DETERMINING THE EFFICIENCY OF SELECTED VEGETATED BIOFILTERS IN REDUCING NUTRIENTS FROM URBAN STORMWATER IN THE CITY OF EKURHULENI, SOUTH AFRICA

By

Mulalo Justice Bvumbi
20361734

Dissertation submitted as a requirement for the degree Master of Engineering:
Civil Engineering

in the

FACULTY OF ENGINEERING & TECHNOLOGY

DEPARTMENT: CIVIL ENGINEERING

at the

VAAL UNIVERSITY OF TECHNOLOGY

VANDERBIJLPARK

Supervisor: Professor GM Ochieng

Co-supervisor: Dr SS Rwanga

November 2021

Declaration

I, Mulalo Justice Bvumbi, do hereby declare that this dissertation is the result of my investigation and research and that this has not been submitted in part or full for any degree or for any other degree to any other university.

03/11/2021

M.J Bvumbi

Date

Acknowledgements

First, I like to thank God for providing me with knowledge and wisdom during this study. I also wish to record my appreciation to all the people who have consistently supported me in numerous ways to complete this project. My sincere gratitude goes to my supervisor Professor GM Ochieng and my Co-supervisor, Dr SS Rwanga, for their guidance and assistance throughout the project. I equally acknowledge all VUT lecturers and staff whom I interacted with while doing my project. I would also like to thank my colleague Humbulani Sadiki and my wife Rachel Bvumbi for their support and encouragement from the beginning of this project to the end.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BMP: Best Management Practice
CBD: Central Business District
CoCT: City of Cape Town
CoE: City of Ekurhuleni
COD: Chemical Oxygen Demand
DOE: Design of experiments
DWAF: Department of Water Affairs and Forestry
DWA: Department of Water Affairs
DWS: Department of Water and Sanitation
EMM: Ekurhuleni Metropolitan Municipality
ERWAT: East Rand Water Care Company
GRPP: Green Roof Pilot Project
HRT: Hydraulic Retention Time
NEMA: National Environmental Management Act
SuDS: Sustainable Urban Drainage Systems
TP: Total Phosphorus
TSS: Total Suspended Solids
TN: Total Nitrogen
WRC: South African Water Research Commission
WSDP: Water Services Development Plan
WSUD: Water Sensitive Urban Design

Abstract

Over time, the quality standard of stormwater in the City of Ekurhuleni (CoE) has deteriorated due to industrial, commercial, residential and farming activities. Stormwater quality directly impacts the treatment chain of potable water, and therefore, it should be kept in check at all stages. Innovations in the biofiltration process can provide useful, practical solutions to overcome crucial stormwater pollution problems. In 2013, the CoE developed stormwater design guidelines and standards to be implemented for the design of stormwater management, which include the principles of Water Sensitive Urban Design (WSUD) and Sustainable Urban Drainage Systems (SuDS) in particular. The CoE stormwater design guidelines and standards do not provide details on how the city plans to implement SuDS treatment trains to reduce stormwater pollution experienced by the city. This study aimed to verify the efficiency and effectiveness of vegetated biofilters on the stormwater treatment using CoE – Olifantsfontain's natural stormwater and to determine the most suitable vegetation to be used in the region. The CoE experimental case study was conducted to assess the efficiency of selected vegetated biofilters in lowering the concentration of orthophosphate (PO_4^{-3}), ammonium (NH_4^+), and nitrate (NO_3^-) from Tembisa/Olifantsfontain stormwater.

In the experimental setup, six selected plant species were planted into 30 vegetated biofilter columns, namely: *Agapanthus praecox* (Dryland plant), *Carpobrotus edulis* (Dryland plant), *Stenotaphrum secundatum* (Dryland plant), *Zantedeschia aethiopica* (Wetland plant), *Typha capensis* (Wetland plant) and *Phragmites australis* (Wetland plant). The six species were grouped according to general habitats, i.e. three wetland and three dryland plants. Wetland plants were planted into fifteen vegetated biofilters, and dryland plants were also planted on another fifteen vegetated biofilters. The biofilters contained layers of sandy loam soil, coarse sand and gravel sand. Each biofilter had a designated inlet and outlet section fitted with a gate valve to control retention time. The raw stormwater consisting of natural nutrient pollutants was applied to each vegetated biofilter through the inlet section. The samples were collected from the inlet and outlet of the six grouped vegetated biofilters during the month of June. All six plant species reduced outflow concentrations of PO_4^{-3} and NH_4^+ by an average of 99% and 98%, respectively. The results also show that all plant species excluding *Phragmites australis* were able to reduce NO_3^- with outflow concentrations being reduced by an average of 58%. From the results obtained, it may be concluded that all the six plant species may be suitable variants to be applied as biofilter material for the purposes of treating urban stormwater in the CoE. The reason is that the determined removal efficiencies for bio-retention fall within 50% – 60% for PO_4^{-3}, and 40% - 50% for NH_4^+ and NO_3^- respectively. The results also show that if the plant species were applied for SuDs in the CoE, there could be a great improvement in the urban stormwater quality with the consequent improvement in both surface and groundwater quality of the receiving water bodies in the area. Regardless of the nutrient removal by selected plant species, the inclusion of vegetation in a field setting would slow flow

rates and thus encourage infiltration into the soil, improve water quality, and support urban biodiversity. In the CoE, all the selected species could be used in the SuDS treatment trains targeting PO_4^{-3}, NH_4^+ and/or NO_3^-. The case study results provide a informed records for the CoE in the future/intended application SuDs in the upgrade/rehabilitation of its stormwater system.

CHAPTER 1: INTRODUCTION

1.1 Background

Water is fundamental to our quality of life, economic growth, and the environment we live in. Effective stormwater management is central to providing clean water and healthy water bodies. With a booming economy and growing population, South Africa faces increased pressure on its water resources, a problem compounded by pollution. Urban stormwater is one of the major polluters of our water resources. It carries pollutants such as oil, chemicals, lawn fertilisers, nutrients and solids directly to streams and rivers, where they seriously harm water quality (Lin et al. 2015; USEPA, 2003). According to National Evironmental Management Act (NEMA) (1998), every South African citizen has the right to live in a protected environment, for the benefit of present and future generations, through reasonable measures and legislation that prevent pollution, support and promote environmental conservation. This includes secure ecologically sustainable development and the use of natural resources while promoting socio-economic development.

The water supply problem has recently received attention. It is a key point of discussions in different spheres of government in South Africa due to recent drought in some parts of the country such as Western Cape (WC), Eastern Cape (EC), part of KwaZulu Natal (KZN) and other regions. According to Van Rooyen and Versfeld (2010), South Africa is water scarce country. It is very close to the full utilisation of all readily accessible water resources. The remaining water resources are distant from centres of water demand area, which makes the water more expensive to supply (Van Rooyen & Versfeld, 2010). Many catchments, such as the Vaal river system and Olifants, are under threat, with water supply exceeding the available demand (Van Rooyen & Versfeld, 2010). It is, therefore, necessary to protect and reduce the pressure on these limited resources from pollution caused by urban stormwater (De Klerk et al.2016).

Marsalek et al. (1999) defined stormwater as the runoff from pervious and impervious surfaces in predominantly urban environments. Impervious surfaces include roofs, driveways, pavements, footpaths, and roads. Urban stormwater is the main contributor of water pollution to the water resources of urban environments (Marsalek et al., 1999). Major pollutants found in urban stormwater are nutrients such as phosphate, nitrate, nitrite and ammonia. Nutrient overload is the primary course of eutrophication in our water resources and many water bodies of other countries. The traditional stormwater engineering approach focuses on solving flooding problems and does not address stormwater quality problems (Fletcher et al. 2015; Van Roon, 2007). Municipalities have been growing interested in including the ideals of "sustainable development" in urban engineering, mainly municipal services engineering (Matthews, 2010).

Many developed countries such as Australia, USA and China are replacing conventional engineering design with Sustainable Urban Drainage Systems (SuDS). The aim is to manage the quantity (flow rates and total volume) and quality of stormwater runoff as close to the source as possible and return the flow of water within urban areas to a pre-development state (Hatt, Fletcher and Deletic., 2009; Bratieres et al., 2008). The internationally recognised trends at the forefront of urban water management best practice are found in Water Sensitive Urban Design (WSUD) (Bratieres et al., 2008). WSUD is a holistic way to urban water management that focuses on the relationship between the urban environment and the urban water cycle, while SuDS, as a component thereof, focuses attention on stormwater management and the sustainability of alternative technologies (Wendling and Dumitru, 2021; CIRIA, 2007). In particular, SuDS makes use of a treatment train of elements to achieve three objectives, namely the reduction of stormwater volumes, improving stormwater quality, and improving site amenity and urban biodiversity (CIRIA, 2007; Ghani et al., 2008).

Biofilters are gaining acceptance and are being applied to a range of developments according to size, location and appearance (Hatt et al., 2009). Typical examples of biofilters include green roofs, vegetated biofilters, roadside swales, retention and detention ponds and natural wetland (Melbourne Water, 2005). Biofilters operate by slowing flow rates and thereby supporting the natural processes of infiltration, sedimentation and biological uptake (Melbourne Water, 2005). Significantly, biofilters afford substantial benefits related to the quality and quantity of stormwater runoff and provide an opportunity to promote amenity and biodiversity within the urban context. According to Hatt et al. (2009), biofilters have been found to reduce runoff volumes.

The research study investigated the efficiency of vegetated biofilters to reduce nutrients from stormwater in the CoE. It was important to conduct this study although related studies have been conducted elsewhere due to the climatic differences between the areas. Different climatic conditions have a substantial impact on vegetated biofilters performance (Ambrose &Winfrey, 2015). Therefore, studies on the efficiency of vegetated biofilters conducted in Australia, Cape Town or any other country cannot be the same as those undertaken in the CoE due to different climatic conditions, nature of stormwater as well as pollutant concentration.

1.2 Motivation

This study was motivated by the need to apply appropriate technologies to minimise pollution of our waterways by polluted urban stormwater, especially nutrients, which causes eutrophication of natural water bodies. Conventional stormwater design for the CoE focuses on water collection and discharge to the nearest watercourse (EMM, 2013). These stormwater designs are one of the stormwater management systems considered when designing a transportation-engineering project (CHST, 2011). According to WRC (2013), Water Sensitive Urban Design (WSUD) technologies are an alternative to manage stormwater quantity and quality. It was, therefore, necessary to investigate the performance of these WSUD technologies in addressing stormwater quality. It was also essential to conduct this research to determine if the technology is appropriate for the CoE.

In 2013, the CoE developed stormwater design guidelines and standards to be implemented for the design of stormwater management, which include the principles of Water Sensitive Urban Design (WSUD) and Sustainable Urban Drainage Systems (SuDS) in particular. The CoE stormwater design guidelines and standards do not explain how the city plans to implement SuDS treatment trains to reduce stormwater pollution experienced by the city. The City's stormwater design guidelines also do not provide water quality targets to be achieved.

With the current drought situation and global environmental changes, South African municipalities should focus on the collection of stormwater and stormwater quality. It is important to conduct this study to integrate the engineering process with the natural process to improve stormwater management. The information resulting from this study can assist the CoE and other municipalities to improve stormwater design guidelines and standards and assist developers, town planners, and engineers in making informed decisions and choices in terms of appropriate stormwater design technologies involving biofilters in the study area.

1.3 Problem statement

The urbanisation process improves people's lives and results in economic development; however, it negatively affects the urban environment. As a result of urbanisation, surface runoff increases and water pollution increases too as a consequence of this. In Gauteng province, urban stormwater is regarded as the main source of water pollution. The expansion of urban areas of the CoE in the East Rand of Gauteng has severely disrupted and altered the natural flow of water within the hydrological cycle (EMM, 2015). In particular, stormwater plans and designs in these areas have sought to collect runoff and dispense it as efficiently as possible via the closest watercourse (WRC, 2013). However, such measures often give too much attention to protecting the collection area without considering the negative impacts on the receiving environment, such as downstream flooding and the accumulation of land-based pollution in water bodies (Echols, 2008).

A report by the Department of Environment (EMM, 2015) identified the CoE as one of the major polluters of the Vaal dam through its stormwater channel. To remedy the situation, part of the recommendations is to treat the stormwater discharge from the CoE before discharging into the Vaal River System. This is the reason why it is important to design stormwater infrastructure that will improve water quality. Stormwater management in the CoE has focused on collecting stormwater from the nearby waterways (EMM, 2013). This type of stormwater design has significantly impacted the receiving watercourses, with the main result being the eutrophication of the natural water bodies.

Stormwater biofilters are considered as one of the most favourable WSUD technologies, which integrate engineering processes with natural processes (Prodanovic et al. 2018). The technology is regarded as a best management practice (BMP). The biofilter system was chosen in this study because it uses a biological active filtration bed to reduce contaminants. CoE is one of the most industrialised areas in Gauteng and results in stormwater polluted by some of those industries. Poor stormwater management also impacts negatively on streams (EMM, 2007). Stormwater biofilter can be a possible solution to reduce nutrients concentration from stormwater.

1.4 Research objectives

1.4.1 Primary objectives

To determine the efficiency of selected vegetated biofilter technology to reduce nutrients from urban stormwater in the CoE.

1.4.2 Specific objectives

i. To assess the nutrients that were reduced more effectively by the different plants species

i. To identify most suitable plant species to reduce selected nutrients from urban stormwater

ii. To Identify which Habitat (Dryland/Wetland) was efficient in reducing the nutrients levels from stormwater.

1.5 Thesis outline

Chapter 1 provides an introduction, motivation for the study, problem statement and the research objectives and serves a vital role in providing background to the research project. It gives the reasons for conducting the research and an overview of what the reader can expect. Chapter 2 begins with the literature review on SuDS treatment train design. It then reviews international and South African biofiltration studies and lastly summarises the previous research and identified gaps. This is followed by Chapter 3, which discusses the research design and methodology. Chapter 4 discusses the efficiency of selected vegetated biofilter technology to reduce nutrients from urban stormwater. Finally, Chapter 5 concludes by discussing the results and offers recommendations to the CoE's engineers and planners.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

The conventional stormwater management is designed to primarily focus on collecting and channelling stormwater to accessible waterways, reducing the risk of flooding in the area. This trend indicates that urban stormwater systems are focusing on quantity management and do not address the issue of water quality (WRC, 2013). An alternative stormwater management approach is to consider the whole stormwater system as part of the urban ecosystem, currently known as Water Sensitive Urban Design (WSUD). WSUD comprises the component of stormwater management known as Sustainable Drainage Systems - SuDs (Mitchell et al., 2007). This approach aims to protect waterways from pollution and is regarded as one of the most promising approaches to reduce nutrients, suspended solids and some heavy metals.

2.2 SuDS treatment train design

There has been growing interest in promoting sustainable development locally and internationally, including the control of stormwater runoff (Ellis et al. 2006). Sustainable Drainage Systems (SuDs) provide a means to attain the needed sustainable development through the holistic management of stormwater. SuDS technology is preferred as it can typically achieve quality and quantity objectives irrespective of a development's size, location or appearance (Hatt et al., 2009). SuDS offer an alternative approach to conventional drainage practices by attempting to manage surface water drainage system holistically in line with the ideals of sustainable development (WRC, 2013). The main objectives of this design are to manage water balances while maintaining and enhancing water quality, encouraging water conservation and maintaining water-related recreational (Beecham, 2003). Prior to the design of any stormwater system, there are several important considerations, including local hydrological cycles; local ground condition; the impact of different types of development as well as the compliance with the law, particularly local by- laws/policies such as CoCT's Management of Urban Stormwater impact Policy, CoJ's Stormwater Management By-laws which aim to manage, control and regulate the quantity, quality, flow and velocity of stormwater runoff from any property in the municipal area (WRC, 2014).

SuDS design includes all the various aspects that link together to control and manage stormwater with the greatest efficiency possible. Stormwater management cannot be accomplished by using a single SuDS option, but it requires a treatment train – also called a 'management' train (WRC, 2013). The effective harvesting, cleansing and routing of stormwater runoff are complex aspects of urban drainage design and management practice (Endicott & Walker, 2003). The efficacy of these control and management processes is generally increased by utilising SuDS "treatment trains", also known as "management trains"

(Wilson et al., 2004, Minton, 2002)

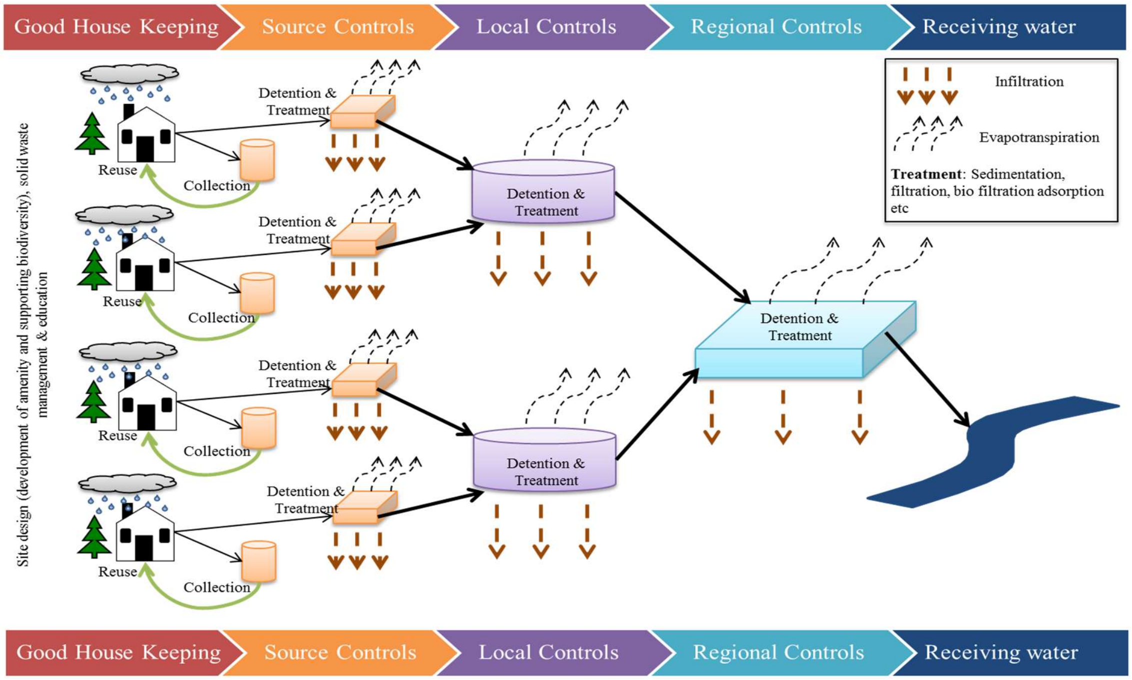


Figure 2.1: A schematic of a SuDs treatment train, 2013 (Source: http://www.uwm.uct.ac.za/uwm/suds/principles)

SuDS treatment trains prioritise water quality treatment for low flows and attenuation and volume control for high flows. Furthermore, the number and size of SuDS treatment train components depend on the sensitivity of receiving watercourses or other environments, the size of contributing catchments upstream, and the expected pollutant concentrations in stormwater runoff inflows (Woods-Ballard et al. 2007).

In addition, elements of the treatment train, which are typically installed above-ground and use vegetation, provide space for recreation and natural habitat and improve urban areas' aesthetic appeal and property values (CIRIA, 2007). The treatment train can be designed to reduce the quantity and pollutant load of urban runoff and provide a number of environmental and social benefits. Bratieres et al. (2008) emphasised the design of biofilter systems as an essential factor in the adsorption of pollutants. Below is the list of advantages and limitations of the SuDS options. The twelve SuDS 'families' are:

2.2.1 Green roof

A roof that is deliberately covered in vegetation may be described as a 'green roof' (Stahre, 2006). The use of vegetative roof covers and roof gardens is an important source of control for stormwater runoff (Figure 2.2). This option provides great benefits in densely urbanised areas where there is less space for other SuDS options.

2.2.1.1 Advantages

i) Green roofs may be established on both existing and new buildings;

ii) The insulation characteristics of green roofs help to regulate building temperatures with consequent savings of energy (Greenstone, 2010);

iii) The biophysical nature of the vegetation used in green roofs may improve air quality;

iv) Green roofs can be designed to closely mimic the pre-development state of the buildings (Greenstone, 2010); and

v) Green roofs can significantly improve amenity and biodiversity where they are implemented.

2.2.1.2 Limitations

i) The implementation phase for green roofs requires experienced professionals who are competent in waterproofing and plant requirements;

ii) Green roofs are generally more costly to implement than conventional roof-runoff practices due to their added structural, vegetative and professional requirements;

iii) The detention of water within the green roof storage layers could result in the failure of waterproofing membranes, which could cause leakage and/or increase the threat of the roof collapsing (Stahre, 2006).

Figure 2.2: eThekwini Green Roof Pilot Project, Durban CBD ((Greenstone, 2010).

2.2.2 Soakaways

Soakaways usually comprise an underground storage area packed with course aggregate or other porous media that gradually discharge stormwater from surrounding soil (MBWCP, 2006; figure 2.3).

2.2.2.1 Advantages

i) Soakaways that are operated and maintained regularly may have design lives of up to 20 years, after which the fill should be replaced (Stahre, 2006);
ii) Soakaways significantly decrease both the runoff volume and rate; and
iii) Soakaways are particularly effective in removing particulate and suspended stormwater runoff pollutants.

2.2.2.2 Limitations

i) Soakaways are not suitable in areas where infiltrating water would negatively impact adjacent structural foundations or adversely affect existing drainage characteristics;
ii) Soakaways are normally limited to relatively small connected areas (Woods-Ballard et al., 2007);
iii) Soakaways do not function well when constructed on steep slopes and in loose or unstable areas;
iv) Sub-drain piping systems must be utilised when soakaways are implemented in very fine silt and clay stratum because of the low infiltration rates; and
v) Sedimentation within the collection chambers will cause a gradual reduction in the storage capacity (Stahre, 2006).


Figure 2.3: Soakaways (WRC, 2013).

2.2.3 Permeable pavements

Permeable pavements refer to pavements constructed so that they promote the infiltration of stormwater runoff through the surface into the sub-layers and/or underlying strata (Woods-Ballard et al., 2007, Figures 2.4).

2.2.3.1 Advantages

i) Permeable pavements reduce stormwater discharge rates and volumes from impervious areas;

ii) Permeable pavements increase the 'usable' area on specified developments by utilising, among other things, roadways, driveways and parking lots as stormwater drainage areas;

iii) Stormwater runoff stored in permeable pavements can be used to recharge the groundwater table and for several domestic purposes;

iv) Lined permeable pavement systems can be utilised where foundation or soil conditions limit infiltration processes; and

v) If correctly designed, constructed and maintained, permeable pavements eliminate surface ponding and freeze-thawing in cold regions (Woods-Ballard et al., 2007).

2.2.3.2 Limitations

i) The implementation of permeable pavements is generally limited to sites with slopes less than 5% (Melbourne Water, 2005);

ii) Permeable pavements should not be constructed overfill materials as these soils could fail when saturated;

iii) Permeable pavements are not normally suitable for high traffic volumes and speed greater than about 50 km/hr, or for usage by heavy vehicles and/or high point loads (Woods-Ballard et al., 2007);

iv) If managed incorrectly, there is great potential for clogging by fine sediment, which significantly reduces the effectiveness of the specified system; and

v) The pollutant removal ability of permeable pavements is lower than most other SuDS options.

Figure 2.4: Permeable Pavements (WSUD, 2011)

2.2.4 Filter strips

Filter strips are maintained grassed areas of land that are used to manage shallow overland stormwater runoff through several filtration processes in a similar manner to buffer strips (Figure 2.5). They can be as simple as uniformly graded strips of lawn alongside a drain (Melbourne Water, 2005).

2.2.4.1 Advantages

i) The installation and maintenance costs for filter strips are relatively low;

ii) The layout of filter strips is quite flexible;

iii) Infiltration of stormwater runoff helps to attenuate flood peaks;

iv) Filter strips generally trap the pollutants close to the source; and

v) Filter strips normally integrate well within the natural landscape to provide open spaces for uses such as recreation (Owen et al., 2008)

2.2.4.2 Limitations

i) The primary limitation of filter strips is clogging of the subsurface drainage media – which is generally the result of poor solid waste management and irregular maintenance practices;

ii) There is relatively limited potential for filter strips to remove fine sediments and dissolved pollutants;

iii) The stormwater runoff needs to be spread out in order for filter strips to operate optimally;

iv) Filter strips have minimal stormwater runoff storage capacity and are not very good at treating high velocity flows; and

v) Because filter strips cannot manage high-velocity stormwater runoff flows, they are not effective on steeply sloping landscapes (Owen et al., 2008).

Figure 2.5: Vegetated filter (WRC, 2013).

2.2.5 Swales

Swales are shallow grass-lined channels with flat and sloped sides (Figure 2.6). Although they are normally lined with grass, alternative linings can be used to suit the characteristics of the specified site (Mays, 2001).

2.2.5.1 Advantages

i) Vegetated swales usually are less expensive and more aesthetically pleasing than kerbs and their associated concrete- and stone-lined channels;

ii) Runoff from adjacent impervious areas is often thoroughly infiltrated in-situ using swales;

iii) Swales retain particulate pollutants as close to the source as possible; and

iv) Swales generally reduce stormwater runoff volumes and delay runoff peak flows (Owen et al., 2002).

2.2.5.2 Limitations

i) Swales typically require a larger land area than conventional kerb and channel drainage systems;
ii) Swales have minimal removal capabilities for soluble pollutants and fine sediment;
iii) Swales are impractical on properties that have a relatively steep topography;
iv) Standing water in swales has the potential to result in the breeding of mosquitoes and the generation of foul odours; and
v) Failure is likely to occur more quickly with swales if they are not properly maintained than with most other SuDS options (Owen et al., 2002).

Figure 2.6: Swale combined with Bioretention areas (WRC, 2013)

2.2.6 Infiltration trenches

Infiltration trenches are excavated trenches filled with rock, other relatively large granular material, or commercial void forming products (Debo & Reese, 2003). A geotextile is used to provide separation between the trench media and the surrounding soil.

2.2.6.1 Advantages

i) Infiltration trenches increase stormwater infiltration and corresponding groundwater recharge;
ii) Infiltration trenches are particularly effective in removing suspended particulates from stormwater;

iii) Due to their relatively narrow cross-section, infiltration trenches can be utilised in most urban areas, including brown-field or retrofit sites; and

iv) Infiltration trenches have a negligible visual impact as they are generally below ground; and

v) Infiltration trenches decrease the frequency and extent of flooding (Belan, 2004)

2.2.6.2 Limitations

i) Infiltration trenches are not appropriate on unstable or uneven land or on steep slopes;

ii) If infiltration trenches are situated in coarse soil strata, groundwater contamination is a possibility;

iii) Infiltration trenches are prone to failure if sediment, debris and/or other pollutants are able to clog the gravel surface and/or backfilled aggregate material (Taylor, 2003); and

iv) They are restricted to areas with permeable soils.

Figure 2.7: Infiltration trenches surrounding car parks (WSUD, 2005)

2.2.7 Sand filters

Sand filters come in many forms. They usually comprise a sedimentation chamber linked to an underground filtration chamber containing sand or other filtration media through which stormwater runoff passes (Debo & Reese, 2003).

2.2.7.1 Advantages

i) Sand filters are particularly effective in removing settleable solids (TSS);

ii) Sand filters are efficient stormwater management technologies in areas with limited space as they can be implemented beneath impervious surfaces;

iii) They manage stormwater runoff effectively on relatively flat terrains with high groundwater tables where bio-retention systems are inappropriate (NCDWQ, 2007);
iv) The filtered effluent can be reused for most non-potable domestic water uses, including toilet flushing, dishwashing and garden watering; and
v) Sand filters may be retrofitted with relative ease into existing impervious developments, constrained urban locations or in series with conventional stormwater management systems (Melbourne Water, 2005).

2.2.7.2 Limitations

i) Premature clogging is likely to occur in sand filters if they receive excessive sediment carrying runoff, especially from construction sites and areas with open soil patches;
ii) Large sand filters are not generally attractive, especially if they are not covered with grass or other vegetation;
iii) Sand filters are generally ineffective in controlling stormwater peak discharges (NCDWQ, 2007);
iv) Sand filters are expensive to implement and maintain relative to most other SuDS options and/or technologies (Taylor, 2003); and
v) Some sand filters, especially if designed and/or implemented incorrectly, may fail, resulting in standing pools of water that have the potential to attract nuisances such as mosquitoes and midges.

2.2.8 Detention ponds

Detention ponds or detention basins are temporary storage facilities that are ordinarily dry but are designed to store stormwater runoff for short periods (Parkinson & Mark, 2005; Figure 2.7).

2.2.8.1 Advantages

i) They can temporarily store large volumes of stormwater, thus attenuating downstream flood peaks;
ii) Detention ponds are relatively inexpensive to construct and easy to maintain;
iii) Detention ponds may serve multiple purposes during drier seasons, particularly as sports fields, play parks or commons. Care should, though, be taken where stormwater may be contaminated with sewage as this will pose health and environmental risks; and
iv) If managed regularly, detention ponds can add aesthetic value to adjoining residential properties and present fewer safety hazards than wet ponds due to the absence of a permanent pool of water (Hussain et al., 2012; McWhirter, 2004).

2.2.8.2 Limitations

i) Detention ponds are not very good at removing dissolved pollutants and fine material;

ii) Detention ponds are generally not as effective in eliminating pathogens as constructed wetlands;

iii) Siltation can be a problem;

iv) The floors of detention ponds can become swampy for some time after major rainfall;

v) For best results, detention ponds should have a large plan area. This takes up valuable land; and

vi) Detention ponds are not very suitable in areas with a relatively high water table or coarse soil, and there is a risk of groundwater contamination (Hobart City Council, 2006).

Figure 2.8: Detention Ponds (Ken-Mark-Turf, 2012).

2.2.9 Retention ponds

Retention ponds, also referred to as 'retention basins', have a permanent pool of water in them (Mays, 2001). They are generally formed by constructing a dam wall (or walls) equipped with a weir outlet structure (Figure 2.8).

2.2.9.1 Advantages

i) The incorporation of retention ponds into the natural landscape promotes biodiversity; they can also be used for recreational purposes where adequate supervision is available;
ii) Retention ponds generally can remove a wide range of common stormwater runoff pollutants;
iii) Retention ponds are one of the most cost-effective SuDS options; and
iv) Stormwater runoff captured in retention ponds can be reused for irrigation or secondary domestic purposes where the water quality is acceptable.
v) Retention ponds often have high community acceptability (Endicott & Walker, 2003, Woods-Ballard, et al., 2007).

2.2.9.2 Limitations

i) The permanent open pool of water creates health and safety concerns and therefore requires social impact considerations at the design stage;
ii) If maintained infrequently or irregularly, the endless open pool of water could display unsightly floating debris and scum. Other nuisances include foul odours and mosquitoes;
iii) Retention ponds usually are restricted to sites with shallow slopes;
iv) Retention ponds require a baseflow or the addition of supplementary water to maintain a specified permanent water line;
v) Retention ponds may attract birds, such as herons, whose faeces can cause an increase in phosphorous in the water; and
vi) Retention ponds are generally not as effective in removing pathogens as constructed wetlands (Campbell, 2001).


Figure 2.9: Retention Ponds (Lakeside Design service, 2012).

2.2.10 Constructed wetlands

Wetlands generally refer to marshy areas of shallow water partially or entirely covered in aquatic vegetation (Figure 2.9). They may be categorised into natural, modified natural, or constructed wetlands. They can provide a vibrant habitat for fish, birds and other wildlife – potentially offering a sanctuary for rare and endangered species (Endicott and Walker, 2003).

2.2.10.1 Advantages

i) Constructed wetlands perform significantly better in the removal of pollutants from stormwater runoff than other regional controls of equal volume;

ii) Constructed wetlands that are effectively incorporated into the urban landscape of neighbouring residences have the potential to add great aesthetic value to those properties provided there is an appropriate level of maintenance, and the quality of water is acceptable;

iii) Small aquaculture wetlands can produce various kinds of food (Hobart City Council, 2006); and

iv) Constructed wetlands can be retrofitted into existing 'flood retarding basins' (Environment Protection Authority – Melbourne Water Corporation, 1999).

2.2.10.2 Limitations

i) Constructed wetlands could potentially attract mosquitoes;

ii) Constructed wetlands are limited to application on relatively flat land as they become costly to incorporate on steep and potentially unstable slopes;

iii) Retention ponds may attract birds, such as herons, whose faeces can cause an increase in phosphorous in the water;

iv) Water that is clean or with low levels of pollution can pick up pathogens from the sediment and exit in a worse condition than on entering the wetland;

v) The maximum inflow should be controlled in order to prevent damage to the wetland. Flooding of the wetland may result in waterlogging of the plants, which in turn results in die-off and a loss in treatment efficiency;

vi) Constructed wetlands may require supplementary water during long dry periods; and

vii) Wind action can cause the re-suspension of organic solids where the water is shallow, potentially resulting in adverse changes in the soil chemistry (WRC, 2013).

Figure 2.10: Constructed Wetland (WSUD, 2005).

2.2.11 Bio-retention areas

Bio-retention areas, also referred to as vegetated biofilter, 'rain gardens' or 'bio-retention filters', are landscaped depressions typically employed to manage the runoff from the first 25 mm of rainfall, bypassing the runoff through several natural processes (Figure 2.10). These processes include inter alia, filtration, adsorption, biological uptake, sedimentation, infiltration and detention. Bioretention areas normally incorporate a series of small stormwater management interventions such as grassed strips for infiltration, temporary ponding areas, sand beds, mulch layers and a wide variety of plant species (Endicott and Walker, 2003).

2.2.11.1 Advantages

i) Bio-retention areas are effective at the removal of most stormwater runoff pollutants;

ii) Due to their flexible application characteristics, bio-retention areas are easily incorporated into a wide variety of landscapes;

iii) Stormwater runoff rates, volumes and flood peaks are effectively attenuated with the correct use of bio-retention areas; bio-retention areas are generally satisfactory as retrofit options; and

iv) Bio-retention areas can be made aesthetically pleasing (Melbourne Water, 2005).

2.2.11.2 Limitations

i) Bio-retention areas are normally impractical in areas with steep or persistently undulating slopes;

ii) Bio-retention areas are not suited to areas where the water table is shallower than 1.8 m (Endicott & Walker, 2007);

iii) Bio-retention areas require frequent maintenance to remain aesthetically appealing; and

iv) If there is poor housekeeping in the adjacent areas, then there is an increased chance of clogging.

Figure 2.11: Bio-retention Areas (WSUD, 2005).

2.3 Stormwater Biofiltration

The use of vegetated biofilters is central to the functioning of most SuDS elements and, therefore, to the treatment train as a whole (CIRIA, 2007). Biofilters operate by slowing flow rates, thereby supporting the natural processes of infiltration, sedimentation and biological uptake (Melbourne Water, 2005). Significantly, biofiltration affords significant benefits relating to the quality and quantity of stormwater runoff and provides opportunities to promote amenity and biodiversity within the urban context.

Biofilters play a central role in improving the quality of water flowing through the treatment train, with each element responsible for a specific portion of the pollutant spectrum (Bratieres et al., 2008). The advantage of the biofilter is that it removes coarse contaminants such as litter, slows the rate of flow, and encourages infiltration and the removal of sediment, nutrients, organics and heavy metals (Melbourne Water, 2005).

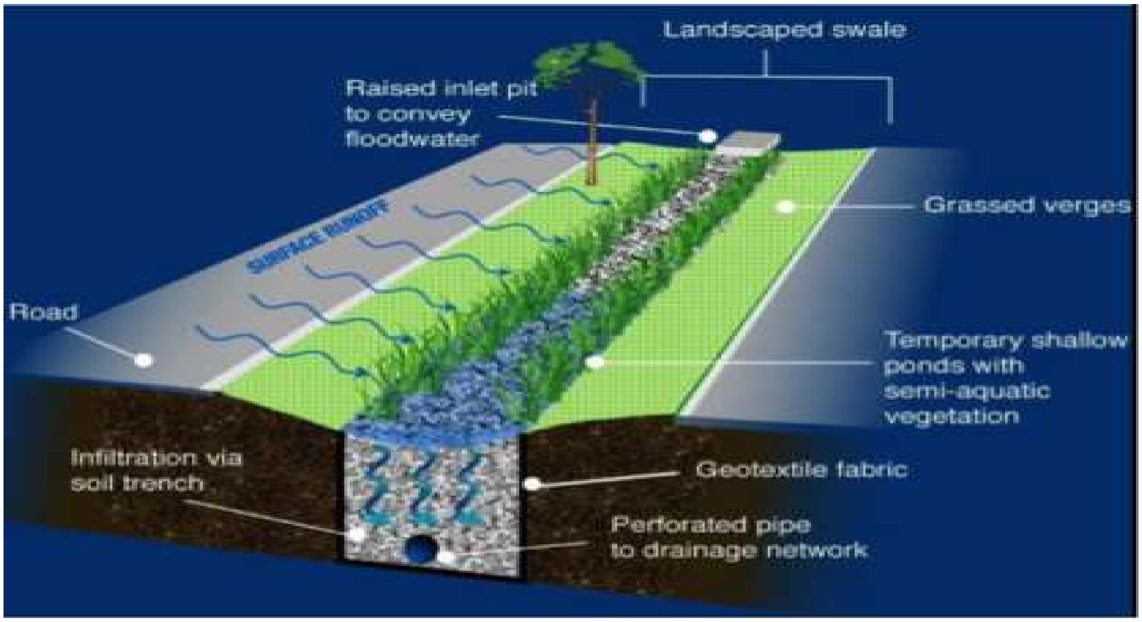


Figure 2.12: Schematic of a typical biofilter (Zinger et al., 2007)

Biofilters are components of SuDs and are considered as one of the stormwater Best Management Practices (BMP). According to Zinger (2010), vegetated biofilters are regarded as stormwater Best Management Practice (BMP), which uses a biologically active filtration bed to reduce pollutants. The system is recommended because it reduces stormwater pollutants such as nutrients by using vegetation in an aesthetic design. Zinger (2010) further argues that vegetated biofilters are currently undergoing further development to effectively reduce pathogens and make it an effective stormwater harvesting treatment technology.

2.4 Previous Biofilter And Related Suds Research Conducted International

According to Hatt et al. (2007), there are several encouraging results in reducing stormwater pollutants by using vegetated biofilters. Hatt et al. (2007) conducted trials, which indicated that vegetated biofilters could be designed to achieve the compulsory water quality standards applicable for stormwater use. Read et al. (2008) state that stormwater filtration through sand without plants can effectively reduce specific concentrations of metals, phosphate and suspended solids (SS). According to Read et al. (2008), it is essential to make the right choice of the soil composition to avoid soil that contains too much organic matter. With soil that has too much organic matter, there can be nitrate leaching, and water samples will show an increase in nutrient load (Read et al., 2008). Henderson et al. (2007) confirmed that the best media for vegetated biofilter seems to be sandy-loam. Vegetation in the media was found to significantly improve the efficiency of nitrogen and phosphorus removal and retain more nutrients during the initial flush after an inter-event dry period.

According to Bratieres et al. (2008), vegetated biofilters effectively reduce the suspended solids concentrations of about (90-96%) and phosphorus (70-94%). Results also show that total nitrogen (TN) reduction varies considerably (15-65%) due to the leaching of nitrate (NO3) from biofiltration systems (Bratieres et al., 2008). Other studies have investigated the hydraulic performance of biofilters (Hatt et al., 2009). The same results about the effectiveness of vegetated biofilters in reducing nutrients have been confirmed by other researchers (Fletcher et al., 2007; Henderson et al., 2007; Davis et al., 2006). However, the performance of vegetated biofilters in removing nutrient contaminants varies between plant species (Read et al., 2008).

In a study of vegetated biofilters, Bratieres et al. (2008) found that only two of the five plant species (*Carex appressa* and *Melaleuca ericifolia*) removed more than 70% of total nitrogen. However, where orthophosphate is the primary contaminant, biofilter systems consistently removed a mean value of 80%. According to Revitt et al. (2004), not all plants effectively remove pollutants; this means that some plants could remove one nutrient and fail to remove the other. In another study, Henderson et al. (2007) found that vegetated pots retained 63-77% of nitrogen and 85-94% of phosphorous, respectively, while non-vegetated pots leached nitrogen. If a reduction in total nitrogen (TN) is the primary objective, then an appropriate biofilter configuration must be used to prevent, for example, the leaching of nitrates (Davis et al., 2006). Fletcher et al. (2007) found that although nitrogen removal varied greatly, suspended solids and phosphorus were consistently reduced by 96% and 80%, respectively, regardless of design layout. Nonetheless, the choice of plants was a factor in determining the effectiveness of nitrogen removal.

Biofilters come in different forms, from vegetated filters, ponds, rain gardens, bioretention systems to bioswales, but all can control stormwater quantity in urbanised environments. Biofilters come with different benefits and opportunities such as preventing flooding, stormwater runoff management and water quality treatment (Ambrose & Winfrey, 2015). The following section discusses the different types of biofilters, their advantages and limitations

2.5 Previous biofiltration and related SuDS research conducted in South Africa

Despite progress in the installation of various SuDS projects in Cape Town, Durban and Johannesburg, there is currently very little research into the actual performance of biofilters in South Africa (WRC, 2013). It is important for South African municipalities to understand the importance of managing stormwater quality instead of only focusing on quantity. For this reason, it is essential to conduct biofiltration and SuDS related research in different municipal areas to identify the most suitable vegetation and types of soil to be used for each region.

2.5.1 The performance of plant species in removing nutrients from stormwater in biofiltration systems in Cape Town

The study conducted in Cape Town by Milandri (2011) was to investigate the performance of nine locally occurring plant species is Agapanthus praecox, Carpobrotus edulis, Elegia tectorum, Pennisetum clandestinum, Stenotaphrum secundatum, Zantedeschia aethiopica, Ficinia nodosa, Phragmites australis and Typha capensis, to remove PO_4^{-3}, ammonia (NH_3) and nitrate (NO_3^-) found in urban stormwater. The results show that vegetated biofilter reduced the average concentrations of PO4 by 81%, NH_3 by 90% and $NO_3^-$was removed by an average of 69%. The results of the study highlighted three important factors in the design of biofilters: that a substantial proportion of nutrients can be captured or absorbed by plants; that the soil medium is an important factor in the removal of orthophosphate and ammonia; and that plant choice is essential in the removal of nitrate (Milandri, 2011).

In the CoCT, SuDS are expected to play an important role in improving the quality of runoff from all urban areas (CoCT, 2009). The study highlighted the importance of including a variety of plants in SUDS design because the plant species varied in removing each nutrient and enhancing biodiversity in an urban environment (Milandri, 2011).

2.5.2 Green Roof Pilot Project in KwaZulu Natal Province (eThekwini Municipality)

Green roofs are preferred as a component of the SuDS treatment train. Basically, the green roof pilot project is a response to the higher temperatures and increases in the frequency and severity of floods and droughts expected as the result of climate change (Greenstone, 2010). This treatment train can be included in the new building design or retrofitted into existing developments. A green roof is a roof with a suitable gradient planted with low growing, drought resistant, indigenous vegetation in a shallow, lightweight growing medium (Wanielista et al., 2008).

In a move to assess this technology in a local setting, the eThekwini Municipality initiated the Green Roof Pilot Project (GRPP) in 2008 as part of their Municipal Climate Protection Programme (MCPP) (Greenstone, 2010). The project was implemented in phases where 85 indigenous plant species were planted in Phase 1, focusing on promoting biodiversity and reducing runoff volumes and roof temperatures. Thirty- seven of the plants survived the rooftop conditions, with results demonstrating that temperature and runoff volumes were both significantly reduced compared to the bare roof. A strong emphasis has been placed on identifying climate change adaption projects that will improve the resilience of the City to future developmental, social and environmental challenges (Greenstone, 2010).

2.5.3 SuDS for managing surface water in Diepsloot informal settlement, Johannesburg, South Africa

Sustainable drainage systems (SuDS) imitate natural water management processes in catchments degraded due to urbanisation. The study conducted in Johannesburg by Fitchett in 2017 aimed to reduce the quantity of stormwater runoff and improve water quality. Domestic wastewater discharged into the informal lanes compound the difficulty in managing rainwater in the informal settlement of Diepsloot in Johannesburg. The preliminary study by Fitchett (2017) investigated the introduction of SuDS to enhance existing surface water interventions as a low-cost, flexible approach. Using action research methods, the residents and researchers designed, constructed and refined small-scale interventions at two sites close to the Jukskei River. While the primary intention of the research was to reduce standing water in the public areas, water quality testing results indicated that the SuDS reduced concentrations of pH and Conductivity in the stormwater. Nitrate and phosphate concentrations were slightly lowered by introducing permeable channels and soakaways, while these interventions had a moderate effect on the chemical oxygen demand of the stormwater. A low concentration reduction was possibly achieved due to the fact that there was no vegetation planted around the permeable channels and soakaways, which could have assisted in reducing more concentration of nutrients.

2.9 Effect of Hydraulic Retention Time (HRT)

Results of previous studies by Milandri (2011), Bratieres et al. (2008), and Read et al. (2008) show that biofiltration can significantly remove stormwater pollutants. However, the removal efficiency depends on the applied hydraulic retention time (Suprihatin et al., 2017). Hydraulic retention time is one of the factors that affect pollutant removal efficiency and the quality of treated water. Microbially mediated nitrification in biofilters is a typical process of converting ammonia- N to nitrite-N and nitrate-N and further converting nitrate-N to N2 via denitrification (Song et al., 2020). Therefore to achieve the removal of total Nitrogen, suitable hydraulic retention is required. Song et al. (2020) maintain that choosing a suitably long hydraulic retention time is critical to completing the aerobic denitrification process.

In particular, dissolved oxygen (DO) concentration, temperature, C/N ratio, carbon source, pH, nitrate loading rate, and hydraulic retention time (HRT) affect the performance of the aerobic denitrification process. Increasing HRT leads to decreasing effluent nitrate-N concentrations and increasing nitrate-N removal efficiencies. In the study about the effect of hydraulic retention time for the aerobic denitrification process, the results obtained by Song et al. (2020) showed that over 98% of Nitrogen was removed. However, ammonia-N and nitrite-N levels were below 1 mg/l when influent nitrate-N was below 150 mg/L and HRT over 5 hours. The maximum nitrogen removal efficiency and nitrogen removal rate were observed at HRT of 6 or 7hrs when influent nitrate-N was 150 mg/L. (Song et al., 2020). In a study of the biofiltration process, Suprihatin et al. (2016) obtained removal efficiencies of 81.9%, 91.1%, 84.1%, and 86.1% on ammonium, TSS, turbidity, and colour, respectively, at 2hrs hydraulic retention time. The biofiltration system can reduce the ammonium concentration from 0.05–0.22 mg/l to 0.02–0.13 mg/l. Depending on the applied hydraulic retention time, the ammonium removal rates within the hydraulic retention time range were 40.0% - 82.8%. Ammonium removal increased with increasing hydraulic retention time (Suprihatin et al., 2016).

2.10 Interdisciplinary partnerships

Municipal government and utility leaders responsible for providing reliable water, wastewater, and stormwater management are confronted by several significant trends affecting the future of cities. These trends include the need to increase the social and economic benefits created by urban infrastructure, improving collaboration among overlapping agencies and jurisdictions, making the transition from "fast conveyance" to "closed-loop" systems, introducing public stakeholders into decision-making and program implementation, and preparing for extreme events" (Brown, 2007).

Interdisciplinary partnerships are an essential element of the design and management of SuDS schemes. Scholars widely suggest that a successful design team incorporates a range of disciplines, of which civil engineers are simply one element (Woods-Ballard et al., 2007; Ellis et al., 2006). Ellis et al. (2006) encourage urban practitioners to establish interdisciplinary partnerships within their means for added effectiveness at all stages of the implementation of urban development, such as SuDS schemes. This strengthens the decision-making processes, which for the selection of these schemes involves a variety of stakeholders within public and private sectors, who contribute differing powers and opinions to different urban spheres (Ellis et al., 2006).

2.11 Brief On Previous Research And Identify Gaps

Previous research was done by Milandri (2011), Bratieres et al. (2008), and Read et al. (2008) on biofiltration process application in stormwater quality improvement proved biofilters' ability to reduce stormwater pollutants such as heavy metals, nutrient and suspended solids. Although the research was done locally and internationally by Milandri (2011), Bratieres et al. (2008) and Read et al. (2008) was able to reduce nutrients from the stormwater, the researchers in their studies used synthetic stormwater other than natural stormwater. It is therefore essential to conduct this research using natural stormwater. It is also important to note that stormwater characteristics and climatic conditions are not transferrable to all regions. There are no records of similar stormwater biofilter studies in the CoE area. Due to the identified gaps, there was a need to conduct a stormwater biofilter study in the CoE to verify this technology's efficiency and effectiveness.

This study was important to verify the ability of vegetated biofilter on the removal of nutrients using natural stormwater found in the CoE other than synthetic stormwater from the laboratory. The study was also conducted to determine the most suitable vegetation to be used in CoE climate conditions. The following Chapter describes the research design and methodology used.

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

3.1 Site description

As an experimental case study, this study was conducted in a nursery-based type setup based in the CoE (Figures 3.1) with sufficient controls in terms of the inputs such as timing, frequency of irrigation and other variables such as biofilter plant species, size of the biofilter (dimensions and appurtenances) (Figure: 3.2). The nursery-based experiment was based on the reviews of Milandri (2011), Bratieres et al. (2008) and Read et al. (2008). In comparing the studies, Milandri's study done in Cape Town is the closest in similarity to this study, and it was used as a baseline for providing replicable content for the experimental setup. Milandri's study was conducted using synthetic stormwater in a different climatic condition to that of the CoE. Although the study done by Milandri was conducted successfully, there is still a need to conduct this study in a different climatic condition using natural stormwater with natural nutrients concentration. This study was conducted in a greenhouse located in the CoE, Clayville-Olifantsfontain Gauteng, South Africa (Figures 3.1). A greenhouse was used to prevent precipitation from altering the quantity or/and quality of water used in the experiment while maintaining near ambient solar radiation, temperature and humidity conditions. The greenhouse was fitted with open mesh on the sides and with a mesh roof to prevent natural rainfall during the study.

Figure 3.1: Map on where the study was conducted (Source: https://gis.ekurhuleni.gov.za/)

Figure 3.2: Experimental setup (nursery-based type setup vegetated biofilter), 2020

3.2 Experimental Design and Setup

3.2.1 Design of experiment

The randomised block design was used, in which subjects in the experiments were divided into subgroups, referred to as blocks. In this study, the plants was divided according to their species names. Furthermore, they were subdivided according to their habitat. Whether they are from Dryland or Wetland, all these subjects were then assigned to the treatment conditions (treating the plants with different nutrients).

Table 3.1: Illustration of the random block design employed to assign subjects for experiments.

Between-Subjects Factors			
		Value Label	*N*
Species	1	*Phragmites australis*	1
	2	*Stenotaphrum secundatum*	1
	3	*Typha capensis*	1
	4	*Zantedeschia aethiopica*	1
	5	*Agapanthus praecox*	1
	6	*Carpobrotis edulis*	1
Habitat	1	Dryland	3
	2	Wetland	3

From Table 3.1, six (6) species were used, namely: Common Agapanthus (*Agapanthus praecox)*, Common Reed (*Phragmites australis)*, Buffalo Grass (*Stenotaphrum secundatum)*, Bulrush (*Typha capensis)*, Knobby club-rush (*Zantedeschia aethiopica)* and Sour Fig (*Carpobrotis edulis)*. these species were then categorised according to their habitats, whether they are from a Wetland or Dryland.

This research study aimed at determining the efficiency of selected vegetated biofilter technology to reduce nutrients from urban stormwater in the CoE.

3.2.3 Experimental Setup

The experimental model biofilter columns were built from 150 mm diameter x 600 mm polyvinyl chloride pipes. Each pipe with a diameter of 20 mm perforated drainage pipe protrudes from the sealed base of each column. The outflow can be discharged into collection vessels located underneath the column (Figure 3.1).

Each of the six-selected plants, namely: *Agapanthus praecox* (Dryland plant)*, Carpobrotis edulis* (Dryland plant)*, Stenotaphrum secundatum* (Dryland plant)*, Zantedeschia aethiopica* (Wet plant)*, Typha capensis* (Wet plant) *and Phragmites australis* (Wet plant), were planted into the biofilter columns. Figure 3.2 below indicates the drainage layers placed below sandy loam soil, containing coarse sand and gravel to prevent the loss of soil and blockage of drain.

Plant irrigation was done through a drip irrigation system using raw stormwater. The column was filled with approximately 300 mm of soil, below the rim of each column, for water collection and retention throughout irrigation. Raw stormwater was collected using 20 – litre water bottles directly from the stormwater channel/stream situated less than a kilometre away to the place where the experimental setup was situated. Stormwater was stored into 260 litres for irrigation purposes through gravity. The experiment coincided in seasons starting by summer, autumn and winter (i.e., January to July) to allow assessing the operations of the vegetated biofilter in varied seasons of the year. The samples were collected during the wintertime (i.e. June Month). June was the preferred month to collect samples because of the low likelihood of rain diluting raw stormwater. This month was suitable to collect samples as the stormwater quality was more stable without rainfall.

The columns consisted of the following layers (listed from the top, Figure 3.3 below):

- 100 mm ponding zone: ponding zone, also called detention zone.100 mm was chosen as a suitable ponding zone to allow stormwater to the pond before infiltration.
- Sandy loam Soil (300 mm): the biofilter media comprised a 300 mm layer of sandy loam soil above 100 mm of sand to allow roots to have enough space to penetrate. Previous biofilter column studies have demonstrated that loamy sand provides effective removal of both TN and TP when coupled with vegetation (Bratieres et al., 2008)
- Transition layer of coarse sand (100 mm): 100 mm layer of coarse sand was chosen to act as a transition layer. The choice 100 mm layer was a suitable transition layer to provide a bridging layer to prevent the migration of fine particles from the upper filter media to the gravel drainage layer.
- Drainage layer (100 mm): 100 mm layer of gravel sand was used to prevent the loss of soil media and clogging of the drain.
- 20 mm of the outflow pipe was inserted into the drainage layer of approximately 100 mm of fine gravel, which goes to a sampling vessel to the 1-litres container. 1-litre sampling containers were used to adhere to the required sample quantity of the laboratory.

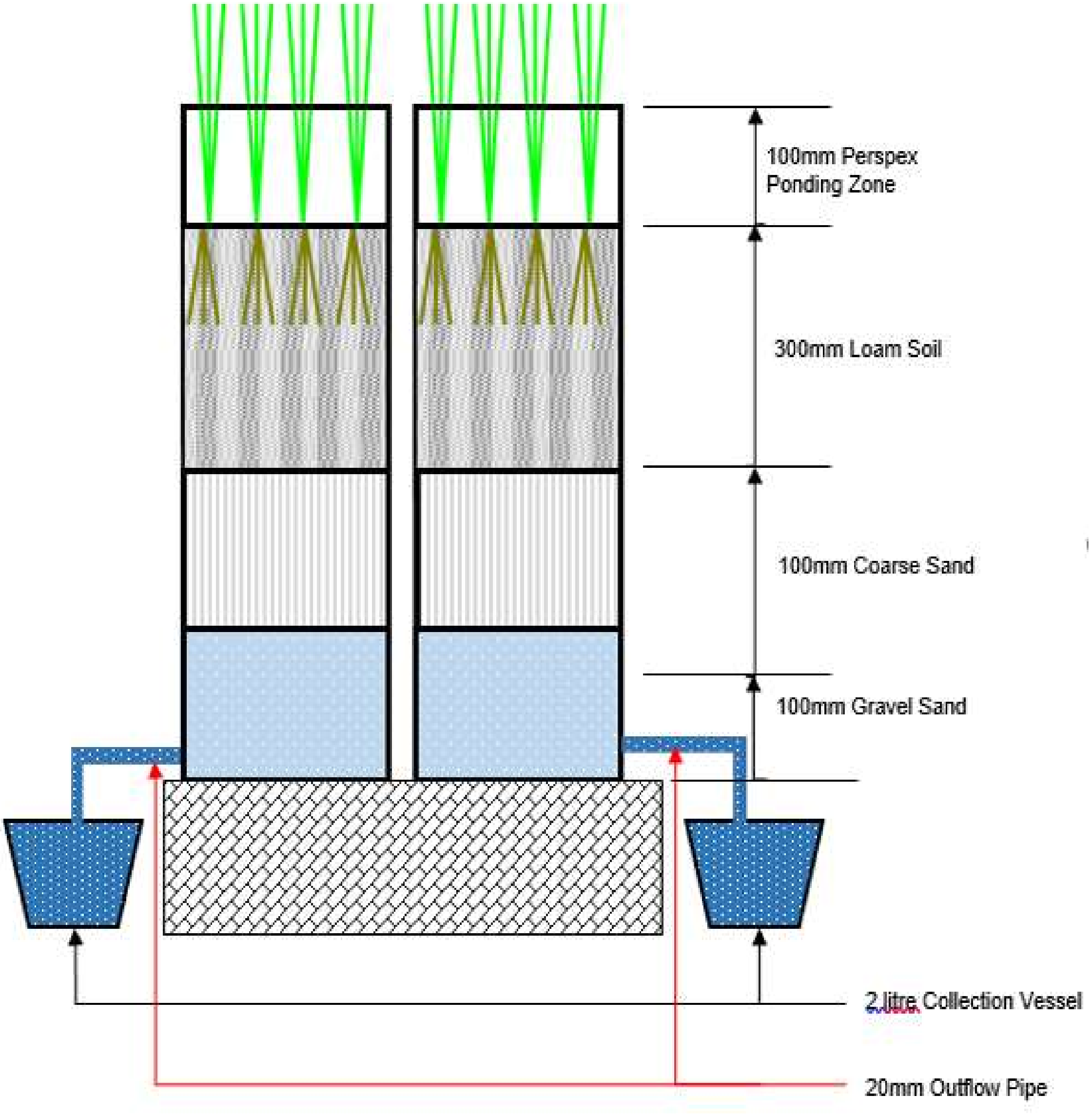


Figure 3.3: Experimental setup (cross-sectional two columns), 2020.

Irrigation design: The irrigation system was installed to ensure that it operates by slowing flow rates, thereby supporting the natural processes of infiltration, sedimentation and biological uptake. The tank of 260-litre capacity fitted with a valve for closing and opening was used raw water transferred from a 260-litre tank to the columns using 20 mm irrigation pipes fitted with drippers. The tank was filled with naturally occurring raw stormwater collected from Tembisa/Olifantsfontain stormwater – Olifantsfontain Water Care Works Upstream and stored in the 260 litres water tank for mixing, sampling and irrigation purposes. Due to the easy access to raw stormwater, fresh, natural raw stormwater was used for irrigation and sampling purposes. The tank was also used to ensure that the same quality of water was used for both irrigation and sampling purposes (Figure 3.4).

Figure 3.4: Pictures show drip irrigation and the tank used, 2020

3.2.4 Plant Choice

The experiment targeted six different plant species (Table 3.2). These plant species are identified as suitable plant species that can survive in South Africa (Milandri, 2011). The selection of these six plants is based on the suitability for use in each of the SuDS elements (e.g. swales, filter-strips and wetlands) and the field experience gained from the extent to which municipalities and landscaping companies have used these plants. In addition, the selection of vegetation is based on suitability for use in the experiment (e.g. maturing rapidly), availability, visual proliferation in local settings, and potential to tolerate fluctuating moisture levels and periods of drought. The species were grouped according to general habitats, which are wetland and dryland plants. This section addressed all three objectives of this study.

Table 3.2: List of species grouped by water demand categories

Genus & species	Common Name
Dryland plants:	
Agapanthus preacox	Common Agapanthus
Carpobrotis edulis	Sour Fig
Stenotaphrum secundatum	Buffalo Grass
Wetland plants:	
Zantedeschia aethiopica	Knobby Club-rush
Typha capensis	Bulrush
Phragmites australis	Common Reed

All selected vegetation is indigenous to South Africa and commonly used in the CoE by landscaping companies due to their drought resistance. However, there is a concern raised about the use of Phragmites, which, when exposed to high nutrient loads, can encroach quickly in streams, ponds, canals and wetlands, forming monocultures and causing ecological damage (Bellavance & Brisson, 2010). According to Milandri (2011), all selected species could possibly be used in the stormwater treatment.

3.2.5 Soil choice

Sandy loam soil was selected as a suitable soil for the study. The sandy loam soil was made of mixing available soil in the area together with natural sand. The selection of sandy loam soil is based on various factors. Firstly, it allows for good drainage. Secondly, both Bratieres et al. (2008) and Read et al. (2008) found that a sandy loam is a good choice of soil for biofiltration study because it is well-drained, low in organic matter and is one of the most effective in removing stormwater contaminants. The study avoided soils rich in the organic matter since such soils mostly contain nutrients, which would compromise the research results and invalidate the conclusions drawn.

3.3 Experimental procedure

The study based the timing of the irrigation frequency on the rainfall patterns of Gauteng as per South Africa Weather Services historical records. Rainfall data from the OR Tambo station was considered mainly due to its location and proximity to the study area. Daily average temperatures are a mild 26°C, with some days reaching a high 30°C. Nights are cooler and, on average, a pleasant 16°C. Johannesburg, Gauteng annual average rainfall of over 800mm is very similar to that of Perth in Australia, and more interestingly, London (SAWS, 2018). In the similar study conducted using the climatic data of Perth in Australia, the dosing volume of water was designed to reflect a biofilter sized to 2.5% of its catchment area and using the annual average actual rainfall for Perth and Melbourne across a twice-weekly frequency (Payne et al., 2013). Due to the similarities of the climatic condition of Perth in Australia and Gauteng in South Africa, this study used the same irrigation timing as used by Payne et al. (2013). A twice-weekly irrigation frequency was used and applied 1.5 litres of stormwater to each column based on the following factors: adequate water for plant growth, soil depth of 400 mm and biofilter size of 150 mm diameter x 600 mm polyvinyl chloride pipes. The study used an equal volume of water for wetland and dryland species to determine how differently they react to moisture regimes. This section addressed all three objectives of this study.

3.3.1 Collection And Treatment Of Experimental Stormwater

The municipality takes environmental samples in more than 100 sampling sites and sends them to East Rand Water Care Company (ERWAT) accredited laboratory. Collected stormwater samples are tested for metals, physical variables (such as suspended solids (TSS), Conductivity, and pH) and a variety of nutrients, including orthophosphate, ammonia and NOx (nitrate and nitrite) (CoE, 2017). Stormwater points monitored by CoE include Tembisa – Olifantsfontain Water Care Works Upstream, amongst others. In the experiments, the study used the raw stormwater taken from stormwater flows into Tembisa stormwater – Olifantsfontain Water Care Works Upstream. The raw stormwater was stored in a 260-litre water tank before irrigation of the experimental biofilter plants. Fresh raw stormwater was used when the irrigation for sampling purposes is taken place in order to achieve the desired concentration.

Tembisa – Olifantsfontain WCW Upstream stormwater point was selected based on historical nutrient concentration data and its availability throughout the year. The stream consists of stormwater from Tembisa residential area, Olifantsfontain industrial area which includes industries such as Nampak, Consol, Albany, Coca Cola and dairy companies which produce stormwater with a high concentration of nutrients. The stormwater form part of Kaal Spruit/Olifant Spruit, which originate from Kempton Park and Tembisa and flow northwards to join the Hennops River in Centurion (CoE, 2017). This section addressed all three objectives of this study.

3.3.2 Assessment of nutrient removal

Water quality samples were collected during the months of June. These began on the 22nd of June 2020 to the 30th of June 2020. The sample was collected from both inlet and outlet of the biofilter (Figure 3.5). The samples were taken to the accredited laboratory for nitrate (NO_3^-), Ortho-phosphate (PO_4^{-3}) and ammonium (NH_4^+) testing (appendix F). This section addressed all three objectives of this study.


Figure 3.5: Picture show sample collection from the outlet, 2020

3.3.3 Experimental data analysis

Analysis of Variance (ANOVA) was used for this study. A two-way ANOVA was used to identify the most suitable vegetation to reduce selected nutrients from stormwater in the CoE and to determine which habitat (Wetland/Dryland) was more effective in reducing nutrients from stormwater. Both one-way and two-way was used in which one-way ANOVA was used to test which nutrient was reduced more effectively by plant species. The significance was considered at a 95% confidence level ($P \leq 0.05$).

Table 3.3: The Tukey and Duncan's Multiple Range Tests

Effluent (mg/l)				
			Subset	
	Nutrients tested	*N*	*1*	*2*
Tukey HSD[a,b]	PO_4^{-3}	*6*	*0.01517*	
	NH_4^+	*6*	*0.09550*	
	NO_3^-	*6*		*1.54383*
	Sig.		*.987*	*1.000*
Duncan[a,b]	PO_4^{-3}	*6*	*0.01517*	
	NH_4^+	*6*	*0.09550*	
	NO_3^-	*6*		*1.54383*
	Sig.		*0.881*	*1.000*

Means for groups in homogeneous subsets are displayed. Based on observed means. The error term is Mean Square(Error) = 0.823.

a. Uses Harmonic Mean Sample Size = 6.000.
b. Alpha = 0.05.

The Tukey and Duncan's Multiple Range Tests are both pairwise comparison tests that are undertaken after ANOVA. These are post hoc tests with an outcome that fails to accept the null hypothesis (also known as post hoc tests). From the table above, Tukey HSD and Duncan multiple range tests show that there is a statistically significant difference between the number of nutrients reduced (P=0.98) for Tukey and (P=0.88) for Duncan (Awadallah, 2019; Isaiah and Yoav,2002).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This study investigated the individual performance of six locally occurring plant species to treat stormwater through the complete or partial removal of three nutrients, namely, (PO_4^{-3}), (NH_4^+) and (NO_3^-). The choice of plant species was based on their probability to tolerate regular inundation of water and their potential application in various SuDS treatment trains. The three objectives of the study will be discussed in this Chapter where Section 4.2 was to assess the nutrients that were reduced more effectively by plant species; Section 4.3 was to identify the most suitable plant species to reduce selected nutrients from stormwater, and Section 4.4 was to identify which Habitat (Dryland/Wetland) was efficient in reducing the nutrients levels from stormwater.

4.1. Data Summary

Descriptive Statistics

This section is conducted to give a summary describing the features that make up the study data. The mean describes the central tendency of each feature in the data. The Standard deviation illustrates how feature values are related to the mean, *N* is the sample size comprised in each feature, maximum and minimum values are from the values found in the samples within a feature.

Table 4.1: The descriptive statistics of influent (before treatment) and effluent (after treatment).

Descriptive Statistics					
	N	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Influent (mg/l)	*18*	*0.739*	*14.200*	*6.45300*	*5.845025*
Effluent (mg/l)	*18*	*0.000*	*3.850*	*0.55150*	*1.108456*
Valid N (listwise)	*18*				

A descriptive statistic showing the mean values of nutrients in influent (mg/l) ($\bar{X}$= 6.45), this was before the plant treatment and the effluent (mg/l) ($\bar{X}$=0.055), this is after the treatment.

Table 4.2: Tests of normality, showing the distribution of the samples.

	Kolmogorov-Smirnov[a]			*Shapiro-Wilk*		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
PO_4^{-3}	0.237	6	0.200*	0.915	6	0.468
NH_4^+	0.237	6	0.200*	0.915	6	0.468
NO_3^-	0.211	6	0.200*	0.905	6	0.406

**. This is a lower bound of the true significance.*

a. Lilliefors Significance Correction

The square root transformed results presented in Table 4.2 indicate that the data has a normal distribution. P>0.05 for all the variables (NO_3^-.NH_4^+ and PO_4^{-3}). The Kolmogorov-Smirnov test showed PO_4^{-3} (P=0.20), NH_4^+ (P=0.20) and NO_3^- (P=0.20). Shapiro-Wilk test showed PO_4^{-3} (P=0.46), NH_4^+ (P=0.46) and NO_3^- (P=0.40). The summary of inflow and outflow concentration data are both presented in table 4.3 below.

Table 4.3: Nutrient Data Analysis (Dryland Plant Biofilter)

Genus & species (Dryland)	**Nutrients Tested**	**Influent (mg/L)**	**Effluent (mg/L)**
Common Agapanthus	(NH_4^+) as N	14.2	0.195
	(NO_3^-) as N	4.42	0.345
	(PO_4^{-3}) as P	0.739	0.005
Sour Fig	(NH_4^+) as N	14.2	0.135
	(NO_3^-) as N	4.42	2.16
	(PO_4^{-3}) as P	0.739	0.066
Buffalo Grass	(NH_4^+) as N	14.2	0.119
	(NO_3^-) as N	4.42	0.348
	(PO_4^{-3}) as P	0.739	0.005

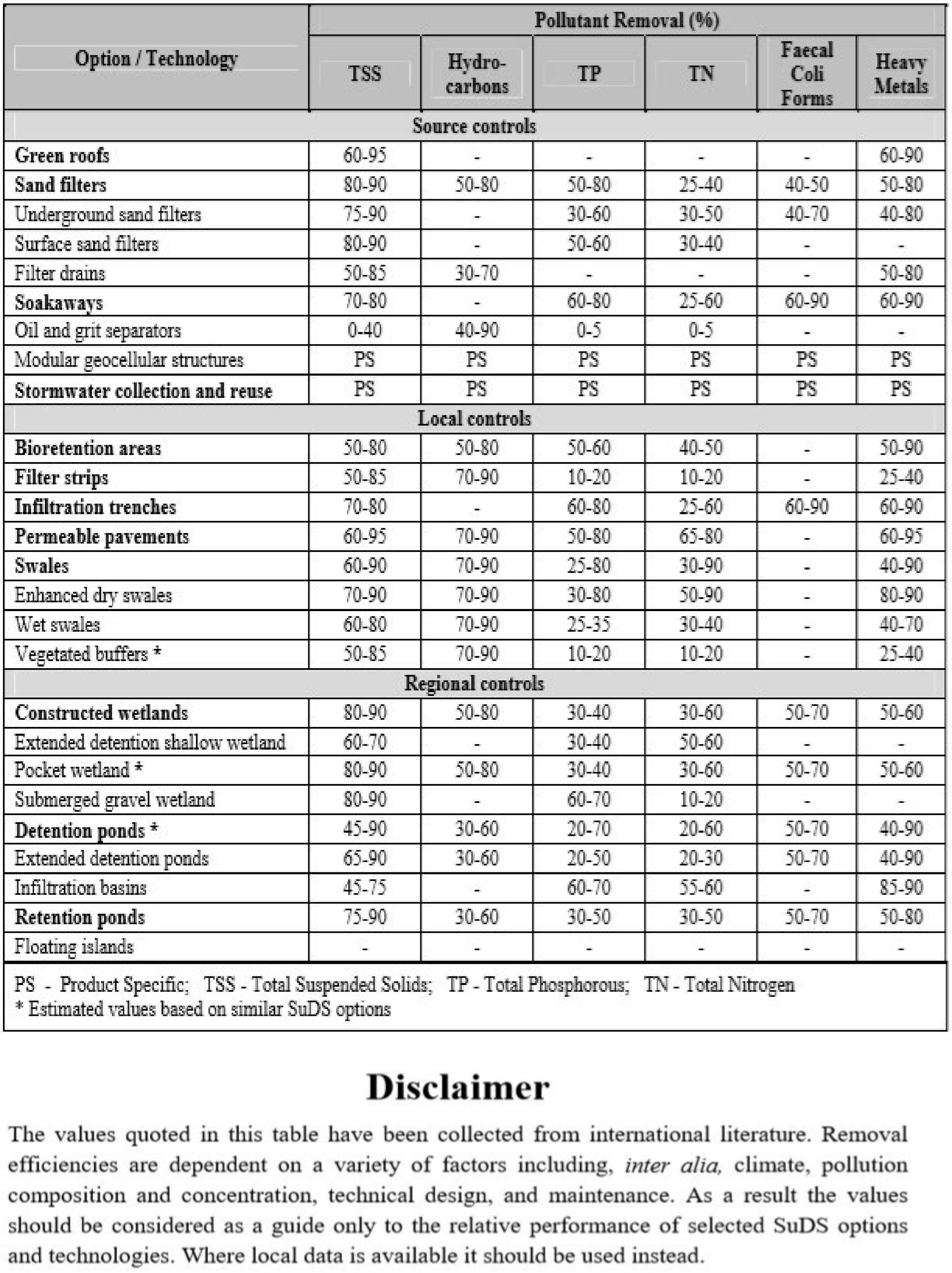
Table 4.4: Removal Data Analysis (Wet Plant Bio-filter)

Genus & species (Wetland)	**Nutrients Tested**	**Influent (mg/L)**	**Effluent (mg/L)**
Knobby Club-rush	(NH_4^+) as N	14.2	0.029
	(NO_3^-) as N	4.42	2.56
	(PO_4^{-3}) as P	0.739	0.005
Bulrush	(NH_4^+) as N	14.2	0.039
	(NO_3^-) as N	4.42	3.85
	(PO_4^{-3}) as P	0.739	0.005
Common Reed	(NH_4^+) as N	14.2	0.056
	(NO_3^-) as N	4.42	4.39
	(PO_4^{-3}) as P	0.739	0.005

4.2 To assess the nutrients that were reduced more effectively by different plant species

This objective assessed the nutrients that were reduced more effectively by plant species in which One-way ANOVA was used. The selected nutrients that were aimed to be removed were (PO_4^{-3}), (NH_4^+) and (NO_3^-). In 2013, the CoE developed stormwater design guidelines and standards to be implemented for the Design of stormwater management, which includes Sustainable Urban Drainage Systems (SuDS) in particular. The City's stormwater design guidelines on SuDS treatment train lack information such as implementation plan and water quality targets to be achieved. However, the national guidelines are recommended as a guide only to the relative performance of selected SuDS options and technologies where the local data is unavailable (South African Guidelines for sustainable Drainage System, 2013). In respect of this objective, a national guideline (Table 4.9) was used for this study.

Table 4.5: Measured pollutant removal capacities of selected SuDS options and technologies ((South African Guidelines for sustainable Drainage System, 2013)



Option / Technology	Pollutant Removal (%)					
	TSS	Hydro-carbons	TP	TN	Faecal Coli Forms	Heavy Metals
Source controls						
Green roofs	60-95	-	-	-	-	60-90
Sand filters	80-90	50-80	50-80	25-40	40-50	50-80
Underground sand filters	75-90	-	30-60	30-50	40-70	40-80
Surface sand filters	80-90	-	50-60	30-40	-	-
Filter drains	50-85	30-70	-	-	-	50-80
Soakaways	70-80	-	60-80	25-60	60-90	60-90
Oil and grit separators	0-40	40-90	0-5	0-5	-	-
Modular geocellular structures	PS	PS	PS	PS	PS	PS
Stormwater collection and reuse	PS	PS	PS	PS	PS	PS
Local controls						
Bioretention areas	50-80	50-80	50-60	40-50	-	50-90
Filter strips	50-85	70-90	10-20	10-20	-	25-40
Infiltration trenches	70-80	-	60-80	25-60	60-90	60-90
Permeable pavements	60-95	70-90	50-80	65-80	-	60-95
Swales	60-90	70-90	25-80	30-90	-	40-90
Enhanced dry swales	70-90	70-90	30-80	50-90	-	80-90
Wet swales	60-80	70-90	25-35	30-40	-	40-70
Vegetated buffers *	50-85	70-90	10-20	10-20	-	25-40
Regional controls						
Constructed wetlands	80-90	50-80	30-40	30-60	50-70	50-60
Extended detention shallow wetland	60-70	-	30-40	50-60	-	-
Pocket wetland *	80-90	50-80	30-40	30-60	50-70	50-60
Submerged gravel wetland	80-90	-	60-70	10-20	-	-
Detention ponds *	45-90	30-60	20-70	20-60	50-70	40-90
Extended detention ponds	65-90	30-60	20-50	20-30	50-70	40-90
Infiltration basins	45-75	-	60-70	55-60	-	85-90
Retention ponds	75-90	30-60	30-50	30-50	50-70	50-80
Floating islands	-	-	-	-	-	-

PS - Product Specific; TSS - Total Suspended Solids; TP - Total Phosphorous; TN - Total Nitrogen
* Estimated values based on similar SuDS options

Disclaimer

The values quoted in this table have been collected from international literature. Removal efficiencies are dependent on a variety of factors including, *inter alia,* climate, pollution composition and concentration, technical design, and maintenance. As a result the values should be considered as a guide only to the relative performance of selected SuDS options and technologies. Where local data is available it should be used instead.

Table 4.6: Comparison table on previous bio-filtration studies

		Nutrient removal-range/mean in percentage (%)		
Author	**Year**	**NH_3/NH_4^+ as N**	**NO_3^- as N**	**PO_4^{-3} as N**
This study	2021	98	57	99
Milandri	2011	91	60	74
Bratieres et al	2008	(70-85%)	(15-65%)	(70-85%)
Henderson et al	2007	(63-77%)	(63-77%)	(85-94%)
Davis et al	2006	(70-85%)	(15-65%)	(70-85%)

4.2.1 One-way ANOVA data analysis

A one-way ANOVA was used to test which nutrient was reduced more effectively by plant species.

The hypothesis for this test:

HO: there is no difference in the amount reduced from each nutrient. H1: there is a difference in the amount of reduction in each nutrient.

Table 4.7: A descriptive statistics summary showing the mean values of nutrients in the stormwater before (influent mg/l) and after treatment (effluent mg/l).

	Nutrients tested	*Mean*	*Std. Deviation*	*N*
Influent (mg/l)	*NH_4^+*	*14.20000*	*0.000000*	*6*
	NO_3^-	*4.42000*	*0.000000*	*6*
	PO_4^{-3}	*0.73900*	*0.000000*	*6*
	Total	*6.45300*	*5.845025*	*18*
Effluent (mg/l)	*NH_4^+*	*0.09550*	*0.065096*	*6*
	NO_3^-	*1.54383*	*1.547986*	*6*
	PO_4^{-3}	*0.01517*	*0.024903*	*6*
	Total	*0.55150*	*1.108456*	*18*

Table above shows that the means from the influent of each nutrient are higher than that of the effluent.

Table 4.8: Test statistics showing the effects of species on the number of nutrients reduced.

Source	species	Type III Sum of Squares	df	Mean Square	F	Sig.
species	Linear	313.449	1	313.449	783.258	0.000
species* Nutrients	Linear	309.750	2	154.875	387.008	0.000
Error(species)	Linear	6.003	15	0.400		

A one-way ANOVA was conducted to examine which nutrient was efficiently reduced from stormwater by plant species. There is a statistical difference F= 387, df= 2, P=0.00 the amount reduced from each nutrient.

Table 4.9: Multiple comparisons of the nutrients considered in the experiment (Effluent)

Multiple Comparisons							
Measure: MEASURE_1							
	(I) Nutrients tested	(J) Nutrients tested	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	NH_4^+	NO_3^-	4.16583*	0.258259	0.000	3.49501	4.83665
		PO_4^{-3}	6.77067*	0.258259	0.000	6.09985	7.44149
	NO_3^-	NH4+	-4.16583*	0.258259	0.000	-4.83665	-3.49501
		PO_4^{-3}	2.60483*	0.258259	0.000	1.93401	3.27565
	PO_4^{-3}	NH_4^+	-6.77067*	0.258259	0.000	-7.44149	-6.09985
		NO_3^-	-2.60483*	0.258259	0.000	-3.27565	-1.93401

Based on observed means.

The error term is Mean Square (Error) = 0.200.

**. The mean difference is significant at the 0.05 level.*

There is a statistical difference in the amount reduced from nutrients, $NH4^+$ compared to NO_3^- and PO_4^{-3} (P= 0.00), NO_3^- compared with NH_4^+ and PO_4^{-3} (P=0.00), PO_4^{-3} compared with NH_4^+ and NO_3^- (P=0.00).

The nutrient removal rate in percentage (%) will be presented on the graph below

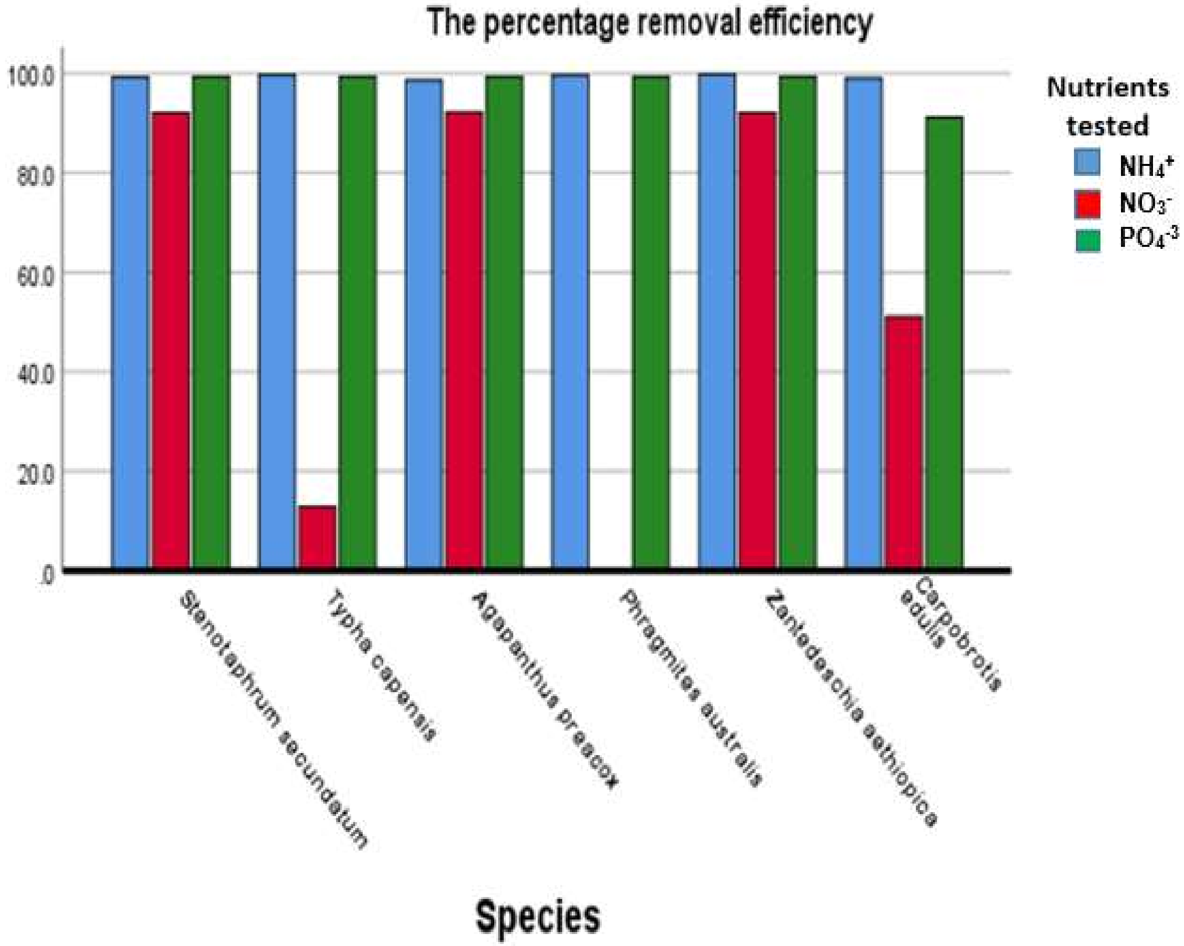


Figure 4.1: The percentage removal efficiency of nutrients by plants species.

A bar graph above presents the percentage removal efficiency of nutrients by plant species from stormwater, as explained below.

Ammonia (NH_4^+): All six plant species were effective in reducing $NH4^+$, with outflow concentrations being reduced by between 91 and 99% with a mean of 98%, as presented on the graph above. The removal efficiency for $NH4^+$ has met the target range of 40% - 50% for $NH4^+$ as per national guidelines for bioretention targets (Table 4.9).

In the reference study that was conducted in Cape Town, South Africa, the same plant species reduced outflow concentrations of NH_4 in the range of 66 to 99%, with a mean of 91% (Milandri, 2011). Similar removal ranges have also been obtained by comparable international studies (Bratieres et al., 2008; Henderson et al., 2007; Davis et al., 2006; Table 4.6).

Nitrate (NO_3^-): All selected plant species excluding Phragmites australis were effective in reducing NO_3^- with outflow concentrations being reduced by between 12- 92% with a mean of 54%. The non-performance of Phragmites australis may be due to the experimental stresses during the winter season. However, the removal efficiency for NO_3^- has met the target range of 40% - 50% for NO_3^- as per national guidelines for bioretention targets (Table 4.9). Milandri researched in South Africa, Cape Town, found a 20-88% reduction in outflow concentrations of Total Nitrogen with a mean of 60% (Milandri, 2011). Referenced international research found a range between 15- 65% Total Nitrogen removal (Bratieres et al., 2008; Henderson et al., 2007; Davis et al., 2006; Table 4.8). The efficiency of this nutrient removal in this study depended on plant species and soil/sand choices. The use of sandy loam (which is the mixture of sand and clay soil) as a soil media also accounted as an advantage to remove the concentration of this nutrient.

Orthophosphate (PO_4^{-3}): The six plant species all reduced outflow concentrations of (PO_4^{-3}), and the removal of this nutrient ranged from 98.6 to 99.8% (mean 99.3%) between species as presented on the graph above (Figure 4.1). The removal efficiency for PO_4^{-3} has met the target range of 50% – 60% for PO_4^{-3} as per national guidelines for bio-retention targets (Table 4.9). In the reference study that was conducted in Cape Town, South Africa, the same plant species reduced outflow concentration of (PO_4^{-3}) in the range of 95% with a mean reduction of 74% (Milandri, 2011). Similar levels of removal were consistent with the findings of similar studies despite the variation between species (Bratieres et al., 2008; Henderson et al., 2007; Table 4.6).

4.3 To identify the most suitable plant species to reduce selected nutrients from stormwater.

A two-way ANOVA was employed to identify the most suitable plant species in reducing nutrients from stormwater. This type of ANOVA was used with the following hypothesis:

Ho: There is no difference in the effect of each species when reducing nutrients from stormwater.
H1: The plant species differently affect the number of nutrients reduced from stormwater.

Table 4.10: A layout of the between subjects' factors that are employed in testing the effects of species on the number of nutrients reduced.

		N
Nutrients tested	*NH_4^+*	6
	NO_3^-	6
	PO_4^{-3}	6
Species	*Buffalo Grass*	3
	Bulrush	3
	Common Agapanthus	3
	Common Reed	3
	Knobby club-rush	3
	Sour Fig	3

The nutrients aimed to be reduced (NH_4^+, NO_3^- AND PO_4^{-3}) and the six (6) plant species.

Table 4.11: Descriptive statistics for species and Nutrients tested regarding the effluent (mg/l) (After treatment).

Descriptive Statistics				
Dependent Variable: Effluent (mg/l)				
Nutrients tested	*Species*	*Mean*	*Std. Deviation*	*N*
NH_4^+	*Buffalo Grass*	*0.11900*	*.*	*1*
	Bulrush	*0.03900*	*.*	*1*
	Common Agapanthus	*0.19500*	*.*	*1*
	Common Reed	*0.05600*	*.*	*1*
	Knobby club-rush	*0.02900*	*.*	*1*
	Sour Fig	*0.13500*	*.*	*1*
	Total	*0.09550*	*0.065096*	*6*
NO_3^-	*Buffalo Grass*	*0.34800*	*.*	*1*
	Bulrush	*3.85000*	*.*	*1*
	Common Agapanthus	*0.34500*	*.*	*1*
	Common Reed	*0.00000*	*.*	*1*
	Knobby club-rush	*2.56000*	*.*	*1*
	Sour Fig	*2.16000*	*.*	*1*
	Total	*1.54383*	*1.547986*	*6*
PO_4^{-3}	*Buffalo Grass*	*0.00500*	*.*	*1*
	Bulrush	*0.00500*	*.*	*1*
	Common Agapanthus	*0.00500*	*.*	*1*
	Common Reed	*0.00500*	*.*	*1*
	Knobby club-rush	*0.00500*	*.*	*1*
	Sour Fig	*0.06600*	*.*	*1*
	Total	*0.01517*	*0.024903*	*6*
Total	*Buffalo Grass*	*0.15733*	*0.174684*	*3*
	Bulrush	*1.29800*	*2.210162*	*3*
	Common Agapanthus	*0.18167*	*0.170392*	*3*
	Common Reed	*0.02033*	*0.030989*	*3*
	Knobby club-rush	*0.86467*	*1.468251*	*3*
	Sour Fig	*0.78700*	*1.189553*	*3*
	Total	*0.55150*	*1.108456*	*18*

The above table shows the mean of the nutrients reduced by each plant.

Table 4.12: A summary of the effects of Species nutrient reduction from stormwater.

Effect		*Value*	*F*	*Hypothesis df*	*Error df*	*Sig.*
Species	*Pillai's Trace*	*0.903*	*51.450*[b]	*2.000*	*11.000*	*0.000*
	Wilks' Lambda	*0.097*	*51.450*[b]	*2.000*	*11.000*	*0.000*
	Hotelling's Trace	*9.354*	*51.450*[b]	*2.000*	*11.000*	*0.000*
	Roy's Largest Root	*9.354*	*51.450*[b]	*2.000*	*11.000*	*0.000*

a. Design: Intercept + Species
Within Subjects Design: Species

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

A repeated-measures ANOVA was conducted to examine the effects of Species on the number of nutrients reduced. There is a statistical difference in the number of nutrients reduced from stormwater by species F=51.45, d.f= 2, ($P<0.05$) for all tests (Table 4.12). The results conclude that different species reduce nutrients from stormwater differently. The null hypothesis is therefore rejected.

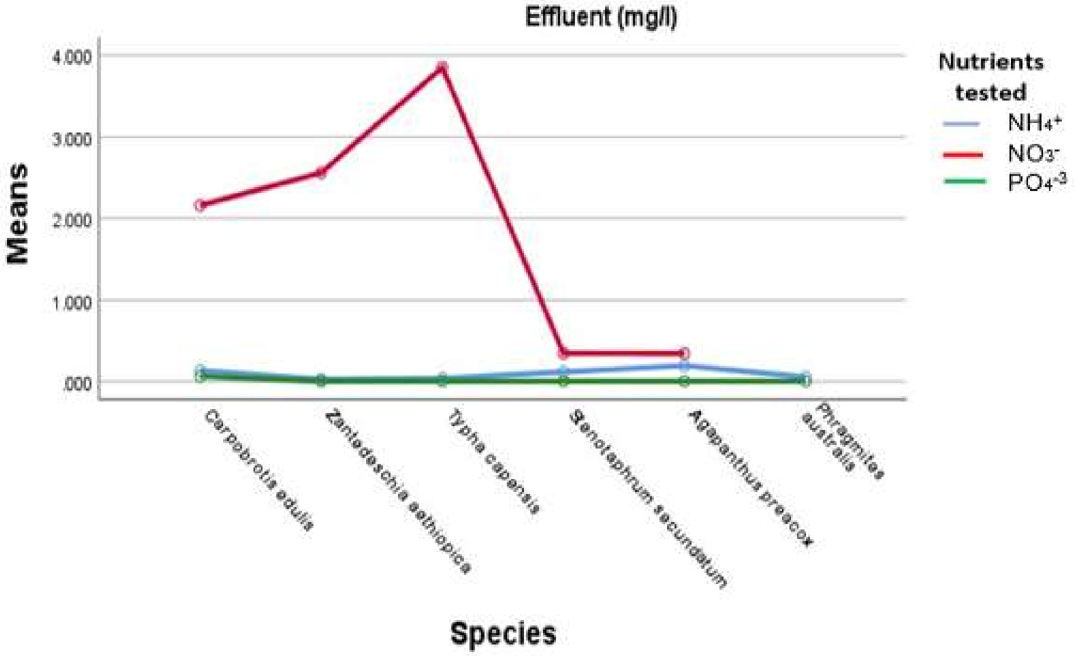


Figure 4.2: The marginal means of nutrients found in different plant species after treatment

The above graph shows the differences in nutrient reductions by species from stormwater. When the Effluent (after treatment) was collected, NO_3^- was the least reduced nutrient from stormwater. Pharagmites australis (Common Reed) was unable to remove NO_3^- from the stormwater; additionally, Typha capensis (Bulrush) was also inefficient plant species in removing NO_3^-. Agapanthus preacox (Common Agapanthus) and Stenotaphrum secundatum (Buffalo Grass) was the most efficient plant species in removing NO_3^-. The above graph shows that PO_4^{-3} and NH_4^+ was removed efficiently by all selected plant species, respectively.

4.4 To identify which Habitat (Dryland/Wetland) was efficient in reducing the nutrients levels from stormwater

A two-way ANOVA was conducted to examine which habitat (Wetland/Dryland) was more efficient in reducing nutrients from stormwater.
The test hypotheses were as follows:

Ho: There is no difference in the performance from each habitat in nutrient reduction. H1: There is a difference between the habitats in terms of reducing nutrients.

Between-Subjects Factors		
		N
Habitat	*Dryland*	*9*
	Wetland	*9*
Nutrients tested	NH_4^+	*6*
	NO_3^-	*6*
	PO_4^{-3}	*6*

Table 4.13: The descriptive statics summary of the nutrient's composition before treatment from each habitat (Influent mg/l).

Descriptive Statistics				
Dependent Variable: Influent (mg/l)				
Habitat	*Nutrients tested*	*Mean*	*Std. Deviation*	*N*
Dryland	NH_4^+	*14.20000*	*0.000000*	*3*
	NO_3^-	*4.42000*	*0.000000*	*3*
	PO_4^{-3}	*0.73900*	*0.000000*	*3*
	Total	*6.45300*	*6.024914*	*9*
Wetland	NH_4^+	*14.20000*	*0.000000*	*3*
	NO_3^-	*4.42000*	*0.000000*	*3*
	PO_4^{-3}	*0.73900*	*0.000000*	*3*
	Total	*6.45300*	*6.024914*	*9*
Total	NH_4^+	*14.20000*	*0.000000*	*6*
	NO_3^-	*4.42000*	*0.000000*	*6*
	PO_4^{-3}	*0.73900*	*0.000000*	*6*
	Total	*6.45300*	*5.845025*	*18*

Dependent Variable: Influent (mg/l)					
Habitat	Nutrients tested	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Dryland	NH_4^+	14.200	0.000	14.200	14.200
	NO_3^-	4.420	0.000	4.420	4.420
	PO_4^{-3}	0.739	0.000	0.739	0.739
Wetland	NH_4^+	14.200	0.000	14.200	14.200
	NO_3^-	4.420	0.000	4.420	4.420
	PO_4^{-3}	0.739	0.000	0.739	0.739

In the influent, the stormwater had an equal amount of each nutrient across the habitats, ($\bar{X}$=14.20) for NH_4^+, ($\bar{X}$= 4.42) for NO_3^- and ($\bar{X}$=0.739) for PO_4^{-3}.

Table 4.14: A summary showing how nutrients differ in habitats

Dependent Variable: Effluent (mg/l)					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11.009[a]	5	2.202	2.675	0.076
Intercept	5.475	1	5.475	6.650	0.024
Habitat	0.559	1	0.559	0.679	0.426
Nutrients	8.882	2	4.441	5.395	0.021
Habitat * Nutrients	1.568	2	0.784	0.953	0.413
Error	9.879	12	0.823		
Total	26.362	18			
Corrected Total	20.887	17			

a. R Squared = 0.527 (Adjusted R Squared = 0.330)

A two-way ANOVA was conducted to examine which habitat (Wetland/Dryland) has plant species that are more effective in reducing nutrients from stormwater. There is no statistical difference in the reduction of nutrients between wetland and Dryland, F=0.679. d.f=1, P=0.44.

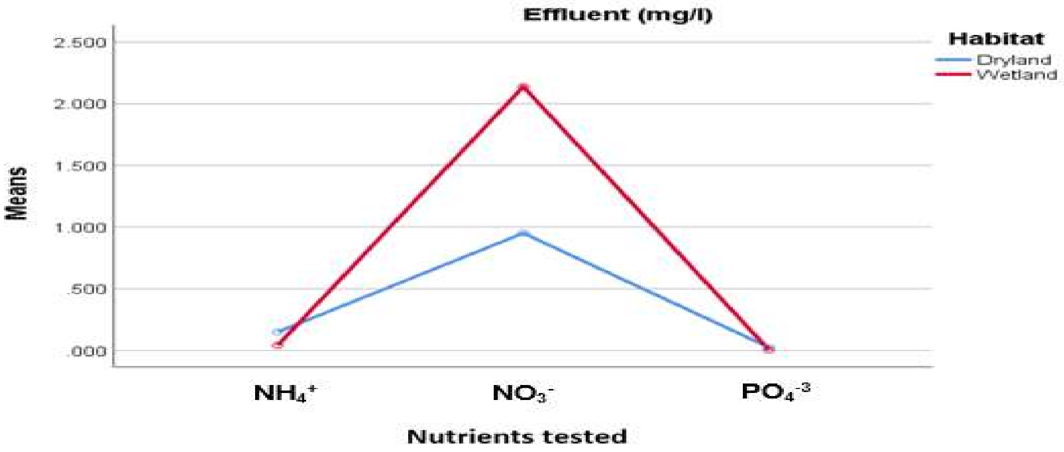


Figure 4.3: Means vs nutrients tested

The graph above indicates that both habitats were efficiently reduce all nutrients with NO_3^- being the least reduced. However, dryland plant species reduce nutrients more effectively than wetland plant species. In a similar study conducted by Milandri (2011) using two-ways ANOVA, the results also show that there was no significant difference between the habitats and favour dryland plant species as the most effective in reducing nutrients from stormwater.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The quality standard of stormwater in many parts of the CoE has been diminished due to industrial, commercial, residential and farming activities. Innovations in the biofiltration process can provide effective solutions to overcome crucial water pollution problems. In 2013, the CoE developed stormwater design guidelines and standards to be implemented for the design of stormwater management, which include the principles of Water Sensitive Urban Design (WSUD) and Sustainable Urban Drainage Systems (SuDS) in particular.

Field and laboratory research conducted at the local and international level has demonstrated that the ability of vegetated filters to remove nutrients depends more on appropriate design, soil/sand and plant choices. Results from this study seek to provide recommendations to CoE's engineers and Planners on suitable vegetated biofilter design to improve stormwater quality. The following section provides insight into the key nutrient-removal results while also identifying suitable plant species for use in the CoE's SuDS treatment trains. The conclusion of this study will be based on the three objectives under sections 4.2, 4.3 and 4.4 above. This was followed by several recommendations.

5.2 Conclusion

one-way ANOVA was used to test which nutrient was reduced more effectively by plant species. The results provide evidence that NO_3^- was the least to be reduced effectively with a lower mean compared to PO_4^{-3} and NH_4^+, which was almost completely removed from stormwater. All six plant species reduced outflow concentrations of PO_4^{-3} and NH_4^+ by an average of 99% and 98%, respectively. The results also show that all plant species excluding *Phragmites australis* effectively reduced NO_3^- with outflow concentrations by an average of 58%.

A two-way ANOVA was used to determine the most suitable plant species to reducing nutrients from stormwater. *Agapanthus preacox* (Common Agapanthus) and *Stenotaphrum secundatum* (Buffalo Grass) was the most efficient plant species in removing NO_3^-. The results also show that PO_4^{-3} and NH_4^+ was removed efficiently by all selected plant species. A two-way ANOVA was again used to examine which habitat (Wetland/Dryland) has plant species that are more effective in reducing nutrients from stormwater. There was no statistical difference between the habitats, however, the means indicate that dryland plant species are more effective than wetland plant species.

5.3 Recommendation

All plant species are recommended for local biofiltration systems targeting all three nutrients. Despite the poor performance of Common Reed on NO3-, the species could still play a role in slowing stormwater flow rates and improving biodiversity. There is a need for a variety of species to be used in SuDS treatment train and not only to target specific nutrients but also to encourage urban biodiversity and provide aesthetic benefits wherever possible. The use of sandy loam (which is the mixture of sand and clay soil) as a soil media accounted as an advantage to remove the concentration of this nutrient and is widely available in the CoE and can be used in the construction of treatment trains targeting these nutrients. Although this study demonstrated that suitable plant choice is essential for the effective removal of NO_3^-, the sandy loam also plays an important role to act as a filter media. It is also important to choose a suitable hydraulic retention time in order to remove the targeted total Nitrogen.

All selected nutrients (PO_4^{-3}, NO_3^- and NH_4^+) were successfully reduced by wetland and dryland plants. However, the wetland plant shows less reduction on NO_3^-, the experimental stresses could have caused this because of winter weather. Therefore, it is recommended to use both dryland and wetland plants as they all demonstrate different strengths and potentials. Regardless of the nutrient removal of each plant species, the inclusion of vegetation in a field setting would slow rates of flow and thus encourage infiltration into the soil and improve water quality and support urban biodiversity. In the CoE, all the selected species could be used in the SuDS treatment trains targeting PO4-3, NH4+ and/or NO3- removal.

6 References

Ambrose, R.F & Winfrey B.K. (2015). Comparison of stormwater biofiltration systems in Southeast Australia and Southern California. *WIREs Water 2015*, 2:131–146. doi: 10.1002/wat2.1064

Beecham, S.C. (2003). Water Sensitive Urban Design: A Technological Assessment. Waterfall, Journal of the Stormwater Industry Association, 2003, 17:5–13.

Belan, G. & Otto, B. 2004. Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management. . Available at:
http://act.americanrivers.org/site/DocServer/CatchingTheRain.pdf.

Bellavance, M.E., & Brisson, J. (2010). Spatial dynamics and morphological plasticity of common reed (Phragmites australis) and cattails (Typha sp.) in freshwater marshes and roadside ditches. *Aquatic Botany,* 93: 129–134.

Bratieres, K., Fletcher, T. D., Deletic, A., and Zinger, Y. (2008). Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study. *Water Research*, 42(14):3930-3940

Brown, R. (2007). 'Cities of the Future', The importance of water infrastructure and the environment in tomorrow's cities, IWA Publishing, London. ISBN: 9781843391364.armitage

CIRIA., (2007). The SUDS Manual. (C697). Classic House, London.

City of Ekurhuleni (CoE), (2017). Water Quality Manual. 2017-2018. City of Ekurhuleni Municipality.

Campbell, S. (2001). Green Cities, Growing Cities, Just Cities? Urban Planning and the Contradictions of Sustainable Development. In S. Campbell & S. S. Fainstein (Eds.), Readings in Planning Theory (second edition). Malden: Blackwell Publishing Ltd.

Davis, A.P., Shokouhian, M., Sharma, H., & Minami, C., (2006). Water quality improvement through bioretention media: nitrogen and phosphorus removal. Water Environment Research 78 (3): 284–293.

Debo, T. & Reese, A. (2003). Municipal Stormwater Management 2nd Edition. Lewis Publishers. Florida. 1141 pp. ISBN: 9781420032260.

De Klerk, A. R., Oberholster, P. J., Van Wyk, J. H., Truter, J. C., Schaefer, L. M. & Botha, A. M. (2016) The effect of rehabilitation measures on ecological infrastructure in response to acid mine drainage from coal mining. Ecological Engineering 95, 463–474.

Echols, S. (2008). Split-flow theory: Stormwater design to emulate natural landscapes. *Landscape and Urban Planning*, 85: 205-214.

Ekurhuleni Metropolitan Municipality (EMM), (2013). Manual for Stormwater Design Guidelines and Standards. Land Development and Infrastructure Planning. Department Roads and Stormwater.

Ekurhuleni Metropolitan Municipality (EMM), (2007). Environmental Management Framework for Ekurhuleni.

Ellis, J., Deutsch, J., Legret, M., Martin, C., Revitt D.M., Scholes, L., Seiker, H. & Zimmerman U. (2006) Water Practice and technology: The DayWater decision support approach to the selection of sustainable drainage systems: A multi-criteria methodology for BMP decision makers. IWA Publishing. Vol. 1, No. 1. ISSN: 1751-231X.

Endicott, J. & Walker, M. (2003). California Stormwater BMP Handbook: Municipal. California.

Environment Protection Authority – Melbourne Water Corporation (1999). Urban Stormwater: Best Practice Environmental Management Guidelines. CSIRO Publishing. Collingwood.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand- Krajewski, J. L. & Mikkelsen, P. S. (2015). SUDS, LID, BMPs, WSUD and more: the evolution and application of terminology surrounding urban drainage. Urban Water Journal 12 (7), 525–542.

Ghani, A.B., Zakaria, N.A., Chang, C.K., & Ainan, A. (2008). Sustainable Urban Drainage Systems (SUDS) - Malaysian Experiences. *11th International Conference on Urban Drainage*, Edinburgh, Scotland, UK, 2008.

Greenstone, C. (2010). eThekwini Municipality Green Roof Pilot Project Report November 2008 to November 2009. Green Roof Designs cc. eThekwini.

Hatt, B. E., Deletic, A. & Fletcher, T. D. (2007). Stormwater reuse: designing biofiltration systems for reliable treatment. *Water Science and Technology*, 55(4), 203- 207.

Hatt, B.E., Fletcher, T.D., & Deletic, A., (2009). Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. Journal of Hydrology 365: 310-321.

Henderson, C., Greenway, M., & Phillips, I., (2007). Removal of dissolved Nitrogen, phosphorus and carbon from stormwater by biofiltration mesocosms. *Water Science and*

Technology, 55 (4): 183–191.

Hobart City Council. (2006). Water Sensitive Urban Design Site Development Guidelines and Practice Notes. Hobart City Council. Tasmania.

Hussain, C.F., Brand, J., Erickson, A.J., Gulliver, J.S. & Weiss, P.T. (2010). Case Study #1: Monitoring a dry detention pond with under-drains, University of Minnesota, A case study on a dry detention pond designed to provide on-site storage up to a 100 year, 24 hour rainfall event. Available at: http://stormwaterbook.safl.umn.edu/content/case-study-1monitoring-dry-detention-pond-under-drains.

Ken-Mark-Turf, (2012). Detention Pond Demucking, Pond Cleanout & Maintenance. http://www.kenmarkturf.com/2011/03/09/ken-mark-turf-provides-retention-and-detention-ponds-maintenance/. Date of access: 13 March. 2022.

Lakeside Design Service. (2012). Available at: Retention Pond General Information. http://lakefrontinc.com/services-ponds.html.

Lim, H. S., Lim, W., Hu, J. Y., Ziegler, A. & Ong, S. L. (2015). Comparison of filter media materials for heavy metal removal from urban stormwater runoff using biofiltration systems. Journal of Environmental Management 147, 24–33.

Marsalek, J., Rochfort, Q., Brownlee, B., Mayer, T. & Servos, M. (1999). An exploratory study of urban runoff toxicity. *Water Science and Technology*, 39(12), 33- 39.

Matthews, S. (2010). Weathering the Storm (Water) in Cape Town, The Water Wheel, South African Water Research Commission, 9 (3), 26-29

Mays, L. (2001). Water Resources Engineering. John Wiley & Sons. New York. ISBN 0-47129783-6. DOI: 10.1002/ep.670200306.

McWhirter, R. (2004). Warriewood Valley Urban land Release, Sustainable Water Challenge 2004, Pittwater: A case study on the application of detention basins for flood detention and water quality improvement purposes. Available at: http://www.pittwater.nsw.gov.au/__data/assets/pdf_file/0019/11944/annual_report.pdf

Melbourne Water, (2005). *WSUD Engineering Procedures: Stormwater.* CSIRO Publishing, Melbourne, Australia.

Minton G. (2002). Stormwater Treatment. Resource Planning Associates. Amica International Inc. Seattle.

Milandri, S. (2011). *An investigation into the performance of vegetated biofilters in removing nutrients from stormwater in the City of Cape Town, South Africa*. Department of Environmental and Geographical Science, University of Cape Town.

Mitchell, R. K., Busenitz, L., Bird, B., Gaglio, C. M., McMullen, J. S., Morse, E. A., & Smith, J. B. 2007. The central question in entrepreneurial cognition research 2007. Entrepreneurship Theory & Practice, 31(1): 1-27.

Moreton Bay Waterways and Catchments Partnership (MBWCP). (2006). Water Sensitive Urban Design – Technical Design Guidelines for South East Queensland. Brisbane City Council and Moreton Bay Waterways and Catchments Partnership. South East Queensland.

North Carolina Division of Water Quality (NCDWQ), (2007). Stormwater Best Management Practices Manual, North Carolina Division of Water Quality, North Carolina.

Owens, S. & Cowell, R. (2002). Land and limits: Interpreting sustainability in the planning process. London: Routledge.

Parkinson, J. & Mark O. (2005). Urban Stormwater Management in Developing Countries. IWA Publishing. London. ISBN: 9781843390572.

Payne, E.G.I., Pham, T., Perran LM Cook, P.L.M., Fletcher, T.D., Hatt, B.E. and Deletic, A. (2013). *Biofilter design for effective nitrogen removal from stormwater – influence of plant species, inflow hydrology and use of a saturated zone.* Monash Water for Liveability, Department of Civil Engineering, Monash University, Australia.

Prodanovic, V., Zhang, K., Hatt, B. E., McCarthy, D. & Deletić, A. (2018). Optimisation of lightweight green wall media for greywater treatment and reuse. Building and Environment 131, 99–107.

Read, J., Wevill, T., Fletcher, T., and Deletic, A. (2008). Variation among plant species in pollutant removal from stormwater in biofiltration systems. *Water Research*, 42(4- 5), 893-902.

Song X., Yang X., Hallerman E., Jiang Y and Huang Z. (2020). Effects of Hydraulic Retention Time and Influent Nitrate-N Concentration on Nitrogen Removal and the Microbial Community of an Aerobic Denitrification Reactor Treating Recirculating Marine Aquaculture System Effluent. Water 2020, 12, 650; doi:10.3390/w12030650

South Africa. National Environmental Management Act 107 (Pretoria: Government Printer, 1998)

South African Weather Service and OR Tambo International Airport. (2018). *Johannesburg*

Climatic Guide.

Stahre, P. (2006). Sustainability in Urban Storm Drainage. Svenskt Vatten. Stockholm. ISBN: 9185159204.

Suprihatin S., Cahyaputri B., Romli M., and Yani M. (2007). “Use of biofilter as pre-treatment of polluted river water for drinking water supply,” Environ. Eng. Res., vol. 22, no. 2, pp. 203–209.

Taylor, S. (2003). New Development and Redevelopment: Stormwater Best
Management Practice Handbook. California Stormwater Quality Association.
California.

Van Roon, M., (2007). Water localisation and reclamation: Steps towards low impact urban design and development. Journal of Environmental Management 83: 437-447.

Van Rooyen, J.A., and Versfeld, D.B. (2010). *Integrated Water Resource Planning For South Africa: A Situation Analysis 2010.*

Wanielista M., Kelly M., & Hardin M. (2008). A Comparative Analysis of Green roof Designs Including Depth of Media, Drainage Layer Materials, and Pollution Control Media. University of Central Florida – Stormwater Management Academy. Florida. FDEP Project number: WM 864.

Water Research Commission, (2013). The South African Guidelines for Sustainable Drainage Systems. Alternative Technology for Stormwater Management. WRC Report No. TT 558/13

Water Research Commission, (2014). Water Sensitive Urban Design (WSUD) for South Africa: Guidelines.

Wendling, L. & Dumitru, A. (2021). Indicators of NBS performance and impact. In: Evaluating the Impact of Nature-Based Solutions: A Handbook for Practitioners, 1st edn (Dumitru, A. & Wendling, L., eds). European Union, Luxembourg, pp. 114–173.

Wilson S., Bray R. and Cooper P. (2004) Sustainable drainage systems: Hydraulic, structural and water quality advice. CIRIA C609. London.

Woods-Ballard B., Kellagher R., Martin P., Jefferies C., Bray R. and Shaffer P (2007). The SUDS Manual. CIRIA 697. Classic House, London.

WSUD (Engineering Procedures for Stormwater Management in Southern Tasmania), (2005).

Stormwater management. Available at: http://www.derwentestuary.org.au/file.php?id=214.

Zinger Y, Deletic A, T.D. Fletcher, P. Breen, T. (2010). A Dual-mode Biofilter System: Case study in Kfar Sava, Israel, 12th International Conference on Urban Drainage, Porto Alegre/Brazil, 11-16 September 2011.

Zinger, Y., Deletic, A. & Fletcher, T. D. (2007). The effect of various intermittent wet-dry cycles on nitrogen removal capacity in biofilters systems. 13th International Rainwater Catchment Systems Conference and 5th International Water Sensitive Urban Design Conference, 21-23 August 2007 Sydney, Australia.

Table A1: Appendix A: Potential human capital for SuDS interdisciplinary partnerships

Professionals	Expertise and knowledge base	Elementary focal point(s) in SuDS
Civil Engineers	Infrastructure design and management	Water Quantity/Quality
Botanists	Vegetation sciences and plant biology	Quality/Amenity and Biodiversity
Architects	Infrastructure conceptualisation and structural aesthetics	Quantity / Amenity and Biodiversity
Climatologists	Climatology issues and concerns, and 'climate change'	Quantity / Amenity and Biodiversity
Economists	Funding, fiscal viability and investment opportunities	All
Engineering Geologists	Engineering geology and earthwork requirements	Quantity
Clients	Conceptual specifications and appointments	All
Environmentalists	Environmental impacts and protection	Amenity and Biodiversity
Epidemiologists	Water-borne diseases, and related health provisos	Quality / Amenity and Biodiversity
Freshwater Ecologists	Urban river restoration, rehabilitation and remediation	Quality / Amenity and Biodiversity
Geohydrologists	Urban groundwater use and requirements	Quantity / Quality
Geomaticians	Spatial data acquisitioning and spatial data management systems	Quantity
Social Anthropologists	Local cultural studies and social impact assessments	Amenity and Biodiversity
Historians	Site heritage and historical significance	Amenity and Biodiversity
Landscape Architects	Urban vegetation and exterior landscape aesthetics	Quantity / Amenity and Biodiversity
Zoologists	Wildlife biology and habitat requirements	Amenity and Biodiversity
Urban Planners	Urban layouts and land-use requirements	Amenity

Table A2: Appendix B: Stormwater pollutants (Krypo, 2004; Opher & Freidler, 2010)

Pollutant Group	Pollutant	Source	Impacts
Nutrients	Nitrogen & Phosphorus	Fertilisers	Excessive nutrients result in eutrophication. They are commonly associated with algal plumes, reduced clarity resulting in decreased bio-diversity.
		Animal waste	
		Organic matter	
		Septic tanks	
Sediments	Suspended & settable solids	Erosion of landscaping	Increased turbidity, sedimentation, smothering of aquatic plant and animal life.
		Erosion of construction sites	
Organic Material	Plant litter	Landscaping	Increased nutrients & sediment.
Pathogens	Bacteria, viruses and protozoa	Failing sewer/sewage systems	
		Animal waste	
Hydrocarbons	Oils & grease & others	Motor vehicle emissions and wear	

		Industrial processes & waste	Public health risk. Contaminated recreational areas. Threat to downstream irrigation water and edible crops. Decreased economic value of natural recreational areas.
Metals	Lead, copper, zinc and others	Motor vehicle wear	
		Industrial leaks	
		Construction materials-galvanised	
Toxic chemicals	Pesticides and herbicides	Agriculture	
		Landscaping	
Solids	Debris & rubbish	Littering	Threat to wildlife. Aesthetic appeal decreased
		Dumping	

Table A3: Appendix C: SuDS key unit processes (Stormwater quality and quantity management)

Rainwater harvesting	The direct capture of stormwater runoff, typically from rooftops, for supplementary water uses on-site.
Infiltration	The soaking of stormwater runoff into the ground thereby physically reducing the volume of stormwater runoff on the surface.
Detention	The slowing down of stormwater runoff before subsequent transfer downstream.
Conveyance:	The transfer of stormwater runoff from one location to another.
Long-term storage	The volumetric control of stormwater runoff in a specified infiltrating area that will drain very slowly.
Extended attenuation storage	The retention of stormwater runoff to protect receiving watercourses in the event of flooding if long-term storage and additional infiltration are not feasible on site
Sedimentation:	The removal of sediment particles attached to pollution in stormwater runoff by reducing flow velocities to ensure sediment particles fall out of suspension.
Filtration and bio-filtration	The filtering of stormwater runoff pollutants that are conveyed with sediment by trapping these constituents on vegetative species, in the soil matrix or on geotextiles.
Adsorption	The process whereby stormwater runoff pollutants bind to the surface of aggregate particles. Types of adsorption include cation exchange, chemi-sorption and absorption.
Biodegradation	The degradation of organic pollutants in stormwater runoff by microbes.
Volatilisation	The conversion of stormwater runoff compounds to gas or vapour typically as a result of heat, chemical reaction, a reduction of pressure or a combination of these.
Precipitation	The removal of soluble metals in stormwater runoff through chemical reactions between pollutant constituents and aggregate in the control structure to form a suspension of insoluble precipitates.
Plant-uptake	The removal of stormwater runoff nutrients and metals through uptake by plants.

Nitrification	The oxidisation of ammonia and ammonium ions in stormwater runoff by microbial factions to form nitrite and nitrate.
Photosynthesis	The breakdown of organic pollutants in stormwater runoff through extended exposure to ultra-violet light.
Stormwater quality and quantity management	This entails rainwater harvesting, infiltration, detention, conveyance and retention of stormwater runoff to protect receiving waters.

Figure A4: Appendix D: Experimental setup (Stormwater Biofilter)

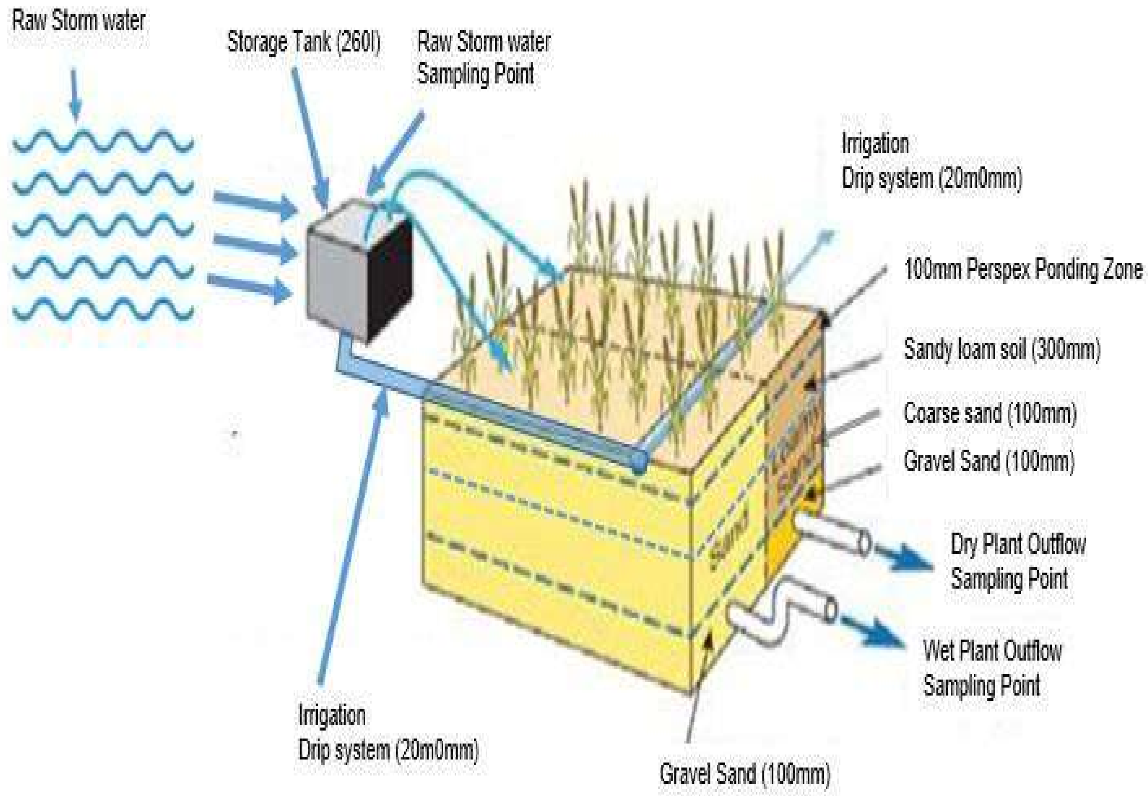
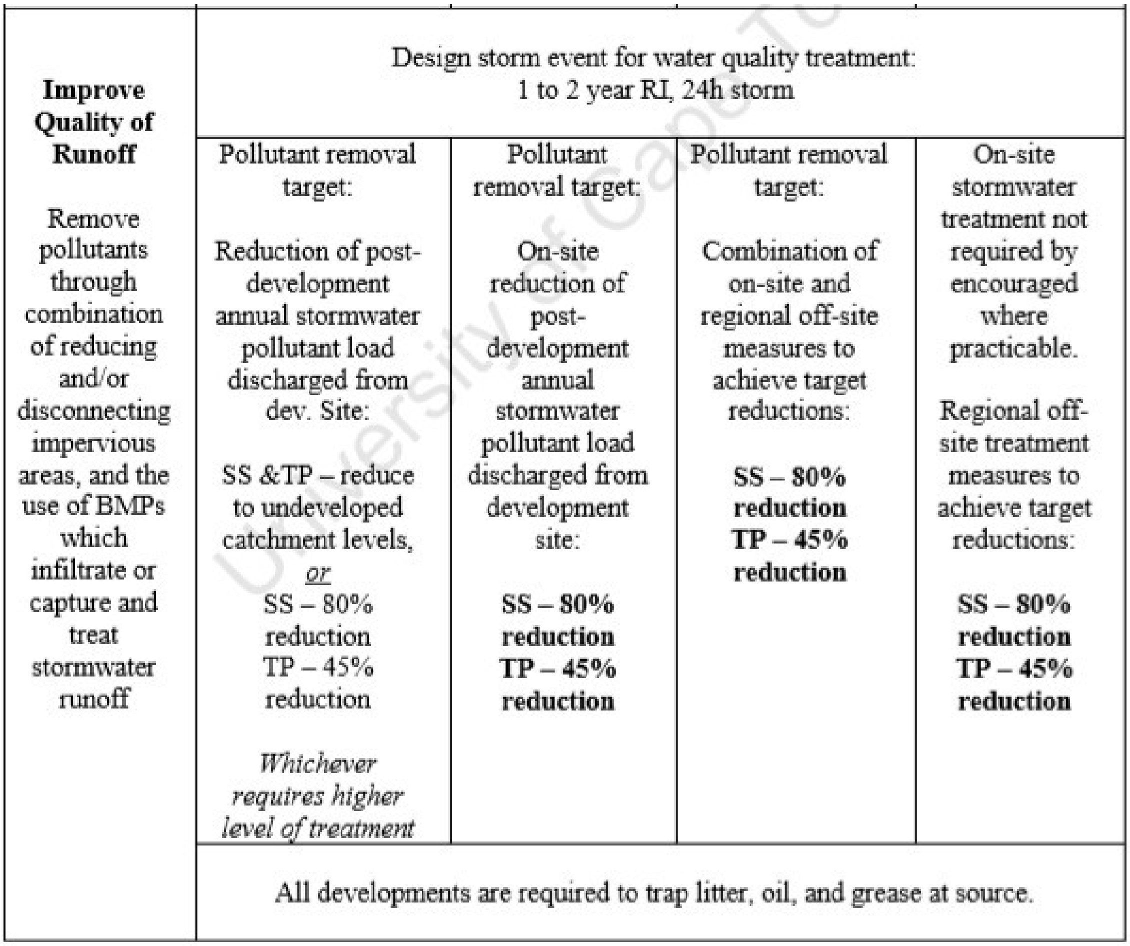


Table A4: Appendix E: CoCT' Criteria for Achieving SuDS Objectives, 2009



Improve Quality of Runoff Remove pollutants through combination of reducing and/or disconnecting impervious areas, and the use of BMPs which infiltrate or capture and treat stormwater runoff	Design storm event for water quality treatment: 1 to 2 year RI, 24h storm			
	Pollutant removal target: Reduction of post-development annual stormwater pollutant load discharged from dev. Site: SS &TP – reduce to undeveloped catchment levels, *or* SS – 80% reduction TP – 45% reduction *Whichever requires higher level of treatment*	Pollutant removal target: On-site reduction of post-development annual stormwater pollutant load discharged from development site: **SS – 80% reduction** **TP – 45% reduction**	Pollutant removal target: Combination of on-site and regional off-site measures to achieve target reductions: **SS – 80% reduction** **TP – 45% reduction**	On-site stormwater treatment not required by encouraged where practicable. Regional off-site treatment measures to achieve target reductions: **SS – 80% reduction** **TP – 45% reduction**
	All developments are required to trap litter, oil, and grease at source.			

(CoCT, 2009)

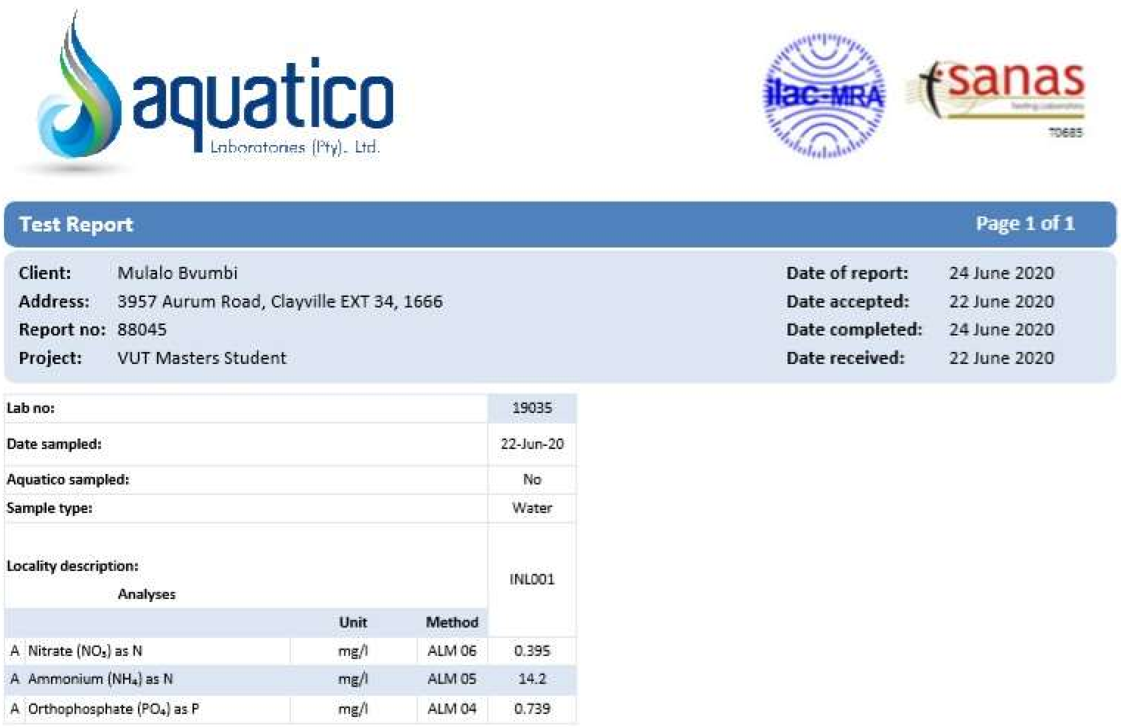
Table A6: Appendix F: Raw Sampling results

aquatico Laboratories (Pty). Ltd.

Test Report **Page 1 of 1**

Client:	Mulalo Bvumbi	**Date of report:**	01 July 2020
Address:	3957 Aurum Road, Clayville EXT 34, 1666	**Date accepted:**	30 June 2020
Report no:	88454	**Date completed:**	01 July 2020
Project:	VUT Masters Student	**Date received:**	30 June 2020

Lab no:			21391
Date sampled:			30-Jun-20
Aquatico sampled:			No
Sample type:			Water
Locality description:			INL001
Analyses	**Unit**	**Method**	
A Nitrate (NO_3) as N	mg/l	ALM 06	4.42



aquatico Laboratories (Pty). Ltd.

Test Report **Page 1 of 1**

Client:	Mulalo Bvumbi	**Date of report:**	24 June 2020
Address:	3957 Aurum Road, Clayville EXT 34, 1666	**Date accepted:**	22 June 2020
Report no:	88045	**Date completed:**	24 June 2020
Project:	VUT Masters Student	**Date received:**	22 June 2020

Lab no:			19035
Date sampled:			22-Jun-20
Aquatico sampled:			No
Sample type:			Water
Locality description:			INL001
Analyses	**Unit**	**Method**	
A Nitrate (NO_3) as N	mg/l	ALM 06	0.395
A Ammonium (NH_4) as N	mg/l	ALM 05	14.2
A Orthophosphate (PO_4) as P	mg/l	ALM 04	0.739

aquatico Laboratories (Pty). Ltd.

ilac-MRA sanas T0685

Test Report Page 1 of 1

Client:	Mulalo Bvumbi	**Date of report:**	24 June 2020
Address:	3957 Aurum Road, Clayville EXT 34, 1666	**Date accepted:**	22 June 2020
Report no:	88043	**Date completed:**	24 June 2020
Project:	VUT Masters Student	**Date received:**	22 June 2020

Lab no:			19028	19029	19030	19031	19032	19033
Date sampled:			22-Jun-20	22-Jun-20	22-Jun-20	22-Jun-20	22-Jun-20	22-Jun-20
Aquatico sampled:			No	No	No	No	No	No
Sample type:			Water	Water	Water	Water	Water	Water
Locality description: **Analyses**			DCA001	DSF002	DBG003	WB002	WKC001	WCR003
	Unit	**Method**						
A Nitrate (NO$_3$) as N	mg/l	ALM 06	0.510	2.33	0.348	1.49	2.39	4.39
A Ammonium (NH$_4$) as N	mg/l	ALM 05	0.195	0.135	0.119	0.039	0.029	0.056
A Orthophosphate (PO$_4$) as P	mg/l	ALM 04	<0.005	0.066	<0.005	<0.005	<0.005	<0.005

aquatico Laboratories (Pty). Ltd.

ilac-MRA sanas T0685

Test Report Page 1 of 1

Client:	Mulalo Bvumbi	**Date of report:**	02 July 2020
Address:	3957 Aurum Road, Clayville EXT 34, 1666	**Date accepted:**	30 June 2020
Report no:	88455	**Date completed:**	02 July 2020
Project:	VUT Masters Student	**Date received:**	30 June 2020

Lab no:			21392	21393	21394	21395
Date sampled:			30-Jun-20	30-Jun-20	30-Jun-20	30-Jun-20
Aquatico sampled:			No	No	No	No
Sample type:			Water	Water	Water	Water
Locality description: **Analyses**			DSF002	WKC001	WB002	WCR003
	Unit	**Method**				
A Nitrate (NO$_3$) as N	mg/l	ALM 06	2.16	2.56	3.85	5.15