives insight into the amount of time needed to implement measures, timespans are divided into the following categories:

- 0-6 months
- 6 months – 1 year
- 1 – 2 years
- 2 – 5 years
- 5 – 10 years

Implementation scale

Gives insight into the scale of implementation for the measure. Indicating if the measure can be implemented by individual water users, needs a communal effort or is even larger than the local users community and needs to involve larger stakeholders as well.

Cost in euros

Gives insight into the costs associated with these measures. Considers the costs calculated for examples, as well as the amount of components that make up the final costs. Measures were divided into the following categories:

- <100
- 100 – 500
- 500 – 1000
- 1000 – 10.0000
- > 10.0000

3. Stakeholders and water users

In this chapter, an analysis of both water users and stakeholders will be provided. As stated in the introduction, multiple parties have a stake in the water system of the Wageningse Eng. A distinction between stakeholders and water users can be made.

Water users

Water users are actors consuming water from the water system within the Eng. Based on their land use activities, users can be grouped into categories. However, differentiation within each of these groups exists. For instance, within the Eng, there are around 600 allotment gardeners active. Just as not all gardeners cultivate the same crops, they also differ in how they view the state of the water system, which water source they use and their visions on both sustainability and how the future management of the water system should look like (H. Savenije & M. Renkema, personal communication, 30 March 2023). Different types of animal keepers are also grouped together. However, the daily water requirements differ greatly between types of animals and some animal keepers may rent plots of land, whereas others own the land themselves (H. Savenije & M. Renkema, personal communication, 30 March 2023). Therefore, whilst this report does speak of user groups, the diversity within a certain user group should be kept in mind as statements and results attributed to one specific group will not necessarily reflect all belonging to that certain group. From here on, the term water user groups will be used, except for the instances applying to a specific individual user.

In Table 2, the different user groups are specified. Whilst some categories such as animal keepers, residents and allotment gardeners are rather self-explanatory, the remaining categories require some explanation. In the Eng, several commercial farmers are active. They mostly cultivate grains and maize. However, the Eng also hosts a vineyard, of which the owners belong to the commercial farmers category. To the hobby- and semi-commercial farmers belong the persons from the picking gardens and the care farm. However, some water users do not fall into any of these categories and therefore belong to the 'other' category (Stichting Wageningse Eng, n.d-a; Stichting Wageningse Eng, n.d.-b; Stichting Wageningse Eng, n.d.-c; H. Savenije & M. Renkema, personal communication, 30 March 2023, Diallo et al., 2022; V. Bennink, personal communication, 31 March 2023; V. Bennink, personal communication, 31 March 2023).

Table 2: The defined water user groups in the Wageningse Eng.

Water user groups
Allotment gardeners
Animal keepers (cows, horses, sheep)
Commercial farmers
Hobby- and semi-commercial farmers
Other
Residents

Interestingly, the sizes of user groups do not necessarily match the size of the corresponding plots of land. The two largest contrasts concern allotment gardeners and farmers. In the Eng, around 600 allotment gardeners are active and are by far the largest user group. However, only 8 per cent of the Wageningse Eng is covered by allotment plots. A reversed situation exists among farmers and animal keepers. In total, 50 per cent of the Eng is covered by either agricultural grasslands or agricultural fields. However, the numbers of users belonging to these two groups is much lower. This mismatch between user groups sizes and corresponding land plot sizes should be kept in mind when assessing either the sustainability of the overall system or the impact of certain measures. For instance, if a certain measure gets adopted by 10 allotment gardeners, the effect of this on the entire water system would be relatively small if not negligible. However, if 10 farmers owning large plots of land decide to adopt a measure, the effect on the water system of the Eng would be much larger.

Besides differing in group size, user groups also consume different amounts of water. For instance, animal keepers consume much more water than allotment gardeners (H. Savenije & M. Renkema, personal communication, 30 March 2023). This partly has to do with the size of land used per individual user. Regarding allotment gardeners, one plot gets divided into multiple smaller sub-plots. Therefore, one allotment gardener ends up with only several m2. Comparing this to the larger plots available to a single animal keeper, the difference in water usage is partly explained. However, another important factor concerns the water intensity of the activity carried out by a user group. Keeping animals alive requires much more water than e.g., watering allotment gardens (H. Savenije & M. Renkema, personal communication, 30 March 2023). Therefore, even if the plots per user were of similar size, the difference in water use would be noticeable. To complicate matters further, water usage within a certain user group also differs. For example, some farmers cultivate crops using drought-resistant seed, which require less water than standard seed. Also, daily water requirements differ per animal (J. Van Dam, personal communication, 18 April 2023; Stakeholder brainstorm, 6 April 2023).

Stakeholders

The term 'stakeholders' originates from the organizational management sphere and was originally defined as "persons or groups that have, or claim, ownership rights, or interests in a corporation and its activities, past, present or future" (Brugha & Varvasovsky, 2000, p.242). However, since then, the term has been modified and applied in other science domains as well (Brugha & Varvasovsky, 2000). Translating this to the context of the Wageningse Eng, results in the following definition; persons or groups that have, or claim, ownership rights or interests in the current and/or future water system of the Wageningse Eng (adapted from Brugha & Varvasovsky, 2000, p.242). Individual stakeholders sharing multiple characteristics such as the same claims and/or interests, can be grouped together into stakeholder groups. Examples of such groups are the nature organizations of the Binnenveld and recreationists. Similarly as with user groups, differentiation exists within these groups. Note that water users are also included as a stakeholder group. The stakeholders and stakeholder groups in the Wageningse Eng are indicated in table 3.

The majority of stakeholder(s) (groups) consists of local and regional (governance) organizations. The more regional organizations might not be as close to the Wageningse Eng geographically speaking, but they do influence water usage within the Eng. For instance, the Waterboard Vallei & Veluwe and the Province of Gelderland can issue a so-called 'Verdringingsreeks' during periods of drought, which limit the water usage of farmers (Vallei en Veluwe, 2017). The municipality of Wageningen also is an important stakeholder since its constituency incorporates the Wageningse Eng as well. From the Foundation Wageningse Eng, several sub-groups are included as stakeholders; the Advisory Board, the Board and the Territorial Advisory Committee. Nature organizations such as Staatsbosbeheer from the neighboring area called the Binnenveld, are also included as stakeholder group (Mooi Binnenveld, 2022). Although outside the scope of this research, the groundwater inside the Binnenveld is affected by whatever happens in the water system of the Wageningse Eng. Recreationists are also included as a stakeholder group; many people visit the Wageningse Eng either by foot or by bike to enjoy the rural scenery. Drastic changes to the landscape might alter their perception and appreciation of the area. Another stakeholder is the WUR Science Shop because it has been asked to look into the issue by the Foundation Wageningse Eng. Therefore, the organization has become interested in the water system of the Eng as well. The last stakeholder group consists of landowners. Throughout time, both the church and an organization called the Four Guilds have been large landowners within the Eng. They rent out plots of land to user groups such as allotment gardeners and animal keepers. As they, and other landowners, have the ultimate say on what happens on their land and facilitate certain types of water, they have been included as stakeholders as well (Stichting Wageningse Eng, n.d-a; Stichting Wageningse Eng, n.d.-b; Stichting Wageningse Eng, n.d.-c; H. Savenije & M. Renkema, personal communication, 30 March 2023, Diallo et al., 2022; V. Bennink, personal communication, 31 March 2023).

Table 3: Stakeholders and stakeholder groups of the Wageningse Eng.

Stakeholder(s) (groups)
Advisory Board SWE
Board SWE
Landowners
Municipality of Wageningen
Province of Gelderland
Nature organizations of the Binnenveld*
Recreationists
Territorial Advisory Committee Wageningse Eng
Vitens
Waterboard Vallei & Veluwe
Water users
WUR Science Shop

*: Co-op Binnenveldse Hooilanden, Foundation Mooi Binnenveld, Staatsbosbeheer

Power relations

Although the measures explained in chapter 6, are targeted towards user groups, it is important to take the power relations among stakeholder(s) (groups), including user groups, into account. In Figure 2, a power-interest matrix regarding sustainable water management measures is provided.

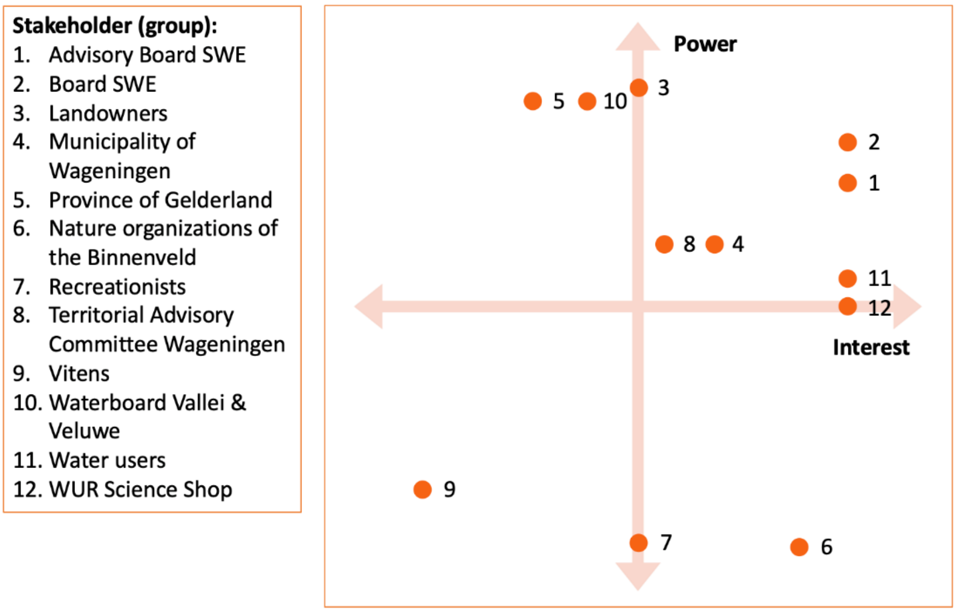

Figure 2: Power relation diagram for the stakeholder groups in the Wageningse Eng. Based on: (Stichting Wageningse Eng, n.d-a; Stichting Wageningse Eng, n.d.-b; Stichting Wageningse Eng, n.d.-c; H. Savenije & M. Renkemapersonal communication, 30 March 2023, D.

As shown by figure 2, those in power are not necessarily the stakeholder(s) (groups) with a passionate interest in sustainable water usage. On the other hand, those interested, lack a powerful position. This could possibly complicate the implementation of measures because user groups such as allotment gardeners depend on the approval of landowners before any (structural) adjustments can be made. However, there is no guarantee that landowners are willing to implement the measures. Although the implementation of measures does not belong to the scope of this research, the power relations do impact the feasibility of measures. For a more in-depth explanation of each stakeholder (group), see appendix IV.

4. Trend- and data analysis

In this section the most important found results based on the data analysis and trend analysis are discussed

Data analysis

The PED in spring and summer is often lower than the PED in autumn and winter as can be seen by looking at the distribution of colors in Figure 3. In this figure the PED summed over the seasons is sorted and plotted from high to low; the colors indicate to which season the plotted PED belongs. The PED in autumn and winter show to be always positive based on the data from 1987-2023 from the KNMI station in Deelen. For the summers and springs, most years showed a precipitation deficit, which thus means a general shortage of water from a meteorological point of view during these seasons. This thus indicates that one would preferably store water during the wetter periods (e.g. during the winter) and use that water again later on in the year when a precipitation deficit develops, for example during the spring and summer.

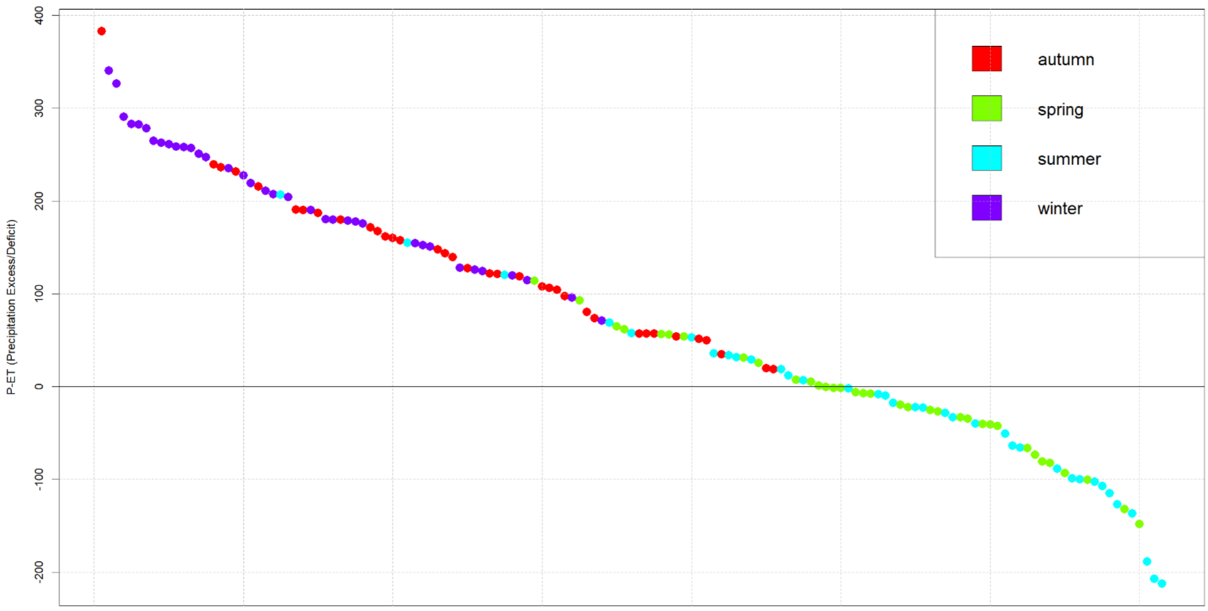

Figure 3: Precipitation deficit/excess (PED) colour coded by season, based on measured precipitation and ETref at the KNMI station in Deelen over the period 1987 - 2023.

To make the droughts during these seasons more tangible for water users in the Wageningse Eng, it is insightful to evaluate how long droughts during the springs and summers lasted and what the magnitude of the developed deficits of these dry periods were. This is indicated in Figure 4. Droughts in this case were defined as day(s) with a negative PED. For subsequent days with a negative PED, the precipitation deficits and durations were summed. Especially for droughts of a short duration multiple droughts can overlap (the points in the left side of Figure 4) due to the plotting order of points. This means that for short droughts the more recent droughts are covering the droughts from longer ago (the points in the lefst side of Figure 4). Longer drought durations generally allow for more intense precipitation deficits, which is also to be expected. The extreme drought during the summer of 2018 clearly is standing out from the rest of the observed dry periods. Apart from this it is not really observed that recently more extreme droughts occurred according to this figure. Still, when looking at Figure 5, it can be observed that the precipitation deficit over the growing season was high (very negative) in the years 2018, 2019 and 2020. Overall, these insights on various drought durations and accompanying intensities (Figure 4) can serve valuable for water users in the Eng when possibly evaluating the timescale of certain measures in combination with their water needs. With this data, it is thus possible to evaluate if a specific measure would be able to bridge a certain precipitation deficit, when focussing on these historical droughts.

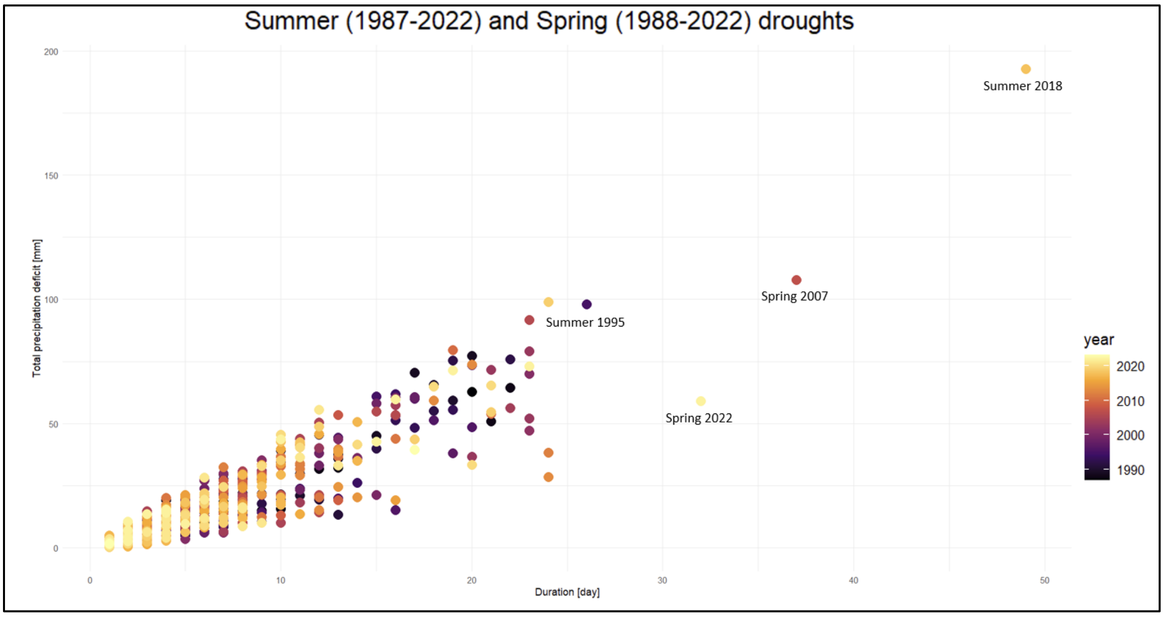

Figure 4: Precipitation deficits (PED) during the springs and summers. The colours indicate the specific years in which the droughts occurred. Some of the most extreme droughts in terms of duration and intensity based on the PED are indicated specifically in the figure.

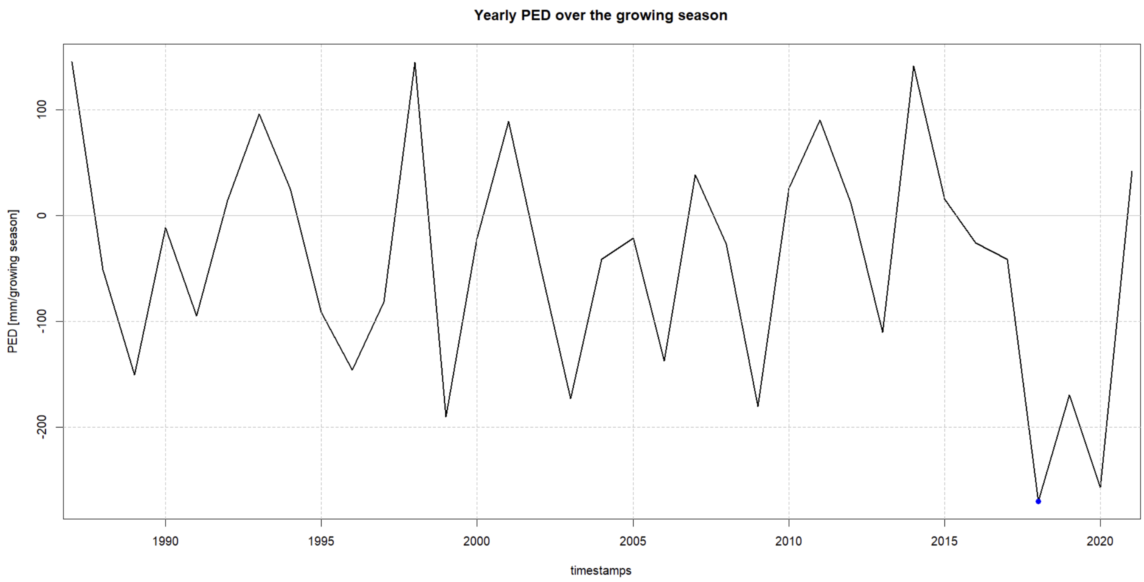

Figure 5: The precipitation deficit/excess over the whole growing season (April until the start of October), based on measured precipitation and ETref at the KNMI station in Deelen over the period 1987 - 2023.

Trend analysis

Reference evaporation (ETref) shows a significant positive trend both on a yearly scale but also on the seasonal scale during all different seasons (Table A2.1 in Appendix II). The steepest trend is found for the ETref during the summers from 1987-2022 (with Spring being second), which was also the most significant trend observed overall for all analyzed variables (Table A2.1 in Appendix II). The trendline and the data are shown in Figure 6. Monthly ETref showed to be quite erratic and no significant trend was found at this timescale (Table A2.1 in Appendix II).

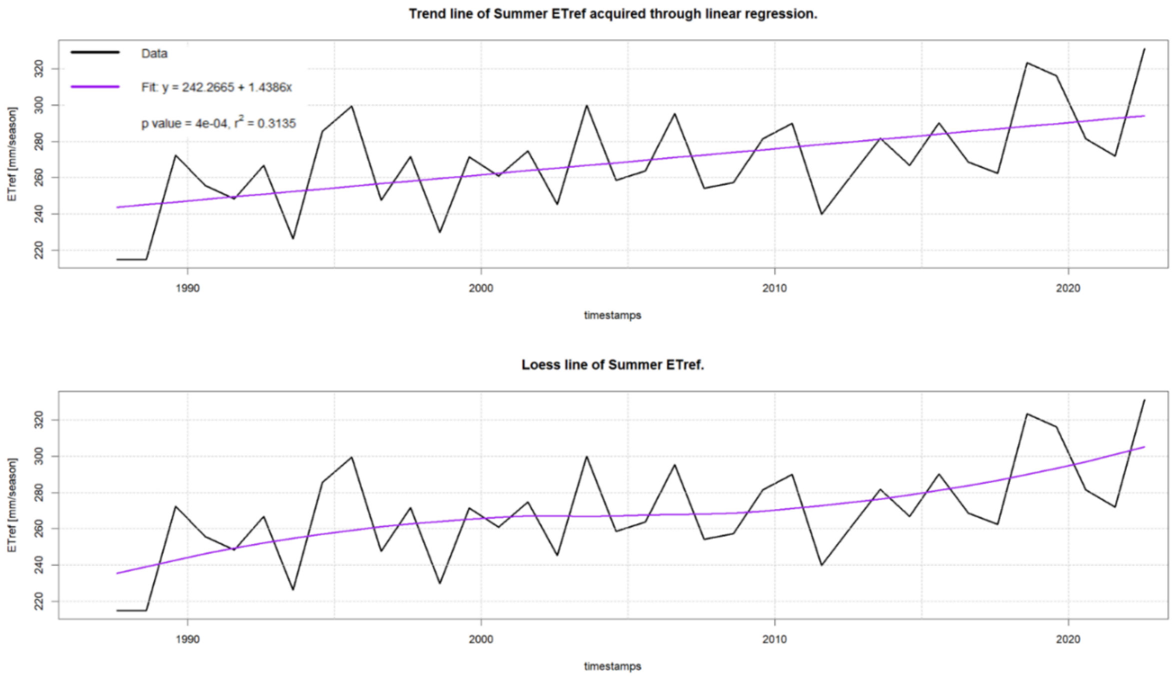

Figure 6: Trend in summer reference evaporation (ETref) based on measured precipitation and ETref at the KNMI station in Deelen over the period 1987 - 2022.

Furthermore, none of the other analyzed variables (P, GW, PED and the SPEI) showed a significant trend at any of the analysed timescales (Table A2.1 in Appendix II). Especially for the PED and SPEI this is somewhat surprising as these variables are both calculated based on the ETref (which does actually show a trend). In Figure 7 the spring SPEI (SPEI-3) is shown along with a fitted trendline, however it should be noted that also for the SPEI over the springs of the analysed data period the trend was not found to be statistically significant and therefore it is chosen to not further use this trend for conclusions.

Since the ETref showed to have a significant positive trend, it was decided to specifically take this variable into account for evaluating the proposed measured that are further discussed in this report. For the evaluated measures, it will be assessed whether they are vulnerable for evaporation. Next to this, the overall significance of certain trends can change in the future. Therefore, the general set-up of this trend analysis will be further incorporated as part of the insight measures in the final decision tree of this report.

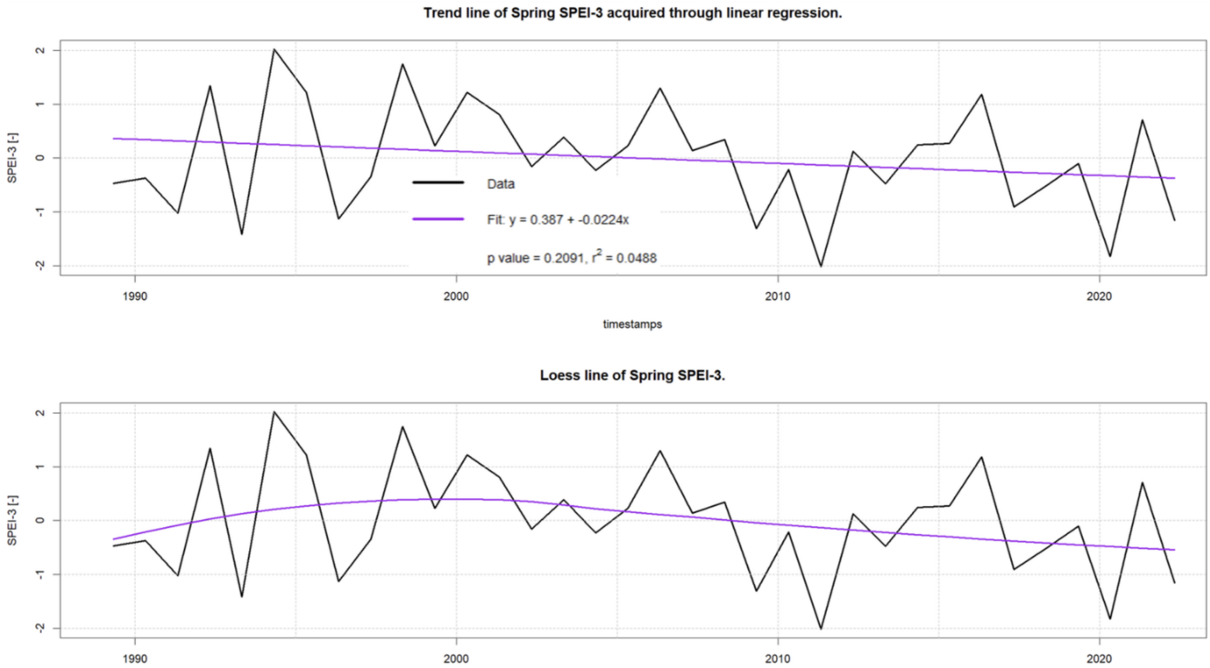

Figure 7: Trend in Spring SPEI-3 (index for drought) based on the data from the KNMI station in Deelen over the period 1988 - 2022.

5. Measures found

This chapter gives an overview of the measures for sustainable water management in the Eng. A longlist of the measures and to which category the measures were assigned is provided.

The exploration of measures was carried out based on four different sources:

- The brainstorm session with stakeholders delivered 10 measures.
- The interviews and stakeholder communications from the previous ACT project delivered 9 measures. Of these measures, 3 were also mentioned in the stakeholder brainstorm session.
- The expert meetings delivered with Jos van Dam, the academic advisor and the two representatives from the Wageningen Municipality delivered 8 measures, and helped make measures suggested by stakeholders and water users more specific.
- Explorative literature search delivered an additional 9 measures and helped making already found measures more specific.

The four exploration methods resulted in a total of 29 measures. The longlist of measures is shown in table 4, a fully worked out list of these measures with short descriptions can be found in appendix V. For each measure, the source it originated from is given in the second column. The sources were abbreviated to; SB = Stakeholder brainstorm; ACT = previous ACT report; EX = expert meeting and LS = literature search.

The last four columns relate to the categories, the division of measures into these categories was discussed in the methods. Various measures are divided over two categories, meaning they can be implemented for both purposes.

Table 4: Showing all measures, their source (SB = stakeholder brainstorm, ACT = previous ACT report, EX = expert meeting, LS = literature search) as well as the categories to which the measures were assigned to (crosses).

Measure	nr.	Source	Insight/awareness	Water use efficiency	Retaining rainwater	Groundwater replenishment
Using local ditches	1	SB			x	x
No mowing/cleaning (of existing ditches)	2	LS				x
Planting more trees / fruit trees	3	SB			x	x
precipitation storage on buildings	4	ACT			x	
Changing land use types	5	LS				x
Using local wet spots	6	SB			x	
Mulching	7	EX		x	x	
Ensuring healthy soils	8	EX		x	x	x
Deeper rooting crops	9	EX		x	x	
No till / less till management	10	SB		x	x	
Efficient use of bare land	11	SB, EX		x	x	
Increasing organic matter in soil	12	ACT		x	x	
Smart sowing by season	13	ACT		x		
Drought resistant plants	14	SB, ACT, EX		x		
Gullies or small pits next to crops	15	ACT		x		
Irrigation based on time of day	16	SB, ACT		x		
Regulations and guidelines	17	ACT	x	x		
Social cohesion	18	LS	x			
Large scale river water infiltration	19	SB				x
Wastewater infiltration	20	LS				x
App / website with insights and forecast	21	LS	x	x		
Smart water meters	22	LS	x	x		
Pasture pumps	23	LS		x		
Retention ponds	24	SB			x	x
Aboveground closed retention (rainbarrels)	25	ACT			x	
Underground retention basins	26	LS			x	
Hedgerows	27	SB, ACT			x	x
Decoupling roads	28	EX				x
Line drains	29	LS				x

6. Measures for sustainable water management in the Eng

This chapter will cover the delineation of measures from the longlist to the shortlist, and will give an explanation for all the measures on the shortlist. These explanations will consist of several examples, calculations on the amounts of water volume saved or infiltrated, a calculation of the costs in euros and/or area taken up, and the timeline and scale regarding possible implementation.

6.1 Delineation of measures into the shortlist

The measures from the longlist were delineated based on the steps explained in the methods. For each step, the concrete actions that were taken are:

1. Measure 1 and 2, related to using local ditches and the mowing and cleaning of ditches, were excluded because they didn't fit into the water system of the Eng. The ditches that are currently present within the Eng, are located mainly in the lower parts of the area, and will therefore have no significant effect on the higher and dryer parts of the Eng.
2. Measures 3, 4 and 5 were removed because they strongly clashed with the vision of the Eng. These three measures were either related to buildings, trees or forestry. The vision strongly discourages new buildings and activities surrounding them. As sightlines and the open character of the Eng are important aspects of the vision, measures regarding tree planting were excluded as well.
3. Measure 6 on small scale soil permeability variations was excluded, as this data was not available and could not be gathered within the timeframe of this project.
4. Measures 7 through 12 were all related to increasing organic matter content in the soil, ensuring healthy soil life and mulching. All of these have been combined into the overarching measure 'soil management'.
5. Measures 13 and 14 were related to crops, these measures were combined into the overarching measure 'crop management'.
6. Measures 15 and 16 were related to irrigation strategies, both have been combined into the overarching measure 'irrigation management'.
7. Measures 17 and 18 were combined into 'large scale infiltration' as both measures related to mobilizing water users and instigating discussions about water use and the regulations surrounding it.
8. Measures 19 and 20 were combined into 'community building measures' as both measures considered large scale infiltration. The only major difference between the two was the source of water used.

The final shortlist contains a total of 14 measures, which are divided over the four categories explained previously. For each measure, a general introduction and an example on how such measure could be implemented within the Eng, is provided. Where possible, the impact on the water system and accompanying costs are calculated. The timeline and scale of implementation are discussed, and interesting opportunities and practical suggestions are given. Measures belonging to the first category, are worked out in less detail, as these are not spatially adaptable and focus on providing information and/or social developments.

Next, the measures were worked out in more detail by incorporating user feedback on the measures obtained in a user feedback session

6.2 Stakeholder feedback session

Obtaining stakeholder feedback on the measure demonstrated some interesting and valuable perspectives. 7 respondents attended the meeting in addition to the project team members. Although, 7 members attended, all of the members were part of the same stakeholder/user group; allotment gardeners. The key discussion points raised after each question and the key questionnaire explanations are summarised in the following. The summarised points include points written on the questionnaire and points raised in the group discussion.

Hedges:
- Width and height of the hedges are important considerations for small parcel owners as this will lead to lacking space and lacking sunlight
- Maybe only suitable around the borders of the Eng.
- Maintenance is problematic as requires a lot of work and unsure how to dispose of cuttings, in particular cuttings with thorns.
- Hedges may contribute towards protection from predators (ex: wolves)

Retention ponds (& infiltration ponds):
- Individual or small-scale ponds are favoured
- Collective and big scale ponds remain unrealistic in terms of transporting water to different users, in terms of agreeing on how to communally manage the pond and in regards to the cost in surface area it would require.

Decoupling from sewage:
- Not a very relevant measure as not many houses on the Eng.
- Potential for decoupling urban areas around the Eng in combination with small retention ponds.
- Potential to ask the municipality to take up this measure.
- Decoupling in urban Wageningen also indirectly helps the Eng and is generally beneficial in the broader context.

Aboveground closed retention:
- plastic rain barrels not very aesthetically fitting for the Eng.
- As an individual measure, does not provide sufficient water retention.
- Lack of space for rain barrels is a limiting factor.
- Flexible measure that can be adapted to individual needs.

Underground retention:
- Underground location is beneficial for the aesthetics of the Eng.
- Very high costs for archaeological excavation would be required.

Soil management: organic matter:
- Most already practice soil enriching with organic matter
- A communal compost system would be beneficial
- Respondents were willing to learn more about this
- Removing organic top soil somewhere and putting it elsewhere as a measure was suggested

Soil management: crops & plants:
- Deep rooting crops, spot watering, agroforestry and permaculture were suggested.
- Disapproval of high-tech measures, within irrigation for example
- The allotment gardeners are hobbyists – not commercial farmers, and need solutions that fit their goals.

General remarks:
- The respondents indicated that they would like to understand how they could best implement the different measures, requiring as much detail on this as possible.
- Emphasis on categorizing the measures by different scales of impact: short term/long term, individual/communal.

- A re-assessment of the general purpose or vision of the area may be needed to find long term solutions.

6.3 Measures on awareness and insight

Measures in this category aim to supply information about the water system of the Wageningse Eng, increase insights of the problems regarding sustainable water management and give more insight in the amounts of water used in the Eng.

Links to information

First of all, two links are provided below which can be used to a get a more general understanding on the groundwater system- and the underlying geology of the Wageningse Eng.

- "Grondwatertools – Thema grondwater": https://www.grondwatertools.nl/thema-grondwater

This website provides an interactive environment for accessing information on groundwater quantity and quality aspects over the Netherlands. Via the dashboard "Grondwaterstanden in Beeld", information can be found on the groundwater levels of several piezometers in the Wageningse Eng. On this dashboard, the historical and current groundwater levels, dynamics of the groundwater levels and general groundwater flow patterns in different geological layers using the "isohypsen" tap can be obtained. The dashboard is user friendly, with explanations given via the icons and the help tab. This website is for example used to gather the historical groundwater level data used in this research and to make Figure A1.1 in Appendix I.

- "DINOloket – Map viewer": https://www.dinoloket.nl/ondergrondmodellen/kaart

In the online map viewer of DINOloket, geological information over the Netherlands can be found. For example, the "BRO REGIS II v2.2" tab can be used to evaluate drilling profiles and self-defined geological cross-sections within the Netherlands. The transect through the Wageningse Eng as displayed in Figure A1.2 in Appendix I was made using DINOloket. Information on the underlying geology is important to understand the larger water system and also put into context how volumes of water abstracted from groundwater compare with the actual available water in aquifers.

Water meters and keeping track of water use

As a starting point water meters can be installed, as it is hard to manage your water use if you don't have specific information on it. These water meters can be connected to groundwater pumps to monitor ground water usage. In the case of rainwater (e.g., from a storage tank or rain barrel) one could keep track of the volume of water used from this storage facility. If a pump is used to get the water from these storage basins (e.g., underground storage tank), then again a water meter can be used to keep track of the volumes used. Keeping track of water use will be an import step to become more aware of the exact quantities of water used and how this might vary over specific periods during the year. The collected information on individual water use can then be shared periodically among all water users in the Wageningse Eng to further stimulate communication between the users.

6.4 Interactive application:

An interactive and up-to-date web- and mobile application that enhances awareness for water users can be created. Within this application, several aspects can be included. This application can be used to supply available information (for example from the links indicated above) specifically for the Wageningse Eng and possibly also for the surrounding area, to make the application as specific as possible. Below, three examples of aspects that could be included as separate tabs within the application are provided.

Meteorological- and hydrological conditions:

Information on the current groundwater levels from available piezometers can be included. Precipitation accumulations, reference evaporation and precipitation deficits/excesses can be supplied using nearby meteorological stations. The available historical data on these variables can be used to further put into perspective the conditions at the moment, to give users an indication on the current conditions with respect to historical conditions. In addition, information on the current- and historical drought conditions can be implemented, to show how long a dry period is lasting and how long historical droughts have been.

An overview of historical droughts can for example be provided using Figure 8. The 1-month SPEI can indicate more shorter term droughts (e.g. meteorological droughts), while the 3, 6 and 12-month SPEI give an indication about longer lasting droughts (*KNMI - Achtergrondinformatie neerslagindexen SPI en SPEI*, n.d.). The magnitude of the specific drought in comparison to historical data will be given by this SPEI index and can be interpreted using Table 5.

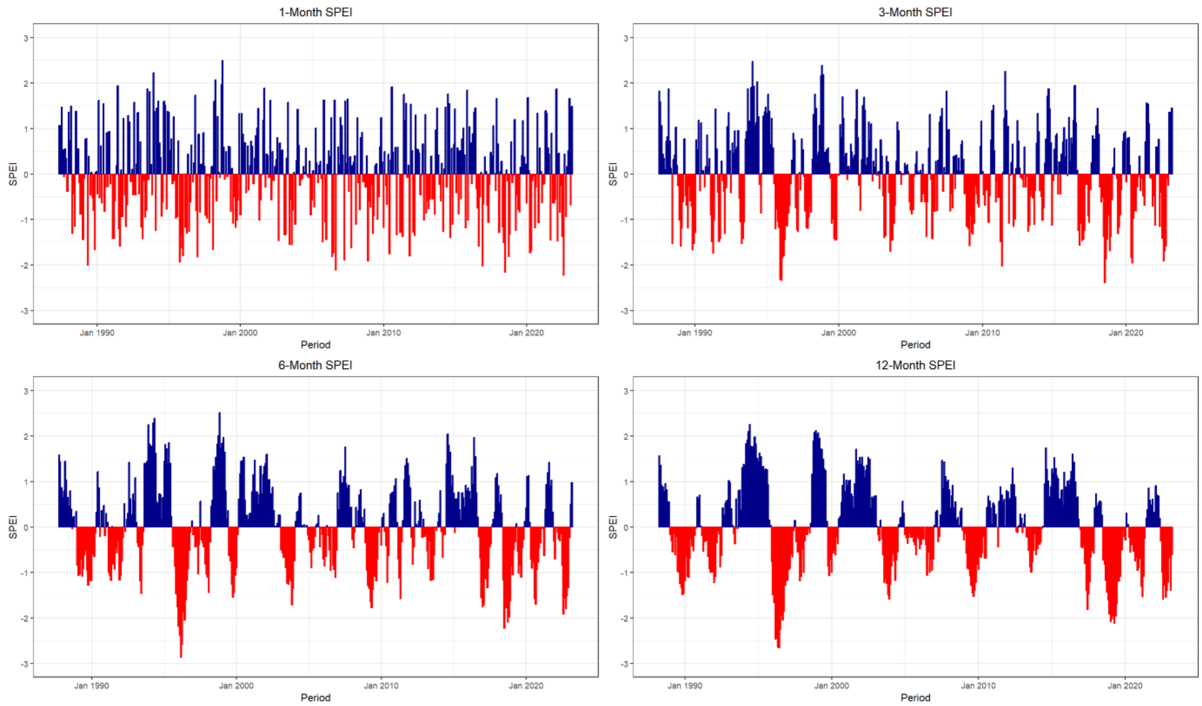

Figure 8: The SPEI over different accumulation timescales based on measured precipitation and ETref at the KNMI station in Deelen over the period 1987 – 2023 (historical droughts).

Table 5: Classification of SPEI. Adapted from (Li, B. et al., 2015).

Moisture Category	SPEI
Extremely wet (EW)	2.00 and above
Very wet (VW)	1.50 to 1.99
Moderately wet (MW)	1.00 to 1.49
Near normal (NN)	-0.99 to 0.99
Moderately dry (MD)	-1.00 to -1.49
Severely dry (SD)	-1.50 to -1.99
Extremely dry (ED)	-2.00 and less

Water use:
This tab will provide the volumes of water tracked by users in the Wageningse Eng. Water users in the Wageningse Eng will all have access to the information on the water usage over the Wageningse Eng as a whole. Combining this information with the actual meteorological- and hydrological conditions can help to stimulate further communication between the different users/user groups and might stimulates a joint approach on the water usage, specified for different periods of the year when needed.

Trends in meteorological and hydrological conditions:
The trend analysis conducted in this research only showed significant trends in reference to evaporation, both on a yearly and on a seasonal scale. Trends in the drought conditions (based on the SPEI) showed to be not significant. Still, it is important to communicate the current trends to the user groups in the Wageningse Eng and keep track of these trends over time. Therefore, a third tab could be included that provides an overview of the current trends regarding meteorological and hydrological conditions, similarly as evaluated in this research.

Examples, cost, timeline and scale:
An example on how the information can be provided in an application is the “Droogteportaal" (https://droogteportaal.nl/droogteportaal/web/), which is an open source, online dashboard. It provides information on drought conditions via different variables, focussing mainly on the higher sandy soils in the Netherlands. Another example is the climate dashboard of the KNMI (https://www.knmi.nl/klimaat), which showcases historical data, trends and forecasts of a selection of meteorological variables for the Netherlands (e.g., temperature, precipitation and SPEI). The dashboard is updated on a daily basis. The aim of the application for the Eng could be a similar dashboard as the examples above, but easier to understand for water users and applied specifically for the Wageningse Eng. If the application is set up than the measure has long-lasting benefits.

Individuals can keep track of their water use and share the used volumes of water via the application. Tracking the water use is predominantly a measure applicable at an individual scale. Nonetheless, if several water users decide to collectively construct a measure (e.g. a shared rainwater collection tank), than they can also collectively keep track of their water use. The application itself is a measure which focuses more on a collective scale to provide all users of the Wageningse Eng with the same information. This measure can be realized relatively quick within a few months but probably an external party with IT experience should be contacted to construct such a dashboard. Another option would be to explore the possibilities of using the HydroNET application (https://www.hydronet.nl/), which is widely used by waterboards and municipalities. The application provides an online and personal dashboard on tailored weather- and water information and is available for cell phones, tablets and computers.

Community building measures

As well as obtaining knowledge and awareness through tools such as weather applications and water meters, stimulating social cohesion between the users of the Eng through a process of community building can increase knowledge and awareness exchange (Kislov, 2012). In this report, social cohesion is understood as the interpersonal dynamics and/or collective efforts that create a sense of common identity and mutual support (Jennings & Bamkole, 2012; Fonseca et al. 2018). In other words, increased social cohesion is considered to increase the positive interactions between the users of the Eng, incorporating increased trust, connectedness, understanding, acceptance and belonging (Jennings & Bamkole, 2012). This can help foster knowledge exchange but also generate a better collective understanding of the Eng and its users. In addition, increased social cohesion can increase the social resilience of the Eng's inhabitants when facing crises, particularly relevant to water crises (Ng et al., 2015). Thus, in general, social mobilisation can be an effective means of tackling the issue of water shortage.

Below are some practical suggestions for stimulating knowledge and awareness exchange through social mobilisation.

- Creating more opportunities for interactions between different members, users and stakeholders of the Eng. This could take the form of a more proactive Eng foundation which could facilitate more activities to unite the different users in the Eng, taking into account inclusivity for all stakeholders and users. This could also occur outside of the Eng foundation through individuals' initiatives.

- Creating a sub-group within the Eng foundation that focuses specifically on the issue of water management. The groups' role would be to evaluate the water situation, communicate the water situation to the members of the Eng and help facilitate communal projects with the objective of retaining the water source. For example, the group could coordinate a project establishing pilot plots with improved agricultural measures on them or organising the communal construction of retention/infiltration ponds. Another example could be to lobby for a municipality financed decoupling initiative in the Wageningse Eng and Wageningen Hoog.

- Creating a platform that helps facilitate the sharing of resources, workforce and partnerships, advice and amongst others. This could occur through the creation of a general exchange platform/website/group chat/noticeboard. For example, horse manure can be transferred directly from horse owners to the allotment farmers or via a communal manure location. Another example is a communally organised organic waste/compost.

- Creating a new project within the Eng foundation that seeks to re-evaluate of the current vision and surrounding regulations of the Eng, including a plan for water management for instance. Similarly, creating a separate vision outside of the one from the municipality could provide a different perspective. In general, the idea is to create a more up-to-date and inclusive understanding of what practices are best fitting for the Eng.

6.5 Measures on efficient water use

When water users are aware of the problems relating to water use on the Wageningse Eng, the next step in the decision tree is to check whether water can be used more efficiently. These measures enable users to use less water to fulfil their (unchanged) needs. Looking at our definition of sustainability, the measures in this category aim to prevent negative effects of water use on the system. Making the water use more efficient reduces the amount of water that has to be retained / infiltrated further down within the decision tree and thus these measures are put here in the decision tree.
The measures in this category are divided into 3 subcategories: measures related to soil management, measures related to crop management and measures related to irrigation management.

Measures in this category aim to promote more efficient water use in the Eng. They focus on giving suggestions and showcasing technologies that can be used by water users to more efficiently use their water. The end-goal of these measures is to decrease the water needs in the Eng.

Crop management

Here measures that are about crop selection are discussed.
Matching the crops growing on the Eng to the soils and weather system on the Eng is a straightforward way to save water.

Costs, timeline and scale

For crops the costs are low; if crops using less water are selected, obviously the water cost drops as well. Timeline wise, it should be possible to swap to a different crop next growing season.

Benefits

- Opportunity to test the measures on small plots
- Relative cheap measure to implement

Limitations

- Not relevant for all water users
- Communicate these measures to all relevant water users.
- Optimal crop(s) might be undesirable

Practical suggestions for crop management

Some water users already grow crops adapted to the Wageningse Eng. The Wageninge Korenschoof cultivates historically cultivated crops like barley and rye. These crops are sown in early Spring and harvested before the end of Summer. Under normal circumstances there is no need for irrigation to grow them (Stakeholder Brainstorm, 2023). This case would save all the water normally used for irrigation.
The cultivation of drought resistant plants is another option. This drought resistance generally translates into a deeper rooting depth. A 10cm increase in rooting depth can deliver up to 50% more water storage in the soil (Wösten & Groenendijk, 2021).
Crops that require less water or are of course also an option. Allotment gardeners could check this (and the drought resistance) for the crops they plan to grow. It is possible to find (general) lists of common crops and their water use and duration of growing season, see for example the paper by (Brouwer & Heibloem, 1985).

Irrigation management

Here measures on irrigation management are discussed. An example is to use (more) targeted irrigation systems instead of sprinklers while keeping in mind the soil saturation. This can on average save 28% water (Snellen & Bartholomeus, 2021). Furthermore it is possible to set up an irrigation schedule based on ET and an water balance (using meteorological data, soil parameters and crop parameters); apps have been developed to help with this, but they are spatially limited to regions surrounding the meteorological stations from which data is obtained (Migliaccio et al., 2015)

Costs, timeline and scale

For irrigation the costs (both monetary as well as amount of water) are extremely dependant on the scale and method: it depends on the size of the area that has to be irrigated and efficiency of the irrigation. Lifetime is estimated to be between 5 to 15 years (https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/improvement-of-irrigation-efficiency).

Benefits

- Opportunity to test the measures on small plots
- Irrigation is important in the region of the Wageningse Eng due to its sandy subsoil
- More efficient irrigation limits both energy costs & water costs

Limitations

- Not relevant for all water users
- Communicate these measures to all relevant water users.

Practical suggestions for irrigation

For farmers who want to improve their irrigation efficiency the following approach is suggested (UNEP-DHI Partnership, 2017):

1. Map current amount and costs of water and energy used for irrigation
2. Locate where water and energy can be saved
3. Let an agronomist calculate the minimum water requirements based on soil type, target crop types and water availability
4. Develop an irrigation efficiency plan
5. Implement the plan & changes
6. Implement monitoring & maintenance for the new irrigation system

For allotment gardeners a suggestion is to put small rain gauges (or weather stations) in their lots to keep track of the amount of precipitation the lot receives and use this to adapt (and minimize) the amount of water used for irrigation.

Pasture pumps

These pumps supply individual animals with drinking water on demand. Water is available for the period that an animals is actively operating the pump (SRUC, 2023). These pumps can be connected to water storage basins or groundwater wells directly. These pumps can only be used by larger animals, such as cows and horses, and are not usable for smaller animals like sheep or goats. They can supply water to about 15 animals per pump, so the amount of pumps needed depends on scale. An example of a pasture pump can be seen in Figure 9.

Figure 9: Example of a pasture pump (SRUC, 2023) .

These pumps prevent the need for open water drinking basins for animals, and thus mitigate the effects of evaporation on animal drinking water sources. Actual calculations for volumes of water saved by this measure are dependent on the amount of animal users, the type and number of animals they keep, and the drinking water supply system they currently use. This information is not available, and out of the scope of this project.

Cost, timeline and scale

Individual pumps with the associated pipeline cost around €280 and can supply around 15 animals (SRUC, 2023). This measure can be implemented in a very short timescale and will continue to save water and mitigate the effects of evaporation on animal drinking water into the future. This measure is relevant for animal keepers of all scales.

Benefits

- Easy and cheap to install.
- Mobility, can be easily moved to other locations
- Little maintenance
- Mitigates water loss to evaporation

Limitations

- Not suitable for sheep and goats
- Needs a steady source of water
- Needs a certain water pressure
- Energy requirement due to pumps

6.6 Measures on retaining rainwater

Measures in this category aim to collect rainwater and retain it for use in the dryer spring and summer periods. These measures are focused on keeping water directly available for water users instead of letting it infiltrate into the groundwater system.

Soil management

This category involves measures relating to the soil and its management. There are different actions which can be taken related to soil management. They aim to increase the amount of water that the soil retains and improve the infiltration capacity of the soil. Effective actions are optimizing the crop rotation so there are no/little periods of bare soil, leaving crop residuals in the field, decreasing the intensity and frequency of soil disturbance and importing organic materials in the form of manure, compost, mulch, etc. (Wösten & Groenendijk, 2021).
An increase in organic matter percentage is directly and indirectly beneficial for the water storage in soils. Starting from bare sandy soil with an >1% organic matter, every percent (om) increase leads to 1-3% more water storage, and the effect decreases with higher organic matter percentages (Wösten & Groenendijk, 2021). An increase in organic matter will improve the soil structure, which leads to better infiltration capacity and a deeper rooting depth. 10cm more rooting depth leads to 50% more water storage (Wösten & Groenendijk, 2021). Soil life also improves infiltration, and water storage in the soil. Soil life can be stimulated by sowing grasses and grains, organic fertilizers, catch crops, and decreasing the intensity and frequency of soil disturbances (Snellen et al., 2017) .
Soil disturbances (for example tillage) can be harmful for the infiltration rates of the soil (de Almeida et al. 2018). Furthermore the longer term effects of tillage on soil quality (in their case silt loam soil) has been studied as well (Karlen et al., 1994). There it was found that no-till practices improved the biological and physical characteristics of the soils, resulting in higher water retaining capabilities of the soil.

Costs, timeline and scale

There already are many initiatives and examples of good practice on the Wageningse Eng. The scale varies per action. Mulching can be applied by allotment gardeners within the Eng (and is sometimes already done), whereas no-tillage practices can be applied by farmers on the Eng. These measures can be applied immediately. The time it takes for these measures to have an effect also differs. For no-tillage it can take 3 years (Dick et al., 1994), whereas mulching can have an immediate effect. The cost of compost is estimated at €500 per ha (De Wit, 2013). The study by Ribera et al. (2014) compared tillage and no-tillage and found that the costs for no-tillage are lower, whereas there was no statistical significant difference in yields between the 2 scenarios. This is generally the case for the comparison between scenarios without and with soil comparison. A comparison between reduced cost of no soil disturbance versus reduced yield (and lower profit) is not made here.

Benefits

- Opportunity to test the measures on small plots
- Opportunity to combine soil management and hedges by using cuttings as mulch
- No-tillage results in less labour and is cheaper compared to tillage

Limitations

- Currently there is no insight in the organic matter contents of the soils in the Eng, this means that it is unknown at what stages soil health is spatially.
- Some of the measures might take time to take effect.
- Due to no-tillage ways to mechanically control weeds is lost.

Practical suggestions

Farmers can switch from tillage to no-tillage farming, which offers a range of benefits including an improved soil quality (Derpsch et al., 2010).
For allotment farmers a lot of information on saving water is readily available online (see e.g., https://velt.nu/tip/hoeveel-water-heeft-jouw-moestuin-nodig or https://landarchconcepts.wordpress.com/water-management-and-conservation/). Experiment regarding soil management can be implemented in example plots that adopt good practices.

Training sessions involving these plots can be organized. There already are many initiatives and examples of good soil management practices on the Eng, so encouraging communication and knowledge sharing between users should be actively encouraged.

Retention ponds

Ponds can store rainwater for dryer times. This measure is aimed at creating more ponds throughout the Eng to help with saving water from surface runoff that is led to these ponds. There are already two ponds located in the Eng, called 'Drenkplaatsen' in the vision of the Eng (Gemeente Wageningen, 2020b). These ponds were historically used by farmers as drinking sites for their animals. They are located in the north-western part of the Eng, one near restaurant 't Gesprek and the other near Droevendaal. As the soils in the area are generally highly permeable, only digging holes for ponds won't be sufficient to realise actual water retention. To realise water storage and prevent infiltration, the ponds will need to be reinforced with a non- to poorly-permeable layer. This can be achieved in different ways. The proposed manner is line an impermeable structure with bentonite or clay (de Vree, 2023). The ponds should be strategically located by taking into account the location of water use and connected catchment area.

Costs, timeline and scale

The costs are estimated from (*Vijver - Klimaatadaptatie Provincie Noord-Brabant*, n.d.).

- Construction costs are €50 / m^2
- Maintenance costs are €7 / m^2

An example of the costs for small pond: a pond has a length of 15 m, width of 8 m and depth of 0.3 m. The construction costs are 6000 EUR and maintenance costs are 720-960 EUR/year to create a storage capacity of 36 m^3.
How implementation time is highly dependent on how the impermeable layer is constructed. Installing a clay/bentonite layer directly creates retention (de Vree, 2023). The measure is suitable for larger land owners, and can be especially interesting to animal keepers. It could also be installed as a collective measure as suggested in the example.

Benefits:

- Benefits local biodiversity
- Can be used as animal drinking spots
- Large volumes stored

Limitations:

- Large surface area
- Vulnerable to evaporation
- Possible archaeological disturbance due to digging (Gemeente Wageningen, 2020a).

Aboveground closed retention

This measures entails artificial rainwater retention basins. They are always closed off from the environment, meaning there is no infiltration into the soils and minimal evaporation. These basins can have different forms, e.g. basic rain barrel and fences (https://www.rainwinner.nl/) etc., and can be placed on the surface. The basin need to be connected to a collecting surface, preferably a roof or paved area. The surface a basin is connected to determines the location of the basin, and thus the location where the water is preferably used.

An average rain barrel stores a volume of 250 l. On the scale of the whole Wageningse Eng of 205 ha, 1.87% is classified as build-up area. This means a total build-up area of 3.83 ha is potentially available to capture water. It is important to take into account the found seasonality in the precipitation deficits/excess in the data analysis chapter and therefore one would preferably also capture the rainfall during the wetter period and then again use this water during the spring and summer. On average the precipitation in the winter is 237 mm (based on the P data of the KNMI station in Deelen from 1988-2023). If one would capture all this water, 9085.4 m^3 of water that can be captured over a whole year with the total build-up area in the Eng. To store all this water, 36342 rain barrels would be needed. To put this into context, this would mean approximately 1 rain barrel per 56.5 m^2 surface area in the Wageningse Eng, so not per m^2 build-up area. Still, it should be noted for this calculation that it is hypothetical example calculation and might change when evaluating this measure individually or cooperatively and therefore this amount of rain barrels can be considered as very large as it focuses on the Wageningse Eng as a whole.

Costs, timeline and scale

For individual scale, a rain barrel is estimated to cost €87 to store 250 liters (*Nature - Regenton*, z.d.). This measure can be implemented on an individual scale as well as a collective scale. When water users collaborate, and connect various roofs and paved surfaces to a shared water storage basin via pipelines. The water can then be used and accessed communally. The implementation of the closed retentions basins can be done rather quick, both for individual and communal used the implementation consists of placing barrels and connecting them to relevant collection surfaces.

Benefits

- Simple installation
- Easy access to stored water
- No evaporation loss
- No infiltration loss

Limitations

- Natural materials are preferred, and storage tanks or barrels are often made of plastic. Options made from natural materials do exist, but are often more expensive to buy and maintain, and have a shorter lifespan.
- Limited roof area
- Size of basin is limited to the runoff area it is connected to.
- Covers surface area

Underground closed retention

This measures entails artificial rainwater retention basins. They are always closed off from the environment, meaning there is no infiltration into the soils and minimal evaporation. These basins can take the form of tanks, cisterns, etc. and are dug into the ground. The tanks need to be connected to a collecting surface, which is most often a roof or paved area, although constructions for catching surface runoff can also be made.

A large underground flat storage tank can for example stores a volume of 20000 l (*Ondergrondse Platte Tanks - Budgettank.nl*, n.d.). Still, it should be noted that this storage tank is quite large and smaller underground tanks are also available, for example on (*Ondergrondse Platte Tanks - Budgettank.nl*, n.d.). On the scale of the whole Wageningse Eng of 205 ha, 1.87% is classified as roofs. Using the same set-up as discussed for the rain barrels and using these large flat underground storage tanks of 20000 l, would result in the placement of 455 of these tanks. To further put this into context this would mean 1 large tank per 0.45 ha surface area of the Wageningse Eng. Still, also for these tanks it should be noted that this is a hypothetical calculation, smaller tanks are also available for more individual use and in this calculation only water captured from build-up area is considered and the area of roads is not considered but could also be considered when considering a measure.

Costs, timeline and scale

Installation of underground basins requires significant amounts of soil disturbance, which makes the costs significantly higher than aboveground closed retention. Storing 20.000 l in a single underground tank will cost approximately €8295 (*Ondergrondse Platte Tanks - Budgettank.nl*, n.d.), but other types of tanks in shape and size are also available. After installation, the maintenance needed is minimal and the tanks will store water indefinitely.
This measure can be implemented on an individual scale as well as a collective scale. When water users collaborate, and connect various roofs and paved surfaces to a shared water storage basin via pipelines. The water can then be used and accessed communally.

Benefits:

- No evaporation loss
- No infiltration loss
- No use of surface area
- Measure is not visible

Limitations:

- Natural materials are preferred, and storage tanks or barrels are often made of plastic. Options made from natural materials do exist, but are often more expensive to buy and maintain, and have a shorter lifespan.
- There is a limited amount of buildings and paved area for collecting water.
- Size of basin is limited to the runoff area it is connected to.
- Possible archaeological disturbance due to digging (Gemeente Wageningen, 2020a).
- Energy requirement due to pumps

6.7 Measures on groundwater recharge

Measures in this category aims at replenishing groundwater levels in the Wageningse Eng water system. These measures are focused on creating new infiltration pathways from paved surfaces and buildings, as well as increasing the amount of water that can infiltrate to the groundwater in agricultural areas.

Hedgerows

Hedgerows are historically used land boundaries, separating different patches of lands and keeping animals in defined areas. They have also been historically used on the Eng, and are still present here, especially in the northern portion. Hedges have many benefits. They break the wind (*decreasing evaporation*), offer shelter to livestock, *improve infiltration rates,* capture carbon, *store rainwater runoff*, provide habitat for pollinators and many other wild animals, increase biodiversity and improve connectivity between habitats (Stiles, 2023; Dover, 2019).

This measure suggests combining new Hedgerows with cultural history in the Eng. Elements like old 'Wildwallen' and 'Houtwallen' and old 'Veedriften' can be used. These cultural elements were mainly used by cattle farmers, who used earthen walls and hedges to keep predators out, and to lead their animals between heather fields, drinking spots and barns (Gemeente Wageningen, 2020b). These elements could be strengthened and/or brought back into the landscape in the form of hedgerows.

The 'Wagenings Milieu Overleg' is a local environmental party. They are actively promoting an ecological connection zone between the Veluwe and Utrechtse Heuvelrug, that runs through the Eng. They propose some concrete suggestions for expanding current hedgerows and planting new ones (Busman, 2015). These steps can be realised as 'quick wins', as the plans have already been made and spatially drawn out, as seen in Appendix VI.

Costs, timeline and scale

Hedges can be realized in various shapes, and the costs for this measures follow the amount of rows planted and the type of plants used. The Wagenings Milieu Overleg recommends using two plants per row per metre, and the use of indigenous plant species that are grown locally (Busman, 2015). Indigenous plants used for hedge planting generally cost €0,55 per plant, and planting cost for a single-row hedge would then come to €110 per 100 metres of hedgerow.

This is a measure that can be implemented within a year, and will have long-lasting benefits. The measure is beneficial for individuals with a significant amount of land, especially those with animals or large patches of farmland. They can also be implemented collectively by allotment complexes or residents, and can act as a nice bonding activity.

Benefits

- Improve microclimate and decrease evaporation
- Livestock shelter
- Increase infiltration rates
- Increase soil moisture
- Capture carbon
- Mitigate surface erosion through runoff
- Benefits local biodiversity
- Natural borders (against predators)
- Cultural value

Limitations

- Large surface area

- Partially clash with the Vision on the Eng
- Maintenance cost and effort

Other opportunities:
Trimmings of hedgerows can be shredded and used to improve the soil structure and increase organic matter content.

Decoupling roads

Excess water from roads is traditionally disposed into the sewer system, and this water is then sent to wastewater treatment facilities. The Wageningen Municipality is actively decoupling these sewer connections, as this leads to decreased pressure on the sewage system during rain events and saves the energy and costs of treating already clean rainwater (Post & Steuten, 2023). Decoupling these connections to the sewers can directly increase the amount of water that is being infiltrated into the soil.

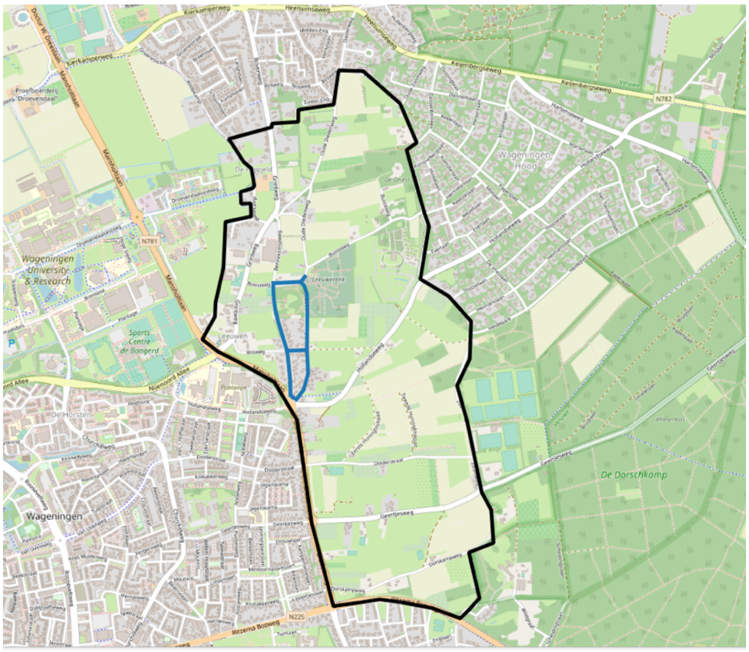

Figure 10: Map showing the outline of the Wageningse Eng and the roads that are still coupled to the sewage system (blue lines).

Most of the roads in the Wageningse Eng aren't connected to the sewer system, but there is a cluster of roads in the western part of the Eng where this is still the case. Portions of the Bennekomseweg, Bosweg, Buissteeg and Oude diedenweg are still connected to the sewer system. Together, these roads take cover 11.440 m², and transport an average of 9840 m³ of water to the sewers over a year with average precipitation. The connected parts of these roads are highlighted on the map as seen in Figure 10.

Cost, timeline and scale
The costs of decoupling paved surfaces from the sewage system is very high. With an average of €35 per m² (Esch & Leusink, 2015) and a surface area of 11.440 m, the cost for decoupling this small portion of roads will be around €400.000.
Decoupling is generally combined with necessary road or sewage renovations conducted by the Municipality, and separately taking on this task is not recommended. This makes decoupling a long-term measure that has to be implemented by the municipality. Combining it with already scheduled renovations can significantly reduce the cost.

The same is true for decoupling in other areas, but calculations regarding the infiltration benefits and costs are out of the scope of this project.

Benefits

- Alleviate rainwater pulse loads on the sewage system
- Save costs and energy in wastewater treatment

Limitations

- Large scale in both space and time
- High implementation costs
- Not directly applicable for any water users
- Possible archaeological disturbance due to digging (Gemeente Wageningen, 2020a).
- Locations in the lower part of the Eng won't have significant impact on the overall groundwater system.

Other opportunities:

- Decoupling higher up in the water system, in Wageningen Hoog or at Sportpark de Zoom, can also be counted as infiltration to the water system that the Wageningse Eng is part of.
- Decoupling on smaller scales within the Eng can also deliver benefits to the water system. Houses that are still connected to a sewage system can decide to decouple their rainwater flows and use this water or infiltrate it into the soil.

Line drains

The soils in the Eng are generally very permeable, but about 8% of the area is covered by paved and unpaved roads. Since the Eng is on a slope, water has a tendency to flow downhill along the easiest route when it cannot readily infiltrate. The roads offer easy pathways that lead significant amounts of water out of the Eng and into the sewers downhill. Water travelling along these roads can be caught with line drains or similar systems (Figure 11) that are installed perpendicular to the flow of water, and led to infiltration ponds or ditches to prevent erosion problems.

Figure 11 1: An example of a line drain (EasyMerchant , 2023).

The water loss due to overland flow is most likely constrained to the larger roads on the east-west axis, as these follow the incline of the slope. No difference between paved and unpaved roads is assumed, as unpaved roads are generally compacted to such a degree that there is no room for infiltration (Bureau Stroming, 2022). The Dorskampweg, Geertjesweg, Dolderstraat, Hollandseweg and Buissteeg fit these criteria, and together take up about 30% of the road surface (about 50.000m²). With the assumption that 70-80% of rainwater will leave the system via overland flow (stichting rioned, 2023), the amount of water that could be saved with this measure is about 42.570 m³ over a year with average rainfall.

Cost, timeline and scale

This measure entails installing line drains and accompanying infiltration solutions in the form of ponds or ditches. The costs will vary strongly based on the type of drains used, the distance between drains, the party performing the roadwork, and the type of infiltration solution used. Because of the many variables, and a lack of clear cost-based guidelines on these types of activities, an approximate cost of this measure cannot be calculated.
This measure can be combined with future road renovations, but can also be implemented on the short term. Especially for unpaved roads this measure will not be incredibly intrusive and can be implemented quickly. Implementation will have to be done by the municipality, or a collective initiative of water users in cooperation with the municipality.

Benefits

- Alleviate rainwater pulse loads on the sewage system downhill
- Save costs and energy in wastewater treatment
- Make water flows more visible
- Doesn’t involve deep digging (no clash with the archaeological limitations)

Limitations

- Large scale in both space and time
- High implementation costs
- Not directly applicable for any water users
- Locations in the lower part of the Eng won’t have significant impact on the overall groundwater system.

Large scale infiltration

The infiltration of river water or wastewater into the water system could act as a form of compensation for the water that is extracted locally and enable more groundwater extraction in the area. This would entail a large pipeline going up the Wageningse berg, and large infiltration basins on top. As well as the need for pre-treatment of the infiltrated water that is of different chemical quality than the groundwater (de Louw et al., 2022; van Dooren et al., 2022).

Two large water extractors, drinking water company Vitens and paper production company Parenco might also benefit from this measure. This can be an opportunity to get funding and benefit many stakeholders and water users surrounding the Wageningse Berg water system(s). Parenco also produces a significant amount of wastewater, which could be recycled and brought back into the water system.

Water quality differences between infiltrated water and groundwater can significantly endanger ecosystems that depend on groundwater like the Binnenveld and Renkums Beekdal. To ensure a matching quality, infiltration water will have to be treated extensively, raising the costs of this measure significantly. On areas similar to the Eng, this problem is mainly with Nitrate washing and resulting acidification of the groundwater. There also are strong guidelines from the European Water Framework Directive, and an extensive study to the risks of this measures on vulnerable groundwater dependent ecosystems needs to be done.

Cost, timeline and scale

This measure entails large scale infrastructural construction costing millions of Euros. A similar project aimed at compensating water lost due to drinking water production near the city of Epe cost around 5.5 million euros and for the yearly infiltration of about 4 million m³ of surface water (Waterforum, 2015). This measure would need to be carried out by the large water companies mentioned before, as well as the Wageningen Municipality, Province of Gelderland, Rijkswaterstaat, and relevant nature organisations like Natuurmonumenten and Staatsbosbeheer. The water users on the Wageningse Eng can play a part in lobbying for this measure and communicating their concerns with these parties.

Benefits

- Raise groundwater levels
- Ensure groundwater availability for various uses
- Ensure drinking water production in the Wageningen area
- Options for significant nature development
- Recycling wastewater streams from Parenco

Limitations

- Large scale in both space and time
- High implementation costs
- Not directly applicable for any water users
- Involvement of large organisations
- Water quality differences between surface and groundwater
- Possible archaeological disturbance due to digging (Gemeente Wageningen, 2020a).

6.8 Decision tree

The measures from the shortlist have been worked out in a decision tree (see Figure 12). The decision tree shows what measures one can take to improve sustainable water management in the Wageningse Eng. All measures contain a score on impact, cost, time and scale. Impact concerns the effect of a measure on water usage, cost is about the construction cost of a measure, time concerns the time it takes for the measure to take effect and scale shows whether a measure can be carried out by individuals or by multiple stakeholders. How measures are scored is shown in Appendix VII.

To move from this decision tree towards the actual implementation of measures there are two recommendations. Once a specific measure is chosen to be implemented, further research (and if applicable a case study) can be conducted to study its effects. The other recommendation is to test measures at a small scale first, to ensure their effectiveness and study them in practice. The final recommendation is to study a (spatially) broader water system than one that is limited to specifically the Wageningse Eng. Take for example a look at the effect of nearby industrial extractions on the (deeper) groundwater levels within the Wageningse Eng.

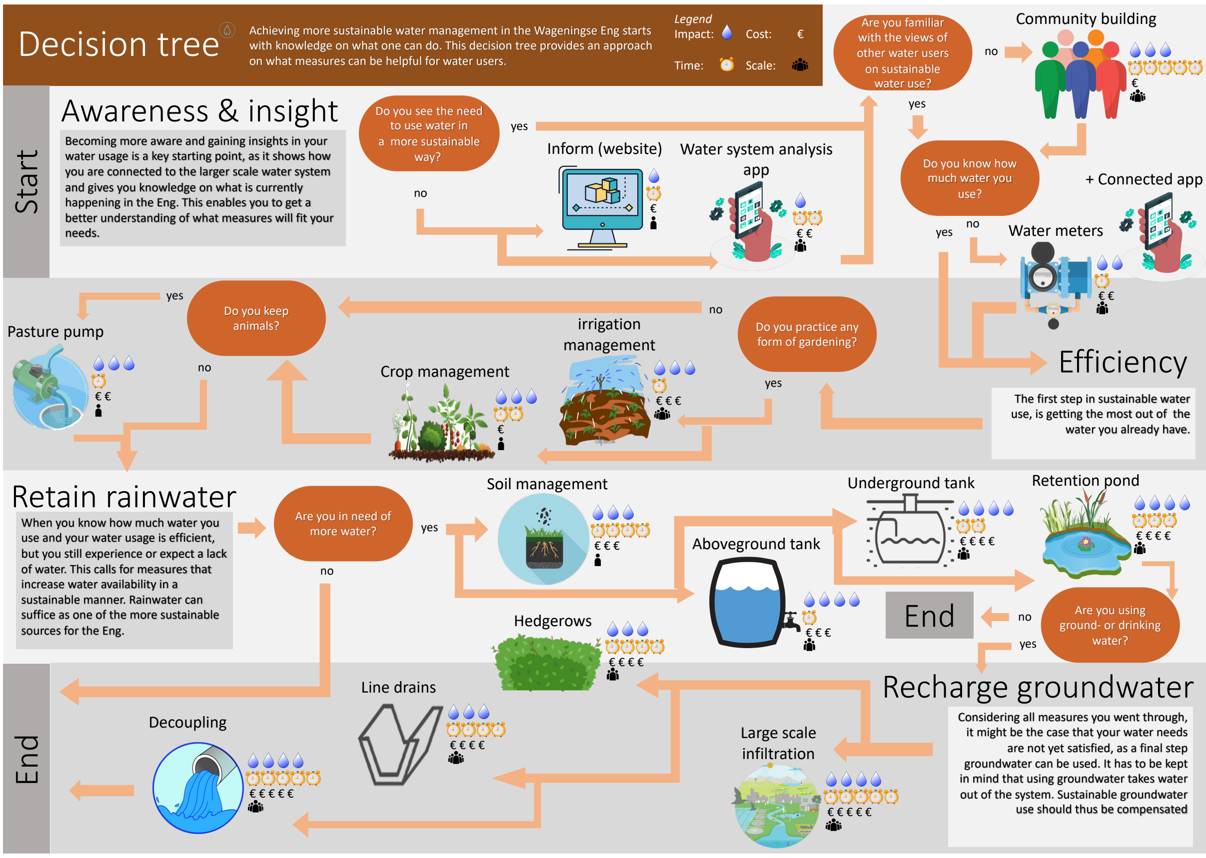

Figure 12: The decision tree for measures that can be implemented in the Wageningse Eng.

7. Discussion

Here the limitations of the research will be addressed. This section is split up in the following sections and will generally follow the order of the sub-research questions. We will cover limitations concerning the water system delineation, future uncertainties and the methods behind our final output.

Delineation of water system

The choice of limiting the water system to the Wageningse Eng in order to provide a realistic time frame for the project, demonstrates some limitations. The water system found in the Eng is both part of and dependent upon the larger water system around the Wageningse Eng. It is to be noted that if fluctuations arise in the wider water system, water in the Eng will also be impacted. Larger influences on the water system such as large-scale agricultural water use or industrial water extraction were beyond the scope of this project due to time constraints. Such considerations were only indirectly incorporated through the use of local trends. A future project may incorporate the larger water systems around the Wageningse Eng and the larger water uses and extractions, for example the water extraction from deeper geological layers by Parenco and Vitens.

Climatic uncertainty

In this research, it was evaluated for the measures whether they would be vulnerable to evaporation, as this was the only variable that showed a significant trend. Still, the current trends might change in the future and harsher droughts, even beyond the expected trends, are still possible. Therefore, the current trends do not directly portray what will happen in the future. For this reason it is also important to keep track of these trends in the future, for example through the proposed application in the measures on awareness and insights. Mainly due to time constraints, climate scenarios, such as the KNMI'14-klimaatscenario's, were not considered and it should be noted that these scenarios also contain uncertainties. Further research could also focus on how the water balance terms such as precipitation and evaporation and possibly trends might change, by actually taken into account the new climate scenarios for the Netherlands (the KNMI’ 23-klimaatscenario’s, which will be published around October 2023 (*KNMI - Op weg naar nieuwe KNMI-klimaatscenario’s*, n.d.)). In addition, from a pragmatic standpoint, the Eng is an inherently dry area due to permeable sandy soil and the elevated location on a geographical slope. Consequently, careful reflection upon which current activities are suited for the Eng is important to be considered amongst the members of the Eng. Although the recommended water measures may facilitate crop growth on dry land types, and general water use efficiency and retention, the present-day Eng may simply not be suitable for certain water intensive practices.

Socio-political uncertainty

Closely related to climatic uncertainty are the future socio-political dynamics that remain very unpredictable. Considering that the Eng remains a primarily recreational space it must be pointed out that in cases of extreme drought, such an area may not be prioritised compared to water use in residential homes and/or other essential water facilities. Local municipalities and water authorities have the obligation to supply residential houses with water but have no obligation to provide recreational areas with desired water supplies (Post & Steuten, 2023). It can be questioned how ethical water use for the sake of recreational activities such as those found within the Eng would be when faced with the issue of large-scale water scarcity. What we can grasp from this concern is that the proposed measures may not ensure water sustainability in the face of droughts due to the socio-political power dynamics. Unfortunately, due to the lacking time and scope of the project, incorporating equitable and non-discriminatory distribution of water into the advice was not possible.

Multi-criteria analysis and Decision tree

The original plan was to use a multi-criteria analysis (MCA) to rank the measures on the shortlist and pick the top 2-3 measures as advice for the water users. See appendix VIII for elaboration on the methods used for the MCA. The MCA was not used because of the following reasons.

First, the estimates used for scoring the measures for the selected criteria was considered to be too vague in comparison to the reality of the Eng. Even though a case study was created in order to provide the detail needed, lacking and under-representative data was too common in the analysis to be performed in an accurate manner. Increased amounts of time would have been necessary to obtain more accurate and stakeholder inclusive data.

Second, we determined that the previous goal of presenting the 2 or 3 measures that scored the best in the MCA was not an effective strategy for reaching our objective (water sustainability in the Eng). The main reason for this was that the Eng represents a complex landscape with many user and stakeholder groups and associated water requirements and uses. Proposing 2 or 3 measures would simply not be able to accommodate the variety of water requirements and uses. Furthermore, the respondents confirmed this consideration in the feedback session, arguing that they wanted a set of concrete measures that they could apply where they see fit rather than an imposed vision of what is best.

Third, the stakeholder feedback session did not yield the results, nor the accuracy of results that was sought after to complete the MCA. The objective of obtaining feedback from different stakeholder groups was not obtained as only one user group was present. Additionally, the respondents did not always fill in the questions on the questionnaire, further reducing the usability of the responses. As a result, the likelihood of implementation and aesthetic value MCA criteria were deemed unusable within the MCA.

Elaborating a more detailed explanation of the measures in combination with a decision tree, provided a more inclusive and applicable research outcome than by using the MCA outputs. The decision tree was also favourable in order to reduce researcher bias. This is the case since with a decision tree no one measure is recommended over another, rather, different measures are suggested for different contexts and/or users based upon the opportunities and limitations of each measure for each user and their water requirements. In this manner, the water users can choose for themselves which context and measures are relevant for themselves. Bias reducing mechanisms were particularly necessary since there was a lack of diversity of user input in the process of obtaining suggested measures in the initial research phase and in obtaining feedback on selected measures in the later phase.

8. Conclusion

Based on the conducted research it can be concluded that the water system at the Wageningse Eng is changing. The current trends show a significant trend in evaporation that is largest during Summer and spring, which is already an intensive period when it comes to water use (e.g. irrigation) on the Wageningse Eng due to the growing season. With an eye on the future and the assumption that this trend in evaporation will continue, it will thus only become a bigger challenge to find ways in which the water management on the Wageningse Eng can become sustainable.

Nonetheless, there is a wide array of measures available to work on sustainable water management proposed in this study. A shortlist of these measures was used to create a decision tree to make the measures as tangible and clear as possible for the user groups within the Wageningse Eng. The advice to the commissioner is to provide this decision tree to the water users within the Wageningse Eng. The decision tree is considered a pathway to sustainable water management on the Wageningse Eng. The tree first checks if measures relating to insight to the water system are required (and provides possible measures). Then the category related to water efficiency is checked, followed by a category on retaining precipitation. The last category is recharging groundwater. If a measure is chosen as output of this decision tree, follow-up research is needed to move from this choice to actual implementation. If none of the measures is chosen, groundwater extraction is the suggested alternative.

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Appendix I - Project delineation

This appendix contains additional materials for the project delineation chapter.

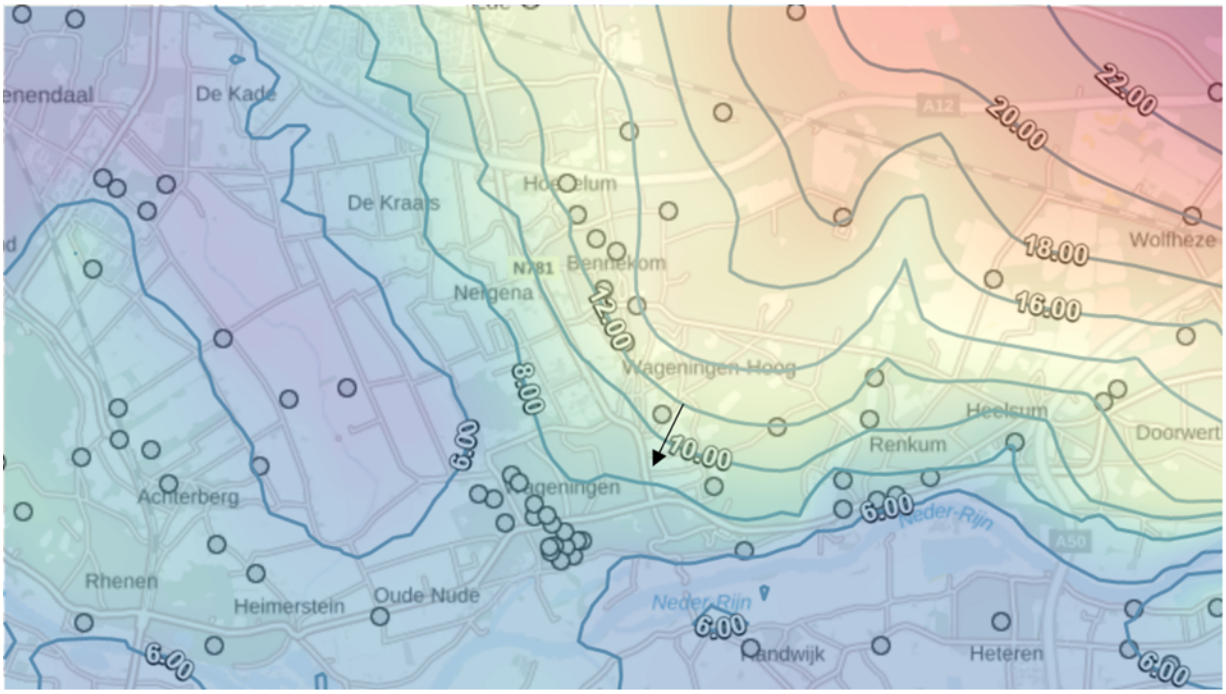

Figure A1.1: Calculated isotypes based on 149 piezometers in the soil layers of the Boxtel Formation (BX) or the ice-pushed ridge deposits (DT) based on data of 2017. This gives an indication of the groundwater flow in the phreatic aquifer in the Wageningse Eng and the larger surrounding area (obtained from (Grondwaterstanden in Beeld, n.d.)). The arrow indicates the general direction of the groundwater flow in the Wageningse Eng area in the first two soil layers.

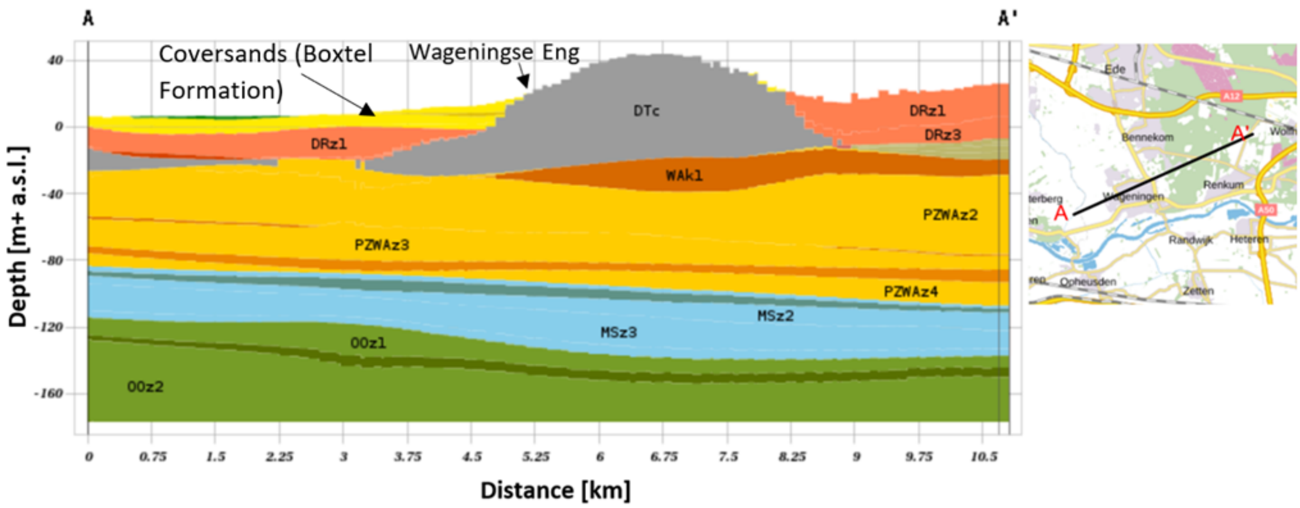

Figure A1.2:: Figure 5: Cross-section of the underlying geology in the surrounding area of the Wageningse Eng. Obtained using BRO REGIS II v2.2 on (DINOloket, n.d.).

Appendix II - Additional figures and tables - trend and data analysis

In this Appendix some additional figures and tables are given based on the data- and trend analysis conducted in this research. The first table gives all important information for the trends that are evaluated in this research. The two figures give a visual comparison between the data from the KNMI station in Deelen and the same data as measured at the Veenkampen meteorological station.

Table A2.14: The fitted trendlines for all the evaluated variables in this research. The distribution column indicated whether the data is normally or non-normally distributed. Furthermore, the slope indicates the magnitude of the trend per time unit, which can be on a monthly basis, a yearly basis or on a seasonal basis.

Category	Time	Distribution	Slope [Category / Time]	Offset	P-value	R squared
P [mm]	Monthly	non-normal	0.0025	67.8197	0.5653	-0.0111
	Yearly	normal	0.4081	855.7086	0.8548	0.001
	Spring	normal	-0.6398	178.1731	0.4692	0.016
	Summer	normal	0.4763	231.6184	0.7079	0.0042
	Autumn	normal	-0.6745	234.7422	0.5511	0.0106
	Winter	normal	0.9323	220.0644	0.3976	0.0211
Etref [mm]	Monthly	non-normal	0.0087	39.9256	0.2711	-0.0248
	Yearly	non-normal	2.3556	522.7667	3.00E-04	0.3754
	Spring	normal	0.7085	168.8044	0.0179	0.1584
	Summer	normal	1.4386	242.2665	4.00E-04	0.3135
	Autumn	normal	0.4965	80.9532	0.001	0.02754
	Winter	normal	0.1409	26.8741	0.0063	0.1993
PED [mm]	Monthly	normal	-0.014	27.9161	0.5105	0.001
	Yearly	normal	-2.2554	331.9802	0.3789	0.0235
	Spring	normal	-1.3483	9.3687	0.1862	0.0523
	Summer	normal	-0.9623	-10.6481	0.5284	0.0118
	Autumn	non-normal	-0.8356	148.1067	0.4456	0.0243
	Winter	normal	0.7914	193.1903	0.4703	0.0154
SPEI [-]	Yearly	normal	-0.0142	0.2548	0.4006	0.0215
	Spring	normal	-0.0224	0.387	0.2091	0.0488
	Summer	normal	-0.0034	0.0143	0.8394	0.0013
	Autumn	normal	-0.0137	0.2416	0.4238	0.0195
	Winter	normal	0.0169	-0.331	0.3201	0.03
GW [m+NAP]	Monthly	non-normal	0.0341	1225.801	0.3305	0.0029
	Yearly	normal	0.5617	1225.8709	0.6321	0.0168
	Spring	normal	0.6501	1239.2255	0.6331	0.0167
	Summer	normal	0.1743	1231.647	0.8925	0.0024
	Autumn	normal	0.3969	1214.7453	0.7345	0.0085
	Winter	normal	0.7386	1219.27	0.4578	0.0373

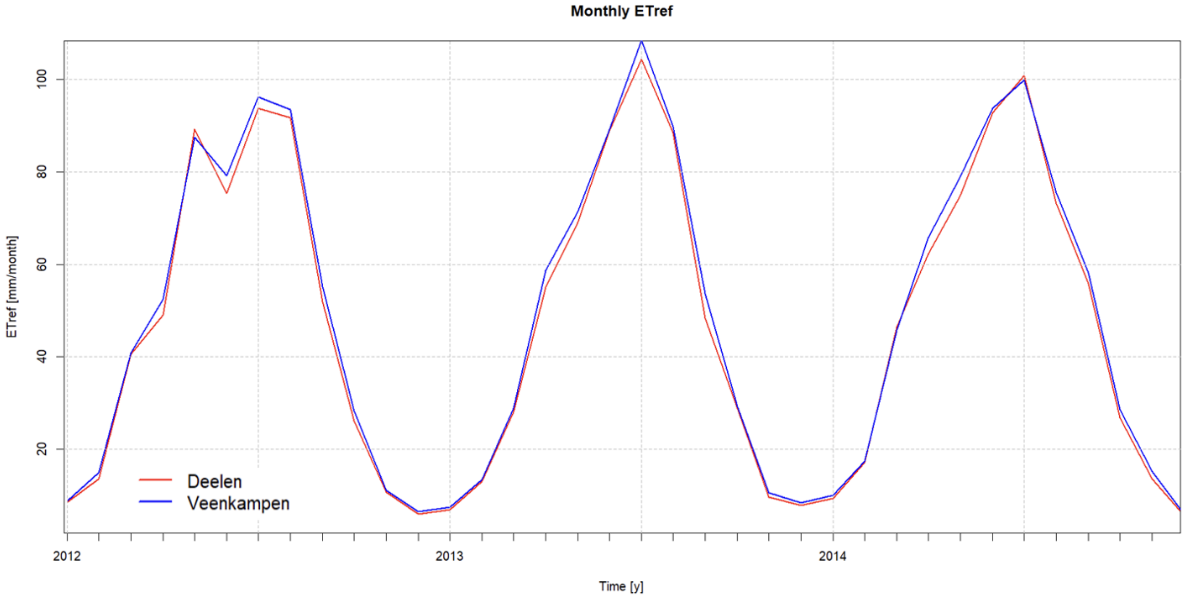

Figure A2.1: Comparison of monthly precipitation data between the Veenkampen- and Deelen weather stations over the years 2012-2014.

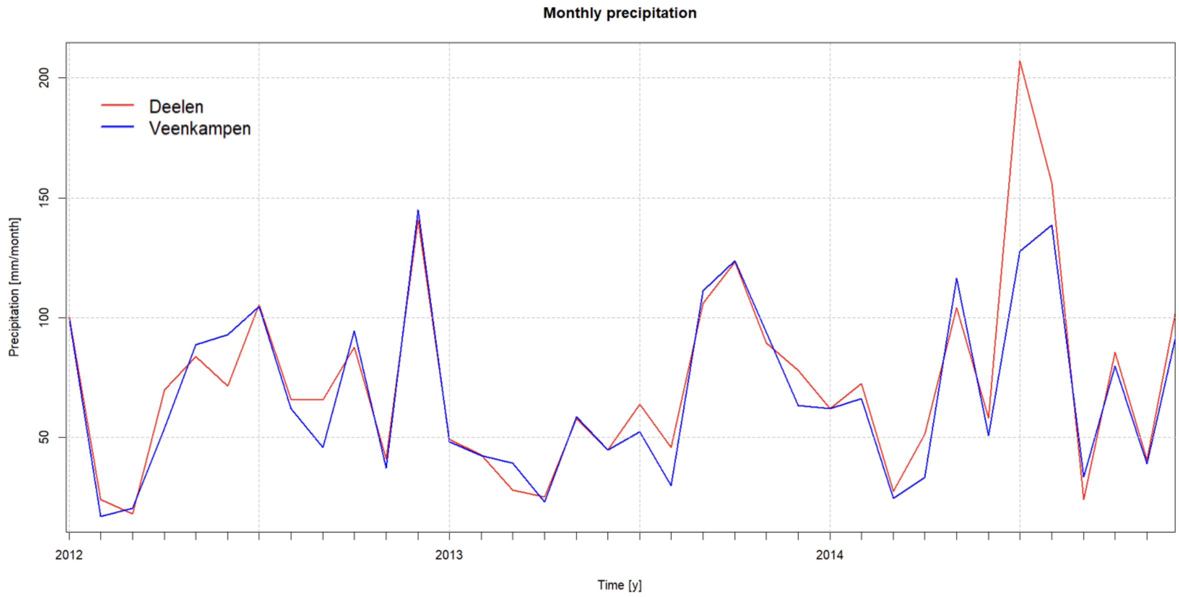

Figure A2.2: Comparison of monthly ETref data between the Veenkampen- and Deelen weather stations over the years 2012-2014.

Appendix III - Stakeholder feedback session documents

1. Hedgerows

Extra information:
Hedgerows are historically used land boundaries, separating different patches of lands and keeping animals in defined areas. They have been historically used on the Eng in the shape of i.e., 'wildwallen', 'houtwallen' and 'Veedriften', and are still present, especially in the northern area.

Hedgerows have many water related benefits, such as decreasing evaporation by breaking the wind, improving infiltration rates and storing rainwater runoff. Aside from these benefits, strengthening and expanding hedgerows would also provide opportunities to create stronger connections with the cultural history of the Eng, increase biodiversity, provide habitats and shelter areas for animals and increase the connectivity between habitats. There are already some concrete suggestions for expanding current hedgerows and planting new ones.

For the Eng, two different types of hedgerows are present and possible; 1) natural shrub hedgerows (width: 3-5m, height: 2.5-3m) and 2) cultural hedgerows (width: 2m, height: 1.5m). The benefits of hedgerows are stronger for natural shrub hedgerows, and weaker but still significant for cultural hedgerows.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Retention ponds

Extra information:
Natural ponds can store rainwater for drier times. There are two natural ponds in the Eng, so-called 'drenkplaatsen' in the Eng vision which historically functioned as drinking places for animals. Even though these two ponds are out of function, they illustrate how retention ponds could look like.

Creating more loose ponds throughout the Eng can help with saving water if surface runoff from roads and pathways is led to these ponds, water can be stored there for the long term. However, due to the high permeability and thus infiltration of the soils, the ponds would need to be reinforced with non-permeable layers, such as bentonite or clay liners. Other limitations are high vulnerability to evaporation and needing to dig in archaeologically interesting areas.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Infiltration ponds

Extra information:

Natural lower or more permeable areas can be used to create (temporary) infiltration ponds. Water from roads, pathways and the surrounding area can be led here via ditches, causing localized infiltration of precipitation towards the groundwater. This will replenish the groundwater table and minimize erosion damage. However, through various soil processes, an impermeable layer can be formed, thereby clogging the bottom of the pond. Therefore, the ponds might need to be dredged occasionally. Another limitation concerns the need to dig in archaeologically interesting areas.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Decoupling from sewage

Extra information:
Roofs and other rainwater flows traditionally end up in the sewer system, especially with buildings and roads. Decoupling these connections to the sewers can increase the amount of water that is being infiltrated into the soil. The decoupled water can be stored and used for other water uses like watering plants and drinking water for animals, or it can be infiltrated into the soil. To implement this measure, an inventory must be created with all buildings that are currently coupled to the sewage system but have the potential to be decoupled.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Aboveground closed retention

Extra information:

This measure entails artificial rainwater retention basins that are closed off from the environment, therefore preventing soil infiltration and evaporation. These basins can take the form of rain-barrels or larger tanks and must be connected to a rainwater collecting surface, such as rooftops, greenhouses, sheds and shelter areas for animal. Because larger artificial water containers don't fit within the vision of the Eng, the measure will take the shape of rain-barrels that individuals can use.

A downside of this measure is that the barrels and tanks are generally made out of plastic or metal. Whilst more natural materials do exist, these are often more expensive, have a shorter lifetime, and need more maintenance.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Underground retention

Extra information:
This measure entails artificial rainwater retention basins that are closed off from the environment, meaning there is no infiltration into the soils and no evaporation. These basins can take the form of tanks, cisterns, etc. and are dug into the ground. These tanks need to be connected to a collecting surface, which in the Eng can be paved surfaces like roads and pathways as well as roofs of buildings, greenhouses, sheds and animal shelters. Water users can collaborate and connect various roofs and paved surfaces to a shared water storage basin via pipelines. The collected water can then be used and accessed communally. Compared to aboveground retention options, water stored below the surface needs to be accessed with a pump, and thus requires energy to be used. This measure also breaks the archaeological limitations on digging deeper than 30cm, as large tanks need to be buried more than 30cm below the surface.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Agricultural measure: soil management

Extra information:

These measures would concentrate on improving and increasing the soil structure and the organic matter content. Effective ways to do so are optimizing the crop rotation so there are no/little periods of bare soil, leaving crop residuals in the field, decreasing the intensity and frequency of soil disturbance and importing organic materials in the form of manure, compost, mulch, etc. An increase in organic matter percentage is directly and indirectly beneficial for the water storage in soils. Starting from bare sandy soil with an >1% organic matter, every higher percentage leads to an 1-3% increase in water storage. An increase in organic matter will improve the soil structure, which leads to better infiltration capacity and a deeper rooting depth. A 10 cm increase in rooting depth results in 50% more water storage. Soil life also improves infiltration and water storage. Soil life can be stimulated by sowing grasses and grains, organic fertilizers, catch crops, and decreasing the intensity and frequency of soil disturbances . This measure can be implemented in experimental or example plots that adopt good practices. Training sessions involving these plots can be organized. There already are many initiatives and examples of good soil management practices on the Eng, so encouraging communication and knowledge sharing between users should be actively encouraged.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Agricultural measure: crop and irrigation management

Extra information:
These agricultural measures involve the type of plants that are being used, the planting regimes of crops and the types of irrigation used. These are all explicitly aimed at saving water. A straightforward way to save water is to match the crops to the soils and weather system of the Eng. Examples of crops being grown on the Eng that do not require irrigation are barley and rye. These crops are sown in early spring and harvested before the end of summer, and have no need for irrigation under normal circumstances. Another option is to cultivate drought resistant plants. These plants have a deeper rooting depth. A 10cm increase in rooting depth can deliver up to 50% more water storage in the soil. Finally, water can be saved by using more efficient irrigation systems. An example consists of targeted irrigation systems based on measured soil saturation. Although costly, these systems are able to reduce water use by 28% on average. These measures can be implemented in experimental or example plots that show the how, and why of these practices. Training sessions on these practices can be organised through the foundation, and communication between water users and the sharing of knowledge on efficient water use should be actively encouraged.

Questions:

1 – On a scale of 0 to 10, to what extent are you able to implement this measure?

0	1	2	3	4	5	6	7	8	9	10

Please provide a short explanation of why it is possible or not possible for you to implement.

2 – On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?

0	1	2	3	4	5

Please provide a short explanation for your answer.

Importance of the criteria used

Please indicate on a scale of 0 to 10, how important each of the criteria in the list below is to you and the stakeholder group you represent.

Stored water: How much rainwater is stored with this measure?

0	1	2	3	4	5	6	7	8	9	10

Infiltrated water: How much water is being infiltrated to the groundwater?

0	1	2	3	4	5	6	7	8	9	10

Sustainability index: How sustainable is this measure based on our definition?

0	1	2	3	4	5	6	7	8	9	10

Vulnerability to evaporation: Is this measure vulnerable to ‘verdamping’?

0	1	2	3	4	5	6	7	8	9	10

Costs (€): How much will this measure cost?

0	1	2	3	4	5	6	7	8	9	10

Costs in area (m^2): How much space will this measure take up?

0	1	2	3	4	5	6	7	8	9	10

Esthetics: Based on the questions in this session

0	1	2	3	4	5	6	7	8	9	10

Ability to implement measures: Based on the questions in this session

0	1	2	3	4	5	6	7	8	9	10

Biodiversity: How does the measure impact biodiversity?

0	1	2	3	4	5	6	7	8	9	10

Impact on archaeology: Do we need to disrupt the soil for this measure?

0	1	2	3	4	5	6	7	8	9	10

Appendix IV - Extensive stakeholder descriptions

Table A4.1 Long-list stakeholders ((Diallo et al. 2022); Stichting Wageningse Eng (n.d.-a); Stichting Wageningse Eng (n.d.-b); Stichting Wageningse Eng (n.d.-c); H. Savenije, personal communication, 30 March, 2023; Stichting Mooi Binnenveld, n.d.; V. Bennink, personal communication, 5 April, 2023.)

Stakeholder	Interest	Power	User	Coalition	Short-list
Advisory Board Foundation	High	Medium/high	No	Board Foundation Wageningse Eng	Yes
Allotment garden users	High	Medium	Yes	Picking gardens, HSCF	Yes
Animal keepers	High	Low	Yes	-	Yes
Board Foundation Wageningse Eng	High	High	No	Advisory Board Foundation, WUR Science Shop	Yes
Co-op Binnenveldse Hooilanden	Low	Low	No	Foundation Mooi Binnenveld, Staatsbosbeheer	No
Farmers	High	Medium/high	Yes	-	Yes
Foundation Mooi Binnenveld	Low	Low	No	Co-op Binnenveldse Hooilanden, Staatsbosbeheer	No
Gemeente Wageningen	Medium	Medium/high	No	Provincie Gelderland	Yes
Parcel owners	Medium	High	Yes/ no	-	Yes
Picking gardens	High	Low	Yes	Vineyard, HSCF	Yes
Provincie Gelderland	Low	Medium	No	Gemeente Wageningen	No
Recreational users	Low	Low	No	-	No
Residents	Medium	Medium/high	Yes	-	Yes
Staatsbosbeheer	Low	Low	No	Co-op Binnenveldse Hooilanden, Foundation Mooi Binnenveld	No
Territoriale Adviescommissie Wageningse Eng (TAWE)	Low/medium	Low/medium	No	Gemeente Wageningen	No
Vineyard	High	Low	Yes	Picking gardens, HSCF	Yes
Vitens	Low	Low	No	Waterboard Vallei & Veluwe	No
Waterboard Vallei & Veluwe	Medium	Medium/high	No	Vitens	No
WUR Science Shop	High	Medium	No	Board Foundation Wageningse Eng	Yes

One user of importance for the larger water system is the Smurfit Kappa Parenco paper factory. However, as this research focuses on the local water system for both trends and measures, to which the factory does not belong, the factory has not been included as a stakeholder.

Stakeholder explanation

- Advisory Board Foundation Wageningse Eng (FEW):

The Advisory Board of the FWE provides advice to the Board of the FWE. In the Advisory Board, all stakeholders from the Wageningse Eng are represented. The majority of these stakeholders are also included as stakeholders in this consultancy project, such as the different user groups mentioned above. Therefore, the Advisory Board is also highly interested in increasing the sustainability of the water system. Because its advises must be taken seriously by the Board of FWE, the Advisory Board is quite powerful (https://wageningseeng.nl/wie-zijn-wij/organisatie/).

- Allotment gardeners:

Within the Wageningse Eng, around 500 allotment gardeners use water on a daily basis. They are also highly interested in sustainable water use and part of them have switched from drinking water to groundwater. Some gardeners are also involved in a pilot project on the transportation of pumped groundwater to their lots. However, the majority of allotment fields are owned by private parties, such as the church. Therefore, the gardeners depend on the approval of parcel owners if certain measures can be implemented, thus limiting their power (personal communication).

- Animal keepers:

Many animal keepers are present within the Wageningse Eng. For keeping their stock alive, water is of course essential, thus most animal keepers will be intrinsically motivated to ensure the sustainability of the water system. However, since not all animal keepers own land, they depend on the approval of land/parcel owners for any adjustments (personal communication).

- Board Foundation Wageningse Eng:

The Wageningse Eng Foundation facilitates and coordinates activities within the Wageningse Eng. The foundation strives for developing and enhancing sustainable practices. Moreover, the board reached out to the WUR Science Shop for help (https://wageningseeng.nl/wie-zijn-wij/ ; description science shop). Therefore, the foundation is highly interested in sustainable water use. Being the overarching body of the area, it enjoys a powerful position.

- Farmers:

Another user group consists of farmers. As with animal keepers, farmers rely on water for the continuation of their businesses. In periods of drought, the water board demands farmers to adjust their irrigation practices, thus impacting their harvest (waterboard source). Therefore, they are likely to be highly interested in measures that increase their water availability. Because they must comply with regulations, they are not free to do whatever they want regarding water use. However, they do enjoy more freedom than e.g., allotment gardeners that rely on the approval on parcel owners.

- Gemeente Wageningen:

The Wageningse Eng is located within the municipal boundaries of Wageningen. In the past, the municipality lead the vision creation of the case area. Representatives are also included in the Advisory Board. Moreover, it enjoys some power in the sense that it can enforce rules and regulations onto users of the water system (personal communication).

- Parcel owners:

As stated above, many allotment users and animal keepers rent land from parcel owners. As they are not directly using the land, not all owners are as interested in sustainable water usage as other stakeholders. However, they do enjoy a powerful position since they decide what can and cannot happen on their lands. They can choose to facilitate sustainable measures but also otherwise (personal communication).

- Picking gardens:

Multiple picking gardens are present within the Wageningse Eng. For the users of these gardens, biodiversity (to which sustainable water practices contribute) plays a central role. However, as is the case with other users, they do not own the land, thus limiting their power.

- Residents:

Although the Wageningse Eng mostly facilitates rural activities, it also harbors residential homes. On their land, residents can decide for themselves whether or not they want to consume water in a sustainable way.

- Vineyard:

Within the Wageningse Eng, a vineyard is present. For the survival of its ranks, the vineyard requires water. However, the vineyard is a standalone actor, which might limit the possibilities for implementing sustainable measures.

- WUR Science Shop:

Upon request by the Board of FWE, the WUR Science Shop is researching how sustainable water usage within the Wageningse Eng can take place, both now and in the future. Even though the foundation and users of the Wageningse Eng will ultimately decide for themselves what kind of measures they want to implement and how this implementation process takes shape, the WUR Science Shop does provide input for these discussions and decisions (V. Bennink, personal communication, 31 March, 2023).

Appendix V - Measure long-list

This appendix contains the long-list of measures. Measures are ordered based on the source they originated from, each measures is described shortly and divided into one or more of the four categories as seen in table A5. The measures that were discussed in the main report have not been shortly summarized in the long-list, as they have already been extensively worked out in the corresponding chapter 6.

Table A5: Overview of the categories used for delineating the measures as well as the number used to indicate these categories in the explanations below.

Category	number
Insight and awareness	1
Efficient water use	2
Rainwater retention	3
Groundwater recharge	4

Measures that were not used based on a mismatch with the environmental conditions on the Eng:

- Using local ditches (3, 4)

There are various old ditches that used to (or still do with extreme precipitation events) carry water. A suggestion to fill these old ditches again or use these systems as water storage can be a water retention measure. Ditches seem to be present primarily in the lower, western parts of the Eng. The conversion of these ditches into water storage is impractical and won't have a significant effect on groundwater replenishment in the lower areas of the Eng.

- Changing land use types (4)

This measures specifically covers large scale changes from coniferous forests to deciduous forest or heathland, which can realize 150 to 250mm of groundwater recharge per year (de Louw, et al., 2022). This measure could be interesting for the Eng, as forest cover is about 7.5% of the total area. However, these patches of forest are already primarily deciduous, and they have an important function for recreational use and biodiversity within the Eng already.

Measures that were not used based on a serious clash with the vision on the Wageningse Eng:

- Planting more trees / fruit trees (3, 4)

As part of the suggestion for planting hedges, the suggestion for planting more trees and/or fruit trees was done. This clashes with the open sightlines that are very important for the Eng.

- precipitation storage on buildings (3)

Storing water on roofs, by increasing the levels of drainage on roofs and/or incorporating plants (usually *Sedum)* into the roof tiling. Water can be stored on the roof for later use, or the roof storage can be used to infiltrate the water into the soil over time. Green roofs can be applied on slanted and flat roofs, but blue roofs are only available on flat roofs with sound constructional support beams.

- No mowing/cleaning (of existing ditches) (4)

A rougher surface decreases waterflow, resulting in water leaving the system less quickly. This could result in more infiltration during wetter periods. Due to the generally very permeable soils in the Eng, surface flows and make the effects of this measures very limited.

Measures that were not used because they required or were dependent on knowledge gaps outside of the scope of this project:

- Using local wet spots (3)

Some suggestions were aimed at using local 'wet spots' where soil permeability is lower than average. These areas can be good spots for the creation of retention basins, as water already naturally gathers there. There is no current insight in where these spots are, and the soil layers under the Eng are classified as a 'complex entity'. The collection of this data is outside of the scope of this project.

Measures on soil management

These measures were combined into a single overarching method for the shortlist, and have thus not been explained here. A full explanation can be found in chapter 6.

- Mulching
- Ensuring healthy soils
- Deeper rooting crops
- No till / less till management
- Efficient use of bare land
- Increasing organic matter in soil

Measures on crop management

These measures were combined into a single overarching method for the shortlist, and have thus not been explained here. A full explanation can be found in chapter 6.

- Smart sowing by season
- Drought resistant plants

Measures on irrigation management

These measures were combined into a single overarching method for the shortlist, and have thus not been explained here. A full explanation can be found in chapter 6.

- Irrigation based on time of day
- Gullies or small pits next to crops

Measures on the shortlist

These measures are not worked out in the long-list, and their full explanation can be found in chapter 6.

- Large scale river water infiltration + Wastewater infiltration
- Retention ponds
- Social cohesion + Regulations and guidelines
- Line drains
- Decoupling roads
- App / website with insights and forecast
- Underground retention basins
- Smart water meters
- Hedgerows
- Aboveground closed retention (rain barrels)
- Pasture pumps

Appendix VI – Map of the Ecological connection zone

This appendix contains the a map of the ecological connection zone.

Figure A6 2: Map of the Ecological connection zone that partially runs through the Eng. yellow coloring and numbers indicate plans for new hedges (Busman, 2015).

Appendix VII – Decision tree criteria

Measure	Impact (1-5)	Time (1-5)	Time explanation	Cost (1-5)	Cost explanation	Scale (1-3)
Inform (measure)	1	1	Informing can be immediate	1	The measure takes time rather than money	1
Water system analysis app	1	1	The app has to be maintained	2	The app has to be maintained	2
Community building	3	5	This is a measure that needs continuous attention	1	The measure takes time rather than money	3
Water meters + connected app	2	1	Timescale relates to water meters, not the app	2	See the cost estimation in appendix VI	2*
Irrigation management	3	1	Over a growing season it is possible to adapt (new installations)	3	Depends on water usage. It is pretty expensive	1
Crop management	3	2	Over a growing season it is possible to adapt	1	If the crops use less water, this might even save money	1
Pasture pump	3	1	Once installed, only rarely maintenance is required	2	See results on pasture pump	1
Soil management	3	4	It takes time for the soil to adapt	3	Depends a lot on implementation, abandoning tillage might even reduce costs	1

Aboveground tank	4	1	Once the tank is there, the tank is there	3	See results on aboveground tanks	2
Underground tank	4	2	An underground tank takes longer to install	4	See results on underground tanks	2
Retention pond	4	3	Depends on method, but this scale is with artificial clay layer.	4	See results on retention ponds	2
Large scale infiltration	4	5	The changes have to be implemented each year to be effective	5	The large scale transport of water required is very expensive	3
Hedgerows	3	4	Hedges will need continuous maintenance	3	See results on hedgerows	2
Line drains	3	4	Depending on scale it might take quite some time to implement	4	Depends on scale of implementation	3
Decoupling	4	5	Decoupling the roads might even take decades (due to municipality)	5	See results on decoupling	3

* This measure can both be individual and communal

Appendix VIII - Multiple Criteria Analysis

The original plan was to compare the measures on the shortlist using a MCA. There are a lot of different aspects in which the measures can be compared. However, these aspects cannot be compared quantitatively. E.g. the amount of water a measure stores or saves cannot directly be compared to the aesthetics of a measure. MCA is suitable for decision making in scenarios both containing qualitative and quantitative criteria, and additionally also works for scenarios with conflicting objectives between the different stakeholders (Mateo, 2012).

The criteria that are chosen to evaluate the measures on are shown in table A8.1.
For some criteria it was useful to do a case study. The general setup of this case study is described first. Then the scoring for different criteria are explained per theme they belong to. After this, the results (scores) of the MCA are given in a table. Finally, an explanation on the costs used for the table are given.

Theme	Criteria	Benefit / cost
Volume of water	Stored water	B
	Infiltrated water	B
	Source of water	B
	Vulnerability to evaporation	C
Life-cycle	Costs (excluding maintenance)	C
	Area/space	C
Stakeholder	Aesthetics	B
	Likelihood of implementation	B
Other	Biodiversity	B
	Archaeology	B

Table A8.1 : Criteria per theme used for the multi-criteria analysis.

General setup of the case studies:

For a selection of the measures, case studies were set up to evaluate some quantitative criteria in the MCA. For the case studies the Wageningse Eng area, which is 205 ha, was scaled down to an area of 10 ha. This ensures each measure has sufficient area to be applied to. All measures are tested in this area of 10 ha. As a retention basin might cover a different scale as a rain barrel, the scale of a single household would for example already not hold to compare the various measures. The land uses within the Wageningse Eng (26 different types) were reduced to 9 different classes and these same fractions of land use are used in the case study situations. See figure A8.2 for a concept art of the area used for the case studies. The case studies are carried out for the following measures: **retention ponds, infiltration ponds, aboveground closed retention and underground retention**. The case studies for these different measurements are carried out to quantify the stored water criteria in the volume of water theme in the MCA.

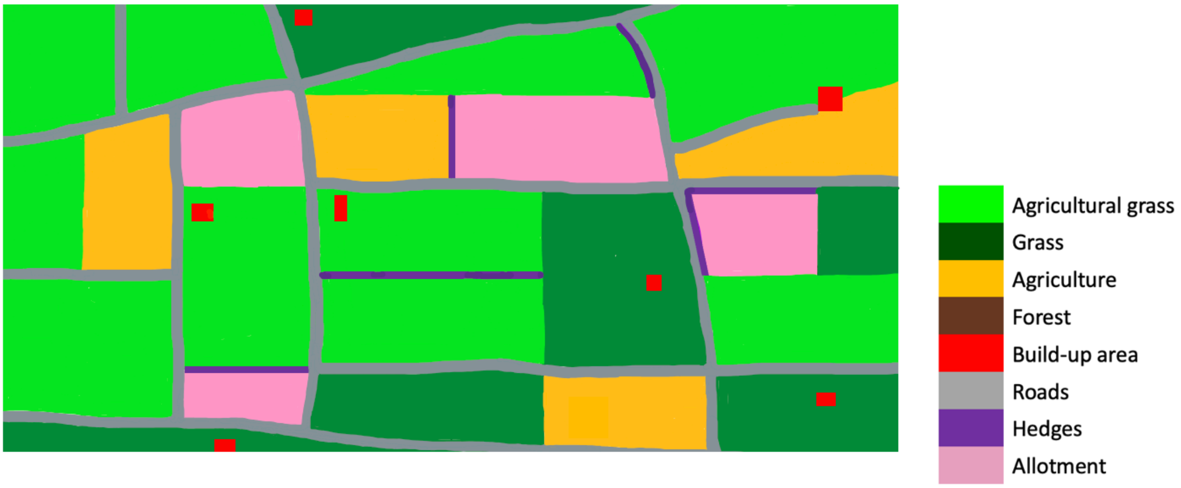

Figure A8.2: Concept art of the case study area referring to the different land uses and their representation (%) in the total area of the Wageningse Eng.

Criteria explanation

Theme 1: Volume of water

Stored water

The score that a measure gets for this criterium ix based on estimations of water use and incoming water for the case study (a scenario like the Wageningse Eng). To get these estimations a case study was conducted, which was explained above.
There are 3 possible scores for this criterium:

- The maximum (3) in case a measure stores enough water to meet the irrigation requirements (based on the study by Diallo et al. (2022)) for the case study.
- A score (2) in case a measure does actually store water, but the amount does not meet the irrigation requirements for the case study.
- The minimum (1) in case a measure does not store water.

The irrigation requirements are based on the water balance established by Diallo et al. (2022) for the Wageningse Eng. The maximum irrigation stemming from groundwater and drinking water obtained from the water balance (the maximum irrigation is applicable during dry periods) was summed. This combined maximum irrigation is normalized per unit of area and then multiplied with the surface of the case study, to obtain the volume of water used when scoring measures on this criterium (the irrigation requirements).

Infiltrated water

There are 3 categories a measure can belong to for this criterium:

- The maximum (3) is given to measures which promote infiltration.
- A neutral score (2) attributed to measures which do not promote, but neither negatively impact water infiltration.
- The minimum (1) for measures that do negatively impact infiltration (a measure like a retention pond (with a waterproof base) would prevent water from infiltrating into the ground).

Source of water

This criterium originally had 5 categories but was later reduced back to 3 categories as only those were relevant for the measures. These categories generally correspond with Vallei en Veluwe (2017), but a new category was added for saving water (and the groundwater extracting categories were removed as they are not relevant for the measures). These are the categories:

- The maximum (3) is given to sources saving water. Measures which increase the efficiency of water use within the Wageningse Eng (and thus reduce the amount of water used) get the highest score within this category.
- The middle score (2) is given to measures that store precipitation.
- The minimum (1) is for measures that promote groundwater infiltration.

It can be argued that some measures fall into multiple categories for this criterium; if this is the case the highest score from the different categories, to which the measure belongs, is selected.

Vulnerability to evaporation

The data analysis showed that there is a (statistically relevant) positive trend for reference evaporation. This criterium was subsequentially added to punish measures that are sensitive to evaporation:

- The high score (2) for measures that are not vulnerable to evaporation.
- The low score (1) for measures that are vulnerable to evaporation (an example would be measures storing water in the open air, like an artificial pond).

Theme 2: Life-cycle

Costs

This criterium represents the cost for establishing each measure. The costs were determined by carrying out a literature search. The costs for maintaining each measure were omitted as such costs were unable to be accurately calculated based upon the available knowledge in the literature. In the cases where a cost range was provided, the highest value was chosen in order to account for the highest costs and to take into account unforeseen costs. First, a generic cost was found in the literature (for example: a retention pond costs 50 euro per m^2) which we then applied to our Wageningen Eng case study measurements (for example: 1225 m^2 of retention pond needed). The applied costs of each measure were ranked from highest cost to lowest cost. In the table, the lowest cost is represented by a lower score, and a higher cost represented by a higher score and ranges from 1 to 8. At the end of this appendix a summary is provided explaining how each applied cost was determined for each measure.

Area

This is a score for the amount of area a measure takes up for the Wageningse Eng case study. Measures taking up less space score better on this criterium. Agricultural measures do not take up additional space (while they may apply to a big area), so they also get a good score.

Theme 3: Stakeholder

In order to provide a more realistic MCA we deemed it important to incorporate the stakeholder's perspectives and preferences for the relevant measures considered. In order to obtain these preferences, a feedback session was organized. The session consisted of presenting the current measures and criteria we elaborated and obtaining feedback on these. Due to the quantitative nature of the MCA, we asked the stakeholders to answer a questionnaire within the meeting itself to obtain directly usable criteria. The results of the questionnaire were immediately discussed amongst ourselves and the stakeholders in order to obtain further understanding of their preferences in a qualitative form.

Likelihood of implementation

The first criteria to be informed by the stakeholders was how likely it is for each stakeholder implement the measure. The question used to obtain the stakeholders view was:

- *On a scale of 0 to 10, to what extent are you able to implement this measure?*

The responses from the questionnaire were transformed into a ranking for use within the MCA.

Aesthetics

we also deemed it important to incorporate the stakeholder's perspectives on the aesthetic considerations of each measure. The question used to obtain the stakeholders view was:
On a scale of 0 to 5, to what extent do you think this measure aesthetically fits in the Eng?
The responses from the questionnaire were transformed into a ranking for use within the MCA.

Theme 4: Other

Biodiversity

This criterium represents the influence that each measure has on the biodiversity of the Eng. A literature search was used to determine the influence of each measure. Positive (3), neutral (2) and negative (1) categories of influence were used, represented by 3, 2, 1 respectively.
The following measures are considered to have a positive influence on biodiversity in the Eng:

- *Hedgerows* (Dover, 2019)*
- *Retention ponds* (Staccione et al., 2021)*
- *Infiltration ponds* (Staccione et al., 2021)*
- *Agricultural measure: soil* (Havlicek & Mitchell, 2014)
- *Agricultural measure: management* (Gomiero et al., 2011)

* These measures received a positive score on the condition that they will be conducted in an ecologically friendly manner.

The following measures are considered to have a neutral influence on biodiversity in the Eng. It is assumed that due to the scale and nature of the measures, there will be a neutral impact on biodiversity.

- *Decoupling rainwater from sewage*
- *Aboveground artificial closed retention basins (water barrels)*
- *Underground retention basin*

Archaeology

The archeological criterium represents the influence that each measure has on the archeological value of the area. We assumed that if the measure breached the 30 cm depth of construction restrictions established by the municipality of Wageningen, it receives a negative score (1). If the measure does not breach the limit it receives a neutral score (2).

Multi-criteria analysis: Score normalization and weights

To enable comparison between the different categories, the scores need to be normalized. Min-max scaling according to formula 1 . This method normalizes the dataset, and gives resulting scores that fall between 0-1.

$$Xnorm = X - Xmin Xmax - Xmin$$

After normalization, the scores were multiplied by the weights assigned to each criteria. Each criteria was assigned a weight of 1, weights were all equal for all criteria to avoid a bias towards a single direction of solutions. The weights assigned result in a sum of 10, resulting in a final scoring between 0 and 10 for each measure and are included in table A8.1 along with the results.

Multi-criteria analysis table and results

The necessary data for the MCA was cumulated, analysed and output in the form of a table (see Table A8.1). The MCA allocated the highest score to the agricultural measure seeking to improve soils ability to retain water, followed by agricultural management practices focused on crops and irrigation. In third position came the use of hedgerows as a means to retain water. This indicates that considering the MCA, soil improvement measures were found to be the most appropriate measures for the Wageningse Eng.

Table A8.1: Multiple Criteria Analysis summary table.

Criteria	cost/benefit	weight	Hedgerows	Retention ponds	Infiltration ponds	Decoupling	Aboveground closed retention	Underground retention	A: soil	A: management
Stored water	B	1	0.50	0.50	0.00	0.00	0.50	1.00	0.50	0.50
Infiltrated water	B	1	1.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
Source of water	B	1	1.00	0.50	0.00	0.00	0.50	0.50	1.00	1.00
Vulnerability to evaporation	C	1	0.00	0.00	0.00	-0.50	-0.50	-0.50	0.00	0.00
Costs (excluding maintenance)	C	1	-0.14	-0.86	-0.71	0.00	-0.57	-1.00	-0.43	-0.29
Area/space	C	1	-0.50	-1.00	-1.00	0.00	-0.11	0.00	0.00	0.00
Esthetics	B	1	0.50	0.00	0.25	0.00	0.75	0.75	1.00	0.25
Likelihood of implementation	B	1	0.50	0.50	0.00	0.50	0.50	1.00	1.00	0.50
Biodiversity	B	1	1.00	1.00	1.00	0.50	0.50	0.50	1.00	1.00
Archaeology	B	1	0.50	0.50	0.50	0.50	0.50	0.00	0.50	0.50
Final scores:			**4.357**	**1.143**	**1.036**	**2.000**	**2.068**	**2.250**	**5.571**	**4.464**

Assumptions made in the case study

Retention and infiltration ponds:

For this measure it is assumed that all water falling on the roads and the build-up area is not infiltrating (or evaporating) and that only this water from roads and build-up area can be used for filling the retention and infiltration ponds.

Furthermore, it is taken into account that land user are not allowed to dig deeper than 30 cm. For calculating the area needed for infiltration and retention basins this depth is thus chosen and with this depth a surface area of needed retention area is calculated to match the maximum irrigation needs.

Aboveground closed retention (rain barrel):

For this measure it is assumed that all water falling on the build-up area is normally not infiltrating (or evaporating) and that only this water from the build-up area can be used for filling the rain barrels.

It is assumed that half of the build-up in this area consists of houses and half is covered by sheds. In addition it is assumed that a house has 4 rain barrels and two rain barrels accommodate a shed. Splitting up the build-up area in our case study area (10 ha) and using an average roof area of 120 m^2 for a household (Ball, 2003) and a shed area of 4 m^2, results in approximately 8 houses and 235 sheds for our case study area and a total of 502 rain barrels needed to match the irrigation needs.

Underground retention:

For this measure it is assumed that all water falling on the roads and the build-up area is normally not infiltrating and that only this water from roads and build-up area is used for filling the underground retention basins.

The year 2018 was taken as example year for the case study. The year 2018 showed the driest growing season over the evaluated 35 years of data (i.e. the PED was the lowest). The precipitation over the growing season in 2018 was still sufficient to meet the irrigation needs.

To calculate the amount of under water retention basins needed to match the irrigation requirements the dimensions of a 20000 L flat plastic underground rain water tank (height. 260 cm, diameter. 230 cm and length 580 cm) are used (*Ondergrondse Platte Tanks - Budgettank.nl*, n.d.).
Hedges:
The hedges have been assigned a 3 the source of water. Hedges have multiple functions, their roots can help with groundwater infiltration (Kiepe, 1995). Hedges also help with reducing evapotranspiration, by reducing the windspeed, as is also observed in the studies by Veste et al. (2020). This would then lead to water saving, which explains why hedges have a 3 for this criterium.

Cost calculation

Below is a summary of how each applied cost was determined for each measure (including the reference for each cost):

Retention pond costs:

- A retention pond costs 50 EUR/m^2 (Vijver - Klimaatadaptatie Provincie Noord-Brabant, n.d.).
- 1225 m^2 of retention pond was required to match the total irrigation needs in the case study used.
- 50 x 1225 = 61,250 EUR

Infiltration pond costs:

- The literature search did not yield any accurate results for the generic costs of infiltration ponds.
- Infiltration ponds were assumed to have a similar yet slightly lower cost than retention ponds since no artificial materials such as plastic lining are needed.
- Infiltration ponds were ranked below (less costly) the cost ranking of retention ponds.

Decoupling rainwater from sewage costs:

- The literature search gave varied decoupling costs, but in the case of the Eng we assume the costs to be restricted to gutter adjustments.
- 25 euro per gutter, 4 gutter pipes per house x 8 houses = 800 EUR (Milieu Centraal, n.d.)

Artificial closed retention basins (water barrels) costs:

- 87 EUR per closed water barrel (Nature - Regenton, z.d.).
- 502 water barrels required to match the total irrigation needs in the case study used.
- 87 EUR x 502 = 43,674 EUR

Underground retention basin costs:

- 8295 EUR per 20,000-liter underground retention basin (Ondergrondse Platte Tanks - Budgettank.nl, n.d.).
- 19 units required to match the total irrigation needs in the case study used.
- 8295 x 19 = 157,605 EUR

Agricultural measure: soil (communal) costs:

- 500 EUR per hectare per year (Belang van bodemorganische stof voor het waterbeheer, n.d.)
- The case study represents 12424 meters of agricultural surface area or 1,242 hectares.
- 500 x 1,242 = 621 EUR per year

Agricultural measure: crops + irrigation (communal) costs:

- No accurate costs were found