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BACHELOR THESIS CIVIL ENGINEERING REPORT

BLUE SPORT PARKS: DEVELOPING A MODEL FOR THE WATER BALANCE OF A SPORTS FACILITY AND EVALUATING WATER ROBUST MEASURES

Waterschap De Dommel

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Colophon

This document contains the final report of the Bachelor Thesis for complementation of the Bachelor Civil Engineering at the University of Twente.

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Preface

In front of you is my bachelor thesis "Blue sports Facilities, developing a model for the water balance of a sports facility and evaluating water robust measures". This product is the final assignment of the third year of the bachelor program of Civil Engineering at the University of Twente. I have conducted this research into the water balance of "Blauwe Sportparken" by developing a model, with use of literature and expert input, which quantitively substantiates water flows. This enables the assessment of prospective water robust implementations at sport facilities, hopefully contributing to the development of more water robust sports facilities in The Netherlands.

This research is conducted at water board Dommel in cooperation with Engineering company Newae from November 2nd 2020 to January 26th 2021. Working at the office proved impossible due to COVID-19, nevertheless I experienced what it is to work for a company and I was warmly welcomed at both instances. Therefore I would like to expressing my gratitude to everyone who was involved in helping me achieve the completion of this research.

My external supervisors, Hans Roelofs from water board Dommel and Jeroen van de Ven from Newae, have been of invaluable help, getting me acquainted with the various concepts of the project "Blauwe Sportparken, setting up contact with experts and providing detailed information from practice. I would specifically like to thank them both for their time, effort and feedback as writing this report would be impossible without them. From the University of Twente I would like to thank Karina Vink for the very enthusiastic guidance and supervision during the entire graduation period. Providing me with quality feedback and taking my academic competences to the next level. I thoroughly enjoyed working on this research with accompanying supervisors. Last but not least I would like to thank family and friends who have been involved in my research, for giving support when I needed it.

Finally, I wish you as a reader a lot of pleasure in reading my bachelor thesis. If you have any further interest, comments or questions regarding this thesis, feel free to contact me.

Ruben Hendrik Christiaan Borst
January 2021, Enschede

Abstract

This research proposal has been developed in cooperation with water board Dommel, engineering company Newae and the University of Twente.

With the implementation of the "Deltaplan Ruimtelijke Adaptatie", The Dutch government set a target of achieving a climate resilient and water robust country by 2050. Currently, the "Nationaal Waterplan", a water related policy, is effective and focuses on the climate resilient and water robust development concerning protection and functioning of water systems in The Netherlands. As a result, the project "Blauwe Sportparken" (English: blue sports facilities) has emerged in the region of water board Dommel. However, the lack of knowledge related to these water robust sports facilities has impeded further advancement. The lack of quantitative insight disables comparison between traditional sports facilities and new more water robust sports facilities in context of the project "Blauwe Sportparken". Consequently, investment is unavailable, counteracting the evolvement towards a water robust country.

This research focuses on bridging the previous mentioned knowledge gap by developing a water balance model which quantifies the water flows at a sports facility and enables the assessment of water robust implementations in The Netherlands. With use of literature studies the general outline of a water balance has been constructed. As model type the bucket model has been selected as guiding principle for its capabilities of effectively mapping the water flows in an area with relatively simple calculations while providing accurate general results. Excel has been adapted as modelling program. The buckets have been adapted for a sports facility where there is distinction between the different type of surfaces. Soil characteristics have been matched with the surface type and the input is set up for sport facility properties.

Six different types of water robust measures have been incorporated in the model in the context of reducing water demand and reusing water. Subirrigation, subsurface drip irrigation and subsurface drip irrigation have been integrated in terms of water demand reducing measures. From literature, the effects of irrigational measures are indisputable. In general form of application, benefits of these systems compared to a traditional sprinkler system range from 35% up until 45%. However, water robust measuring regarding the reusage of water and specifically concerning the storage of water are not as well defined due to their dependency on retention volume, retention period and soil conditions. Nevertheless, the developed Excel model of a water balance for sport facilities proved significant effects of each one of the six water robust measures. Using controlled drainage, excessive water could be stored in a synthetic turf pitch with permeable or impermeable bottom layer or in an aquifer. With these storage availabilities the necessary irrigational water, in comparison to a traditional sprinkler system, could be reduced significantly with 50% - 100%. However, actual outcomes are heavily dependent on various factors such as retention period and storage volume and need further investigation is recommended. Nonetheless, the model shows results that are in accordance with literature statements about predicted effects of water influencing measures.

With this research, a model has been created that can process several scenarios for different sports facilities in The Netherlands concerning the water balance. It provides insight in the different water flows and the expected quantitative effects of six water robust measures. This novel model configuration enables further investigation concerning the knowledge gap of quantitative effects of water robust measures at sports facilities. Consequently, this research contributes towards a more climate resilient, and especially water robust, construction and management of sports facilities in The Netherlands.

Table of Contents

Table of Figures

Table of Tables

Glossary

This Glossary provides the most frequently used key concepts and its description for clarification.

Blauwe Sportparken — *Project "Blauwe Sportparken"(English: blue sports parks) focuses on improving the water balance and reducing water usage at sports parks.*

Water Balance — *Concept which describes the flow of water in and out of a specified hydrological system.*

KNMI — *"Koninklijk Nederlands Meteorologisch Insituut', the Dutch weather institution.*

Seepage — *Slow flow of a liquid moving towards the top layer of the soil due to gravity, permeability and pressure (Dutch: 'Kwel').*

Percolation — *Slow flow of a liquid moving towards the bottom of the soil due to gravity, permeability and pressure (Dutch: 'Wegzijging').*

Stormwater — *Water that originates from rain, snow or ice that runs off land due to the fact that is cannot penetrate surfaces (e.g. roofs).*

Rainwater — *Water that has fallen as rain and has not interfered with any surface where is collected dissolvable materials.*

Drinking water — *Potable water that is safe to drink.*

NAP — *Standard water level of the river Rijn Near Amsterdam measured in meters.*

1. Introduction

1.1. Context

In the Netherlands, predicted scenarios regarding climate change will have a huge impact on the whole water management system. Extreme weather conditions such as heavy rain showers and severe drought will occur more frequently. The Dutch government, provinces, municipalities and waterboards have embraced a collaborative goal of realising a climate-proof and water-robust Netherlands in 2050 (Nationaal Deltaprogramma, 2020). In light of this plan, vulnerabilities have been mapped for each industry. The sport industry has experienced difficulties for the past few years in terms of drought and severe water disruption. Play fields needed to be irrigated and water damage restricted sports activities. The need for climate adaptation has been amplified and the search for functional and sustainable solutions have started. (Rijkswaterstaat, 2015)

In light of this tendency, the concept “Blauwe Sportparken” has been developed by water board Dommel and engineering company Newae. This refers to climate resilient sports parks which have significantly improved their water management and have been constructed in a sustainable way. The water balance of conventional playing fields can be constructed and used in a more efficiently and multifunctional way. A “Blauw Sportpark” focuses on the economical use of water. Rainwater is retained in rainwater collection reservoirs to prevent dehydration. These water storage tanks can also be used during severe rain showers or inundation for collection of excessive water. Moreover, stored precipitation water can be used for the irrigation of natural grass pitches. Besides the water management, a “Blauw Sportpark” focuses also on sustainability during the whole construction project. Re-usage of existing materials, LED light implementations and sustainable contractors are typical examples. (Roelofs & Van de Ven, 2018)

A practical example of such a “Blauw Sportpark” is the in 2018 realized sports park in Sint-Oedenrode named “De Neul”. Due to its location between the rivers Dommel and Dommelarm, high groundwater levels occur, which results in waterlogged fields. This park has been made futureproof, taking into account extreme drought, sever rain showers, inundation and high groundwater levels. Beneath the three synthetic turf pitches, an enormous water storage has been placed. By using controlled drainage, water is retained and, if needed, transported to the natural grass pitches for irrigation at the roots to avoid dissipation of water. (Provincie Noord-Brabant, 2018)

In conclusion, to ensure future usage of sports parks, it is necessary to adapt on short notice. This need results in the build of “Blauwe sportparken” which have been built climate resilient through water management to reduce water vulnerability, enhance water safety and ensure water availability.

1.2. Problem Statement

The region of the water board Dommel consists of partially sandy soils. These areas are depicted as regions which are dependent solely on rainfall. There are hardly any water trajectories, such as canals or rivers. It is observed that groundwater levels in these regions are slowly dropping. This is due to the fact that longer periods of drought occur interchanged by severe precipitation. Moreover, water systems in this area are designed in a conservative way, marked by water drainage as highest priority. Last but not least, groundwater is exploited more extensively by operations such as industries, agriculture, drinking water supplies and sports.

In the “Deltaplan Ruimtelijke Adapatatie” it is stated that The Netherlands should become climate-resilient and water robust in 2050 (Nationaal Deltaprogramma, 2020). Moreover, the country has a “Nationaal waterplan” for the years 2016-2021, a country wide policy regarding water (Rijkswaterstaat, 2015). One of the key elements is the desired development regarding protection and functioning of water systems in The Netherlands. This aims at the development of general acknowledgement to tackle projects in a way that is climate resilient and water robust by 2020. This has boiled down to the project "Blauwe Sportparken" (English: blue sports parks) in 2018 such as 'De Neul'. However, further developments for sports facilities have not found their way through because of the lack of knowledge. One of these knowledge gaps concerns the insight in water balances of sports facilities. This lack of quantitative insight disables comparison between the traditional way and 'new' way of structuring sports facilities along the lines of "Blauwe Sportparken". Parties are not willing to invest extra money in new unquantified measures for which the return on investment is not known. Consequently, this impedes the evolvement towards a water robust country.

1.3. Research Objective

A decreasing groundwater level is a common problem across the region of water board Dommel. This is a problem for sport facilities regarding synthetic turf pitches which cannot retain any water in most cases. Besides that, natural grass pitches require a high maintenance level in terms of water drainage and water irrigation. The project called "Blauwe Sportparken" focuses on enhancing the water balance water and reducing the water usage. In general, water board Dommel focuses on researching methods to improve water retention, complement groundwater and reduce water usage. The project "Blauwe Sportparken" concentrates on sport fields solely to improve the current water situation. It is necessary to acquire more insight into the water balance in the current situation in order to provide better targeted incentives that are genuinely effective.

The problem statement focuses on the problems existing in the operational area of the waterboard Dommel. In order to solve the aforementioned problems, the following research objective has been formulated:

"The objective of this research is to gain insight in the water balance at sports facilities in The Netherlands by developing a model, to enable taking effective measures to enhance the water balance by retaining water, recharging groundwater and reducing water usage."

1.4. Scope

This research focuses on the development of a water balance model and the effects of water robust measures for sports facilities. Since the different kinds of pitches present are comparable, sports facilities as a whole can be investigated. Different water flows result from the water balance which enables assessment of water quantity (Chapter 3.1 elaborates on this general concept). As a result of the identification of water flows, water quality can roughly be assessed by the different origin of water flows (Galkina & Vasyutina, 2018). However, water quality is not investigated in this research since it is of minor importance in this research in terms of the goal. The primary focus is on water quantity; to retain water, recharge ground water and reduce water usage, all quantitative aspects. In case of climate resilience and water robustness, only water usage is taken into consideration. Re-use of materials, sustainable contractors, sustainable materials and other sustainability aspects are not taken into account. For the development of this model, soccer sports facility "Zuideinderpark" in Schijndel will be used as a basis, which is representative of sport fields generally with their various range of available sports. The developed model will provide more insight in the water balance of a sports facility. Effects on the water balance can be quantified by hypothetically implementing new measures. This result can be compared to the water balance of a traditional sports facility.

The research objective constructed in chapter 1.3 results in the following main question.

- *How can the water balance of a sports facility be modelled and what measures are effective in order to create a climate resilient and water robust sports facility?*

In order to design a model that can describe the water balance of a sports facility and also investigate the measures that are effective to support a positive water balance, several sub questions are formulated. This will help narrowing down each specific element of the main question and helps structuring the report.

I. *How is the current water system of a sports facility structured according to literature and expert input?*
   a. *How is a water balance of a sports facility characterised?*
   b. *What variables have an influence on the outcome of a water balance model?*
   c. *How is the water balance of the project "Blauwe Sportparken" structured?*

II. *Which water balance improving measures can be taken at sports pitches in order to retain water, recharge groundwater and reduce water usage?*
   a. *What irrigational measures are commonly used?*
   b. *Which water reducing measures can be used at sports facilities?*
   c. *What water drainage measures are commonly used at sports facilities?*
   d. *How can water be retained at sports facilities?*

III. *What are the effects of water balance improving measures for a sports facility?*
   a. *How do water balance improving measures financially affect a sports facility?*
   b. *What are the quantitative effects of water balance improving measures on sustainability in terms of water usage for a sports facility?*
   c. *What are the quantitative effects of water balance improving measures on playability for a sports pitch?*
   d. *What are the consequences of precipitation on the drainage of water at synthetic turf pitches?*

With help of these questions, a model can be developed, which will provide more insight into a water balance of a sports facility. Moreover, effects on the water balance of sports facilities can be quantified by hypothetically implementing new measures, such as introduced with the project "Blauwe Sportparken". The result can be held against a traditional water balance for comparison. Consequently, a more comprehensive overview of a general water balance and the effects of new water regulating measures is created.

1.5. Reading Guide

This paragraph will contain a short introduction and general outline for each chapter will be provided. In chapter 2 the methodology will be provided for each of the aforementioned research questions. Thereafter the water system of a sports facility will be investigated in chapter 3. The next chapter focuses on the water robust measures that could possibly improve the water balance at sports facilities. With this acquired knowledge, chapter 5 elaborates on the constructed Excel model of a water balance. The observed effects from literature and from the model are discussed in chapter 6. This thesis will conclude with a discussion, conclusion and recommendations for further research.

2. Methodology

In the previous chapters, the problem is has been identified resulting in the research questions in chapter 1.4. This chapter will focus on the combination of both and the development of a plan of approach to perform the research. A comprehensive overview per research question will be provided together with methods to investigate the matter. This will result in a tangible phased plan.

2.1. Research Methods

For a conveniently organized approach, each sub question will be elaborated on in further detail regarding the selected research method.

1) *How is the current water system of a sports facility structured according to literature and expert input?*

In general, this sub question will be answered with use of a literature study and expert input together with belonging datasets to support their claims. The first important thing to investigate is the visualisation and modelling of a current water balance of a football sports facility. The water balance model that is constructed by STOWA (Tanis, Schep, & van Dijk, 2018) will be used as a solid basis for modelling this water balance for an existing soccer facility in Schijndel. The required input data regarding size, structure and current water systems of this sports facility will be offered via water board Dommel. The amount of paved area, drained area, sport pitches, roofs and groundwater facilities, and their internal dependency are suspected important aspects. Further information regarding hydrology of this specific location will be provided as well. The KNMI will be consulted for data sets regarding the weather. Engineering firm Newae will deliver data regarding the construction details of such a sports facility. Moreover, both waterboard Dommel and engineering firm Newae have been closely involved with the project “Blauwe Sportparken”. Detailed information of this project, especially about sports facility “De Neul”, will be supplied by them as well. Furthermore, data sets regarding the current usage of water at this facility will be retrieved from “De Neul” itself. Most of this data is already documented. With use of an expert discussion, the missing elements will be identified at the local instances. This data can be used for calibration and verification of the model. Last but not least, literature research will provide more general information regarding the forming of a water balance. Also, the impact of different more technical details such as soil type, weather conditions and different type of pitches will be deduced from literature. This is all implemented in the model as input information and the result is a quantification of water processes dependent on the specified input data. In this way the model can be used for different sports facilities.

2) *Which water balance improving measures can be taken at sports pitches/facilities in order to retain water, recharge groundwater and reduce water usage?*

To be able to answer this sub question, a literature study together with expert input will be leading. This question is widely formulated in order to have a wide range of possible measures that can be implemented. This range of possibilities concerns irrigation, drainage, water reduction and water retention with several individual solutions per topic, leading to a significant amount of possibilities. However, due to time constraints, an elimination of this list of measures will be needed. The selection of criteria on which this elimination is based will be constructed with use of expert input from Newae. The engineering firm is experienced on this topic and will be leading. Besides that, literature study will help constructing this decision framework with use of sound reasoning. There will be looked at effectivity, amount of usage and research results. Information about each individual topic will be retrieved from Smits Beregening B.V. a company specialized in drainage and irrigation. Furthermore, the company Field Factors will be contacted via water board Dommel to provide general information about synthetic pitches and groundwater retention. The pilot study about water retention at natural grass pitches; “Pilot Hoge Bomen: Waterberging op een natuurgras sportveld” (Köster, et al., 2012), provides also more information about water retention possibilities. The project “Blauwe Sportparken” focuses specifically on improving the current water balances at sports facilities. By looking at direct result of this project; sports facility “De Neul” a few common measures can be deduced. Eventually, approximately 3 up to 6 water balance improving measures will be implemented in the model which can be used for evaluation of the effects.

3) *What are the effects of water balance improving measures for a sports facility?*

This sub question will be addressed with use of data analysis for the largest part. At this stage, the model output is most accurate and extensive as it gets; a water balance is modelled for sports facilities depending on their own characteristics. Even more, the selection of water balance improving measures can be implemented and the results of this improvement can be compared to the original situation. This comparison is essential for determining the effects and evaluation. The different aspects on which the measures will be evaluated are financial, sustainability and playability. For the design of sports facilities, the users can decide which aspect they would prefer most. For the financial part there will be looked at the quantitative effects of the (reduced) water usage and investment costs. Sustainability can be assessed using the modelled effects in terms of water usage for different scenarios. For each measure the effects in terms of water use and re-use can be quantified. Furthermore, a small section of the water sustainability assessment, which is discussed in literature reports such as “Sustainability Performance in Sport Facilities Management” (Lucas, Pinheiro, & Del Río-Rama, 2017), can be applied on sports facility “De Neul” as an example. Furthermore, playability can be assessed by looking at the current norms, drainage capacity during different precipitation scenarios and the effects of the measures in comparison with these norms (Stark, 2011).

2.2. Research Model

The research methods described in section 2.1 are visualized in the following research model (Figure 1) to provide a concise overview of the research methods.

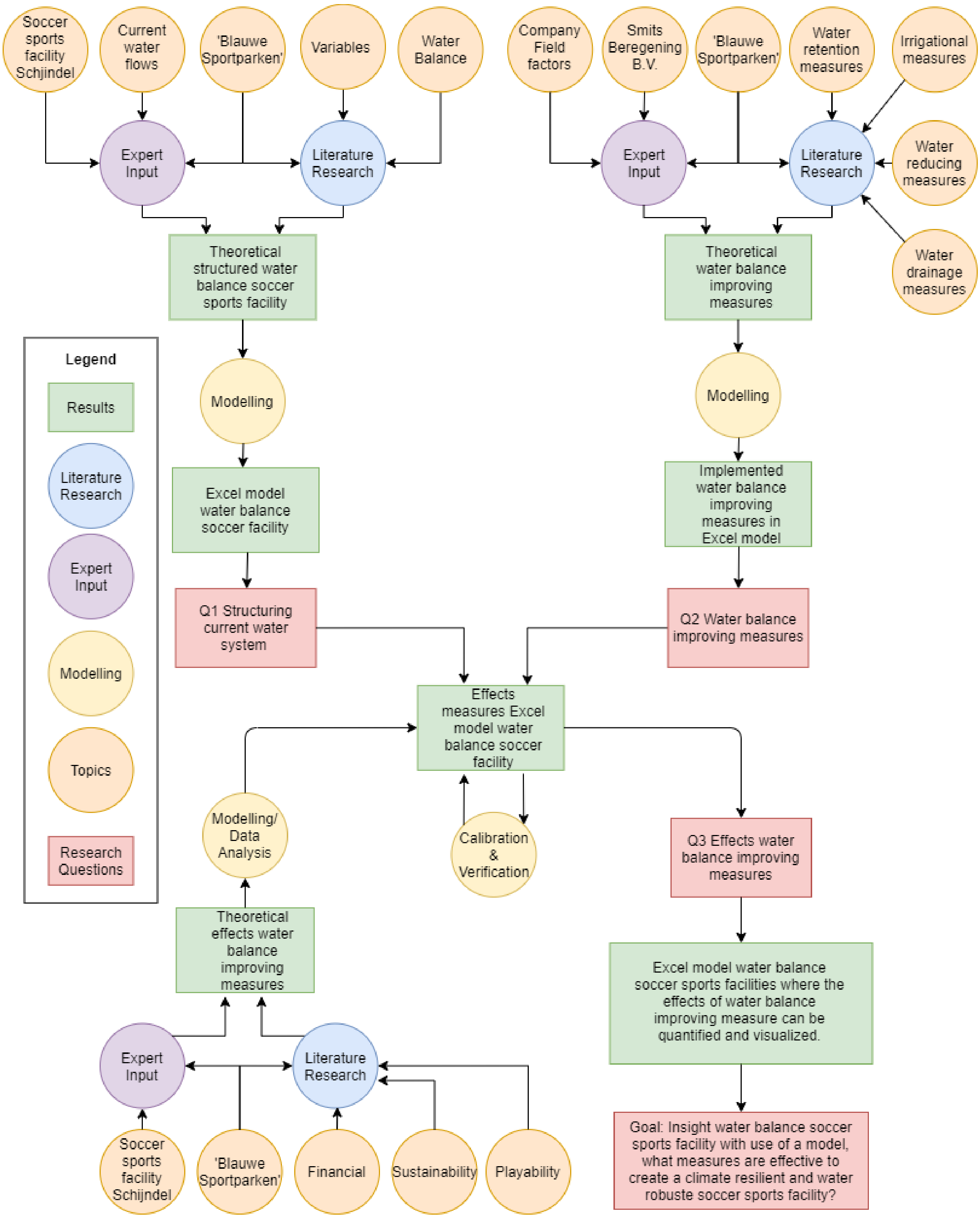


Figure 1: Comprehensive flow chart of the research methods

2.3. Excel Model

With use of the description of the research methods in chapter 2.1 a model will be constructed. This model will most likely be designed with use of the program Excel and with use of a more specific program which focuses on water flows only, such as SOBEK. The most crucial consideration in this decision process is the fact that the final product in the form of a model should be usable and understandable for each person. Excel is a commonly used program for companies, is actively supported with instruction manuals and highly intuitive, therefore enhancing user friendliness. Another benefit of Excel is its primary function; organising lots of data into logical spreadsheets and charts which is useful for data representations and clearness of the model outcomes. Multifunctionality is an advantage, it can model and process almost every data set. A disadvantage is that there are no programmed functions for specific features such as modelling water processes in this case. This could become a problem, because most of the model (except the basis water balance) needs to be built from the ground up. Nevertheless, this also creates the opportunity to incorporate various extra aspects to adapt the model to specific needs. The Excel model that is created by STOWA (Kroes, Van Dam, Jacobs, Groenendijk, & Hendriks, 2008) will be used as a basis water balance model which will be expanded.

Following Figure 2 displays the general scheme which will be followed to construct the model according to the research questions and to support the goal of this research. This is a more technical overview of the input, process, output and (inter)dependent relationships between variables and processes. Because of the numerous interdependent variables, only the most general relationship is visualized to avoid confusion. In the following chapters, the detailed model will be established and elaborated on.

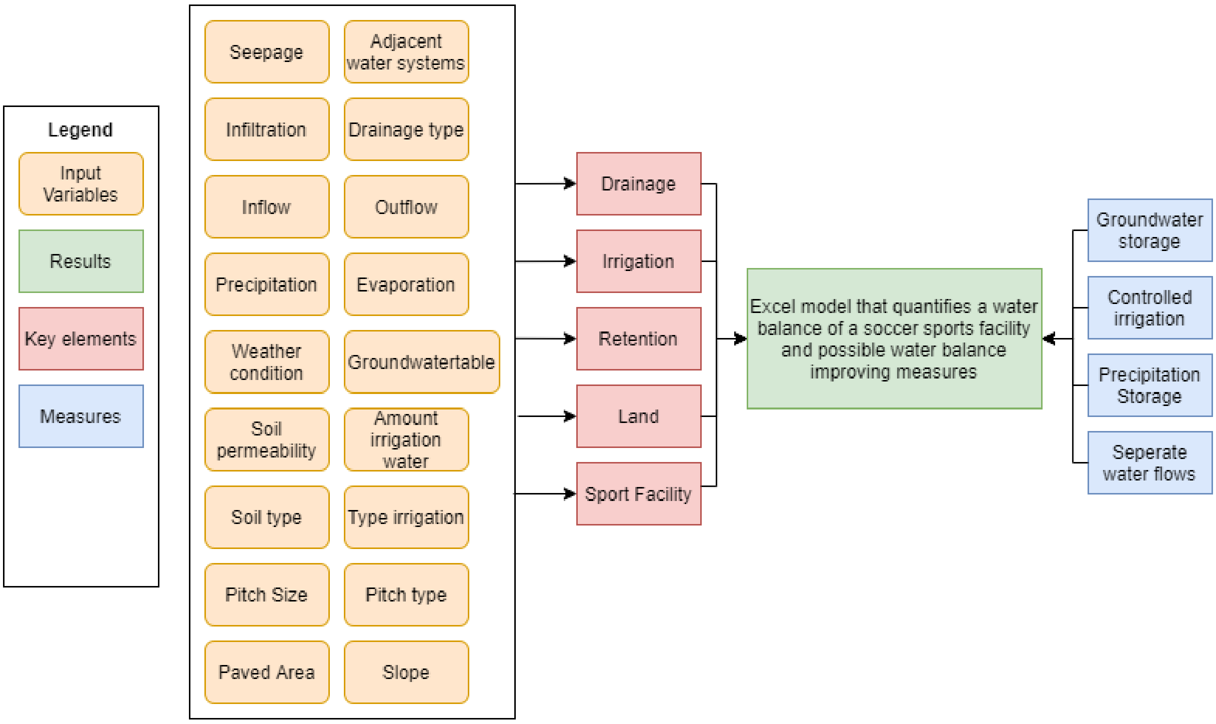


Figure 2: Comprehensive Excel model for the water balance and improving measures

3. The water system structure of a sports facility

In general, the national policy "Nationaal Waterplan" outlines the legislation concerning water, and related measures (Rijkswaterstaat, 2015). Adhering to this policy automatically takes care of the requirements which can be derived from the Dutch water related policies: "Kaderrichtlijn water (KRW), "Richtlijn Overstromingsrisico's (ROR)" and "Kaderrichtlijn Mariene Strategie (KMS)". The conditions stated in the "Nationaal Waterplan" can be used for demarcating the most extreme (but still legal) water standards in the model (Rijkswaterstaat, 2015). The "Stichting Toegepast Onderzoek Waterbeheer" (STOWA), knowledge centre of water boards and provinces of the Netherlands, has constructed a calculation tool for establishing a water balance in cooperation with Witteveen & Bos and Waternet (Tanis, Schep, & van Dijk, 2018). This tool is leading for this research by forming the basis on which the water balance model for sports facilities is constructed. Furthermore, Wageningen University & Research has conducted several researches into smart water reducing and water level management measures and synthetic turf pitches which could help (Boerenbond, 2017). Moreover, the industry "Sport- en Cultuurtechniek" has obliged an investigation about the water benchmarks of sports pitches (Branchevereniging Sport en Cultuurtechniek, 2010) which should be achieved (Stark, 2011). In the following sections, there will be briefly elaborated on the concept water balance and sports facility.

How is the current water system of a sports facility structured according to literature and expert input?

3.1. Water Balance

For the preparation of a water balance, an excel calculation tool has been fabricated (Kroes, Van Dam, Jacobs, Groenendijk, & Hendriks, 2008). For the maintenance of water quantity, it is of great importance to have insight in all sources and processes which have an influence on the water balance. It is necessary to create a comprehensive, quantitative overview of all ingoing and outgoing waterflows; this is part of a water system analysis. Moreover, the results can be used to draw up a balance of the water structure to discover origin and progression of water(flows). This is necessary for guaranteeing sufficient water quantity. The difference with other hydrological tools is that those tools focus primarily on hydraulic bottlenecks in terms of water drainage or water supply. (Tanis, Schep, & van Dijk, 2018)

3.1.1. Water balance elements

In the water balance introduced by STOWA, several water flows are quantified; the water discharge and the amount of water compounds. Using this balance, the origin of several water flows can be tracked as well as the different outflow routes. Moreover, insight is provided in the source, composition and retention time of water. A big advantage of this method is the fact that relatively few definitions of geographical areas are needed to provide an impression of the most important waterflows. A lot of geographical characteristics can be found online, freely available. For parameters such as precipitation, soil type and efflux of water, The Netherlands has a lot of key numbers available.

Important to note; formulating a water balance focuses in the basis on acquiring insight on the functioning of a water system and not on recreating reality as accurately as possible. It is an analysis instrument to predict the scale of several water flows and the effects of implementations. (Kroes, Van Dam, Jacobs, Groenendijk, & Hendriks, 2008)

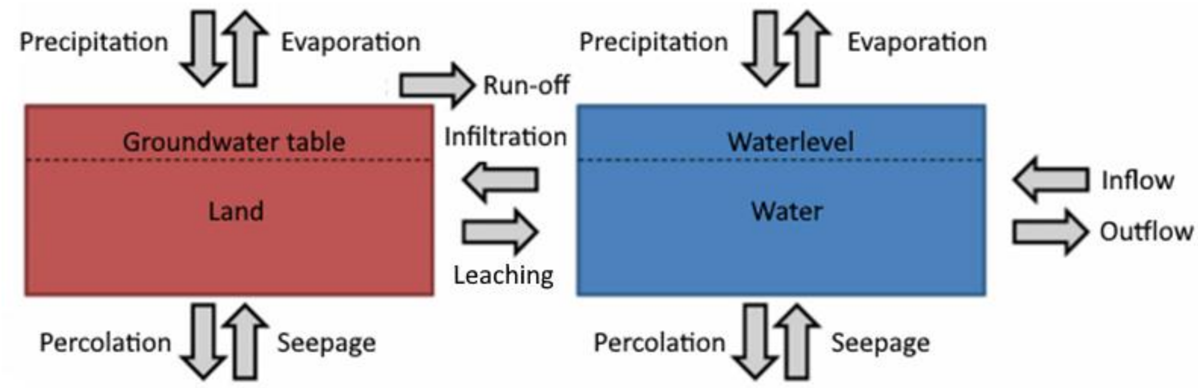


Figure 3: Schematic overview of a water balance (Tanis, Schep, & van Dijk, 2018)

3.1.2. Structure of a water balance

In short, the principle of a water balance is to track which processes or sources are important for the water quantity. The overview of al ingoing and outgoing water sources is called the water balance. If the sum of all inflowing water sources is equal to the outflow, the water volume in an area remains constant. The two other situations, where either the outflow or the inflow is larger, will result in water shortage or water drainage respectively. (Tanis, Schep, & van Dijk, 2018)

In the core, there are four elements which affect how much water flows in and out of an area:

- *The weather*

Precipitation can occur in terms of rain, snow or hail. A distinction is made for the precipitation on surrounding water systems or surrounding fields. This results in different water flows in terms of run-off, evaporation, soil saturation and water infiltration.

- *The landscape*

The type of environment, groundwater flow and soil properties have influence on the water flow. The following types of land surface are common: paved, unpaved and not drained, and drained and unpaved. Next, groundwater flow concerns the amount of seepage or infiltration. A distinction is made for surface water of surrounding water systems and adjacent fields.

- *Water level management*

The water level can vary according to the water-table decisions in a specific bandwidth. Often water levels are distinguished for summer and winter, to accommodate for agricultural use.

- *The connection with other water systems*

The amount of water that will flow to adjacent water systems will be impacted by the type of connection and the type of neighbouring water system.

3.2. Characterisation Sports Facilities

For the application of this research, information about sports facilities is necessary. General information about the usual elements which are present is investigated. Moreover, information about grass pitches and synthetic turf pitches is valuable. The characteristics of these types of pitches and the accompanying requirements to which these pitches comply. Besides that, information about the traditional water system is needed. How are these fields drained, irrigated and designed? This chapter focuses on these elements of sports facilities. General knowledge about the most common practices is summarized and important researches are depicted to provide a solid framework to start analysing current and future situations. These findings answer the following question:

How is a water balance of a sports facility characterised?

In general the water balance of a sports facility complies to the general standards illustrated in Chapter 3.1.1. The four elements which are accountable for the inflowing and outflowing water flows are weather, landscape, water level management and connection with other water systems. Most of these characteristics are rather standard, however a sports facility has a few extraordinary elements to consider. Especially landscape and water level management can be special, these two will be discussed in following sections.

3.2.1. Drainage

In the Netherlands most sport pitches are equipped with traditional drainage(STOWA, 2013). This is needed to account for playability throughout the season. With this type of drainage system the drainage strings give out onto ditches directly. When water rises, through precipitation, to a higher level than the drainage strings, this excessive water will be dissipated. Groundwater can never rise higher than the drainage strings, unless severe weather conditions occur.

3.2.2. Synthetic turf pitches

Typically, synthetic turf pitches are drained by horizontal strings which are positioned above the groundwater table. This does not lower the groundwater table, instead it targets the dissipation of water in the layers above. These pitches can accelerate the removal of rainwater. As a result, this can trigger a desiccation effect. Previous research has already investigated drainage of synthetic turf pitches during extreme precipitation (Fleming et al., 2017). However, little is known about the less severe rain showers. Better insight into the water balance could substantiate more specific measures. What is more beneficial; more intelligent irrigation, controlled drainage or are there other promising techniques? For synthetic turf pitches, the study "Watertoets voor sportvelden" has investigated the contribution of these type of pitches to the dissipation of water. (Lenders & Kool, 2010)

The main reasons for installation of synthetic turf pitches are climatic considerations, there is difficulty in providing adequate natural grass pitches. Synthetic pitches can also be used more often due to less impacts of environmental conditions. Furthermore, yearly maintenance (instead of initial investment) is lower than natural grass pitches. Another benefit these days is their ability to collect and store water for other objectives. The type of synthetic turf pitches are dependent on the sport, the most striking elements are shown in Table 1. (Mandal et al., 2002)

Table 1: Overview of the variety of synthetic turf pitches for different sports(National Institute of Building Sciences, 2017)

Sports Type	Football/Soccer/Rugby	Hockey	Tennis
Type of pitch	Long pile carpets	Waterbased, sand dressed and sand filled pitches	Alternate surfaces, clay, plexipave, other synthetic mate
Structure	Long pile length (35-65mm) with sand or rubber granules	Shorter pile length (<35mm)	Varying
Costs [Dollar]	550 000 – 700 000	300 000(sand) – 600 000(water)	50 000

The schematic water balance in Figure 4: Schematic water balance traditional sports facility has been elaborated with more details which are common for sports facilities, resulting in Figure 6. Besides the most general water flows, more specific water flows are accounted for(Xu et al., 1996), drainage, sewerage and irrigation are included. Moreover, different types of land type are illustrated; unpaved, paved, roofing and combination of these types (Mays, 2001).

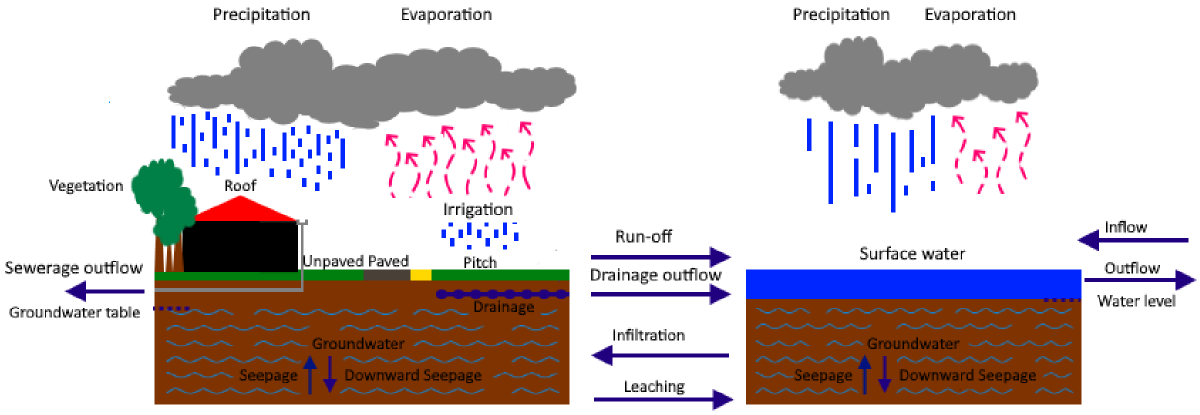


Figure 4: Schematic water balance traditional sports facility

3.3. Variables

In section 3.3.2 the basis of a bucket model can be found. In this small section essential variables will be denoted. This results in the answer to the following question:

What variables have influence on the outcome of a water balance model?

3.3.1. Bucket model

The water balance is constructed with use of the bucket model. For simplification purposes, the region of investigation is scaled down to several small buckets. Since sports facilities generally have an small surface in terms of hectares, a bucket model is valid. With the input data, classified above in the section necessary data, water will flow between those small buckets. The exchange of water is dependent on the four elements, mentioned in the section structure of a water balance, which are accountable for the eventual size of water flows. Each bucket has its own homogenous characteristics, such as soil type, permeability, size, paved, unpaved, drained, inclination, etc. Each region will be translated to several smaller buckets with their own properties to be able to analyse the eventual water balance. (Tanis, Schep, & van Dijk, 2018)

3.3.2. Necessary data

The first step in setting up a water balance is the demarcation of the water system or area that is investigated. It is useful to find a, hydrologically speaking, logical boundary of the area. It is important to note how the area is connected to adjacent areas. The following list displays the minimum set of data that is needed (Tanis, Schep, & van Dijk, 2018):

- Surface open water [m^2]
- Surface paved area [m^2]
- Surface unpaved area [m^2]
- Precipitation [mm/d]
- Evaporation [mm/d]
- Minimum and maximum water level [m+NAP]
- Water-table level [m+NAP]

3.4. Project "Blauwe Sportparken"

In chapter 3.2 traditional sport facilities are investigated. A new innovation has occurred with the transformation from traditional sport facilities to more climate resilient facilities. The main aspect which is addressed is the water management of a sports facility, because this element of sustainability has not been addressed in most projects. The topic sustainability is interwoven during the whole building process. Re-use of materials, sustainable contractors and LED implementations are common factors. The project 'Blauwe Sportparken' focuses on this transformation to more climate resilient sports facilities and seeks for more water robust solutions at sports facilities. Currently two sports facilities have been adapted in light of this theme. From these practical examples, the water balance related aspects are considered in the following sections. Water robust solutions that are concerned with water retention at these sports facilities are investigated, resulting in following research question:

How is the water balance of the project "Blauwe Sportparken" structured?

3.4.1. De Neul

Sports facility 'De Neul', located in Sint-Oedenrode, has to cope with high ground water levels due to its location near the Dommel. In 2019, the facility is transformed to a water robust and climate resilient sports facility (*Blauwe Sport-parken - Newae*, n.d.). There are three synthetic turf pitches and three natural grass pitches. Beneath the synthetic turf pitches rain water is stored in an underground water storage of approximately 2600 cubic metres. By means of controlled drainage, the water is retained and if necessary the water will be directed to the natural grass pitches. With this technique the groundwater levels are manually controlled by the sports club. The retained rain water is recycled for irrigational purposes for the natural grass pitches. Root irrigation is used to reduce water exploitation and wastage. Moreover, this technique prevents desiccation by slowly letting the water infiltrate in the soil. Besides, the area is protected for high water levels with use of a system with beams that block the water. (*Innovatie in de Schijnwerpers: Sportpark de Neul in Sint-Oedenrode - SportInnovator*, n.d.)

3.4.2. Roomburg

In Leiden, sports facility the 'Roomburg' has adapted their facility in order to become more climate resilient. In the new situation, the facility has become self-sufficient in terms of water. The main goal is to retain water as much as possible and restore the groundwater volume where possible. Precipitation water is stored in the synthetic turf pitches at the facility. In total there are three hockey pitches and nine tennis courts, which need a total of 350 m3 for irrigational purposes only. In The Netherlands on average 850mm of precipitation is expected. With the available data the calculations resulted in a necessary water storage of 1200 cubic metres. Basic assumptions are that a field with water retention 75% of the irrigated water returns to the water storage and the other 25% will disappear due to evaporation and spray drift. A pitch without water retention is assumed to recharge 10% of the irrigated water. The water storage is 20 cm high and has a minimum present water volume of 350 cubic meters. Instead of coarse material with big pores (used at 'De Neul'), a system of infiltration crates is used to create enough space for the water. This way a water balance can be constructed where several factors can be influenced. The starting points are that no external water is added for irrigational purposes, only rain water, and no overflowing toward surface water. The system is self-regulating, the sports club should only start the irrigation themselves. Altogether, water quantity is safeguarded, and water quality is accounted for by the implementation of a water filter. Furthermore, temperature control is inserted; the water should never exceed a temperature above 20 degrees. To assure water quality, water meters are inserted and once in the 3 months a water sample is checked. Even rain water that falls on the pavement or the roof of the canteen can be redirected to the groundwater storage. Without precipitation and a full water storage, the sports facility can irrigate for six weeks. If needed, water can be extracted from the surface water. And last but not least, the constructed field has more fibres than regular turf pitches, which enable the ability to retain spray water, therefore reducing the amount of irrigation moments. (Stuivenberg, 2020)

3.5. Water balance elements

For both sport facilities which are part of the project 'Blauwe Sportparken' roughly the same techniques are used. Besides more climate resilient improvements such as LED lights, reuse of materials and sustainable contractors, the water robust measures are examined more closely. Used techniques are: water retention in synthetic turf pitches, controlled drainage and root irrigation.

3.5.1. Water retention

The principle of water retention in synthetic turf pitches is rather simple in general terms; a bucket is created which is controlled by opening up or closing the drainage system beneath. Figure 5 displays how such a synthetic turf pitch is constructed in general. The first three layers are not unusual, however, instead of a layer of sand beneath the stabilisation layer is replaced with a layer of coarse rock (generally varying between 20 and 40 cm). This creates, due to the large pores, a large retention volume for precipitation water. When coarse natural stone is used with diameter varying between 30 and 60 mm, and a height of 40cm for the layer, the hollow space is 40% in the construction. Resulting in a water storage capacity of 160L per square meter. For an average soccer pitch, approximately 8000 m^2 of turf, this results in a water storage of 1300 m^2. (*WABER-Systeem® - GKB Groep*, n.d.)

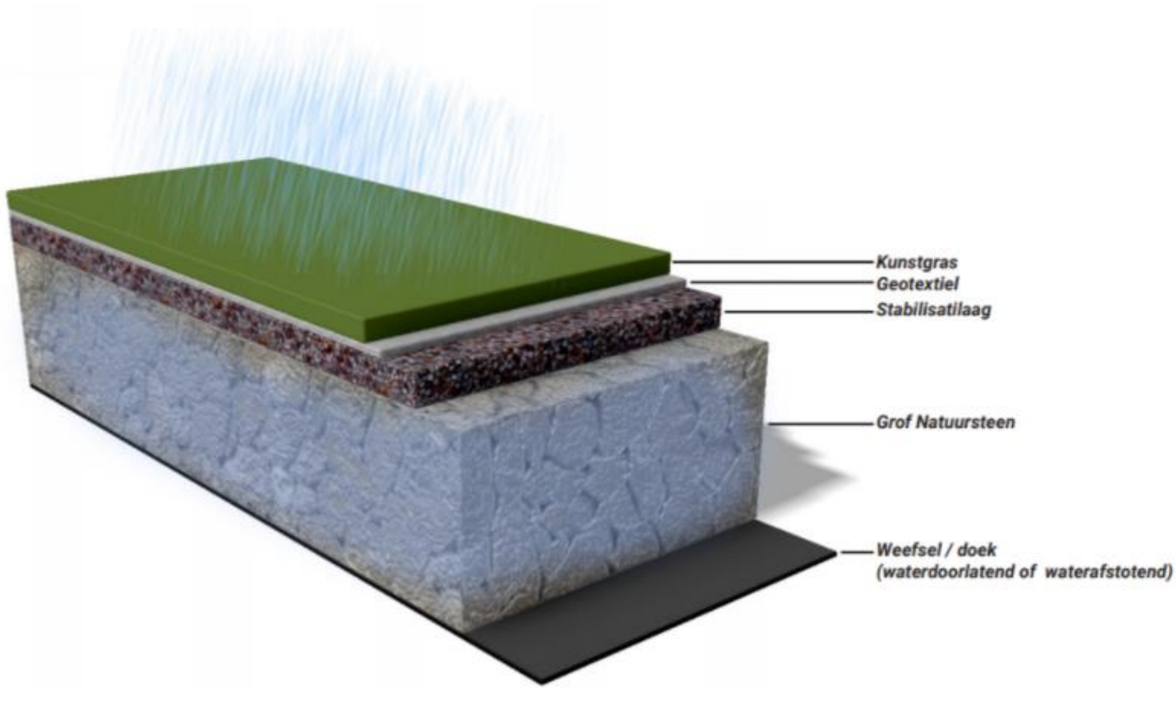


Figure 5: Comprehensive overview of the construction of a synthetic turf pitch with water storage beneath the pitch.

3.5.2. Controlled Drainage

At the sports facilities controlled drainage is implemented in order to regulate the water flows concerning the water retention storage. In chapter 4.3.2 the principle of this functioning system is elaborated into further detail. At the 'De Neul' the system is regulated manually by converting the pipes of the waterflow, this is illustrated in Figure 8: Controlled drainage visualized *(Palmans et al., 2017)*. During the summer period, the water is not able to flow out of the drainage system, increasing the water volume in the pitch construction. During the winter period, the drainage system is functioning just as a normal drainage system. Whenever needed this in and outflow of the drainage system can be controlled, for example during heavy rainfall or situations where the water buffer is already filled. This way water security can be guaranteed throughout the season because in each situation an adequate volume of water is contained. (Stuivenberg, 2020)

3.5.3. Irrigation

The retained water is used for irrigational purposes. With this system there is no drinking water, groundwater or surface water required for this type of activities. This reduces the input of external water tremendously and enhances the water robustness of the sports facility. At 'De Neul' root irrigation is implemented, reducing the water usage and increasing groundwater recharge.

3.5.4. Waterflows

In Figure 6 all waterflows of the project 'Blauwe Sportparken' are visualized to see the cohesion between water flows. Note: the difference with Figure 4 is the introduction of root irrigation, water storage, roof disconnection from sewerage and the indication of different surface types.

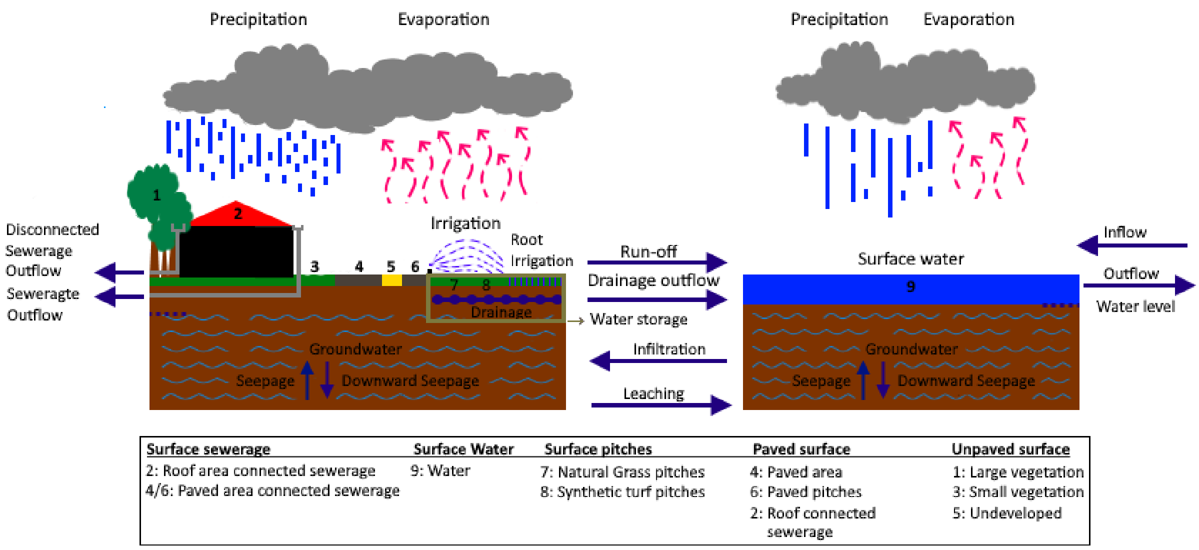


Figure 6: Overview of all water flows derived from a general water balance and from project 'Blauwe Sportparken'.

4. Water balance improving measures sports facilities

Which water balance improving measures can be taken at sports pitches in order to retain water, recharge groundwater and reduce water usage?

4.1. Irrigation

What irrigational measures are commonly used?

To invest water savings it is essential to understand how water is delivered to the soil. Irrigation efficiency can have great impact on the amount of water required for irrigation as can be seen in following equation (Milne & Gray, n.d.):

$$V_{irr} = \frac{I \times A_{field} \times 10}{\varepsilon_{irr}} \tag{1}$$

Where V_{irr} is the irrigation volume, A_{field} the surface area, I the amount of irrigation and ε_{irr} the irrigation efficiency factor. The Queensland Water Commission (Water Commission, n.d.) has estimated this irrigation efficiency factor for several irrigation types. These values can be used as a guide for generic trends as significant differences occur in practice within each irrigation system due to variable user practices.

Table 2: Overview of the different irrigation system efficiencies (Water Commission, n.d.)

Irrigation system	Soil Type		
	Clay	Loam	Sand
Drip	0.95	0.95	0.95
Microspray	0.5	0.5	0.55
Spray – Day	0.5	0.5	0.6
Spray – Night	0.55	0.6	0.65
Sprinkler – Day	0.65	0.65	0.65
Sprinkler – Night	0.75	0.75	0.75

It can be observed that the moment of the day has a relative large impact on the effectiveness of the irrigation system. By just implementing an irrigation schedule, and spray or sprinkle at night, already ten percent irrigation water can be economized. From an operational view, following guidelines should be adhered to for the most optimal irrigation scenario (Bos et al., 2009):

- Water at night instead of during the day: more evaporation will occur
- Do not irrigate during bad weather conditions such as heavy winds: uniformity decrease
- Only wet to the depth of the grass root system, otherwise percolation will take over
- Split watering schedules into short periods, rather than one long period, this increases water retention, otherwise it will be saturated
- Adjust water to the needs of the field, focus on wear and tear places

Currently, in turf irrigation there are three main techniques that are considered and evaluated in this report; spray (sprinkler) irrigation, subsurface drip irrigation and subirrigation. (Gale, n.d.)

4.1.1. Sprinkler Irrigation

The conventional method to irrigate sport pitches is sprinkler irrigation. The main reason for this is reliability, simplicity and comparative low capital costs (Milne & Gray, n.d.). The three main sprinkler techniques that are used:

- Portable sprinkler: an inexpensive option, requires more labour costs than other methods, sprinklers are also more vulnerable.
- Quick coupling valves: are medium ranged in terms of expense, but require a bit labour. However, this technique can be less efficient.
- Automatic pop-up sprinklers: expensive option, require little labour but uniformity and efficiency are high.

The benefits accompanying these type of sprinklers are the well-established technique, the visual monitoring and the common use. The more expensive the more automated and the general rule of thumb is that greater automation results in greater efficiency. (Water Commission, n.d.)

However, there are also some drawbacks from this system of sprinklers. The most important one is the uniformity of irrigation. The circular of radial precipitation from a sprinkler causes more precipitation near the sprinkler head than at greater distance, due to the larger area the water must cover (Milne & Gray, n.d.). To compensate for this lack of uniformity, overlapping is required, resulting in more water usage than actually needed. A triangular pattern (as can be seen in Figure 6) gives a reasonable uniformity for the greatest costs effectiveness. The applied pressure has also influence on the uniformity. Low pressure creates a donut patter with more delivery at the outer range than near the centre, whereas high pressure creates an opposite effect; more water delivery near the centre than near the edge. (Gale, n.d.)

Another disadvantage is the influence of wind and evaporation. Winds affect the uniformity and increase the rate of evaporation. The raindrop size also matters; small raindrops lead to greater evaporation loss contrary to larger raindrops, which damage the soil and turf. (Bos et al., 2009)

Sprinkler systems can deliver the necessary volume of water for irrigation for a range of efficiencies. However, some unnoticeable side effects occur, the application of water to the surface results in smaller roots. This decreases the ability to withstand periods of drought since roots are unable to reach deeper into water reserves. This effect can be tackled by reducing the irrigation frequency.

Irrigating to much water is considered as a problem too for sprinkler irrigation (specifically for high labour systems). When the precipitation rate of the sprinkler exceeds the percolation rate of the soil, runoff and ponding become a problem. This could cause problems such as the washing out of nutrients and polluting environmental surroundings near the facility.

Another negative side effect of the use of a sprinkler installation is the increased energy use. The energy consumption tends to be higher due to many extra pumps that are needed to maintain water pressure. Decrease of energy use can be reached by using variable speed pumps that allow optimisation of pressure requirements. (Milne & Gray, n.d.)

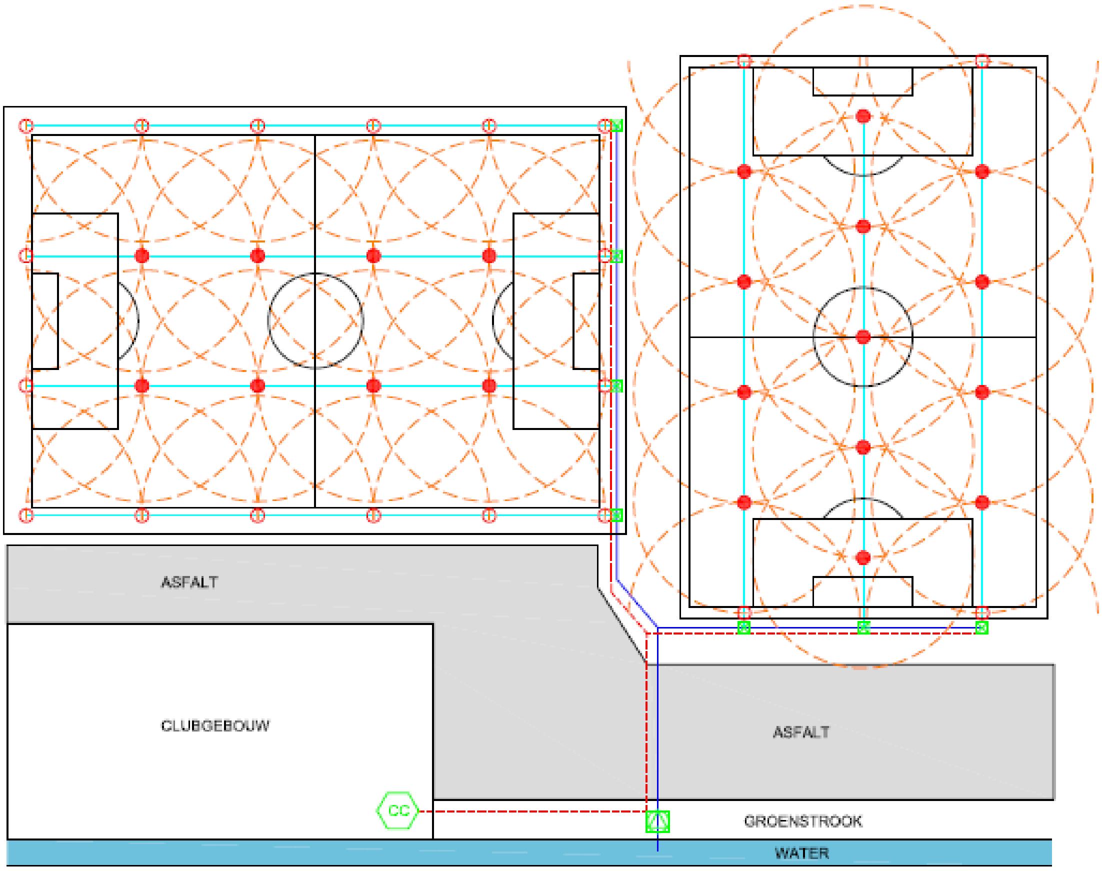


Figure 7: Overview most common sprinkler irrigation systems for (soccer) pitches

4.1.2. Subsurface drip irrigation

Another type of irrigation methods is the subsurface drip irrigation (SDI). In this system, the water is applied directly to the root area of with use of porous pipes or drip tapes with inbuilt emitters. These emitters have a specific flow rates and ensure turbulence while minimising blocking of water. The biggest advantage of this system is the uniformity of the distribution of irrigation water. The success rate of this system is highly dependable on the soil type and permeability moreover. (Milne & Gray, n.d.)

The effects on crop growth are undisputed; water requirements are reduced or yields increase significantly. In general, SDI is more efficient regarding water usage and it produces less runoff than with traditional sprinkle irrigation. Besides solving runoff problems, percolation problems have been shown to reduce as well. Both effects enhance the environmental improvement of irrigation with less washout of nutrients. Nutrients can, in some systems, be applied to the rootzone using the same system. (Bos et al., 2009)

Other advantages are the increased flexibility for irrigation, at any time the field can be irrigated. Moreover, under almost each weather condition, subsurface drip irrigation can be applied. This is very useful for sports facilities with excessive use or situated at inconvenient locations in terms of weather characteristics. Even vandalism is reduced. Furthermore, energy costs will decrease, due to the lower pressure requirements when compared to traditional sprinklers. Maintenance will also decrease due to the less mechanical parts in the system. Application is also safer for irrigation with lower quality waters, reason is the lack of contact between users and the irrigation water. (Lucas et al., 2017)

However, there are some disadvantages as well. The most significant one is the emitter/pipe clogging. This can be caused by root intrusion, soil clogging or chemical precipitation. Root intrusion can be solved by including herbicides in the water or system itself, or increasing the irrigation frequency creating a constant saturated zone, which disables root growth. Soil clogging occurs most frequently when shutting down the system; a vacuum may form, which could suck soil particles in. A solution can be found in the placement of air and vacuum release valves in the system. Another disadvantage is the limited monitoring in comparison to spray irrigation which is visually checkable. Monitoring can be down by looking at the growth or via secondary techniques such as pressure and flow sensors. Unfortunately, isolating problems is more difficult and maintenance can be costly because the field is also unusable. Another limitation of the system is the fact that when overseeding needs to take place, this system cannot be used because water is needed at the soil surface.

4.1.2.1. Air injection

From experimental studies it has been found that in addition to subsurface drip, irrigation air can injected as well. This injection of air results in even better results in terms of water reduction compared to traditional sprinklers. (Abuarab et al., 2013)

4.1.3. Subirrigation

Another, not common, method is the use of subirrigation. This is the practice of artificially raising the water table to ensure enough water available to the turf without generating extra evaporation. The water is stored just below the root zone and with use of capillary action the plants can absorb water. In essence, subirrigation creates a large impervious bucket below the rootzone. With perforated pipes water will be delivered or drained to the root zone. The uniformity of irrigation is way higher than sprinkler systems. Overflow pipes ensure that the artificial water table does not waterlog the rootzone. There exist two methods of performing subirrigation; varying the water table or retaining a fixed water level. A fluctuating water table results in more wealthy yield in comparison to a fixed water level. (Milne & Gray, n.d.)

With this method, water will be saved once the water reserve has been established creating an artificial water table. Due to the capillary functioning, the plants are receiving the necessary water. However, the amount of water in the root zone is limited reducing evaporation losses. This also results in less runoff when precipitation occurs and rainfall can be retained more due to the storage capacity in the root zone. Percolation losses are also reduced this way. Also, root growth is more extensive which makes a field more tolerant to droughts. (Milne & Gray, n.d.) Compared with sprinkler irrigation, subirrigation systems consistently substantiate a reduce of water usage, primarily because excess water is reused in the soil instead of lost due to drainage. Overall water reduction is shown to be 56% on average. (Ferrarezi et al., 2015)

Disadvantages of this technique are comparable to subsurface drip irrigation. Investment is significant and maintenance is less regular, however, can be very expensive when needed. Furthermore, monitoring is only possible through secondary techniques. (Gale, n.d.)

4.2. Water reducing measures

Large volumes of water are often consumed at sports facilities offering much room for improvement. There can be distinguished several types of water; drinking water, surface water and ground water. Each type occurs at a sports facility and is different from one another in terms of water quality. This determines for which activities the water type can be used. In order to determine which water reducing measures can be implemented in the model a preliminary investigation has been executed. Possible water reducing measured are investigated in this section with research question:

Which water reducing measures can be used at sports facilities?

4.2.1. Reduce Water demand

Drinking water is used for all domestic activities that occur at a sports facility. Serving water in the canteen, washing activities, flushing toilets and showering are the most common practices. Possible water reducing (demand) measures for this type of water can be ultra-low flush toilets, hand-dryers, sinks that automatically stop the water flow when not in use, low-flow shower heads and other fixtures which decrease the standard water flow (National Institute of Building Sciences, 2017). Also, measures which focus on influencing patterns of people could help, for example turning off water outlets completely. Moreover, introduction of water systems that control water supplies and turn it of outside of operating hours increase water conservation. (Gibson et al., 2008)

Moreover, water demand can be reduced for irrigational activities using smart technology. With sensors and modelled irrigation systems it can be ensured that over-irrigation does not occur. There are two ways of determining the needed irrigation, via weather based model predictions (with climatic data) or sensors. (Salazar, R., Rangel, J.C., Pinzon, C., Rodriguez, 2013)

The second method is more accurate because the soil moisture content can be measured directly and more frequently. Side benefit of this method is the improved environmental performance, by decreasing the amount of nutrient washing away to ground water. Irrigation efficiency has a significant contribution on the required amount of water need for irrigation. In chapter 4 more in depth information regarding irrigational techniques is given. (Gibson et al., 2008)

Last but not least, for natural grass pitches the type of grass influences the ability of efficient water use. Warm-season grasses, couch or kikuyu grass, are much more drought resistant dan cool-season grasses such as ryegrass or fescue or poa annua. These type of warm-season grasses have lower rates of evapotranspiration, resulting in lower maintenance needed for growth and retaining quality. (Bigelow & Munshaw, 2014) Moreover, they have deeper root structures that are able to extract water for a longer time, recovery abilities are better and their tolerance to lower quality water is higher. Average cool season sport fields need 9,9ML per hectare per year compared to 6,8 ML per hectare per year for warm-season sports pitches. Boiling down to a saving of 30% in water use. When overseeding takes places during winter periods, most optimal grass type can be inserted for each situation, reducing water usage even more. (Sports Environment Alliance, 2019)

4.2.1.1. Re-use Water

Besides reducing the water demand, used water can be re-used. This covers the use of water that is generated from waste water and that achieves a quality that is sufficient for the intended use. Sometimes additional treatment to waste water is necessary, depending on the utilisation of the reused water. (European Commission, 2016)

One type of water that is available at a sports facility is rain water falling on roofs. This is perceived to be a different kind of water than stormwater. Rain water, or sometimes called roof water, has not contacted surfaces that are generally are perceived as polluted, such as roads and gardens. This kind of water is in most cases not usable as drinking water due to the contamination of construction material of the roof, piping and storage. This type of water can be used for irrigation, nevertheless it is useful to check the concentrations of various elements such as lead, copper and metals, before applying it. Typically, rainwater is suitable for irrigation without treatment leading to low costs. It is dependable on weather conditions, but it could meet some irrigation requirements of a sports facility.(Epa et al., 2004)

Besides rainwater, there is another type of water that can be collected; stormwater. Stormwater is the definition for precipitation water that is collected from a typically large area from all surfaces within a catchment. It is characterised by the various contact moments with all type of surface such as roads, gardens, pavements. It is seen as contaminated, hence resulting in slightly lower quality than roof/rain water. Besides that, it is usually available in large volumes. (Rahman et al., 2016)

4.2.2. Material influence

The material of a sports pitch is also from great importance regarding the water retentiveness. The average water consumption of turfgrasses during a regular summer period is about 3-4mm (Bigelow & Munshaw, 2014). Under these circumstance a pure sand layer will provide soil water for approximately 4-5 days. While most retentive soil treatments, adding other water-retentive amendment components, results in water provision for 9-12 days. (Hejduk et al., 2012)

4.3. Drainage

In the water balance of a sports facility it could already be seen that drainage is an essential element. At the two sites of the project 'Blauwe Sportparken' a controlled drainage system play a big role in the water robustness of the facility. From research (source), it has been concluded that the drainage at synthetic turf pitches and gravel pitches for different kind of sports are comparable, so no distinction will be made. This section will elaborate on this topic providing more background knowledge. To build a comprehensive model current available drainage systems for sports facilities are investigated, answering next research question:

What water drainage measures are commonly used or can be used at sports facilities?

4.3.1. Traditional Drainage

In the Netherlands, most sport pitches are equipped with traditional drainage (Fleming et al., 2017). This is needed to account for playability throughout the season (KNVB, 2018). With this type of drainage system the drainage strings give out onto ditches directly. When water rises, through precipitation, to a higher level than the drainage strings, this excessive water will be dissipated. Groundwater can never rise higher than the drainage strings, unless severe weather conditions occur. This type of drainage has the big disadvantage that is not possible to retain more water in the ground than the height of the drainage tolerates. (Milne & Gray, n.d.)

4.3.2. Controlled Drainage

To retain water for a longer period in the ground, controlled drainage could help. This system enables control of the drainage with use of an additional pipe. The drainage strings will, instead of a ditch, be attached to a big pipe which will be connected to a 'control dwell' which ultimately is attached to the original ditch. The law of communication vessels states that the water level in the ground and in the 'control dwell' will level out, this is visualised in Figure 8. This way one can control the water level by simply increasing the height of the pipe that is connected to the ditch. (Palmans et al., 2017)

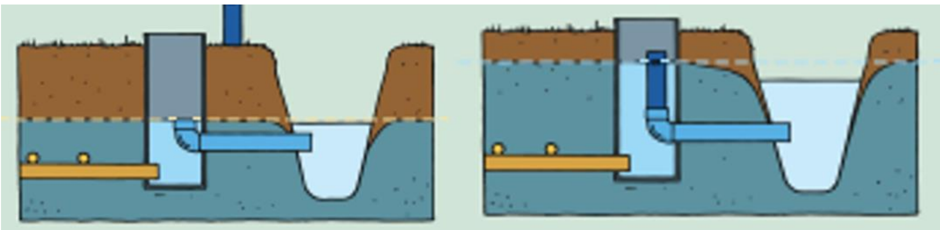


Figure 8: Controlled drainage visualized (Palmans et al., 2017)

In Figure 8 a control pipe (colour: dark blue) is indicated, this is the simplest variant of controlled drainage which occurs most frequently in practice(STOWA, 2013). However this system can be advanced by adding computer control. In that situation, the height of the control pipe is determined by a computer system. This has the advantage that direct measurement and adjustment is possible as well as more precise control of the water level which is beneficial for severe conditions. (Bakel et al., 2008)

4.3.3. Advantages

The most beneficial aspect of controlled drainage is the ability to retain more water in the ground throughout the season. This positively affects the consistency of the ground in terms of moist. When the groundwater reservoir is larger, droughts have less impact. Moreover, positive environmental impact is a result since nutrients can be adsorbed better by the ground through longer water retention periods (Palmans et al., 2017).

4.4. Water retention

Water retention is maybe the most important topic and has great influence on the water robustness of a sports facility. In this section the different ways of retaining water at a sports facility are evaluated with following research question:

How can water be retained at sports facilities?

4.4.1. Water storage

In order to use an alternative water source than drinking water, it is important to evaluate the possible storage options. Water needs to be available mostly at a constant rate, under these conditions the storage capacity will be critical for the reliability of the system. The material used to contain the water is important for the quality of water and for the potential reusable water amounts. Three main storage technologies are artificial lakes and ponds, aquifer recharge, and water tanks. (Burszta-Adamiak & Spychalski, 2020)

4.4.2. Artificial Lakes and ponds

An obvious way of storing large volumes of water is storage in an artificial lake or pond. If enough land is available, this is a relatively cheap water storage option. However, sports facilities generally are located in or near a city where land prices are high. Benefits of this option are the increased visual aspects and increased habitable conditions (Rahman et al., 2016). The environment is more pleasing to neighbouring residents, it could even create a new useful open space for the local community. It also increases biodiversity, however, the water should not be stagnant for too long due to the forming of algae. Another downside is the exposure to environmental conditions such as evaporation. This type of storage is, in comparison to the other type of storages, the least costly. However, a lack of space could be a problem, as well as the aesthetically unattractive view when being empty. (Milne & Gray, n.d.)

4.4.3. Aquifer recharge

To store large volumes of water aquifer recharge can be used. An aquifer is a underground layer of water-bearing soil, where water can be retrieved using a water well. Depending on the soil, different degrees of hydraulic-conductivity of aquifers occurs as depicted in Figure 9.

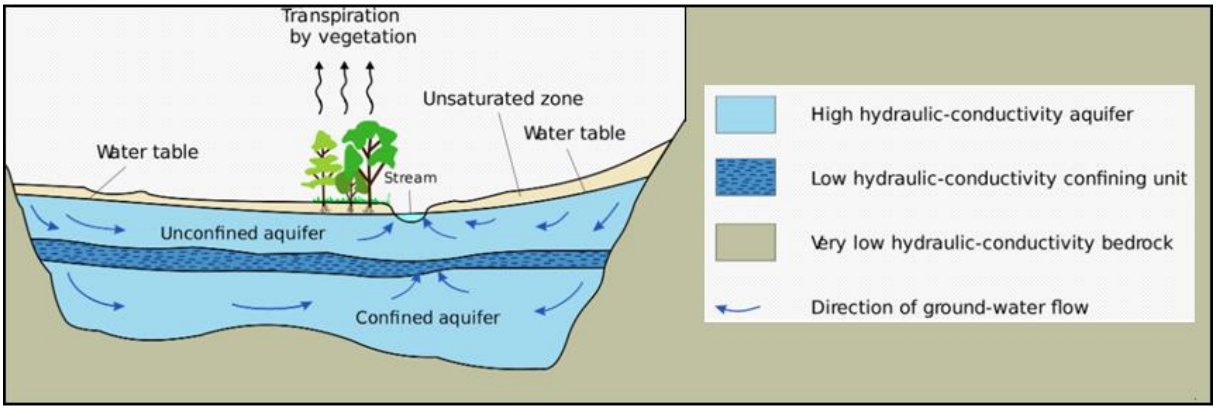


Figure 9: Overview of an aquifer (Aquifer - Wikipedia, n.d.)

This type of storage helps to reduce the footprint of the storage, making it more suitable where land is an issue. Environmental conditions will limit water losses with only percolation from the storage instead of evaporation. Another benefit is the long-time residence with loss of viral and bacterial contamination as a results. (Milne & Gray, n.d.)

Currently, techniques to store rainwater in underground aquifers are available for sports facilities. A company like Field Factors is specialized in implementing this type of water storage resulting in the availability of fresh water from the own sports facility. By introducing a biofilter, water is purified, reducing health risks and algae growth. Water can be stored in natural aquifers for future use. (Fieldfactors, 2021)

4.4.4. Artificial aquifer

Another type of storage that can be used, that is slightly different from natural aquifers or other storage types, is a shallow storage facility that is constructed with use of a modular storage system type (such as infiltration crates). This creates an artificial aquifer which created just beneath the surface. This type of storage is constructed at sports facility 'Roomburg', for detailed information see chapter 3.4.2.

4.4.5. Water Retention Tanks

Storage tanks for water can be useful but are typically only economical on a small scale. This is due to the required materials such as metal, concrete and plastic that go into these tanks. Cost estimates can be made using following equation:

$$C = 19.394 * V^{0.873} \tag{1}$$

Where V is the volume in Litres, C is the cost in Australian dollars. Tanks in the kL range are affordable, ML tanks become quite expensive. Benefits of these storage tanks are that they are separated from the adjacent environment. Contamination from outside water is prevented, so quality is maintained better. (Milne & Gray, n.d.)

4.4.6. Water storage provision

Besides the different water storage options, the storage that is most suitable depends on the provision of water needed. There are three scenarios which have large influence on the necessary volume of storage required. (Burszta-Adamiak & Spychalski, 2020)

Between irrigations periods

This type of storage is used when the required irrigation water cannot be supplied instantaneously by a recycled water pipeline or dwell. For an irrigation rate of 15mm/ha per week a storage volume of 50kL/ha is assumed to be sufficient. A tank of this size is available in a price range of 15 000 to 20 000 dollar.

Between rainfall periods

When storage is needed for the periods between average rainfall, generally stormwater reuse systems are adapted. It is estimated that on average, once a month the storage is refilled by natural precipitation. This results a storage volume needed of approximately 0.6 ML/ha which provides 15mm/ha of irrigation per week.

Extended dry periods

This type of storage focuses on larger amounts of water that need to be captured during for example spring or autumn periods. For a minimum of 2 months without rainfall, a storage volume of 1.22ML/ha for an average irrigation rate of 15mm/ha per week.

5. Model Water Balance Sports Facility

In this chapter the constructed Excel model for a water balance of sports facilities is described. This model has been established through literature research, expert input and logical reasoning. The results of the first two research questions have been used as input for the construction of the model. As a basis. the STOWA water balance is used which describes the relationship between the influential factors in a water balance (chapter 3.1). The first sub question resulted in the outlines of an excel model for the water balance of a sports facility. The second sub question led to implementations for the model which have been inserted in the model. After accomplishing a working Excel model, with all mentioned input, calibration and verification generated a tweaked and tuned excel model which can quantify the effects of water balance improving measures for sports facilities. The following sections describe the structure and functioning of the model together with aforementioned steps of the design cycle.

5.1. Design Cycle

The design cycle used for constructing the water balance model is common practice and consists of the following elements which are illustrated in Figure 10. First, the problem is analysed which resulted in the selection of a model type; a water balance and the systems boundaries; sports facilities. After creation of a rough conceptual design of the model, different model methods have been considered. Consequently excel has been chosen for simplicity, generosity, wide range of possibilities and user friendliness. With use of this conceptual design (Figure 2) and research questions the more detailed required information could be acquired resulting in a final model layout (Figure 11) and model type; the bucket model, built on a basis model from STOWA (Tanis et al., 2018). Now the model could be constructed leading to a first design. The core of the model has been constructed, as well as the input and output. This prototype model has been updated with many functions, including water robust implementations, through several small design cycles. Eventually, this prototype was tested (calibration, verification and validation) and further optimized until it functioned according to its needs. Last but not least the model design has been evaluated by the commissioning parties and resulted in final layout. With this model the final results could be retrieved.

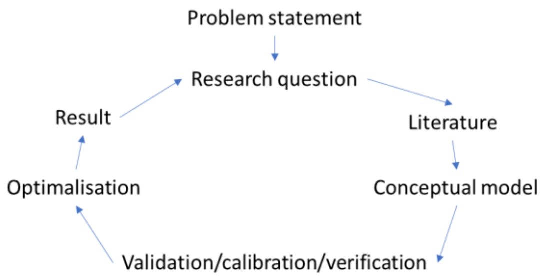


Figure 10: Design cycle model

5.2. Structure

The model is an excel file with Visual Basics for Applications (VBA) Code and interactive features such as buttons, graphs and pop-ups. Area composition, water levels, meteorological information form the basis in order to create a water balance of a sports facility. A bucket model is adapted to represent the actual water flows and different areas. In 2015, a sports facility consisted of 1 hectare of surface area on average, and 95% of the sports facilities had a surface area less than 20ha (Visser, 2010). Due to this relatively small surface area of sports facilities, the adaptation of a bucket model is sufficient in terms of accuracy. The water system of an area is categorized in several types of small buckets with the same homogenous properties. This simplifies the water flows and enables calculation for different sport facilities. As time step one day is chosen to be most suitable. Most precipitation, evaporation and water level data sets are available in daily format. The goal of this research is to acquire insight in the water balance over a sports facility, implying a longer period. It is common to analyse the water balance on an yearly scale, increasing the time step would significantly impact the function of the model in terms of run time. Little differences in water flow will be noticed with a small timestep due to the low flow velocity in soil. Annually, the (for example hourly) input differences will cancel out due to these small differences in flow. Figure 11 shows an overview of the model structure, each part will be discussed into more detail in the next sections.

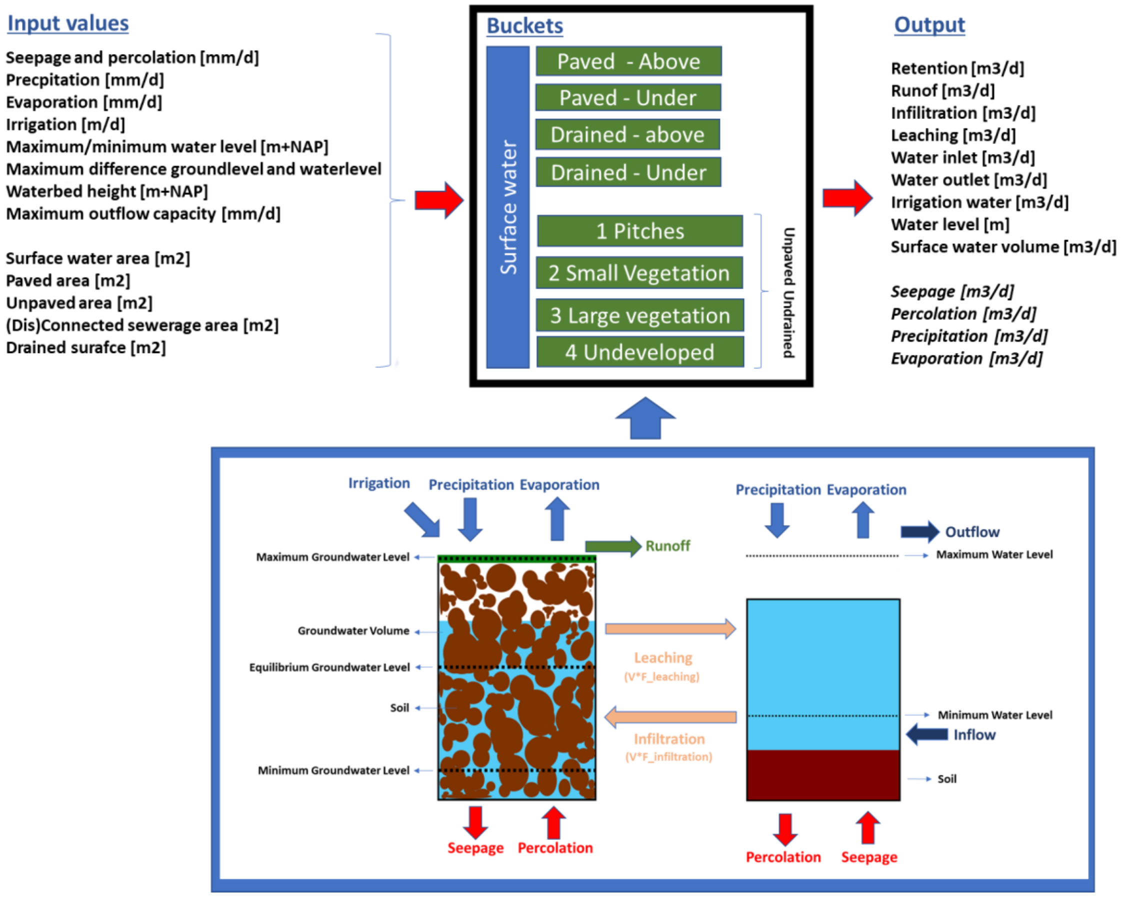


Figure 11: Comprehensive overview of the structure of the water balance model

5.3. Buckets

The area that needs to be analysed will be simplified to several small buckets. In the model there exists a water bucket and eight land buckets. Each buckets has its own homogenous characteristics.

5.3.1. Water bucket

The water bucket represents all surface water, it contains perfectly mixed surface water, has a fixed surface and a fixed water bed height. The sum of all water flows determines if the water level increases or decreases. If the water level is beneath the minimum allowable value, inlet water is modelled to safeguard the minimum tolerated water level. If the water level is situated above the maximum allowable value, outlet water is modelled to maintain the maximum tolerated water level. This is visualized in Figure 12.

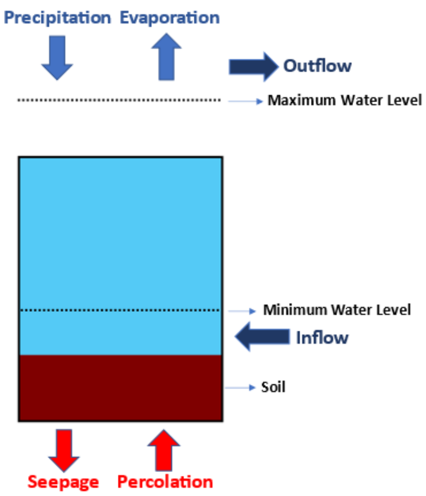


Figure 12: Overview of the water bucket with all water flows

5.3.1.1. Land bucket

There are five different types of land buckets implemented in the model. Each bucket has different characteristics and conditions. Also, different types of water flows occur in each bucket.

Table 3: Overview of the different type of land buckets and their characterisation

Paved – above	Paved – beneath	Unpaved Drained – above	Unpaved Drained - beneath	Unpaved undrained
Not connected to sewerage	Not connected to sewerage	No infiltration from the surface water, due to drainage strings that are positioned above the water level	Water surplus is dissipated through drainage system	Four buckets, with different soil characteristics depending on the type of land
Water exchange with 'Paved – beneath' is not possible because of the closed surface	Water exchange with 'Paved – above' is not possible because of the closed surface	Water exchange with 'Unpaved – drained' is possible	Surface water run-off does not occur	Used for Vegetation, Sand, undrained sports pitches and grass
Precipitation dissipated at the same day, excluded 2 mm water that remains due surface texture	Connection to groundwater and surface water	No seepage/percolation occurs due to the drainage strings.	Seepage/percolation, leaching/infiltration are present	Seepage/percolation, precipitation/evaporation, leaching/infiltration and run-off are present
Precipitation/evaporation and run-off are present	Seepage/percolation and leaching/infiltr	Precipitation/evaporation and run-off are present		

	ation are present			

5.3.1.2. *Geohydrological soil characteristics*

Each land bucket has its own geohydrological soil characteristics which are included in the model. This concerns several factors which are dependent on the soil type in each bucket. There are seven values which need to be assigned for each bucket;

- subsurface outflow factor [-]

Groundwater fraction that leaches to the surface water. This only occurs when the groundwater volume is larger than the equilibrium groundwater volume. These values have been found in the 'cultuurtechnisch vademecum', varying from 0.3-0.7 to 0.03-0.07 per day.

- subsurface inflow factor [-]

The amount of water that infiltrates from the surface water into the soil of the land bucket, expressed as fraction of the present groundwater. Infiltration only occurs when groundwater volume is smaller than the equilibrium groundwater volume. The subsurface inflow factor is almost in each situation smaller than the subsurface outflow factor due to the fact that the amount of water in general is smaller than the amount of land.

- retention volume factor [-]

The retention volume is the effective space between soil particles, which is filled completely with saturation. It concerns the effective space because a fraction of the water volume will stick to the soil particles instead of flowing out. Hence this concerns the maximal fraction of the soil that will be used by the ingoing and outgoing water fluxes. In the Netherlands this varies from 0,25 for sand up and till a maximum of 0,7 for clay.

- max groundwater level [m]

The maximum allowable groundwater level in comparison to the equilibrium groundwater level. This is the difference between the water level in ditches and ground level. For the bucket 'paved – above' it represents the maximal water layer on top of the paved area.

- equilibrium groundwater level [m]

When the groundwater level is higher than this value, it will leach to the neighbouring surface water. When the groundwater level is lower the water will infiltrate. This equilibrium water level is per definition set at 0, it is not connected to the surface water level. A groundwater level of 0 is in the model equal to a groundwater volume of 0 m3. A groundwater level below the equilibrium groundwater level is indicated as a negative value, and vice versa.

- minimum groundwater level [m]

This parameter is only used for the bucket 'paved – above'. The value is 0 due to the impermeable layer of pavement which disables a negative groundwater volume. Since this bucket always above the groundwater level there is no infiltration possible.

- initial groundwater level [m]

The initial groundwater level is compared to the equilibrium water level. This only affects the first months of simulation, because in the long run there will develop an equilibrium situation. Standard initial groundwater level is equal to the equilibrium water level (0m).

- (Minimum) evaporation rate [-]

In the model is has been accounted for the different types of evaporation depending on the type of land bucket with use of a (minimum) evaporation rate factor. The more water at the surface, the more water can evaporate. Consequently, the normal evaporation rate is applicable when water is at equilibrium ground water level or above. The minimum evaporation rate is applicable when the groundwater is below the equilibrium groundwater level.

At the input sheet, the type of soil which is present at the sports facility is selected, which is roughly divided into three categories: permeable (sand), semi-permeable (loam) and impermeable (clay). The accompanying soil characteristics as described in above section will be selected and applied. These factors have been derived from the 'Cultuurtechnisch Vademecum' (1988). In Appendix E overview of each soil type with the accompanying factors per bucket are visualized. In general, the following trend is noticeable; from sand towards clay, the outflow factor and the inflow factor reduce, while on the contrary the retention factor increases. Furthermore, the more vegetation available, the more surface contact, the higher the evaporation rates.

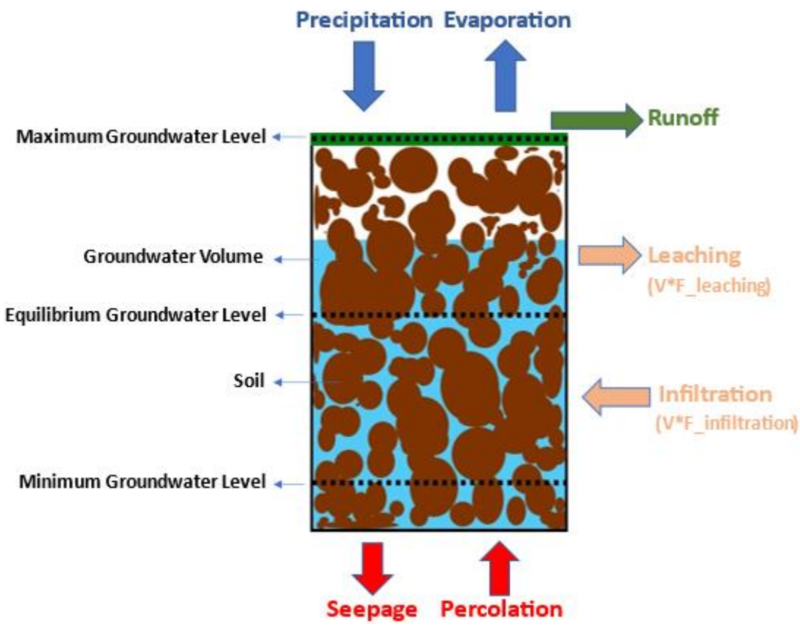


Figure 13: Overview of a land bucket with all possible water flows, for the specific land buckets the available water flows differ

5.3.2. Groundwater

The groundwater volume and groundwater level are related according to following formula 2

$$Groundwater\ volume\ [m3] = surface\ [m2] * groundwater\ level\ [m] * porosity\ [-] \quad (2)$$

This volume varies through the influence of seepage/percolation, infiltration/leaching and precipitation/evaporation. In reality the groundwater level is directly related to the surface water level, in this water balance this relationship is indirect. The groundwater level is always relatively compared to the equilibrium groundwater level, which is 0m, in each land bucket. This simplifies the calculation for inflow and outflow volumes. Groundwater volume is negative when the groundwater level is beneath equilibrium groundwater level and vice versa. With a negative groundwater volume, infiltration from the surface water will take place. With a positive groundwater volume, leaching from the land bucket into the surface water will occur.

The final values for each bucket and value can be found in Appendix E. Each bucket is assumed to be homogeneous so this simplifies the assigned entries. Each factor or value has been carefully selected with use of expert input and literature reports.

5.3.3. Combined sewerage

Combined sewerage is taken into account for indicated areas where water will not flow to the surface water but will dissipate by the sewerage system. This water will flow out of the model and is not taken into account. Only in case of extreme precipitation exceeding the sewerage capacity, the excessive

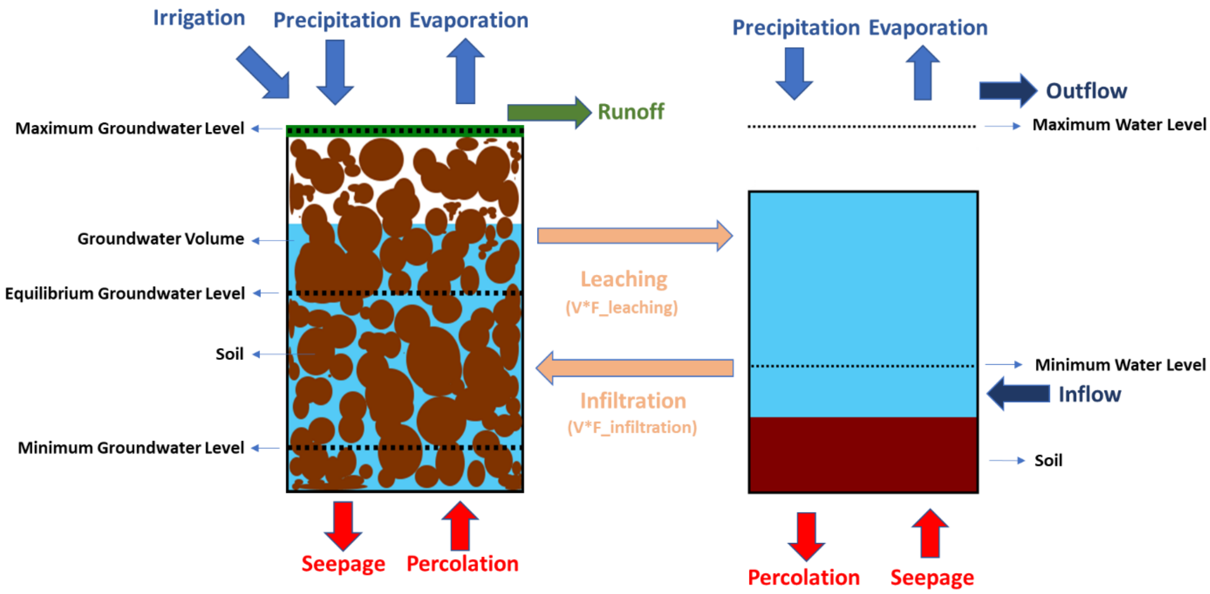


Figure 14: Comprehensive overview of a land bucket, the water bucket, their interaction and all present water flows

water will flow into the surface water.

5.4. Input

This section elaborates on the model input. First, all input parameters are mentioned and in the following sections the specific input variables will be discussed. An overview of the core input is provided, the core input of the model can be divided into four elements:

- Water level management
  - Minimum/Maximum water level, otherwise water will be let out/in
- Weather conditions
  - Precipitation (rainfall, snow and hail)
  - Evaporation
- Landscape characteristics
  - Surface type
    - Run-off
  - Groundwater flow
    - Seepage and percolation
  - Soil characteristics
    - Soil type, porosity, infiltration and leaching

- Distinguished in balance: paved, unpaved undrained, unpaved drained (and sewerage connection)
- Connection to other water systems

This results in the following list with a minimum of necessary data which substantiate a proper functioning of the model. All of these elements should be included in the model to provide as much accuracy as possible. The elements can be divided into two categories; area composition and (vertical) water flows.

<u>(Vertical) Water flows</u>

- Maximum difference between water level and ground level height
- Minimum and maximum acceptable water level [m+NAP]
- Waterbed height [m+NAP]
- Seepage and percolation [mm/d]
- Maximum outflow capacity [m3/d]
- Precipitation [mm/d]
- Evaporation [mm/d]
- Irrigation [mm/d]

<u>Area composition</u>

- Surface water area [m2]
- Paved area [m2]
- Unpaved area [m2]
- Connected sewerage area [m2]
- Drained surface [m2]

5.4.1. Area Composition

First, the area that needs to be analysed should be demarcated. It is important that the area is as much as possible a closed hydrological entity. The boundaries of the selected area of the sports facility should be rivers, ponds, ditches, etc and water levels should be equivalent. To be precise; the range between maximum and minimum water level should be equal. In the water balance all surface water is modelled as a whole with consistent water level management values.

In the model these values are specified for a sports facility. The area composition input is divided in the following elements which are incorporated in the model:

- Surface sports synthetic turf pitches (e.g. tennis, hockey, soccer), drained or undrained
- Surface natural grass pitches (e.g. soccer or hockey), drained or undrained
- Surface paved pitches (e.g. athletics, or basketball)
- Paved surface (e.g. Asphalt, tiles, gravel, bricks)
- Unpaved surface (Small vegetation, large vegetation and undeveloped land)
- Area connected to sewerage (Roof and paved area)
- Water surface (e.g. river, ditches, ponds, etc.)

In Appendix B these input elements are visualized.

5.4.2. Vertical waterflows

After the input regarding the area composition, the vertical water flows are inserted. This concerns the precipitation and evaporation for a giving period. The precipitation data set can be retrieved from the nearest KNMI station. At this station, the crop transpiration ('referentiegewasverdamping') is measured too, this can be inserted as the evaporation. The real evaporation is dependent on the soil, for the water bucket, this is automatically transformed to open water evaporation, which is higher in the summer than winter. This performed by transformation factors stated by a study in 1988. Furthermore irrigation can be inserted for a given period in mm per day.

Seepage and percolation are the following vertical waterflows being considered. In the model only the name 'seepage' will occur, whereas the plus or minus sign indicates if it concerns seepage (+) or percolation (-). There is distinction between the water bucket and the land buckets. Seepage water in land buckets mixes with precipitation water and is able to wash out to the surface water. Per type of bucket the seepage (mm/d) during the winter and summer period can be inserted. The net seepage value is concerned . This means that e.g. -2mm/d (percolation due to minus sign), is established by 4mm/day seepage and 6 mm/day percolation. For estimating these seepage values the seepage maps from NHI can be used (model output LHM411). The raster size of these maps is 250x250m which is in most case accurate enough. If needed, more details can be administered from water boards in the region of the sports facility.

Last but not least, water management values have to be inserted. This concerns the maximum and minimum water level for the inserted area per season. Furthermore, the initial water level, the maximum difference between water level and ground level the water bed height and the maximal outflow capacity of pumping stations needs to be established.

In Appendix B it is visualized how these input values are displayed in the model. For overview, all the vertical water flows (or related) input values are visualized in following main points:

- Precipitation [mm/d]
- Evaporation [mm/d]
- Irrigation [mm/d]
- Minimum and maximum acceptable water level [m+NAP]
- Maximum difference between water level and ground level height
- Waterbed height [m+NAP]
- Seepage and percolation [mm/d]
- Maximum outflow capacity [m3/d]

5.5. Input Processing

5.5.1. Horizontal waterflows

After implementation of al input values, the water balance is constructed by the model. Each value is transformed to cubic metres per day. The model recalculates for each day of the inserted period the value of each water flow. The vertical water flows are inserted as input, however, the horizontal waterflows are dependent on the input and are explained in this section. It is good to note that in the water balance the ground water level is not directly connected to the surface water level.

Leaching

The process of groundwater flowing towards surface water, especially during wet periods. Leaching will occur when the ground water level is higher than the equilibrium water level.

Infiltration

The process of surface water flowing towards groundwater, especially during dry periods. Infiltration will occur when the groundwater level is lower than equilibrium water level.

Runoff

During heavy rain showers, the soil is not able to absorb the precipitation water, this will flow towards the surface water. In the water balance, there is a difference between runoff at a paved and unpaved area.

Sewerage

Precipitation that falls down at the area connected to the sewerage will directly be transported to the main sewerage. In the model sewerage water will disappear instantly from the model. Retention capacity of the sewerage is estimated to be 7 mm and the pumping capacity is 0,7mm/hour. When the sewerage is not able to deal with amount of precipitation that needs to be exported the necessary water will be added to the surface water volume.

5.6. Result

The summation of all vertical and horizontal waterflows will result in a certain water volume in the water bucket. With this water volume and the inserted input area dimensions the water level can be determined according to following formula 3:

$$Surface\ water\ level = \frac{surface\ water\ volume}{surface\ water\ area} \qquad (3)$$

The input data also consider a maximum and minimum water level for the water bucket. This is necessary for the model to determine how much water needs to be imported or exported in by pumping stations in order to maintain the maximum or minimum water level. If the modelled water level exceeds the maximum water level the difference will be sluiced out of the model. If this value is greater than the maximum sluicing capacity the water level will rise above the assigned maximum water level. When the modelled water level is lower than the minimum water level, water will be let in the area with an infinite inlet capacity.

5.7. Implementations

In order to make the water balance of a sports facility more water robust, several implementations are incorporated in the model. This way, the original situation of a sports facility can be compared to a theoretical new situation with implementation of water robust measures. The following paragraphs will elaborate on the possible implementations that are implemented in the model. Concerning irrigation, three types have been selected; root irrigation, sub irrigation and droplets irrigation. Controlled drainage is concerned as more water robust implementation compared to traditional drainage. This system is related to the three different types of storage that have been selected: Aquifer water storage, water storage in a synthetic turf pitch with impermeable bottom and permeable bottom.

5.7.1. Irrigation

For irrigational implementations the same technique and assumptions are used in the model. From literature, see chapter 4.1, general water saving percentages are established for each irrigation type. The original irrigation (assumed to be sprinkler irrigation) of the sports facility is corrected with a factor depending on the type of irrigational implementation. The used value are depicted in following table 4.

Table 4: Overview of irrigational implementations and their reduction factor in comparison to sprinkler irrigation systems

	Reduction factor
Subirrigation	0,55 (45%)
Subsurface Drip Irrigation (SDI)	0,65 (35%)
Subsurface Drip Irrigation + air injection	0,60 (40%)

5.7.2. Drainage

From literature, another beneficial implementation concerning drainage has been found; controlled drainage. With sports facilities controlled drainage is directly connected to storage capacity and water storage management. Since controlled drainage determines the water flow rate out of drains by shutting or opening the drainage strings, resulting in storing or draining water for a given period. This fact is used for setting up the theory behind the implementations of water storage in following section.

5.7.3. Storage

For storage implementations the general concept of implementation is the same for each inserted implementation. From literature, the following three water storage methods are deduced which are incorporated in the model. Water can be stored in an aquifer, in a synthetic turf pitch with impermeable bottom layer, or in a synthetic turf pitch with a permeable bottom layer. The storage of water in lakes or ponds has been left out because most sport pitch do not possess that much space. Otherwise, lots of assumptions concerning the retention volume (depth, surface area) should be accounted for.

Storage synthetic turf pitch

Storage in synthetic turf pitches work as follows: water that is drained in normal situations is stored in the soil beneath the pitch accounting for the retention room between soil particles, by shutting of the drainage. When water is needed for irrigation the model verifies if there the present water volume is greater than the needed irrigation volume. If so, the necessary water will be subtracted from the storage volume and irrigated. If not, normal irrigation is applied. When the water storage volume exceeds the capacity, drains will open again. With a permeable bottom layer, seepage and percolation will diffuse a part of the water. With an impermeable layer, only 10% of the storage water is vulnerable for seepage and percolation. In the model a retention period can be inserted which controls the drains.

Storage aquifer

Water retention using an aquifer uses also controlled drainage. In the model it is assumed that water storage in the aquifer is unlimited. So during the whole modelling period, water will be stored in a underground water bubble. There is no direct relation with any bucket, so seepage or percolation will not occur. However, from literature it is obtained that roughly 85% of the stored water amount can actually be reused due to evaporation, system losses, seepage and percolation. Consequently, when irrigational water is required, only 85% of the stored water can be used.

To provide a comprehensive overview the following Figure 15 visualizes all implementations.

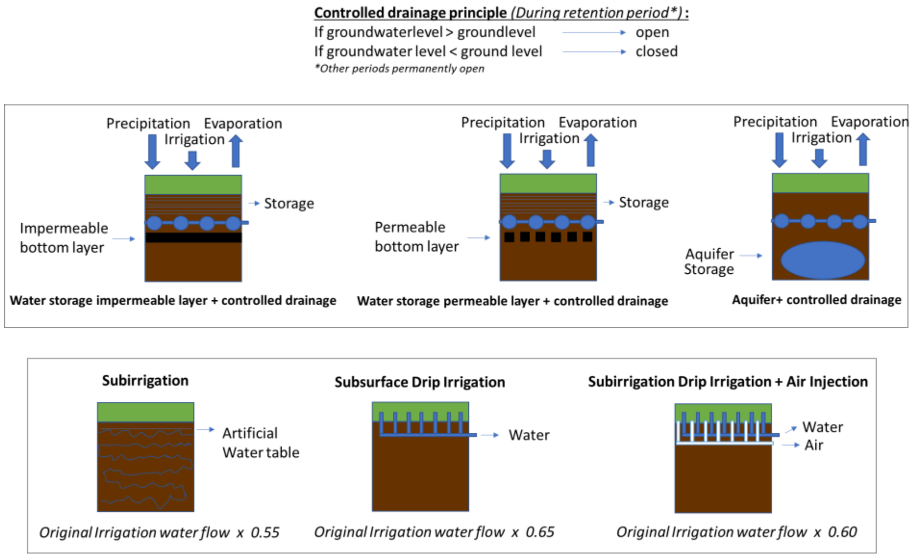


Figure 15: Comprehensive overview of included model implementations of water robust measures

5.8. Assumptions

Throughout previous sections, a variety of assumptions have been mentioned. To provide an overview, this section lists all assumptions of the model shortly.

- Small total input area of sports facility (<20 ha)
- Homogenous characteristics land/water buckets
- Constant waterbed level
- Constant maximum difference between ground level and the water level
- Constant surface area of the land/water buckets
- Sewerage capacity is 7 mm per m^2, pumping capacity is 0.7mm/hour
- Sewerage water does not end up in surface water, hence sewerage water flows are not in the model. Only in case of exceeding pump capacity sewerage water is redirect to the surface water.
- Unlimited aquifer storage
- Seasonal water level input will suffice
- Water is standing still or flowing at low flow rates (<5m/s)
- The water in the water system has a retention period larger than one day
- Land use types are divided into 2 categories; small vegetation and large vegetation
- Sport pitches are divided in three categories;
    - synthetic turf pitches
    - natural grass pitches
    - paved pitches

5.9. Output

The main goal of this water balance model for sports facilities is to acquire more insight in the water fluxes. The first step of the model outcome is the identification of all water flows present and their interaction. This is automatically done by the model after inserting the input values. Main output is the summation of all discharges for a given period. These set of data is visualized in a graph. The content of this graph can be one or more of the following discharges:

- Retention [m3/d]
- Surface water volume [m3/day]
- Runoff [m3/d]
- Infiltration [m3/d]
- Leaching [m3/d]
- Water inlet [m3/d]
- Water outlet [m3/d]
- Total irrigation water [m3]
- Water level [m]
- *Precipitation [m3/d]*
- *Evaporation [m3/d]*
- *Seepage [m3/d]*
- *Percolation [m3/d]*

Most of these water discharges are not interesting on its own. Instead, a combination can be very useful in order to choose between different water robust implementations at the sports facility. Two output values are nevertheless very convenient and accurate for estimating the effects of potential water robust measures. The water inlet and water outlet of the model from great importance. These values represent the modelled value of the necessary water that should be pumped out or in depending on the maximum and minimum surface water level. The total amount of inlet and outlet water can be a good indication for the water robustness of a sports facility. The lower this amount of inlet and outlet water, the less dependency on external water. However, this does hold true for each situation, larger sport facilities probably have larger inlet and outlet water flows in comparison to smaller sports facilities independent their water robustness. A sports facility can be compared to its own performances in terms of water inlet and outlet for several years (with or without water robust measures). This introduces the relative comparison method; if the inlet and outlet water is presented relatively to the total size of a sports facility, this increases accuracy of the outcome. Hence, the degree of water robustness of a sports facility can be computed by calculating the total net volume of inlet and outlet water relative to the size of the calculated area.

5.10. Functioning

Users can go to the user interface on the sheet "Input Sports Facility". All cells and all other sheets which are not necessary to control the model are locked. The whole model is manageable from one sheet. In general, one works from the left side to the right side. First, on the left under heading "Input" all input data is inserted, see Figure 20 in Appendix B.

Thereafter, the model can be controlled indicated by the heading 'Control Model'. The period that needs to be visualized can be inserted, together with several elements that can be visualized in the graph. Last but not least applicable implementations can be applied. The buttons 'Delete graphs', 'Graph Initial Situation', 'Graph New Situation' and 'Graph Comparison Situations' are used as control buttons to execute the model, see figure 21 in Appendix C.

Last but not least, the output of the model can be seen under the tab 'Output Model'. An overview of a few core numbers; calculated inlet water, calculated outlet water, irrigation and leaching is provided. Moreover, the figures concerning the initial situation, new situation and comparison is visualized. See figure 22 in Appendix D. Note that the figures in Appendix B, C and D provide only an exemplary overview, no other calculations in this report are connected.

5.11. Limitations

The bucket model is used to construct water flows for a sports facility. This to obtain the goal of acquiring quantitative insight in the water balance of a sports facility. Consequently there are some limitations of this model which are listed:

- Hydraulic bottlenecks are not considered, the main goal is identification of the water flows at a sports facility;
- Water quality is not considered in this model, due to the main target of getting quantitative insight in the amount of water flows at a sports facility;
- Water systems that are characterised by a water retention time of less than one day cannot be analysed due to calculation time step of one day;
- Rapid flowing water (>5m/s) cannot be calculated thoroughly in this model. The assumption has been made that water is slowly (<5m/s) streaming or stationary;
- Input limitations, for each bucket homogenous aspects are considered.

5.12. Calibration, Validation and Verification

In the end the model is calibrated, validated and verified. With the calibration, the model is compared to known standards to see if the model is accurate. The verification ensures that the model works according to its claimed operating features, checking if the model works correctly. Last but not least verification ensured that the model function is in compliance with the original intentions. The three topics are discussed shortly (Trucano et al., 2006)

5.12.1. Calibration

The goal of calibration is to ensure the measurement accuracy of this model compared to an known standard, is it accurate enough. As a known standard, the STOWA ("Stichting Toegepast Onderzoek Waterbeheer") water balance model has been used. This is a general water balance which is used for relative large areas. The water balance model of a sports facility could be compared by inserting generic values of the different types of surfaces in both models. The maximum difference in outcomes was approximately 10%. It is assumed this results in enough model accuracy to model sports facilities. Since these areas are a lot smaller assumptions regarding constant variables and characteristics are more substantiated. It is approximated that the results can be different from reality in the range of 2 to 12%, this is according to the general accuracy of the bucket model(Romano et al., 2011). Implementations could not be checked with the STOWA model, and specific structure of the model did also differ. As a second way of assessing the accuracy a hydrology expert from water board Dommel examined the made assumptions and structure of the model. Findings where satisfying, considering the general goal of this research project. Last but not least, the implementation results could not entirely be calibrated due to unavailable measurement data at sports facility 'De Neul'. This is advisable to investigate in further research.

5.12.2. Verification

Verification is intended to ensure correct operation of the model according to its stated specifications. In order to do this several tests, listed below, have been performed which have been concluded successfully. These tests ensure the consistency of the model and try to avoid inconsistencies and errors in terms of coding an logic. (Murray-Smith, 2015)

- Test inserting minimum values (0)
- Test inserting maximum values
- Test applying buttons in a different sequence

The three aforementioned tests are operated with the same goal; as a result of such a test the model should not become corrupt. Maximum and minimum values should not interfere the functioning of the model. Moreover, several button combinations have been performed in order to exclude possible misfunctioning and excluding button wrong interdependencies between buttons.

- Cells add up (to 0)

Initially, at the calculation sheet several control columns have been placed which should always result in 0 when inserting input data into the model. The column 'Residual' in each bucket, should always be 0. Furthermore, in each bucket there are some logically derived outcomes which could not occur. The 'Gross inlet volume' could never be more than the water influenceable water flows for the specific bucket. Moreover, 'Retention' could never be bigger than the water volume in the bucket. And the 'Total outlet' could never be bigger than the present water volume in each bucket.

- Run-time errors

The model has been run several times to ensure general run-time errors have been avoided.

- Calculation manually comparison

On the 'Calculation' sheet, all the buckets and the belonging formulas can be found. Each calculation formula in the first row has been checked whether the output was as expected. The other rows did not have to be checked on the outcome, only on the correct extrapolation of the first formula due the autofill function of Excel.

Sensitivity analysis

With use of a short sensitivity analysis the values that have a big impact on the model outcome have been targeted (Trucano et al., 2006). The model factors that have big influence are; the retention volume factors, irrigation data, the water surface area and the water level.

5.12.3. Validation

Last but not least, model validation has been executed. This ensures that the model system satisfies the stated functional intent of the system; providing insight in the water balance of a sports facility. Does the model meet the needs in a larger system and can it deliver the desired results?

From chapter 5.8 several assumptions can be noticed, chapter 5.11 focuses on the limitation of the model. These limitations are the main results of the validation process. Main assumptions automatically generated a number of limitations. With testing of the model these limitations were confirmed and specified. However, these limitations which resulted from validation are not hazardous for achievement of the functional intent of the model. The model produces is able to produce output for several years of data and clearly visualizes the water flows.

6. Effects water balance improving measures for a sports facility

After investigation of the water balance of a sports facility and the different water robust measures that are available, this chapter focuses on the combination of both topics. The created model can quantify possible effects of water robust measures for a sports facility. Firstly, with use of literature expected outcomes due to the implementation of water robust measures at sports facilities are identified. Sports facility 'Zuideinderpark' in Schijndel is used as an exemplary and representative sports facility to define the model input. The outcomes of the model are then discussed for each topic. Altogether, this chapter answers the following research question:

What are the effects of water balance improving measures for a sports facility?

6.1. Financial effects

With the general goal of becoming more water robust, the main idea is to become self-sufficient in the end. This results in water usage from the facility itself, which is aimed at using less external water as possible. The effects due to these water balance improving measures can be observed financially, however, they depend on the rate of self-sufficiency in terms of water extraction.

How do water balance improving measures financially affect a sports facility?

From chapter 5.4 it can be noticed that there are a few sources of incoming water flows. Water originates from precipitation and irrigation, the latter is important for estimating the effects of a more water robust sports facility. When precipitation can be stored in a few ways at a facility, as can be noted from chapter 4.4. Groundwater can be stored in the synthetic turf pitches, ground water reservoir and tanks. With this storage, less water has to retrieved from groundwater for irrigation and other activities such as cleaning, cooling and leisure activities.

With the reduction of the extraction of groundwater with use of pump at the sports facility, less groundwater taxes have to be paid. The costs for water extraction are composed of the permission request, leges, publication costs, accountability costs and provincial groundwater taxes. These taxes vary per province of The Netherlands; 0.81 cent/m^3 up and till 2.54 cent/m^3. The total costs for the extraction of 40000 m3 groundwater per year including all ancillary costs, ranges from €2250 up to €7350, depending on the province. (Stoof & Ritsema, 2006)

In The Netherlands prices for the extraction of surface water rare solely determined by the costs leges for permissions. There are no publication costs, accountability costs or taxes per unit of surface water that is extracted. However this extraction is dependent on the available water volume and extraction limitations during the summer, hence not often used at sports facilities. The total costs are much lower compared to groundwater extraction, ranging from €26 up to €400. (Stoof & Ritsema, 2006)

Some sport facilities retrieve water from the main drinking water supplies, in this case less water has to be retrieved. The price of drinking water consists of three elements (Nederland Leeft met Water, 2004):

- The water company charges for the delivered drinking water;
- The water boards charge money for the purification of sewerage water;
- The municipalities charge for sewerage rights, an amount of money for the construction and maintenance of sewerage.

In the future it is expected that the prices for drinking water will rise due to three problems. The current price setting does not account for exhaustion of drinking water resources of high quality. Also, the external effects such as desiccation are not taking into consideration. Moreover, this system does not stimulate technical efficiency and cost reduction. Since the water companies do not compete (monopolist situation regulated by the government) and are able to pass-on all additional costs for drinking water supply. The prices for groundwater are also expected to rise over time due to the same reasoning. Add to these expected trends the given knowledge that The Netherlands will become more and more climate resilient and the focus shifts from excessive usage of groundwater to more economized usage. Altogether, water balance improving measures will become more and more financially attractive over the years. (Diederen et al., 2002)

The pricing of one m^3 (1000 Litres) of drinking water costs on average €1,21 excluding taxes and €1,60 including taxes of the year 2019 (Kowalski, 2019). In 2020, the drinking water costs per cubic meter varies between 1,04 and 1,74euros. The exact amount depends on the regional water company and can vary depending on the origin of the water, infrastructure costs and administrative costs. (Gelder, 2020)

In conclusion, depending on the origin of the extracted water at sports facilities, water costs can be significant. In the example of the model outcome results, for a specific sports facility (see chapter 6.2), 13896 m^3 of irrigation water is used. In the worst case scenario of using drinking water to irrigate for the highest price possible in The Netherlands (€1,74), up to €24335 can be saved on annual basis.

6.1.1. Operational costs

Water balance improving measures introduce in most cases more autonomous systems. In terms of irrigation; the more water robust the less human operational costs. Although sports facilities often benefit from a large pool of volunteers, less working hours are always beneficial. (Burszta-Adamiak & Spychalski, 2020)

Furthermore, due to a constant provision of water to the field, adapted to the current needs taking into account climatical impacts, result in better field quality. This results in less maintenance costs and a longer lifecycle. Studies suggest that implementation of more precise irrigation measures such as drip irrigation will result increase the additional lifespan, quantification is not present. (Diederen et al., 2002) Although it has been stated that irrigation synthetic turf pitches increase the longevity, however the rate of increase is unknown(Smart Connection Consultancy, 2015).

6.1.2. Initial investment costs

In chapter 4.4.1 some numbers already passed the revue, concerning initial investment costs for the construction of the water storage. In following table 5 all financial numbers related to the initial investment costs are provided in a comprehensive overview.

Table 5: Initial investment costs for different types of storage

Type of storage	Volume	Price [€]
Water tank (cast in-situ concrete)	1 ML	330 000
Pond/lake storage	1 ML	165 000
Artificial aquifer	1 ML	370 000

Initial investment costs, which are mostly applicable on each of the storage types, are investments for a pumping system and a filtration or treatment system. This will cost in excess around 80 00 euros. Furthermore, an overview of different types of water robust measures are incorporated in following table 6.

Table 6: Initial investment costs for different types of water robust measures including drainage and irrigation

Type	Price [€/hectare]

Subsurface irrigation	40 000 - 50 000
Subirrigation	53 000 - 60 000
Sprinkler irrigation	25 000 - 35 000
Controlled drainage	2400
Normal drainage	1200

6.2. Model results

After complementation of the model, the model has been used to globally analyse the sports facility 'Zuideinderpark' in Schijndel for the year 2019. The results of this simulation are provided in this section. The target of the outcomes is to get a feeling for the effects of the different implementations. Only the most general numbers are presented here. In the model various other results are possible to retrieve, listed in chapter 5.9. First the area was demarcated according to following figure 16.

Figure 16: Decmarcation of the input area of sports facility "Zuideinderpark" for the model (NHI, 2020)

Secondly, all input data is determined that needs to be inserted into the model. Seepage and percolation numbers are retrieved from the NHI, precipitation and evaporation from the KNMI, water level data from water board Dommel (Water board Dommel, 2020), irrigation data from the sports facility and surface numbers have been estimated using Google Maps.

Table 7: Input data for sports facility 'Zuideinderpark'

Area	Surface	Geo hydrology	Winter [mm/d]	Summer [mm/d]
Natural grass pitches	51 000 m^2	**Seepage - water**	0	0
Synthetic turf pitches (drained)	40 000 m^2	**Percolation – water**	-0,25	-0,1
Paved area	8 000 m^2	**Seepage – paved**	-0,25	-0,1
Paved pitches	2 000 m^2	**Seepage – drained**	-0,25	-0,1
Small vegetation	21 000 m^2	**Seepage – unpaved undrained areas**	-0,25	-0,1
Large vegetation	3 000 m^2			
Undeveloped	2 000 m^2	**Ground permeability**	Permeable (Sand)	
Roof connected to sewerage	5 000 m^2			
Water elements	10 000 m^2			

Table 8: Water related input for sports facility "Zuideinderpark"

Water level period	Min [m+NAP]	Max [m+NAP]
15/03-01/05	7,5	8
01/05-15/08	7,3	7,8
15/08-01/10	7,3	7,8
01/10-15/03	7,8	8,3
Initial water level	7,5	
Maximal outflow capacity	1000000 m^3/day	
Maximum difference between water level and ground level	0,5 m	

As mentioned earlier, the input data displayed in table 7 and table 8 is gathered from the year 2019. Some types of implementations need a storage period; an inserted period where drainage water is contained if possible. Before and after this storage period the water can freely flow in and out, the inserted period is 01-04-2019 up and till 10-07-2019. The combination of all these input variables resulted in the following results, displayed in table 9.

Table 9: Overview of the results of an example; sports facility 'Zuideinderpark'

Implementations	Situation	Initial situation	New situation	New vs initial
None	Outlet water	28891	-	-
	Irrigation volume	13986,00	-	-
	Leaching	-28891	-	-
Subirrigation	Outlet water	28891	25035	-3855
	Irrigation volume	13986,00	8435,70	-5550
	Leaching	-28891	-25035	3855
Subsurface drip irrigation	Outlet water	28891	24400	-4490
	Irrigation volume	13986,00	7698,60	-6287
	Leaching	-28891	-24400	4490

Subsurface drip irrigation + air injection	Outlet water	28891	23801	-5090
	Irrigation volume	13986,00	6953,10	-7033
	Leaching	-28891	-23801	5090
Water storage aquifer	Outlet water	28891	22903	-5988
	Irrigation volume	13986,00	7035,00	-6951
	Leaching	-28891	-22903	5988
Water storage with permeable bottom layer	Outlet water	28891	13457	-15433
	Irrigation volume	13986,00	0,00	-13986
	Leaching	-28891	-13413	15478
Water storage with impermeable bottom layer	Outlet water	28891	11044	-17846
	Irrigation volume	13986,00	0,00	-13986
	Leaching	-28891	-11044	17846

Note that normally, the calculated inlet water is also displayed, however, in this situation there was none present so these results are omitted from the table.

6.3. Sustainability effects

What are the quantitative effects of water balance improving measures on sustainability in terms of water usage for a sports facility?

Sustainable development is most commonly defined in literature as "the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs". This development being implemented results in a sustainable sports facility. Sustainable initiatives work with the environment rather than against it (Sluttell, 2006).

Due to the occurrence of more extreme weather during the last few years, sport facilities have become more prone to climactic impacts . They dry out more quicker, receive less natural irrigation through precipitation, have limited water due to water restrictions, deteriorating water quality and potentially more dangerous playing grounds (Sports Environment Allicance, 2019)

Water conservation is one of the main topics regarding sustainability for sports facilities(Schumacher, 2016). The tendency of reducing overall water consumption and substituting potable water with sustainable alternatives such as rainwater, recycled water and stormwater is extreme good in terms of sustainability. (Lucas et al., n.d.)

Introduction of installation of AAA rated systems, alternative water sources as main water source and water reduction measures impacts the sustainability of a sports facility significantly (Sawyer et al., 2014). Reusing rainwater for irrigation is considered to be the best in solution terms of the lowest carbon footprint. In terms of energy this relies only on the energy for pumping. (Lucas et al., n.d.)

Sustainable water management is ensured by increasing the water robustness of a sports facility. This is achievable via the following water management concepts (Sports Environment Alliance, 2019):

- Compute the requirements for watering
- Investigate how much water is used and how much is necessary
- Improve watering practices
- Improve the water efficiency of sport pitches
- Improve the efficiency of systems and equipment
- Improve the water security by exploration of alternative water sources as supply
- Implement a strategy for situations where water is not available or excessive water plays a role

Introduction of optimal grass type depending on the season (overseeding) approximately 30% less water can be used. A natural gras sports field uses around 6,8ML/ha per year for warm-season grass types instead of 9,9ML/ha per year for cool-season grass types. The usage of subsurface drip irrigation can result in water savings of up to 40% in comparison to traditional sprinkler systems due to minimal evaporation or runoff. (Bigelow & Munshaw, 2014) Furthermore, sustainability in terms of water reduces the overall costs of operating facilities.

In conclusion, a relatively large and significant amount of water can be saved and actively increases the sustainability rate of a sports facility.

6.4. Playability effects

What are the quantitative effects of water balance improving measures on playability for a sports pitch?

This research question is hard to elaborate on due to its subjectivity and therefore hard to quantify. The only method considered for measuring the impact of water balance improving measures, that is quantifiable, is the increased usability of a sports pitch. It is assumed that playability originates largely from usability. Usability is determined according to the general rules of the association for sport in the Netherlands ('Branchevereniging Sport en Cultuurtechniek'). The most influential factor is the drainage capacity of pitches. The water robust effects that are from importance for sport pitches are the type of irrigation, the type of pitch and the accompanying type of drainage and its capacity. This creates roughly three categories that need to be checked for quantitative effects; irrigation, pitch type and drainage. (Branchevereniging Sport en Cultuurtechniek, 2017)

First, drainage and pitch type are investigated simultaneously, due to their interrelation, regarding the water dissipation effect. In the study "Onderzoek waternormering sportvelden" the situation of a pitch is schematized as the amount of paved area. Overview of the results per type of area are visualized in following Figure 17 & Figure 18 (Branchevereniging Sport en Cultuurtechniek, 2010).

huidige situatie	sportveld ongedraineerd	natuurgrasveld gedraineerd	gravel/kunstgras gedraineerd	asfalt/ondoorlatend kunststof
onverhard ongedraineerd	0%	43%	56%	100%
sportveld ongedraineerd	0%	43%	56%	100%
onverhard gedraineerd		37%	49%	100%
natuurgrasveld gedraineerd			12%	63%
gravel/kunstgras gedraineerd				51%

Figure 17: Sports pitches in areas with a bad permeable ground layer

	toekomstige situatie		
huidige situatie	natuurgrasveld gedraineerd	gravel/kunstgras gedraineerd	asfalt/ondoorlatend kunststof
onverhard gedraineerd	20%	38%	100%
natuurgrasveld gedraineerd		18%	80%
gravel/kunstgras gedraineerd			62%

Figure 18: Sports Pitches in areas with a permeable ground layer

These guidelines give an indication of the rate of water dissipation as a consequence of the construction of a sports pitch. This dissipation of water is expressed as a percentage increase in paved surface. In a situation where there is an upgrade from an unpaved, undrained area or undrained sports pitch to a undrained sports pitch there is no difference in drainage. In every other situation the dissipation of water is increased (severely). Implementation of water robust measures includes in most case the construction of a new or adapted sports pitch. Consequently, the playability is increased by introducing water robust measures concerning the drainage of sports pitches.

Secondly, irrigation is discussed as third large input factor for the usability, and playability, of a sports pitch. The management of sports' pitches can be seen as specialised work. Maintaining appropriate grass quality in drier and wet conditions is difficult. This involves the supplementation of resources such as irrigation, fertilisers, mowing and weed management. Restricting one of these actions will decrease the ability of the turf to provide enough grass quality. However, with introducing water robust measures, generally the uniformity of irrigation increases, resulting in a more constant pitch. Reduction of water does not be tantamount to reduction of quality of pitches. On the contrary, more focus on weak spots, prevention of overwatering and irrigating to little, leads to better performance according to (SportsTurf, 2016).

7. Discussion

The initial situation which resulted in this research concerns the lack of quantification of water robust effects at sport facilities in The Netherlands. This investigation worked towards the creation of a generic water balance model for sports facilities in The Netherlands. This section will elaborate on the outcomes and limitations of this research study.

7.1. Novelty

First of all, the implementation of water robust measures at sports facilities in The Netherlands is a relatively new topic which caused difficulties regarding literature research. A detailed water balance of a sports facility has not been constructed yet, water robust implementations have been investigated in a qualitative way only. Consequently, less quantitative information is available from previous research and case studies. Altogether, this unexplored research topic severely complicated this study regarding model setup, model validation and calibration. To enable investigation, the lack of information has been compensated by stating assumptions and presuming simplifications concerning the model structure, model setup and model implementations.

7.2. Model setup

Consequently, several assumptions have been made in order to developed the water balance model for sports facilities. For achievement of the objective of this research a bucket model is satisfactory. However, adaptation of the bucket model resulted in the assumption of a lot of variables and reduction of accuracy. Main water flows and the main surface types are incorporated in the model. However, due to the limited availability of buckets, it is assumed that (depending on the input size) various hectares have exactly the same characteristics and the buckets are homogeneous. For more detailed information, section 5.11 with limitations of the model can be seen, boiling down to the reduction of accuracy. Altogether, these mentioned effects decrease the model accuracy and veracity by approximately 2 to 12% for average situations. Expansion of the amount of buckets could increase the model accuracy.

Furthermore, the implementation of water robust measures is based on literature values and theorems in combination with common sense. However, all of these implementations have been examined individually in different case studies. Combination of implementations has not occurred yet and generates uncertainties regarding dependability and influenceability due to their influence on the same water flows. The model visualizes and calculates water volumes and water flows with a time step of a day, and assumes steady flow (<5m/s) or stationary water, which limits the use. Moreover, a direct link between groundwater and surface water is not present. Together with the simple assumptions of the functioning of water robust measures, the model is only suitable for acquiring a comprehensive overview of a water balance sports facility.

Last but not least, execution of calibration, verification and validation has been limited by available measurement data sets. The main bottleneck is the availability of quantitative measurements from case study material. Only two sports facilities in The Netherlands 'De Neul' and 'Roomburg' have introduced a combination of water robust implementations. Reliable measurement data is not available yet, so for these type of model elements only (theoretical) literature values have been used. Analysis of water robust measures in practice with obtained data from one of those two sports facilities over the period of a couple of years will increase validity.

8. Conclusion

This research focussed on bridging the knowledge gap of the (quantitative) effects of the implementation of water robust measures at sports facilities in The Netherlands. The objective was to gain insight in the water balance of sports facilities in The Netherlands by development of a model, to enable effective implementation of water robust measures.

A selection of promising water robust implementations have been incorporated in the model. As water balance improving measures, three types of irrigation and three types of storage are included which can be selected. With the bucket model input the initial situation of the water balance of a sports facility can be computed. Moreover, a theoretical new situation including implemented water robust measures can be calculated.

From literature, the effects of the irrigational measures were clear, water reduction in comparison to a traditional sprinkler system ranged from 35% up until 45%. The water balance improving measures regarding the storage of water (in combination with controlled drainage) were not stated as clearly due to their dependency on retention period, water storage volume and ground conditions. However, both type of water robust measures resulted in significant positive number in terms of water reduction according to the developed model. When drained water was being stored in an aquifer layer or in the construction of a synthetic turf pitch (with or without permeable layer), the necessary irrigational water volume in comparison to a traditional sprinkler system reduced significantly with 50% - 100%. However, the outcomes are heavily dependent on various factors such as retention period and storage volume an cannot be compared this way. Nevertheless, these results are an valuable indication that these water robust measures have significant impact. The model shows outcomes that are in line with literature statements about forecasted results of water balance improving measures. With this model, an endless set of scenarios for different sports facilities can be computed to acquire insight in the water balance for an initial and new situation with water robust measures.

Altogether, an excel model is constructed which is able to process input data of a sports facility in The Netherlands. The model transforms this rough data set into different water flows depending on the soil characteristics and (inter) dependent relationships. A large set of data is produced by the model which provides a generic comprehensive overview of the water balance of a sports facility. This model is a first step towards the development of a sufficiently accurate water balance model and creates a new perspective on the water balance of a sports facility. Consequently, the model bridges a part of the knowledge gap of (quantitative) effects of implementation of water robust measures. Which is essential to achieve a more climate resilient and water robust construction and management of sports facilities in The Netherlands.

9. Recommendations

To allow for a more a more accurate study that investigates the water balance of sports facilities including the implementation of water robust measures a set of recommendations are formulated in this section. The following elements are advised to investigate into more detail to enable further development towards a more accurate water balance model of a sports facility.

First of all, the current model uses the bucket model that enables area simplification boiling down to several buckets with homogenous characteristics depending on the surface type. This way of modelling is suitable for this specific research goal. However, by introducing more buckets with more specific soil characteristics, the model accuracy can be expanded. More distinction between different surfaces can be implemented with their own specific characteristics. Furthermore, model input variables can be examined to enhance more detailed input to account for variations of sports facility types in The Netherlands. An increase in the model time step should be considered to enable more sophisticated calculation of water flows. This also improves the ability to calculate effects of different extreme scenario's such as heavy rainfall for a typical year.

To enhance model accuracy and veracity it is advised to extend the calibration, verification and validation process. It is recommended to acquire more measurement data from water robust sports facilities such as 'De Neul' and 'Roomburg'. This way, the most adaptable sets of measurement data can be used to develop the model even further and increase its accuracy significantly. At least several years of data, containing extreme year preferably, should be inserted and compared. The ME and RSME performance measures should be checked, and be lower than 0.5 for an acceptable model(Romano et al., 2011).

Water robust implementations should be worked out in more detail. The behaviour of water flows resulting from these implementations should be analysed and this higher level of detail should be incorporated in the model. With use of more adequate measurement data from water robust sport facilities the actual effects can be quantified. With these results from practice, the interdependency between implementations can be assessed and taken into account.

Furthermore, in this model six implementations are taken into account. It is suggested to implement more innovative implementations to offer a full range of possibilities. This way, the best solution for each sports facility can be composed. Suggested are; water management implementations such as adding water schemes for irrigation times and turning of water supplies. Also, water reducing measures such as different showerheads, economical sinks could be beneficial. Finally, water storage types such as tanks or water storage in surface water should also be considered as implementation.

Excel is sufficient for this research due to the specific goal and the intended group of users. In order to provide more model reliability, it is advised to explore other modelling systems that have more processing power for large data sets and formulas. The functioning of the model could also be improved. With introducing more automatic features an even better user interface can be constructed. More output results could be visualized at once, automatic figure scalability could be introduced, and automatic fill in procedures could be useful to enhance user-friendliness.

Currently, the model provides overview of the water flows in an initial situation, new situation and comparison of both situations for sports facilities. The model outcome could be expanded in terms of financial and water related sustainability output (e.g. small sustainability assessment). Investigation could elaborate on the financial aspects and values that are incorporated with different types of water robust measures. This way, the model can effectively be used for convincing municipalities or water boards of the significance of the construction of water robust sports facilities; 'Blauwe Sportparken'.

10. References

Abuarab, M., Mostafa, E., & Ibrahim, M. (2013). Effect of air injection under subsurface drip irrigation on yield and water use efficiency of corn in a sandy clay loam soil. *Journal of Advanced Research*, *4*(6), 493–499. https://doi.org/10.1016/j.jare.2012.08.009

Aquifer - Wikipedia. (n.d.). Retrieved January 21, 2021, from https://nl.wikipedia.org/wiki/Aquifer

Bakel, van P. J. T., Boekel, van E. M. P. M., & Noij, I. G. A. M. (2008). Model onderzoek naar effecten van conventionele en samengestelde, peilgestuurde drainage op de hydrologie en nutriëntenbelasting. In *Alterra-rapport*. https://edepot.wur.nl/19013

Bigelow, C., & Munshaw, G. (2014). *Your Resource for Safer Fields • Brought to you by the Sports Turf Managers Association and its charitable Foundation, The SAFE Foundation • ph. 1-800-323-3875 • www.stma.org Water Conservation Best Management Practices for Sports Facilities Best Manageme*. www.stma.org

Blauwe Sport-parken - Newae. (n.d.). Retrieved January 21, 2021, from https://newae.nl/projecten/sportpark-de-neul/

Bos, M. G., Kselik, R. A. L., Allen, R. G., & Molden, D. J. (2009). Water requirements for irrigation and the environment. In *Water Requirements for Irrigation and the Environment* (Vol. 9781402089480). Springer Netherlands. https://doi.org/10.1007/978-1-4020-8948-0

Branchevereniging Sport en Cultuurtechniek. (2010). *BSenC rapportage Onderzoek waternormering sportvelden*. www.bsenc.nl

Branchevereniging Sport en Cultuurtechniek. (2017). *Wetten en Regels*. https://sportvloeren.sport.nl/

Burszta-Adamiak, E., & Spychalski, P. (2020). Water savings and reduction of costs through the use of a dual water supply system in a sports facility. *Sustainable Cities and Society*, 102620. https://doi.org/10.1016/j.scs.2020.102620

Cultuurtechnische vereniging. (1988). *Cultuur technisch vademecum Werkgroep Herziening Cultuurtechnisch vademecum Cultuurtechnische vereniging, 1988*. https://library.wur.nl/WebQuery/hydrotheek/288191

Diederen, P., Bunte, F., Staalduinen, L. van, Huygen, A., & Uytewaal, E. (2002). *De Prijs van water*. https://library.wur.nl/WebQuery/wurpubs/fulltext/42651

Epa, U., Supply, W., Resources Division, W., & Smith, C. (2004). *2012 Guidelines for Water Reuse*.

European Commission. (2016). *COMMON IMPLEMENTATION STRATEGY FOR THE WATER FRAMEWORK DIRECTIVE AND THE FLOODS DIRECTIVE Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the WFD*. https://ec.europa.eu/environment/water/pdf/Guidelines_on_water_reuse.pdf

Ferrarezi, R. S., Weaver, G. M., Van Iersel, M. W., & Testezlaf, R. (2015). Subirrigation: Historical overview, challenges, and future prospects. In *HortTechnology* (Vol. 25, Issue 3, pp. 262–276). American Society for Horticultural Science. https://doi.org/10.21273/horttech.25.3.262

Fieldfactors. (2021). *Bluebloqs technologie | regenwaterzuivering by Field Factors*. https://fieldfactors.com/nl/technologie

Fleming, P. R., Frost, M. W., Simpson, M., Everett, R., & Gibbs, R. J. (2017). Drainage Behavior of Sports Pitches–A Case Study Review. *Itsrj*, *13*(1), 649. https://doi.org/10.2134/itsrj2016.06.0450

Gale, L. (n.d.). *Irrigation for sports turf | Pitchcare*. Retrieved January 17, 2021, from https://www.pitchcare.com/news-media/irrigation-for-sports-turf.html

Galkina, E., & Vasyutina, O. (2018). Related content Reuse of treated wastewater. *IOP Conference Series*. https://doi.org/10.1088/1757-899X/365/2/022047

Gelder, van K. (2020). • *Netherlands: drinking water price per company 2020 | Statista*. Statista. https://www.statista.com/statistics/597953/drinking-water-price-in-the-netherlands-by-company/

Gibson, F., LLoyd, J., Bain, S., & Hottell, D. (2008). *(No Title)*. *4*(2), 26–32. http://ww.w.thesmartjournal.com/greenissues.pdf

Hejduk, S., Baker, S. W., & Spring, C. A. (2012). *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science Evaluation of the effects of incorporation rate and depth of water-retentive amendment materials in sports turf constructions Evaluation of the effects of incorporation rate and depth of water-retentive amendment materials in sports turf constructions*. https://doi.org/10.1080/09064710.2012.687396

Hooghart, J. C., & Lablans, W. N. (1988). *Van Penman naar Makkink : een nieuwe berekeningswijze voor de klimatologische verdampingsgetallen : eindrapport van de Project- en Begeleidingsgroep Verdampingsberekeningen | Hydrotheek*. https://library.wur.nl/WebQuery/hydrotheek/349766

Innovatie in de schijnwerpers: Sportpark de Neul in Sint-Oedenrode - SportInnovator. (n.d.). Retrieved January 17, 2021, from https://www.sportinnovator.nl/nieuws/innovatie-in-de-schijnwerpers-sportpark-de-neul-in-sint-oedenrode/

KNVB. (2018). *KWALITEITSNORMEN VOETBALACCOMMODATIE*. https://www.knvb.nl/downloads/bestand/1466/kwaliteitsnormen-voetbalaccommodatie

Kowalski, H. (2019). *How much does an m^3 of water cost in the Netherlands? - DACHIST Network Netherlands*. https://www.dachist.org/en/netherlands/energy-and-water/questions/costs-tap-water-netherlands.html

Lucas, S., Pinheiro, M. D., & De la Cruz Del Río-Rama, M. (2017). Sustainability performance in sport facilities management. In *Sports Management as an Emerging Economic Activity: Trends and Best Practices* (pp. 113–138). Springer International Publishing. https://doi.org/10.1007/978-3-319-63907-9_8

Lucas, S., Silva-Afonso, A., Ferreira, V., Lucas, S., Silva-Afonso, A., & Ferreira, V. (n.d.). *Energy for Sustainability 2013 Sustainable Cities: Designing for People and the Planet IMPROVING BY SUSTAINABILITY IN SPORT FACILITIES*.

Mandal, U. K., Sundara Sarma, K. S., Victor, U. S., & Rao, N. H. (2002). Profile water balance model under irrigated and rainfed systems. *Agronomy Journal*, *94*(5), 1204–1211. https://doi.org/10.2134/agronj2002.1204

Mays, L. W. (2001). *Water resources engineering*. Wiley,.

Milne, N., & Gray, P. S. (n.d.). *SUSTAINABLE OPTIONS FOR SPORTS FIELDS SUSTAINABLE OPTIONS FOR SPORTS FIELDS SUSTAINABLE OPTIONS FOR SPORTS FIELDS*.

Murray-Smith, D. J. (2015). *Methods of Model Verification* (pp. 77–83). Springer, Cham. https://doi.org/10.1007/978-3-319-15099-4_6

National Institute of Building Sciences. (2017). *Taking the Field: Advancing Energy and Water Efficiency in Sports Venues*.

https://cdn.ymaws.com/www.nibs.org/resource/resmgr/files/NIBS_GSA_TakingTheField_Fina.pdf

Nederland Leeft met Water. (2004). *Waterwijzer*. https://library.wur.nl/ebooks/hydrotheek/1768466.pdf

NHI. (2020). *NHI Data Portaal*. https://data.nhi.nu/

Palmans, S., Luys, L., PVL, Vanbriel, M., & Agrobeheercentrum Eco. (2017, October 20). Is peilgestuurde drainage goed voor gewas en milieu. *Management&Techniek*. https://edepot.wur.nl/429450

Rahman, M. M., Hagare, D., & Maheshwari, B. (2016). *Use of Recycled Water for Irrigation of Open Spaces: Benefits and Risks* (pp. 261–288). Springer, Cham. https://doi.org/10.1007/978-3-319-28112-4_17

Romano, N., Palladino, M., & Chirico, G. B. (2011). Parameterization of a bucket model for soil-vegetation-atmosphere modeling under seasonal climatic regimes. *Hydrol. Earth Syst. Sci*, *15*, 3877–3893. https://doi.org/10.5194/hess-15-3877-2011

Salazar, R., Rangel, J.C., Pinzon, C., Rodriguez, A. (2013). Irrigation System through Intelligent Agents Implemented with Arduino Technology. *ADCAIJ : Advances in Distributed Computing and Artificial Intelligence Journal*, *2*(3), 29–36. https://doi.org/10.14201/ADCAIJ2014262936

Sawyer, T. H., Judge, L. W., Gimbert, T. L., Goldfine, B., Hypes, J. A., Hypes, M., Larue, R. J., Johnson, D. L., Judd, M., Miller, J. J., Rogers, D., Petersen, J. C., Rushing, G., Seidler, T. L., Walker, H., & Weaver, T. (2014). *Journal of Facility Planning, Design, and Management Editor Associate Editor Editorial Board*. www.sagamorejournals.com,

Schumacher, J. (2016). *Environmentally Sustainable Practices at Small Community Sport Facilities*. https://opencommons.uconn.edu/gs_theses/874

Smart Connection Consultancy. (2015). *THE SMART GUIDE TO SYNTHETIC SPORT SURFACES*.

Sports Environment Allicance. (2019). *FUTURE PROOFING COMMUNITY SPORT AND RECREATION FACILITIES | 1 Future Proofing Community Sport & Recreation Facilities A Roadmap for Climate Change Management for the Sport and Recreation Facilities Sector 2 | A Roadmap for Climate Change Management for th*.

SportsTurf. (2016). *FIELD SCIENCE: Managing water for playability SPORTS FIELD AND FACILITIES MANAGEMENT Mapping to improve field management Leo Goertz tribute BMPs: What things REALLY cost*. www.sportsturfonline.com

Stoof, C. R., & Ritsema, C. J. (2006). *Waterwinning voor beregening*. www.greenkeeper.nl

STOWA. (2013). *Controlled drainage | STOWA*. https://www.stowa.nl/deltafacts/zoetwatervoorziening/delta-facts-english-versions/controlled-drainage

Stuivenberg, N. (2020, December 7). *Geen kraan-, grond- en oppervlaktewater meer op hockeyvelden*. https://www.fieldmanager.nl/article/34860/geen-kraan--grond--en-oppervlaktewater-meer-op-hockeyvelden

Tanis, H. R., Schep, S. A., & van Dijk, A. (2018). *Waterstromen in beeld: Handleiding bij de excelrekentool waterbalans*. STOWA.

Trucano, T. G., Swiler, L. P., Igusa, T., Oberkampf, W. L., & Pilch, M. (2006). Calibration, validation, and sensitivity analysis: What's what. *Reliability Engineering and System Safety*, *91*(10–11), 1331–1357. https://doi.org/10.1016/j.ress.2005.11.031

WABER-systeem® - GKB Groep. (n.d.). Retrieved January 17, 2021, from https://www.gkbgroep.nl/producten/waber-systeem/

Water board Dommel. (2020). *HydroNET Portal - Applicaties - HydroWatch 2.0 Kaart*. https://embed.hydronet.com/embed.aspx?id=6200&h=b4b15f45e9

Water Commission, Q. (n.d.). *WATER EFFICIENCY GUIDELINE PLEASE USE ONLY WHAT YOU NEED-TARGET 200 Effi cient irrigation for water conservation guideline Effi cient irrigation for water conservation guideline 2*. Retrieved January 21, 2021, from www.qwc.qld.gov.au

Xu, C. Y., Seibert, J., & Halldin, S. (1996). Regional water balance modelling in the NOPEX area: Development and application of monthly water balance models. *Journal of Hydrology*, *180*(1–4), 211–236. https://doi.org/10.1016/0022-1694(95)02888-9

11. Appendices

11.1. Appendix A

Drinking water producers ranked per price per cubic meter water in the Netherlands for the year 2020.

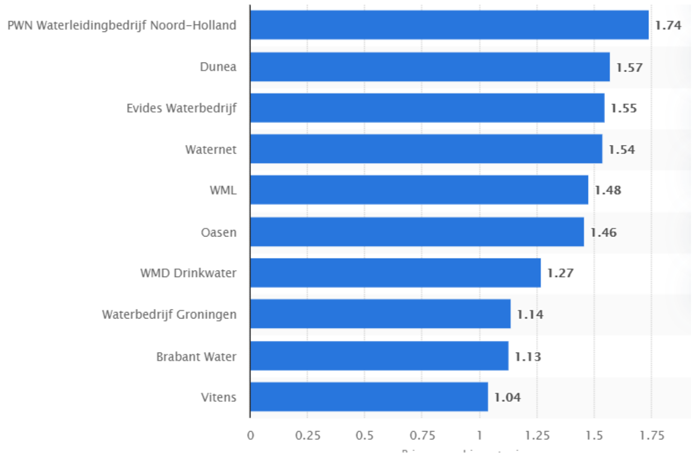
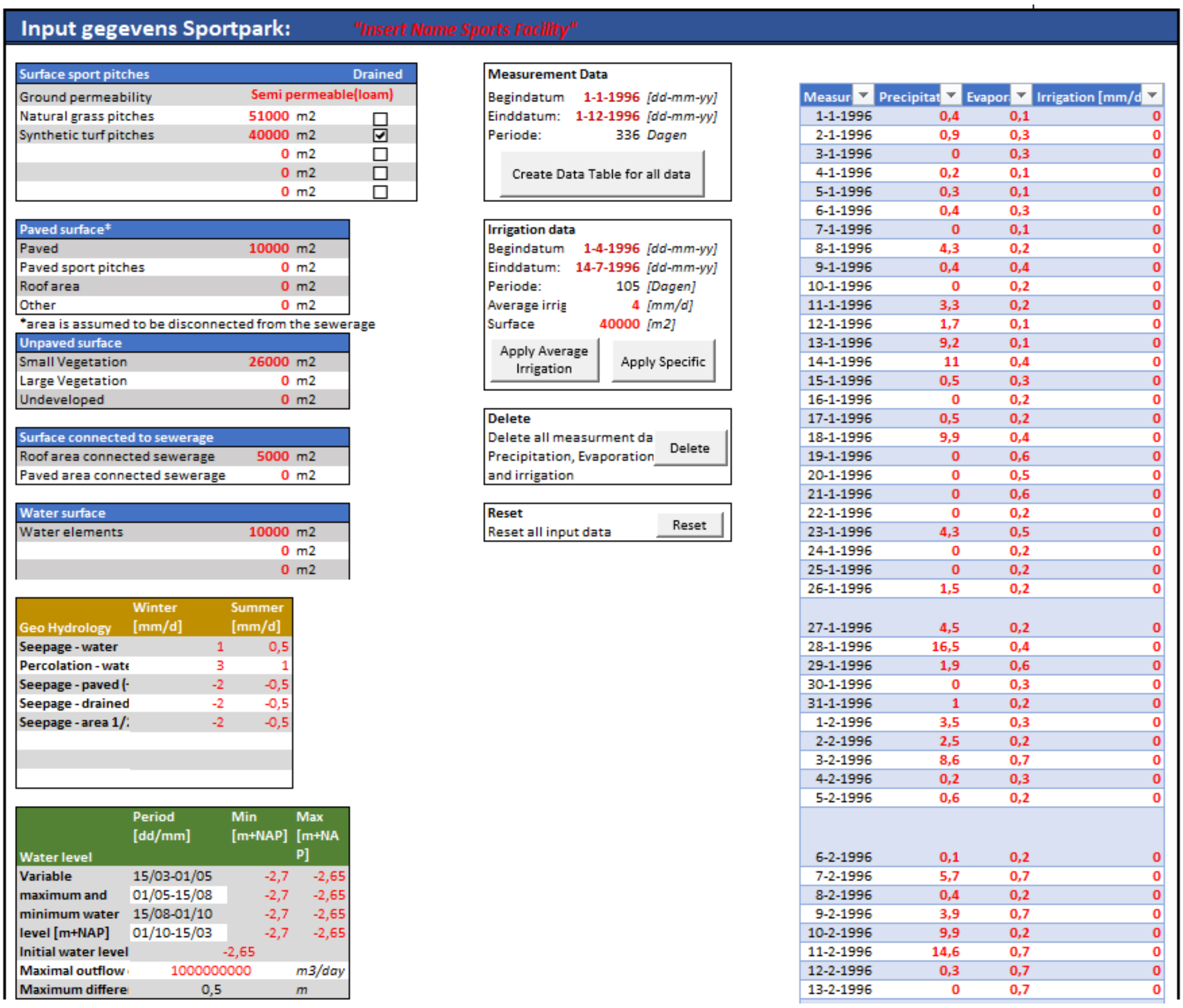


Figure 19: Drinking water prices ranked per company in terms of price

11.2. Appendix B

Input sports facility water balance model visualized.



Input gegevens Sportpark: *"Insert Name Sports Facility"*

Surface sport pitches			Drained
Ground permeability	Semi permeable(loam)		
Natural grass pitches	51000	m2	☐
Synthetic turf pitches	40000	m2	☑
	0	m2	☐
	0	m2	☐
	0	m2	☐

Paved surface*		
Paved	10000	m2
Paved sport pitches	0	m2
Roof area	0	m2
Other	0	m2

*area is assumed to be disconnected from the sewerage

Unpaved surface		
Small Vegetation	26000	m2
Large Vegetation	0	m2
Undeveloped	0	m2

Surface connected to sewerage		
Roof area connected sewerage	5000	m2
Paved area connected sewerage	0	m2

Water surface		
Water elements	10000	m2
	0	m2
	0	m2

Geo Hydrology	Winter [mm/d]	Summer [mm/d]
Seepage - water	1	0,5
Percolation - wate	3	1
Seepage - paved (-	-2	-0,5
Seepage - drained	-2	-0,5
Seepage - area 1/:	-2	-0,5

Water level	Period [dd/mm]	Min [m+NAP]	Max [m+NAP]
Variable	15/03-01/05	-2,7	-2,65
maximum and	01/05-15/08	-2,7	-2,65
minimum water	15/08-01/10	-2,7	-2,65
level [m+NAP]	01/10-15/03	-2,7	-2,65
Initial water level	-2,65		
Maximal outflow	1000000000		m3/day
Maximum differe	0,5		m

Measurement Data

Begindatum	1-1-1996	[dd-mm-yy]
Einddatum:	1-12-1996	[dd-mm-yy]
Periode:	336	Dagen

Create Data Table for all data

Irrigation data

Begindatum	1-4-1996	[dd-mm-yy]
Einddatum:	14-7-1996	[dd-mm-yy]
Periode:	105	[Dagen]
Average irrig	4	[mm/d]
Surface	40000	[m2]

Apply Average Irrigation | Apply Specific

Delete
Delete all measurment da Precipitation, Evaporation and irrigation — Delete

Reset
Reset all input data — Reset

Measur	Precipitat	Evapor	Irrigation [mm/d
1-1-1996	0,4	0,1	0
2-1-1996	0,9	0,3	0
3-1-1996	0	0,3	0
4-1-1996	0,2	0,1	0
5-1-1996	0,3	0,1	0
6-1-1996	0,4	0,3	0
7-1-1996	0	0,1	0
8-1-1996	4,3	0,2	0
9-1-1996	0,4	0,4	0
10-1-1996	0	0,2	0
11-1-1996	3,3	0,2	0
12-1-1996	1,7	0,1	0
13-1-1996	9,2	0,1	0
14-1-1996	11	0,4	0
15-1-1996	0,5	0,3	0
16-1-1996	0	0,2	0
17-1-1996	0,5	0,2	0
18-1-1996	9,9	0,4	0
19-1-1996	0	0,6	0
20-1-1996	0	0,5	0
21-1-1996	0	0,6	0
22-1-1996	0	0,2	0
23-1-1996	4,3	0,5	0
24-1-1996	0	0,2	0
25-1-1996	0	0,2	0
26-1-1996	1,5	0,2	0
27-1-1996	4,5	0,2	0
28-1-1996	16,5	0,4	0
29-1-1996	1,9	0,6	0
30-1-1996	0	0,3	0
31-1-1996	1	0,2	0
1-2-1996	3,5	0,3	0
2-2-1996	2,5	0,2	0
3-2-1996	8,6	0,7	0
4-2-1996	0,2	0,3	0
5-2-1996	0,6	0,2	0
6-2-1996	0,1	0,2	0
7-2-1996	5,7	0,7	0
8-2-1996	0,4	0,2	0
9-2-1996	3,9	0,7	0
10-2-1996	9,9	0,2	0
11-2-1996	14,6	0,7	0
12-2-1996	0,3	0,7	0
13-2-1996	0	0,7	0

Figure 20: Overview picture of the Excel water balance model of the input data

11.3. Appendix C

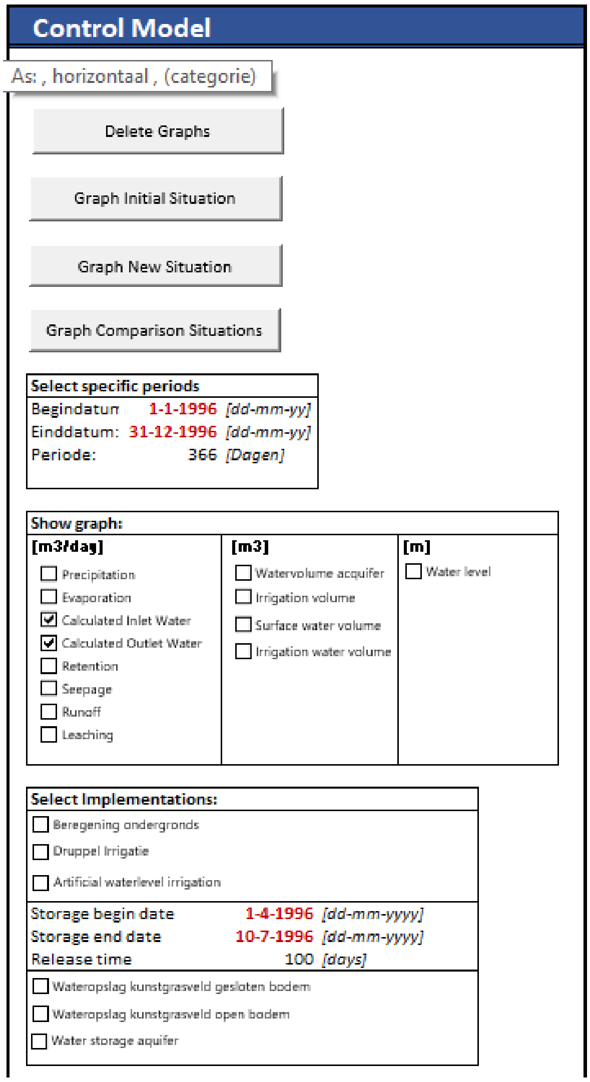


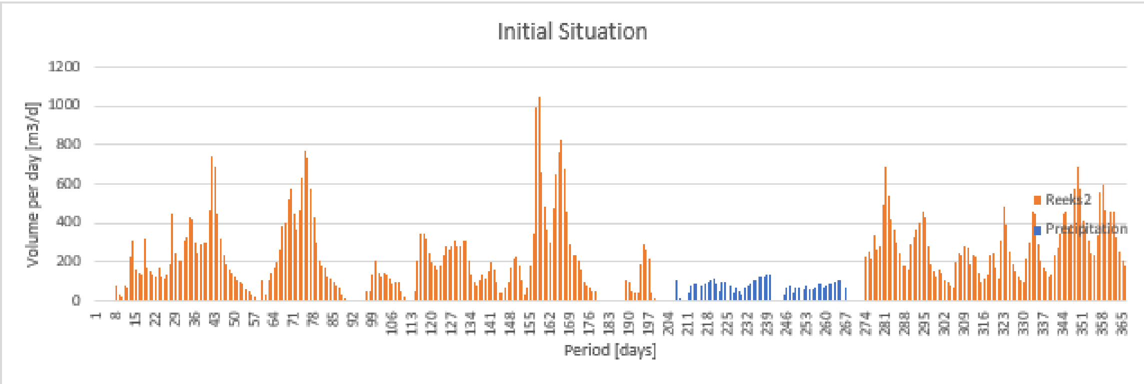
Figure 21: Overview of the "Control Panel" of the Excel water balance model

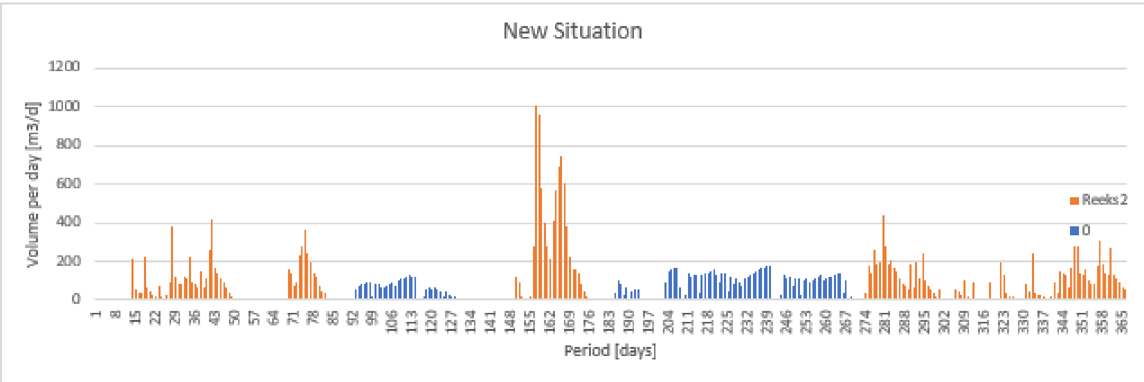
11.4. Appendix D

Output Model

List with core numbers:

Numbers	*Year* 1996	INITIAL		NEW		New VS Initial	
Calculated inlet wa		4256	*[m3]*	10057	*[m3]*	5801	*[m3]*
Calculated outlet w		66676	*[m3]*	23329	*[m3]*	-43346	*[m3]*
Irrigation		########	*[m3]*	########	*[m3]*	0	*[m3]*
Leaching			*[m3]*	-	*[m3]*	-	*[m3]*





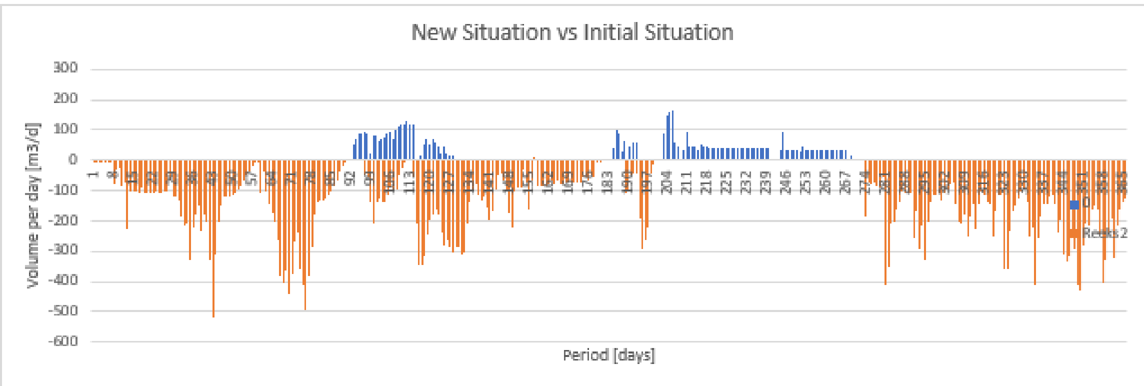


Figure 22: Overview of an example of the output visualization in the Excel water balance model

11.5. Appendix E

Overview of the different soil types with their characterisation values.

Table 10: Permeable (Sand)

Buckets -->	Paved above	Paved under	Drained above	Drained under	Unpaved undrained 1 (pitches)	undrained 2 (Small Vegetation)	undrained 3 (Large Vegetation)	Unpaved undrained 4 (Undeveloped)
f_subsurface_outflo	0,00	0,001	0,50	0,001	0,09	0,09	0,09	0,09
f_subsurface_inflow	0,00	0,001	0,00	0,001	0,04	0,04	0,04	0,04
Retention volume	1,00	0,20	0,45	0,30	0,30	0,30	0,30	0,30
max. groundwater le	0,002	0,50	0,70	0,20	0,50	0,50	0,50	0,50
equilibirum groundw	0	0	0	0	0	0	0	0
min. Groundwater le	0	x	x	x	x	x	x	x
initial groundwater l	0	0	0	0	0	0	0	0
Evaporation rate cro	1	0	1	0,75	0,9	0,95	1,1	0,8
Min. evaporation rat	1	0	0,75	0,25	0,5	0,55	0,65	0,4

Table 11: Semi permeable (loam)

uckets -->	Paved above	Paved under	Drained above	Drained under	Unpaved undrained 1 (pitches)	undrained 2 (Small Vegetation)	undrained 3 (Large Vegetation)	Unpaved undrained 4 (Undeveloped)
f_subsurface_outflo	0,00	0,001	0,50	0,001	0,06	0,06	0,06	0,06
f_subsurface_inflow	0,00	0,001	0,00	0,001	0,03	0,03	0,03	0,03
Retention volume	1,00	0,20	0,45	0,40	0,40	0,40	0,40	0,40
max. groundwater le	0,002	0,50	0,70	0,20	0,50	0,50	0,50	0,50
equilibirum groundw	0	0	0	0	0	0	0	0
min. Groundwater le	0	x	x	x	x	x	x	x
initial groundwater l	0	0	0	0	0	0	0	0
Evaporation rate cro	1	0	1	0,75	0,9	0,95	1,1	0,8
Min. evaporation rat	1	0	0,75	0,25	0,5	0,55	0,65	0,4

Table 12: Impermeable (clay)

uckets -->	Paved above	Paved under	Drained above	Drained under	Unpaved undrained 1 (pitches)	undrained 2 (Small Vegetation)	undrained 3 (Large Vegetation)	Unpaved undrained 4 (Undeveloped)
f_subsurface_outflo	0,00	0,001	0,50	0,001	0,03	0,03	0,03	0,03
f_subsurface_inflow	0,00	0,001	0,00	0,001	0,01	0,01	0,01	0,01
Retention volume	1,00	0,20	0,45	0,50	0,50	0,50	0,50	0,50
max. groundwater le	0,002	0,50	0,70	0,20	0,50	0,50	0,50	0,50
equilibirum groundw	0	0	0	0	0	0	0	0
min. Groundwater le	0	x	x	x	x	x	x	x
initial groundwater l	0	0	0	0	0	0	0	0
Evaporation rate cro	1	0	1	0,75	0,9	0,95	1,1	0,8
Min. evaporation rat	1	0	0,75	0,25	0,5	0,55	0,65	0,4