From Drainage to Reuse:

Realistic Strategies for Cost-Effective Rainwater Harvesting in the Netherlands

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Levi Duthler (s2682672)

University of Twente Supervisor: dr.ing. R. Arendt (Rosalie)

Hofmeijer Civiel- en Cultuurtechniek supervisor: C.J. Hofmeijer (Chiel)

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Author Note

This bachelor thesis was conducted in collaboration with Hofmeijer Civiel- en Cultuurtechniek. Correspondence concerning this thesis should be addressed to Levi Duthler, l.duthler@student.utwente.nl.

Abstract

This thesis investigates whether and how rainwater harvesting systems (RWHS) can be practically and cost-effectively implemented in Dutch infrastructure projects, using natural grass sports fields as a case study. In this case, the field serves as the catchment area and the irrigation as the water demand. The study begins by outlining the growing problems related to water supply and stormwater management. The literature review identifies a lack of research related to non-potable applications and associated costs. The research combines a practical case study with evaluations that discuss legal constraints, design considerations, and different alternatives. Systems with diverse characteristics are discussed (e.g., foil basins, Rainshell+FHVI, DrainTalent, and Permavoid). The capital costs of these systems are estimated and compared. A simplified simulation model was developed to estimate the reuse potential and overflow volume of different system configurations. This method was applied to the specific case study and could be adapted to a different context. Rainwater harvesting systems (RWHS) remain an economic challenge when considered solely as an alternative water source. The upfront costs are high, and the operational expenses are uncertain. However, they could be justified through optimisation via multifunctional design, regulatory harmonisation, and strategic system configuration, offering clear benefits in terms of rainwater management and reuse.

Contents

1. Introduction

This thesis assesses how RWHS (rainwater harvesting systems) for non-potable applications can be integrated in infrastructure projects in the Netherlands. The specific focus is on the integration with natural grass sports fields, these fields have high irrigation demands during dry periods, while simultaneously featuring engineered drainage systems to manage excess rainwater. This makes them a potentially high-impact case for rainwater harvesting. A large portion of this research will also be transferable to other contexts. To better understand the problem context the following sections are first discussed: *background and context*, *the problem statement*, and finally *the research questions*. The main topic is rainwater harvesting and more specifically the systems used to harvest rainwater. To establish a working definition of rainwater harvesting systems a common definition is presented. According to Swati (2025) a rainwater harvesting system hereafter referred to as a RWHS, is:

> A technology that collects and stores rainwater for human use. Rainwater harvesting systems range from simple rain barrels to more elaborate structures with pumps, tanks, and purification systems.

1.1 Background and Context

Climate change is increasingly affecting daily life in the Netherlands. It is expected to increase in severity, leading to more extreme precipitation events and prolonged periods of drought. There are also increasing concerns about the effects of climate change on water quality (Kamp et al., 2021). In the study by Klopstra et al. (2005), water shortages and the impacts they had were explored. Under current climate conditions, the Netherlands experiences significant water shortages. It has been estimated that at the time of the study by Klopstra et al. (2005) these shortages led to an average reduction of 10% in agricultural yield, and already caused issues for shipping, energy, nature, and recreation. When considering the best-case climate scenario, the average precipitation shortage is expected to increase by 6%, and in the worst case by 75% (Klopstra et al., 2005). This highlights the need for adaptive water management solutions.

In 2022, around 1.117×10^6 m^3 of drinking water was used within the Dutch economy (Centraal Bureau voor de Statistiek, 2024). Most of this water was used for non-potable (not suitable for drinking) applications (Centraal Bureau voor de Statistiek, 2024). Existing infrastructure in the Netherlands is mainly designed to quickly get rid of rainwater, which wastes a potential water resource and can increase the risk of flooding and water nuisance during extreme rainfall events. It is estimated that around two-thirds of the Dutch sewers still operate as a combined system (RIONED, 2019), where rainwater and wastewater flow through the same sewer system. Local regulations try to address some of these issues by mandating local rainwater buffering and infiltration and the separation of sewer systems. Most municipalities require new construction projects to include solutions that relieve pressure on sewage systems through sustainable water management (Verordening op de opvang, verwerking en afvoer van hemel- en grondwater 2023 voor nieuwbouw, 2023). One potentially high-impact application of RWHS is in natural grass sports fields. These fields have high irrigation demands during dry periods, while simultaneously featuring engineered drainage systems to manage excess rainwater.

This thesis specifically focuses on natural grass sports fields; therefore, the basic concepts and standard practices are discussed. This is to better understand how rainwater harvesting could be implemented in natural grass fields. These fields, such as soccer fields and golf courses often contain drainage systems to maintain payability of the turf. Typically, these systems consist of perforated drainage pipes installed at an invert depth of 0.5 to 0.6 meters, spaced 4 to 6 meters apart, embedded in a sand layer with certified properties (e.g., M3c or M3d) (Eric Bals, n.d.). The systems work by lowering the groundwater table and quickly discharging excess water. The topsoil needs to have the right granular buildup and organic matter content. This ensures proper drainage, stability and growing conditions.

This research will be conducted at Hofmeijer Civiel- en Cultuurtechniek. This company is active in land and water management works, sports and recreation infrastructure, earthmoving operations, civil engineering works and consultancy-and-design services. The company's involvement in projects where water discharge and irrigation demand coincide, provides a suitable environment for assessing the potential of RWHS.

1.2 Problem Statement

This thesis aims to explore how RWHS can be effectively designed and evaluated for Dutch infrastructure projects. For this purpose, balancing water conservation needs, stormwater management issues, cost considerations, and the technical and regulatory feasibility are critical. There are plenty of water-related problems that could have already led to the widespread use of RWHS, but barriers hindering the adoption seem to exist. In natural grass sports fields, the mismatch between water availability and demand can pose issues. The turf requires large amounts of irrigation in periods when water is particularly scarce. Currently, two different water authorities have restricted the extraction of water. The water authority Waterschap Vallei en Veluwe has restricted surface water extraction from 15 May 2025 onward, and at the time of writing is still active (Waterschap Vallei en Veluwe, 2025). Waterschap De Dommel had implemented a temporary ban on groundwater extraction in four regions of Brabant from 1 April 2025 to 1 June 2025, from the first of June forward, extraction for irrigation is allowed between 17:00 and 11:00 (Waterschap De Dommel, 2025). Reusing captured rainwater offers a practical solution to support irrigation during dry periods, while also reducing strain on the surface water and groundwater reserves.

The potential of rainwater harvesting in the Netherlands has been assessed before. A group of researchers from TU Delft performed a desk study and examined rainwater as a potential drinking water source. From this, they found that for potable use, extensive purification and testing are necessary and estimated costs are higher than the conventional water supply

(Hofman-Caris et al., 2018). This indicates one of the potential barriers for the adoption of RWHS: higher cost. The focus of the study by Hofman-Caris et al. (2018) was on potable uses, and while additional combined benefits of stormwater management are mentioned, no analysis was made to examine the benefits and costs when using a multi-purpose system. Assessing and designing a RWHS as a dual-purpose system for both water conservation and stormwater management could potentially decrease the cost barrier. Between 2005 and 2006 the RIVM (Dutch National Institute for Public Health and the Environment) conducted multiple studies on the quality of rainwater in the Netherlands. These revealed that 96% to 100% of collected rainwater samples contained faecal contamination, with pathogens such as E. coli, Campylobacter, Salmonella, and Legionella. The authors estimated that even when using the water for toilet flushing it might not meet the maximum set theoretical infection risk (one infection per 10.000 people per year) from the Waterleidingbesluit, the former Dutch drinking water decree, which has since been replaced by the Drinkwaterwet and Drinkwaterbesluit (Italiaander and de Roda Husman, 2007). This could be a major challenge and potentially limits untreated reuse of harvested rainwater even for non-potable applications. This highlights the need for an assessment of the literature related to water quality from reusing rainwater and the available treatment methods, and their effectiveness.

1.3 Research Questions

During the research, the following questions will be answered to explore how RWHS can be effectively designed and evaluated for Dutch infrastructure projects.

Main Research Question:

1. How can a context-specific RWHS be integrated into Dutch infrastructure projects for non-potable applications in a cost-effective and technically feasible manner?

Sub-Questions:

1. What physical and regulatory requirements apply to the site-specific RWHS?
2. How do different RWHS perform in terms of water reuse efficiency and storage capacity, based on a simplified hydrological model?
3. What are the expected costs of different systems, and how do they compare to a conventional design?

2. Literature Review

This chapter reviews the existing research on RWHS. It provides an overview of the current state of knowledge. The review covers the concept of *Rainwater Harvesting*, the *Regulatory Context*, *Contaminants and Quality Standards*, *Economic Assessment*, *Storage Models*, and *Gaps in the Literature*. Altogether this forms the foundation for designing and evaluating RWHS.

2.1 Rainwater Harvesting

According to Campisano et al. (2017), urban rainwater harvesting consists of the concentration, collection, storage and treatment of rainwater from rooftops, terraces, courtyards, and other impervious building surfaces for on-site use. More broadly, it is a technology that collects and stores rainwater for human use (Swati, 2025). A RWHS consists of several main parts. Most importantly, a catchment area is needed to collect rainfall. This rain needs to be transported to the storage location. From this storage location, the water needs to be distributed and typically brought up to pressure for use. Somewhere in between filtration and/or treatment can take place to improve the water quality. Figure 1 shows a typical RWHS configuration, including example components.

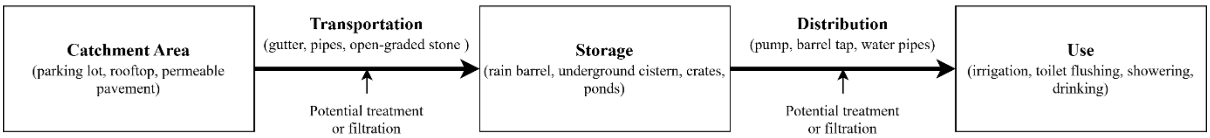

Figure 1 Diagram of typical RWHS configuration

A distinction is also made between conventional and new RWHS. The main difference is the incorporation of multiple objectives and the use of new technologies. One of these multi-objective types of systems is one that balances both detention and retention storage objectives, to provide water conservation and stormwater management benefits. This can also be integrated with other elements like infiltration systems, tank overflows, first-flush diversions, and dual-storage releases (Campisano et al., 2017).

One important idea related to rainwater harvesting and more specifically to a multi-purpose RWHS is Integrated Urban Water Management. According to Mitchell (2006) Integrated Urban Water Management is a comprehensive approach to urban water services, viewing water supply, drainage, and sanitation as components of an integrated physical system, and recognizes that the physical system sits within an organisational framework and a broader natural landscape. Integrated Urban Water Management is summarized as follows:

- Consider all parts of the water cycle, natural and constructed, surface and subsurface, recognising them as an integrated system.
- Consider all requirements for water, both anthropogenic and ecological.
- Consider the local context, accounting for environmental, social, cultural, and economic perspectives.
- Include all stakeholders in planning and decision-making processes.
- Strive for sustainability, aiming to balance environmental, social, and economic needs in the short, medium, and long term.

This approach emphasizes not only ecological and sustainability concerns, but also the broader cultural and economic context, with a focus on balancing needs over different time scales. These principles form the conceptual basis for designing integrated RWHS.

2.2 Regulatory Context

In the Netherlands there is no single national regulation mandating rainwater buffering or infiltration, but most municipalities have adopted local ordinances that impose requirements on new developments. The local regulations typically prohibit the discharge of rainwater into the sanitary sewer system and most often mandate on-site infiltration and storage of rainwater for new developments to compensate for an increase in impermeable surfaces (Verordening op de opvang, verwerking en afvoer van hemel- en grondwater 2023 voor nieuwbouw, 2023).

Reusing rainwater as a non-potable water source is regulated by the Drinkwaterbesluit (2024), based on definitions and authority provided in the Drinkwaterwet (2024). The Drinkwaterwet (2024) provides exemptions for water used in ways that pose no health risk, while the Drinkwaterbesluit (2024) defines a specific category of non-potable water, named huishoudwater, intended exclusively for toilet flushing. The Drinkwaterwet (2024) states that certain provisions of the act may be declared inapplicable for water intended solely for uses that do not pose health risks to consumers, as determined by general administrative order. Such water is then subject to specific quality, production, and distribution requirements to be laid down in that order (Drinkwaterwet, 2024, art. 1, lid 2). This means that the water intended for non-potable use does not have to meet the strict standard of drinking water. The Drinkwaterbesluit defines household water as water referred to in Article 1, paragraph 2, of the Drinkwaterwet, which is intended exclusively for toilet flushing (Drinkwaterbesluit, 2024, art. 1, lid 1). Additional regulatory authority is granted to the Minister to establish further health-based requirements concerning the production, distribution, and use of household water, distinguishing between system types (Drinkwaterbesluit, 2024, art. 3, lid 1). Under these provisions, providers of collective systems may not supply household water to consumers without prior ministerial exemption, unless they fall outside the designated categories (Drinkwaterbesluit, 2024, art. 3, lid 2). Furthermore, providers must ensure that household water is used only for toilet flushing, as far as it lies within their control (Drinkwaterbesluit, 2024, art. 4). The source of household water is also legally restricted. According to Article 5 of the Drinkwaterbesluit (2024), it may only be produced from rooftop-harvested rainwater or groundwater. Alternative sources are only permitted if deemed safe by the regulatory authority (Drinkwaterbesluit, 2024, art. 5, lid 1 and 4).

All of this means that collective systems supplying multiple consumers can only be used for toilet flushing unless a ministerial exemption is granted. Private systems are not explicitly prohibited from being used for other non-potable purposes. This means that, in practice, other applications beyond toilet flushing are possible for private systems, but there are no specific national standards that regulate these systems. For instance, irrigation with harvested rainwater on a sports club facility is not explicitly prohibited.

Currently the Dutch government is exploring the potential for mandating greywater and rainwater reuse systems in new buildings with the goal of addressing future drinking water shortages. Mandates on reuse systems are being explored as an addition to the Besluit bouwwerken leefomgeving (Bbl). A report by I. Phernambucq et al. (2023) examined if and how drinking water savings could be incorporated into the building regulation. RWHS and greywater reuse systems have the potential to reduce drinking water demand by 30 to 48 litres per person per day, depending on the system configuration. The report discusses how climate change and increasing water demand will put pressure on drinking water supplies. This makes alternative water sources crucial for long-term sustainability. Additional research into the health risks of using rainwater and greywater for non-potable purposes such as toilet flushing and irrigation is advised before the authors recommend implementation. The key concerns are bacterial contamination, system maintenance, and user awareness. Flanders, Germany, and Australia have already adopted policies on rainwater reuse. These case studies have shown that legal mandates increase adoption rates (Phernambucq et al., 2023).

2.3 Contaminants and Quality Standards

In section 1.2, the potential health risks associated with rainwater harvesting were already briefly discussed. Harvested rainwater can contain high concentrations of different microbial and chemical contaminants. These can originate from different parts of the environment. According to Sánchez et al. (2015) the quality of rainwater is influenced by three main stages: contamination from atmospheric pollutants, runoff from the catchment surface, and issues arising during its collection, filtration, and storage. Pollutants from the atmosphere contribute to a range of chemical contaminants, for example nitrogen compounds, phosphorus, sulphates, chlorides, and heavy metals. These can originate from road traffic, industrial activities, and long-distance atmospheric transport. Sánchez et al. (2015) report that nitrogen concentrations in rainwater can reach 2 mg/L, which is significantly higher than the threshold for algal growth in storage tanks (>0.3 mg/L). Microbial contaminants in harvested rainwater primarily stem from faecal droppings, biofilm build-up, and decomposing organic matter on catchment surfaces. A multitude of bacteria and pathogens, such as *E. coli*, *Enterococci*, *Salmonella*, *Campylobacter*, *Cryptosporidium*, *Giardia*, and *Legionella* have been detected in collected rainwater samples. The concentrations can be influenced by animal activity, catchment surface cleanliness, and weather conditions. Fungal spores and bacteria can also originate from wind-blown particles. While microbial risks exist, several studies have suggested that with proper treatment, harvested rainwater remains a viable and safe supplementary water source (Ahmed et al., 2010; Simmons et al., 2001; de Man-van der Vliet, 2014). Mazurkiewicz et al. (2022) examined rainwater quality in three different underground retention tanks in Poland. The samples taken from these tanks mostly met the physicochemical quality standards for drinking water, but microbiological quality remained an issue. The concentration of coliform bacteria reached up to 19,300 CFU/100 mL. The bacterial concentration was also variable and reflected seasonal temperature changes, with higher measurements during warmer periods. These measured values could pose health risks, particularly when aerosolized or in direct contact with users (Mazurkiewicz et al., 2022).

These findings show that the chemical parameters in harvested rainwater likely remain within acceptable limits for non-potable uses such as sports field irrigation, but microbial contamination poses a potential risk. High nutrient content in the harvested water could remain an issue by leading to algal growth in storage tanks. Given the variability of the quality and the unpredictable factors influencing this quality, the determination of clear microbial quality standards is important to ensure the safe reuse of rainwater. There is an absence of national quality standards for harvested rainwater. There are however international standards set for similar applications, arguably the most important one being Regulation (EU) 2020/741, which establishes minimum requirements for the reuse of treated wastewater in agricultural irrigation. It sets the standards based on different level of human exposure and crop type (Minimum Requirements for Water Reuse, 2020). Although not fully applicable to all potential applications, it does give a standard that can be adapted for different use cases. Below in table 1 the different quality classes are shown. All the contaminants should be monitored weekly or twice a month depending on the contaminant and the quality class. Table 2 shows the standard the water needs to meet. These classes, with their minimum standard provide useful guidelines for assessing the quality of harvested rainwater. While these standards were designed for the reuse of treated wastewater, they still help determine the minimum treatment requirements for RWHS, depending on the intended end use.

Table 1 Classes of reclaimed water quality and permitted agricultural use and irrigation method, adapted from table 1 of Minimum Requirements for Water Reuse (2020)

Water quality class	Crop category (*)	Irrigation methods
A	All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Drip irrigation (**) or other irrigation method that avoids direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods (***)
(*) If the same type of irrigated crop falls under multiple categories of Table 1, the requirements of the most stringent category shall apply. (**) Drip irrigation (also called trickle irrigation) is a micro-irrigation system capable of delivering water drops or tiny streams to the plants and involves dripping water onto the soil or directly under its surface at very low rates (2–20 litres/hour) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers. (***) In the case of irrigation methods which imitate rain, special attention should be paid to the protection of the health of workers or bystanders. For this purpose, appropriate preventive measures shall be applied.		

Table 2 Reclaimed water quality requirements for agricultural irrigation, adapted from table 2 of Minimum Requirements for Water Reuse (2020)

Reclaimed water quality class	Indicative technology target	Quality requirements	
		E. coli (CFU/100 ml)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10	*Legionella* spp.: < 1 000 cfu/l where there is a risk of aerosolization. Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage.
B	Secondary treatment, and disinfection	≤ 100	
C	Secondary treatment, and disinfection	≤ 1 000	
D	Secondary treatment, and disinfection	≤ 10 000	

There are still discrepancies between the quality of untreated rainwater and the set minimum acceptable levels outlined in Regulation (EU) 2020/741. Mazurkiewicz et al. (2022) reported coliform levels of up to 19,300 CFU/100 mL in underground storage tanks. This is double the limit set for Class D water.

To conclude, a wide range of contaminants can be present in harvested rainwater. The exact concentrations will depend on multiple factors, both environmental and related to the harvesting system used. To minimize health risks and meet regulatory standards, treatment of harvested rainwater will likely be necessary. Therefore, it is important to take a closer look at the available treatment methods. These findings will later be used to determine safe microbial limits for sprinkler irrigation.

2.3 Economic Assessment

A key barrier to RWHS adoption is its potentially higher cost compared to conventional water sources. For this reason, it is crucial to understand how this could be evaluated. When evaluating a system, two categories of costs can be considered: the capital expenditures (CAPEX) and the operational expenditures (OPEX). CAPEX includes all upfront investments required for the construction and implementation of the system, such as materials, labour, and installation (Batchelor et al., 2011). For a RWHS, the CAPEX varies depending on system type, storage volume, and regional factors. In most cases, it represents the bulk of the total life-cycle cost. The operating expenditures (OPEX) consist of the recurring costs of operating, managing, and maintaining the RWHS over its life span. Batchelor et al. (2011) determined that for a RWHS, the OPEX tends to be low compared to CAPEX. This life-cycle cost perspective provides a view of the total investment required for sustainable operation.

Tap water prices are important for contextualizing the economic viability of RWHS. The largest water supplier in the Netherlands is Vitens. In 2025, the price of drinking water is € 1.25 / m^3 (incl. 9% VAT) a 20% increase from the price in 2024 € 1.04 / m^3 (incl. 9% VAT) (Vitens, 2025b). To maintain the supply of a sufficient amount of drinking water, large investments in expansion and replacement of facilities are necessary, and the demand is expected to keep increasing (Vitens, 2025a). These facts could suggest further increases in water prices. This price increase may improve the relative cost-effectiveness of RWHS.

2.4 Storage Models

System performance estimation is important to effectively design a RWHS, balancing supply and demand while ensuring cost-effectiveness and long-term reliability. The two main approaches for storage modelling are Yield Before Spillage (YBS) and Yield After Spill (YAS). These differ in how rainwater is allocated, affecting the resulting reservoir size.

The YBS model meets immediate water demand before determining how much rainwater to store. This approach results in smaller reservoirs, which risks supply shortages during dry periods. Jing et al. (2017) developed a YBS-based daily water balance model to optimize RWHS efficiency.

The storage balance for YBS can be expressed as (Jing et al., 2017):

$$S_t = \begin{cases} 0, \ Q_{t-1} + S_{t-1} - D_{t-1} \leq 0 \\ Q_{t-1} + S_{t-1} - D_{t-1}, \ \ 0 < Q_{t-1} + S_{t-1} - D_{t-1} \ \leq V \\ V, \ \ Q_{t-1} + S_{t-1} - D_{t-1} > V \end{cases} \qquad \text{(eq. 1)}$$

S_t (volume of rainwater remained in the storage unit at the beginning of the t_{th} day [m^3])
Q_{t-1} (collectable stormwater runoff generated from the contributing areas the (t_{th}-1) day [m^3])
S_{t-1} (volume of rainwater remained in the storage unit at the beginning of the (t_{th}-1) day [m^3])
D_{t-1} (water demand on the (t_{th}-1) day [m^3])
V (designed storage capacity of storage unit [m^3])

The YAS model first simulates filling the reservoir before meeting water demand. This method results in a larger reservoir size. Corrêa et al. (2024) developed a YAS-based model, in an attempt to optimize the storage in Brazilian RWHS projects. Their approach uses statistical rainfall parameters (mean annual, monthly, and daily precipitation), non-potable water demand factors, and runoff coefficients and catchment characteristics.

The general storage balance equation for YAS is defined as (Corrêa et al., 2024):

$$Y_t = min\begin{cases} D_t \\ V_{t-1} \end{cases} \qquad \text{(eq. 2)}$$

$$V_t = min\begin{cases} V_{t-1} + Q_t - Y_t \\ S - Y_t \end{cases} \qquad \text{(eq. 3)}$$

$$Q_t = (C \cdot R_t \cdot A) - DT_t \qquad \text{(eq. 4)}$$

Q_t (rainwater collected on t_{th} day [m^3])
Y_t (rainwater available to meet the demand on t_{th} day [m^3])
D_t (demand for rainwater on t_{th} day [m^3])
V_t (rainwater volume in reservoir on t_{th} day [m^3])
S (reservoir storage capacity [m^3])
C (runoff coefficient)

R_t (daily rainfall on t_{th} day [m^3])
A (surface area for rainwater collection [m^3])
DT_t (water discharge for cleaning, first flush, on t_{th} day [m^3])

The runoff coefficient (C) or stormwater capture efficiency, representing the fraction of rainfall converted into useable runoff, is a key input for both models. An experimental measurement of C can be used to improve accuracy. A direct field method could involve creating or selecting a test setup where collected rainwater can be measured, either applying a known rainfall depth or measuring natural rainfall using a rain gauge, measuring the volume of collected runoff to determine the efficiency of water capture.

$$C = \frac{Usable\ Runoff(mm)}{Rainfall(mm)} \qquad \text{(eq. 5)}$$

Using large-scale monitoring, rainfall data and drainage outflow measurements to refine estimates over multiple events is also possible. These values, along with site-specific rainfall statistics and water demand factors, inform RWHS design to balance storage size and water availability efficiently. Choosing between YBS and YAS models impacts the estimated storage capacity. The YAS model is likely the better option in this project where the aim is to have the combined function of stormwater management and rainwater harvesting. This is not explicitly taken into consideration in either of these models, therefore, a model must be adapted to explicitly incorporate stormwater management functions. The models can help determine what storage capacity to use. They provide insight into the expected performance of a system and the general equations could be adapted to a more specific context and be used when optimizing for different objectives.

2.5 Gaps in Literature

RWHS have been extensively studied. Despite this, several research gaps remain. The application of RWHS in non-residential infrastructure projects in the Netherlands is limited. While the potential multi-functionality of RWHS has been mentioned (Campisano et al., 2017), studies on their practical application are lacking. Most of the current research focusses on residential applications or systems intended for potable use, leaving non-potable applications outside of the residential setting underexplored. The existing economic assessments focus on household-scale systems or potable reuse scenarios (Hofman-Caris et al., 2018). Yet the economics of other applications like sports fields remain unknown. This study aims to fill the gap by exploring, and evaluating alternatives and configurations for a RWHS intended for natural grass sports fields.

3. Research Design and Methods

This chapter describes the methods used to explore, compare, and evaluate RWHS. The process includes defining legal and technical requirements, exploring system alternatives, simulating expected performance, and comparing the costs.

3.1 Case Definition

A hypothetical case was chosen to explore applicable regulatory requirements and guide the evaluation of rainwater harvesting options. The case is the renovation of a hypothetical natural grass football field in the municipality of Voorst. The field has typical dimensions of 77 m by 113 m (69 m by 105 m field with a 4 m safety zone), resulting in an area of 8,701 m^2. The field requires complete renewal of the drainage system and improvements in soil. The project has a 1000 m^2 increase in impervious surface area, bringing the local regulatory requirements for stormwater into effect. The case serves as the reference for the system exploration and performance evaluations in the following chapters.

3.1 Requirements and Available Options

The regulatory requirements, the water quality requirements, the system configurations and the potential components for a RWHS for the specific case need to be identified. The aim is to define constraints and evaluate the available system options. The requirements are derived from both national and local regulations. To determine the water quality standards, the Regulation (EU) 2020/741 is applied to the specific case, by identifying the most appropriate water quality class. The resulting criteria inform the design constraints. To evaluate the available system options, different commercially available products and solutions are explored. The information is collected from product documentation, manufacturer datasheets, relevant case studies, and input from communication with suppliers and end-users. These options are explored in combination with their pros and cons. The outcome of this phase is a set of design constraints along with a range of feasible components and configuration concepts that can serve as a rainwater harvesting solution.

3.2 System Configurations

This section outlines plausible rainwater harvesting system configurations. It compares these to a conventionally drained field that serves as the reference case. The alternatives are selected based on the identified existing systems and available components and on their relevance to natural grass sports fields. Different options are presented with unique features. They are presented to support qualitative comparisons, enable economic assessment, and provide an overview of the available options. The comparison will be done in terms of cost, water storage, water reuse, irrigation savings, and field drainage efficiency.

3.3 System Evaluation

The aim of this section is to evaluate the hydrological performance and economic feasibility of RWHS. To evaluate the expected performance of the RWHS, a Yield After Spill (YAS) storage model was used. The storage model was adapted by separating the volume that is used for reuse (retention) and the volume that serves as temporary stormwater buffer (detention), as shown in Figure 2.

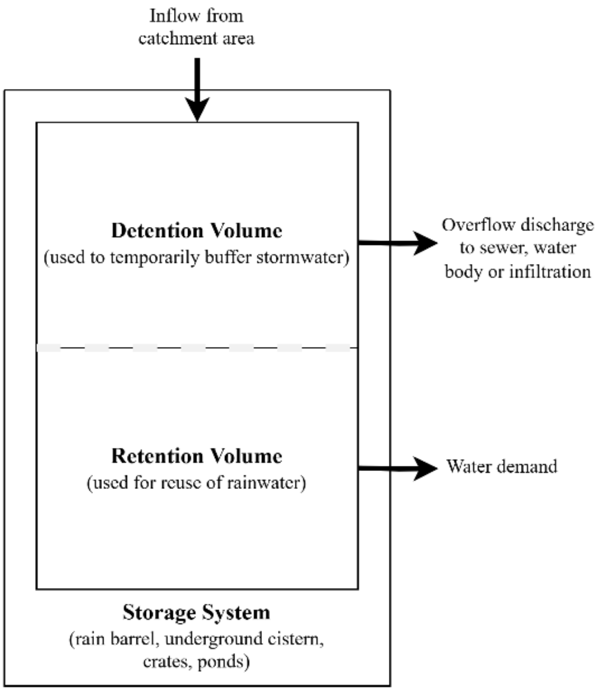

Figure 2 Conceptual layout of a dual-function storage system separating reuse from temporarily buffering rainwater

The model simulates the water balance daily, based on daily rainfall, evapotranspiration, and irrigation demand. This helped to determine performance indicators such as reuse efficiency, buffer overflow, external irrigation volume, and buffer utilisation. To evaluate not just technical feasibility but also practical viability, the systems were assessed economically.

To assess the economic feasibility of implementing rainwater harvesting in sports fields, a cost comparison was made. This compares different alternatives and a conventional drainage system without reuse. The evaluation is focussed on the CAPEX, as it is expected to be the largest share of the life cycle costs. The comparison includes the costs for the needed components such as storage units, pumps, treatment options, installation, material deliveries and associated construction activities. The data for determining the CAPEX comes from a wide range of sources, including vendor quotations, public catalogues, recent project cost data, internal price databases, and direct input from system developers. Only the total aggregated costs are presented to maintain confidentiality. Assumptions are made regarding site-specific practices where applicable. The OPEX are analysed by estimating the water savings and assessed qualitatively.

4. Requirements

This chapter presents the constraints that will help guide the RWHS design. It includes the water quality and regulatory requirements.

4.1 Water Quality Requirements

Reusing rainwater carries microbial risks that should be mitigated. This could be done by adhering to defined quality standards. Regulation (EU) 2020/741 sets minimum quality requirements for the reuse wastewater for agricultural irrigation (Minimum Requirements for Water Reuse, 2020). Although not originally intended for sports field irrigation, it will still be used as a benchmark based on expected levels of human exposure. The regulation focuses on food safety and worker protection. The regulation contains four quality classes D to A, which will be evaluated to determine an appropriate classification. The lowest class D permits all irrigation methods, and is intended for industrial, energy, and seeded crops (Minimum Requirements for Water Reuse, 2020). Even though sports field vegetation is not consumed, protective measures are required when using spray-based irrigation. Measures such as restricted access are impractical for open-access public fields and unlikely to be enforced. Therefore, class D is not considered suitable. Class C only applies to drip irrigation systems (Minimum Requirements for Water Reuse, 2020). These are incompatible with sports field irrigation, where sprinklers are used. Therefore, Class C is not considered a viable option. Class B is intended for crops where workers may come into contact with wet plant material (Minimum Requirements for Water Reuse, 2020). Although the context differs, this classification assumes indirect exposure through skin contact and aerosols, comparable to those encountered on sports fields. For this reason, class B is considered an appropriate benchmark for safety. Since sprinkler systems create aerosols, the Legionella spp. requirements associated with all classes with aerosolization risks are also applicable.

The quality and monitoring requirements under Class B are as follows (Minimum Requirements for Water Reuse, 2020):

1. E. coli: ≤ 100 CFU per 100 mL, tested once per week

2. Legionella spp.: < 1,000 CFU per L, tested twice per month

4.2 Regulatory Requirements

This section presents the regulations applicable to the specific case. The local ordinance on the discharge of rainwater and groundwater from the municipality of Voorst is the primary regulation governing stormwater management in this area (Verordening op de afvoer van hemelwater en grondwater 2023 gemeente Voorst, 2023). According to this ordinance, it is prohibited to discharge into the sanitary or pressurized sewer system, except for specific areas (Art 2.1.1 and 2.1.3). This case includes an increase of 1,000 m² in impervious surface, a detention or infiltration facility with a minimum capacity of 36 mm (Art 2) must be provided, resulting in a required detention volume of 0.036 m x 1,000 m^2 = 36 m³. Additionally, the Program Water 2020–2025 of the municipality of Voorst states that during the redesign of public spaces, the disconnection of rainwater will be employed as a means for both system efficiency and sustainability (Gemeente Voorst, 2020). On top of this, national water regulations still apply. These address reuse systems like this specifically but prohibit the use of collective systems. Therefore, the reuse system should stay within the premises of the sports facility.

The regulatory requirements are as follows:

1. No discharge to the sanitary or pressurized sewer system is permitted, unless explicitly allowed in designated zones.

2. Rainwater disconnection is expected as a standard sustainable measure during the redevelopment of public spaces.

3. A detention or infiltration facility with a minimum capacity of 36 mm for every m² of added impervious surface must be provided (resulting in 36 m³ for this project).

4. Non-potable water systems are prohibited from being used as a collective water supply.

5. Design Options and Considerations

This chapter identifies and discusses the available options that can be used in the design of a RWHS suitable for natural grass sports field. It focusses on existing systems, and available components.

5.1 Existing Systems

Several systems for natural grass sports fields in the Netherlands incorporate, or could incorporate, rainwater harvesting. This helps to establish context, examine the available options, and set up the comparative analysis in the following sections. Some of these systems feature unique irrigation options, therefore a brief discussion on sprinkler irrigation is given first.

There are two irrigation options available for natural grass sports fields. The conventional solution is via a sprinkler system, but solutions for subsurface irrigation are also available. Field studies have shown wind drift and evaporation losses for sprinkler irrigation typically ranging between 25% and 36% under field conditions, with some extreme cases approaching 50% (Aminpour et al., 2023). Subsurface irrigation substantially reduces these losses. Subsurface irrigation alone is typically insufficient, because it cannot always supply enough water, due to limitations of capillary rise for example. Fields are also often pre-wetted before matches (G. Olthuis, personal communication, 2025). As a result, it is uncommon for fields to rely exclusively on subsurface irrigation.

One system is DrainTalent. It is a system designed for water management on natural grass sports fields. It integrates drainage, infiltration, aeration, and water reuse if a buffer is used. DrainTalent uses a network of closely spaced drains (1.4 m apart), connected to a reversible pump system that can both extract and re-infiltrate water into the soil (DrainTalent, 2024). The subsurface re-infiltration of water gives this system an efficient irrigation option, by minimizing losses experienced with typical sprinkler systems. The system typically consists of 20 cm of topsoil, underlain by 22 cm of drainage sand, where the drains are located. Underneath the field is an impermeable membrane. Instead of discharging all excess water, a portion can be buffered in an external tank for later reuse, either re-infiltrated into the soil or supplied to the irrigation system.

Permavoid is a system with similar functions, but it uses crates instead of drainage pipes. These have a void ratio of 96% and are used to store the water under the field. A void ratio of 96% means that nearly the entire internal volume of the crates is available for water. According to the supplier one full-size pitch (~8,000 m²) can store between 600 and 1,120 m^3 of stormwater, depending on the crate height and the maintained water level in the crates. The water is passively delivered to the root zone of the grass via capillary fibre columns (Permavoid, 2020). In figure 3 the layered build, up of the system can be seen. The key difference between these solutions is that Permavoid provides storage capacity underneath the field, whereas DrainTalent requires less construction material but depends more on external storage if reuse is desired.

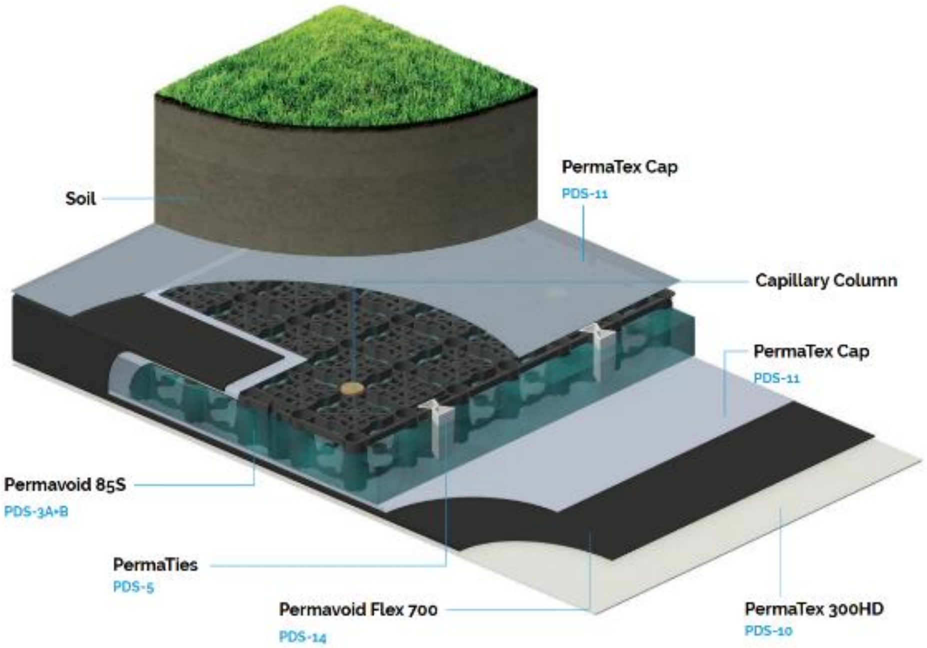

Figure 3 Permavoid Sports System: Hybrid and Natural Grass (Permavoid, 2020)

The Waber system developed by GKB and Finovi (previously TopGrass), was primarily aimed at utilization under synthetic turf. It aims to combine water storage and pressure distribution in an integrated construction. It consists of geotextile that is either water permeable or repellent, depending on whether the design aims for infiltration or water reuse. Above this, a coarse gradation of natural stone with a high void ratio to achieve the capacity is placed to store water. On top of this the stabilizing layer to achieve the sport technical requirements is placed covered by a permeable geotextile. Covering it all is the synthetic turf. The suppliers mention that the system could be used for natural grass, the specifics are not mentioned nor is a case study available yet. (Finovi, 2025) (GKB, 2025) The basic build up for a synthetic turf field can be seen in figure 4.

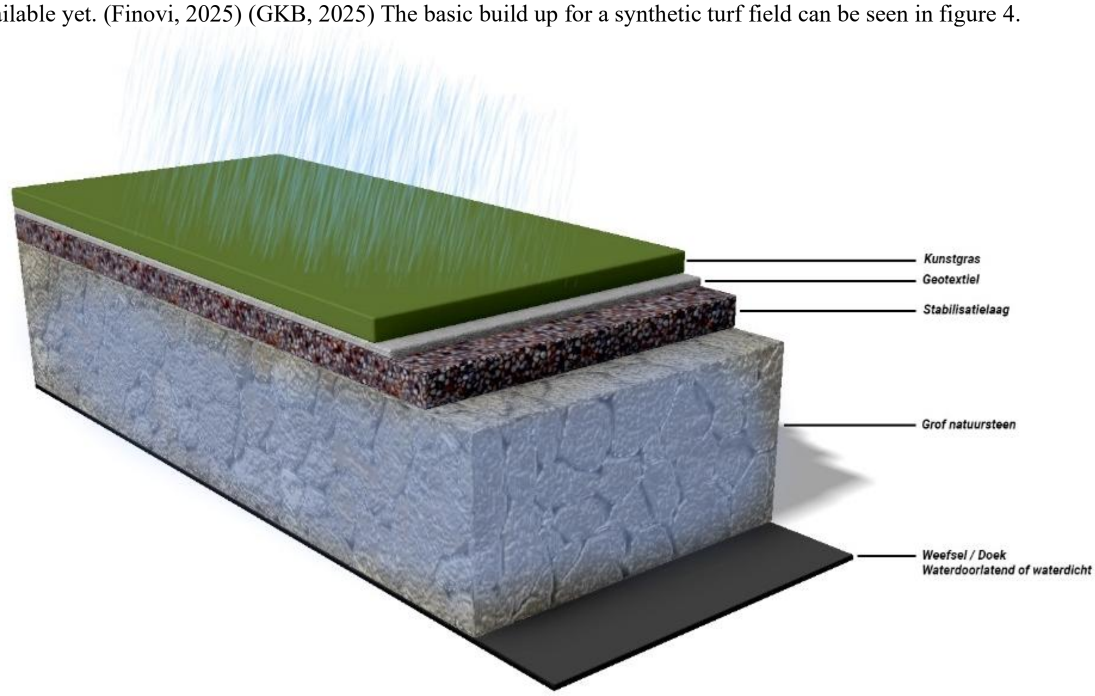

Figure 4 WABER®-system for a synthetic turf field (GKB, 2025)

A promising integrated solution that addresses both spatial constraints and groundwater recharge needs is the combination of RainShell and Fast High Volume Infiltration. It combines Rain Shell from EWB, an underground system that collects, filters, and buffers rainwater using natural materials such as shells and minerals, making it suitable for both infiltration and storage. The system also incorporates the Fast High Volume Infiltration technique owned by Van Tongeren Watertechniek: a patented method for fast vertical infiltration, even in clay and peat soils (Valkema, 2025). The Rain Shell system is stable enough to serve as a base for a sports field, making it structurally suitable for load-bearing applications such as under natural grass sports fields. The shell-mineral mixture features a low specific gravity and a high porosity of approximately 70%, though these values vary depending on the proportion of filtering minerals used. (G. Pannekoek, personal communication, 2025) The rainwater passes minerals, which removes dissolved contaminants, such as heavy metals, mineral oils, and PAHs. Fine organic particles and microbiological contaminants that pass through the wall of the inlet distribution drain are broken down in the system. This is because the Rain Shell functions as a bioreactor in which aerobic and anaerobic conditions alternate. Very fine inorganic particles do not cause clogging, as the shell fragments in the system provide a large contact surface. Sand or silt that passes through a settlement tank or sand trap accumulates in the inlet distribution drain, which can be inspected and cleaned with standard sewer cleaning techniques (EWB, 2025). Fast High Volume Infiltration is a way to quickly infiltrate water and is based on the principle that infiltrating water into specific infiltration layers within an aquifer is significantly more efficient than infiltrating into the entire aquifer (Van Tongeren, 2025). In a sports field application, the RainShell system can be installed beneath the topsoil to provide filtration and storage, while simultaneously serving as the fields drainage. The excess rainwater can be conveyed to the vertical infiltration unit for groundwater recharge. Since this promotes net infiltration, conventional groundwater-based irrigation can still be used during dry periods to supplement irrigation from the stored water. The standout feature of this system is the integration of filtration, storage, and infiltration in a compact system based on sustainable materials.

A more conventional drainage system could also be adapted for rainwater harvesting. A standard drained field sports uses subsurface drainage pipes connected to a collector drain. This conventional setup could be incorporated with a larger external storage. Normally the collected water is discharged immediately to surface water. Such a system would require a larger buffer volume and lack the advantage of subsurface irrigation, increasing irrigation losses. It consists of a sub-surface drainage network. Conventionally drains have a diameter of 65mm and are placed in parallel ditches spaced 4 to 5 meters apart. These drainpipes can connect to a collector drain that brings the water to the location of discharge. The drainage pipes are surrounded by gravel or coarse sand (Kowalewski et al., 2015). In the Netherlands specifically, the drains are almost exclusively surrounded by drainage sand, instead of gravel.

To summarize, DrainTalent delivers water efficiently to the soil but lacks integrated storage. Permavoid provides in field storage and supplies the soil through the capillary columns but requires a large number of plastic crates. The Waber system is promising for synthetic turf but lacks verified applicability to natural grass. The system also uses a large amount of heavy material and needs a relatively deep excavation. The RainShell + Fast High Volume Infiltration system combines treatment, buffering, and deep infiltration. This results in a compact format, addressing space limitations and makes it well fitting within the Integrated Urban Water Management framework.

5.2 Available Components

This section provides an overview of component options for a RWHS. It discusses five subsystems: water treatment, storage, irrigation, discharge, and monitoring. The goal is to support informed design decisions.

5.2.1 Treatment Options

Microbial contamination is a primary concern when harvesting rainwater. Standards for rainwater quality have been established. However, making sure that the harvested water meets these requirements will require treatment. This section outlines available alternatives.

A common treatment method is incorporating a first-flush system. This diverts the first portion of runoff that contains the highest concentration of contaminants. Tsanov et al. (2023) concluded that using a first flush system significantly reduces microbial contaminants in harvested rainwater. First-flush systems are primarily designed for roof runoff, making them less applicable to surface runoff from sports fields. Another option is a screen filter. These remove contaminants, such as large inorganic debris (Haman & Zazueta, 2024). However, the effectiveness against reducing microbial contamination and algae is low (Haman & Zazueta, 2024).

Sand filters remove suspended solids, heavy metals, and pathogens effectively (Raimondi et al., 2023). There is a wide variety in sand filter designs, resulting in significant variation in their effectiveness. The filters also decrease in effectiveness over time and require a significant amount of space. Ceramic filters are effective at removing bacteria and particulate matter and require little space (Raimondi et al., 2023). The downside is the need for frequent replacement and limited flow rate. Granular activated carbon filters are effective at removing organic compounds, but the microbial removal capabilities are limited (Raimondi et al., 2023), making these of limited use when filtering water intended for irrigation.

Bacteria are small, ranging in size from 0.5 to 5 µm (Sapkota, 2023). Therefore, coarser mechanical filtration methods like screen filters will be ineffective at removing them. Membrane filters have gained more interest in treating rainwater. Membranes are compact and have different capabilities depending on the pore size used. The smaller the pore size the more contaminants are filtered out, however it also means more pressure is needed, membrane fouling occurs quicker, and the flow rates are lower (Liu et al., 2021). The membranes are categorised by pore size. Microfiltration membranes (size 0.1–5 µm) remove suspended solids and large bacteria. However, their ability to remove viruses and dissolved organic compounds is limited (Liu et al., 2021). Ultrafiltration membranes (pore size 5–100 nm) also remove smaller pathogens, and some macromolecules. Nanofiltration membranes (pore size 1–2 nm) remove most organic compounds, divalent salts, and microorganisms. Reverse osmosis membranes can even remove monovalent ions and trace organic compounds (Liu et al., 2021). When choosing the route of membrane filtration, it is important to realise while the smaller pore membranes remove more compounds, it causes higher energy demands and cost. For example, for irrigation reverse osmosis would achieve quality levels far exceeding the requirements, which highlights a trade-off between water quality and treatment costs.

A treatment option that is directly targeted at microbial safety is disinfection. It increases the microbial safety of the harvested water by inactivating micro-organisms. One option is chlorination. Highly effective against most pathogens and provides residual protection to the water. However, chlorination requires chemical storage and leads to the formation of disinfection by-products. It also has limited efficacy against chlorine-resistant protozoa such as Cryptosporidium (Raimondi et al., 2023). An option that does not produce by-products is UV disinfection, that is also highly effective against pathogens. It does lack the residual effects of chlorination and requires low turbidity of water in order to function efficiently. (Raimondi et al., 2023)

To summarise, different treatment methods have different upsides and downsides, and the choice ultimately depends on the type of contamination in the influent water and the required water quality. And a combination of methods could provide a suitable option.

5.2.2 Storage Options

Storage plays an important role in RWHS. One storage option consists of polypropylene crates placed under a field to store water, thereby conserving above-ground space. They are modular and are available in different sizes. Periodic monitoring is required to assess potential compaction and fouling. Cleaning may be necessary depending on inspection outcomes (Pötz, 2016). Other porous materials could serve similar water buffering functions. For example, a layer consisting of coarse lava or Grauwacke can be used. Other materials may be used, provided they form a stable foundation, while also having a large void space (Bouwmeester, 2024). Tanks or cisterns can also be used for water storage. Above-ground tanks have the benefit of easy access for both inspection and maintenance. The downside is the space they occupy, which can be undesirable from an aesthetic and practical perspective. Underground tanks preserve surface usability but require extensive excavation and installation effort, with the benefit of more constant temperatures, which helps avoid potential freezing (Jarrett, 2022). A foil basin is an above-ground water storage option that consists of a partially excavated and often raised above the natural ground level using earthen embankments lined with foil. These basins are frequently used in horticulture. These basins can be covered by nets or floating foils to prevent fouling and evaporation. Although not commonly seen in the Netherlands outside of horticulture, they could be used for other applications. Foil basins offer a relatively low cost per cubic meter of storage at larger volumes, making them economically attractive in situations where space is available, and aesthetics is less critical. However, their size can be a disadvantage. (Stowa, 2018)

Table 3 Comparison of Storage Options

Storage Type	Location	Notes
Polypropylene crates	Below ground	Modular; risk of fouling
Porous aggregates (lava, Grauwacke)	Below ground	Must be stable & high void space; risk of fouling
Above-ground tanks	Above ground	Easy to access; space-consuming
Underground tanks	Below ground	A more constant temp; high install effort
Foil basins	Partially above	Common in horticulture; net/foil cover required

The storage methods offer a different balance between trade-offs. Selection depends on factors such as available space, maintenance access, structural requirements, and visual impact.

5.2.4 Discharge Options

As introduced in section 3.3, the storage system will be designed to serve both a retention and a detention function. This dual function supports both water conservation and stormwater management. The detention volume must be actively discharged to maintain available capacity. For this, a dedicated discharge mechanism is needed.

The simplest method to discharge water is through a passive overflow. This could for example be a vertical pipe overflow weir installed at a fixed height, allowing water to flow once the level is exceeded. The main advantage of this is the full control over the overflow level while remaining simple and easy to maintain. However, the exact discharge rate is harder to control, because the discharge rate depends on the water level above overflow, meaning the discharge rate cannot be kept constant. If control over the discharge rate is desired a pump could be used to discharge the water. This gives more control over the discharge rate and could be incorporated with sensors and programmed to respond to expected weather. Using a pump does increase the costs, complexity, and maintenance demands. It is still wise to implement a passive overflow in the case of a power outage, pump failure or when storage is completely full.

The second consideration is the discharge location. There are three main options for this: discharging to the sewer system, surface water, or an infiltration facility. Infiltration is a potential discharge option if the site-specific conditions are suitable. This is the case when soil permeability is sufficient, groundwater levels are not too high, and the infiltrating water does not pose risks for contamination or conflicts with nearby sensitive structures or vegetation (Hau et al., 2024). It can help with groundwater recharge. Discharge to surface water is a viable solution when receiving waters are available within practical proximity. It can prevent overloading sewer systems. It is in most cases considered less favourable to infiltration. According to a STOWA report on stormwater management, infiltration is prioritized because pollutants tend to remain concentrated in the top layer of the soil and the environmental effects of these pollutants are often smaller than in surface water (Boogaard &

van der Hulst, 2004). Discharge to sanitary systems is not allowed in most cases, so discharging to the sewer system requires a stormwater-only sewer to be available.

The discharge approach should ultimately align with local regulations, system demands, and the physical characteristics of the project site.

5.2.5 Monitoring Options

Including monitoring devices in the RWHS can help to track valuable data and detect malfunctions. The first option is a level sensor. According to ACT (2024) some common sensors are the Float Level Sensors, Continuous Level Float Sensors, Capacitive Level Sensors, Ultrasonic Level Sensors, Optical Level Sensors, and Pressure Level Sensors.
Float sensors range from simple devices detecting fixed thresholds, to high accuracy continuous sensors. Continuous float sensors can provide more detailed readings; they achieve this by using a magnetic float and resistive rod. Capacitive sensors detect changes in the dielectric constant of the medium and work well with non-conductive tanks, like the ones frequently used in RWHS. Ultrasonic sensors are installed above the liquid's surface as they measure the distance from the water's surface to the sensor using sound pulses. In contrast, optical sensors utilize infrared light to detect the presence of liquid at a certain location, making them comparable in its capability to basic float sensors. Pressure sensors are submersible devices that measure hydrostatic pressure to calculate depth of a liquid. The appropriate sensor depends on a multitude of factors like tank accessibility, installation environment, required accuracy. (ACT, 2024)

Another useful monitoring device is a flow meter. It can be used to track water usage. This data can help in evaluating the system performance and provide information for system optimization and sizing. According to Eriks (2025) different measuring principles can be used in electronic flow meters. The first type is calorimetric flowmeters, these are known for their durability, but the downside is that they measure the speed of water at the head of the sensor. During high velocities, the difference in the profile of flow can be significant. A vortex flowmeter measures flow, temperature, and pressure, these give reliable measurements during changing condition and have the advantage of already measuring pressure and temperature. Electromagnetic flowmeters are available in a wide range of sizes and does not have moving parts and has a low-pressure loss. Ultrasonic flowmeters are accurate and have the same other benefits as electromagnetic meters. There are also variants available than can be clamped onto existing pipes. (Eriks, 2025)

6. System Configurations

This chapter presents the system configurations based on the specific case and options identified earlier. The options will be discussed in terms of benefits and drawbacks and their unique features. The different components of the system will also be explained in sufficient detail for the economic evaluation. The primary focus is on the hydrological performance of each system.

Table 4 Presentation of Alternatives

Alternative 0	A conventional drainage system with direct discharge
Alternative 1	A conventional drainage system with a foil basin
Alternative 2	Rainshell + Fast High Volume Infiltration
Alternative 3	DrainTalent System with a foil basin
Alternative 4	Permavoid System

Since sprinklers are also used pre-game to improve playing conditions, sprinkler systems are assumed to be needed in all the alternatives. For this reason, these are not discussed here. It is important to note that some of these systems include alterative irrigation methods that can save additional water.

6.1 Alternative 0: Conventional Drainage

Alternative 0 is a standard drainage configuration without water reuse or buffering. It serves as the reference for all other alternatives, where all the irrigation water is extracted from ground water. It is made up of horizontal subsurface drainage pipes (PP450 Ø65 mm) placed at 4-meter intervals, embedded in sand-filled trenches, and positioned at an invert level of 0.60m. Before the drains are installed the upper soil is prepared and profiled to establish a stable and well-draining field. All the drains are connected to an inspection and maintenance chamber (drainage inspection pit Ø315 mm). This allows for access to the drains and gives the ability to more easily clean them. The chambers are connected to a main discharge pipe (PVC Ø125 mm), which transports the water to a surface water body. This serves as the baseline scenario providing the function of removing excess water from the field.

6.2 Alternative 1: Conventional Drainage + Foil Basin

Alternative 1 builds upon alternative 0, by adding water storage and reuse. This can be achieved by incorporating a covered foil basin. The foil basis consists of earth embankment covered by an impermeable membrane (LDPE). The water flows from the drainage system to a control pit, where the water gets pumped to a foil basin using a high capacity pump. The foil basin stores the water. The basin must reserve a portion of its volume for temporary detention or infiltration. The rest is available for irrigation. The untreated water might not meet the requirements for water quality; therefore, a water treatment unit needs to be present. This is placed between a suction pump that transports the water from the foil basin to the irrigation system. The combination used in this case will be fine filtration followed by UV disinfection. The detention capacity of the foil basin will be maintained by a small pump discharging excess water to surface water.

6.3 Alternative 2: Rainshell + Fast High Volume Infiltration

Alternative 2 is the Rainshell + Fast High Volume Infiltration configuration. It consists of a layer of washed shells mixed with filtering minerals below the field, with the thickness of the layer depending on the desired storage. Before building the layers, the whole field needs to be excavated to the level of the bottom of the shell layer. The bottom of the excavation is lined with an impermeable membrane. The shell layer is covered by permeable geotextile above this the topsoil layer with a thickness of around 20 cm is placed. The level in the shell layer is maintained through an overflow pit that is connected to the drains or drain in the shell layer. Since the mineral filtering properties diminish over time (expected life is span 30 years) while the storage capacity (expected life span 100 years) remains functional, an external filtering unit is recommended. This ensures that the water treatment minerals can be replaced without needing to rebuild the storage layer with minerals mixed in (personal communication Ger Pannekoek, 2025). An external unit containing the standard Rainshell mineral mix filters the water before it flows to a drain and is transported to a pump pit. Excess water during heavy precipitation events is rapidly infiltrated through Fast High Volume Infiltration. This is useful when a larger surface or field is connected to the system. If supplemental ground water is needed this will be less than the water that has been infiltrated in the through Fast High Volume Infiltration. One large benefit of this system is the amount of water that can and will be treated during the life cycle of the system, this includes the water infiltrated by Fast High Volume Infiltration.

6.4 Alternative 3: DrainTalent

Alternative 3 is a configuration using the DrainTalent system. It is made up of horizontal subsurface drainage pipes placed at 1.4-meter intervals, in a layer of drainage sand, and positioned at an invert level of around 0.42 m below surface level. Before building the layers, the whole field needs to be excavated to the level of the bottom of the drain. The drains are connected to three main discharge and supply pipes. This transports the water to the pump or from the pump to the drains to supply water. The bottom of the excavation is lined with an impermeable membrane. The sand layer is around 22cm, and above this the topsoil layer with a thickness of around 20 cm is placed. To reuse the water the same storage and treatment configuration could is used as presented in alternative 1. The water can be pumped back into the field or to supply the irrigations system. This system reduces irrigation demand by recharging soil moisture via subsurface irrigation, though the exact savings are difficult to quantify. For the Draintalent system the same configuration treatment and storage configuration will be used as in alternative 1 with the foil basin and filtration and UV disinfection configuration.

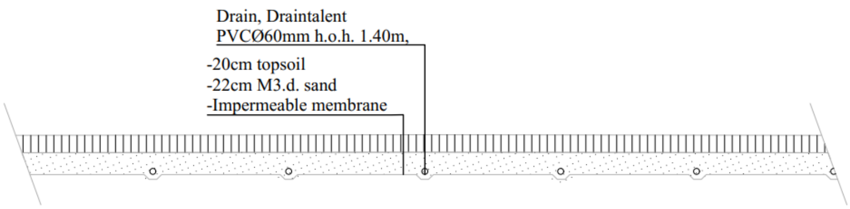

Figure 5 Cross-section of the DrainTalent system (Alternative 3), with subsurface drains at 1.4 m intervals in a sand layer over an impermeable membrane

6.5 Alternative 4: Permavoid

Permavoid is a system with similar functions and benefits to Draintalent, but it uses crates instead of drainage pipes. These have a void ratio of 96% and are used to store the water under the field. The water is passively delivered to the root zone of the grass via capillary fibre columns (Permavoid, 2020). The biggest difference between these solutions is that Permavoid provides storage capacity underneath the field, whereas DrainTalent requires less construction material but depends more on external storage if reuse is desired. The water level in the crates is used to regulate the moisture of the soil. In anticipation of heavy precipitation, the crates can be fully emptied, to clean the system and to allow for quick drainage and renewal of the water (personal communication Geert Olthuis, 2025). This system already has a partial water buffer built in under the field. Geert Olthuis (2025) estimated the system reduced irrigation demand by around half compared to nearby fields without Permavoid, based on his experiences with the fields he manages that do not have the Permavoid system. To reuse the water the same storage and treatment configuration could be used as presented in alternative 1. The system also incorporates air shaft to regulate the pressure in the air layer above the water in the crates, this can be used to create underpressure making drainage faster, or overpressure, supplying air to the soil. In figure 6 a cross section of the system can be seen. This includes a control pit to manage the water level in the crates. On the left side the air shaft to manage pressure is located.

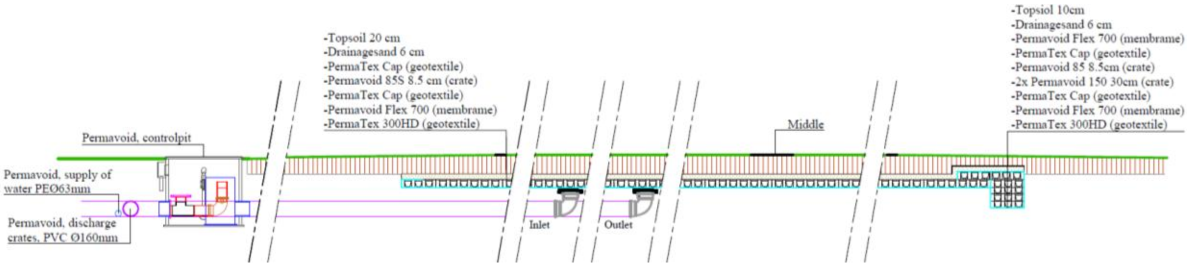

Figure 6 showing stacked storage crates with geotextile and membrane layers for subsurface water storage and capillary irrigation. The system includes a control pit for water level management and an air shaft to regulate pressure in the air layer above the crates.

7. Simulation of Performance

This chapter presents a model capable of simulating the daily water balance of a RWHS. This can be used to estimate performance indicators, such as the reuse efficiency, the utilisation of storage, and the occurrence of overflows. The model is based on a single natural grass sports field, with no additional water input except for the precipitation and irrigation water that falls on the field. The water from the RWHS is used solely to meet the irrigation demand of the field. This represents an extreme test case that is characterised by a mismatch between water availability and irrigation demand across seasons. For this model, the runoff from 1,000 m^2 of added paved area of the case study is not considered.

7.1 Simulation Model

The model presented is adapted from the one by Corrêa et al. (2024), as shown in chapter 2.4. It incorporates their general order of operations and flow logic. To model a RWHS, which functions as both a reuse system and stormwater buffer, the storage is conceptually divided into two functional components:

1. Reuse Storage (retention): Where water is stored for future use.
2. Buffer Storage (detention): A temporary storage to slow stormwater runoff.

These are not necessarily separate tanks and may represent different functional zones within the same storage. The following water flows are modelled:

1. Rainwater onto the field. (inflow)
2. Irrigation onto the field. (inflow)
3. Inflow fills the reuse storage, and thereafter the buffer storage.
4. If both are full the excess water overflows. (outflow)
5. Water is withdrawn from the reuse volume based on irrigation demand. (outflow)
6. Water discharges from the buffer volume through an overflow. (outflow)

The variables that are tracked daily are:

VolumeBuffer (Volume of rainwater in the buffer storage on the t_{th} day [m^3])
VolumeHarvest (Volume of rainwater in the harvesting storage on the t_{th} day [m^3])
AdjustedInflow (Adjusted inflow of rainwater on the t_{th} day [m^3/day])
BufferInflow (Inflow to buffer section on the t_{th} day [m^3/day])
HarvestInflow (Inflow to harvest section on the t_{th} day [m^3/day])
WaterReuse (Volume of rainwater reused on the t_{th} day [m^3/day])
ExternalIrrigation (Volume of water supplemented outside of the system the t_{th} day [m^3/day])
ETLoss (Volume of rainwater lost due to evapotranspiration on the t_{th} day [m^3/day])
Overflow (Overflow of water storage on t_{th} day [m^3/day])
BufferDischarge (Discharge of water from buffer storage t_{th} day [m^3/day])

The following input parameters are used:

TotalVolume (Max total storage capacity [m^3])
TotalVolumeBuffer (Max buffer storage capacity [m^3])
TotalVolumeHarvest (Max harvesting storage capacity [m^3])
Precipitation (Precipitation [m])
Irrigation (Irrigation demand [m])
Area (Catchment surface [m^2])
C (Runoff coefficient [-])
ET (Evapotranspiration [m])
BufferDischargeRate (Buffer Discharge Rate [m^3])

$$\text{AdjustedInflow} = (\textit{Precipitation} + \text{Irrigation}) \times \text{C} \times \text{Area} \qquad \text{(eq. 6)}$$
$$\text{HarvestInflow} = \max(0,\ \min(\text{AdjustedInflow},\ \text{TotalVolumeHarvest} - \text{VolumeHarvest})) \qquad \text{(eq. 7)}$$
$$\text{BufferInflow} = \max(0,\ \min(\text{AdjustedInflow} - \text{HarvestInflow},\ \text{TotalVolumeBuffer} - \text{VolumeBuffer})) \qquad \text{(eq. 8)}$$

$$\text{Overflow} = \max(0,\ \text{AdjustedInflow} - \text{HarvestInflow} - \text{BufferInflow}) \quad \text{(eq. 9)}$$
$$\text{WaterReuse} = \min(\text{Irrigation},\ \text{VolumeHarvest}) \quad \text{(eq.10)}$$
$$\text{ETLoss} = \min(\text{ET x Area},\ \text{VolumeHarvest}) \quad \text{(eq. 11)}$$
$$\text{BufferDischarge} = \min(\text{VolumeBuffer},\ \text{BufferDischargeRate}) \quad \text{(eq. 12)}$$
$$\text{VolumeBuffer} = \text{VolumeBuffer (previous time step)} + \text{BufferInflow} - \text{BufferDischarge} \quad \text{(eq. 13)}$$
$$\text{VolumeHarvest} = \text{VolumeHarvest (previous time step)} + \text{HarvestInflow} - \text{WaterReuse} - \text{ETLoss} \quad \text{(eq. 14)}$$
$$\text{ExternalIrrigation} = \max(0,\ \text{Irrigation} - \text{WaterReuse}) \quad \text{(eq. 15)}$$

Rainfall and irrigation are first adjusted to account for losses, forming the effective inflow to the system. The runoff coefficient is assumed to be 0.9, representing the fraction of rainfall and irrigation water that reaches the catchment surface. The runoff coefficient incorporates the losses of infiltration to the surrounding soil, and wind drift. First the inflow fills the reuse storage. Any remaining water fills the buffer. If both are full, the system overflows. Water is harvested from the reuse volume based on daily demand, while water in the buffer is discharged at a fixed rate. The model tracks the flows and storages over time. The water reused from storage is withdrawn to meet irrigation demand. It is reapplied to the field and treated as part of the total applied irrigation.

The model accounts for seasonal losses due to evapotranspiration by subtracting it from the storage. This simplifies the tracking of these losses, which in reality occur before the water reaches the storage. As the model focuses on long-term trends rather than short-term variability, no delay or lag is included between rainfall/irrigation and drainage. Water is assumed to enter the storage system on the same day it falls. The discharge from the buffer zone follows a system-specific outflow function, dependent on buffer storage volume modelled daily. In this model the discharge from the detention volume is simplified as a constant outflow rate.

Evapotranspiration is the most significant loss mechanism considered. The losses are computed according to eq. 11. To determine the actual evaporation, the reference evapotranspiration can be estimated using the Makkink method, which is employed by the Royal Netherlands Meteorological Institute (KNMI, 2025). This method estimates reference evapotranspiration from a well-watered grass surface using two inputs, incoming shortwave radiation and air temperature. Although simpler than the Penman method, it provides comparable results under standard conditions (De Bruin and Lablans, 1998). The evapotranspiration from this method represents the reference crop evapotranspiration, defined as the rate of evapotranspiration from an extensive (hypothetical) surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. The actual crop evapotranspiration (ET_c) is the reference evapotranspiration multiplied by the crop coefficient (K_c), (De Bruin and Lablans, 1998) see Eq.16. The average value for the crop coefficient for turf grass is 0.9 (Allen et al., 1998). This value is used in this model.

$ET_c = K_c \times ET_0$ (eq. 16)
ET_c (Actual crop evapotranspiration [m])
K_c (Crop coefficient [-])
ET_0 (Reference evapotranspiration [m])

The Royal Netherlands Meteorological Institute (KNMI) has around 325 precipitation stations around the Netherlands (KNMI, 2025). They publish precipitation data over a 24-hour period (08:00 UTC to 08:00 UTC the next day) publicly. This makes it possible to simulate entire years on a daily basis, aligning with the model. Because of the high coverage, there is a measurement location nearby most locations in the Netherlands. Monthly reference evapotranspiration values for 2024 are provided by KNMI, based on the Makkink method. These are used to compute seasonal ET_c values. Table 5 shows the monthly ET_0 and ET_c values averaged across all base stations (KNMI, 2025). The evapotranspiration volume is computed as the product of daily ET_c (in meters) and field area.

Table 5 Crop Evapotranspiration per Month

Month	JAN	FEB	MRT	APR	MEI	JUN	JUL	AUG	SEP	OKT	NOV	DEC
ET_0(m)	0.105	0.141	0.366	0.605	0.916	0.984	1.025	0.964	0.582	0.306	0.110	0.053
ET_c(m)	0.095	0.127	0.329	0.545	0.824	0.886	0.923	0.868	0.524	0.275	0.099	0.048

The irrigation is based on an estimated demand in an average year for a natural grass field. The estimated irrigation demand from January-December in m/day is: [0.000, 0.000, 0.000, 0.001, 0.002, 0.003, 0.003, 0.0025, 0.0015, 0.0005, 0.000, 0.000]

The model is implemented in Python and runs on a daily timestep. It can be used to model any period, but multi-year or hydrological year simulations are needed to capture seasonal dynamics, particularly the accumulation of storage in wetter winter months and its depletion during drier summer periods. Daily precipitation is sourced from KNMI datasets, with data from a weather station closest to the location of interest. Evapotranspiration is applied as a fixed daily value per calendar month, based on monthly averages. Irrigation is incorporated in two ways: as a component of daily water demand (i.e. reuse), and as an input to the system, representing the portion of irrigation not lost to evapotranspiration. All storage dynamics, including reuse, overflow, and buffer discharge, are simulated using the equations defined earlier. The full implementation is provided in the appendix B. Below the main assumptions are summarized:

-No infiltration to subsoil.
-Weather data is spatially representative.

-Monthly reference evapotranspiration values are applied as constant daily values.
-The turf is assumed to be well-watered.
-Water is assumed to reach the system on the same day it falls.
-No internal soil storage or capillary retention is modelled.
-Irrigation is a monthly constant value applied each day, not changing over the years.

The simulation model gives an approach to evaluating the performance of a RWHS. It is, however, subject to several simplifying assumptions that must be understood. One assumption is that irrigation and evapotranspiration demand remain constant year to year. This assumption ignores the reality of interannual climatic variations. Evapotranspiration and irrigation can vary significantly from year to year, so while the model can be used to simulate the average expected performance and does account for variations in precipitation, it might not be a reliable performance indicator in more extreme years. Furthermore, the use of a single runoff coefficient (C = 0.9) to represent a variety of losses is operationally convenient but hydrologically crude. It assumes uniform behaviour independent of the soil conditions and amount of precipitation. The treatment of evaporation as the only explicitly modelled loss is another simplification. Other losses are implicitly accounted for by the runoff coefficient. Additionally, the model assumes no lag between precipitation and system inflow. Although, this might be less of an issue considering the longer period modelled. Despite these limitations, the model still serves its intended purpose of providing a first evaluation to compare and design RWHS. If more detail is required site-specific calibration, more specific climate data, and a deeper integration of soil-water interactions could significantly improve the model's predictive reliability, particularly under variable or extreme conditions.

7.3 Sensitivity Analysis

Although this model does not attempt to simulate the precise behaviour of the alternative systems presented in Chapter 6, it provides general insights into how key design variables affect reuse efficiency and overflow under the specific precipitation and irrigation described before. To evaluate how key design parameters affect system performance, a one-at-a-time sensitivity analysis was conducted. This section assesses how different configuration for the specific case study of an 8,701 m^2 natural grass sports field preforms. It does not consider any of the water from the paved areas flowing into the system.

In this section a sensitivity analysis is presented to show the impact of the main design parameters. It will compare the impact these have on the ReuseEfficiency (WaterReuse / TotalIrrigationDemand), as well as the overflow from the system. The average from the years 2010–2024 is taken. The following parameters varied:
Harvest Volume [m^3]: Total volume allocated for storing reusable water.
Buffer Volume [m^3]: Total volume allocated for temporary stormwater detention.
Buffer Discharge Rate [m^3/day]: The maximum daily outflow from the buffer volume to the environment.

The base values used serve as a medium sized system that discharge the buffer within a day. This can help understand how the system is expected to preform based on changes in these key design characteristics.

Harvest Volume = 200 m^3
Buffer Volume = 36 m^3
Buffer Discharge Rate = 36 m^3/day

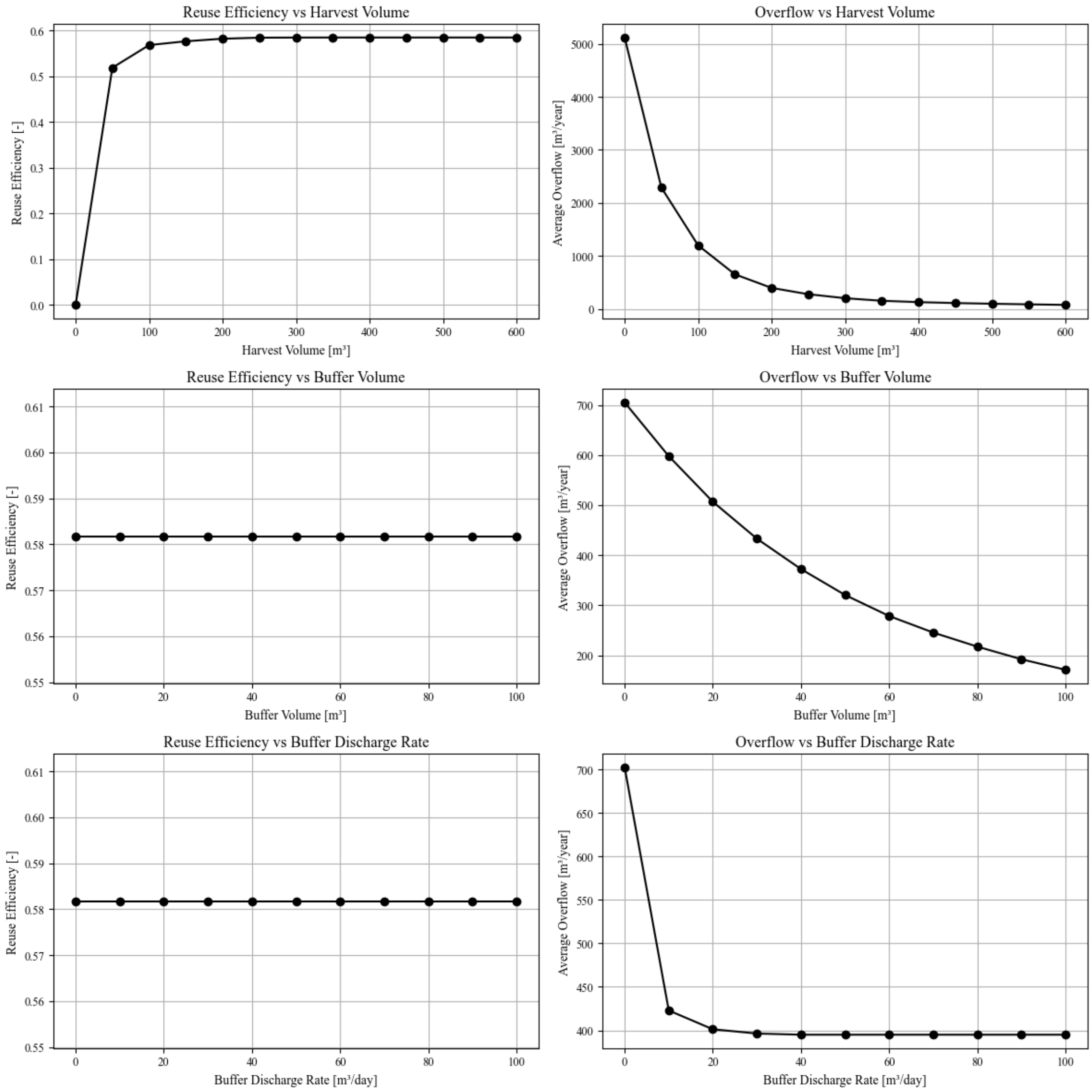

Figure 6 OAT sensitivity analysis results for an 8,701 m² natural grass sports field with irrigation as the sole water use. Parameters: Harvest Volume = 200 m³, Buffer Volume = 36 m³, Buffer Discharge Rate = 36 m³/day.

Harvest Volume

The plot of Harvest Volume versus Reuse Efficiency shows a steep increase in efficiency up to approximately 100 m³, beyond which the curve levels off just below 0.6. This indicates that additional storage improves reuse efficiency significantly up to a point but offers diminishing returns beyond that. To achieve higher reuse efficiency beyond this threshold, larger catchment area would need to be connected to the system to increase inflow. This supports expert recommendations to connect larger catchment areas to a RWHS (personal communication, Joris Bevaart, 2025; Ger Pannekoek, 2025). A similar trend is observed in the Overflow response. Overflow decreases sharply as harvest volume increases but begins to flatten out slightly later. This may be due to extreme precipitation events that continue to exceed storage even at higher volumes. In this case, the catchment simulated includes only the field, which limits the total inflow.

Buffer Volume

As expected, buffer volume has no impact on reuse efficiency, since water stored in the buffer is not reused. However, it has a clear effect on overflow. Increasing buffer volume leads to a consistent reduction in overflow. The effectiveness of even modest buffer volumes may be attributed to seasonal variation: during winter months, irrigation demand is zero while precipitation is high, leading to frequent buffer use. This makes buffer sizing relevant even when average daily inflow appears modest.

Buffer Discharge Rate

The discharge rate also has no effect on reuse efficiency, again due to its independence from the reuse system. However, its effect on overflow is significant. Given the model’s daily timestep, discharge rates equal to or exceeding the buffer volume will empty the buffer completely each day, allowing full capacity for the next event. Conversely, if the discharge rate is too low relative to buffer volume, the buffer cannot recover capacity in time for new inflow, leading to higher overflow.

7.4 Case Analysis

In this section four different scenarios will be further analysed and compared. In the table below the scenarios are shown. The scenarios represent trade-offs between systems storage, discharge rate, and the expected performance.

Table 6 Different Simulation Scenarios

Scenario	Harvest Volume [m³]	Buffer Volume [m³]	Buffer Discharge Rate [m³/day]
1	200	36	36
2	100	10	10
3	300	100	100
4	300	36	9

The first scenario represents the basic design. The second one presents a small storage solution, with the buffer discharge rate set equal to the buffer volume, allowing it to fully empty daily, preventing it from becoming a bottleneck. Scenario 3 is the largest storage solution, that is somewhat oversized for the inflows simulated in this specific case. The fourth scenario uses large storage, but with a reduced buffer discharge rate. This setup helps isolate the effect of a slower buffer discharge rate and can help assess how slower discharge affects system overflows and buffer utilization. The results and plots of performance indicators can be found in appendix A. Below is a short description of the average results. Buffer usage is defined as the average fraction of the buffer being filled throughout the whole simulation. Indicating how much the buffer is utilised.

Scenario 1
This configuration performs well as a balanced baseline. It achieves moderate reuse efficiency of ~0.58 and a modest overflow of ~396m^3/year, largely due to the combined functionality of both storage types. The buffer usage is relatively low at ~0.02.

Scenario 2
The reuse efficiency drops only slightly to ~0.57 due to insufficient harvest volume. The small buffer leads to more overflow ~1762 m^3/year. The system is operating closer to capacity resulting in a higher buffer usage of ~0.08.

Scenario 3
Scenario 3 shows a negligible increase in reuse efficiency of ~0.58. The overflow is significantly reduced to ~72m^3/year . The buffer usage is minimal at ~0.01.

Scenario 4
The reuse efficiency is virtually the same as for the first scenario with ~0.58. Despite the large total storage capacity, the overflow remains modest with ~224m^3/year. The buffer usage is slightly higher with ~0.02, as a result of discharging water slower resulting in a higher average buffer storage volume.

7.5 Conclusion

This section showed a simulation-based assessment of a dual-function RWHS. The model can be used to get a first quantification of the performance of different storage configurations. The model itself could also be adapted for different cases other than a single natural grass field where water is only used for irrigation. This can be achieved by changing the model inputs and parameters. The sensitivity analysis showed strong gains in reuse efficiency up to about 100 m³, after which returns diminish rapidly. This highlights the importance of balancing the inflow availability, water demand, and storage. The model provides a tool to evaluate the expected performance of a system, or at the very least gives an idea about the size of storage needed. This also shows that the reuse potential when only using the water for irrigation is capped at around 60%, this cap theoretically be higher if a larger catchment area would be connected to the system, like the additional paved areas from the case study.

8. Economic Evaluation

This section gives a CAPEX comparison of the alternatives discussed in Chapter 6. The analysis will be based on vendor input, recent comparable projects, and internal price databases. The total estimated renovation costs are based on price levels from 2025 and exclude VAT. Due to confidentiality, individual component pricing is withheld within this report. All costs for the renovation of the field are included except for the sprinkler irrigation system, fences, pavements, and any optional elements such as new goal posts and dug outs. The CAPEX estimates presented in Table 7 are based on a full renovation of the field, this includes: excavation, installation of drains, material costs, and integration of functional system components. In these estimates all excess soil is assumed to be processed on site (no disposal costs of soil). The costs are based on current available data and vendor input but may not reflect final implementation costs. The goal is to provide a comparative overview, not a definitive pricing model.

Table 7 Results of Economic Analysis (CAPEX)

	CAPEX (€)
Alt. 0: Conventional Drainage	36,000
Alt. 1: Foil Basin	59,000
Alt. 2: Rainshell + FHVI	220,000
Alt. 3: DrainTalent	310,000
Alt. 4: Permavoid	424,000

Therse results show a large variation in the costs of the alternatives. These range from €36,000 for conventional drainage (Alt. 0) to €424,000 for the Permavoid system (Alt. 4). The solution adding a foil basin (Alt. 1) adds an additional estimated cost of €23,000. This shows the minimal expected additional investment cost of a project wanting to incorporate rainwater harvesting at this scale. The Rainshell + FHVI system (Alt. 2) is a more advanced and integrated system intended to combine treatment, storage, and infiltration of rainwater. The investment cost of a full field renovation incorporating this system is approximately €220,000. The systems not primarily designed for rainwater harvesting are Draintalent and Permavoid. Draintalent's main feature is the ability to actively drain water from the soil and reinfiltrate water into the soil, by using a pumping unit. The Permavoid system adds crate storage under the field. Within the system, air pressure can be partially regulated, allowing water to be quickly drained. This system also allows for passive irrigation through the capillary columns in the crates. The cost calculation does not include the additional cost required to adapt these systems to full RWHS. These systems still have the highest capital costs but do have clear benefits when it comes to field management. Since this is only the CAPEX and not the total cost of ownership, the actual financial picture could shift dramatically depending on maintenance.

The irrigation demand of a sports field was estimated to be around 3600 m^3. This water can come from different sources: groundwater, surface water, and tap water. Tap water is not the most common water source for soccer fields. However, it is the only source with a known water quality, while groundwater and surface water are commonly used directly without monitoring the quality or using treatment. Therefore, this simplified analysis assumes that the entire irrigation demand is currently met using tap water. In 2025 the price of tap water from Vitens is € 1,15 per m^3 of water. This results in a yearly expense of (€ 1,15 per m^3) x 3600 m^3 = € 4,140 if the full irrigation demand were to be met using tap water. On the first of June 2025, the price of electricity is € 0,268 / kWh (Energievergelijk, 2025). Assuming an energy consumption of 0.5 kWh per m^3 this would result in an annual energy usage of (0.5 kWh per m^3) x 3600 m^3 = 1,800 kWh. At the current price level these costs 1,800 kWh x (€ 0,268 / kWh) = € 482.40, yielding a potential saving of € 3,657.60 per year. This would result in a payback period as shown in table 8.

Table 8 Payback Period

Alternatives	Payback period (years)
Alt. 1: + Foil Basin	6.3
Alt. 2: Rainshell + FHVI	50.3
Alt. 3: DrainTalent	74.9
Alt. 4: Permavoid	106.08

This simplified analysis results in high payback periods, even when compared to tap water. This analysis excludes other costs beyond electricity and water and does not take the additional cost of increased maintenance, replacement of components etc. into account. The only alternative that is likely to have a longer life span than the payback period is alt. 1. Even under optimistic assumptions, these systems are not economically viable if evaluated solely as alternatives to tap water.

The operating and long-term maintenance costs (OPEX) are not fully included in the quantitative analysis due to limited data availability. Therefore, operational differences need to be addressed qualitatively. All alternatives, excluding Alt. 0, rely on pumps and other electricity consuming components, which generate recurring costs. The foil basin system requires regular replacement of filters and periodic replacement of UV components, adding to OPEX. Maintenance for the other systems may involve flushing (drainage pipes) or emptying and inspection of subsurface crates (Permavoid) and drain replacements over time. For the conventional drainage system periodic flushing is required. Although lifespan data is limited for most systems, personal communication with Ger Pannekoek (2025) indicated that the Rainshell storage system has an expected life span of over 100 years, while the mineral mix typically requires replacement every 30 years, depending on site-specific conditions. This is also the reason that for applications under a sports field an external filter is recommended to allow for easy replacement of minerals.

These findings indicate that higher CAPEX is generally associated with increased system complexity and functional benefits. However, the long-term performance, adaptability, and maintenance demands must be weighed carefully in investment decisions. Given the early stage of cost data and the exclusion of a long-term financial analysis, these findings should be seen as a preliminary comparison rather than a prescriptive investment guide. It provides a general overview of expected costs. The next section discusses the applications of alternatives.

9. Comparison of Alternatives

Table 9 below gives a summarized overview of the five alternatives discussed. They are compared based on capital cost, payback period (based on tap water savings), drainage method, storage, treatment method, scope of water treatment, and irrigation options. This helps show the tradeoff between the systems. More details, caveats, and limitations can be found in the previous chapters.

Table 9 Results of Comparison of Alternatives

	Cost (€)	Payback Period (years)	Drainage Method	RWHS Storage	Water Treatment Method	Scope of Water Treated	Irrigation Options
Alt. 0: Conventional Drainage	36,000	-	Perforated drainage pipes (4m spacing)	No	No	No water	No additional options
Alt. 1: + Foil Basin	59,000	6.3	Perforated drainage pipes (4m spacing)	Yes (250 m^3)	Filtration + UV disinfection	The water reused for irrigation	No additional options
Alt. 2: Rainshell + FHVI	220,000	50.3	Integrated shell-based drainage system	Yes (250 m^3)	Filtering mineral mix	The water reused for irrigation and the water infiltrated through FHVI	No additional options
Alt. 3: DrainTalent	310,000	74.9	Active perforated drains (1.4 m spacing), capable of regulating pressure	Yes (250 m^3)	Filtration + UV disinfection	The water reused for irrigation	Subsurface irrigation through drains
Alt. 4: Permavoid	424,000	106.1	Crate-based subsurface drainage, capable of regulating pressure	Yes (710 m^3), available as a buffer and to supply water for subsurface irrigation	None	None	Subsurface Irrigation through capillary columns

There are large differences between the five alternatives. Each alternative has potential value, depending on the context and objectives of a project. Alternative 0, the conventional drainage system, remains the most practical option for most renovations. It is the least expensive option and currently functions well with sufficient natural water supply and reliable drainage infrastructure present in most locations. Although this might become an issue in the future. As it stands it offers a simple, low maintenance solution. In contrast, the other options are designed with more specific goals in mind. Alternatives 1 through 4 tend to benefit from economies of scale, making them more suitable for larger scale installations. This contrasts with the small case study considered in this project. Alternative 1, the foil basin, could be suitable for sites with sufficient space. It provides an affordable system through the use of a simple and scalable storage that can be integrated into a conventional drainage layout. A more integrated approach offering combined storage, infiltration, and water treatment can be provided by alternative 2 (Rainshell + FHVI). It is well suited for projects aiming for groundwater recharge and the management of multi-source runoff, including paved areas. The treatment system is effective at removing common pollutants, making it a strong choice where water quality improvement is a key concern. The other alternatives 3 (Draintalent) and 4 (Permavoid) are designed for high-performance natural grass sports fields. These systems offer pressure-regulated drainage, allowing use of the field even during heavy rainfall. This offers a solution for fields that need to maintain a high quality and remail playable year round. However, when water conservation and water quality benefits are the primary concern, the other systems such as Alt. 1 or 2 can deliver greater value at a lower cost.

10. Conclusion

The aim of this research was to explore how RWHS can be effectively designed and evaluated for Dutch infrastructure projects, with a specific focus on natural grass sports fields. This chapter answers the research questions and summarizes the main findings.

How can a context-specific RWHS be integrated into Dutch infrastructure projects for non-potable applications in a cost-effective and technically feasible manner?

A context-specific RWHS can be integrated into Dutch infrastructure projects by aligning the system design with local regulatory requirements, determining the desired water quality, selecting treatment methods, and assessing the performance of a proposed system. Making it cost effective requires focusing on the multifunctionality of RWHS (e.g., stormwater management, compliance with buffer/infiltration rules, improved runoff quality). This also requires a broader view of the benefits outside of monetary value. The systems can help manage stormwater, meet buffering and infiltration regulations, and contribute to runoff quality improvement.

What physical and regulatory requirements apply to the site-specific RWHS?

RWHS must adhere to both national and local regulations. In the selected case in the municipality of Voorst, discharging rainwater into the combined sewer system is not allowed, and a minimum detention volume of 36 mm must be realized for every added m^2 of impermeable surface. Most municipalities in the Netherlands have similar regulations in place. The national regulations prohibit the use of collective non-potable systems for multiple consumers unless they are exempted. They do not discuss private RWHS, making systems of this type mostly unregulated. Rainwater harvesting carries clear infection risks, so even though it is not regulated, certain standards are still recommended. Regulation (EU) 2020/741 Class B can be used as a conservative standard for irrigation water.

How do different RWHS perform in terms of water reuse efficiency and storage capacity, based on a simplified hydrological model?

The analysis is based on a simplified YAS (Yield After Spill) model, adapted for the specific case of a natural grass sports field serving as the catchment area, and the only use being irrigation of that field. Harvest volume had the largest impact on reuse efficiency. For this specific case, the returns from increasing storage volume diminished rapidly beyond 100 m^3, indicating that a larger catchment surface is required to fully meet irrigation demand. This also implies that required storage volumes will largely depend on the size of the connected catchment area. A sports field presents an extreme case for rainwater harvesting, as irrigation demand is highest when rainfall and evaporation are lowest and vice versa. Overflows also decrease with an increase in the total storage size, but it is also affected by the rate of discharge from the buffer volume. Lower discharge rates limit the system's responsiveness to consecutive rainfall events, leading to higher overflow volumes.

What are the expected costs of different systems, and how do they compare to a conventional design?

The economic evaluation showed that integrating rainwater harvesting brings significant extra upfront investments. In the analysis performed in this thesis, the investment costs for a full field renovation incorporating some sort of rainwater harvesting were compared to a conventional design. This indicated that a simple solution, such as a foil basin with external treatment, is likely to bring the lowest extra cost. Integrated systems like Permavoid and Draintalent bring significant extra cost but do have additional benefits. Both systems have subsurface irrigation options that can reuse water infiltrated in the soil. These are also designed to optimize natural grass pitches. Rainshell+FHVI offers the most comprehensive approach to sustainable water management among the alternatives considered.

Altogether, these findings indicate that RWHS in Dutch infrastructure is both technically feasible and legally permissible for non-potable applications. From an economic perspective they are still quite unattractive as an alternative water source but become more attractive once their multifunctionality is taken into account.

11. Discussion

This study shows that RWHS are both technically and legally feasible in Dutch infrastructure projects. However, they are only economically viable when they deliver multiple benefits. In simple terms: these systems will not save you money on your water bill. But they can help manage heavy rainfall, reduce water pollution, and meet regulatory buffer and infiltration requirements.

This aligns with findings from Hofman-Caris et al. (2018), who examined the usefulness of rainwater harvesting for potable uses in the Netherlands. They concluded that rainwater harvesting was significantly more expensive than the centralized existing drinking water supply, but prices get closer once the scale of the RWHS increases. They noted that rainwater will have to be collected anyway due to increasing extreme rainfall, so it might as well be used. For non-potable applications like irrigation, the requirements are lower, so in areas where stormwater needs to be captured regardless, this becomes a logical step. From a more practical perspective, RWHS implementation makes the most sense when water supply, drainage, and storage are integrated from the start. This could be in the development of new sports parks or residential areas. This aligns with the thinking approach advocated for by Mitchell (2006), where water infrastructure is treated as part of a larger, interconnected system. However, barriers remain. Currently the Dutch regulations prohibit collective non-potable systems unless exempted. This in combination with separation of responsibilities inside municipalities, could complicate the realization of larger scale integrated systems.

This research has several limitations. The economic comparison relies on estimated capital expenditures and excludes operational costs, making a full life-cycle cost analysis impossible. This is combined with a lack of data about the expected life of the different proposed alternatives. The rainwater harvesting model simplifies hydrological processes and lacks calibration. Furthermore, this thesis focused on a natural grass sports field, which is an atypical catchment with a unique demand pattern. Although treatment options were explored, no quantitative evaluation of treatment performance was conducted.

Future research should focus on:

- Developing and validating more detailed hydrological models for RWHS performance
- Comprehensive life-cycle cost analyses, including both CAPEX and OPEX
- Broader case studies that include varied catchments, such as mixed-use urban areas
- Empirical research on water quality outcomes from different treatment methods

The monitoring and evaluation of existing RWHS systems can also inform regulations and help define practical standards and guidelines. So, while RWHS may not be a perfect solution, they could be a promising alternative water supply if designed and implemented with scale, multifunctionality, and long-term adaptability in mind.

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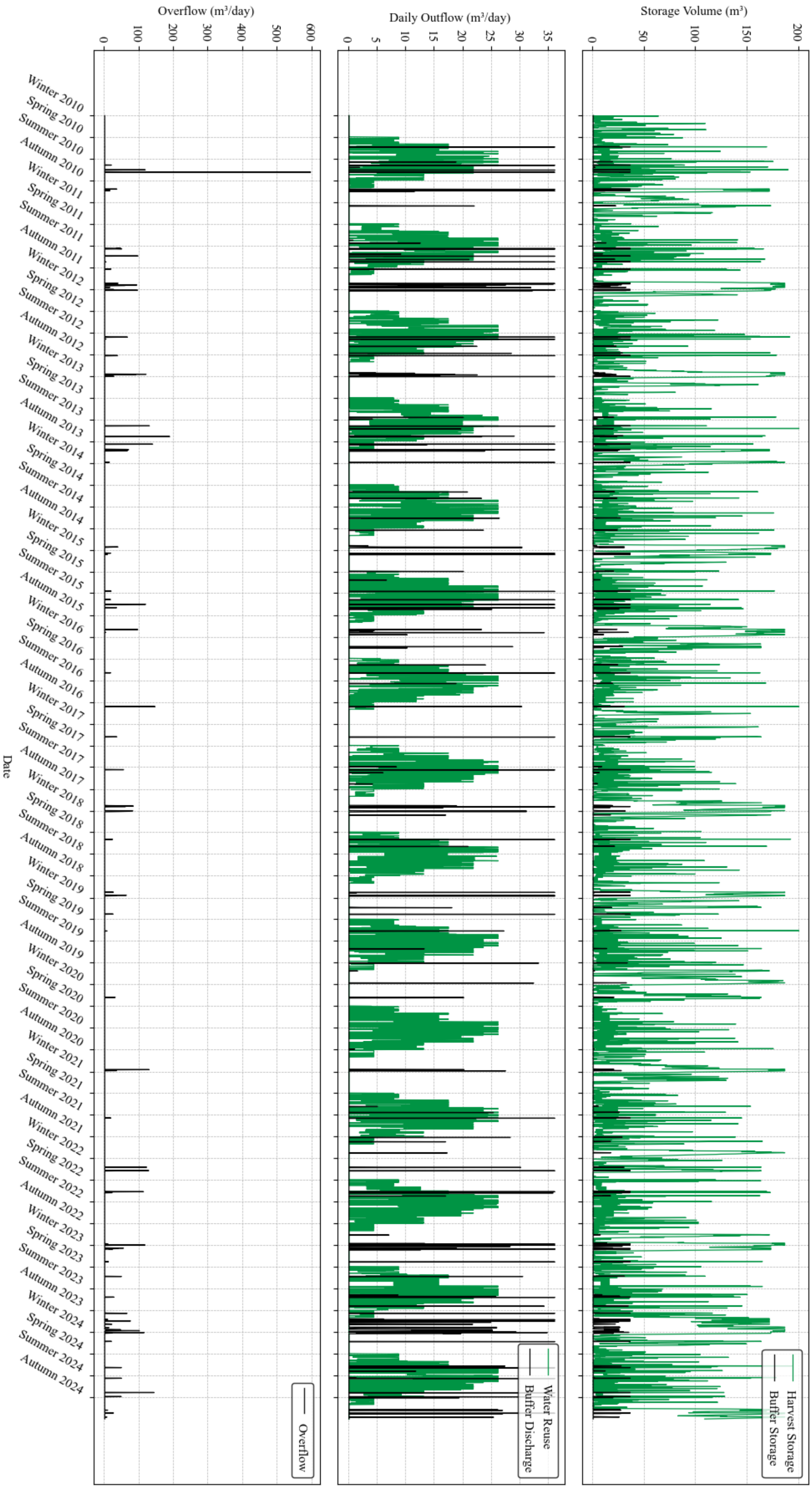
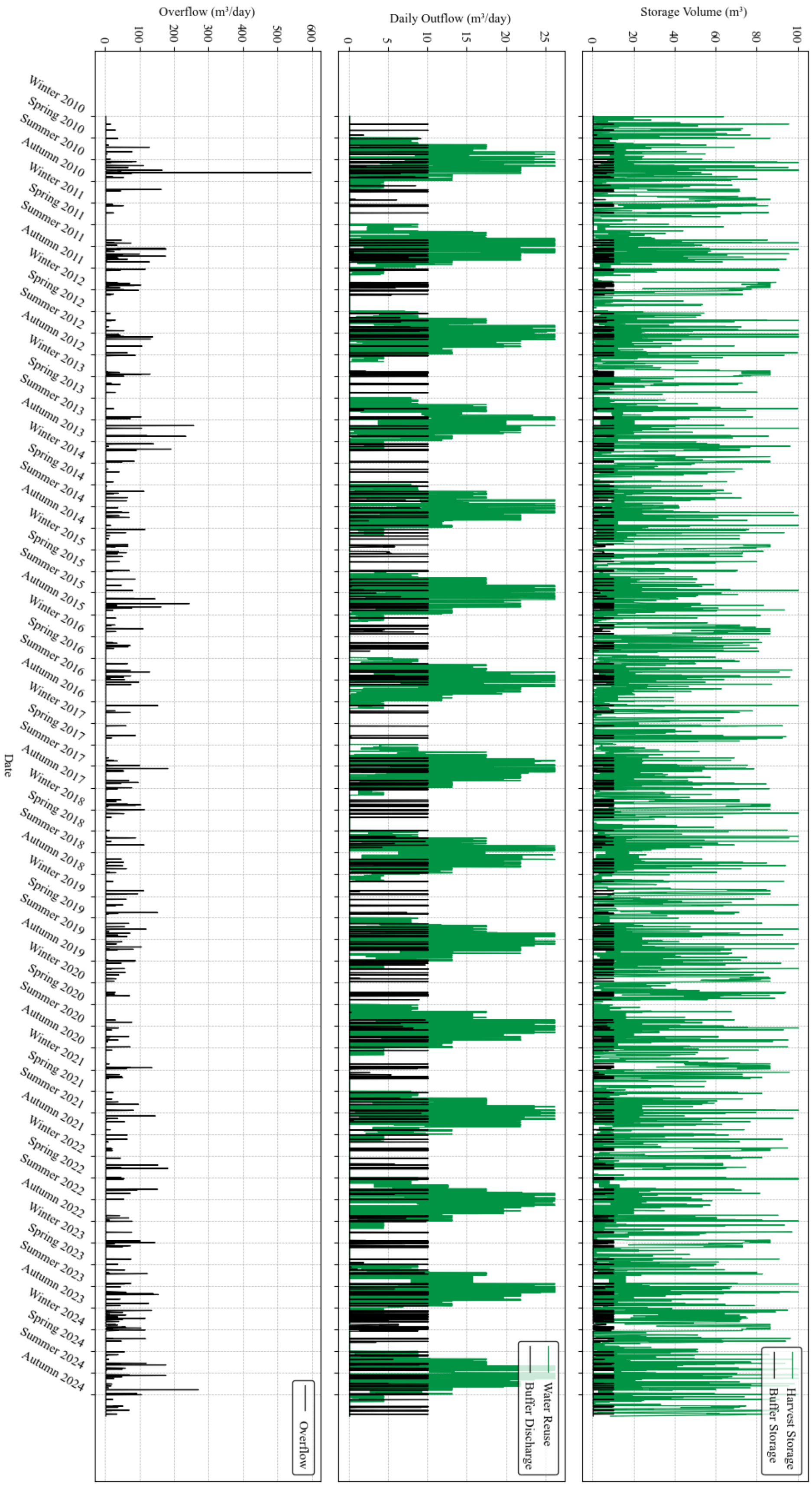
Appendix

A. Results from Model



Scenario 1


Overflow (m³/day)
Daily Outflow (m³/day)
Storage Volume (m³)
Date
Overflow
Water Reuse
Buffer Discharge
Harvest Storage
Buffer Storage

Scenario 2


Overflow (m³/day)
Daily Outflow (m³/day)
Storage Volume (m³)
Date
Overflow
Water Reuse
Buffer Discharge
Harvest Storage
Buffer Storage

Scenario 3


Overflow (m³/day)
Daily Outflow (m³/day)
Storage Volume (m³)
Date
Overflow
Water Reuse
Buffer Discharge
Harvest Storage
Buffer Storage

Scenario 4

Results sensitivity analysis:

ReuseEfficiency	OverflowRate	HarvestVolume	BufferVolume	BufferDischargeRate
0.567843	0.122671	100	36	36
0.576208	0.066537	150	36	36
0.581762	0.040292	200	36	36
0.584005	0.028215	250	36	36
0.58426	0.020414	300	36	36
0.581762	0.040292	200	36	36
0.581762	0.03278	200	50	36
0.581762	0.023716	200	75	36
0.581762	0.017609	200	100	36
0.581762	0.008953	200	150	36
0.581762	0.04311	200	36	10
0.581762	0.040645	200	36	25
0.581762	0.040292	200	36	36
0.581762	0.040292	200	36	50
0.581762	0.040292	200	36	75

Scenario 1:

Year	Overflow	WaterReuse	ExternalIrrigation	ETLoss	TotalIrrigationDemand	BufferDischarge	ReuseEfficiency	OverflowRate	BufferUtilization
2010	898.256	2126.437	1467.076	7059.289	3593.513	248.0917	0.591743	0.087236	0.018881
2011	494.3061	2184.698	1408.815	6491.144	3593.513	464.853	0.607956	0.050567	0.035377
2012	501.4406	2143.317	1450.196	6278.078	3593.513	386.0164	0.596441	0.054197	0.029297
2013	714.1871	1989.658	1603.855	6321.649	3593.513	400.4739	0.55368	0.076287	0.030477
2014	53.55543	2154.455	1439.058	6498.51	3593.513	171.7194	0.59954	0.006076	0.013068
2015	374.8841	2235.113	1358.4	7420.621	3593.513	368.0702	0.621985	0.036303	0.028011
2016	162.3029	2106.077	1487.436	6831.896	3593.513	153.4623	0.586077	0.017763	0.011647
2017	325.9841	2166.114	1427.399	6950.092	3593.513	214.825	0.602785	0.033207	0.016726
2018	391.5758	1911.784	1681.729	5718.015	3593.513	260.012	0.53201	0.048095	0.01941
2019	30.74378	2036.121	1557.392	7813.768	3593.513	172.2415	0.56661	0.003073	0.013108
2020	194.2727	2018.11	1575.403	6645.02	3593.513	145.1742	0.561598	0.02153	0.011018
2021	17.46013	2137.749	1455.764	6805.931	3593.513	128.5846	0.594891	0.00195	0.009786
2022	578.0232	1929.708	1663.805	6039.496	3593.513	237.5346	0.536998	0.064862	0.020817
2023	681.2202	2090.589	1502.924	8333.965	3593.513	797.4325	0.581768	0.057667	0.057948
2024	506.2486	2128.613	1464.9	8098.741	3593.513	502.0351	0.592349	0.045575	0.038102

Scenario 2:

Year	Overflow	WaterReuse	ExternalIrrigation	ETLoss	TotalIrrigationDemand	BufferDischarge	ReuseEfficiency	OverflowRate	BufferUtilization

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2010	2266.993	2120.782	1472.731	5791.389	3593.513	239.0402	0.590169	0.220164	0.06549
2011	2317.295	2113.038	1480.475	5084.904	3593.513	322.5848	0.588015	0.237056	0.088379
2012	1736.407	2057.315	1536.198	5319.918	3593.513	313.7449	0.572508	0.187675	0.085723
2013	2048.484	1956.532	1636.981	5223.593	3593.513	211.8017	0.544462	0.218812	0.058028
2014	1209.238	2110.305	1483.208	5372.983	3593.513	239.9973	0.587254	0.137188	0.065753
2015	1842.795	2198.507	1395.006	6071.648	3593.513	302.5821	0.611799	0.178451	0.082899
2016	1401.818	2063.903	1529.61	5575.911	3593.513	196.3684	0.574341	0.153421	0.053653
2017	1577.5	2112.828	1480.685	5798.386	3593.513	266.6039	0.587956	0.160694	0.075782
2018	1330.991	1882.922	1710.591	4869.651	3593.513	241.1733	0.523978	0.163476	0.063335
2019	1662.215	1991.771	1601.742	6163.157	3593.513	305.0632	0.554269	0.166168	0.083579
2020	962.1448	1955.227	1638.286	5900.981	3593.513	251.9791	0.544099	0.106626	0.068847
2021	1101.658	2071.56	1521.953	5645.483	3593.513	238.8406	0.576472	0.123027	0.065436
2022	1910.186	1900.559	1692.954	4891.491	3593.513	236.3429	0.528886	0.214349	0.067491
2023	2746.208	1994.433	1599.08	6784.674	3593.513	435.7698	0.555009	0.232475	0.116649
2024	2313.116	2078.582	1514.931	6623.828	3593.513	349.3206	0.578426	0.208236	0.095443

Scenario 3:

Year	Overflow	WaterReuse	ExternalIrrigation	ETLoss	TotalIrrigation Demand	BufferDischarge	ReuseEfficiency	OverflowRate	BufferUtilization
2010	547.7129	2165.94	1427.573	7419.659	3593.513	186.5089	0.602736	0.053192	0.00511
2011	46.67335	2204.05	1389.463	6922.495	3593.513	361.783	0.613341	0.004775	0.009912
2012	73.03738	2144.274	1449.239	6647.707	3593.513	423.9952	0.596707	0.007894	0.011585
2013	24.93133	1999.664	1593.849	6887.05	3593.513	541.3717	0.556465	0.002663	0.014832
2014	0	2154.455	1439.058	6641.821	3593.513	31.5081	0.59954	0	0.000863
2015	9.73009	2260.694	1332.819	7875.95	3593.513	249.4937	0.629104	0.000942	0.006835
2016	0	2106.512	1487.001	7166.297	3593.513	81.36483	0.586199	0	0.002223
2017	44.50858	2166.114	1427.399	7129.947	3593.513	216.4449	0.602785	0.004534	0.006066
2018	120.5448	1927.446	1666.067	5887.521	3593.513	334.876	0.536368	0.014806	0.009039
2019	0	2036.121	1557.392	8068.775	3593.513	0	0.56661	0	0
2020	0	2018.11	1575.403	6764.94	3593.513	151.8429	0.561598	0	0.004149
2021	0	2137.749	1455.764	7046.755	3593.513	0	0.594891	0	0
2022	41.56072	1937.539	1655.974	6423.917	3593.513	229.0568	0.539177	0.004664	0.009015
2023	102.7948	2105.903	1487.61	8782.594	3593.513	978.1769	0.586029	0.008702	0.02406
2024	71.49671	2128.613	1464.9	8664.348	3593.513	360.8769	0.592349	0.006436	0.00986

Scenario 4:

	Year	Overflow	Water Reuse	ExternalIrrigation	ETLoss	TotalIrrigationDemand	BufferDischarge	ReuseEfficiency	OverflowRate	BufferUtilization
0	2010	628.8865	2165.94	1427.573	7419.659	3593.513	105.3353	0.602736	0.061076	0.017989
1	2011	210.3206	2204.05	1389.463	6922.495	3593.513	198.1358	0.613341	0.021515	0.031407
2	2012	347.6819	2144.274	1449.239	6647.707	3593.513	149.3507	0.596707	0.037578	0.027666
3	2013	350.303	1999.664	1593.849	6887.05	3593.513	216	0.556465	0.037418	0.041345
4	2014	0	2154.455	1439.058	6641.821	3593.513	31.5081	0.59954	0	0.005482
5	2015	84.4766	2260.694	1332.819	7875.95	3593.513	174.7472	0.629104	0.00818	0.028797
6	2016	45.36483	2106.512	1487.001	7166.297	3593.513	36	0.586199	0.004965	0.006831
7	2017	181.5086	2166.114	1427.399	7129.947	3593.513	79.44489	0.602785	0.01849	0.014103
8	2018	351.4613	1927.446	1666.067	5887.521	3593.513	103.9596	0.536368	0.043168	0.019486
9	2019	0	2036.121	1557.392	8068.775	3593.513	0	0.56661	0	0
10	2020	88.5819	2018.11	1575.403	6764.94	3593.513	63	0.561598	0.009817	0.011642
11	2021	0	2137.749	1455.764	7046.755	3593.513	0.26103	0.594891	0	0
12	2022	226.6175	1937.539	1655.974	6423.917	3593.513	108	0.539177	0.02543	0.023288
13	2023	590.2625	2105.903	1487.61	8782.594	3593.513	406.4738	0.586029	0.049968	0.071861
14	2024	254.609	2128.613	1464.9	8664.348	3593.513	198	0.592349	0.022921	0.033245

B. Model Code

```python
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

file_path = "neerslaggeg_DEVENTER_689.txt"

with open(file_path, 'r', encoding='latin1') as f:
    lines = f.readlines()

header_index = next(i for i, line in enumerate(lines) if line.strip().startswith('STN,'))
df = pd.read_csv(file_path, skiprows=header_index)
df.columns = df.columns.str.strip()

df = df[['YYYYMMDD', 'RD']]
df['Date'] = pd.to_datetime(df['YYYYMMDD'], format='%Y%m%d')
df['Precipitation'] = pd.to_numeric(df['RD'], errors='coerce') * 0.0001

df = df[(df['Date'].dt.year >= 2010) & (df['Date'].dt.year <= 2024)]
df = df[['Date', 'Precipitation']]
df['Month'] = df['Date'].dt.month

#Estimated Monthly Irrigation for Natural Grass (in meters/day)
irrigation_monthly = [0.000, 0.000, 0.000, 0.001, 0.002, 0.003,
                      0.003, 0.0025, 0.0015, 0.0005, 0.000, 0.000]

df['Irrigation'] = df['Month'].apply(lambda m: irrigation_monthly[m - 1])

# Monthly ET and Crop Coefficient
ET0_monthly = [0.105, 0.141, 0.366, 0.605, 0.916, 0.984,
```

```
                   1.025, 0.964, 0.582, 0.306, 0.110, 0.053]
Kc = 0.9
ETc_monthly = [et0 * Kc for et0 in ET0_monthly]

#System Parameters
Area = 8701  # m²
TotalVolumeHarvest = 300  # m³
TotalVolumeBuffer = 36    # m³
BufferDischargeRate = 9  # m³/day

VolumeHarvest = 0
VolumeBuffer = 0

results = []

for _, row in df.iterrows():
    P = row['Precipitation']
    I = row['Irrigation']
    ET = ETc_monthly[row['Month'] - 1] / 30

    C = 0.9
    AdjustedInflow = (P + I) * C * Area

    HarvestInflow = max(0, min(AdjustedInflow, TotalVolumeHarvest - VolumeHarvest))
    BufferInflow = max(0, min(AdjustedInflow - HarvestInflow, TotalVolumeBuffer - VolumeBuffer))
    Overflow = max(0, AdjustedInflow - HarvestInflow - BufferInflow)
    WaterReuse = max(0, min(I * Area, VolumeHarvest))
    ExternalIrrigation = max(0, I * Area - WaterReuse)
    ETLoss = min(ET * Area, VolumeHarvest)
    BufferDischarge = min(VolumeBuffer, BufferDischargeRate)

    VolumeHarvest = max(0, VolumeHarvest + HarvestInflow - WaterReuse - ETLoss)
    VolumeBuffer = max(0, VolumeBuffer + BufferInflow - BufferDischarge)

    results.append({
        'Date': row['Date'],
        'AdjustedInflow': AdjustedInflow,
        'HarvestInflow': HarvestInflow,
        'BufferInflow': BufferInflow,
        'Overflow': Overflow,
        'WaterReuse': WaterReuse,
        'ExternalIrrigation': ExternalIrrigation,
        'ETLoss': ETLoss,
        'BufferDischarge': BufferDischarge,
        'VolumeHarvest': VolumeHarvest,
        'VolumeBuffer': VolumeBuffer
    })

results_df = pd.DataFrame(results)

plt.rcParams.update({
    "font.family": "Times New Roman",
    "font.size": 11
})

fig, axs = plt.subplots(3, 1, figsize=(18, 10), sharex=True)

green = "#009444"
black = "#000000"

#Storage Volumes Plot
axs[0].plot(results_df['Date'], results_df['VolumeHarvest'], label='Harvest Storage',
            color=green, linestyle='-', linewidth=0.9)
axs[0].plot(results_df['Date'], results_df['VolumeBuffer'], label='Buffer Storage',
            color=black, linestyle='-', linewidth=0.9)
axs[0].set_ylabel('Storage Volume (m³)')
axs[0].legend(loc='upper right', frameon=True, facecolor='white', edgecolor='black')
axs[0].grid(True, linestyle='--', linewidth=0.5)

```

```python
#Daily Outflows Plot
axs[1].plot(results_df['Date'], results_df['WaterReuse'], label='Water Reuse',
            color=green, linestyle='-', linewidth=0.9)
axs[1].plot(results_df['Date'], results_df['BufferDischarge'], label='Buffer Discharge',
            color=black, linestyle='-', linewidth=0.9)
axs[1].set_ylabel('Daily Outflow (m³/day)')
axs[1].legend(loc='upper right', frameon=True, facecolor='white', edgecolor='black')
axs[1].grid(True, linestyle='--', linewidth=0.5)

#Overflow Plot
axs[2].plot(results_df['Date'], results_df['Overflow'], label='Overflow',
            color=black, linestyle='-', linewidth=0.9)
axs[2].set_ylabel('Overflow (m³/day)')
axs[2].set_xlabel('Date')
axs[2].legend(loc='upper right', frameon=True, facecolor='white', edgecolor='black')
axs[2].grid(True, linestyle='--', linewidth=0.5)

#X-Axis Labels
season_labels = {
    1: 'Winter', 2: 'Winter', 3: 'Spring', 4: 'Spring',
    5: 'Spring', 6: 'Summer', 7: 'Summer', 8: 'Summer',
    9: 'Autumn', 10: 'Autumn', 11: 'Autumn', 12: 'Winter'
}
tick_dates = pd.date_range(start=results_df['Date'].min(), end=results_df['Date'].max(), freq='QS')
axs[2].set_xticks(tick_dates)
axs[2].set_xticklabels([f"{season_labels[d.month]} {d.year}" for d in tick_dates],
                       rotation=60, ha='right')

plt.subplots_adjust(bottom=0.15)
plt.tight_layout()
plt.show()

#Annual KPIs
results_df['Year'] = results_df['Date'].dt.year

annual_kpis = results_df.groupby('Year').agg({
    'Overflow': 'sum',
    'WaterReuse': 'sum',
    'AdjustedInflow': 'sum',
    'BufferDischarge': 'sum',
    'ExternalIrrigation': 'sum',
    'ETLoss': 'sum',
    'VolumeBuffer': 'mean'
}).reset_index()

df['Year'] = df['Date'].dt.year
irrigation_annual = (df['Irrigation'] * Area).groupby(df['Year']).sum().reset_index()
irrigation_annual.columns = ['Year', 'TotalIrrigationDemand']

annual_kpis = pd.merge(annual_kpis, irrigation_annual, on='Year')

annual_kpis['ReuseEfficiency'] = annual_kpis['WaterReuse'] / annual_kpis['TotalIrrigationDemand']
annual_kpis['OverflowRate'] = annual_kpis['Overflow'] / annual_kpis['AdjustedInflow']
annual_kpis['BufferUtilization'] = annual_kpis['VolumeBuffer'] / TotalVolumeBuffer

annual_kpis = annual_kpis[['Year', 'Overflow', 'WaterReuse', 'ExternalIrrigation', 'ETLoss',
                           'TotalIrrigationDemand', 'BufferDischarge',
                           'ReuseEfficiency', 'OverflowRate', 'BufferUtilization']]

print("\n=== Annual KPIs ===")
print(annual_kpis.round(2))

annual_kpis.to_clipboard(index=False)
```

C. Communication Notes

Telefoonverslag Geert Olthuis (Field Manager Heracles Almelo)
Datum: 16-05-2025
Het veld verbruikt ongeveer de helft van het sproeiwater ten opzichte van de trainingsvelden n zonder Permavoid-systeem. Het veld wordt op een vochtgehalte van circa 18% gehouden. Dit wordt bereikt door verschillende waterniveaus aan te houden in de drie afzonderlijke secties van het veld. Aanvullende beregening wordt toegepast indien nodig. Tweemaal per jaar wordt het volledige veldsysteem geleegd voorafgaand aan regenperiodes. Dit gebeurt om vers water toe te laten in het systeem en vervuiling op lange termijn te beperken. Bovendruk wordt toegepast als luchtisolatie wanneer de veldverwarming wordt ingeschakeld. Onderdruk wordt ingezet om het veld actief leeg te trekken bij overbelasting of excessieve regenval.

Teams meeting verslag Joris Bevaart (Directeur Finovi)
Datum: 21-05-2025
Waterhergebruik en infiltratie op sportparken wordt gezien als een kansrijke en nuttige toepassing. Bij kunstgrasvelden wordt ondergrondse berging toegepast, deze wordt idealiter gekoppeld aan omliggende dakoppervlakken om de opvangcapaciteit te vergroten. Projecten bij gemeenten komen vaak moeilijk van de grond door een scheiding tussen sportafdelingen en civiele techniek/infrastructuur. Toepassing van ondergrondse berging onder natuurgrasvelden is een goed idee en verdient verdere aandacht, maar wordt op dit moment nog weinig toegepast.

Telefoonverslag Ger Pannekoek (Founder Rain Shell)
Datum: 03-06-2025
Het Rain Shell®-systeem is stabiel genoeg om als onderbouw van een sportveld te dienen. Het soortelijk gewicht van het systeem is variabel en afhankelijk van de samenstelling, met name de hoeveelheid gebruikt mineraal mengsel. In combinatie met DSI®/FHVI-techniek van Van Tongeren Watertechniek ontstaat een compact en geïntegreerd systeem. Binnen dit systeem wordt regenwater eerst gefilterd via Rain Shell® en daarna geïnfiltreerd in het grondwater. In droge jaren wordt eventueel aanvullend grondwater gebruikt voor beregening, maar per saldo is er sprake van netto infiltratie.

Telefoonverslag Ger Pannekoek (Founder Rain Shell)
Datum: 12-06-2025
Het waterniveau in de opslag wordt geregeld door een overstorthoogte in de bak. Het gaat hierbij om één bak met twee functies: wateropslag voor gebruik (onder de overstorthoogte) en berging bij neerslagpieken (boven de overstorthoogte). Dit systeem wordt gereguleerd via een aparte put met een overstort. De aan- en afvoer van water verloopt via drains in de waterbergingslaag. Bij een sportveld kunnen ook andere bronnen, zoals dakoppervlakken, op dit systeem worden aangesloten. Onder sportvelden worden zuiverende mineralen toegevoegd aan het schelpenmateriaal. Omdat deze mineralen op termijn hun filterende werking verliezen, terwijl de bergingscapaciteit behouden blijft, wordt er aanvullend een aparte put met filterende mineralen geplaatst. Het water stroomt na opslag door deze filterput. Onderaan deze put ligt een drain die het water afvoert naar een pompput, zodat het hergebruikt kan worden voor irrigatie of andere toepassingen.