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An investigation into the performance of vegetated biofilters in removing nutrients from stormwater in the City of Cape Town, South Africa

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Plagiarism Declaration

I, Stefan Milandri hereby declare that the study ‘An investigation into the performance of vegetated biofilters to treat stormwater in the City of Cape Town, South Africa’ is my own work and has not been submitted before for any other degree or to any other university. All sources I have used or quoted have been indicated and acknowledged as complete references.

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List of Abbreviations

ARI	Average Recurrence Interval
ASR	Aquifer Storage and Recovery
BMP	Best Management Practice
CBD	Central Business District
CoCT	City of Cape Town
COD	Chemical Oxygen Demand
DWAF	Department of Water Affairs and Forestry
GPT	Gross Pollutant Trap
GRPP	Green Roof Pilot Project
MCPP	Municipal Climate Protection Programme
PVC	Polyvinyl Chloride
SuDS	Sustainable Urban Drainage Systems
WSDP	Water Services Development Plan
WSUD	Water Sensitive Urban Design

University of Cape Town

Abstract

In 2009, the City of Cape Town (CoCT) adopted a stormwater policy which mandates that new and existing developments should reduce the concentrations of phosphorus and suspended solids in stormwater runoff by 45% and 80% respectively, but offered no explicit guidance about how these water quality targets might be achieved. This study aims to contribute to the limited knowledge that exists about the performance of local plant species to treat stormwater. A large nursery-based study was conducted to investigate the performance of nine locally occurring plant species to remove orthophosphate (PO_4^{-3}), ammonia (NH_3) and nitrate (NO_3^-) found in urban stormwater. A synthetic stormwater concentration was applied to each species together with a control of consisting only of soil (Malmesbury shale). The discharge was collected from a drainage pipe at the base of each of the 300 containers. The results show that all species (excluding *Ficinia*) reduced the average concentrations of PO_4^{-3} by 81% and NH_3 by 90%. By contrast, NO_3^- was removed by an average of 69% (excluding *Elegia* and *Phragmites*) with eight of the nine species removing significantly more than the control. The species that performed well for all three nutrients include *Agapanthus* and turf grasses, *Stenotaphrum* and *Pennisetum*. The results of the study highlight 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 PO_4^{-3} and NH_3 ; and that plant choice is essential in the removal of NO_3^- . Future research should test plant species in both the laboratory and field settings, and should include additional contaminants such as household detergents, heavy metals and bacteria.

Chapter 1 – Introduction

1.1 Introduction

The expansion of urban areas has severely disrupted and altered the natural flows of water within the hydrological cycle (Atlanta Regional Commission, 2001; Zalewski, 2000; Livingston, 1992). In particular, stormwater plans and designs in urban areas have sought to collect runoff and dispense of it as efficiently as possible via the closest watercourse (Van Roon, 2007; Bottcher *et al.*, 1995). However, such measures often gave too much attention to protecting the collection area without considering the negative impacts on the receiving environment such as downstream flooding, the accumulation of land-based pollution in water bodies, and the depletion of the water table by reducing permeable surfaces (Echols, 2008; Grimm, 2007; Villarreal *et al.*, 2004; Livingston, 1992). While the levels of stormwater contaminants such as sediment, nutrients, heavy metals, hydrocarbons and pathogens are often fairly low, their cumulative effect adversely impacts on the quality of surface and ground water (Lee *et al.*, 2004; Miltner *et al.*, 2004).

The negative implications of excess stormwater runoff affects the majority of urban centres, depending on factors such as urban design, topography, rainfall, vegetative cover, drainage and the extent to which cities have supported the expansion of flood control projects in line with the growth of urban populations (Maine Department of Environmental Protection, 2006). Moreover, continued reliance on traditional stormwater engineering may lead to further deterioration of receiving waters because the quality of stormwater runoff is often linked to the level and state of development in the catchment (Steedman, 1988). This highlights the need to address the limitations of conventional stormwater management to not only reduce flooding and improve water quality, but to protect the environment, improve amenity value and bolster urban biodiversity (UN, 2007; Villarreal *et al.*, 2004).

1.2 Sustainable Urban Drainage Systems

Many developed countries are replacing conventional engineering approaches with alternatives that aim 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 *et al.*, 2009; Bratieres *et al.*, 2008; Van Roon,

2007). Two internationally recognised trends, at the forefront of urban water management best practice, are found in the concepts of Water Sensitive Urban Design (WSUD) and Sustainable Urban Drainage Systems (SuDS) (Bratieres *et al.*, 2008; Van Roon, 2007; Hobsons Bay City Council, 2002). WSUD is a holistic approach 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 (CIRIA, 2007; Brisbane City Council, 2006). 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 (Ghani *et al.*, 2008; CIRIA, 2007).

Biofilters are gaining acceptance and are being applied to a range of developments according to size, location and appearance (Hatt *et al.*, 2009). Biofilters filter stormwater runoff through vegetated soil through detention and biological uptake (Melbourne Water, 2005). Typical examples of biofilters include green roofs, vegetated filter-strips, roadside swales, retention and detention ponds and natural or artificial wetlands.

Various researchers have demonstrated that biofilters are able to substantially reduce the concentration of suspended solids (90-96%), heavy metals (>90%) and phosphorus (70-94%) (Bratieres *et al.*, 2008; Fletcher *et al.*, 2007; Henderson *et al.*, 2007; Davis *et al.*, 2001, 2003, 2006). Results also show that total nitrogen (TN) removal varies considerably (15-65%) due to the leaching of nitrate (NO_3^-) from biofiltration systems (Bratieres *et al.*, 2008). Only two other studies have investigated the hydraulic performance of biofilters (Hatt *et al.*, 2009; Hunt 2003). Biofilters were often believed to be ineffective in reducing runoff volumes (Melbourne Water, 2005; ARC, 2003) although such assumptions were rarely supported by empirical data or modelling. Furthermore, Hatt *et al.*, (2009: 320) note that “biofilters can attenuate flow peaks and reduce overall flow volumes, and so can play a role in restoring flow regimes closer to their pre-development”.

1.3 South African Stormwater Context

“The rapid growth of urban areas in South Africa, especially formal and informal high-density housing settlements, has been accompanied by an equally dramatic increase in the volumes of contaminated runoff and this in turn has accelerated the degradation of streams,

rivers, lakes and estuaries” (Ashton & Bhagwan 2001: 1). In particular, high nutrient loads arising from untreated sewerage, detergents and fertilizers stimulate the growth of invasive plant species and algae, and a reduction in dissolved oxygen levels that could result in eutrophication (Bratieres *et al.*, 2008; Healy *et al.*, 2007; Bottcher *et al.*, 1995). In South Africa the focus has primarily been on reducing runoff peaks by constructing retention and detentions ponds, and removing it via the stormwater system, with little being done to improve stormwater quality other than with the exception of some studies that have emphasized the design and efficacy of litter traps (Armitage & Rooseboom, 1999) and those that have studied the reduction in impacts when highly polluted water is redirected to wastewater treatment plants (Duh *et al.*, 2008). This discussion raises the need to consider alternative stormwater solutions such as WSUD and SuDS, both of which demand an integrated approach to managing the urban water cycle, and have potential to reduce flooding as well as improve site amenity and water quality prior to being discharged into freshwater systems.

Since 1985 the City of Cape Town (CoCT) has expanded its footprint by 40%, though “...mostly without coordinated direction, management or alignment with infrastructure provision” (CoCT 2006: 4). For example, between 1985 and 2005 the city grew at an average rate of 1232 hectares per year, nearly doubling the footprint to that of the 70s and early 80s (CoCT, 2007). Unchecked urban sprawl has spread deeply into outlying agricultural land and areas of conservation value (CoCT, 2006), in which a greater proportion of this growth has been in low-density residential development (CoCT, 2007). Development has resulted in the removal of natural habitat, which has compromised biodiversity of species and resulted in a widespread reduction of ecosystem services (Daily, 2000; Zalewski, 2000; Niemczynowicz, 1999). These patterns of development place strain on municipal service provision, and increase the occurrence of flooding and accumulation of contaminated stormwater runoff (Ashton & Bhagwan, 2001).

In a move to address these stormwater issues, the CoCT drafted a stormwater policy in 2009 based on the principles of WSUD and SuDS (Appendix A). This policy establishes measures to deal with the quantity and quality of stormwater at its source, and to return stormwater flows to predevelopment levels (CoCT, 2009). In particular, the policy sets water quality targets which recommend that new and existing developments situated in catchments with sensitive freshwater systems should aim to reduce phosphorus and suspended solids by 45%

and 80% respectively (CoCT, 2009). While various forms of nitrogen are also monitored by the CoCT, they were not included in the water-quality targets, and neither were any heavy metals. Nonetheless, the current targets provide an important step in addressing water-quality issues in the CoCT.

1.4 Rationale

The CoCT is currently facing a number of challenges in the implementation of the SuDS treatment train. Firstly, although the international research has demonstrated that SuDS biofilters can reduce runoff volumes and improve quality, there is difficulty in quantifying the extent to which these technologies meet design objectives in the local context (especially with respect to water quality). Most research has been conducted in developed countries where heavy metals are often the primary concern. While their research has shown reductions in nitrogen and phosphorus, their nutrient loads are lower in concentration than levels suggested in the CoCT's stormwater policy. However, the CoCT's SuDS policy only includes water-quality targets for phosphorus and suspended solids, and does not address issues related to excess nitrogen or flooding. Nitrogen may have been excluded due to the focus on reducing eutrophication, which can be encouraged by high phosphorus levels. The CoCT may also wish to focus their attention on the two primary pollutants (CoCT, 2009).

In addition, the performance of vegetation in removing contaminants varies between plant species (Read *et al.*, 2008) and is affected by local climatic conditions (Bratieres *et al.*, 2008). This suggests that knowledge about the performance of local species is an imperative in determining the performance of biofilters.

1.5 Aim and Objectives

1.5.1 Aim to the Study

The aim of this study is to investigate the performance of nine locally occurring plant species to treat stormwater in the City of Cape Town through the removal of orthophosphate (PO_4^{-3}), ammonia (NH_3) and nitrate (NO_3^-), and thereby reducing overall nutrient loads.

1.5.2 Specific Objectives

The aim will be achieved by:

- Assessing the ability of the nine selected plant species to remove the three nutrients from stormwater
- Assessing the physical growth-response of the plant species to these nutrients
- Identifying plant species suitable for use in the CoCT's SuDS treatment trains.

1.6 Study Method

The study investigates the ability of nine plant species (five dryland and four wetland species) to treat stormwater in a glasshouse experiment. The experiment was conducted between April 2009 and September 2010 in a glasshouse at the University of Cape Town. Thirty plants per species, along with a control, were individually planted into tall containers each fitted with a drainage pipe for the collection of the discharge.

Initially all plants were given potable water during an establishment period. From March 2010 ten plants of each species and the control were randomly selected to receive either potable water, synthetic Stormwater 1 (S1) or Stormwater 2 (S2) (\pm double concentration of S1). After six months, water quality samples were collected at three-week intervals from the inflow and outflow pipes and taken to a laboratory for analysis.

1.7 Thesis Outline

Chapter 2 begins by discussing the SuDS philosophy and the centrality of the treatment train. It then reviews international biofiltration literature and the means by which these technologies achieve quality improvement objectives. Although SuDS are also used reduce the quantity of stormwater runoff, a separate section on this was not included as the current research did not address this issue. Various examples of biofiltration research in South Africa are then discussed. This is followed by Chapter 3 which discusses the research methods. Chapter 4 discusses the performance of the nine plant species in removing stormwater nutrients and the physical growth-response of selected plant species, before listing the species in order of nutrient-removal performance. The results of this study not only demonstrate that several of the selected plant species removed significantly more than

the control, but that levels of nutrient removal (especially NO_3^-) were often higher than similar international biofiltration research. Finally, Chapter 5 concludes with a synthesis of the results, a concluding discussion and offers recommendations for further research.

Chapter 2 – Sustainable Stormwater Management

2.1 Introduction

Conventional engineering solutions have typically been designed to remove urban stormwater runoff by redirecting the unwanted accumulation of water via pipe and canal networks to the closest watercourses (Van Roon, 2007; Bertrand-Krajewski *et al.*, 2000; Bottcher *et al.*, 1995). However, while such measures often reduce the risk of flooding in one area, it negatively impacts on the receiving environment elsewhere (Dietza & Clausen, 2008; Villarreal *et al.*, 2004). Many developed countries are now replacing this approach with alternatives that incorporate sustainability principals into the design and operations of stormwater systems (CIRIA, 2007; Lundin & Morrison, 2002). These alternatives seek to manage the quality and quantity (total volume and flow rates) of stormwater runoff as close to the source as possible in an effort to return the flow of water to pre-development conditions (Hatt *et al.*, 2009; Dietza & Clausen, 2008; Van Roon, 2007). The City of Cape Town (CoCT) Catchment, Stormwater and River Management Branch are actively incorporating two such alternative approaches into plans and policy, namely Water Sensitive Urban Design (WSUD) from Australia, and Sustainable Urban Drainage Systems (SuDS) from the United Kingdom (Bratieres *et al.*, 2008; Van Roon, 2007; Hobsons Bay City Council, 2002). WSUD is an holistic approach to urban water management that focuses on the relationship between the urban environment and the urban water cycle, that is the integration of stormwater, water supply and waste water management, while SuDS focuses largely on stormwater management and the use of alternative technologies and techniques (CIRIA, 2007; Brisbane City Council, 2006). The inclusion of such measures is an effort to transform stormwater from being characterised as waste water to a resource that enhances the urban environment and promotes water security (Hatt *et al.*, 2009; Villarreal & Bengtsson, 2004).

SuDS systems are typically designed to achieve three objectives which include reducing the impact of urban development on the quantity and quality of stormwater runoff; and enhancing urban space, for example, through provision of aesthetically pleasing recreation space and in increasing opportunities for natural habitat (Bratieres *et al.*, 2008; Martin *et al.*, 2007; Van Roon, 2007; Tuccillo, 2006). While these objectives are equally important and should be achieved whenever possible, the degree to which each objective is addressed will

depend on characteristics and constraints of each site (CIRIA, 2007). SuDS makes use of a treatment train or series of drainage techniques, which includes technologies such as sand filters, vegetated filter-strips, roadside swales, retention and detention ponds, and natural or artificial wetlands (CoCT, 2009; CIRIA, 2007; Van Roon, 2007). Central to the treatment train is the use of biofilters (i.e. vegetated filters) which not only have potential to slow the rate of flow, but to improve the natural processes of infiltration, attenuation and water quality (Van Roon, 2007; Livingston, 1992). These elements within a treatment train are gaining acceptance as they can be applied to a range of developments according to size, location and appearance (Hatt *et al.*, 2009).

The following section discusses the role of the SuDS treatment train as an alternative to conventional stormwater management. In essence the treatment train provides a series of drainage techniques that help return the flow of water in a catchment to pre-development levels (Dietza & Clausen, 2008; CIRIA, 2007). The importance of biofilters in the treatment train is then discussed, with a particular focus on stormwater quality improvements arising from the use of SuDS biofilters. This is followed by a discussion on the availability of biofiltration research in South Africa. Of the case studies that are cited, only the Green Roof Pilot Project (GRPP) in Durban deals specifically with SuDS biofiltration (City of Durban, 2010). However, two additional case studies that deal with the treatment of agricultural effluent were also included as they provide useful insights for SuDS wetlands. Finally, the chapter concludes with a discussion on the effectiveness of biofilters and possibility of implementing them in the CoCT.

2.2 SuDS: The Treatment Train

Any attempt to support the SuDS objectives and return the flow of water in a catchment to predevelopment levels must be addressed through the use of a ‘treatment train’ (CIRIA, 2007; Knox City Council, 2002). In essence, the treatment train can be visualized as a continuum between the point where water falls on the surface to the point where it re-evaporates and is lost through the transpiration of plants or when it finally reaches receiving waters (Atlanta Regional Commission, 2001). This concept underpins the design of functional SuDS schemes which operate through a series of vegetated drainage techniques that gradually reduce the pollution, flow rates and volumes of stormwater that enter receiving water bodies (Figure 1) (Australian WSUD Guidelines, 2007; CIRIA, 2007).

Figure 1 demonstrates how runoff is collected from various sources, cleaned of gross pollutants and passed through various conveyance and discharge controls to gradually remove pollutants and reduce flow volumes and flow rates. Examples include sand filters, vegetated filter-strips, roadside swales, retention and detention ponds, and natural or artificial wetlands (Australian WSUD Guidelines, 2007). Of the available SuDS elements, wetlands are found to be one of the most effective at improving water quality due to prolonged detention, which encourages sedimentation, and the biological uptake of nutrients (Australian WSUD Guidelines, 2007; EA, 2003; Knox City Council, 2002). A detailed description of the primary elements of the treatment train is available in Appendix B.

Unlike conventional systems that remove runoff as quickly as possible, the treatment train makes extensive use of biofilters which slow the rate of flow and enable the natural processes of infiltration, attenuation and quality improvement to pre-development levels (CoCT, 2009; Van Roon, 2007; Livingston, 1992). In addition, elements of the treatment train, which are typically installed above-ground and use vegetation, provide space for recreation and natural habitat, and have the potential to improve the aesthetic appeal and property values of urban areas (CIRIA, 2007). The treatment train can be designed to reduce the quantity and pollutant load of urban runoff, but also to provide a number of environmental and social benefits.

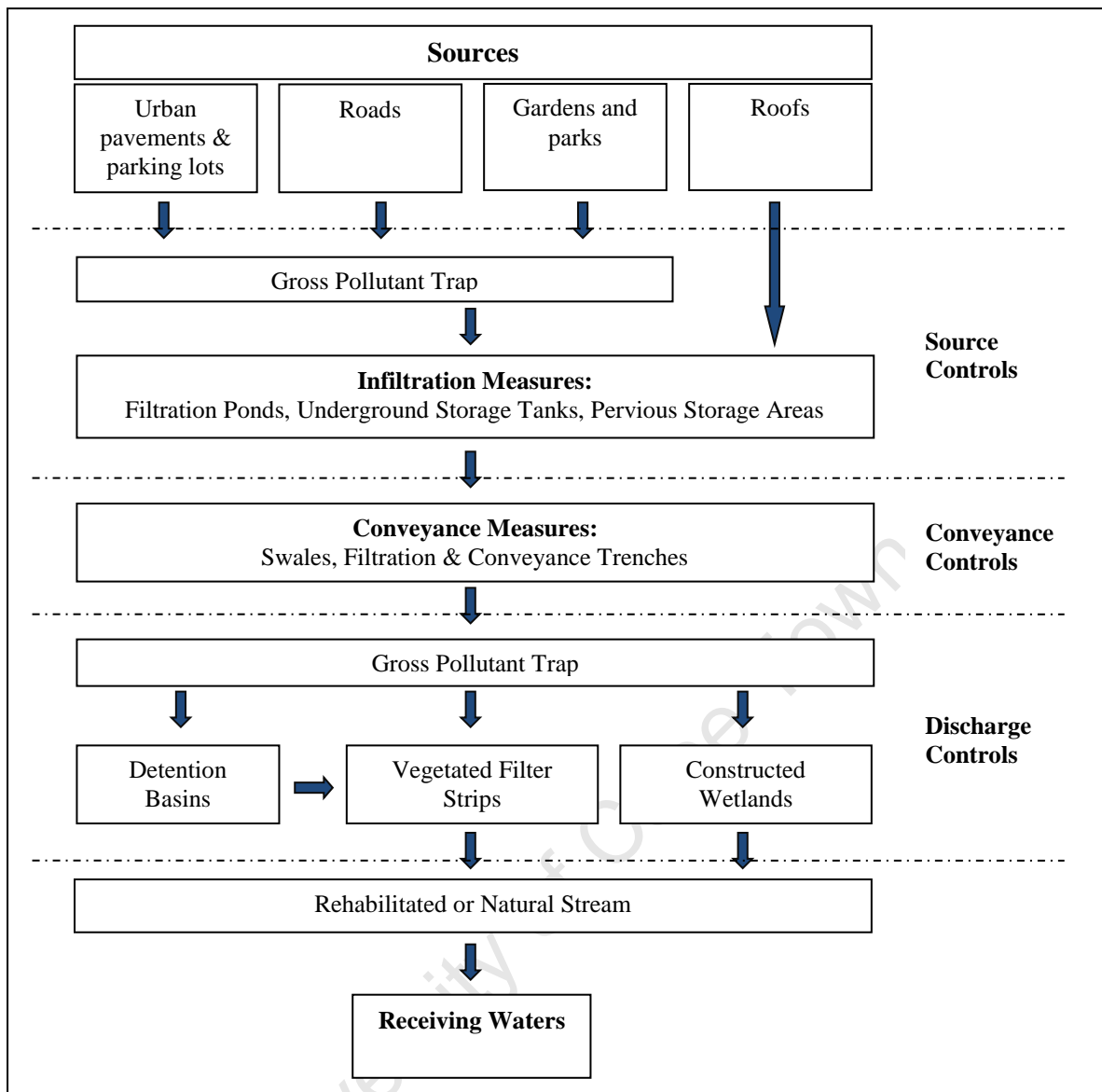


Figure 1: Treatment train (adapted from: Knox City Council, 2002: 17)

According to CIRIA (2007: 12) “...stormwater should be managed in small, cost-effective landscape features located within small sub-catchments rather than being conveyed to and managed in large systems at the bottom of drainage areas (end of pipe solutions).” In this context, stormwater management should start with techniques preferably higher in the treatment train and use natural conveyance schemes such as swales and filter-strips (Knox City Council, 2002). However, some reticulation systems may be required if space is restricted or if the gradient of the slope is too steep (CIRIA, 2007; Idaho Department of Environmental Quality, 2005). CIRIA (2007: 12) note that “water should be conveyed elsewhere only if it cannot be dealt with on site”. Finally, increasing the number of treatment train elements used in a series typically improves overall performance, while pre-treatment

(e.g. sediment traps) and regular maintenance is necessary to achieve the long-term efficacy of the system (CIRIA, 2007; Knox City Council, 2002). The following subsections describe the manner in which SuDS elements address both quantity and quality, and show the linkages between the two. For instance, the use of biofilters encourages infiltration, which both reduces the total runoff volume and enables the sedimentation of suspended solids and adhered heavy metals.

2.3 Biofiltration

SuDS technology is gaining popularity as it can typically attain quality and quantity objectives irrespective of a development's size, location or appearance (Hatt *et al.*, 2009). In addition, the use of biofilters is central to the functioning of most SuDS elements and therefore to the treatment train as a whole (CIRIA, 2007). As mentioned previously, biofilters operate by slowing flow rates, thereby supporting the natural processes of infiltration, sedimentation and biological uptake (Melbourne Water, 2005). Significantly, biofiltration not only affords significant benefits relating to the quality and quantity of stormwater runoff, but also provides opportunities to promote amenity and biodiversity within the urban context. Although biofilters have been found to reduce runoff volumes (Hatt *et al.*, 2009; Hunt, 2003), the current study focused on quality control and therefore only discusses literature related specifically to this.

2.3.1 Addressing Quality Control

A spectrum of natural water treatment processes can be incorporated into the design of the SuDS treatment train. As discussed in the previous chapter, the use of biofilters plays 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 (Table 1) (Tuccillo, 2006). A treatment train removes coarse contaminants such as litter; slows the rate of flow; and encourages infiltration and the removal of sediment, nutrients, organics and heavy metals (Muthanna *et al.*, 2007; Melbourne Water, 2005). However, certain pollutants, such as sediment, are far more prevalent than others (Idaho Department of Environmental Quality, 2005). Sediments increase turbidity and clog receiving water bodies, which increases the risk of flooding, decreases storage capacity of detention and retention ponds, and negatively impacts on the environment (Cullum *et al.*, 2006; Maine DEP, 2006;

Livingston, 1992). As such the treatment train seeks to remove coarse sediments as early as possible so as prevent the clogging of subsequent SuDS elements. Sediment often transports adsorbed heavy metals; which reduce water quality; have the potential to contaminate potable water supplies; and are harmful to aquatic fauna at elevated levels (Idaho Department of Environmental Quality, 2005). In addition, biofilters have also been found to be effective in the direct uptake of dissolved nutrients such as nitrogen and phosphorus.

Table 1: Relationship between particle size and hydraulic loading (Adapted from: Australian WSUD Guidelines, 2007)

Size Range (µm)	Pollutant				Treatment Measure				Hydraulic Loading Rate
	Litter	Sediment	Nutrients	Metals	GPT's	Swales	Detention Ponds	Wetlands	
>5000 Gross									1,000,000-100,000
5000-125 Coarse									50,000-5,000
125-0.45 Fine									2500-1000
10-0.45 Colloidal									500 - 50
<0.45 Dissolved									10

Studies show that biofilters are effective in retaining heavy metals, suspended solids and phosphorus (P), although the removal of total nitrogen (TN) varies (Hatt *et al.*, 2009; Hsieh and Davis, 2005a,b; Davis *et al.*, 2001, 2006). In a series of laboratory studies, Davis *et al.*, (2001, 2003, 2006) showed a substantial reduction in the concentration of heavy metals (>90%), phosphorus (70-85%) and ammonia (NH₃), but variable TN removal (15-65%) from less than 20% nitrate (NO₃⁻) retention in biofiltration systems. Bratieres *et al.*, (2008) confirmed these results, adding that biofilters were able to remove more than 90% of suspended solids.

In spite of this, there has been limited research in studying the causes of fluctuations in treatment performance. 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. In a parallel study, 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. The choice of soil media also contributes to pollutant removal. For example, while Davis *et al.*, (2001) notes that organic matter improves the removal of heavy metal removal, but it may also encourage nutrient leaching (Hsieh and Davis, 2005a, b). In addition, while increased media depth improved phosphorus removal, it may result in an increase in the leaching of nitrates (Davis *et al.*, 2006).

Bratieres *et al.*, (2008) emphasized the design of biofilter systems as an important factor in the absorption and adsorption of pollutants. 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). In a study of vegetated biofilters, Bratieres *et al.*, (2008) found that only two of the five plant species (*Carex appressa* and *Melaleuca ericifolia*) were able to remove more than 70% of Total Nitrogen. However, where Total Phosphorus is the primary contaminant, biofilter systems consistently removed a mean value of 80%, although the levels of organic matter in the soil media were low (Bratieres *et al.*, 2008). Nonetheless, not all plants effectively remove pollutants (Revitt *et al.*, 2004). Read *et al.*, (2008) found that while *Juncus* species removed nutrients they were unable to absorb lead and therefore support the use of a mixture of species to deal with a variety of target pollutants. However, plant selection should consider more than just the pollutant removal, and should include the ability of individual species to survive stressful situations such as drought or flood (Bratieres *et al.*, 2008).

In the CoCT, SuDS are expected to play an important role in improving the quality of runoff from all urban areas (CoCT, 2009). Specifically, SuDS provides a buffer against point and non-point pollution by containing polluted water as close to the source as possible thereby reducing the pollutant load that enters receiving water bodies (Bratieres *et al.*, 2008; CIRIA, 2007; Bolund & Hunhammar, 1999). The widespread use of fertilizers and detergents together with the poor drainage in informal settlements results in the transfer of suspended solids and nutrients to receiving waters and raises the risk of eutrophication (Bratieres *et al.*, 2008; Ashton & Bhagwan, 2001; Bottcher *et al.*, 1995).

2.4 Biofiltration Research in South Africa

Despite progress in the installation of various SuDS projects in Johannesburg, Durban and Cape Town, there is currently very little research into the actual performance of biofilters in South Africa. In this regard, only the green-roof project in Durban provides an example of SuDS biofiltration research (City of Durban, 2010). Nonetheless, research applicable to SuDS has arisen from the use of wetlands to treat agricultural effluent (e.g. fertilizer, pesticides and winery effluent) in the Western Cape Province (Burton *et al.*, 2007; Schulz and Peall, 2001). However, as mentioned previously, the CoCT is yet to conduct SuDS biofiltration research, but rather has focused attention on setting targets for the removal of suspended solids and phosphorus (CoCT, 2009). In the interim, the CoCT has incorporated various SuDS projects such as the use of permeable paving on the Grand Parade in the CBD.

2.4.1 Green Roof Pilot Project: eThekweni Municipality (Durban)

Whilst the use of green roofs is gaining popularity as a component of the SuDS treatment train as they can be retrofitted into existing developments their occurrence in the South African context is almost non-existent, especially for runoff quality improvements (City of Durban, 2010). In a move to assess this technology in a local setting, the eThekweni Municipality (Durban) initiated the Green Roof Pilot Project (GRPP) in 2008 as part of their Municipal Climate Protection Programme (MCP) (City of Durban, 2010). During Phase 1 of the project, 85 indigenous plant species which were planted into two lightweight growth mediums, with the focus of the research being on promoting biodiversity and reducing runoff volumes and roof temperatures. Thirty-seven of the plants survived the roof-top conditions, with results demonstrating that temperature and runoff volumes were both significantly reduced compared to the bare roof. Due to the success of Phase 1, the GRPP commenced with Phase 2 in December 2009. The report stated that it this would include testing different soil and plant types to increase reductions in temperature and runoff volumes, and importantly it would start monitor runoff quality.

2.4.2 Wetland Treatment

In South Africa there has been little by way of research directly related to SuDS biofilters. However, due to their relatively low treatment costs and labour requirements, wetlands are gaining popularity as a means of treatment of point and non-point pollution (Akcil and

Koldas, 2006; Schulz and Peall, 2001). This is especially true for the treatment of effluent from agricultural and mining sectors (Burton *et al.*, 2007; Schulz and Peall, 2001). Unfortunately, the design is still largely based on European and American research (Batchelor and Loots, 1997). Nonetheless, compared to other SuDS elements, wetlands are among the most effective at water purification (EA, 2003).

2.4.2.1 Agricultural Pollution: Fertilizer and Pesticides

Wetlands are widely recognised for their retention of nutrients and sediments (Schulz and Peall, 2001). However, far less is known about the removal of agricultural chemicals (Baker, 1993), with few studies that have referred to the ability of wetlands to remove herbicides and other organic chemicals (Lewis et al 1999).

In the South African context, the past few decades has seen a drop in the water quality in rivers in the Western Cape Province (Schulz and Peall, 2001). This situation has also occurred in the middle and lower reaches of the Lourens River as a result of increasing agriculture, with associated increases in sediment from the removal of indigenous flora (Tharme et al.,1998). However, research has not been conducted on the extent to which agricultural chemicals are responsible for the degradation of the Lourens River (Schulz and Peall, 2001). In this context, a vegetated wetland was constructed along a tributary of the Lourens River to ascertain the ability of a wetland to reduce various forms of agricultural pollution (i.e. both pesticides and fertilizer).

The wetland retaining total suspended solids, orthophosphate, and nitrate by 15%, 54% and 70% respectively during the dry season¹ and 78%, 75%, and 84% during wet conditions² (Schulz and Peall, 2001). Moreover, the insecticide azinphos-methyl, introduced in runoff at 0.85µg/ℓ, was reduced by between 77% and 93%, while the insecticides chlorpyrifos and endosulfan, introduced at 0.02 and 0.2 µg/ℓ respectively were undetected in samples taken from the outlet (Schulz and Peall, 2001). Significantly, a toxicological evaluation of the wetland showed an 89% reduction of toxic contaminants, clearly demonstrating the ability of constructed wetlands to remove agricultural chemicals (Schulz and Peall, 2001).

¹ Rainfall less than 2 mm per day.

² Rainfall between 2-35 mm per day.

2.4.2.2 Treatment of Winery Effluent

South Africa's winemaking industry disposes approximately one billion litres of effluent annually, much of which is pumped directly into the nearest watercourse (Burton *et al.*, 2007). This is true for all the main drainage basins of the Western Cape Province, namely the Breede, the Berg and the Olifants Rivers (Burton *et al.*, 2007). This pollution, and that from agriculture (e.g. fertilizers and pesticides), contributes to eutrophication and de-oxygenation of rivers and ground water (Bratieres *et al.*, 2008; Burton *et al.*, 2007; Bottcher *et al.*, 1995).

Effluent from the wine industry can be treated in a conventional treatment plant, although such measures are often unaffordable for the small cellars (Burton *et al.*, 2007). As such, the construction of wetlands has been chosen as the means by which to treat effluent from wineries (Burton *et al.*, 2007). Not only do they provide cost-effective treatment, but they require no chemicals and little maintenance, while providing marketing potential for wineries, e.g. recreational and conservation areas. However, there is minimal local research that has been conducted in the treatment of such effluent. Burton *et al.*, (2007) conducted a feasibility study to investigate the development and design of wetlands to treat effluent from wineries. This investigation provided a better understanding of the sensitivities of plants exposed to high chemical oxygen demand (COD), furthered the understanding of wetland hydraulics, and providing insight into the complex interaction that enable micro-organisms and plants to treat winery effluent.

All species used in that study were indigenous. *Typha capensis* (Bulrush) and *Zantedeschia aethiopica* (Arum Lily) were most prevalent. These species showed rapid vegetative growth in response to the added nutrients and in the ability of these species to absorb the nutrient load (Burton *et al.*, 2007). The authors recommended these plants for use in constructed wetlands. The contribution of these observations to the current study is discussed further in the following chapter under the section on plant choice.

2.5 Summary

Worldwide, the focus of SuDS biofiltration has been the treatment of urban stormwater through the removal heavy metals, suspended solids and nutrients. Studies have

demonstrated at least 90% removal of heavy metals and suspended solids, and 70-94% removal of phosphorus (Bratieres *et al.*, 2008; Fletcher *et al.*, 2007; Henderson *et al.*, 2007; Davis *et al.*, 2001, 2003, 2006). However, results also show that total nitrogen (TN) removal varies considerably (15-65%) due to the leaching of nitrate (NO_3^-) from biofiltration systems (Bratieres *et al.*, 2008). In the South Africa urban setting however, where the impact of suspended solids and high nutrient loads is seen as the primary water quality issue, very few studies have measured the actual performance of biofilters in removing nutrients and therefore guide the design of biofilters targeting specific nutrients. One example in the urban context includes the construction of a green roof in Durban's Green Roof Pilot Project (City of Durban, 2010). The first phase of this project did not investigate water quality improvements, but found significant reductions in runoff volumes and ambient temperatures. Other indirectly related agricultural wetland research of Schulz and Peall (2001), showed reductions in nutrients from fertilizer and provides insight into wetland design. Due to the international success of biofilters at improving water quality, and the variability of plant species in removing nutrients (Read *et al.*, 2008), a preliminary laboratory-based study that investigates the nutrient-removing performance of locally occurring plants, was identified as an important point from which further research could proceed. The following chapter describes the materials and methods used.

Chapter 3 – Material and Methods

3.1 Site Description

This laboratory experiment (August 2009 – September 2010) was based on the research of Bratieres *et al.*, (2008) and Read *et al.*, (2008) and was conducted in a glasshouse at the University of Cape Town, South Africa. The glasshouse prevented precipitation from altering the quantity or quality of water used in the experiment, while maintaining near ambient solar radiation, temperature and humidity conditions.

3.2 Experimental Design

3.2.1 Plant Choice

The experiment made use of nine plant species. The selection of these plants was based on the suitability for use in each of the SuDS elements (e.g. swales, filter-strips and wetlands), the extent to which these have been used by municipalities and landscaping companies, 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 (Table 2). The nine species were grouped according to general habitats i.e. four wetland and five dryland plants. In this manner a number of species suitable for each SuDS element (e.g. swales, green roofs and wetlands), were included. However, due to time constraints, the choice of species focussed partly on rapidly maturing genera, which were able to reach physiological maturity within the experimental timeframe, and thus provide an accurate calculation of each species' capacity to remove nutrients. For simplicity, plants are referenced by their genus.

Table 2: List of species grouped by water demand categories

Genus & species	Common Name
Dryland plants:	
<i>Agapanthus praecox</i>	Common Agapanthus
<i>Carpobrotus edulis</i>	Sour Fig
<i>Elegia tectorum</i>	Thatching Reed
<i>Pennisetum clandestinum</i>	Kikuyu Grass
<i>Stenotaphrum secundatum</i>	Buffalo Grass
Wetland plants:	
<i>Zantedeschia aethiopica</i>	Arum Lily
<i>Ficinia nodosa</i>	Knobby Club-rush
<i>Phragmites australis</i>	Common Reed
<i>Typha capensis</i>	Bulrush

All selected dryland and wetland plant species are indigenous to South Africa (except *Pennisetum*) and are used widely in the CoCT by municipalities, landscaping companies and homeowners due to their drought resistance and ornamental value (Bardsley & Edwards-Jones, 2007; Brown, et al. 1998; Duncan, 1998; Pooley, 1998; Rumball, 1991). Although *Pennisetum* is classified as invasive (Cilliers & Bredenkamp, 2000), it has also been used extensively because of its ability to tolerate harsh conditions (Muscolo *et al.*, 2003). There are also concerns about the use of *Phragmites* and *Typha*, 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; Hudon *et al.*, 2005; Rickey & Anderson, 2004). Nonetheless, all nine species could potentially be used in the SuDS treatment train, and were thus included within this preliminary experiment. Seven of the nine plant species³ were obtained from New Plant Nurseries situated in George, in the southern Cape. A portion of the soil was removed from each 4kg planter-bag, part of which was combined with the Malmsebury shale during planting. Five of these species⁴ were delivered in four kg planter bags, while the *Phragmites* and *Typha* were sourced from open ground. The two remaining turf-grass species (*Pennisetum* and *Stenotaphrum*) were sourced from a local nursery and came in the form of grass plugs. All species were planted

³ *Agapanthus*, *Carpobrotus*, *Elegia*, *Zantedeschia*, *Ficinia*, *Phragmites* and *Typha*.

⁴ *Agapanthus*, *Carpobrotus*, *Elegia*, *Zantedeschia* and *Ficinia*.

in August 2009 and irrigated with tap water for seven months to mature and adjust to the growing conditions, and thereafter received the stormwater treatments.

3.2.2 Soil Choice

The selection of Malmesbury shale as the soil medium was based on a number of factors. Firstly, due to the focus of the experiment, the use of a local, naturally occurring soil was chosen. Commercially available soil in the CoCT is typically sandy, dominated by three different forms, namely Malmesbury shale, Philippi sand and river sand. Secondly, both Bratieres *et al.*, (2008) and Read *et al.*, (2008) found that a sandy loam, well drained and low in organic matter, was most effective in removing stormwater contaminants. Malmesbury shale was found to drain at 400 ml /minute, compared to the Philippi and fine river sands which drained much slower. Malmesbury shale is also low in organic matter, which

3.2.3 Experimental Setup

A total of 300 containers were constructed from 150 mm x 500 mm polyvinyl chloride (PVC) pipes, each with a 22 mm (diameter) perforated drainage pipe that protruded from the sealed base of each container so that the outflow could be discharged into collection containers placed immediately below each container (Figure 2). In August 2009, each species was individually planted into 30 containers of Malmesbury shale soil, except the turf-grasses (*Pennisetum* and *Stenotaphrum*), which were planted with five plants per container to ensure rapid soil cover. A number of drainage layers were placed below the Malmesbury shale comprising of coarse silica sand and gravel to prevent the loss of soil media and clogging of the drainage pipe. The soil column was filled to approximately 5 cm below the rim of each container for the collection and retention of water during irrigation. All plant species were irrigated with tap water from August 2009 until February 2010 to reach a mature stage.

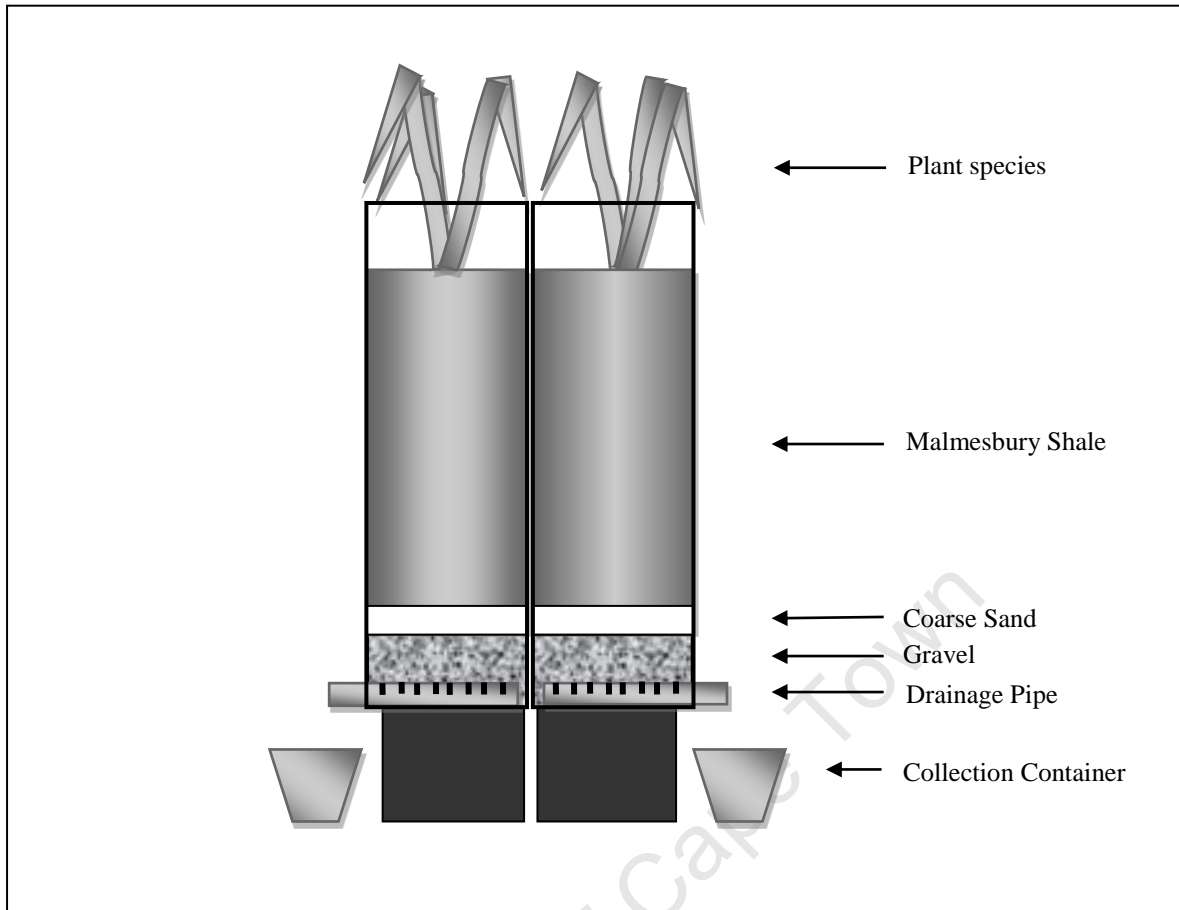


Figure 2: Experimental setup (cross-section of two containers in the nursery)

An automated irrigation system was installed to ensure a regular irrigation regime (every three days). It consisted of a computer (Irritrol® Junior™ MAX) controlling three relays (24V A/C), which was programmed to control the timing of the three pumps (Foras® PE-50M). Each pump transferred the water from a 500ℓ water tank using 15 mm irrigation pipes attached to 100 containers fitted with drippers (4ℓ/hr.). Each tank provided water for one of the three different treatments, namely tap water, synthetic Stormwater 1 (S1) or Stormwater 2 (S2) ($\pm S1 \times 2$) (Table 2). Thus each species, and the control, had 10 replicates per treatment. The tanks containing S1 and S2 were each fitted with a submersible pump that continually circulated the nutrient solution to prevent stagnation and ensure the dispersion of nutrients. In addition, an in-line electric valve (24V A/C) was installed to turn on with each pump to prevent the loss of water from the tanks via siphoning. Each tank was fitted with an external clear pipe with 100ℓ levels marked on the tank, between 0 and 400ℓ to assist with the re-filling of the tanks.

3.3 Experimental Procedure

The timing of the irrigation regime (every three days) was based on the regularity of rainfall during Cape Town's six wettest months (SAWS, 2011), while the amount of 1 l was applied to each pot based on two factors, namely adequate water for both plant growth and outflow-sample analysis. In similar studies the irrigation volume was based on typical annual rainfall and on a biofilter being 2% of its catchment size (Bratieres *et al.*, 2008; Read *et al.*, 2008). However this presents a number of issues. Firstly, the accurate measurement of runoff in a catchment is complicated due to variable infiltration rates from different soil types and human induced changes. Not only is the volume of runoff generated from hard surfaces (e.g. roofs and roads) much higher than planted areas, but also it is difficult to differentiate between conventional and permeable paving, and the soil compaction of various planted areas. In addition, rainfall may differ widely within a catchment. For example, although the annual rainfall for the CoCT averages 531 mm per annum (SAWS, 2011), annual rainfall varies between the Cape Flats and surrounding mountains.

Stormwater quality is yet to be monitored on a widespread scale across the CoCT. However, the CoCT does measure the stormwater quality at three sites. These include the Lotus Canal at the N2 highway, Theo Marais Canal in Montague Gardens Industrial Area, and Kleinvlei Canal at Old Faure Rd. Routine samples are tested for suspended solids (TSS) and a variety of nutrients including ortho-phosphate, ammonia and NO_x (nitrate and nitrite) (CoCT, 2009). The current study combined the stormwater data from these three sites and used the 75th percentile value to produce 'synthetic stormwater' at two concentration levels (i.e. S1 & S2) using laboratory chemicals (Table 3). This not only provided a realistic composition of local stormwater nutrients, but also enabled standardised inflow concentrations. The nutrient solution of known concentration and volume (S1 or S2 concentrations) was placed into each of the two 400 l water tanks, and replaced every eight days.

Table 3: Stormwater solution (S1 and S2)

Nutrient	Chemical source	S1 (conc. mg/l)	S2 (conc. mg/l)
Orthophosphate	PO ₄ ⁻³	1.470	2.620
Ammonia	NH ₃	0.567	2.202
Nitrate	NO ₃ ⁻	3.117	5.983

Efforts were made to add suspended solids to the synthetic stormwater. Clay was collected in Hout Bay, sieved through a 125 µm sieve and added to S1 and S2. However, despite the fine particle size and submersible pumps intended to maintain sediment suspension, the sediment gradually settled down causing a rapid drop in concentration within the first few days of the experiment. In addition, the organic matter decomposed in the tanks potentially altering the concentration of nutrient levels. As such the use of sediment was discontinued and the tanks were washed out.

3.3.1 Assessment of Nutrient Removal

Samples were collected on three occasions during the study. These began on the 13th of July 2010 and were repeated three weeks apart. Water samples were taken from each tank (inflow) and the outflow of every second container per treatment per species. The samples were analysed in the Water Analysis Laboratory at the University of Cape Town and tested for ortho-phosphate (PO_4^{-3}), ammonia (NH_3) and nitrate (NO_3^-). All samples were analysed using a Hach Spectrophotometer (DR 2700 model).

Unless noted, all the results are presented as the total reduction in concentration determined by subtracting the sample concentration from the inflow concentration. Although the analysis of percentage removal could be faulty if stormwater were sourced from a field-based source due to fluctuating inflow concentrations (Bratieres et al., 2008), the percentage removal by all containers were compared within the current study as inflow concentrations were premixed to standardized levels. The inflow and outflow concentration data are both presented (Appendix D).

3.3.2 Measurement of Plant Growth

From February to August 2010, a variety of physical plant-growth parameters were recorded on a monthly basis to analyse the relationship between nutrient concentration and plant growth. The analysis included tallies of the number of stems, length of longest stem or leaf, number of leaves, presence of flowers, number of flowers and/or fruit and length of flower stem. However, the number and choice of measurements depended on the physical characteristics of each plant species. For example, it was possible to measure these variables for *Phragmites*, but impractical for the turf-grass *Stenotaphrum*. In addition, the growth of

the *Zantedeschia* was complicated to monitor because of natural cycles of dying back and re-growing (especially during the summer months).

3.4 Data Analysis

A 2-way analysis of variance (ANOVA) was used to assess both the effect of species and concentrations of stormwater (S1 and S2) on nutrient removal and the physical growth-response of selected plant species. The nutrient removal data, for all three nutrients and between stormwater treatments, were transformed by arcsine square root transformation (Sokal & Rohlf, 1995), and plant growth data were log transformed where appropriate. Duncan's Multiple Range technique was used to separate the averages that were significantly different at $P \leq 0.05$.

3.5 Limitation of the Study

This laboratory research had two main limitations. Firstly, it did not take site-specific conditions such as hydrology and climate into account. Even though laboratory results have found vegetated biofilters to be exceptionally effective at treating polluted water (Hatt et al., 2009; Bratieres et al., 2008; Davis et al., 2001, 2006), the results need to be confirmed under field settings, where runoff timing, frequency and composition would vary, and include additional pollutants such as nutrients and suspended solids. Secondly, plants were tested in isolation, which did not take account of site-specific ecology or the impact of competition between plant species.

Chapter 4 – Results & Discussion

4.1 Introduction

As described earlier, this study investigates the individual performance of nine locally occurring plant species to treat stormwater through the complete or partial removal of three nutrients, namely, PO_4^{-3} , NH_3 and NO_3^- . The experiment is based upon similar biofiltration studies from other countries (Bratieres *et al.*, 2008; Read *et al.*, 2008; Davis *et al.*, 2001, 2006), in that the choice of plant species was selected to tolerate regular inundation of water and could be used in various SuDS treatment trains. The three objectives of the study will be discussed in this Chapter. Section 4.2 assesses the ability of each plant species to remove nutrients from stormwater; Section 4.3 assesses how plant growth responds the stormwater nutrients; and Section 4.4: identifies plant species suitable for use in the CoCT's SuDS treatment trains.

4.2 Analysis of Nutrient Removal: Dryland and Wetland Species

This section analyses the performance of the nine plant species, grouped into dryland and wetland plants, in absorbing or adsorbing nutrients. Initially it was presumed that dryland plants would remove more nutrients than wetland plants because the latter functions through prolonged detention, which was not provided in the current research (Australian WSUD Guidelines, 2007; EA, 2003; Knox City Council, 2002). The absence of standing water, due the irrigation regime of one litre per container ever two days, was thus expected to favour the nutrient-removal performance of the terrestrial dryland plants. However, a nested ANOVA design showed that there was no significant difference between them (Table 5). As such all the plants are analysed together. A nested ANOVA was used because the species in two groups were different and therefore negated the use of a normal ANOVA.

Table 5: Plant form: wetland vs. dryland species. Numbers following F-statistics are degrees of freedom using nested ANOVA. Ns = not significant.

Plant form	F-statistics		
Wetland & dryland species	Phosphorus	Ammonium	Nitrate
F-statistic 1,254	0.4 ns	0.1 ns	1.3 ns

4.2.1 Orthophosphate (PO_4^{-3})

The nine plant species all reduced outflow concentrations of PO_4^{-3} and the removal of this nutrient ranged from 7-95% (mean 74%) between species (Figure 3). The control removed a mean 79% for S1 and S2, while the six most effective species (*Agapanthus*, *Pennisetum*, *Stenotaphrum*, *Zantedeschia*, *Phragmites* and *Typha*) were up to 16% more effective than the control and reduced outflow concentrations of PO_4^{-3} by a total of 80-95% for the same stormwater treatments. Similar levels of removal were not only consistent with the finding of similar studies (Bratieres *et al.*, 2008; Read *et al.*, 2008; Fletcher *et al.*, 2007; Henderson *et al.*, 2007; Davis *et al.*, 2001, 2003, 2006), but exceed the CoCT's recommendation of a 45% reduction in phosphorus (CoCT, 2009). Only one species for S1 (*Phragmites*), and four species for S2 (*Agapanthus*, *Pennisetum*, *Stenotaphrum* and *Typha*) removed significantly more than the control. *Carpobrotus* performed similarly to the control for S1, but was significantly less effective for S2, removing only 66%. The two remaining species (*Elegia* and *Ficinia*) were both significantly less effective than the control for both stormwater treatments and removed a mean of 46% and 15% respectively. This may have been due to the fact that they were planted with more organic matter trapped in their roots, which according to Hsieh and Davis (2005a, b), may encourage the nutrient leaching.

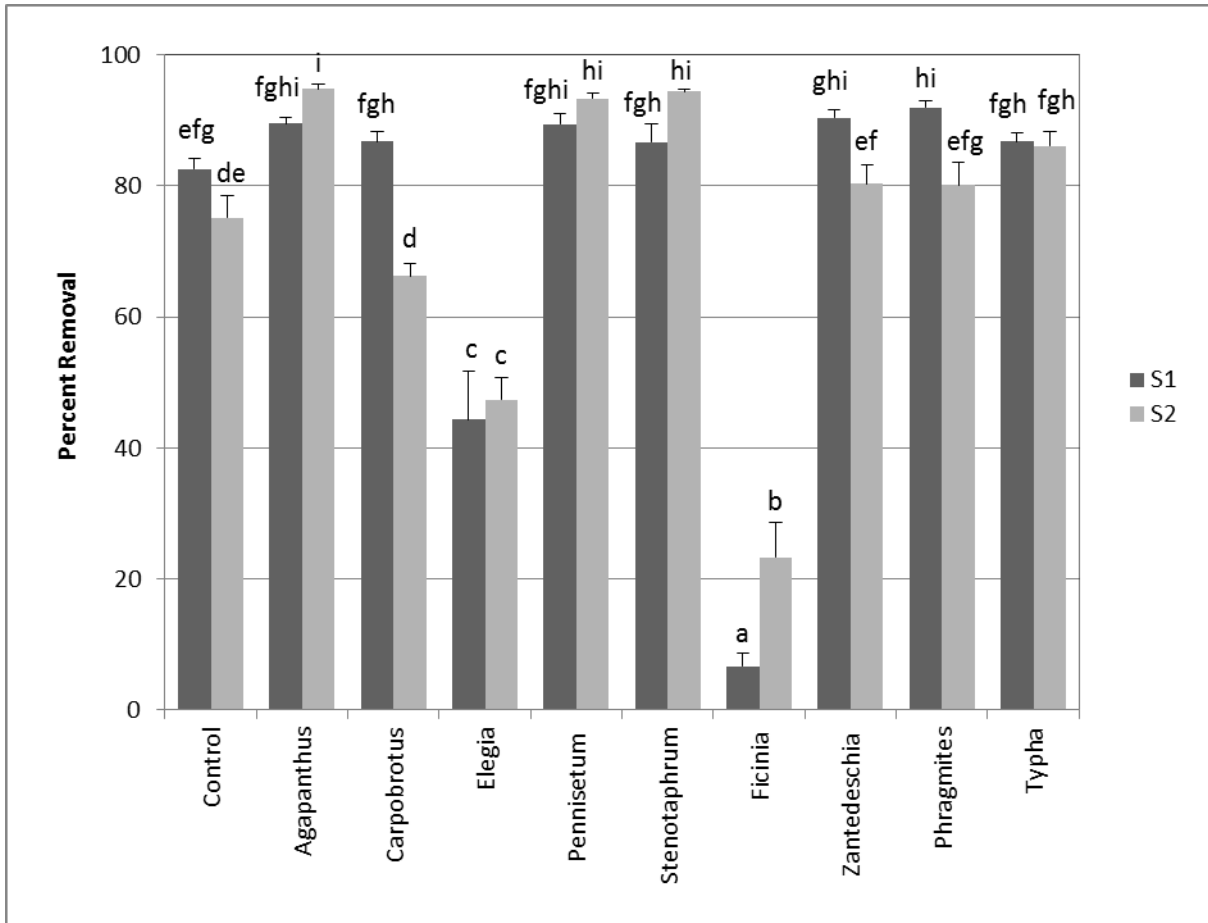


Figure 3: Percent Removal of PO_4^{-3} by all species and control. Bars are means \pm SE. Different letters show significant difference at $P \leq 0.001$. S1 and S2 represent the two stormwater treatments.

Despite the overall efficiency of most plant species in reducing total outflow concentrations of PO_4^{-3} , when compared to the control the plants (excluding *ELEGIA* and *FICINIA*) only accounted for a small percent of total removal. For example, the six most effective species (*Agapanthus*, *Pennisetum*, *Stenotaphrum*, *Zantedeschia*, *Phragmites* and *Typha*) were only between 4-20% more effective than the control for both treatments (S1 mean 7%; S2 mean 13%). The first three species removed a mean of 19% for S2. Comparatively, *Carpobrotus* was not significantly different to the control, while *ELEGIA* and *FICINIA* were significantly less effective. These results indicate the important role of Malmesbury shale as a filter for the removal of PO_4^{-3} in the CoCT, and are consistent with the results of Bratieres *et al.*, (2008) and Fletcher *et al.*, (2007) who found at least 77% total removal, irrespective of the presence of plants. However, although the plant species removed only a small proportion of applied PO_4^{-3} when compared to the control, the presence of vegetation in a field setting could possibly slow rates of flow, thus encouraging infiltration into the soil and improving water

quality.

In line with international studies, the current research found that the control (soil only) was responsible for most of the PO_4^{-3} removal (Bratieres *et al.*, 2008; Read *et al.*, 2008). The accumulation of PO_4^{-3} in the soil of biofiltration systems has long-term maintenance implications to prevent this nutrient from leaching into the ground water. Maintenance may require measures such as replacing the soil, or possibly harvesting vegetation (e.g. mowing grassed swales) and disposing of it in an appropriate manner (e.g. landfill or municipal compost). Otherwise, decomposing plant material will return nutrients to the soil. Although trapping PO_4^{-3} in biofiltration systems reduces impacts on receiving freshwater systems in the short term, they must be appropriately designed and include the monitoring of nutrient accumulation and the possible replacement of contaminated soil.

4.2.2 Ammonia (NH_3)

The nine plant species were effective in removing NH_3 with outflow concentrations being reduced by between 66-99% for both S1 and S2 (mean 91%), while the control removed a mean of 85% for the same treatments (Figure 4). Similar removal-ranges have also been obtained by comparable international studies (Bratieres *et al.*, 2008; Fletcher *et al.*, 2007; Henderson *et al.*, 2007; Popov *et al.*, 2006; Davis *et al.*, 2001, 2003, 2006). In the current study, the two most effective species, namely the turf-grasses *Pennisetum* and *Stenotaphrum*, were significantly more effective than the control (up to 22%) for both stormwater treatments, reducing outflow concentrations of NH_3 by a total of 97% for S1 and 99% for S2. *Agapanthus*, *Ficinia*, *Zantedeschia*, *Phragmites* and *Typha* were significantly more effective than the control for S1, while these species, and *Carpobrotus* and *Elegia* were not significantly different from the control for S2.

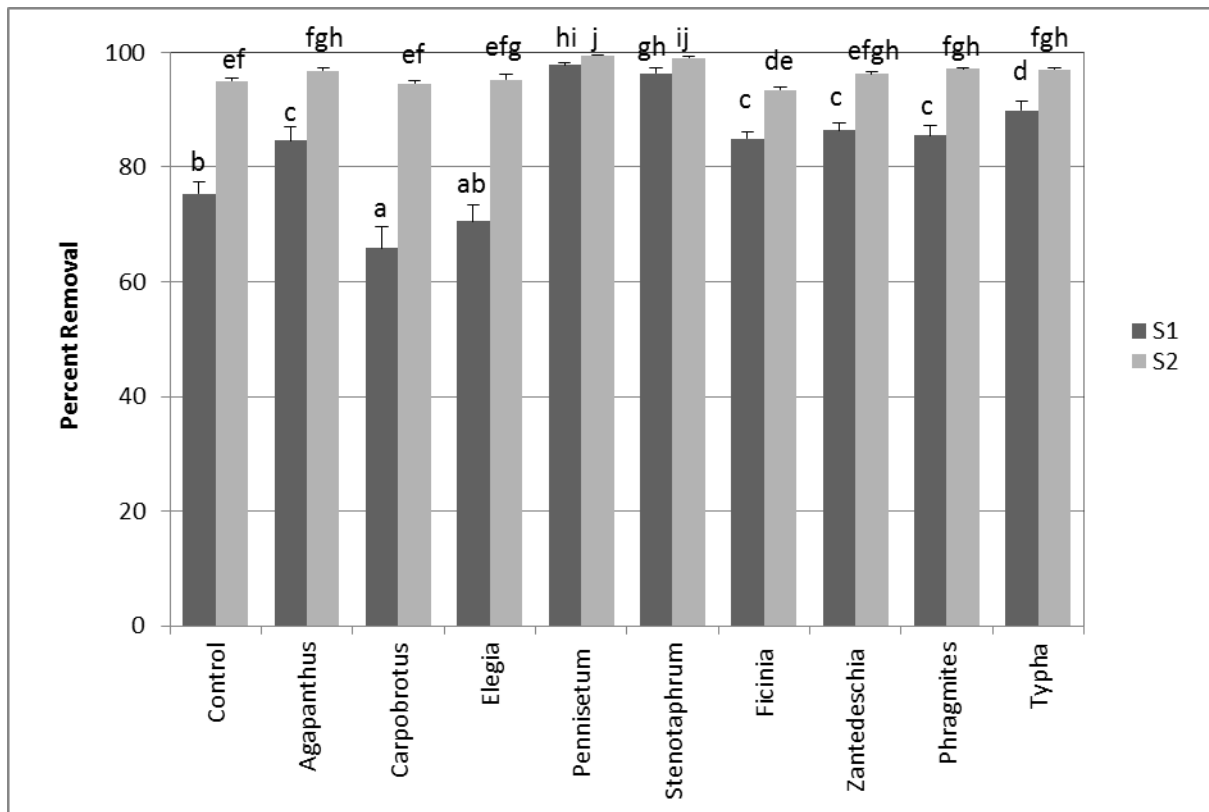


Figure 2: Percent Removal of NH₃ by all species and control. Bars are means ± SE. Different letters show significant difference at $P \leq 0.001$. S1 and S2 represent the two stormwater treatments.

The vegetated pots were generally more effective than the control regardless of the stormwater treatment, indicating a level of NH₃ removal by the plant species themselves. The turf-grasses *Pennisetum* and *Stenotaphrum* were significantly more effective than the control, with the plants reducing outflow concentrations by 22% and 4% for S1 and S2 respectively. By contrast, *Agapanthus*, *Ficinia*, *Zantedeschia*, *Phragmites* and *Typha* removed 9-15% for S1, and up to 2% for S2. *Carpobrotus* was less effective than the control for both stormwater treatments while *Elegia* was less effective than the control for S1 and a mere 0.2% more effective for S2. These results indicate the central importance of soil as a filter in removing this nutrient, and are consistent with the findings of Bratieres *et al.*, (2008). Nonetheless, the presence of vegetation in a field setting could possibly slow rates of flow, thus encouraging infiltration into the soil and improving water quality. As with PO₄⁻³, there are maintenance concerns related to the accumulation of NH₃ in the soil. Similar maintenance procedures such as replacing the soil or harvesting vegetation and disposing of it in an appropriate manner could also be appropriate.

4.2.3 Nitrate (NO₃⁻)

Previous research found between 15-65% Total Nitrogen removal due to less than 20% of NO₃⁻ retention (Fletcher *et al.*, 2007; Hatt *et al.* 2007; Davis *et al.*, 2001, 2003, 2006). However, the current study showed far better NO₃⁻ removal despite the variation between species (Figure 5). The nine species reduced outflow concentrations of NO₃⁻ by 20-88% for both stormwater treatments (mean 60%), while the control removed just 22% and was significantly less effective than eight of the species (excluding *Phragmites*). The turf-grasses *Pennisetum* and *Stenotaphrum* were the two most effective species (up to 70% more than control) and reduced total outflow concentrations by a total mean of 76% for S1, and 85% for S2, with the latter treatment being removed by significantly more than all other species. The next five most effective species (*Agapanthus*, *Carpobrotus*, *Ficinia*, *Zantedeschia* and *Typha*) reduced outflow concentrations by a total of 49-75%. For the two remaining species (*Elegia* and *Phragmites*), only *Elegia* was significantly more than the control. The higher NO₃⁻ removal-rates demonstrated in the current study may in part be due to the use of drip irrigation, which unlike the more rapid irrigation of Bratieres *et al.*, (2008) and Read *et al.*, (2008), would have percolated more slowly through each pot, thus allowing more time for the uptake of water and dissolved nutrients (Trowsdale & Simcock, 2010; Muscolo *et al.*, 2003; Duncan, 1998; Savchenko *et al.*, 1997). This may have encouraged the rapid growth-rates of selected species which occurred in response to applied nutrients (Appendix C). However, the poor performance of *Phragmites* may be due to the experimental stresses. Not only were immature plants used, but as mentioned above, *Phragmites* alone was the only plant species to be attacked by aphids, which were physically removed (spraying water). Those parts of the plants that were attacked, namely the new shoots and leaves became yellow and started to die back.

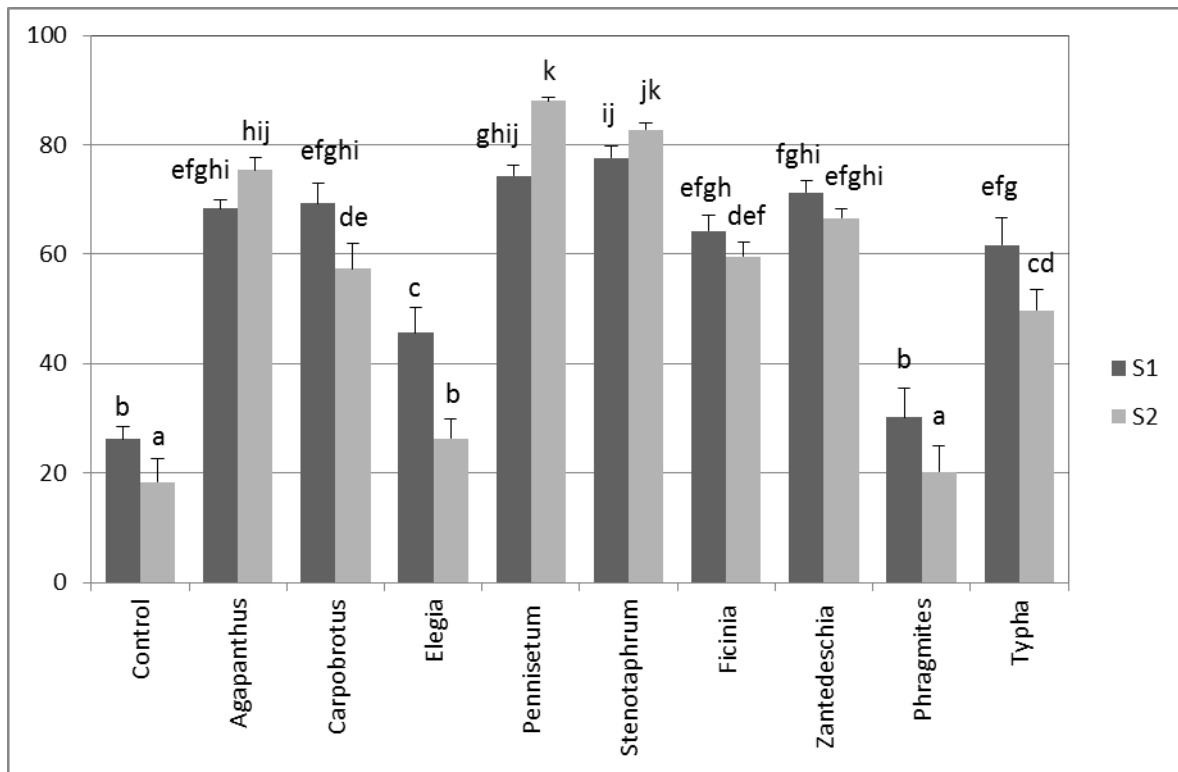


Figure 3: Percent Removal of NO_3^- by all species and control. Bars are means \pm SE. Different letters show significant difference at $P \leq 0.001$. S1 and S2 represent the two stormwater treatments.

While the removal of NO_3^- varied from 20-88%, all nine plant species removed a greater percentage of this nutrient than the control, indicating a level of removal by the plant species themselves. In particular, seven of the species removed significantly more than the control. As with the removal of PO_4^{3-} and NH_3 , the turf-grasses *Pennisetum* and *Stenotaphrum* were the two most effective species and reduced outflow concentrations of NO_3^- by 48-70% for both stormwater treatments when compared to the control. They were also significantly more effective than all other species for S2. The next five species (*Agapanthus*, *Carpobrotus*, *Ficinia*, *Zantedeschia* and *Typha*) also removed significantly more the control with removal ranging between 31-57% when compared to the control. *Elegia* was only significantly more effective than the control for S1, while *Phragmites* was not significantly different to the control. Despite the variation of the nine species in reducing outflow concentrations of NO_3^- when compared to the control, total removal was far better than other biofiltration research with only *Elegia* matching the $<20\%$ NO_3^- removal found in other studies (Fletcher *et al.*, 2007; Hatt *et al.* 2007). As the removal of this nutrient was primarily dependent on specific species, correct plant choice, and harvesting vegetation and disposing

of it in an appropriate manner are necessary to prevent decomposing plant material from returning nutrients to the soil.

4.3 Analysis of Plant Response to Treatment: Leaf and Stem Measurement

Of the physical plant-growth parameters recorded, only the number and length of leaves showed significant increases in growth compared to those receiving tap water (Figure 7 and 8). The increase in growth suggests that plants have absorbed and/or adsorbed the applied nutrients in comparison to those plants that only received tap water. This has important implications for the design and long-term maintenance of biofiltration systems, as it highlights the need to consider aspects such as competition between plant species, and the ability of plant species to tolerate and recover more quickly from external stressors (e.g. human and/or vehicular traffic, wind or variable moisture levels), as well as developing maintenance plans that incorporate differences in plant growth between species and elements of the treatment exposed to different nutrient loads (e.g. grassed swales exposed to higher nutrient inputs may require more regular mowing). The following discussion focuses on the significant increases in number and length of leaves, and highlights a number of issues which increased growth rates of specific species have on the CoCT. Individual graphs (leaf length and leaf number) of selected are included in Appendix C.

The application of stormwater concentrations S1 and S2 resulted in significant increases in leaf length for several species (Figure 6). These included two dryland species (*Agapanthus* and *Pennisetum*) and two wetland species (*Phragmites* and *Zantedeschia*). Only *Pennisetum* showed significant increases in leaf length in response to both stormwater treatments, with this species showing increased growth-rates in response to the application of stormwater within the first month. *Agapanthus* and *Zantedeschia* showed a similar pattern, although there was no significant difference between stormwater treatments. *Phragmites* showed a significant increase in leaf length but only for those plants irrigated with S2 water. These four species were also typically effective in removing applied nutrients with outflow concentrations being removed by 80-95% for PO_4^{-3} , 84-99% for NH_3 and 66-88% for NO_3^- (excluding *Phragmites*).

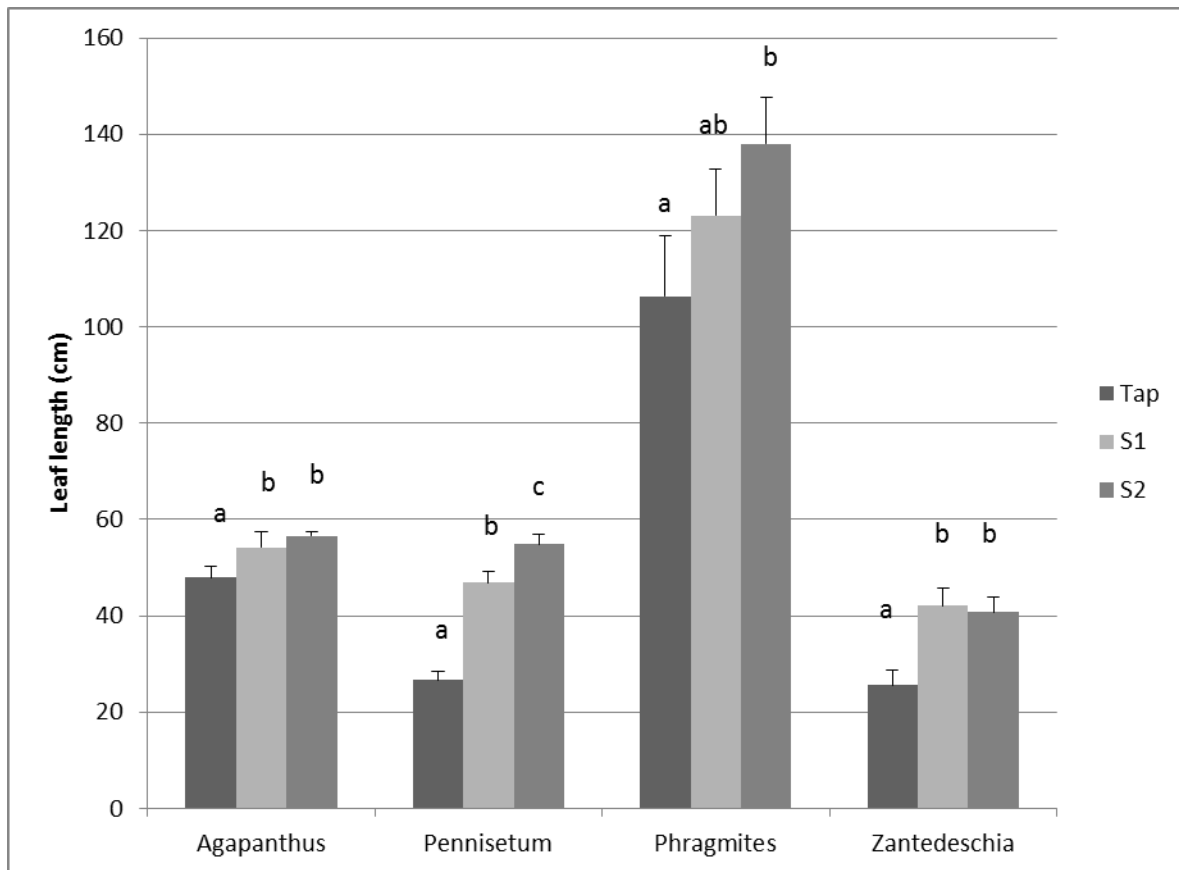


Figure 6: Length of longest leaf in response to tap water and the stormwater treatment (S1 & S2). Bars are means \pm SE. Different letters show significant difference at $P \leq 0.001$. S1 and S2 represent the two stormwater treatments.

The application of stormwater (S1 and S2) also significantly increased the leaf number of several species (Figure 7). These included *Agapanthus* and *Phragmites* as well as the wetland plants *Ficinia* and *Typha*. *Agapanthus* and *Typha* showed significant increases in leaf number in response to the application of both stormwater treatments (S1 and S2). However, in the case of *Ficinia*, the only significant increases in leaf number were found in those plants that received S2 water. *Phragmites* showed a significant increase in leaf number but there was no significant difference between treatments S1 and S2. These species were also typically effective in removing applied nutrients with outflow concentrations being removed by between 80-94% for PO_4^{-3} (excluding *Ficinia*); 85-97% for NH_3 ; and 50-75% for NO_3^- (excluding *Phragmites*). However, the study did not attempt to determine which of the three nutrients were responsible for the increase in growth. Nonetheless, the observed relationship indicates a physical growth-response as a result of the absorption of nutrients.

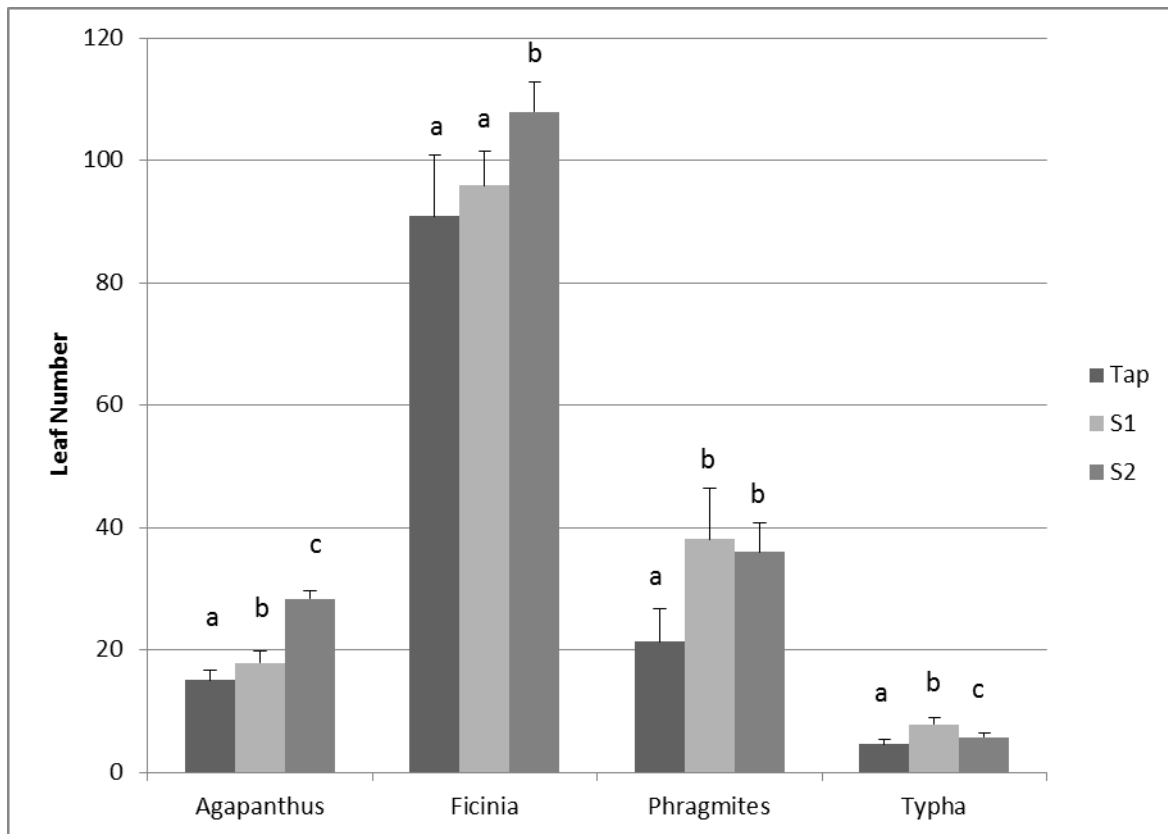


Figure 7: Differences in leaf number in response to stormwater treatment (S1 & S2). Bars are means \pm SE. Different letters show significant difference at $P \leq 0.001$. S1 and S2 represent the two stormwater treatments.

As discussed, the application of synthetic stormwater resulted in an increase in the growth of leaf length⁵ and/or numbers of leaves⁶ of selected species when exposed to one or both stormwater treatments. Although these species are widely used in the CoCT these results indicate that there are a number of considerations such as competition and the impact of this on maintenance plans must be noted. For instance, there are concerns however around the invasiveness of *Phragmites* (which showed significant increases for both parameters) and *Typha*, which can spread quickly, out-compete other species and form monocultures when exposed to high nutrient loads (Bellavance & Brisson, 2010; Hudon *et al.*, 2005; Rickey & Anderson, 2004). As such, maintenance plans will need to ensure that if they are used, they must be kept within a certain area. The other wetland plants *Zantedeschia* and *Ficinia* also showed significant in growth for one parameter, highlighting growth response of all wetland plants used. *Pennisetum*, which is invasive, is also widely used in the CoCT because it requires little maintenance, should only be used in confined spaces (Cilliers & Muscolo *et al.*,

⁵ *Agapanthus*, *Pennisetum*, *Phragmites* and *Zantedeschia*

⁶ *Agapanthus*, *Ficinia*, *Phragmites* and *Typha*

2003; Bredekamp, 2000). It showed rapid increases in leaf length in response to the application of both stormwater treatment (Appendix C), and will thus require more regular mowing if exposed to stormwater nutrients. Although *Pennisetum* was planted with five grass plugs per container to represent more accurately the grass cover of a swale, this would likely have had little impact on leaf length. The above mentioned species were also typically effective in removing all three nutrients, with some of the species removing significantly more than the control for one or both treatments especially in the case of the response to NO_3^- . It is not possible to determine which of the three nutrients were responsible for the increase in growth as there is no separate growth assessment for the nutrients. Nonetheless, the observed relationship indicates that plant species which showed a significant physical growth-response were generally also effective in the absorption of each of the three nutrients.

4.4 Identification of Plants for Potential Use in the CoCT's Treatment Trains

As noted previously, this preliminary laboratory-based study sought to identify the extent to which individual plant species could act as biofilters by removing PO_4^{-3} , NH_3 and NO_3^- from a synthetic stormwater concentration. It is this knowledge of individual plants species that can be used to design SuDS treatment trains that target a selection of nutrients found in urban stormwater. Table 4 lists the selected plant species and the control in rank order according to the mean values for the absorption of each nutrient. From the table it is evident that *Pennisetum*, *Stenotaphrum* and *Agapanthus* were generally the three most effective species in removing all three nutrients, and that most of the plant species were more effective than the control. These former species removed at least 91% of both PO_4^{-3} and NH_3 , and 72% of NO_3^- . *Phragmites*, *Typha* and *Zantedeschia* removed at least 85% and 91% of PO_4^{-3} and NH_3 respectively. *Zantedeschia* occupied a central position (fourth and sixth) across all nutrients and removed PO_4^{-3} , NH_3 and NO_3^- by 85%, 91% and 69% respectively. Comparatively, *Elegia*, *Ficinia* and the control were consistently among the least effective in removing nutrients.

Table 4: List of species and control (highlighted grey) in order of mean performance values (percent removal) for each nutrient.

Rank	PO ₄ ⁻³	NH ₃	NO ₃ ⁻
1	Agapanthus (92%)	Pennisetum (99%)	Pennisetum (81%)
2	Pennisetum (91%)	Stenotaphrum (98%)	Stenotaphrum (80%)
3	Stenotaphrum (91%)	Typha (93%)	Agapanthus (72%)
4	Phragmites (86%)	Agapanthus (91%)	Zantedeschia (69%)
5	Typha (86%)	Phragmites (91%)	Carpobrotus (63%)
6	Zantedeschia (85%)	Zantedeschia (91%)	Ficinia (62%)
7	Control (79%)	Ficinia (89%)	Typha (56%)
8	Carpobrotus (77%)	Control (85%)	Elegia (36%)
9	Elegia (46%)	Elegia (83%)	Phragmites (25%)
10	Ficinia (15%)	Carpobrotus (80%)	Control (22%)

While plants such as *Pennisetum*, *Stenotaphrum* and *Agapanthus* consistently removed a high percent of each nutrient, possibly as a result of rapid growth rates (Figure 7 & 8)⁷, some species were effective in removing particular nutrients and not others. For example *Ficinia* removed only 15% of PO₄⁻³, but removed 89% and 62% of NH₃ and NO₃⁻ respectively. In addition, *Phragmites* removed 86% of PO₄⁻³ and 91% of NH₃, but only 25% of NO₃⁻. A similar pattern occurred with the control, which removed 79% of PO₄⁻³, 85% of NH₃, but only 22% of NO₃⁻.

Although plants varied (sometimes dramatically) in their removal of each nutrient, the current results highlight the importance of including a variety of plants in SuDS design, to not only target a spectrum of nutrients, but also support urban biodiversity. Even if particular plant species are not effective in removing nutrients, their presence in a field setting could possibly slow rates of flow, thus encouraging infiltration into the soil and improving water quality. This is consistent with the finding of Bratieres et al., (2008) and Read et al., (2008) who found that plant species varied in their pollutant-removal performance such that a spectrum of species should be included in biofilter design. Although groundwater recharge via SuDS is only suitable if the groundwater will not be contaminated,

⁷ No physical growth-rate measurements were taken for *Stenotaphrum* due to its growth habit

PO_4^{-3} and NH_3 are fairly stable in the first layer of soil and thus pose little danger of contamination, especially if the soil is monitored and replaced if contaminated.

In the CoCT, all the selected species could be used in the SuDS treatment train, starting with dryland species such as *Pennisetum*, *Stenotaphrum*, and *Agapanthus* in filter-strips, green roofs and/or swales, and wetlands planted with configurations of *Ficinia*, *Phragmites*, *Typha* and *Zantedeschia*. In this way nutrient-rich stormwater runoff could be passed through the treatment train to gradually improve water quality from the point where it falls until it enters freshwater systems. The use of these species in combination not only makes use of their individual nutrient-removal performance, but could also encourage the inclusion of less effective species for aesthetic or biodiversity purposes. Care must however be taken with species such as *Pennisetum*, *Phragmites* and *Typha*, due to their aggressive growth rates, especially when exposed to high nutrient levels (Bellavance & Brisson, 2010; Hudon *et al.*, 2005; Cilliers & Bredenkamp, 2000). In the current study, all three of these species showed significant increases in growth in response to stormwater (Figure 7 & 8).

Chapter 5 – Conclusion

5.1 Introduction

In 2009, the City of Cape Town (CoCT) adopted a progressive stormwater policy that seeks to incorporate sustainability into the design and operations of stormwater systems (CoCT, 2009; CIRIA, 2007; Knox City Council, 2002). The policy is based on the concept of Sustainable Urban Drainage Systems (SuDS) which focuses specifically on the management of stormwater through the use of a treatment train of technologies (CIRIA, 2007). At an international level, field and laboratory research has demonstrated that the ability of vegetated filters to remove nutrients depends on appropriate design and plant choice, with various considerations being necessary to target specific pollutants (Bratieres *et al.*, 2008). For instance, not only must plant species survive local climatic conditions and fluctuating nutrient and moisture levels, but nutrient retention varies between plant species (Read *et al.*, 2008; Revitt *et al.*, 2004). Results from this study, seek to contribute to the design of local biofiltration systems as they provide evidence of local plant- and soil-specific nutrient removal. The following section provides insight into the key nutrient-removal results, while also identifying plant species suitable for use in the CoCT's SuDS treatment trains. This is followed by a number of recommendations.

5.2 Plant Selection based on Nutrient Removal

When a reduction in PO_4^{-3} is required all plant species (excluding *Ficinia*) and the control performed well and reduced outflow concentrations by a mean of 81%. The seven most effective species (*Agapanthus*, *Pennisetum*, *Stenotaphrum*, *Carpobrotus*, *Zantedeschia*, *Phragmites* and *Typha*), reduced outflow concentrations by a mean of 87%, demonstrating the suitability of these plants for use throughout treatment train elements (e.g. filter-strips, swales and wetlands) targeting this nutrient. The overall mean results are comparable with international biofiltration studies that reduced phosphorus by between 70-85% (Bratieres *et al.*, 2008; Fletcher *et al.*, 2007; Henderson *et al.*, 2007; Davis *et al.*, 2001, 2003, 2006); well above the CoCT's stormwater policy targets for phosphorus removal (CoCT, 2009).

If a reduction in total nitrogen is required, biofiltration design must select plant species capable of removing both NH_3 and NO_3^- (Bratieres *et al.*, 2008; Fletcher *et al.*, 2007).

International research has demonstrated that biofilters have been effective in NH_3 (>85%), although total nitrogen removal has typically been variable due to less than 20% of NO_3^- retention (Fletcher *et al.*, 2007; Hatt *et al.* 2007; Henderson *et al.*, 2007; Davis *et al.*, 2001, 2003, 2006). Although the CoCT measures the concentration of these nutrients in stormwater runoff samples, they are yet to be included in the city's stormwater policy water-quality targets (CoCT, 2009). The current study applied both nutrients to the plant species and control to aid the design of biofiltration systems that targets a range of nutrients.

Outflow concentrations of NH_3 were reduced by a mean of 90% across all plant species and the control, which corresponds with the findings of similar biofiltration research (Bratieres *et al.*, 2008; Fletcher *et al.*, 2007; Henderson *et al.*, 2007; Davis *et al.*, 2001, 2003, 2006). As with PO_4^{3-} removal, the plants played only a small role in removing NH_3 when compared to the control. However, the removal of NO_3^- was found to be far higher than previous findings for many of the plant species, thus indicating a substantially higher total nitrogen removal. All the plant species (excluding *Elegia* and *Phragmites*) reduced outflow concentrations of NO_3^- by a mean value of 69%. In addition, the removal of this nutrient was far more dependent on the presence of vegetation, with species such as *Pennisetum* and *Stenotaphrum* accounting for 60% of total NO_3^- removal when compared to the control. This supports the need for the inclusion of specific plant species (e.g. *Agapanthus*, *Carpobrotus*, *Pennisetum*, *Stenotaphrum*, *Ficinia*, *Zantedeschia* and *Typha*) when seeking to retain both NH_3 and NO_3^- .

In the current research, plants typically improved the removal of all three nutrients that were applied when compared to the control (especially NO_3^-), despite variation between nutrient and plant species. However, for PO_4^{3-} and NH_3 the plants themselves (dryland and wetland) provided only a small proportion of total removal (e.g. mean value of 10%). These results highlight the significance of this local soil media (i.e. Malmesbury shale) as a stormwater filter of these nutrients in the CoCT, and are consistent with the results of Bratieres *et al.*, (2008) and Read *et al.*, (2008). Malmesbury shale is widely available in the CoCT and can be used in the construction of treatment trains targeting these nutrients. Although the selected plant species removed only a small proportion of applied PO_4^{3-} and NH_3 when compared to the control, the use of vegetation in a field setting would slow rates of flow, thus encouraging infiltration and enabling the soil to act as a filter. Choice of plant species could then be based on their ability to survive fluctuating moisture levels and focus on

supporting urban biodiversity. However, as mentioned above, the control removed only 20% of total NO_3^- and was the second least effective container. This reiterates the need to include plant species in the biofiltration design of SuDS systems targeting this nutrient. In the CoCT, all the selected species could be used in the SuDS treatment trains targeting PO_4^{-3} , NH_3 and/or NO_3^- , starting with dryland species such as *Pennisetum*, *Stenotaphrum*, *Agapanthus*, *Carpobrotus* and *Elegia* in filter-strips, green roofs and swales, and wetlands planted with configurations of *Ficinia*, *Phragmites*, *Typha* and *Zantedeschia*. In this way nutrient-rich stormwater runoff could be passed through the treatment train to gradually improve water quality from the point where it falls until it enters freshwater systems.

5.3 Recommendations

This research has shown that plant species selection must be based on specific nutrient-removal targets (e.g. phosphate and/or total nitrogen). For example, while PO_4^{-3} and NH_3 were effectively removed by all species and the control, removal of NO_3^- was not only variable across plant species, but was on average removed far more effectively by the plants themselves i.e. plant species were between 12-74% more effective than control, with the turf-grasses *Stenotaphrum* and *Pennisetum* as the most effective species. There were however exceptions with plant species such as *Ficinia*, which removed 89% of NH_3 and 62% of NO_3^- , but only 10% of PO_4^{-3} . Plant species that performed well across the board, and are thus recommended for local biofiltration systems targeting all three nutrients, include four dryland plants (*Agapanthus*, *Carpobrotus*, *Pennisetum* and *Stenotaphrum*) and two wetland plants (*Zantedeschia* and *Typha*). Despite the poor performance of the remaining species (*Elegia*, *Ficinia* and *Phragmites*) for at least one nutrient each, they could for example still play a role in slowing flow rates, and improving biodiversity. There is a need for a variety of species to be used in the treatment train not only to target specific nutrients prior to release of runoff into freshwater systems, but also encourage urban biodiversity and provide aesthetic benefits wherever possible.

Secondly, the removal of PO_4^{-3} and NH_3 were minimally affected by plant choice, indicating the important role of soil to act as a filter. The use of Malmesbury shale as a soil media accounted for 75-83% of PO_4^{-3} and 75-95% of NH_3 . This is significant in the CoCT, as it is widely available and can thus be recommended as a soil-media in biofiltration systems targeting these nutrients. Although this study demonstrated that plant choice is essential for

the effective removal of NO_3^- , the control still accounted for 10% of total removal, and can thus also contribute to the total removal of this nutrient. Regardless of the nutrient-removal of each plant species, the inclusion of vegetation in a field setting would not only slow rates of flow, and thus encourage infiltration into the soil and improve water quality, but also support urban biodiversity.

Finally, future research is needed to investigate a variety of issues in both laboratory and field settings. These include pollutant-, plant- and soil-related issues. While the current study focussed on the removal of PO_4^{3-} , NH_3 and NO_3^- , additional contaminants such as household chemicals, heavy metals, pathogens and suspended solids should be tested, as well as their accumulation in soil and potential toxicity. Furthermore, a wider variety of plant species is necessary not only to increase urban biodiversity, but to understand competition between species and their ability to tolerate climatic and site-specific stress (e.g. regular inundation, human traffic and mowing). Longer term studies are also required to understand the impact of these issues on pollutant removal. Although Malmesbury shale was effective in removing PO_4^{3-} and NH_3 in the current study, the effect of depth and type of soil on long-term pollutant removal and long-term maintenance should also be considered. Investigating these issues will guide the implementation of SuDS in the CoCT and provide decision-makers with the knowledge to address the particular treatment train needs in municipalities throughout the city.

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Appendix A: Criteria for Achieving SuDS Objectives in Various Development Scenarios

SuDS Objectives	Greenfield Developments and Brownfield & Existing Development Sites located in catchments of sensitive receiving water systems	Brownfield & Existing Development Sites >50 000m ²	Brownfield & Existing Development Sites 4000m ² – 50 000m ² and Total impervious area (exist & new) > 15% of site	Brownfield & Existing Development Sites < 4000m ² and Total impervious area (exist & new) > 600m ²
<p>Improve Quality of Runoff</p> <p>Remove pollutants through combination of reducing and/or disconnecting impervious areas, and the use of BMPs which infiltrate or capture and treat stormwater runoff</p>	Design storm event for water quality treatment: 1 to 2 year RI, 24h storm			
	<p>Pollutant removal target:</p> <p>Reduction of post-development annual stormwater pollutant load discharged from dev. Site:</p> <p>SS & TP – reduce to undeveloped catchment levels, <i>or</i> SS – 80% reduction TP – 45% reduction</p> <p><i>Whichever requires higher level of treatment</i></p>	<p>Pollutant removal target:</p> <p>On-site reduction of post-development annual stormwater pollutant load discharged from development site:</p> <p>SS – 80% reduction TP – 45% reduction</p>	<p>Pollutant removal target:</p> <p>Combination of on-site and regional off-site measures to achieve target reductions:</p> <p>SS – 80% reduction TP – 45% reduction</p>	<p>On-site stormwater treatment not required by encouraged where practicable.</p> <p>Regional off-site treatment measures to achieve target reductions:</p> <p>SS – 80% reduction TP – 45% reduction</p>
	All developments are required to trap litter, oil, and grease at source.			

(CoCT, 2009)

Appendix B: Elements of the SuDS Treatment Train

Depending on the design objectives and constraints (e.g. space), various elements of the SuDS ‘treatment train’ can be used to achieve the required outcomes. Each alternative has a specific function, and varies in its ability to manage quantity or quality (Australian WSUD Guidelines, 2007). In most cases, the elements are used in combination as individual elements are seldom able to achieve the desired objectives on their own (CIRIA, 2007). A number of the most significant elements, as determined by the Australian WSUD Guidelines (2007) and Knox City Council (2002) are set out below in detail. These include gross pollutant traps, detention basins, sand filters, swales, constructed wetlands, ponds or lakes, aquifer storage and recovery, and permeable pavements. Each element plays a specific function within the treatment train regardless of whether it utilizes biofilters or not.

B.1 Gross Pollutant Traps

Gross pollutant traps are designed to remove particles with a diameter of larger than 5 mm (e.g. litter and organic debris) from stormwater systems prior to discharge into receiving waters (Knox City Council, 2002). Depending on the need, their design can range from a simple to fairly complex structure. Simple designs include a variety of grated drains or litter traps, while more advance alternatives include return flow litter baskets (Knox City Council, 2002).

B.2 Detention Basins

Detention ponds or basins are built to temporarily store and treat water during storm events (CIRIA, 2007; Parkinson and Mark, 2005; Villarreal *et al.*, 2004). Their primary function is to reduce peak flows, filter pollutants by promoting sedimentation, encourage bacterial activity and promote infiltration directly in to the ground (Field and Sullivan, 2003; Hobsons Bay City Council, 2002). As such, they are typically constructed at the inlet to constructed wetlands or bioretention basins.

A reduction in flow rates typically enables the sedimentation of 70-90% of particles larger than 125 μ m, although sedimentation is dependent on basin size and storage capacity (Australian WSUD Guidelines, 2007). Furthermore, detention basins are generally designed

to attenuate the discharge from 1 or 2-year ARI (Average Recurrence Interval) events (Australian WSUD Guidelines, 2007). If flow volumes exceed this design discharge, excess water is redirected via a spillway to a bypass drain to prevent the re-suspension of sediment already accumulated in the basin (Knox City Council, 2002).

B.3 Sand Filters

Sand filters are designed to improve water quality through sedimentation. Unlike detention ponds, they do not retain much water, but simply filter it as it drains through (SCCG, 2003; Hobsons Bay City Council, 2002). They are important in urban stormwater management as they can be constructed in confined space where the use of vegetation is unfeasible (e.g. underground) (Australian WSUD Guidelines, 2007).

Sand filters typically include three compartments, which allow for sedimentation, sand filtration and overflow of excess water (Australian WSUD Guidelines, 2007). The first compartment enables the collection of coarse material and medium to large sediment, while the sand filter removes most of the remaining of medium to coarse sediment although including some finer particulate matter and dissolved pollutants (Australian WSUD Guidelines, 2007). Despite being effective, sand filters require may regular maintenance to prevent clogging of the filter and a subsequent drop in infiltration capacity.

B.4 Swales and Buffer Strips

Swales and buffer strips are shallow, grassed channels designed to convey, retain and treat large volumes of runoff (Parkinson and Mark, 2005; Knox City Council, 2002). The vegetation slows the water down, promoting infiltration and the removal of sediment and the nutrients and heavy metals adhered to them (Hobsons Bay City Council, 2002). Although water quality treatment is most effective for small to medium flow rates, swales and buffer strips can provide a small amount of detention provided the cross sectional design is relatively large compared to the flow rate (Australian WSUD Guidelines, 2007).

Pollutant removal from a swale or buffer strip relies on a number of factors including longitudinal slope (1-4% slope), the height of vegetation and the swale's size (Australian WSUD Guidelines, 2007). Under these circumstances, swales effectively remove sediment

particles larger than 125µm, and while they are fairly inefficient at removing fine sediment, they provide an important phase in the SuDS ‘treatment train’ (Australian WSUD Guidelines, 2007; Knox City Council, 2002). In steep areas check dams can be constructed to reduce concerns around higher velocities (e.g. erosion and safety) (Australian WSUD Guidelines, 2007)

B.5 Constructed Wetlands

Although occurring naturally, wetlands can be constructed or modified from their natural state (Field and Sullivan, 2003). Constructed wetlands are shallow ponds containing a high proportion of marsh and wetland vegetation compared to open water. Prolonged detention enables effective pollutant removal though the removal of fine sediment (and adhered pollutants) and biological pollutant uptake (Australian WSUD Guidelines, 2007; Knox City Council, 2002). In contrast to retention or detention ponds, wetlands are more effective at water purification (EA, 2003).

Wetlands are typically constructed with a sediment trap at the inlet, followed by a vegetated zone and bypass for high flows (Australian WSUD Guidelines, 2007; Knox City Council, 2002). The macrophyte zone is usually constructed with a depth of between 0.25m and 5.5m, allowing for a detention time of 48 to 72 hours, while the choice of plant species is based on a specific need (e.g. target pollutant) (Read *et al.*, 2008; Australian WSUD Guidelines, 2007).

If the need for flow-control is identified, wetlands can be constructed with additional retention or detention capacity (Australian WSUD Guidelines, 2007). However, if flows surpass design volumes, excess water can be redirected via a bypass channel to prevent damage to the vegetation and the re-suspension of pollutants (Australian WSUD Guidelines, 2007).

B.6 Retention Ponds

Ponds and lakes permanently retain and treat stormwater runoff by promoting sedimentation, adsorbing nutrients and heavy metals and ultraviolet disinfection (Australian WSUD Guidelines, 2007; Debo and Reese, 2003). They have a large storage capacity and may allow

for controlled releases of water over several days (North Carolina Division of Water Quality, 2007; Woods-Ballard *et al*, 2007; Field and Sullivan, 2003).

Although occurring naturally, those in the urban setting are usually artificial being constructed from a simple dam wall, which also functions as a weir, or by removing soil to below natural levels (Australian WSUD Guidelines, 2007). Ponds and lakes can also form part of stormwater reuse or detention schemes.

Ponds and lakes should not be used in isolation but should follow wetlands or other pre-treatment alternatives (Australian WSUD Guidelines, 2007; Knox City Council, 2002). In addition, the outlets can be constructed to emulate pre-development runoff for a variety of flow volumes. Finally, as a measure to prevent water quality problems, ponds and lakes should be designed to retain their contents for at least 20 to 30 days (Australian WSUD Guidelines, 2007).

B.7 Aquifer Storage and Recovery

Aquifer storage and recovery (ASR) is a cost effective method of recharging subsurface aquifers via pumping or gravity feed (Australian WSUD Guidelines, 2007). In this way, water can be pumped out and reused during the dry season instead of storing it in large surface reservoirs.

When considering this method of storage, the overarching priority is the protection of ground water quality (Idaho Department of Environmental Quality, 2005; Hobsons Bay City Council, 2002). As such, ASR systems are usually preceded by a constructed wetland, lake or detention pond, which provide short-term storage and help to remove pollutants (Australian WSUD Guidelines, 2007). However, the level of treatment prior to transferral to the aquifer depends on current groundwater quality and its probable use.

The feasibility of using an ASR system is determined by the local hydrology, subsurface geology and the existence and character of aquifers (Australian WSUD Guidelines, 2007). In certain circumstances the use of ASR may be limited if the salinity of the aquifer is higher than desired levels (Australian WSUD Guidelines, 2007).

B.8 Permeable Pavement

Due to concerns around the extensive use of impermeable surfaces, permeable paving has developed as an alternative, which allows the filtration of stormwater into the underlying substrate (Australian WSUD Guidelines, 2007; Knox City Council, 2002). Such surfaces are commercially available and include concrete grid pavements, concrete or plastic modular pavements and pavements made from special asphalts (Australian WSUD Guidelines, 2007).

Permeable paving effectively enables the achievements of a number of water management objectives such as reduction in peak flows, improved groundwater recharge, improved stormwater quality and a reduction in space used exclusively for stormwater management (Australian WSUD Guidelines, 2007). However, high traffic loads on permeable pavement should be avoided to minimise groundwater pollution (Hobsons Bay City Council, 2002; Idaho Department of Environmental Quality, 2005). As such, permeable pavements are optimally suited to residential use or areas dedicated to pedestrians (e.g. pavements).

University of Cape Town

Appendix C: Plant-Growth Measurements: Leaf Length and Leaf Number

Physical plant-growth measurement commenced in February and continued for 6 months (except *Phragmites*). Nutrients were added to S1 and S2 shortly after the second measurement. Significant differences are represented by differences in alphabetic letters at $P \leq 0.05$.

C1. Leaf Length

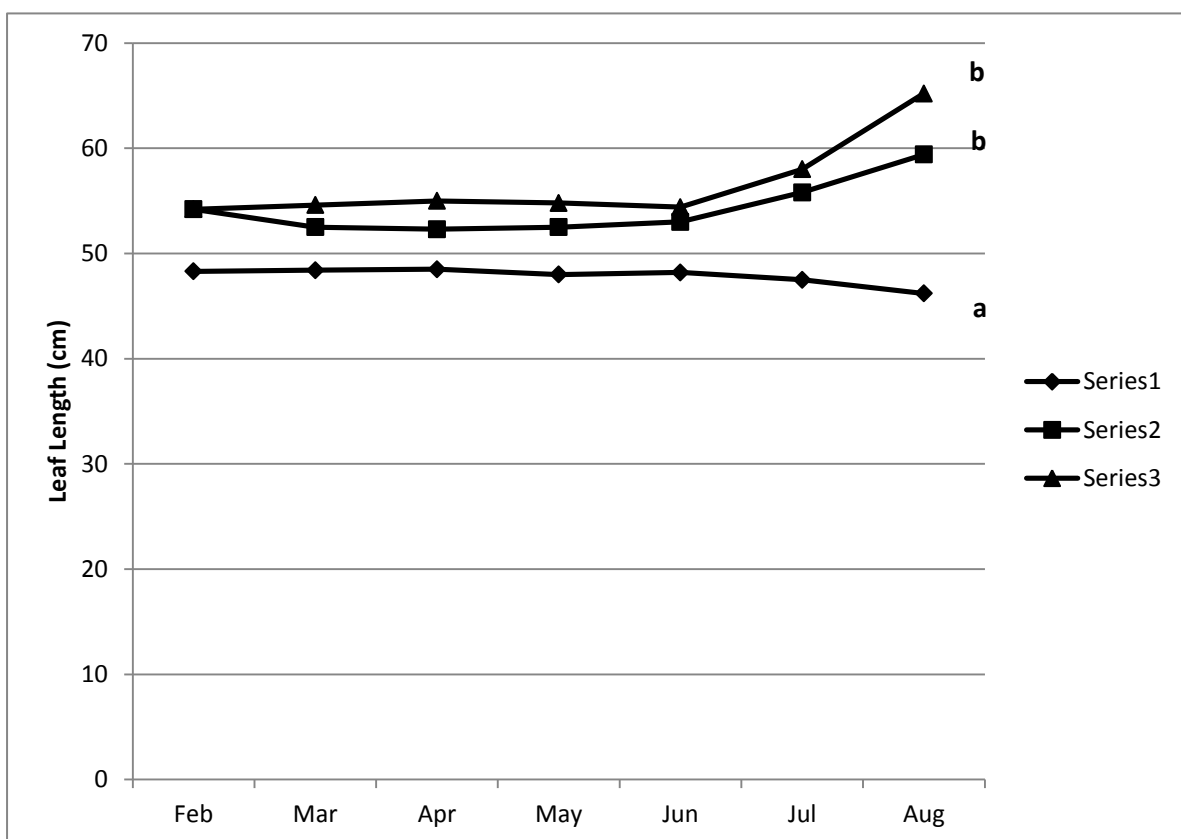


Figure 8: *Agapanthus*: Length of longest leaf. Different letters show significant difference at $P \leq 0.05$.

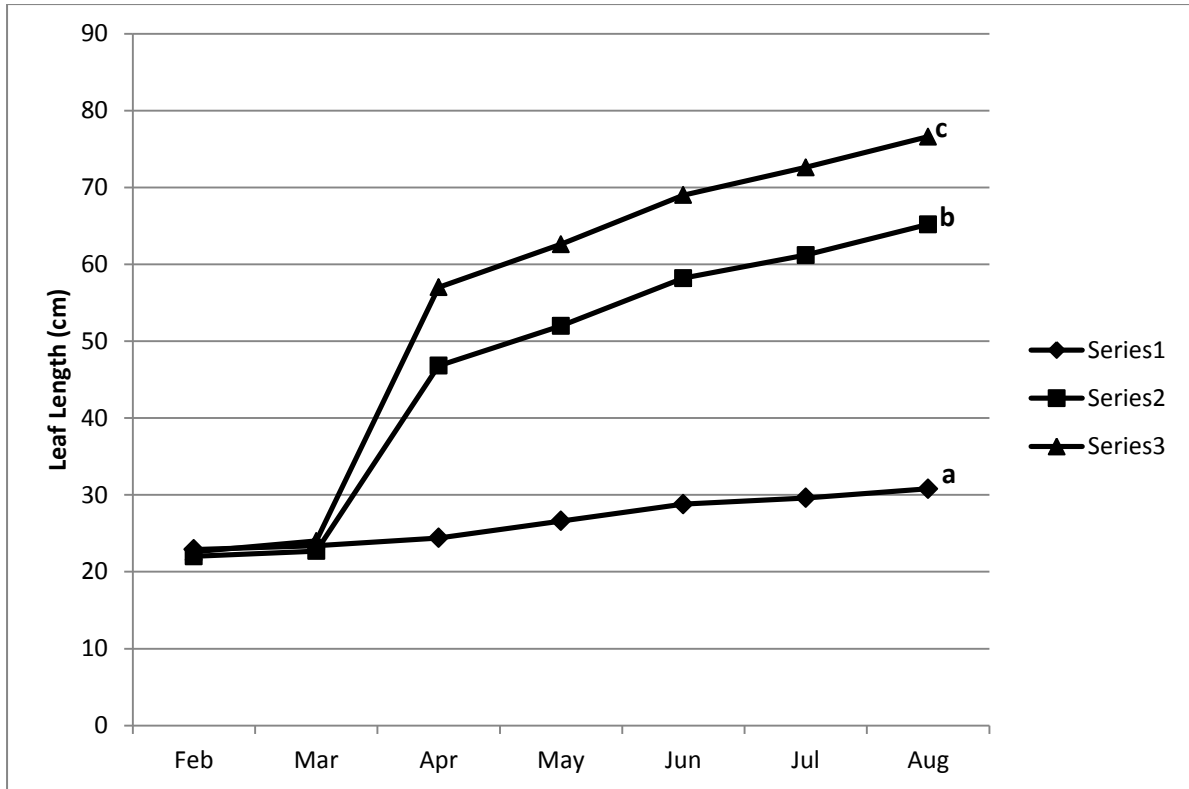


Figure 9: *Pennisetum*: Length of longest leaf. Different letters show significant difference at $P \leq 0.05$.

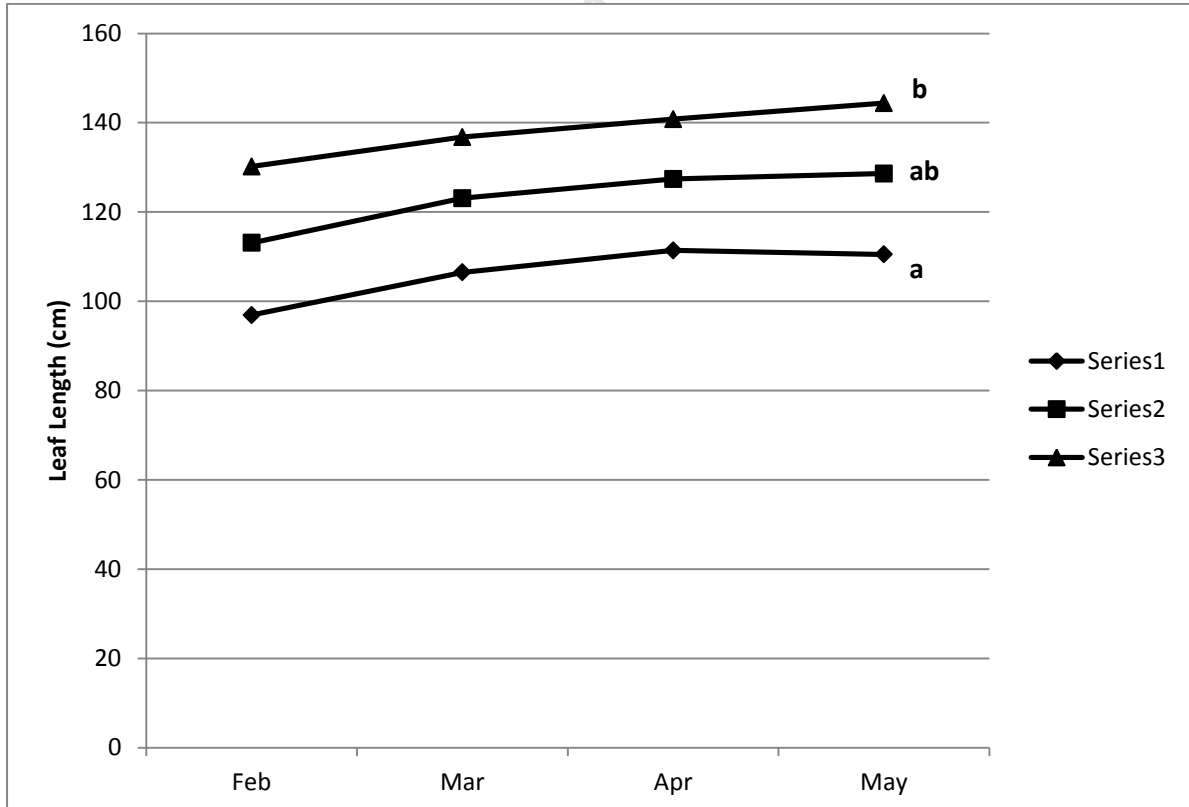


Figure 10: *Phragmites*: Length of longest leaf. Different letters show significant difference at $P \leq 0.05$.

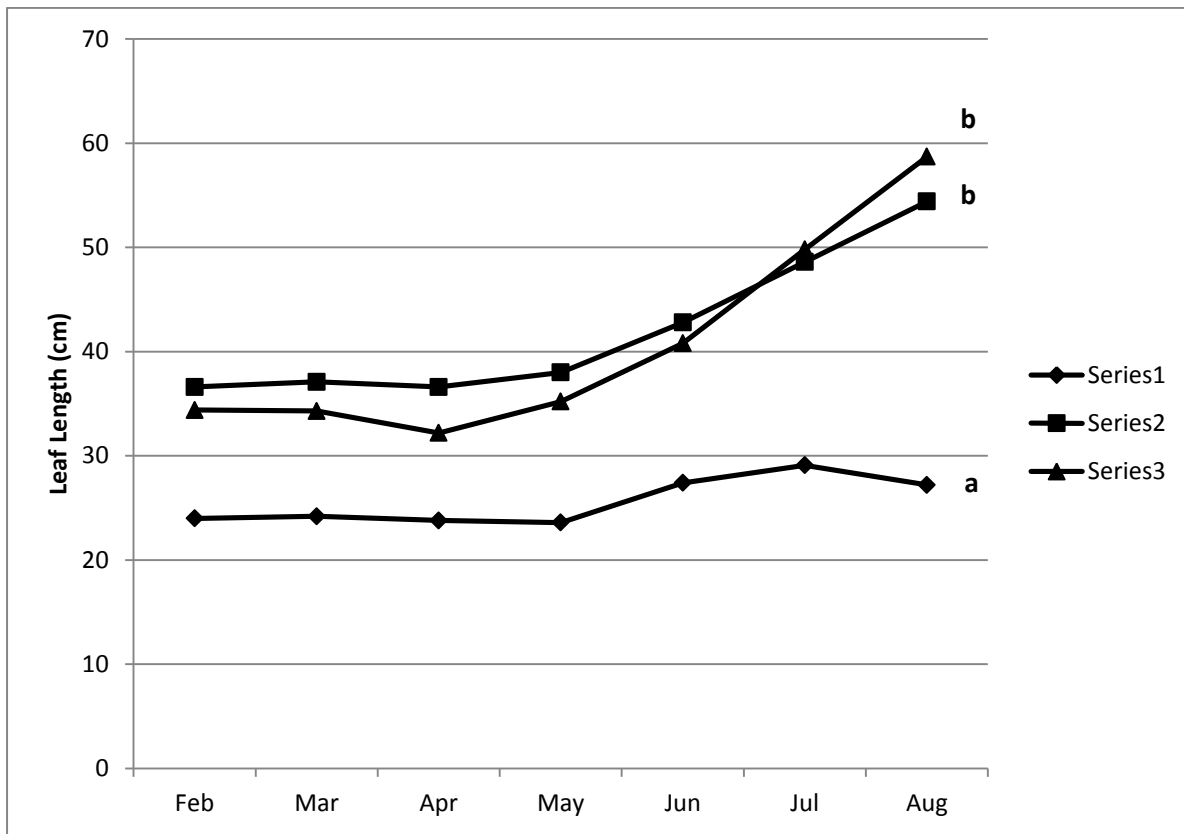


Figure 11: Zantedeschia: Length of longest leaf. Different letters show significant difference at $P \leq 0.05$.

C2. Leaf Number

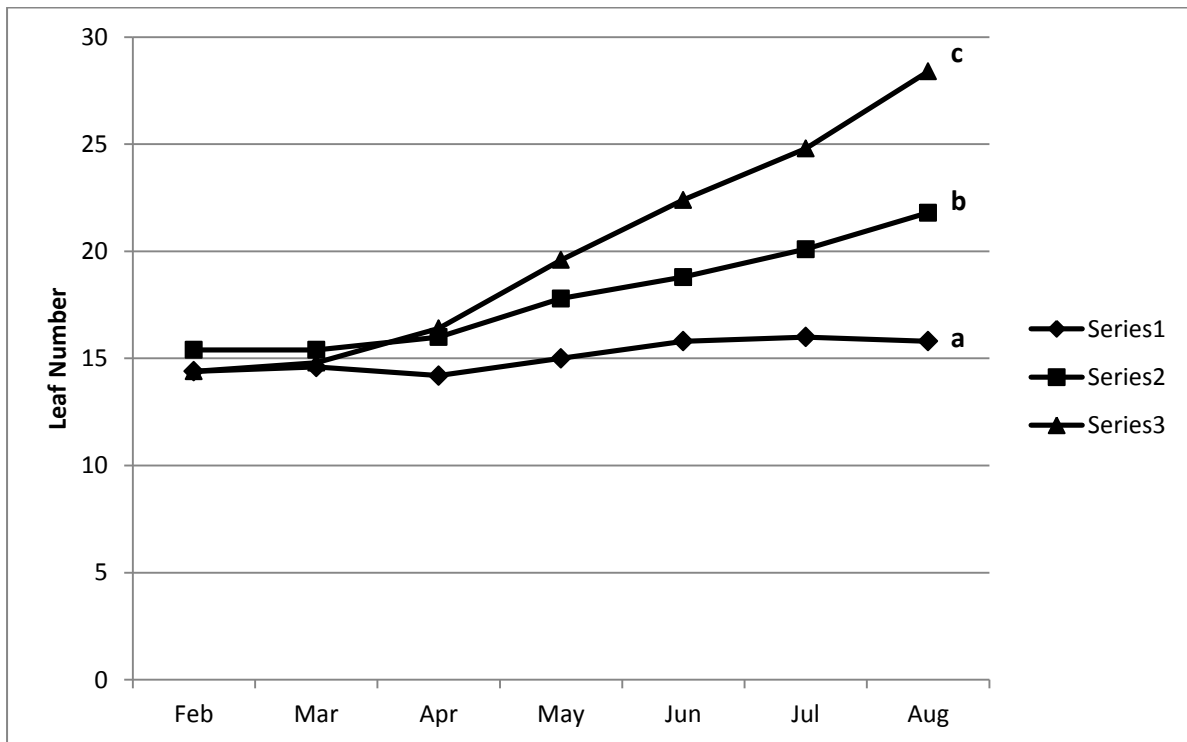


Figure 12: *Agapanthus*: Number of leaves. Different letters show significant difference at $P \leq 0.05$.

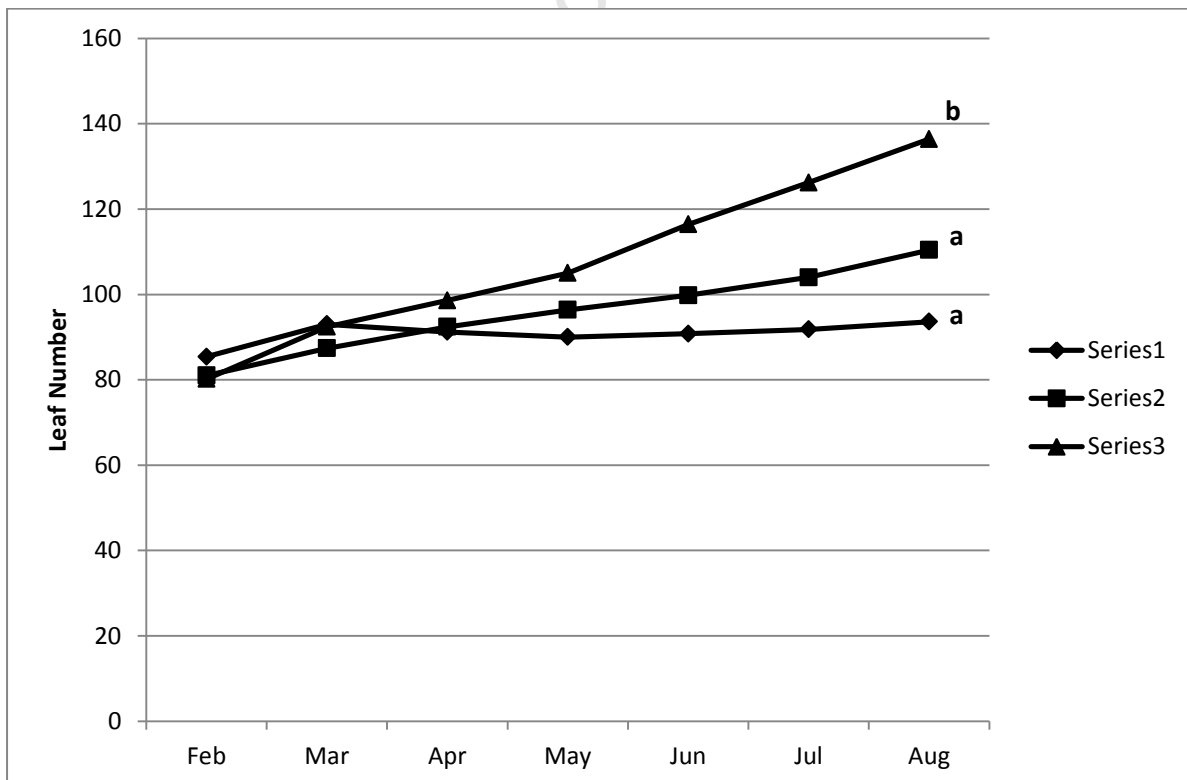


Figure 13: *Ficinia*: Number of leaves. Different letters show significant difference at $P \leq 0.05$.

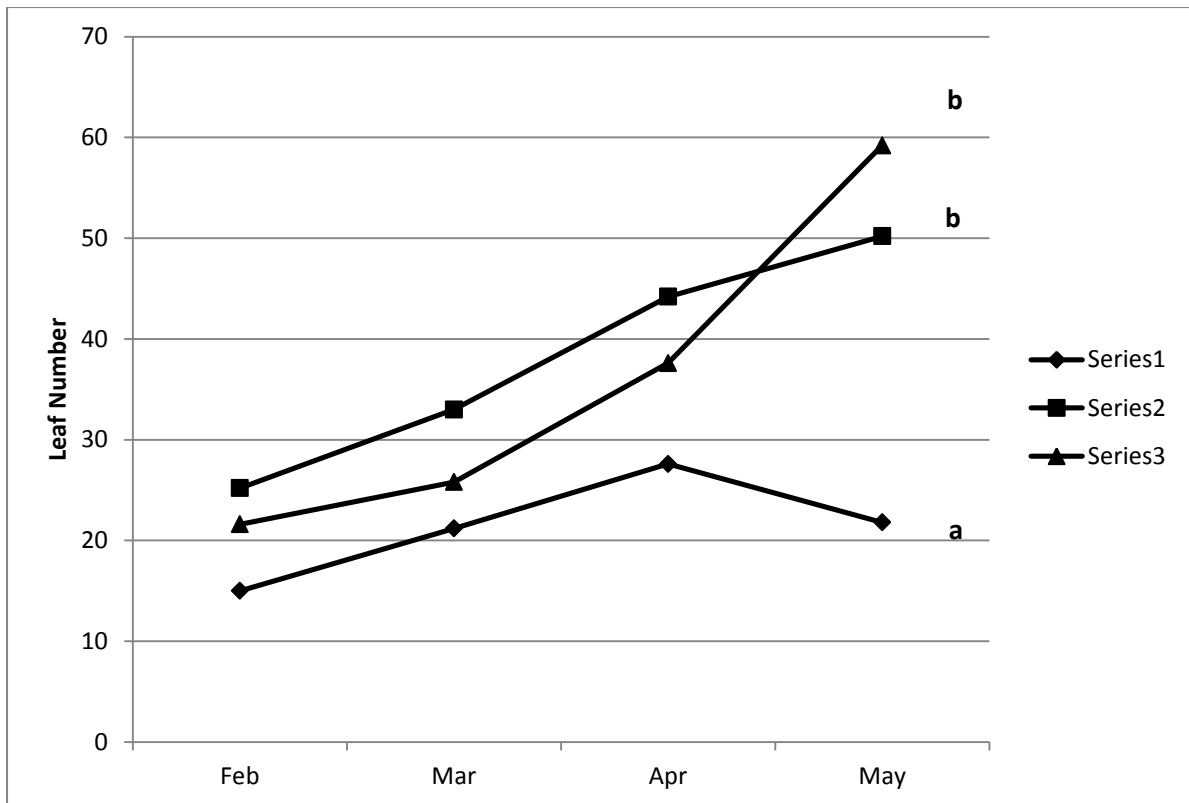


Figure 14: *Phragmites*: Number of leaves. Different letters show significant difference at $P \leq 0.05$.

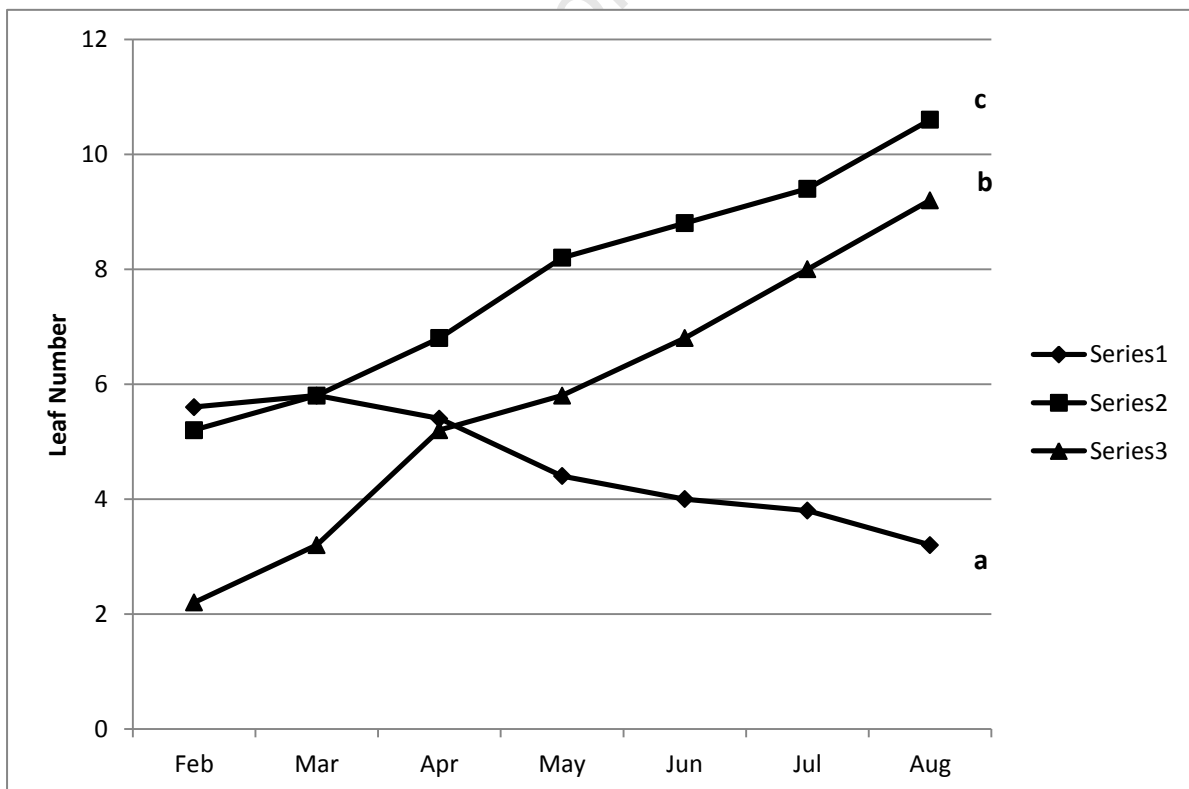


Figure 15: *Typha*: Number of leaves. Different letters show significant difference at $P \leq 0.05$.

Appendix D: Nutrient Removal Data

Outflow concentrations									
Note, tank (inflow) concentrations are below species									
Orthophosphate									
Common Reed					Bulrush				
Treatment	Rep No	Sample 1	Sample 2	Sample 3	Treatment	Rep No	Sample 1	Sample 2	Sample 3
Tap water	1	0.16	0.12	0.11	Tap water	2	0.19	0.13	0.07
Tap water	16	0.09	0.15	0.13	Tap water	10	0.45	0.33	0.09
Tap water	20	0.09	0	0.2	Tap water	18	0.24	0.17	0.07
Tap water	23	0.11	0.46	0.08	Tap water	24	0.13	0.45	0.04
Tap water	28	0.27	0.28	0.08	Tap water	28	0.29	0.27	0.08
S1	4	0.1	0.31	0.13	S1	3	0.25	0.2	0.23
S1	6	0.19	0.21	0.24	S1	5	0.24	0.15	0.21
S1	13	0.08	0.12	0.05	S1	7	0.33	0.25	0.08
S1	17	0.09	0.08	0.05	S1	21	0.25	0.11	0.08
S1	24	0.08	0.11	0.1	S1	29	0.26	0.17	0.11
S2	2	0.74	0.96	1.1	S2	6	0.99	1.19	1.16
S2	9	0.15	0.25	0.56	S2	9	0.99	0.49	0.61
S2	11	0.18	0.32	0.79	S2	15	0.49	0.47	0.27
S2	14	0.79	1.04	0.44	S2	17	0.15	0.15	0.31
S2	25	0.04	0.21	0.22	S2	30	0.13	0.09	0.22
Arum Lily					Ficinia				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	4	0.28	0.39	0.17	Tap water	4	0.85	0.94	0.91
Tap water	7	0.16	0.4	0.24	Tap water	6	1.07	1.28	0.95
Tap water	9	0.69	0.62	0.67	Tap water	10	1.49	1.4	1.31
Tap water	16	0.15	0.19	0	Tap water	12	1.37	1.25	1.12
Tap water	23	0.64	0.72	0.32	Tap water	27	1.84	1.7	1.89
S1	2	0.14	0.16	0.08	S1	1	1.21	1.2	1.18
S1	14	0.17	0.11	0.14	S1	8	1.29	1.27	1.28
S1	18	0.15	0.33	0.1	S1	20	1.4	1.58	1.55
S1	24	0.62	0.47	0.46	S1	24	1.74	1.7	1.55
S1	26	0.07	0.17	0.07	S1	26	1.54	1.66	1.52
S2	1	0.92	0.17	0.32	S2	2	1.58	1.71	1.4
S2	5	0.78	0.74	0.64	S2	13	1.53	1.36	1.45
S2	13	0.19	0.29	0.31	S2	18	1.81	1.96	1.64
S2	20	0.18	0.43	1.22	S2	19	2.83	3.02	3.12
S2	27	1.65	1.39	1.17	S2	23	2.87	2.83	2.95

Control					Thatching Reed				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	1	0.21	0.92	0.08	Tap water	4	0.3	0.51	0.27
Tap water	3	0.13	0.23	0.25	Tap water	9	0.36	0.32	0.25
Tap water	9	0.16	0.16	0.16	Tap water	16	0.17	0.46	0.14
Tap water	15	0.28	0.22	0.17	Tap water	20	0.37	0.78	0.24
Tap water	20	0.33	0.31	0.11	Tap water	22	0.5	0.4	0.55
S1	4	0.23	0.37	0.47	S1	1	0.27	0.93	0.86
S1	10	0.19	0.27	0.24	S1	6	0.86	1.48	1.03
S1	13	0.15	0.36	0.22	S1	10	0.53	1.79	0.34
S1	23	0.24	0.37	0.22	S1	19	0.39	0.44	0.33
S1	25	0.2	0.18	0.14	S1	29	0.85	1.38	1.12
S2	6	0.34	0.75	0.98	S2	2	0.92	1.31	1.3
S2	17	0.21	0.15	0.42	S2	12	1.25	1.17	1.42
S2	19	0.38	0.9	0.96	S2	14	0.49	1.44	1.8
S2	26	0.39	0.76	0.5	S2	24	1.35	1.56	1.73
S2	28	0.63	1.08	1.32	S2	26	1.55	1.63	1.75
Agapanthus					Sour Fig				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	6	0.3	0.46	0.26	Tap water	2	0.27	0.22	0.23
Tap water	8	0.34	0.17	0.12	Tap water	6	0.15	0.23	0.2
Tap water	11	0.37	0.27	0.17	Tap water	15	0.13	0.28	0.09
Tap water	16	0.27	0.24	0.11	Tap water	17	0.12	0.2	0.15
Tap water	21	0.35	0.13	0.12	Tap water	27	0.15	0.23	0.1
S1	2	0.24	0.18	0.16	S1	7	0.21	0.26	0.13
S1	10	0.1	0.1	0.11	S1	14	0.19	0.37	0.1
S1	17	0.16	0.19	0.08	S1	20	0.11	0.3	0.1
S1	24	0.14	0.15	0.12	S1	24	0.14	0.21	0.28
S1	26	0.27	0.22	0.09	S1	28	0.4		0.49
S2	1	0.14	0.17	0.13	S2	1	0.72	1.06	1.1
S2	4	0.13	0.18	0.08	S2	4	0.54	0.65	0.55
S2	15	0.26	0.29	0.08	S2	11	0.87	1.14	1
S2	22	0.05	0.13	0.1	S2	13	0.77	2.83	1.07
S2	29	0.06	0.15	0.08	S2	21	1.06	1	0.78
Buffalo Grass					Kikuyu Grass				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	2	0.11	0.17	0.16	Tap water	3	0.23	0.4	0.11
Tap water	4	0.1	0.13	0.19	Tap water	11	0.15	0.36	0.14

water					water				
S1	4	0.04	0.13	0.05	S1	3	0.07	0.05	0.09
S1	6	0.1	0.08	0.05	S1	5	0.09	0.05	0.06
S1	13	0.12	0.08	0.07	S1	7	0.05	0.01	0.01
S1	17	0.11	0.013	0.09	S1	21	0.1	0.04	0.02
S1	24	0.16	0.08	0.06	S1	29	0.15	0.04	0.03
S2	2	0.05	0.05	0.04	S2	6	0.13	0.08	0.05
S2	9	0.08	0.06	0.05	S2	9	0.1	0.05	0.05
S2	11	0.08	0.04	0.07	S2	15	0.09	0.09	0.07
S2	14	0.63	0.09	0.03	S2	17	0.08	0.02	0.02
S2	25	0.1	0.1	0.05	S2	30	0.07	0.05	0.05
Arum Lily					Ficinia				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	4	0.24	0.1	0.14	Tap water	4	0.09	0.11	0.17
Tap water	7	0.19	0.16	0.19	Tap water	6	0.06	0.13	0.06
Tap water	9	0.11	0.06	0.1	Tap water	10	0.1	0.11	0.11
Tap water	16	0.09	0.07	0.11	Tap water	12	0.09	0.14	0.15
Tap water	23	0.1	0.05	0.13	Tap water	27	0.15	0.2	0.22
S1	2	0.11	0.06	0.09	S1	1	0.09	0.09	0.1
S1	14	0.41	0.04	0.11	S1	8	0.05	0.05	0.05
S1	18	0.11	0.06	0.11	S1	20	0.05	0.1	0.1
S1	24	0.08	0.06	0.1	S1	24	0.1	0.07	0.09
S1	26	0.07	0.03	0.04	S1	26	0.1	0.11	0.13
S2	1	0.09	0.09	0.07	S2	2	0.1	0.12	0.16
S2	5	0.35	0.08	0.04	S2	13	0.14	0.16	0.16
S2	13	0.12	0.09	0.09	S2	18	0.15	0.2	0.2
S2	20	0.13	0.06	0.05	S2	19	0.09	0.09	0.1
S2	27	0.11	0.06	0.05	S2	23	0.23	0.14	0.12
Control					Thatching Reed				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	1	0.09	0.08	0.13	Tap water	4	0.1	0.11	0.08
Tap water	3	0.16	0.11	0.17	Tap water	9	0.15	0.15	0.15
Tap water	9	0.1	0.12	0.2	Tap water	16	0.14	0.16	0.24
Tap water	15	0.15	0.08	0.14	Tap water	20	0.09	0.07	0.05
Tap water	20	0.08	0.07	0.21	Tap water	22	0.13	0.12	0.14
S1	4	0.18	0.12	0.17	S1	1	0.12	0.17	0.27
S1	10	0.13	0.09	0.19	S1	6	0.23	0.26	0.29
S1	13	0.12	0.24	0.17	S1	10	0.12	0.1	0.14
S1	23	0.08	0.12	0.15	S1	19	0.14	0.14	0.16

S1	25	0.12	0.05	0.17	S1	29	0.12	0.13	0.11
S2	6	0.18	0.08	0.14	S2	2	0.07	0.03	0.02
S2	17	0.13	0.02	0.14	S2	12	0.17	0.26	0.23
S2	19	0.17	0.09	0.14	S2	14	0.2	0.1	0.06
S2	26	0.1	0.04	0.13	S2	24	0.09	0.09	0.06
S2	28	0.09	0.06	0.14	S2	26	0.09	0.06	0.05
Agapanthus					Sour Fig				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	6	0.22	0.14	0.17	Tap water	2	0.17	0.11	0.19
Tap water	8	0.11	0.07	0.21	Tap water	6	0.21		0.07
Tap water	11	0.05	0.05	0.06	Tap water	15	0.12	0.04	0.08
Tap water	16	0.06	0.07	0.07	Tap water	17	0.14	0.09	0.13
Tap water	21	0.13	0.07	0.07	Tap water	27	0.11	0.12	0.16
S1	2	0.04	0.04	0.005	S1	7	0.25	0.26	0.24
S1	10	0.24	0.04	0.03	S1	14	0.11	0.05	0.2
S1	17	0.12	0.08	0.11	S1	20	0.17	0.16	0.18
S1	24	0.13	0.07	0.11	S1	24	0.29	0.23	0.29
S1	26	0.09	0.06	0.07	S1	28	0.11		0.17
S2	1	0.13	0.1	0.1	S2	1	0.13	0.16	0.13
S2	4	0.09	0.09	0.08	S2	4	0.05	0.09	0.08
S2	15	0.15	0.04	0.06	S2	11	0.05	0.16	0.09
S2	22	0.06	0.02	0.04	S2	13	0.07	2.19	0.12
S2	29	0.03	0.02	0.05	S2	21	0.16	0.19	0.16
Buffalo Grass					Kikuyu Grass				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	2	0.02	0	0.02	Tap water	3	0.03	0.09	0.09
Tap water	4	0.03	0	0.02	Tap water	11	0.05	0.04	0.02
Tap water	17	0.03	0.02	0.03	Tap water	19	0.04	0.05	0.02
Tap water	23	0.03	0.02	0.01	Tap water	26	0.01	0.02	0.03
Tap water	29	0.05	0.01	0.01	Tap water	29	0.04	0.07	0.03
S1	1	0.04	0	0	S1	1	0	0.01	0
S1	6	0.03	0.01	0.05	S1	5	0.03		0.02
S1	15	0.03	0	0.01	S1	14	0.02	0.01	0.02
S1	21	0.04	0	0.01	S1	18	0.02	0.02	0
S1	26	0.02	0.02	0.01	S1	21	0.02	0	0.01
S2	7	0.03	0	0.03	S2	4	0.02	0	0.02
S2	11	0.02	0	0	S2	8	0.01	0.01	0
S2	13	0.09	0	0.01	S2	12	0.03	0.01	0.01
S2	16	0.04	0	0.03	S2	17	0.01	0	0.02
S2	20	0.02	0.02	0	S2	23	0.02	0.01	0

Tap water	7	0.2	0.2	0.2	Tap water	6	0.3	0.2	0.2
Tap water	9	0.2	0.2	0.1	Tap water	10	0.3	0.4	0.5
Tap water	16	0.4	0.3	0.1	Tap water	12	0.3	0.2	0.3
Tap water	23	0.6	0	0.4	Tap water	27	0.2	1.1	0.3
S1	2	1.1	1	0.7	S1	1	1.1	0.6	1.6
S1	14	0.8	2.2	1	S1	8	1.2	1.4	1.7
S1	18	0.3	0.8	0.6	S1	20	1.4	1.5	0.7
S1	24	1.2	1.2	0.7	S1	24	0.9	1.2	0.9
S1	26	1.2	1.2	0.6	S1	26	0.6	1	0.9
S2	1	2.5	1.8	1.8	S2	2	2	1.3	3.1
S2	5	2.1	2.9	1.6	S2	13	1.9	2.1	2.1
S2	13	1.6	1.9	1.7	S2	18	0.7	1	0.8
S2	20	2.6	1.6	2.3	S2	19	3	3.4	2.1
S2	27	2.7	2.3	1.6	S2	23	3	3	2
Control					Thatching Reed				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	1	0.4	3.4	0.6	Tap water	4	0.1	0.3	0.3
Tap water	3	0.3	0.1	0	Tap water	9	0.2	0.3	0.2
Tap water	9	0.4	0.2	0.3	Tap water	16	0.1	0.4	0.4
Tap water	15	0.2	0.1	0.9	Tap water	20	0.3	0.4	0.3
Tap water	20	0.3	0.1	0.1	Tap water	22	0.3	0.3	0.3
S1	4	2	2.1	2.4	S1	1	1.2	1.9	1.4
S1	10	2.1	2.3	2.5	S1	6	1.5	2.6	2.3
S1	13	2.5	2	2.7	S1	10	0.9	1.1	1.9
S1	23	2.7	0.2	4	S1	19	1	1.4	1.5
S1	25	2.7	2.1	1.9	S1	29	1.9	2.3	2.5
S2	6	3.9	5.6	7.1	S2	2	3.7	4.6	5
S2	17	4.4	4.5	5.1	S2	12	3.7	3.7	4.4
S2	19	4.7	3.3	6.2	S2	14	3.3	5.5	3.5
S2	26	2.8	5.4	8.5	S2	24	4.4	7.3	4.9
S2	28	5	4.7	7.6	S2	26	3.4	5.8	5.3
Agapanthus					Sour Fig				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No.	Sample 1	Sample 2	Sample 3
Tap water	6	0	0.3	0.3	Tap water	2	0.2	0.2	0.5
Tap water	8	0.4	0.4	0.6	Tap water	6	0.3		0.3
Tap water	11	0.1	0.2	0.5	Tap water	15	0.5	0.7	0.4
Tap water	16	0.4	0.3	0.3	Tap water	17	0.4	0.4	0.5
Tap water	21	0.1	0.2	0.2	Tap water	27	0.1	0	0.5

S1	2	1.1	1.1	1	S1	7	0.6	0.8	0.7
S1	10	0.8	1.2	1	S1	14	1.3	1.3	0.5
S1	17	0.7	0.9	0.9	S1	20	0.4	0.6	0.9
S1	24	0.7	0.9	1.3	S1	24	1.3	0.9	0.9
S1	26	1.1	0.8	1.3	S1	28	1.9		1.3
S2	1	0.9	1.2	1	S2	1	2.6	1.9	2.3
S2	4	1.4	1.4	1.3	S2	4	2.2	1.5	0.9
S2	15	0.6	1.8	2.7	S2	11	4.8	1.6	1.8
S2	22	1.7	1.5	1.2	S2	13	6.6	6.5	4.2
S2	29	3.4	2.2	2.1	S2	21	3.8	2.4	3.1
Buffalo Grass					Kikuyu Grass				
Treatment	Rep No.	Sample 1	Sample 2	Sample 3	Treatment	Rep No	Sample 1	Sample 2	Sample 3
Tap water	2	0.5	0.4	0.3	Tap water	3	0.5	0.2	0.5
Tap water	4	0.4	0.4	0.3	Tap water	11	0.2	0.6	0.3
Tap water	17	0.1	0.4	0.8	Tap water	19	0.5	0.4	0.5
Tap water	23	0.2	0.3	0.5	Tap water	26	0.2	0.3	0
Tap water	29	0.3	0.2	0.5	Tap water	29	0.3	0.5	0.6
S1	1	0.5	0.7	0.5	S1	1	0.5	0.8	0.7
S1	6	0.3	0.8	0.5	S1	5	0.7		0.9
S1	15	0.8	0.6	1	S1	14	0.7	0.9	0.7
S1	21	1.1	0.5	0.8	S1	18	0.4	0.9	1.1
S1	26	0.7	0.7	0.8	S1	21	0.7	1.3	0.9
S2	7	0.9	1	1.1	S2	4	0.7	0.6	0.6
S2	11	1.1	1.1	1.3	S2	8	1.4	1.3	1.3
S2	13	1.1	0.9	1	S2	12	0.6	0.8	0.8
S2	16	1.1	1.1	1.4	S2	17	0.5	0.6	0.9
S2	20	0.6	0.6	1	S2	23	0.8	0.7	1
Tank Concentration									
	Sample 1	Sample 2	Sample 3						
Tank 1	0.4	0.2	0.4						
	0.6	0.3	0.4						
	0.5	0.25	0.4						
Tank 2	3.3	2.9	3.2						
	2.8	3.8	2.7						
	3.05	3.35	2.95						
Tank 3	6.6	5.3	4.7						
	6.5	6.1	6.7						
	6.55	5.7	5.7						