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Inês Freire da Silva

Climate Change Adaptation Measures: Specificities of Green Infrastructures in Urban Water Management

Dissertação de Mestrado Integrado em Engenharia do Ambiente na área de Especialização em Território e Gestão do Ambiente, orientada pela Professora Doutora Isabel Pedroso de Lima e pelo Professor Doutor Floris Boogaard e apresentada ao Departamento de Engenharia Civil da Faculdade de Ciências e Tecnologia da Universidade de Coimbra

September 2022

Faculdade de Ciências e Tecnologia
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"Toute réussite déguise une abdication"
Simone de Beauvoir

RESUMO

As alterações climáticas preconizadas pelos modelos climáticos, e a avaliação do seu potencial impacto no ambiente urbano, tornam urgente aumentar a resiliência das cidades de forma a poderem enfrentar novos cenários climáticos.
As preocupações incluem a crescente variabilidade da precipitação, bem como episódios de ondas de calor, que potenciam o agravamento das cheias e inundações urbanas, o stress térmico, e a disponibilidade de água para diferentes fins.
Em particular, medidas para controlar as águas pluviais de drenagem na origem, nomeadamente a adoção de soluções baseadas na natureza (NBS – Nature Based Solutions, em inglês), entre outras, são iniciativas importantes que permitem o alargamento das alternativas existentes para enfrentar as mudanças esperadas no regime hidrológico e melhorar a gestão da água, em áreas urbanas.
Além disso, a adoção destas medidas contribui para facilitar a transição para cidades e territórios mais sustentáveis.
Este estudo centra-se em algumas das soluções de infraestruturas verdes (por exemplo, paredes de água pluvial, telhados verdes, entre outros) instalados nos Países Baixos (por exemplo, na cidade de Groningen), no que diz respeito às suas características e integração em sistemas públicos de drenagem pluvial, e ao seu funcionamento e aplicabilidade em áreas urbanas densamente construídas. Para este efeito, realizou-se uma estadia na cidade de Groningen, criando a oportunidade de a estudante contactar com estudos realizados sobre o tema na Universidade de Ciências Aplicadas de Hanze (HUAS), as condições de campo, e as ações promovidas que envolvem residentes e autoridades no setor da água, para a implementação de medidas que contribuam para a adaptação e mitigação das alterações climáticas nas áreas urbanas. Esta interação com a HUAS, está enquadrada pelo projeto ERASMUS+IMPETUS, no qual a Universidade de Coimbra participa. A estudante avalia e discute a aplicabilidade de tais infraestruturas tendo em conta as condições locais em Portugal.

Palavras-chave:

Sistemas de drenagem, infiltração, NBS, irrigação, inundações, sustentabilidade

ABSTRACT

Changes in the climate advocated by climate models, and the assessment of their potential impact on the urban environment, make it urgent to increase the resilience of cities to face new climate scenarios. Concerns include increasing rainfall variability and heat waves' episodes, which potentiate the aggravation of urban inundations and floods, heat stress, and the availability of water for different purposes.

In particular, measures to control stormwater drainage at the source, namely the adoption of nature-based solutions (NBS), among other solutions, are important initiatives that allow the broadening of existing alternatives to face expected changes in the hydrological regime and improve water management, in urban areas. In addition, they contribute to facilitating the transition to more sustainable cities and territories.

This study focuses on some of the green infrastructures' solutions (e.g., rainwater walls, green roofs) installed in The Netherlands (e.g., in the city of Groningen), with respect to their characteristics and integration in public pluvial drainage systems, and their operation and applicability in densely built urban areas. For this purpose, a stay in Groningen created the opportunity to research green infrastructure at the Hanze University of Applied Sciences (HUAS), the field conditions, and the actions promoted that involve the residents and water authorities, for the implementation of measures that contribute to the adaptation and mitigation of climate change in urban areas. This interaction with HUAS is framed by the project ERASMUS+ IMPETUS (Innovative measurement tool toward urban environmental awareness), in which the University of Coimbra participates. The student assesses and discusses the applicability of such infrastructures bearing in mind the local conditions in Portugal.

Keywords:

Drainage systems, infiltration, NBS, irrigation, floods, sustainability

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ACRONYMS AND ABBREVIATIONS

LID - Low Impact Development

SUDS - Sustainable Urban Drainage Systems

CC - Climate Change

GI - Green Infrastructure

GR - Green Roof

NBS - Nature-based solutions

UNDP - United Nations Development Programme

UCP - United Care Products

Wadi -Water drainage and infiltration

WW - Water Wall

DEC- Departamento de Engenharia Civil

Leca - Lightweight expanded clay aggregate

IPMA - Instituto Portugês do Mar e Atmosfera

1 INTRODUCTION

1.1 Framework

Cities provide essential services for the population; they are spaces of growth and of innovation. They can be considered as drivers for the development of the economy, but not everything is positive about urbanisation. Studies show that Europe is highly urbanised, and the tendency is for this urbanisation to continue growing. During the last decades, urban sprawl has increased, which has been accompanied by a demand for housing, infrastructures and transport, and ends up causing changes in the environment, this has significant consequences for the populations (EEA, 2016).

A direct consequence of population growth and development is soil sealing. This, combined with the removal of the vegetation cover, modifies the natural drainage conditions and potentiates the risk of flooding (Saraiva, 2008). When extreme events, such as floods or heavy precipitation, occur (or their risk of occurrence is higher), it is necessary to have the ability to react, recover, adapt and create solutions, for example, green infrastructures (GI), in order to reduce the vulnerability of urban areas. The importance of having GI is becoming increasingly recognised. GI include parks, trees, rain gardens, green roofs, walls and facades and several more. With these solutions, it is possible to add GI to a city, which will help with the management of urban water and with minimising urban heat islands that originate from traffic, industry and the buildings themselves that retain solar energy.

The city of Groningen, in the north of The Netherlands, is a perfect example of a city that has been adapting to the changing climate with several aesthetics, open spaces and reservoirs that allow to storage rainwater that can be used later, for different purposes.

The stay of the author in the city of Groningen, during 2022, in the framework of this master thesis work, allowed her to contact with other urban environments, challenges and solutions, as well as to get involved in ongoing studies, in particular, on swales, and also to witness the functioning of the infrastructure water wall. These GI are investigated at the Hanze University of Applied Sciences (Groningen, The Netherlands) and are related to urban water management. Swales and rainwater walls will be presented in chapter 3. Alongside with this practical experience, the author got acquainted with a science platform called ClimateScan. This platform has been developed to introduce users to GI and to help identifying and mapping GI's, worldwide. This platform has already mapped over 8000 nature-based solutions (NBS) and has become the biggest database of climate adaptation. The idea of this platform is that it will inspire stakeholders to take ideas of NBS that exist elsewhere and implement them in order to make their cities more resilient to climate change and promote groundwater recharge. Information and details about the infrastructures that are being presented can be found on the platform ClimateScan.

With the help of this platform, it is possible to get familiar with different types of NBS that are being adopted throughout the world, which allows us to broaden the understanding of mitigation measures and of GI's that are used in other countries and adapt them to our own environment, according to the territory's conditions.

1.2 Aim & Objectives

The work carried out and presented in this dissertation is intended to show how climate change adaptation measures can contribute to a better knowledge and dissemination of the application of green solutions based on nature, for water management. It also aims at discussing in what way these infrastructures present in The Netherlands have the potential to be applied to the conditions in Portugal. It contributes to disseminate information and show the advantages of green infrastructure and how they can help to fight climate change i.e., to create mitigation measures.

This document might also contribute to inspire and motivate the adoption of behaviours that consequently help to mitigate the impact of flood phenomena. Several infrastructures will be presented but only two will be more scrutinised. This allows the reader to get a brief idea of what GI are, what are their main aims and how they can help cities to be more resilient to climate change.

The text includes photos of various types of infrastructures that can be found in the city of Groningen and how they blend into the city. The examples shown also allow to see how the Dutch culture, instead of fighting against water, embraces and includes it in the city ending up creating different and enjoyable places.

This work pretends to show that it is possible for people and nature to coexist and overcome, in a certain way, problems that result from urbanisation. At last, although the reuse of rainwater is already a reality at many places, this work discusses current solutions that aim at this goal by explaining how to implement solutions suitable for cities, so that this practice is possible and a reality in urban environments.

1.3 Organisation of the dissertation

The present dissertation is organised in five chapters. The first one, the introduction, gives the framework for developing this dissertation work, introducing the problematic behind the topic, from a current perspective. It leads to the objectives of this work and its development.

In chapter two, a literature review was carried out. It starts by addressing urbanisation and the problems it entails. The consequences of urbanisation are also reviewed to establishing a connection between this type of land use and the impact of soil sealing on the water cycle. In this chapter the flooding problem (a consequence from the urbanization) is also addressed, as well as how climate change might amplify the problems caused by soil sealing (like floods). Finally, in the same chapter, some solutions are presented that can help to mitigate the problems mentioned. These solutions, known as Green Infrastructures, are considered a type of urban water management measure.

The third chapter focuses on two green solutions that have been studied during the stay in The Netherlands, in the city of Groningen. This study took place over two months (March to May) allowing the author to get insight and increased knowledge on the way urban water management issues are addressed in that country. The type of soil and the weather found in the study area, in The Netherlands, is also presented in chapter 3.

In the fourth chapter, on results and discussion, the data collected from experimental work carried out in the city of Groningen are presented; these data have all been provided by Professor Floris Boogaard and his research team from Hanze University of Applied Sciences. The purpose of this chapter is to interpret the results and understand how the two green infrastructures are important adaptation measures in urban water management.

Lastly, chapter five gives general conclusions about the dissertation work carried out and also suggestions about climate change adaptation measures that can be integrated into the city of Coimbra, in Portugal.

2 STATE OF THE ART

2.1 Urbanisation

Urbanisation is a long-term process characterised by the increase of population living in cities and the extension of urban areas. The process of urbanisation began with the industrial revolution and is spreading, and it has negative effects on the environment (CEMAT, 2011) One of the mains factors of the urbanisation it's the promise of jobs and prosperity, ending up by pull people to cities. However, despite the advantages of going to the cities there are several problems that come with the spreading, one of the most pressing problems facing the world today is the environmental degradation.

Given this urbanization context and current global environmental threats, the concept of sustainability will, in the long term, succeed or fail in cities (Oliver-Solà et al., 2009). Research in the area of sustainable urban infrastructure reveals the need to design and manage engineering systems in light of both environmental and socioeconomic considerations.(Sahely et al., 2011). It is necessary to incorporate the care of city green spaces as a key element in urban planning, since rapid population development and urban expansion have transformed what were natural areas into engineered infrastructure. For most cities, the groundwater systems are a connecting component between the elements of urban infrastructure.

It is important to understand that the urban processes have influence on groundwater and the conditions of this have an impact on urbanisation process. Urbanisation is a pervasive phenomenon of the current days, and sustainable urban development is considered to be one of the greatest challenges faced by the world (Gogu, 2022). One of the goals from the United Nations Development Programme (UNDP) is called sustainable cities and communities. This goal says that in order to achieve sustainable development it's necessary to change the way infrastructures are build and manage urban spaces.

This means investing in public transportation, create more green public spaces, improve urban planning. With these ideas along with others is possible to mitigate and adapt to climate change as a consequence by 2030 the number of deaths affected by natural disaster including water related disasters as significantly reduce (*Sustainable Development Goals | United Nations Development Programme*, 2021.).

In order to achieve the aims incentives are needed, explaining to the populations the benefits of GI and creating laws that will help to accomplish sustainability as it happened in France, where according to The Guardian, (2015) in published news article, the French parliament decreed that the rooftops on new buildings must have plants or solar panels.

2.2 Impact of soil sealing on the water cycle

Soil and land are vital resources and the foundation of much of humanity development. However, land use for urbanisation and infrastructure is increasing and so has the surface area sealed. Soil sealing together with the removal of vegetation maximises flood risk, affects the water cycle, jeopardises biodiversity and contributes to global warming (Brun & Band, 2000; Sanders, 1986; Commission for Environment, 2014).

Soil sealing is understood as the "destruction or covering of soils by buildings constructions and layers of completely or partial impermeable artificial material. It is the most intense form of land take and is essentially an irreversible process'' (Gundula Prokop et al., 2011). It is considered to be one of the main processes of soil degradation, its increase is significant and affects several essential services such as water absorption, filter capacity as well biodiversity. In figure 2.1, it is possible to see, on the left-hand side, an urbanised space with roads and houses and some forestation; on the right-hand side of the image, it is possible to check the same zone with black to indicate the impermeable zone. With this image it's visible that the waterproofed area is relatively larger than the permeable one. This is a situation that we see nowadays.

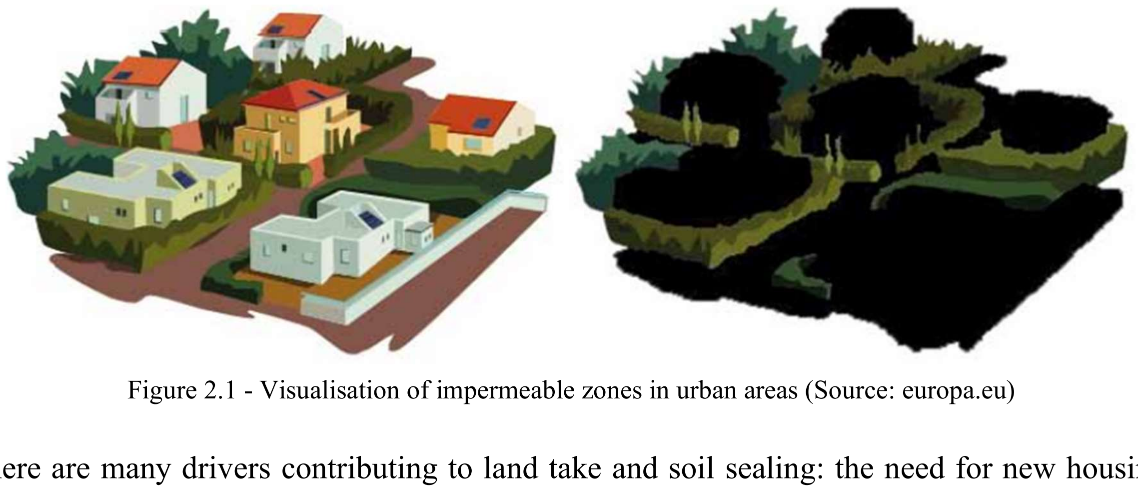

Figure 2.1 - Visualisation of impermeable zones in urban areas (Source: europa.eu)

There are many drivers contributing to land take and soil sealing: the need for new housing, industry or transport infrastructure are examples behind soil sealing in order to respond to a better quality of life due to a growing population. Soils play a crucial role in our life's and among their many functions, the highlights go to the capacity of filtering water and moderating its flow removing contaminants and minimising the risk of flooding. When we waterproof the soil, we are eliminating a huge part of its utility. As a consequence of this waterproofing, we prevent the infiltration of water into the soil. In figure 2.2 it is possible to observe a sequence of images showing what happens to the water as construction progresses and, consequently, the soil becomes more impermeable. The impact caused by soil sealing leads to a reduction of the water that can infiltrate into the soil, and it also applies pressures on the hydrological cycle leading to changes in the status of watersheds.

A properly functional soil can retain up to 3750 tonnes of water per hectare, the equivalent to almost 400 mm of rainfall (European Commission & Directorate-General for Environment, 2014).

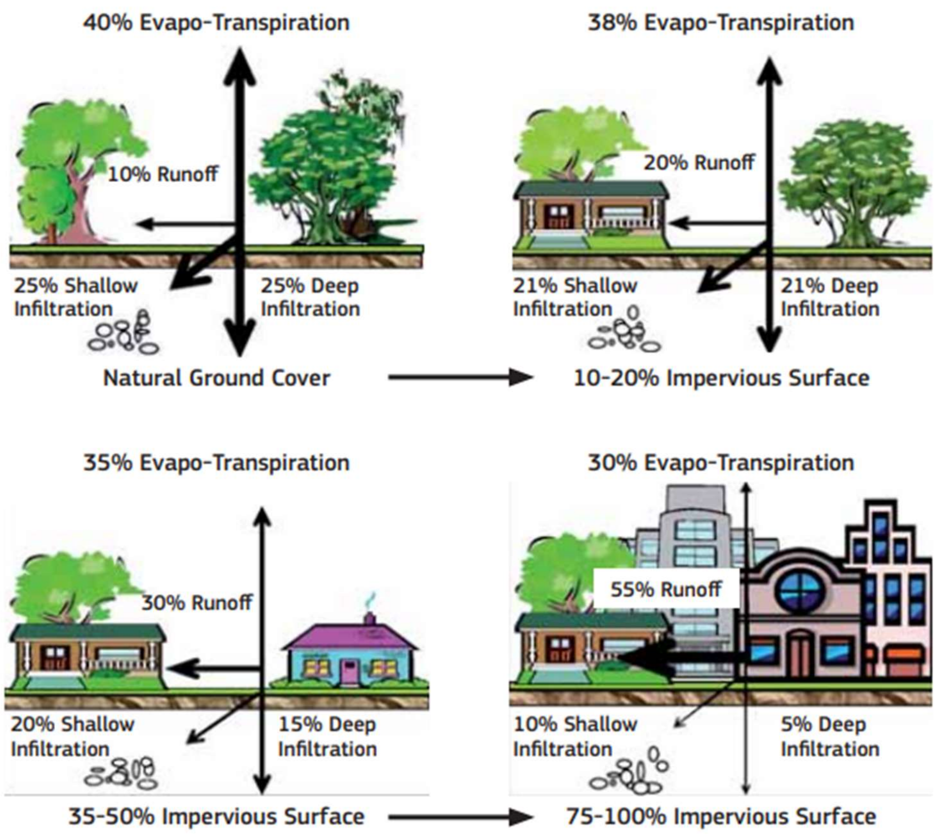

Figure 2.2 - The influence of land cover on the hydrological cycle (Source: https://op.europa.eu/pt/publication-detail/-/publication/e9a42c93-0825-4fc0-8032-a5975c8df3c0)

Urbanisation is a process that causes a major change in the water cycle due to sealing which reduces the amount of rainwater that the soil can absorb and, in some cases, can even totally prevent absorption.

Sustainable urban water management is now a priority in order to increase the quality of life and environmental quality. Some impacts caused by the increase in sealing can be highlighted: infiltration as the area of open spaces has been reduced, the volume of the surface runoff due to the reduction of the infiltration area and has consequence infiltration time decrease which can cause flooding and inundation and finally evapotranspiration which has a cooling effect (European Commission & Directorate-General for Environment, 2014; Santos et al., 2017)

With regard to infiltration, soil texture is usually the most significant variable. Clayey soils have a higher water retention capacity than sandy soils that drain more easily. Furthermore, the infiltration of rainwater can increase the time it takes for rainwater to reach the river, reducing the risk of flooding.

Secondly, the volume of the surface runoff: it is well known that a soil with more vegetation facilitates more the infiltration of water into the soil. Part of the higher vegetation, like trees, intercepts the water which can evaporate before it reaches the ground (European Commission & Directorate-General for Environment, 2014). The creation of green infrastructures such as green roofs contribute to preventing surface runoff (Harper et al., 2015). However, it is important to note that soil has a higher capacity of absorb water than green infrastructures.

At last, the impact on evapotranspiration caused by soil sealing can alter the meteorological conditions because of the cooling effect. By waterproofing the soil, more water remains on the surface increasing surface runoff, which affects the hydrological cycle (European Commission & Directorate-General for Environment, 2014).

To sum up, when vegetation is removed for the sake of urbanisation, natural conditions are automatically altered, generating a series of consequences such as an increase in surface runoff (de Lima et al., 2010)

2.3 Flooding

Floods are an element of nature. They can happen on several places of Earth and when there is too much water and at one time. Floods have a considerable impact on cities, as they can cause huge damage and destruction of property, and economic activities are potentially exposed to flood, due to the fact that most urban communities are situated near water sources such as coasts and rivers (Zevenbergen et al., 2010).

Floods also can happen fast and sometimes unexpectedly. According to the Directive 2007/60/CE of the European parliament and of the Council of 23 October 2007 ‘flood’ means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems.

In an urban area the management of surface runoff has been highlighted as a key driver for flood risk. Surface runoff is not only generated by flow that is in excess of the rate of infiltration, but also on saturated topsoil layers and on water bodies (lakes, rivers and streams).

According to Mobini et al., (2022) there are different causes of urban flood; it can be caused by the coast, or it can have fluvial, pluvial or even groundwater origin. Apart from this, regardless of their origin, floods all have a direct environmental impact because they end up carrying waste.

Because precipitation is one of the causes of flood and climate change scenarios for Europe predict an increase of precipitation and for prolonged periods at some locations, as a consequence, Europe will be more vulnerable to floods since it is expected that them become more frequent. (*Consequências Das Alterações Climáticas*, n.d.)

Depending on the state of soil saturation, runoff can change. When a heavy rainfall occurs, it can exceed the infiltration capacity of the soil, resulting in floods. Also, depending on the accumulated rainfall the frequency and magnitude of floods also varies (Leal, 2013).

According to, among others, Lencastre & Franco, (2006) and Leal (2011), it is possible to distinguish two points of view in relation to the flood concept.

The first point of view is from a hydrological perspective: flood situation occurs when precipitation causes direct surface runoff. The other perspective is more geographical: it defines that, potentially, when precipitation occurs, it increases the flow of watercourses, causing overflows and the flooding of the margins and the surroundings areas due to the shape the watercourse (Zêzere et al., 2006). Another important factor is the soil itself since the infiltration depends on its characteristics.

2.4 Impact of climate change

The problem of climate change (CC) is the most urgent issue of our time. Human activity is gradually affecting the Earth's climate due to the huge amount of greenhouse gases it adds to those already present in the atmosphere. When this happens, these additional gases eventually amplify the greenhouse effect, and ultimately cause the Earth's temperature to rise, producing global warming and affecting the climate. This has consequences from changing weather patterns affecting food production to rising sea levels, bringing effects such as the risk of flooding. In order to mitigate the effects of climate change urgent action is needed.

Greenhouse gases are emitted naturally through the earth's surface and are essential to life. Without these gases, the average temperature of the Earth would decrease to an extent that would make life on the planet impossible. When sunlight hits the Earth's surface, some of its energy is absorbed and warms the soil and oceans. The rest of the energy goes back into space, but some of it is trapped in the atmosphere and warms the Earth. This phenomenon is known as the "greenhouse effect". It is thanks to the greenhouse effect that the planet's temperature is maintained and becomes pleasant.

The CC is one of the biggest and most challenging environmental problem due to the impact it has at the global scale. Several studies have been done about CC. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was created; the main objective of the IPCC is to provide scientific information reports to develop policies to help with the climate change. According to, e.g., Field et al. (2014) changes in many extreme weather events have been observed for a long period and increases in the number of heavy precipitation events have been reported.

A new recently report from IPCC identify that widespread impacts to people and ecosystems, among others, have resulted from observed increases in the frequency and intensity of climate and weather extremes; it is also stated that these impacts have been attributed to the humanity, and that the extent and magnitude of climate change impacts are higher than estimated in previous assessments (Langsdorf et al., 2022).

Cities are particularly vulnerable to the impacts of climate change, partly as a result, of the high degree of artificialization of its territory, the dependence on poor quality infrastructures and population concentration. Furthermore, the effects of CC in these areas may increase due to their inherent characteristics and depending on location. In addition, processes of anthropic origin, which contribute to altering the composition of the atmosphere, might increase vulnerability factors. Actions that build resilience and enable sustainable development can speed up successful climate-change adaptation globally (Alcoforado et al.,2009; Field et al. 2014).

2.5 Green Infrastructures as a measure in urban water management

The idea of urban green spaces has been suffering changes throughout history, it was basically related to the progress that the city has undergone over time. Since the XIX century the only function of green spaces were just the tour the stay and leisure time (Castel-Branco & Soares, 2007).

However, with the course of time and due to the emergence and consolidation of environmental concerns in recent years, there has been a need to intervene in the management of green areas; in other words, the focus has shifted from individual green areas to create green infrastructures (Madureira et al., 2011). As already stated, the development of infrastructure is crucial to the economy. New and emerging drivers, such as climate change, severe weather events are pushing community and private investors to seek out new.

Although GI is not a new concept, this topic is significant for the city and territorial planning (Eisenman, 2013). They represent an attractive option as it can help with these questions about the climate. GI are considered to be a more streamlined approach to managing the impacts of rainfall events and also evidence show that solutions from green infrastructures provide noise reduction, carbon sequestration and recreation opportunities.

Following this line of thought and according to the European Commission's Communication, a GI is considered to be a tool that helps to achieve benefits via nature-based solutions. In other words, it’s a network of semi and natural areas, that can incorporate green spaces and services from ecosystems on which the comfort and quality of human life are based.

GI’s have multiple functions that end up being advantages, they allow the conservation of biodiversity, drain water and create green spaces besides this they are considered to be measures for adapting to climate changing.

Interventions at the level of the storm drainage system is a process that can be considered negative. Is expensive and not always easy and can be impractical. Therefore, measures should be implemented that allow for water management beyond the drainage systems in order to reduce the risk of flooding

Many techniques of stormwater management have been being developed and they can be termed differently: Low Impact Development (LID) or Sustainable Urban Drainage Systems (Qin et al., 2013).

These techniques include green roofs, porous pavement and swales, among others. LID or SUDS have been being recommended as an innovative solution for stormwater management because it has been improving the environmental quality of the cities (Montalto et al.,2007). SUDS are part of green infrastructure and end up replicating natural processes

As stated, SUDS are more sustainable than traditional drainage systems, due to the fact that instead of dealing with water as a problem that needs to be solve quickly, they are designed to manage water flow rates helping with the environment quality, protect or improve the water quality. From blooming roof gardens to the permeable pavements from tree that cover streets, GI take place in many forms and can often hide in plain sights. Some examples are:

1. Green Roof

A green roof consists of the development of vegetation covering over a built-up surface. Intentionally created or through the formation of habitats so that it self-established. Green roofs can be developed on flat or sloping roofs (Raposo, 2013).

Although in the literature there is a range of green roofs, in this dissertation it will be used the term Green Roof, which, in its definition, covers all types, since the objective is to understand how green roofs can work as sustainable urban drainage system. In order to understand how it works, it is necessary to first understand the layout of a green roof as can be seen in the figure 2.3.

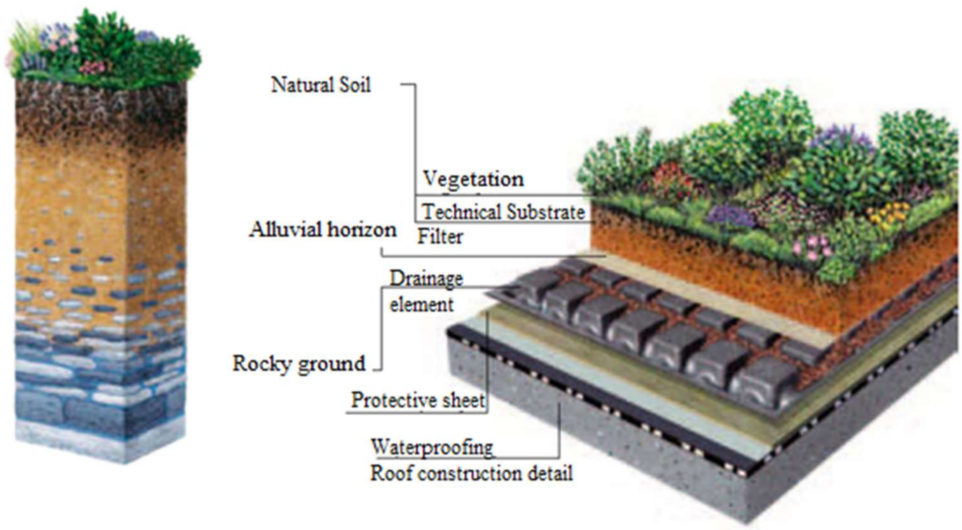

Figure 2.3 - Scheme of a green roof (Source: zinco)

A normal structure for a green roof includes a surface vegetation layer on a substrate, which is the growing medium, it also includes a geotextile filter layer, and an aggregate drainage layer. All layers must be supported by a waterproof membrane, with an additional layer of insulation between it and the roof itself.

The design of green roofs allows to intercept the rainfall, as a consequence as it flows through the vegetation, it slows down. Part of the rainwater is stored in the drainage layer and absorbed by the vegetation, the rest is discharged from the roof in the normal way (via gutters and downpipes). The flows rate from the green roof are lowered and attenuated, and the total volumes discharged from the roof are also reduced compared to a normal roof (*Individual NWRM Green Roofs*, 2013.).

In addition to the contribution of the GR in reducing and managing stormwater runoff, the use of this infrastructures contributes to the growth of green spaces providing a series of environmental and socio-economic benefits: stormwater quality and treatment, habitat for plants and animals, aesthetic and landscape valorisation, regulation of noise levels regulation of urban temperature, improvement of air quality and provides space for recreation and leisure. (About Green Roofs — Green Roofs for Healthy Cities, 2018.; Raposo, 2013) as we can observe in figure 2.4.

Figure 2.4 - Green Roof at the Zernike Campus – Groningen

Turning a conventional roof into a green roof will automatically provide the services that a green roof will provide. These services are mostly at an economical level meaning that infiltrations can be prevented and also protection from the sun's rays is provided. This help reducing the maintenance costs of the buildings.

At the environmental level an increase of green area in the urban context is generated, bringing back nature, which generates an increase of biodiversity. The green area also increases, which helps in the reduction of atmospheric pollution, and finally, in a more indirect way, in the management of rainwater.

Socio-communal services are related to the reduction of extreme climatic phenomena and generate an increase in the quality of life. An example of this last service is the Praça de Lisboa in Porto, an area that was somewhat forgotten and degraded and is now a leisure area, figure 2.5.

Figure 2.5 - Praça de Lisboa in Porto - construction stage (left) and green roof (right) (Source: JPN and SustentArqui)

2. Permeable pavements

Permeable pavements provide a pavement suitable for pedestrian and for traffic. Is an alternative infrastructure to the traditional pavement that it is used to promote infiltration of the water instead of running of. The result is a reduction in the volume of water flowing through the drainage system.

Water can percolate directly into the subsoil or alternatively, it can be held in a reservoir structure beneath the paving for re-use, infiltration or delayed discharge. A permeable pavement is a general term, and it is possible to distinguish two types (Susdrain, n.d.-a).

The first one is called porous pavement in which water infiltrates across the entire surface, the second type is the permeable pavement where the material can be arranged in order to provide void space allowing water to infiltrate through those voids. In figure 2.6 it’s possible to observe examples of permeable pavements.

Figure 2.6 - Types of permeable pavements (Source: SUDS manual and author)

The permeable pavements can be laid in several ways in order to allow proportion of runoff to be stored and used for various non-potable applications such as irrigation or toilet flushing as we can see in the figure 2.7.

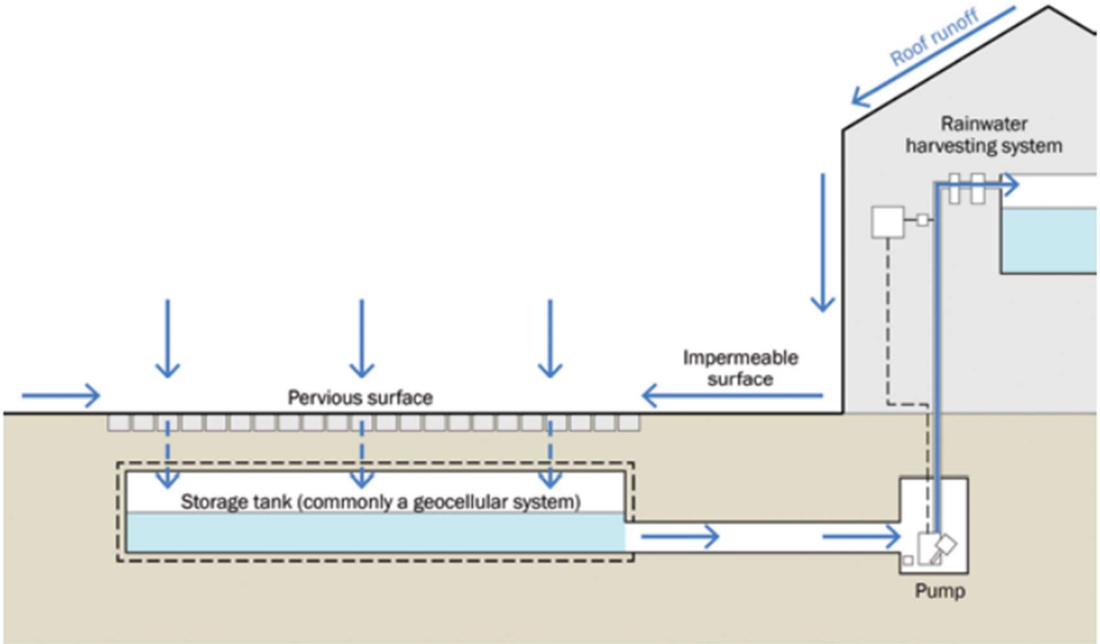

Figure 2.7 - Example of utility of permeable pavements (Source: SUDS manual)

3. Rain gardens

Rain Gardens also referred to as bioretention filters are structural stormwater areas that capture and treat stormwater runoff from rainfall events.

Rain gardens are used for dealing and treating runoff from frequent rainfall events. They are small depressions in the ground that help reducing the volume of water at the surface, by promoting the infiltration of it into the soil.

This infrastructure brings benefits by helping treat the pollution that result from urbanised area. Besides that, it also has a cooling effect due to evapotranspiration. (Susdrain, n.d.-b; Woods Ballard et al., n.d.). Figure 2.8 shows an example of a rain garden near to an urban area.

Figure 2.8 - Rain Garden (Source: NWRM)

The rain gardens are an excellent example of how SUDS components can be incorporated into a streetscape with reduced impact on the primary purpose of an urban space. They are applicable to most types of development and can be used in both residential and non-residential areas.

4. Retention Ponds

Retentions ponds are a type of GI that allows to collect the water from the surrounding area to the park. The path of the water passes through different layers of vegetation until it reaches the retention pond. These reservoirs were created with the aim of accumulate rainwater, ending up creating green spaces, valuing leisure areas and helping in reducing the risk of flooding. There are various types of retention basins according to Lourenço, (2014):

- Implementation in relation to the ground surface - open or underground basins.
- Hydraulic Behaviour - basins with permanent water level or dry
- Positioning in relation to the drainage collector - basins in series or parallel.

Figure 2.9 shows an example of a retention pond in the city of Groningen.

Figure 2.9 - Retention Pond, Groningen

This illustrates how the flows generated by soil sealing, resulting from precipitation, can be stored in retention ponds, solving flood situations and, at the same time, minimising drought problems by reusing the retained water for other purposes. On the other side, the storage effect allows to improve the quality of the retained water through the decantation effect of the suspended solid materials and helping to reduce the concentration of pollutants.

According to Liu & Jensen, (2018) the search for both immediate solutions and long-term transitions towards sustainability, green infrastructures (GI) are increasingly linked to urban water management.

They can be planted with trees, shrubs and other plants, improving their visual appearance, contributing to the aesthetic and landscape value and providing habitats for wildlife, where the vegetation is denser (European Comission, 2015).

3 MATERIAL AND METHODS

3.1 Introduction

The following chapter will focus on two types of green infrastructures for the development of climate change adaptation measures for urban water management: the water wall and the swale. For each case the location as well as the way the GI works, and its advantages will be presented. Soil tests are also presented in order to understand how the soil configuration can influence the water infiltration into the swales.

3.2 Study area

The results presented are for Groningen, which is the capital and main municipality in the province of Groningen, situated in the north of The Netherlands. Figure 3.1 show that this is a small city with a population of 230000 inhabitants. The city is practically flat, and as can be seen in the figure 3.1; topography reveals altitude variations up to 12 m, most of which is at a height of about 7 m above sea level

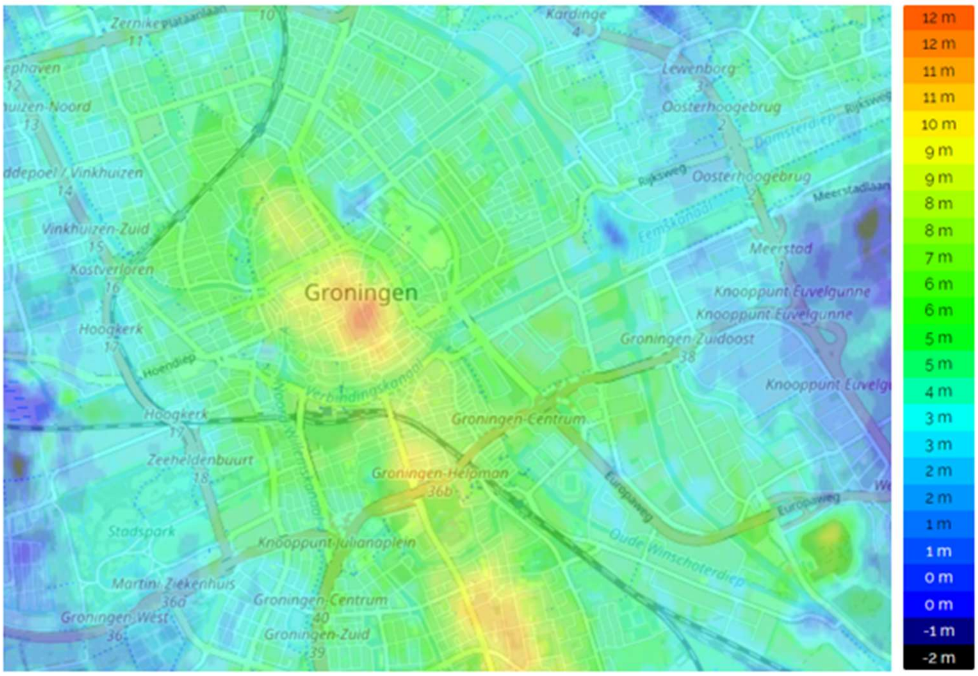

Figure 3.1 - Topografy of Groningen (Source: Topographic Map)

Waterbedrijf Groningen, the water authority of the Dutch city, relies on groundwater for the preparation of drinking water. This comes from the Drents Plateau. There are extraction areas that the company uses for water to be pumped to be consumed later on. Surface water from Drentsche Aa is also used.

Groningen has an oceanic climate due to its north-easterly position. This sort of climate features moderate temperature winters and cool summers. Precipitation is quite common throughout the year, which implies there is no dry season. On average, the northern provinces support lower temperatures compared to the southern provinces as is the case of the city of Groningen figure 3.2 that shows that Groningen is situated in the north of the Netherlands.

Figure 3.2 - Location of the study area - City of Groningen

3.3 Water Wall

This section addresses the Water Wall (WW) studied in this work, which is located at the Zernike Campus (HUAS), in the city of Groningen. This infrastructure was created in 2017 with the aim of making climate adaptation possible in urban areas.

This system has been installed at various places in The Netherlands, however, the WW located at the Zernike Campus is mostly meant to do further investigation. This infrastructure can be described as innovative because it stores water in height (*i.e.*, using a vertical reservoir), therefore using very little ground surface as can be seen in figure 3.3.

Figure 3.3 - The water wall system in Zernike Campus in Groningen

The water wall tries to respond to problems as lack of green spaces, flood risks, quality of public spaces, among others. In this case, it collects the rainwater in 5 meters vertical tubes and storages it, which allows to reduce flooding and help with water scarcity situations. Tube's diameter is 160 mm, and the area of the rooftop is approximately 36 m^2. The system has three water discharge points, which is explained further below:

1) One at the top (inside the gutter), at the rainwater entry, which can also act as an emergency exit in case the WW is full. The excess rainwater will then flow through the gutter, as it happens regularly in all buildings.

2) One exit about one meter height above ground level, to make it possible to fill a bucket or attach a hose.

3) One outlet right above ground level, which is usually slightly open so the water has a continuous flow and is allowed to be discharged (via a concrete gully) onto the parking lot, where the rainwater can easily infiltrate into the ground.

Figure 3.4 it's a scheme that shows how the water flows from the roof to the inlet of the pipes filling the water wall.

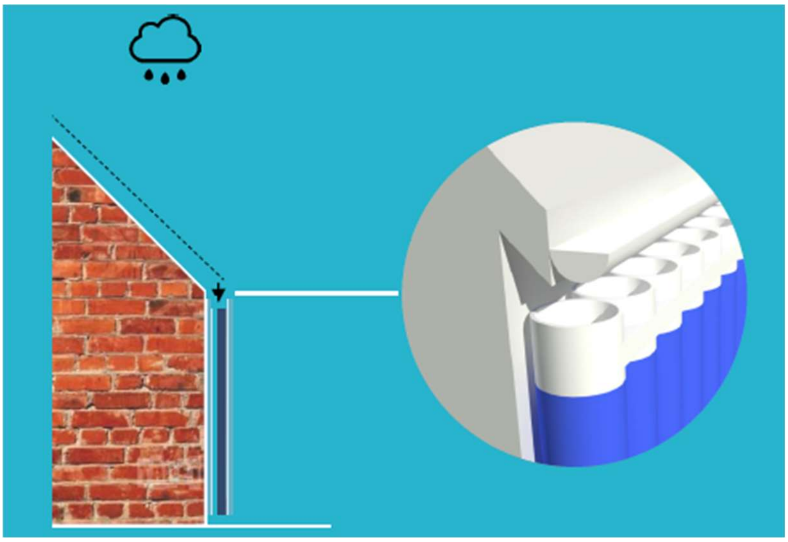

Figure 3.4 - Water inlet through the gutter into the water wall (Source: Anfibia Solutions)

The water stored in the WW can later infiltrate into the soil or be used for irrigating gardens or even cleaning works. At the same time, it is possible to create more green area as the pipes, being vertical, can be located on empty facades allowing vegetation to be placed around them ending up creating a green area/wall. This naturally will attract biodiversity such as insects like bees.

The total water storage capacity of the WW is approximately 500 L, the equivalent to 100 water bottles of 5 L.

The WW concept aims to be multifunctional, not only by combining water storage with vertical vegetation but also esthetics such as creative design and art works. Other benefits from the WW are that it can be easy installed at existing buildings and custom-made design since it is formed by a modular pipe system.

3.3.1 Water quality parameters analyzed

The water quality assessment was based on the use of Hach water quality strips (see the example on figure 3.5). Organoleptic and physic-chemical parameters were analysed. The water quality measurements were conditioned to the test tapes available at the time.

The water to be tested is stored in the pipes and located outside the building; as such, it is exposed to temperature differences that occur throughout the day. To determine if the water quality could be used for irrigation the following parameters were selected: nitrate, nitrite, phosphate (PO_4^-), iron, pH, chlorine, hardness and total alkalinity. In chapter 4.2 a comparison is made with the maximum recommended and maximum permissible values present in the Portuguese Decree-Law No 236/98 of 1 August.

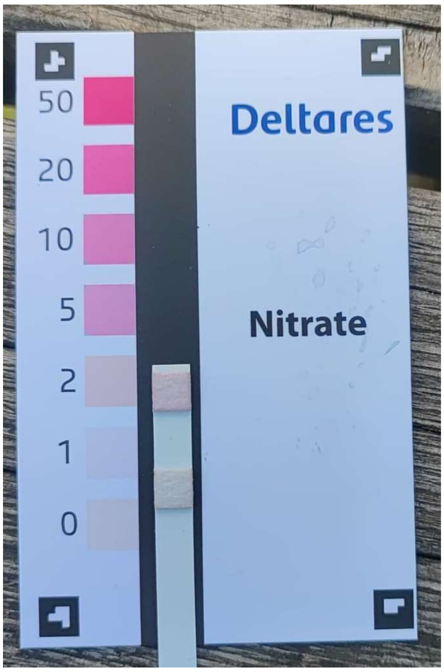

Figure 3.5 – Example of test strip for assessing nitrate concentration

Nitrates (NO_3^-) and nitrites (NO_2^-) are compounds that contain nitrogen and three and two oxygen atoms, respectively, and are thus part of the nitrogen cycle in the environment. It is necessary to measure nitrate and nitrite since nitrate and nitrite are nutrients and a vital source of nitrogen for plants and other complex organisms that consume them. Consisting of one atom of nitrogen (N) and three atoms of oxygen (O), the nitrate ion occurs spontaneously in soil. Since nitrite quickly oxidises to nitrate, its presence in surface waters is rare. Equations (1) and (2) identify the reaction that shows how to get to nitrate (NO_3^-) from nitrite (NO_2^-).

$$NH_3 + \frac{3}{2}O_2 \rightarrow NO_2^- + H_2O \tag{1}$$

$$NO_2^- + \frac{1}{2}O_2 \rightarrow NO_3^- \tag{2}$$

Nitrate is a contaminant that needs to be monitored more regularly in agricultural areas due to the use of fertilisers. It is important to monitor nitrate levels in potentially contaminated spring waters, as their treatment is difficult. Excessive concentrations of nitrite and nitrate can pose health risks.

In the study conducted on the water sample collected from the WW, the total alkalinity was also measured. While the pH is measured to determine whether the water sample is acidic or basic in the case of alkalinity is a measure of the ability of water to resist changes in pH or the ability of the water (solution in study) to absorb acid without changing its pH. Total alkalinity is a measure in ppm of the alkaline ions present in water.

The pH is a parameter that although it may not seem very necessary is in fact important. Defined as hydrogen power, it measures the hydrogen ion concentration in solution and is also referred to as the degree of acidity or alkalinity and is a determined value which is based on a defined scale (Trick et al., 2018):

- acid solution - pH < 7
- neutral solution - pH = 0
- basic solution - pH > 7

This parameter influences the position of chemical equilibrium of chemical reactions in aqueous solutions.

The hardness of the water is another parameter measured. Is associated with the presence of magnesium and calcium dissolved in water. It is considered hard water when there are significant amounts of these salts and soft when there are small amounts. In this case, the hardness of the water is measured for the calcium carbonate $CaCO_3$.

Chlorine is a natural element that is found in gaseous form and at ambient temperature. Due to the fact that chlorine is highly reactive it is usually bound with other elements. Chlorine, which is a strong oxidizing agent, helps deactivate microorganisms by breaking through the cell membrane. It is used to treat water to help disinfect, to ensure that water is free of bacteria it helps combat diseases that are transmissible through it.

Phosphorus due to its high reactivity, does not exist naturally as a free element. It occurs in the form of phosphate (PO_4^{-3}). Elevated levels of phosphate in water can have a significant impact on the surrounding ecosystem. High phosphate levels in source water can lead to eutrophication and the appearance of algae due to the fact that accelerate their growth. Besides this algae's cause odour and taste problems, they are in aesthetically way unpleasing and mostly important can create a huge demand for oxygen. The oxygen depletion is toxic to leaving animals in the water causing disturbances to the aquatic environment.

Finally, iron is a metal and high concentrations of iron ions in water bodies cause odour and discolouration due to their precipitation. In chapter four a table is presented with the values obtained from the measurements of the water quality tapes.

On the issue of water quality one that must be taken into consideration in an infrastructure that collects, and stores rainwater, like the WW, is the phenomena known as first flush. The first flush is a concept concerning the quality of water. It is the initial volume of runoff in urban catchments during rainfall events that contain the highest pollutants levels (Bach et al., 2010).

Contaminated irrigation water has been recognized as the reason of previous foodborne outbreaks. Several studies have found evidence of pathogens in freshwater sources intended for irrigation (Morgado et al., 2022). According to Islam et al., (2004) studies had shown evidence of transmission of pathogens from irrigation water specifically pathogenic *Salmonella spp* and *Escherichia coli*.

To address the noted microbial risks from harvested rainwater, a first-flush system could be included in the water wall, to help to help minimise the contamination of water by microorganisms of biological origin.

3.3.2 Determination of the runoff coefficient

When assessing the amount of rainwater that will be used, it is important to mention that not all the water that falls will be collected. This is due to the initial losses that occur when precipitation turns into runoff. These losses are due to several processes: evaporation, slope of the surface, the type of material. (Sousa, 2015)

Although the structure is already built, improvements can be made if desired if the structure is to be used for further experimental studies for example, it is important to identify the runoff coefficient, which is the ratio between the total amount of runoff and the total amount of water that falls on the drained area.

For that purpose, it would be necessary to monitor the amount of water in the roof area. For this reason, reservoirs are needed to observe the volumes of water runoff from the roof area. It is also important to quantify the rainfall that occurs at the site, by using udometers.

The objective would be to record the amount of water precipitated as well as the respective volume that run off from the cover. With this it was possible to estimate the runoff coefficient through the ratio of the volume of run-off and the amount of precipitation. With this information it would be possible to calculate the runoff coefficient.

3.4 Swales - Water Drainage and Infiltration

In this section we will approach the topic of swales. Unlike water walls (WW) this type of infrastructure has existed since the 1990s and contrary to WW, the swales are widespread and almost every municipality in the Netherlands has this infrastructure. In the figure 3.6, it is possible to have an idea of how much widespread this infrastructure exists in The Netherlands.

According to Witkowski et al., (2022) swales are widely used in Sustainable Urban Drainage Systems (SuDS); they can decrease peak flow, collect and retain water and improve groundwater recharge. The difference between swales and retention ponds is that retention ponds consist of a permanent pond area. Although different, they work to the same effect, reducing the amount of water by minimising flooding. According to Venvik & Boogaard (2020) rainwater can transport pollutant, that accumulate in the soil. These pollutants re considered as potential toxic elements (PTE) such as lead (Pb), cooper (Cu) and zinc (Zn). Due to that, the study will emphasis on these elements due to their prevalence and their toxicity in high concentrations.

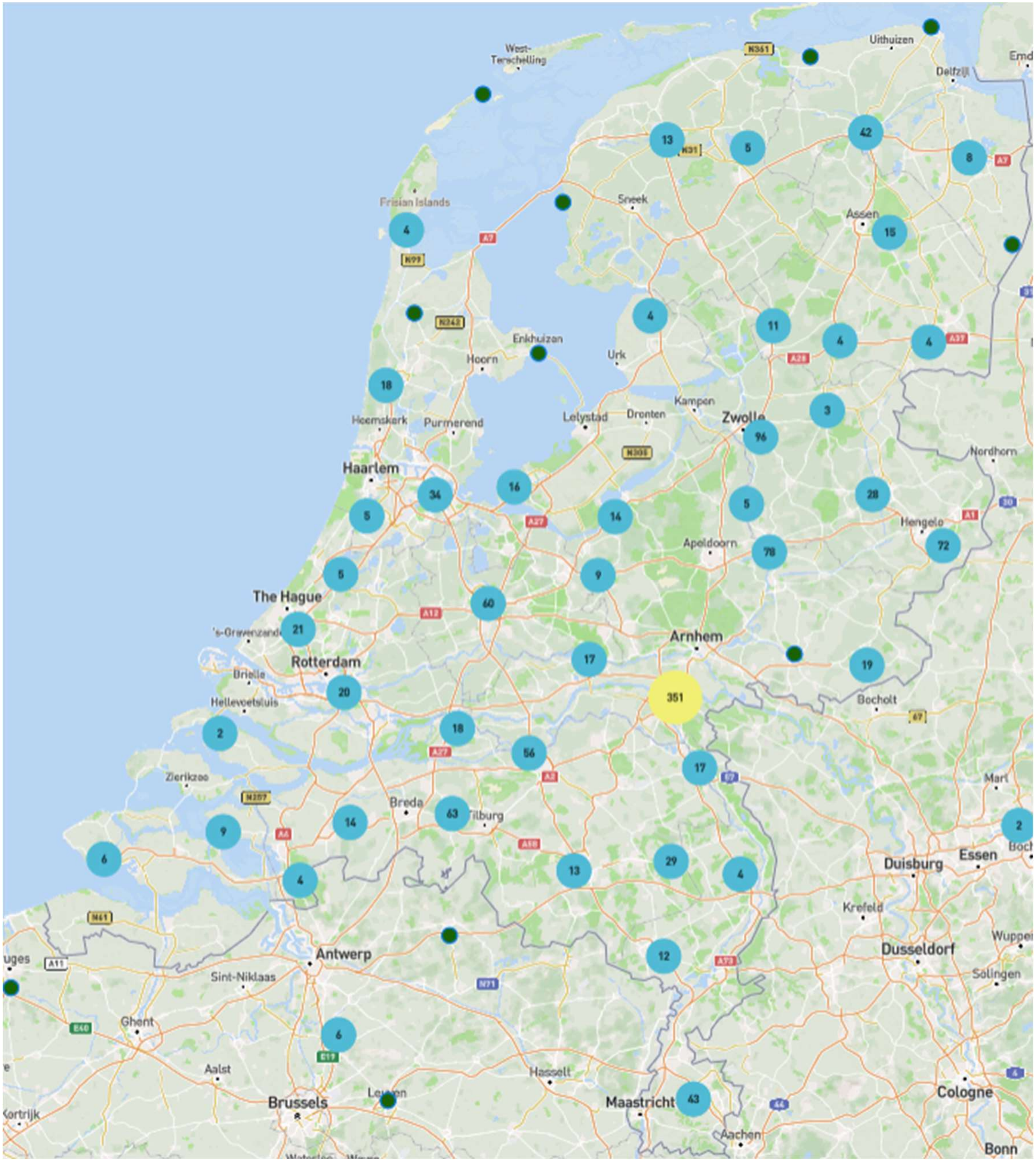

Figure 3.6 - Map with the number of swales in The Netherlands (Source: ClimateScan - Interactive map)

A swale is considered to be a green infrastructure located in the urban area. The rainwater coming down from the roofs and roads ends up flowing to green areas that are at a lower level. This system allows to storage the water and purifying it, after that the water infiltrates into the ground. In other words, instead of going to the sewers it flows through gutters above the soil into the swale.

The key characteristic of the swale is this infrastructure underneath which storages and drains the water, like infiltration crates, granulate granules and drainpipes, has can be seen in figure 3.7.

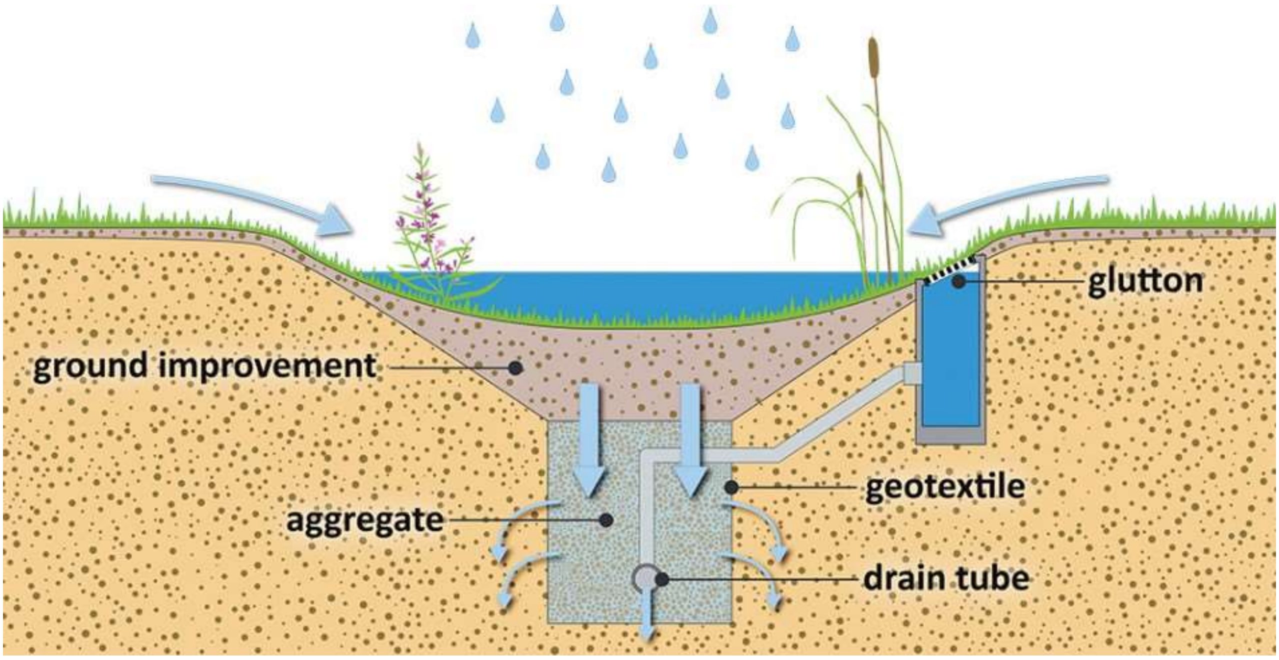

Figure 3.7 - Schematic section of a swale (Source: Boogaard et al. (2006)

Sometimes swales can fill up, this happens during periods of intense rain. Because of this situation often there are slokops (glutton, see figure 3.7). The glutton is only used when the swale is full. The water flows through the glutton into a drain that goes into a trench with LECA that forms an aggregate. This should be wrapped by a sand proof geotextile so that water can pass through but prevent garbage. However, most of the water in the swale infiltrates into the subsurface. That water is filtered into the top layer of the soil.

The swales are used mostly to control how the water infiltrates into the soil, when a period of intense rains happens. How fast or slow it goes depends on how the type of soil can influence the flowing rate.

It was possible to assist in tests that were made to several swales that already exist to see their behaviour and then analysed the results from the tests. The methodology that is being presented was used both in the city of Groningen in the north of The Netherlands (see subchapter 3.3- figure 3.1) and in the city of Limmen, figure 3.8. It is essential to find a place in an urban area to perform the tests as shown in figure 3.9, to understand how these structures help in urban water management

Figure 3.8 - Location of Limmen (Source: Google Maps)

Figure 3.9 - Urban area in Limmen

After choosing the location, a section of the swales under study is chosen and a barrier is created with plastic and sandbags. It’s also placed in different points of the section three stakes; these are only used to locate the divers.

Divers are water sensors; they are small devices that allows to measure the water pressure and can recording surface water levels. Also, rulers are used to be able to proceed with the measurements, in other words rulers are placed in the section of study, in this case two were used, so that is possible to verify if the swale is infiltrating well and how much time does it take to infiltrate the water. Finally, after everything is set, the section in question must be filled with water.

Since it does not always rain, and water is needed to proceed with the experiment a water tank is used to fill the section. It should be noted that no water is being wasted as the water used for all the tests is not drinking water. The establishment of a 10 cm water depth over the ground surface allows to simulate the behaviour of a swale during heavy rainfall, as can be seen in the figure 3.10 (which is the same place as shown in figure 3.9).

Figure 3.10 - Section of the swale under study in the city of Limmen in The Netherlands

For the case study in the city of Groningen, an infiltration test was used to simulate highly intense rainfall and measure the emptying time. It is necessary to consider some topics to carry out the infiltration tests: i) the place where the tests will be carried out - it must be spacious enough to allow the water tank to pass; ii) the area to be filled with water must be marked off; and iii) the water cannot leave the area of the swale where the tests are taking place

Finally, accurate measurement of surface infiltration is needed, which is achieved through the use of divers: that allowed to record the reduction of the water layer over time.

3.5 Type of soil

Another, important factor is the soil. By definition, soil is understood as the natural aggregation of mineral particles. These particles result from chemical decomposition and physical disintegration. The spaces that aren't occupied by the particles, called voids, may be filled with water, air or both, and constitute part of the total volume of the soil.

It is therefore usual to state that soil is a three-phase material, since it can be made up of three distinct phases: solid, gaseous and liquid. It is imperative that from these three phases, the solid one has to exist always. Of the other phases (gaseous and liquid), only one of them might exist, as illustrated in figure 3.11.

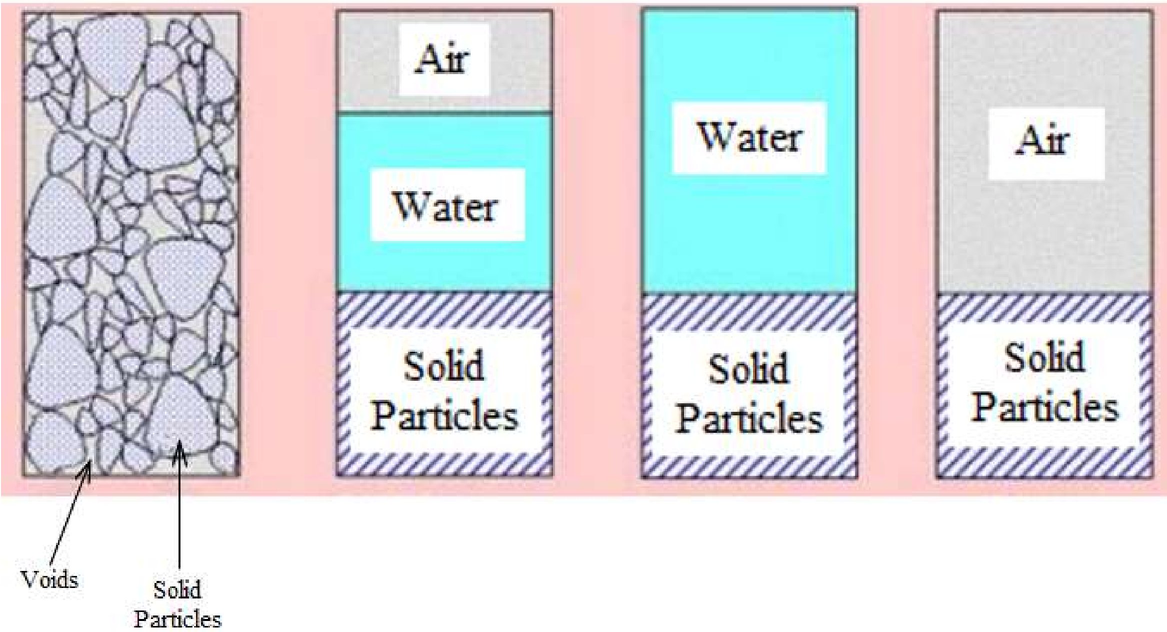

Figure 3.11 - Representation of soil configuration (Source: Classes material)

The soil can act as a “strainer”. Contamination of urban soils with heavy metals can be of natural origin or anthropogenic origin.

It is stated in Abrahams, (2002) that the contamination of the soils has implications to human health. It can happen through different ways like ingestion, especially in young children, in outdoor activities since they are more vulnerable and fonder for eating non-food things. According to Kooner et al., (2014) a heavy metal is any one of a number of elements that exhibits metallic properties, normally these elements have an atomic number of 21 or higher.

Heavy metals are elements that can be present in the environment in vary wide concentrations. Soils in the urban areas normally can be contaminated by the traffic with Lead (Pb), Zinc (Zn), Copper (Cu) and others (Alloway, 2013).

- Lead (Pb)

According to the periodic table, lead belongs to the representative elements with atomic number 82 and is considered to be a non-essential element, i.e., it is considered to be toxic. Exposure to high levels of this metal can cause adverse health problems. It is usually present in sedimentary rocks.

- Copper (Cu)

This element is classified as being a transition element whose atomic number is 29. Although it is an essential element, its presence in high concentrations can be toxic. Its toxicity is greater in acid soils, so it is possible to decrease its toxicity by increasing the pH of the soil.

- Zinc (Zn)

Zinc, like Cu, is one of the transition elements. It has an atomic number of 30. This element is naturally present in soils and normally clay soils have high concentrations of Zn in comparison with other soils.

For the collection of the soil sample to see the type of the soil, one piece soil auger was used (Figure 3.12). In total, approximately 1 m of soil was removed. From right to left, the first layer is the one that was at the bottom and was also the layer that was very saturated, next we have the middle layer, following the top layer which was dry (figure 3.12).

Figure 3.12 - Different layers from the soil

In order to classify the type of soil, soil samples brought from The Netherlands were analysed in Portugal, in the Geotechnics Laboratory of the Civil Engineering Department of the University of Coimbra. The tests were carried out in accordance with the specifications of the National Civil Engineering Laboratory (in Portuguese LNEC).

The LNEC standard E196 - Granulometric Analysis (Sedimentation) was used as a help document for the granulometric analysis of the samples. The purpose of this norm is to determine quantitatively the soil particle's size distribution. Each sample was analysed by following the same procedure, which will be explained as follows, describing the materials that were used as well as their function.

Firstly, it was used as utensils: a mortar and pestle with a rubber coated hand. This serves to produce the disintegration of the clods of soil without reducing the individual size of the particles (Figure 3.13)

Figure 3.13 - Disintegration of the soil samples using mortars

Secondly, reagents were prepared: A solution of sodium hexametaphosphate was used. The soil particles are normally aggregated by cementing action, this solution, allows the disintegration of these particles, by chemical processes, making it easier to determine the granulometric composition of the soil.

Later the sample went to the shaker to proceed to the mechanical agitation; this helps to create an artificial current in the sample so it forces the sample to hit in the shaker and lateral sticks, the aim of this phase is in case there are larger fragments they would break without reducing the fraction of the sample.

This led to part of the sample being release and part was deposited. The deposited part was subsequently subjected to washing which helped to separate the finer grains from the coarse grains. A graduated cylinder of 1000 cm^3 with a 45 cm height and 6 cm diameter and ASTM sieves through which the soil sample was passed. As it is shown in the figure 3.14.

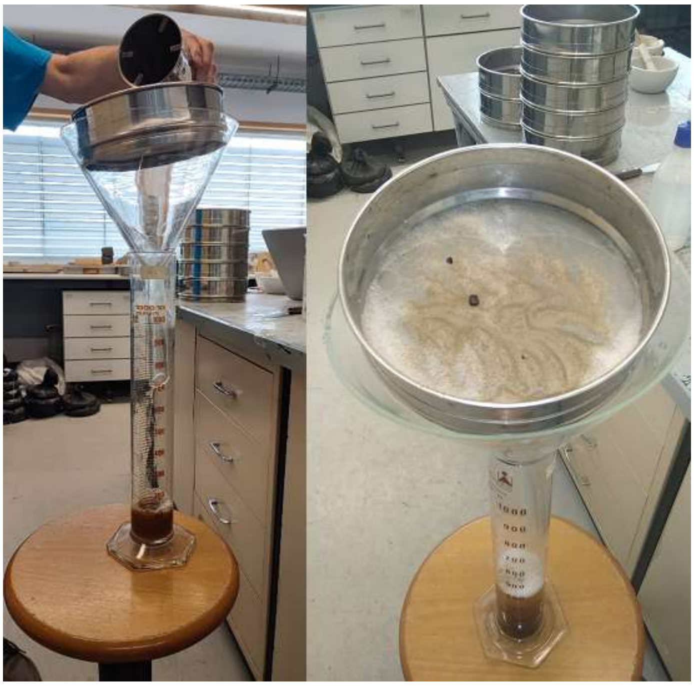

Figure 3.14 - Washing of the initial mass of the sample

After the washing process it can be said that two phases have been taken: first one concerning the finer grains and subsequently another concerning the coarser grains.

After identifying the reagents and utensils to be used, it is necessary to proceed to the meniscus correction. This step is important because when you put the densimeter in the measuring cylinder, the solution inside the cylinder automatically rises, and if you do not make the corrections, you will obtain a wrong grain size curve.

Another important aspect, to be taken into consideration, is the preparation of the sample that according to LNEC specification E 195 is necessary to have a certain amount of material to perform the tests. Which did not happen.

So related to the finer grains, the samples were shaken in the measuring cylinders, after the concentration was uniform and the sediment started to accumulate at the bottom of the cylinders. The heights were recorded after 1 min, 2 min, 5 min, 15min 30 min 60 min 250 min 1440 min (corresponding to one day) and 2880 min (corresponding to two days). As well the temperature. This is necessary because asymmetric heating of the suspension causes convection currents which affect the sedimentation results (Figure 3.15). In the annex C is possible to find the tables related to each sample related to times recorded.

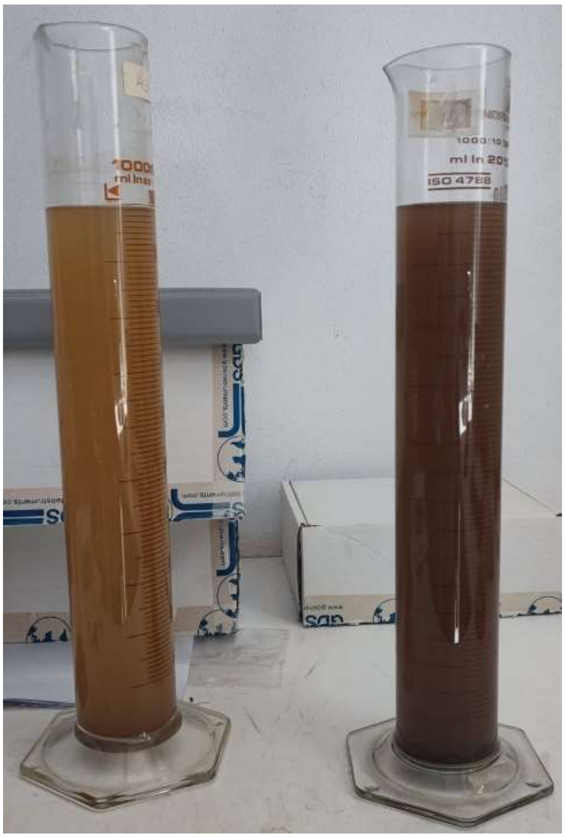

Figure 3.15 - Both of the samples in the phase of sedimentation

At first glance, sample A was found to be light-coloured, odourless and non-foaming. On the other hand, sample B was darker in colour, had a strong smell and when the cylinder was shaken it showed that it foamed. These factors in sample B indicate that the soil layer had organic matter.

In parallel with sedimentation, the two samples collected were sieved. The sieving process started with a nº10 sieve, that is with an opening of 2.00 mm, followed by the following sieves (in descending order) 0.850 mm (nº 20), 0.425 mm (nº 40), 0.250 mm (nº 60), 0.150 mm (nº 140) and 0.075 mm (nº 200). This process makes it possible to separate the grains from the coarser part of the sample (Figure 3.16). It is possible to get an idea, with this stage of the process, what type of soil is existent, as there is a large amount of material in both samples on the 0.250mm sieve as it can be seen in the figure 3.17.

Figure 3.16 - Set of sieves used

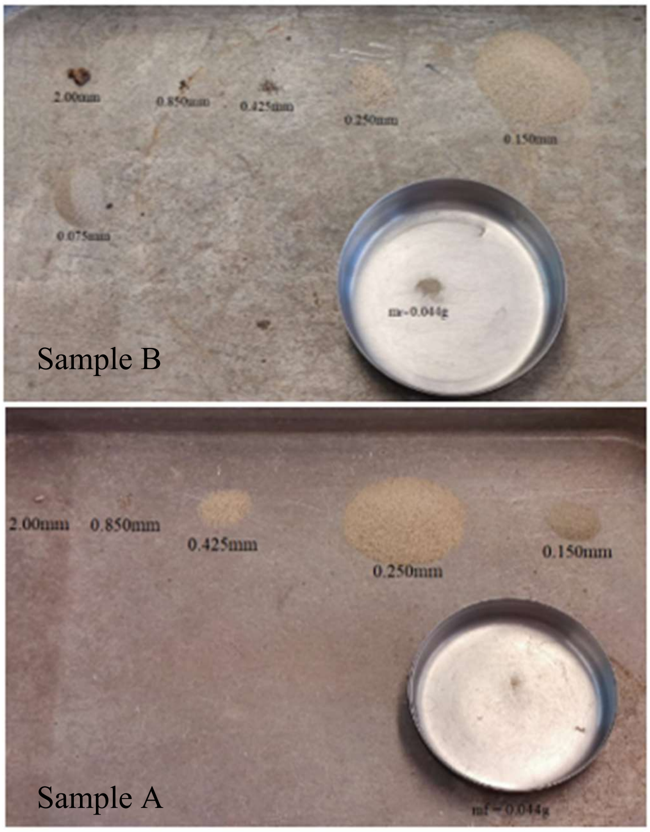

Figure 3.17 - Fractions of the soil from samples A and B collected from the city of Limmen

A sieve curve will be obtained which will indicate the percentages of silt, clay and sand. The sieve size curve is the graphical representation of the granulometric composition and is obtained by two experimental processes: sieving for the coarse fraction and sedimentation for the finer fraction. With this information along with the Ferret triangle - which is considered to be one of the simplest classifications and is based on the constituent fractions of a soil - it was possible to classify the type of soil.

The granulometric analysis according to LNEC specification E196 -1966 was performed as follows, for both samples:

The first part of this analysis begins with coarse sieving, i.e., the fraction of the material retained on the 2mm sieve. The material, due to the fact of being very fine, was not retained on the sieve. The second part of the procedure is the fraction that passed through the 2mm. The mass of the material that passed the sieve 10, was oven-dried - (M_d). The fine sieving carried out, getting the weight of the retained material (M_r). The remaining material (M_s) was used for sedimentation (Equation 1):

$$M_d - \sum M_r = M_s \qquad (1)$$

The percentage of retain material (M_{Rt}) was calculated using the following expression (2):

$$\frac{M_r * 100}{Md} = M_{Rt} \qquad (2)$$

The cumulative percentage of retained material is given by the sum of the percentage of retained material expressed by equation (3):

$$\sum M_{Rt} \qquad (3)$$

The cumulative percentage of passing materials is given by equation (4):

$$100 - \sum M_{Rt} \qquad (4)$$

With this information, it was possible to obtain table 3.1 from which the values of the accumulated percentage of passes were used to obtain the granulometric curve figure 3.18. The exact procedure was taken to sample B.

Table 3.1 - Values of material for sample A

Nº Sieve	Grid	Weight of the retained material	% Retains	% Cumulative retained material	%Cumulative Passing Material
20	0.850	0.038	0.15	0.15	99.85
40	0.425	0.019	0.08	0.23	99.77
60	0.250	1.104	4.42	4.65	95.35
100	0.150	22.445	89.87	94.52	5.48
200	0.075	1.317	5.27	99.79	0.21

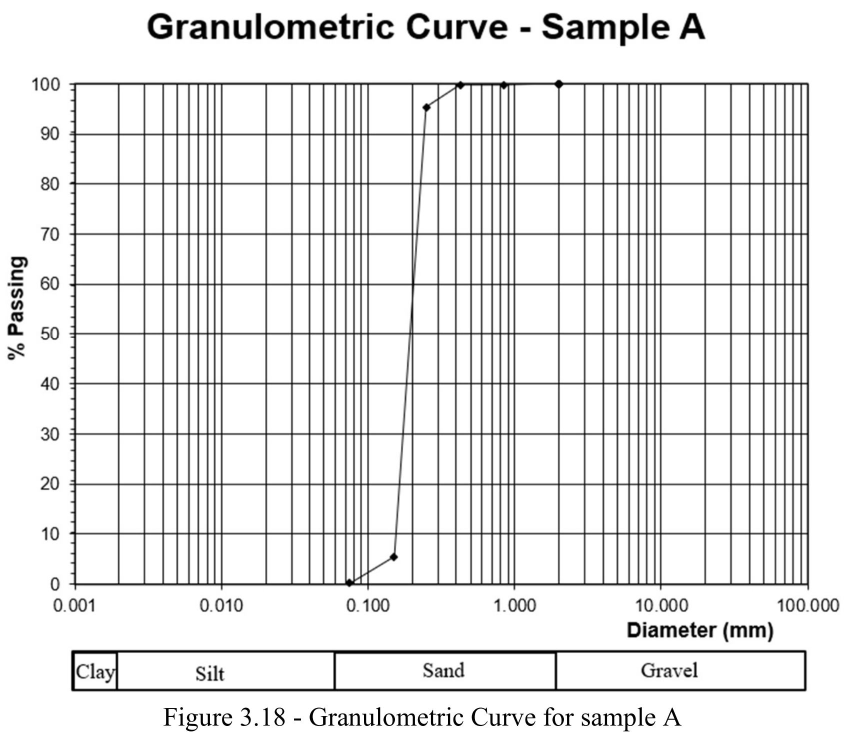

Figure 3.18 - Granulometric Curve for sample A

4 RESULTS AND DISCUSSION

4.1 Introduction

The present chapter will present the data collected on the water wall as well as on the swales. Regarding the Water Wall, it will be presented information concerning water quality that was inside the pipes. Regarding the swales, all data in this chapter were provided by Professor Floris and his research team and refer only to the tests carried out in Groningen.

This chapter attempts to show how these two infrastructures can be of added value in assisting with the management of water in urban areas, as their applicability in cities can help in the prevention of certain problems as mentioned in chapter 3.3 and 3.4 and in the treatment of runoff water.

4.2 Water wall

This section will focus on the WW. Certain conditions under which the tests were carried out may affect the results obtained. In particular, the weather conditions, as the tests took place in early May, when temperatures are already higher.

Since the water wall is relatively new there is no maintenance plan yet. The maintenance procedure is relatively basic: in autumn the water drains are opened to empty the pipes. This happens because in winter temperatures are lower, so as not to freeze and eventually break the pipes, the taps are opened. At this time of year, the rain itself irrigates. Near spring, the taps are closed again and the water in the pipes is used in summer.

Finally, the water storage in the pipes is the result of water flowing from surfaces (in this case the roof); when the pipes fill up, the water is directed elsewhere. This intended to indicate that the water present in the tubes could have been there for some time.

For these reasons tests were carried out to understand to what extent this water could or could not be used for irrigation. The water was taken from an exit (on the WW) about one meter height above ground level.

4.2.1 Quality of the water in the pipes

It should be noted that the water is stored in a completely closed Polyvinyl chloride (PVC) pipe. These are located outside the building, so they are exposed to temperature differences. Water quality in the tubes was assessed at the beginning of May. Specifically on the 6th. The environment temperatures were between 18ºC and 19ºC and it was verified that the sky was cloudy.

The tests started by analyzing the organoleptic parameters of the water. It was odorless, without any type of visible residue (to the naked eye), although it was difficult to notice the water had a practically nil yellow coloration and was insipid. As can be seen in figure 4.1:

Figure 4.1 - Collected water from the WW in Zernike Campus - Groningen

Regarding to physical-chemical quality of rainwater, the tests carried out using water quality tapes, were compiled and gave rise to data in table 4.1:

Table 4.1 - Results obtained from water quality tapes for the analysis of the water collected from the WW

Tests:	Concentration
Nitrate	]1, 2] ppm
Nitrite	0 ppm
Phosphate	-
Iron	]0; 0.15] ppm
Chlorine	0 ppm
Hardness	25 ppm
Alkalinity	]0 ; 40] ppm
pH	6.3

The water that is stored in the pipes can be used for various purposes. Depending on the intended uses, it is necessary to follow the water quality standards.

According to COUNCIL DIRECTIVE 98/83/EC of 3 November 1998 on the quality of water intended for human consumption: considers that, measures must be taken to ensure good quality in surface waters and groundwaters in order to ensure standards of quality standards for drinking water (*EUR-Lex - 31998L0083 - EN - EUR-Lex*, 1998.).

Table 4.1 presents results for the water quality, assessed using tapes. The nitrate value in mg/L is]0.99; 1.99] which is below the recommended value for irrigation water: 50 mg/L according to Decree-Law Nº 236/98 of 1st August of the Ministry of Environment, (1998).

The pH has a value of 6.3 which is lower than the recommended value for irrigation. However according to the maximum permissible value stated in Decree-Law Nº 236/98 of 1st August of the Ministry of Environment, (1998) the pH can be within the following limit: (4.5 - 9.0). So, the observed value of the water wall is within the limits. The parameter involving iron varied between]0, 0.149] mg/L. The value for iron is 5 mg/L, which is within the limits.

About the parameter related to phosphate, the tapes did not obtain any data of any kind according to the water test tapes. And the nitrite and chlorine concentrations were zero.

Although this was a very limited study, on average, rainwater is suitable to be used for a variety of non-potable purposes, according to the parametric limits from the Decree-Law Nº 236/98 of 1 August, this water could be suitable for irrigation.

The water present in the water wall is not fit for human consumption. Even if treatments such as filtration and sedimentation (low-cost treatments) were carried out, there was always a risk of Legionella or other diseases.

Climate change is stressing irrigation water sources, increasing the need to evaluate alternative waters such as harvested rainwater (Morgado et al., 2022). The water wall system is an alternative to the use of non-potable water, meaning that instead of using potable water for irrigation it is used non-potable water.

To address the noted microbial risks from harvested rainwater, a few studies have assessed the effectiveness of a variety of treatment systems, including first flush systems - a system that collects the first gallons of runoff water at the beginning of a rainfall event (Gikas & Tsihrintzis, 2012). In figure 4.2 is possible to see a scheme of a first-flush system.

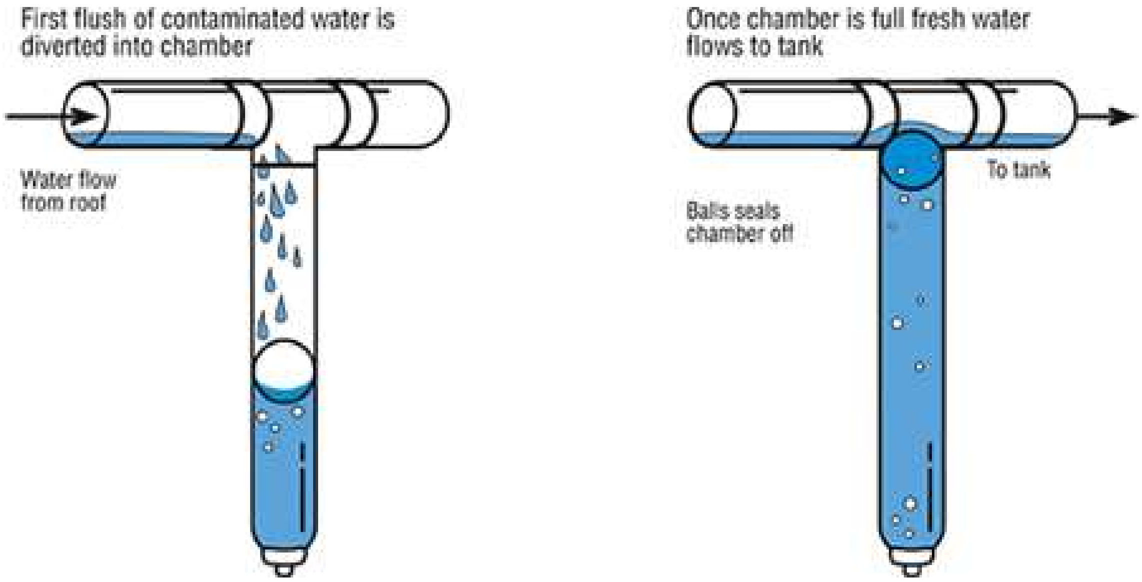

Figure 4.2 - Scheme of a first-flust system (Source: RainBank Rainwater systems)

4.2.2 Runoff coefficient

The main function of the water wall is the reuse of rainwater for other purposes. For that reason, the water wall is a rainwater harvesting system (in Portuguese SAAP). In addition to this, the water wall brings other benefits, such as reducing the amount of water that flows from roofs, terraces and other surfaces. As a result, less water flows onto roads, helping to minimise flooding in urban areas.

Given the nature of the rainwater collection surface in the present case study, the runoff coefficient has to be assessed to have better insight into runoff volumes. In the absence of data for the calculation of the runoff coefficient (procedure described in subchapter 3.3.2), the runoff coefficient will be adopted considering the ANQIP technical specification, ETA 0701 (version 7).

The surface that drains the water into the water wall pipes is an impermeable roof. (Surface of metal). In terms of values, this flow coefficient can be considered a value larger than 0.9.

4.3 Swales

This section presents various types of information: infiltration of water in the soil, soil contamination by heavy metals and the type of soil. All the data related to the infiltration of water and contamination of the soil by heavy metals presented have been provided by Professor Floris Boogaard and his research team from HUAS. Data about the type of the soil was determined in DEC.

The process presented in subchapter 3.3, to execute the tests on the swales was carried out in Limmen city. However, the results that will be presented, refer to the city of Groningen, since the process applied was the same.

In the city of Groningen, the tests were carried out at two locations, therefore data for two swales are available. So, figure 4.3 illustrates the first location where the infiltration test was carried out in Paddepoel, as well as the resulting graphs - Figure 4.4. The second place where the same procedure was performed can be seen in figure 4.5 alongside with the respective graph, showing the curve that result from the infiltration test figure 4.6.

Figure 4.3 - View of the swale infiltration test that was carried out in Paddepoel in Groningen, The Netherlands (Source: ClimateScan)

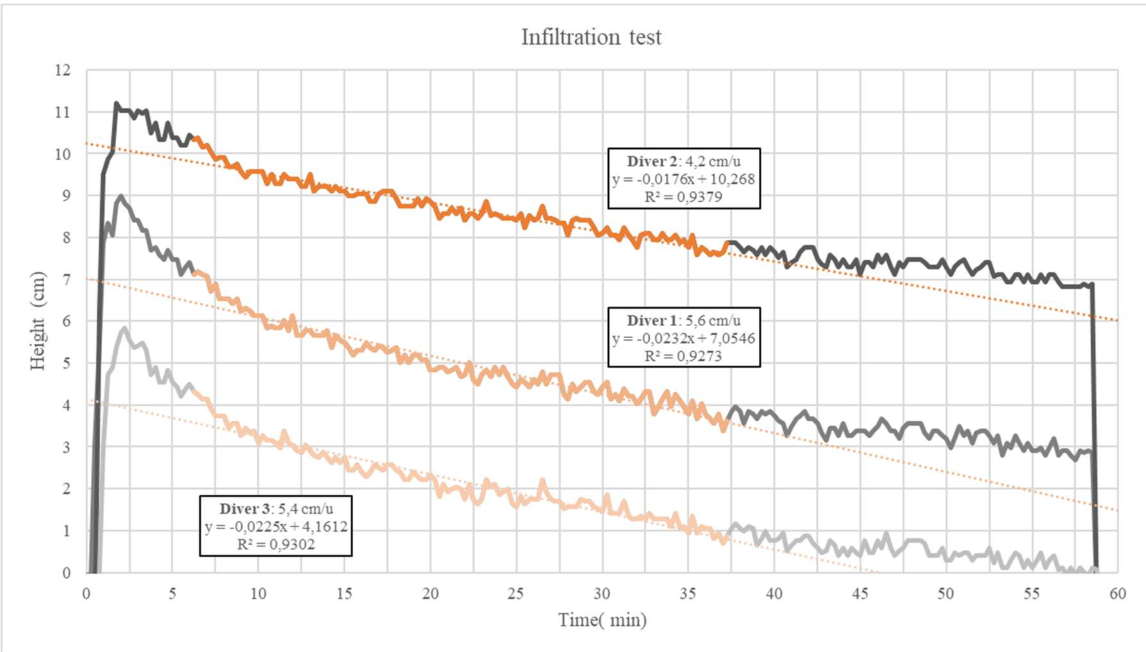

Figure 4.4 - Curve resulting from the swale infiltration test in Paddepoel (Source: HUAS).

In figure 4.4 although the height of the water in the beginning is different, it is possible to see that for the three divers under normal conditions show similar patterns.

The three divers we're located at the same place, and it is possible to observe that the curves are almost straight, they show a bit of curve and also that with the gradual increase in time we have lower infiltration rates.

Between the minutes 55 and 60 the graphic shows a vertical line. The vertical line is due to the fact that the test has been stopped

Figure 4.5 - Place where the infiltration test was carried out in the United Care Products (UCP) in the city of Groningen (Source: ClimateScan)

Figure 4.6 shows a similar curve to that in figure 4.4, however, this swale emptied almost completely; in other words, almost all the water has seeped through. For both cases a linear model was used in an attempt to model the infiltration over a period of time. The parameters in the figure refer to the height of the water decreasing as a function of the time that passes.

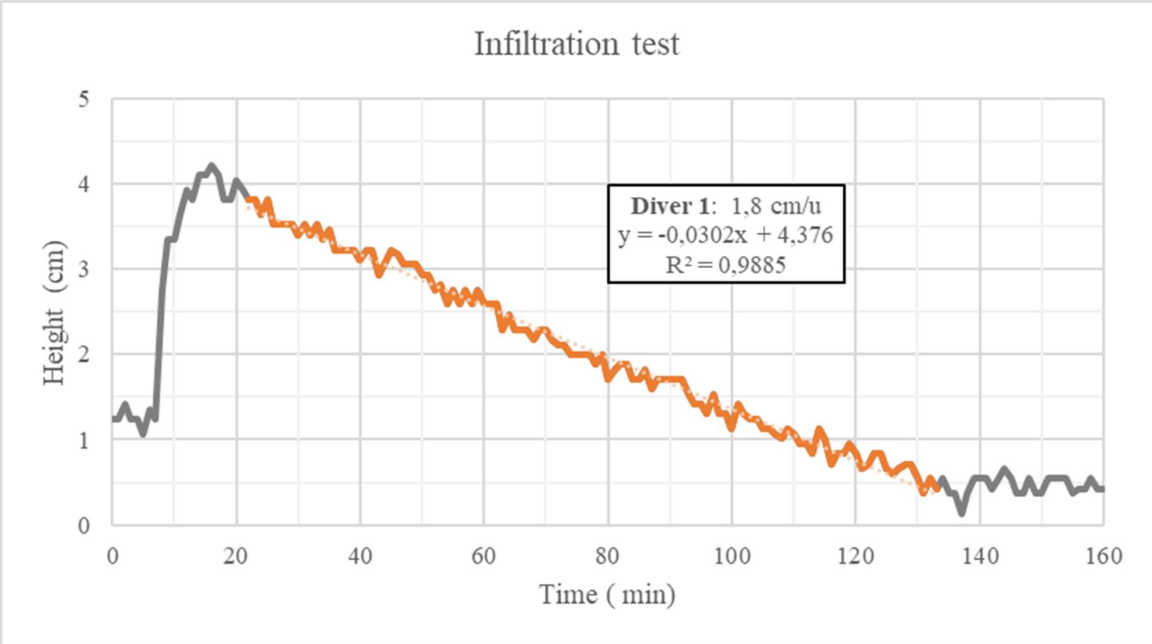

Figure 4.6 - Curve resulting from the swale infiltration test in the UCP (Source: HUAS)

In the graphic represented in figure 4.4, the correlations vary between 0.92 and 0.93. On the other hand, graph in figure 4.6 shows a correlation of 0.98. Correlation is how it fits into a straight line, with the perfect fit corresponding to a correlation value of 1. If all the measures do not fit the line correlation is low (going to 0), and here it is noted that the correlations are very close to 1. The closer this number is to 1, means that better the formula represents the data, which is good.

In both figures we can see that the tests show that when rainfall occurs the behaviour of the infiltration in the ditch shown graphically is a linear straight line. This behaviour can be explained by the type of soil present. Infiltration happens in two phases: during the first one the water will fill the holes and spaces that exist on the top layers of the soil (like a sponge). On the second phase, it starts the infiltration into the deeper soil. The fact that the graph is almost a linear straight line depends on the first phase of infiltration, because the water disappears into the empty spaces.

This information is in accordance with the results obtained since it is possible to verify that in the places where the tests were carried out there was a rapid infiltration of water by the soils. Meaning that, for the graphic in figure 4.4 the time started counting when the water height reached 10 cm after about an hour it was clear that the water had infiltrated. On the second location illustrated by the graphic in figure 4.6 it took around 2 hours to start the water dropping from 4cm high to almost 0 cm. This behaviour can happen due to the fact that the swales might already have stored some water, making the infiltration time bigger or shorter.

To conclude, swales are usually used as Sustainable Urban Drainage Systems (SuDS) that can reduce highest flow, collect and retain water and improve groundwater recharge so it's possible to accomplish, the swale because of their unique characteristics, it helps minimizes overflow preventing flooding and it helps improving surface water quality.

As previously mentioned, in addition to the infiltration tests, soil contamination tests were carried out. Table 4.2 presents the metals that were tested and the limit values that are the desirable level that the city of Groningen would like to stay under.

The intervention value is a level that once is passed, an intervention must be taken. Intervention in this case means that is necessary to remove the polluted soil and replacing it with fresh soil, to keep measure safe for children and animals.

Table 4.2 - Dutch threshold values for heavy metals in soil (Source: Venvik & Boogaard, 2020)

Metal type	Target value (mg/kg)	Intervention value (mg/kg)
Lead	85	530
Zinc	140	720
Cooper	36	190

Following the information given in Table 4.2, the concentrations of the different heavy metals were measured in the two study sites, from which the following two graphs were obtained. In the graph in figure 4.7 it is possible to see three lines related to the intervention value and three dashed lines and several points corresponding to location and presence of each element. The values are the same presented in table 4.2.

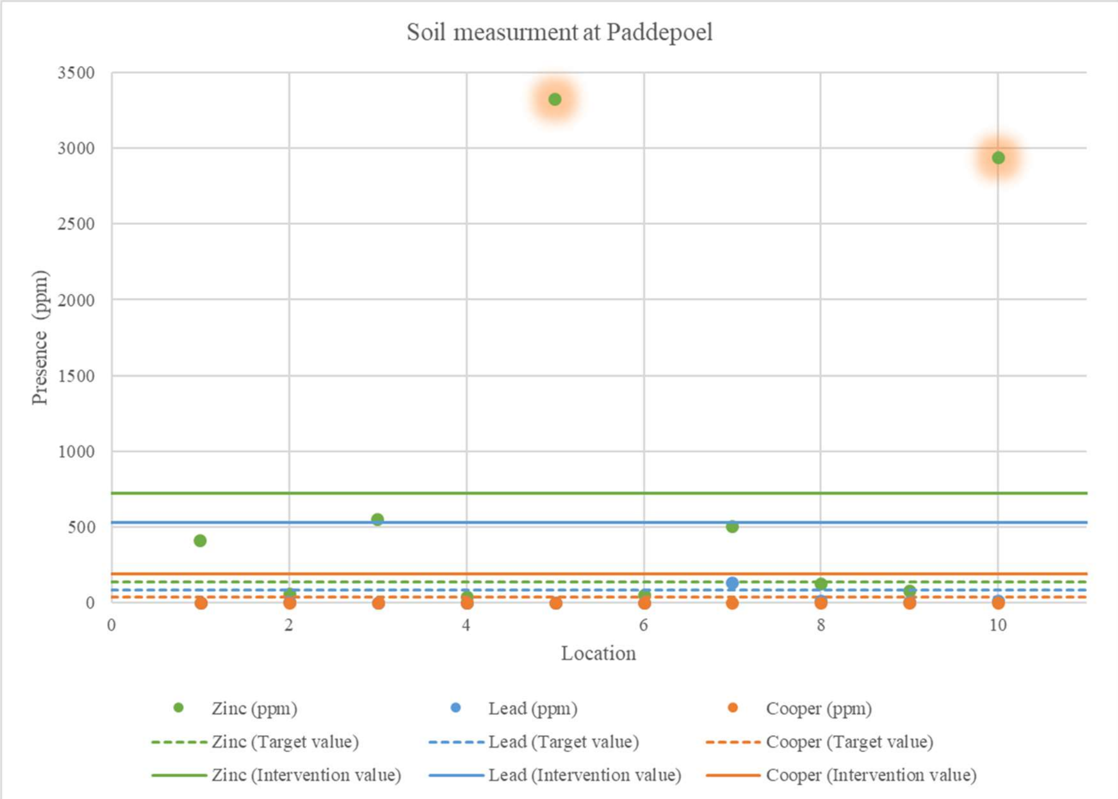

Figure 4.7- Soil contamination measurements (Paddepoel in city of Groningen)

The dots are the concentrations of heavy metals. It is clearly that zinc is the element with the highest presence reaching values in order 3320 ppm and 2939 ppm (in annex A it is possible to find the values of each of the points marked on both graphs) by going beyond the intervention value line and the target value line on location 5 and 10. Only on location 2, 4, 6 and 9 the values are below the target value line and the intervention value line.

On the other side, both elements, cooper and lead they remain below the intervention value. However, it is still possible to see that the element Lead in location 7 is above the target value. This means that it is necessary to act in that location in order to minimize the amount of zinc present at these locations by removing the polluted soil

In the graph presented in figure 4.8, the same "basis" is found. It is interesting and it can be seen that none of the elements that are being studyed reaches the intervention values or the target values

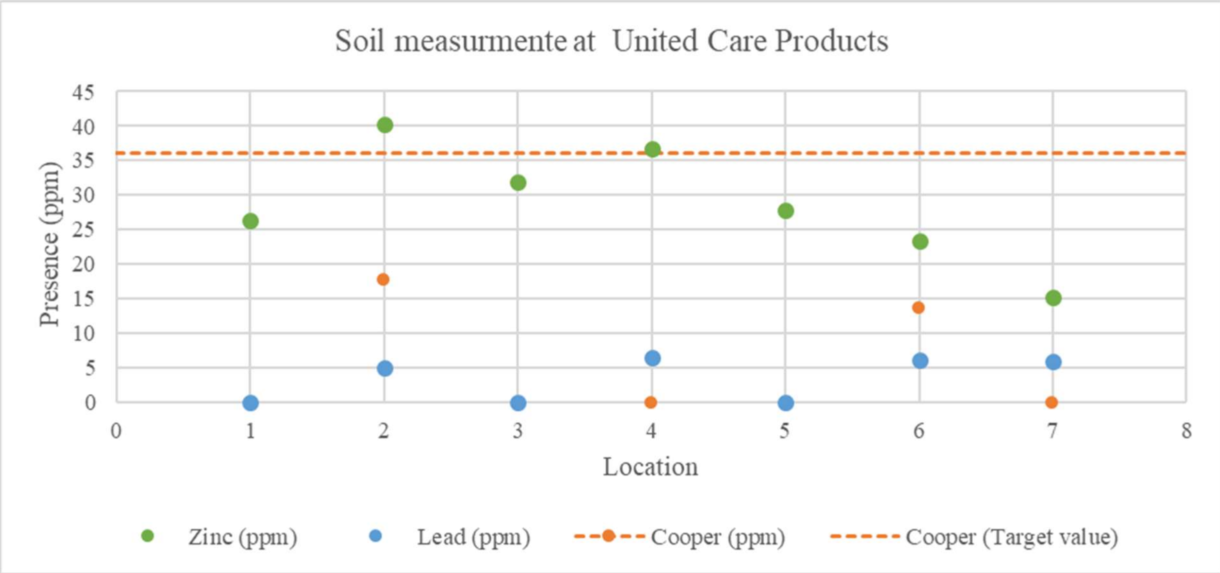

Figure 4.8 - Soil contamination measurements (UCP)

Despite not exceeding any of the limits mentioned in Table 4.2. Zinc is the element that as more presence than the others although it does not exceed the target or intervention value. The presence of Lead and Cooper in locations like 1, 3, 4, 5 and 7 is below of the limit of detection (LOD).

Comparing the data from both of the locations where the tests were carried out the UCP area as much less presence of Zinc than the place in Paddepoel. However, despite being a low value (17.66 ppm) when comparing both of the places, UCP has more presence of cooper than Paddepoel.

It can be concluded that the soils that are closer to the roads or that are near to places where traffic circulates will have more predisposition to become contaminated. In the graphs that were presented is possible to confirm the presence of this elements since their locations is in urban areas.

4.4 Soil type analysis

In addition to this, it is important to mention the soils samples that were analysed. The type of soil can also have an influence on the way in which it infiltrates water; so, it is important to refer that the samples' analysis indicated that the soils were sandy. Also, they show presence of certain materials that were found in the samples: Lightweight expanded clay aggregate (in Portuguese LECA).

This material can alter the soil mechanics. In the sample collected the leca had about 2 to 4mm it is used to stabilise the soil, when blended with other growing mediums such as soil and peat, it can improve drainage, retain water during periods of droughts. This explain the presence of peat in the deeper layers but also shows that this soil has been 'treated' for this purpose.

In this way it is necessary to carry out tests to understand the condition of the soils so that, if necessary, they can be treated in such a way that when there is heavy rainfall, they are prepared to drain the water. Despite these mechanisms it can be found other drainage conditions as mentioned before, in sub chapter 3.3 figure 3.5. Where is possible to see a scheme explaining how these system works. If a heavy rainfall happens the system is prepared with slokop (glutton) which is only used when the swale is full of water. In those cases, the water flows through that infrastructure.

Regarding the type of soil, firstly it was possible to conclude that the metre of soil removed had 3 different layers. Further on based on the data that was obtained and which is illustrated in table 3.1, in the chapter on materials and methods; for each sample, the respective granulometric curve was obtained, they can be both seen in the annex D.

The information from the graphics along with the Ferret's triangle showed the following results: In the sample A (green dot) the total percentages of silt and clay is about 8% and the percentage of sand is 92%. Regarding to sample B (red dot), silt + clay gave a total of approximately 6% and sand had a percentage of 94%.

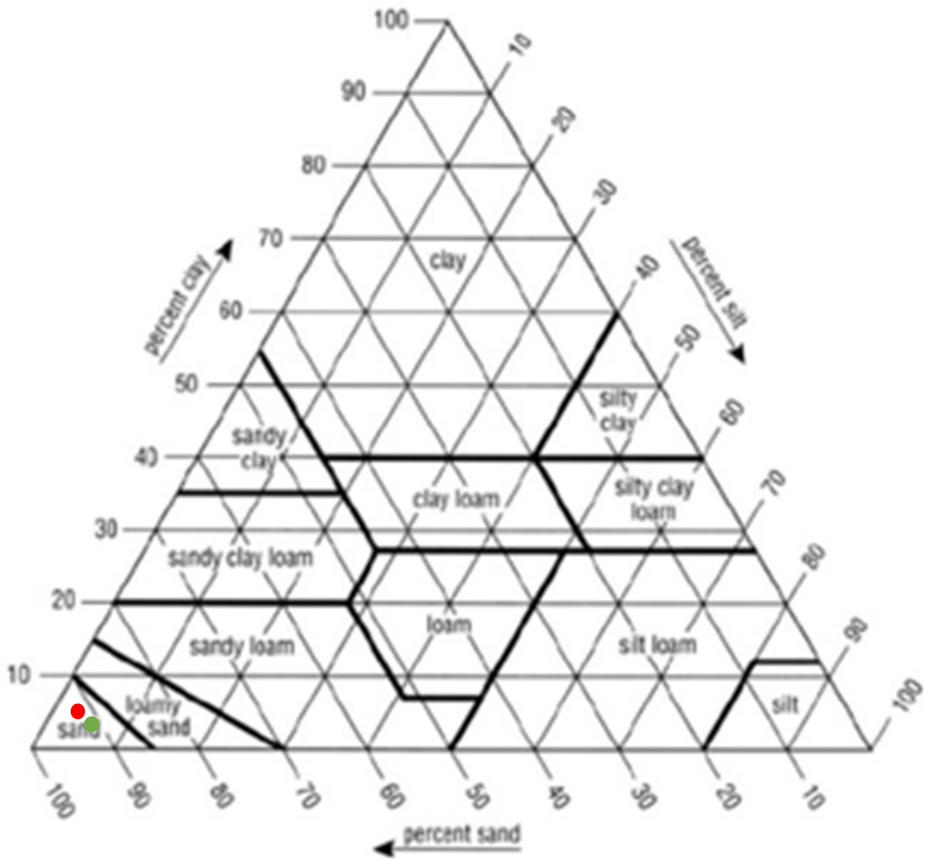

Figure 4.9 - Ferret's triangle with sample A and B marked. These soil samples were collected in Limmen, in The Netherlands.

A soil to be classified as being a sandy soil needs to have more than 80% of sand fraction. By appealing to the two samples that were taken from the two top layers and with the help of the Ferret's triangle it was possible to classify the soil as being sandy, for both samples.

5 PILOT PROJECT PROPOSAL

Water is indeed an important natural resource and a fundamental component of the environment, and as such it must be protected, preserved and improved. It is essential that its quality be monitored according to its type of use.

As such, the main core of the following proposal is to promote the creation of green infrastructures whose aim is to improve stormwater management in urban environments, in order to solve problems such as the lack of green spaces in urban areas that help decrease surface runoff and consequently alleviate urban flooding issues.

Clearly, solutions based on nature imply other benefits, regarding biodiversity and people's quality of life.

In this way, it is proposed the installation of a water wall in the Civil Engineering Department (DEC in Portuguese), with coordinates 40.18559º N, 8.41524º W, at the Faculty of Sciences and Technology of the University of Coimbra (FCTUC in Portuguese), as a pilot green infrastructure, whose construction and maintenance will not have high costs. The idea would be to create the largest possible water wall with a height equivalent to that of the department building by incorporating it into the DEC infrastructure. It is also proposed the implementation of a swale to be located also at the same FCTUC site, at the location with coordinates 40.186547º N, 8.413484º W. This second proposal will be explained further on.

This proposal takes into consideration what has been witnessed by the author on the Zernike Campus during the stay in Groningen. For this reason, this project proposal may leave out certain project details that may be important for its implementation. Further studies and information should be collected as well as direct contact with the infrastructure in order to execute this idea.

i. WaterWall

In general terms, and in an attempt to follow the ideals presented in this dissertation, the creation of this infrastructure proposes the following:

- Adoption of an urban drainage structure to improve stormwater management in urban areas

- Reduction in the formation of pools of water that occur after heavy rainfall, in the parking lot adjacent to the DEC building

- Adding value to the DEC building itself

- Promoting more sustainable and user-friendly practices regarding water use and management

- Water storage

In order to better clarify what is proposed here and to make the treatment of the information more efficient, a scheme of the water wall proposed is presented in figure 5.1, using the Auto Cad tool (the draw is not to scale and is purely illustrative, to give an idea of the final design).

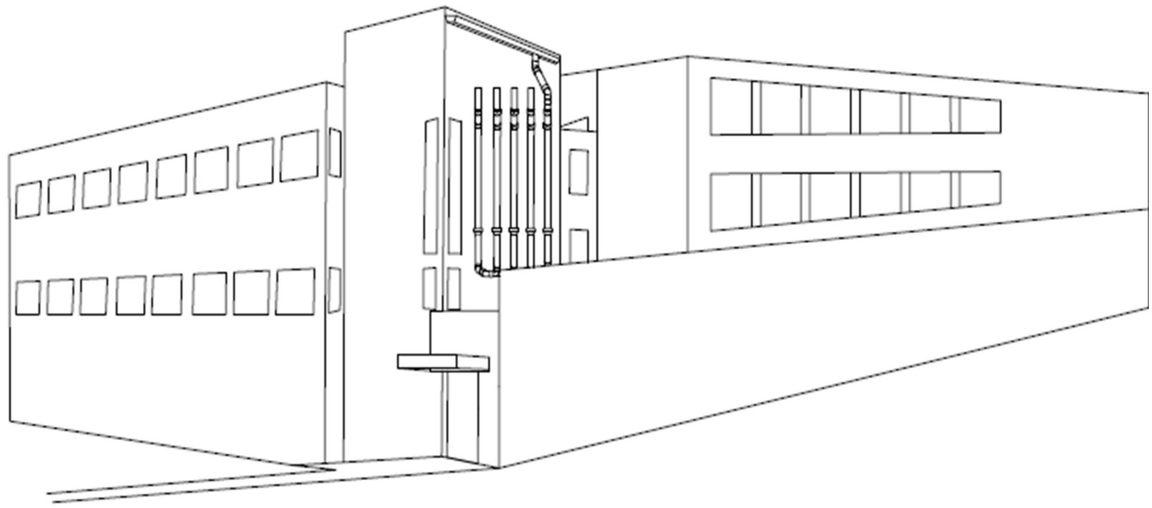

Figure 5.1 - Proposal of construction of a Water Wall on the building of the Department of Civil Engineering (FCTUC), in Coimbra, Portugal.

The selection of the location is the result of a previous study by Sousa (2015) that, in a way, also aimed at rainwater management, which indicated an area on the roof of the department building adjacent to the Laboratory of Hydraulics, Water Resources and Environment. This place already has a rainwater collection pipe which could be used as a connection to the water wall.

It is also proposed, as constructive criticism of the existing WW, a system that would have to be thought of to allow the visualisation of the quantity and height of the water present in the pipes.

In addition to this, and in a secondary phase, the addition of vegetation, using plants that are characteristic of the area, around the pipes would make it possible also to create an infrastructure with two functions and not only one: create a system that helps managing water in urban areas, and helps promoting biodiversity.

Oher important aspect to be mentioned is the roof top. Quoting (Sousa, 2015) it is necessary to characterize the water collection surface since it influences the utilization of rainwater. The roof is flat and covered with a layer of gravel that is placed on top of a layer of needled geotextile, followed by another layer of roof mate (extruded polystyrene), a second layer of geotextile and finally the waterproofing layer.

The study by Sousa, (2015) estimated a runoff coefficient of 0.6, based on experimental data. This value is in accordance with the technical specification of ANQIP ETA 0701. This specification recommends a coefficient of 0.6 values for flat roofs with gravel (which is the case of the roof).

It is also proposed that this WW would allow for a total water storage of about 500 L, considering it formed by 5 pipes of 5 m height and a diameter of 160 mm (similar to the WW in Groningen). The existing cover rainwater harvesting area is of around 25.22 m^2, which was used to collect water for the water wall. The amount of effective precipitation is about 19.8 mm, to make a total of 500 L and using the coverage area. Assuming a runoff coefficient of 0.6, the harvest of the calculated rainwater volume requires a total rainfall depth of 33 mm.

Knowledge of the rainfall regime at the study site is indispensable in order to the rainwater harvest potential, which determines the sizing of the rainwater harvesting system. For Coimbra, the annual precipitation is shown in figure 5.2 and the average monthly precipitation is shown in figure 5.3, for the period 1941-2012. The most recent precipitation data were not available, so the data reported by Sousa (2015) and IPMA (in portuguese Instituto Português do Mar e da Atmosfera) are presented .

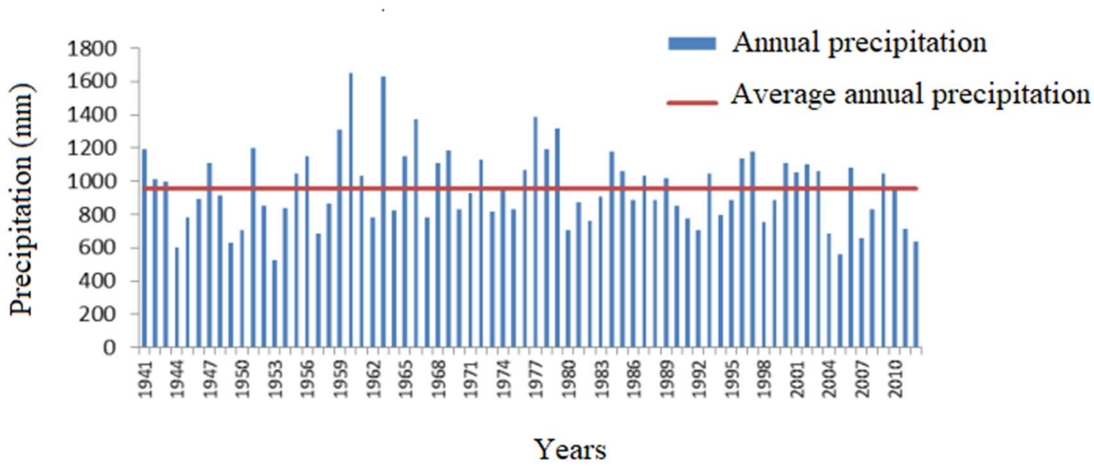

Figure 5.2 - Annual precipitation and mean annual precipitation in Coimbra from 1941 to 2012

In the period represented in figure 5.2, the average annual rainfall in Coimbra was 959.5 mm and the minimum and maximum annual precipitation recorded were, respectively, 524.2 mm and 1651.4 mm.

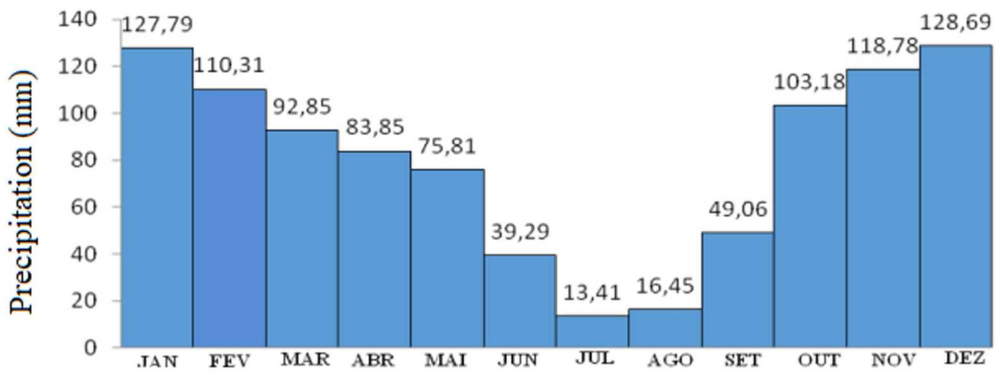

Figure 5.3 - Average monthly precipitation in Coimbra from 1941 to 2012

It should be noted in figure 5.3 that January and December are, on average, the months with the highest precipitation and July is the month with the lowest precipitation.

The Portuguese territory is divided into 3 rainfall regions, having developed for each region curves of intensity, duration and frequency (IDF) with return periods from 2 to 100 years.

An IDF curve is the graphical representation of the probability that a given average rainfall intensity may occur. The IDF curves establish the relationship between rainfall intensity precipitation and duration of precipitation, as a function of the return period. The parameters that make up the IDF curves are the intensity in mm/h, duration and the frequency.

Coimbra is located in rainfall region A; in figure 5.4 are represented the IDF curves for region A.

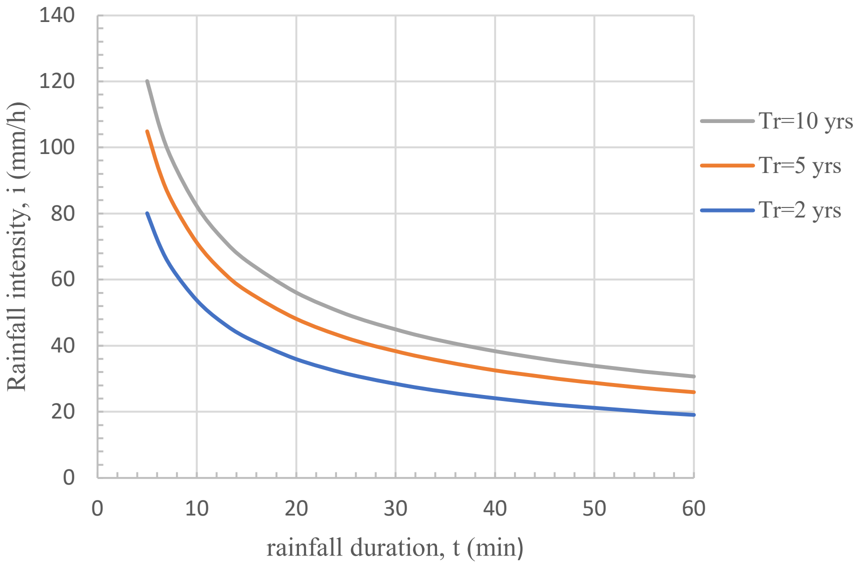

Figure 5.4 - IDF curves zone A, Portugal

With this infrastructure it will be possible to irrigate and cleaning purposes, i.e., never for human consumption. This way it is possible to give a "second life" without creating water waste and without wasting drinking water. The use of rainwater for undrinkable purposes in urban areas seeks the reduction of potable water consumption, which is needed since drinking water is becoming increasingly scarce.

Presently, Portugal is facing a severe drought situation that has already imposed several restrictions to different water uses, to safeguard that the supply of water for human consumption is not at risk. Since climate change scenarios for this geography predict the aggravation of drought episodes, it is important to consider different measures in water management to help dealing with such type of events and conditions.

ii. Swale

Urban areas often suffer from water management problems. Peak discharges in drainage systems – caused by a lot of water that enters the sewer system in a short period of time - are common. Some of the water originates from the various surfaces that occur in an urban area: roofs, streets, terraces. There is a difficulty for the water to infiltrate into the ground and as such it is directed into a sewer system (Boogaard & Wentink, 2005).

The functioning of the swale system (section 3.4 from chapter 3) involves certain urban planning, i.e., in urban areas rainwater is collected from the roofs or streets into the sewer system. In the case of swales, a gutter is constructed through which the water from the roof's flows.

Swales do not have a concrete form. Variations in their shape, size and vegetation allow them to be integrated into the neighbourhood. Due to that it is possible to create various types of swales.

Figure 5.5 indicates the location the swale, in yellow, that is proposed in this study to be built in Campus II of the University of Coimbra, as well as the corresponding drainage area represented by the blue arrows.

Figure 5.5 - Draw illustrating the location of the swale and drainage area (Source: Google earth), in Campus II of the University of Coimbra.

Using the Google Earth tool, the area that drains into the drainage element under study was drawn, figure 5.6. An area of approximately 34779m ^{2} was obtained.

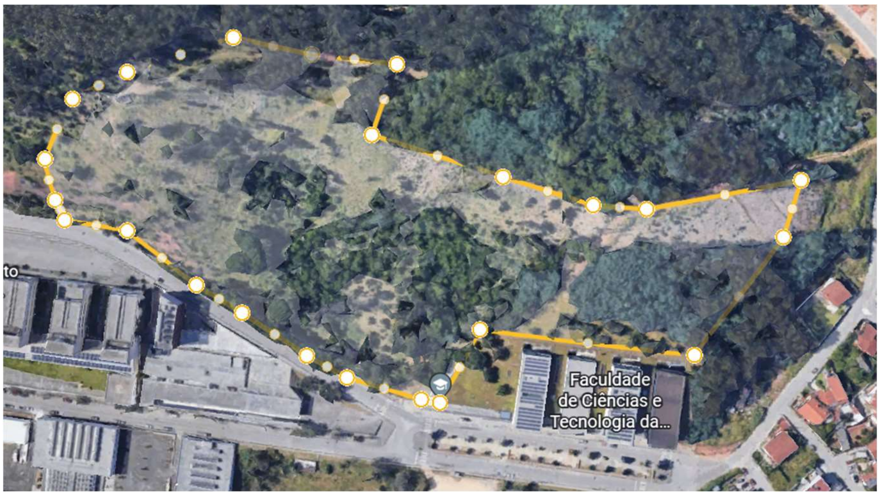

Figure 5.6 - Schematic representation of the swale drainage area (Source: Google earth) superimposed on a view of the Campus II of the University of Coimbra

As it has already been mentioned, no rule determines that a swale has a certain shape. It must however have certain characteristics that allow it to be built. The site (figure 5.5) referred represents optimal conditions for building a swale because of the characteristics of the spot: it is close to a slope, buildings and traffic paths.

For these reasons this is a suitable choice for a swale. There is also a ditch on the site that will help channel the water to the swale, as it is shown in figure 5.7. In addition to this, the site has a drainage area large enough for the swale construction (Figure 5.8).

Figure 5.7 - Place of the swale and drainage ditches at FCTUC

The design of the swale is purely illustrative and serves only to represent the place to be built as well as the shape it should have, considering the place where it is located, in order to make the best use of the site (figure 5.5).

In the case of the project proposal, a swale of about 30 m^2 could be built in that area (3 m wide and 10 m long). Assuming that the height of the swale is about 1.50 m from the road to the base of the swale it's possible calculate the volume that it could hold.

Imagining a cross-section on the swale, it is easy to see that it has a trapezoid shape. So, the volume for the swale would be around 52,5m^3. This means that the swale would have a storage capacity of 52500 L of water.

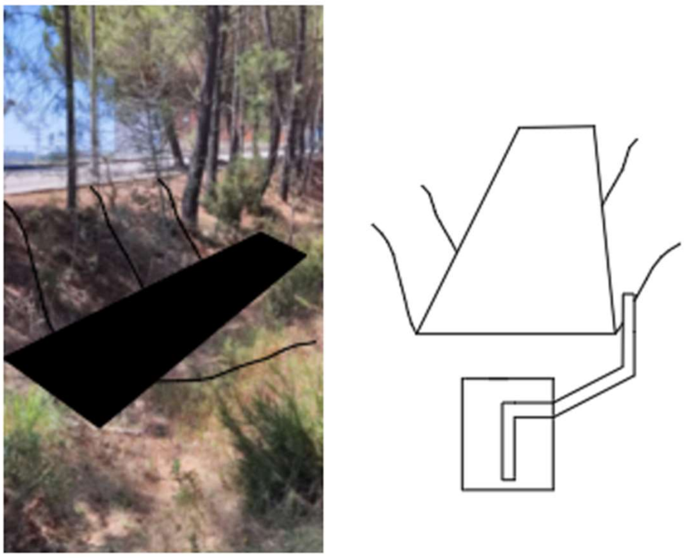

Figure 5.8 - Scheme of the swale in FCTUC

The water that falls on the road itself is routed into the gutter. The gutter helps transport the water into the swale.

Another issue that should be kept in mind while building the structure of the swale is the type of soil. The soil has to be worked in order to have characteristics that allow a good capacity to store water. In this sense, referencing (Boogaard et al., 2006) the upper layer should have a soil that allows the grass to develop (also to become more resistant to walk on).

Below ground there should be a trench into which LECA is placed and which forms an aggregate. This should be wrapped by a geotextile so that water can pass through but prevent debris. A drain should also be included to help water infiltrate and connect to a more permeable soil.

The construction of a swale brings benefits such as:

- Creation of more green spaces
- Creation of leisure areas
- It acts as a strainer, leading to a first 'cleaning' of the water
- Increase of permeable areas
- Reduction of flooding

6 FINAL CONSIDERATIONS

Increased urbanisation accompanied by disorderly construction has led often to the destruction of green areas replaced by asphalt and cement, creating soil sealing. This has led to the degradation of landscapes as well as ecosystems, which consequently had a negative impact on the services they provide. Conflicts caused between the urban system and nature have led to an increase in flooding, a loss of green areas, an increase in air pollution and many others. This increase is amplified by climate change that make cities even more vulnerable.

Therefore, the construction of green infrastructure, which can be considered an effective strategy for environmental upgrading in urban areas, has become an obligation all over the world. These types of infrastructures are solutions that differ from conventional engineering because they are inspired by, recreate and simulate natural processes.

That said, this dissertation work has focused on two innovative structures: Water Wall and Swales. The acquaintance with these structures resulted from a stay of the author in Groningen, in The Netherlands, where the contact with the structures' creators allowed the author to have a comprehensive vision on the design and applicability of these structures, namely that it is possible to design several types of structures with the same purpose: water management in urban environments.

The swale requires greater planning for its construction and management, whereas the water wall can simply be placed anywhere and in any shape, as it is modular. The main function of the water wall is the reuse of rainwater for other purposes. Although the water wall is a much simpler structure when compared to the swale, both help in reducing the amount of surface rainwater to be drained by conventional pluvial urban drainage systems.

One consequence of their application is that they have the potential to minimize floods. However, it was concluded that the water wall stored water could be used for irrigation. If it were for human consumption, high-cost treatments would have to be carried out. This infrastructure might facilitate the creation of associated green spaces. The swale, on the other hand, allowed the storage of large quantities of water and the creation of more/larger green spaces and leisure areas that the municipalities could take advantage of.

In terms of the application of these types of structures in the city of Coimbra and focussing on the Campus II of the University of Coimbra, this work proposes that the creation of both structures that were studied are further investigated but it gives as examples: i) a water wall in the Civil Engineering Department building and ii) the swale near the Earth Sciences Department.

The study of these solutions would allow to perform tests and show the importance of implementing these structures in the planning of urban areas susceptible to urban inundation problems such as the city of Coimbra. Thus, it is expected that this dissertation serves as an informative document that can somehow create interest in these solutions and show that it is possible to implement these infrastructures, be it on a roof or on a bus stop or on a facade in order to help on the road to sustainability.

Finally, it was found that there is still a lot of lack of confidence and resistance from people towards applying green infrastructures as part of the urban drainage system, certainly because this theme is still in some way "unknown". Only in recent times, with the problem of climate change, have green infrastructures started to be more noticed and appreciated. It is thus necessary to show the benefits and services they provide, so that the barrier created to the implementation of green infrastructures falls. For this, creating incentives and support as well as legislation to help promote the creation of GI's is an important step to take.

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8 ANNEXES

8.1 ANNEX A

Location:	**Wadi Paddepoel**				
Coordinates:	Description:	Zinc (ppm)	Lead (ppm)	Cooper (ppm)	Depth (cm)
1 - X: Y:	Inflow point pipe	413	5	<4	0-1
2 - X: Y:	Behind tortoiseshell	63	6	<4	0-1
3 - X: Y:	Behind hooked tortoise	549	<1	<3	0-1
4 - X: Y:	Middle wadi	42	<1	<3	0-1
5 - X: Y:	Inflow point	3320	<9	<3	0-1
6 - X: Y:	Reference point	53	<7	<4	0-1
7 - X: Y:	Other side	507	129	<7	0-1
8 - X: Y:	Entry point	129	15	<4	0-1
9 - X: Y:	Lamp post	83	6	<4	0-1
10 - X: Y:	Lamp post inflow	2939	13	<7	0-1

Location	**Wadi United Care Products**			
Coordinates:	Description:	Zinc (ppm)	Lead (ppm)	Cooper (ppm)
1 - X: Y:	Gullet	26.37	< LOD	< LOD
2 - X: Y:	Directly under inflow point left	40.33	5.03	17.66
3 - X: Y:	Directly under inflow point right	31.82	< LOD	< LOD
4 - X: Y:	Inflow point 40 cm to deepest point	36.79	6.47	< LOD
5 - X: Y:	Inflow point 40 cm to deepest point	27.88	< LOD	< LOD
6 - X: Y:	Reference measurement on the slope	23.46	6.21	13.72
7 - X: Y:	Deepest point of wadi at infiltration point	15.27	6	< LOD

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8.2 ANNEX B

Qualidade das águas destinadas à rega

Parâmetro S	Expressão dos resultados	VMR	VMA	Observações
Alumínio (*Al*)	mg/l	5,0	20	Risco de improdutividade em solos com *pH*<5,5. Em solos com *pH*>7 o risco de toxicidade é eliminado por precipitar o aluminião.
Arsénio (*As*)	mg/l	0,10	10	Toxicidade variável consoante as culturas, oscilando entre 12 mg/l para a erva--do-sudão e 0,05 mg/l para o arroz.
Bário (*Ba*)	mg/l	1,0		
Berílio (*Be*)	mg/l	0,5	1,0	
Boro (*B*)	mg/l	0,3	3,75	Para solos de textura fina e em curtos períodos recomenda-se como concentração máxima 2 mg/l.
Cádmio (*Cd*)	mg/l	0,01	0,05	Tóxico para o feijoeiro, beterraba e nabo em concentrações da ordem dos 0,1 mg/l em soluções nutritivas. Recomenda-se limites mais restritivos, dado este ião se acumular nas plantas e no solo, podendo prejudicar o ser humano.
Chumbo (*Pb*)	mg/l	5,0	20	As concentrações muito elevadas podem inibir o desenvolvimento celular das culturas.
Cloretos (*Cl*)	mg/l	70	–	Para a cultura do tabaco recomenda-se uma concentração inferior a 20 mg/l, não devendo exceder os 70 mg/l.
Cobalto (*Co*)	mg/l	0,05	10	Tóxico em soluções nutritivas para a cultura do tomate na ordem dos 0,1 mg/l. Tende a ser inactivo em solos neutros ou alcalinos.
Cobre (*Cu*)	mg/l	0,20	5,0	Tóxico em soluções nutritivas com concentrações entre 0,1 mg/l e 1 mg/l para diversas culturas.
Crómio total (*Cr*)	mg/l	0,10	20	Por se desconhecer o seu efeito tóxico, recomendam-se limites mais restritivos.
Estanho (*Sn*)	mg/l	2,0		
Ferro (*Fe*)	mg/l	5,0		Não tóxico em solos bem arejados, mas pode contribuir para a acidificação do solo, tornando indisponível o fósforo e o molibdénio.
Flúor (*F*)	mg/l	1,0	15	Inactivado em solos neutros e alcalinos.
Lítio (*Li*)	mg/l	2,5	5,8	Tolerado pela maioria das culturas em concentrações superiores a 5 mg/l; móvel no solo. Tóxico para os citrinos a baixas concentrações (<0,075 mg/l).

Parâmetro S	Expressão dos resultados	VMR	VMA	Observações
Manganés (*Mn*)	mg/l	0,20	10	Tóxico para um certo número de culturas desde algumas décimas até poucos mg/l, mas normalmente só em solos ácidos.
Molibdénio (*Mo*)	mg/l	0,005	0,05	Não é tóxico em concentrações normais. Em solos ricos em molibdénio livre as forragens podem no entanto ocasionar toxicidade nos animais.
Níquel (*Ni*)	mg/l	0,5	2,0	Tóxico para um certo número de culturas entre 0,5 mg/l e 1 mg/l; reduzida toxicidade para *pH* neutro ou alcalino.
Nitratos (NO_3)	mg/l	50		Concentrações elevadas podem afectar a produção e qualidade das culturas sensíveis. No plano de fertilização da parcela convirá contabilizar o azoto veiculado pela água de rega.
Salinidade: CE SDT	 dS/m mg/l	 1 640		Depende muito da resistência das culturas à salinidade, bem como do clima, do método de rega e da textura do solo.
SAR (1)		8		Depende da salinidade da água, características do solo e do tipo de cultura a ser irrigada.
Selénio (*Se*)	mg/l	0,02	0,05	Tóxico para culturas em concentrações da ordem dos 0,025 mg/l. Em solos com um teor relativamente elevado em selénio absorvido as forragens podem ocasionar toxicidade nos animais.
Sólidos suspensos totais (SST).	mg/l	60		Concentrações elevadas poderão ocasionar colmatagem em solos e assoreamento nas redes de rega, bem como entupimentos nos sistemas de rega gota-a-gota e aspersão, bem como neste último sistema a água poderá provocar depósitos sobre as folhas e frutos.
Sulfatos (SO_4)	mg/l	575		
Vanádio (*V*)	mg/l	0,10	1,0	Tóxico para diversas culturas em concentrações relativamente baixas.
Zinco (*Zn*)	mg/l	2,0	10,0	Tóxico para diversas culturas numa gama ampla, toxicidade reduzida a $pH>6$ e solos de textura fina ou de solos orgânicos.
pH	Escala de Sorensen	6,5-8,4	4,5-9,0	
Coliformes fecais	/100 ml	100		
Ovos de parasitas intestinais	N/l		1	

8.3 ANNEX C

SAMPLE 1

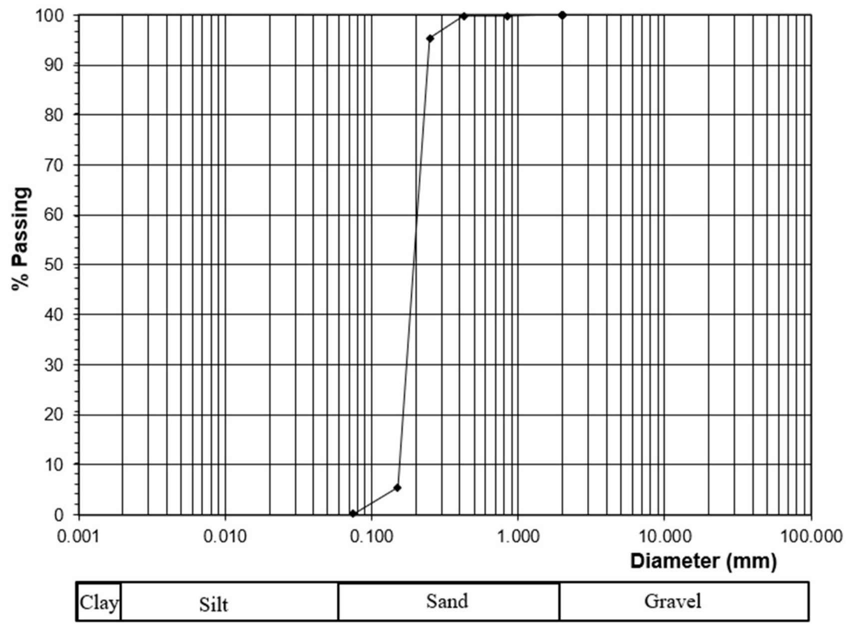
t (min)	Densimeter readings	Temperature ºC
1	1.0070	26.1
2	1.0050	26.1
5	1.0050	26.1
15	1.0045	26.1
30	1.0045	26.1
60	1.0045	25.0
250	1.0045	24.5
1440	1.0045	24.9
2880	1.0045	24

SAMPLE 2

t (min)	Densimeter readings	Temperature ºC
1	1.0065	27.0
2	1.0065	27.0
5	1.0055	27.0
15	1.0050	26.2
30	1.0050	26.1
60	1.0050	25.9
250	1.0050	24.9
1440	1.0050	24.8
2880	1.005	24

8.4 ANNEX D

Granulometric Curve - Sample A



Granulometric Curve - Sample B