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Name	Student number	Signature	Date
Lauren Brooks	BRKLAU009		23 November 2015

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Abstract

Urbanisation and climate change have been recognised as fundamental causes of water scarcity and drivers for advocating sustainability. Sustainable Urban Drainage Systems (SuDS) is the stormwater component of Water Sensitive Urban Design (WSUD) which aims to modify conventional urban drainage approaches.

Efficient and sustainable management of stormwater is promoted by SuDS technologies. Rare implementation of SuDS technologies into developments is a key issue which could be attributed to SuDS implementation being a fairly new concept in South Africa.

This research project has focused on the development of a Decision Support System (DSS) which guides decision-makers through a selection process towards suitable SuDS technologies for a development. The selection chart format chosen has been regarded as a simple means of interpreting and communicating the information related to SuDS.

To complete this research project, a study of 'The South African Guidelines for Sustainable Drainage Systems' and the 'Water Sensitive Urban Design for South Africa: Framework and Guidelines' has been conducted. The DSS is the first SuDS selection chart of its kind to have been developed in support of these recent WRC publications.

A series of diagnostic questions form the framework of the DSS. The user would have the option to choose the most appropriate response from those provided. Selected responses form decision-flow paths directed towards suitable SuDS technologies for implementation in South Africa.

Relevant information pertaining to the technologies have been incorporated into the DSS in order to offer further assistance with the selection process. The stormwater design hierarchy has been followed by the DSS, therefore the quantity, quality, amenity and biodiversity management of stormwater have been addressed in the appropriate order.

Progression through the DSS should allow the user to gather sufficient information on which to base a convincing selection. It is anticipated that the user would have acquired a general understanding of the SuDS technology options after having worked through the DSS. As a decision support tool, the DSS is intended to be convenient and user-friendly for decision-makers, regardless of their profession.

On the basis of the outcomes of this research project, it has been concluded that the DSS developed has the potential to assist the selection of suitable SuDS technologies for a development through the facilitation of a decision-making process.

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Definitions of technical terms and acronyms

Technical terms

Please note that these definitions are acquired from the Water Sensitive Urban Design (WSUD): Framework and Guidelines as well as the South African Guidelines for Sustainable Drainage Systems and apply to the use of terms in this document.

Adsorption refers to the process whereby stormwater runoff pollutants bind to the surface of aggregate particles.

Biodegradation refers to the degradation of organic pollutants in stormwater runoff by microbes; reaction, a reduction of pressure or a combination of these.

Catchment here refers to the area contributing runoff to any specific point on a watercourse or wetland.

Channel here refers to any natural or artificial watercourse.

Climate change is a continuous phenomenon and refers to the change in global climatic conditions, e.g. as a result of temperature increases due to anthropogenic emissions.

Conveyance is the transfer of stormwater runoff from one location to another.

Detention is the slowing down of stormwater runoff before subsequent transfer downstream.

Drainage may refer to: (1) the removal of excess ground-water or surface water by gravity or pumping; (2) the area from which water bodies are removed; or (3) the general flow of all liquids under the force of gravity.

Extended attenuation storage is the retention of stormwater runoff to protect receiving watercourses in the event flooding if the long-term storage and additional infiltration o\are not feasible on site. •

Filtration refers to the filtering of stormwater runoff pollutants that are conveyed with sediment by trapping these constituents on vegetative species, in the soil matrix or on geotextiles.

Flood means a temporary rise in water level, including ground water or overflow of water, onto land not normally covered by water.

Greenfield refers to any site including parkland, open space and agricultural land which has not previously been used for buildings and other major structures.

Green roof is a roof on which plants and vegetation can grow. The vegetated surface provides a degree of retention, attenuation, temperature insulation and treatment of rainwater.

Hydrology refers to the physical, chemical and physiological sciences of the water bodies of the earth including: occurrence, distribution, circulation, precipitation, surface runoff, stream-flow, infiltration, storage and evaporation.

Impervious surface here refers to surfaces which prevent the infiltration of water. Roads, parking lots, sidewalks and rooftops are typical examples of impervious surfaces in urban areas.

Infiltration is the soaking of stormwater runoff into the ground thereby physically reducing the volume of the stormwater runoff on the surface.

Long term storage is the volumetric control of stormwater runoff in a specified infiltrating area that will drain very slowly.

Nitrification is the oxidisation of ammonia and ammonium ions in stormwater runoff by microbial factions to form nitrite and nitrate.

Permeability refers to the ability of a material to allow water to flow through when fully saturated and subjected to an unbalanced pressure.

Plant-uptake refers to the removal of stormwater runoff nutrients and metals through uptake by plants.

Precipitation is the water received from atmospheric moisture as rainfall, hail, snow or sleet, normally measured in millimetres depth.

Rainwater harvesting is the direct capture of stormwater runoff, typically from rooftops, for supplementary water uses on site.

Resilience refers to the preservation or enhancement of adaptive capacity, i.e. the capacity of a system to preserve core functioning in the presence of shocks and long-term changes.

Retrofitting refers to the modification or installation of additional or alternative stormwater management devices or approaches in an existing developed area in order to achieve better management of stormwater.

Runoff generally refers to the excess water that flows after precipitation.

Sedimentation is the removal of sediment particles attached to pollution in stormwater runoff by reducing flow velocities to ensure sediment particles fall out of suspension.

Stormwater is water resulting from natural precipitation and/or accumulation and includes rainwater, groundwater and spring water.

SuDS is the abbreviation for sustainable drainage systems or sustainable urban drainage systems, which are a sequence of management practices and/or control structures or technologies designed to drain surface water in a more sustainable manner than conventional techniques.

Surface runoff is that part of the runoff that travels over the ground surface and in channels to reach the receiving streams or bodies of water.

Surface water means sources of water found in rivers, lakes, pans and dams.

Sustainable development can be considered as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

Treatment train (individual devices connected in series to improve overall treatment performance).

Watercourse means any river, stream, channel, canal or other visible topographic feature, whether natural or constructed, in which water flows regularly or intermittently including any associated storage and/or stormwater attenuation dams, natural ‘vleis’ or wetland areas.

Acronyms

CoCT	City of Cape Town
DWA	Department of Water Affairs
ECSA	Engineering Council of South Africa
EGS	Ecosystem Goods & Service
IUWM	Integrated Urban Water Management
NDP	National Development Plan
SA	South Africa
SuDS	Sustainable Urban Drainage System
UWM	Urban Water Management
WRC	Water Research Council
WSC	Water Sensitive City
WSS	Water Sensitive Settlement
WSUD	Water Sensitive Urban Design

1. Introduction

Background to the research project

Global issues of climate change and rapid urbanisation exacerbate the problems related to water scarcity worldwide. These issues threaten the livelihoods of the urban population and the state of the natural land and water environments.

1.1 Water Sensitive Urban Design (WSUD) offers an additional approach to conventional Urban Water Management (UWM). WSUD practices take a holistic view on the components of and places greater prominence on water in an urban setting.

Urban development generally replaces free-draining surfaces with impermeable surfaces. Infrastructure such as pipes and canals form conventional drainage systems which typically drain impermeable surfaces. Conventional drainage systems generally focus on eliminating local flood inconveniences and ignore the water quality, amenity, and biodiversity aspects of stormwater management. Besides reducing the natural permeability characteristics, development results in a loss of vegetation (Armitage et al., 2013).

Sustainable Urban Drainage Systems (SuDS), the stormwater component of WSUD, relates to specific aspects of the urban water cycle. There is a need for a more integrated approach to managing urban water systems through alternative systems-based approaches. A reason for this would be for urban regions to progress into resilient and sustainable places of living. Implementation of SuDS technologies can potentially improve the water quantity, quality, amenity and biodiversity management of a development.

This research project is based on the content of the 'South African Guidelines for Sustainable Drainage Systems' and the 'Water Sensitive Urban Design for South Africa: Framework and Guidelines'. These recent Water Research Council (WRC) publications have been developed in order to provide direction with regards to SuDS implementation and WSUD practices in the South African context.

A Decision Support System (DSS) has been developed in the format of a selection chart. The DSS developed is the first of its kind which intends to support the efforts of the WRC publications. In an attempt to assist the decision-maker with the selection of suitable SuDS technologies, the DSS seeks to guide the user through the decision-making process.

Inform the decision-maker on and encourage the implementation of SuDS technologies and WSUD practices, is an intention of the DSS. Potential opportunities for improved stormwater management are highlighted in the DSS.

The selection chart draws on the content of the SuDS guidelines and presents the information in a more convenient, user-friendly manner. The DSS, along with the 'SuDS guidelines' are intended for use by all practitioners; therefore, possibly promote the notion of interdisciplinary partnerships at all levels and applicable phases of development.

1.2 Aim and objectives

The aim of this research project is to develop a guide for decision-makers which facilitates the process towards suitable SuDS technology selection.

Objectives of this research project are to develop a practical and user-friendly DSS for the selection of SuDS facilities that:

i.) Provides guidance through the SuDS selection process and facilitate the UWM decision-making process; from o be informed on;

ii.) Incorporates components of WSUD, relevant SuDS technologies for implementation in South Africa, the concept of a treatment train and can be used with existing stormwater DSS;

iii.) Can be used by decision-makers and stakeholders involved in a development project, regardless of their professional background, from a conceptual design phase.

1.3 Limitations of the research

Limitations of the research project are as follows:

i.) The DSS developed focuses on SuDS, the stormwater component of WSUD.

ii.) The selection chart format of the DSS developed is a simple system for manual use with minimal technical detail.

iii.) The research project provides guidelines for SuDS selection therefore, the suggested solutions would not be the only and final answer to specific urban water management problems.

1.4 Report outline

The research project comprises of the following information:

Chapter 2 is a literature review that provides relevant contextual information to help substantiate the preceding sections. WSUD, SuDS and DSS are themes examined in the literature review. This is to aid the understanding the role of SuDS as a component of the concept of WSUD in a South African context as well as suitable existing decision support tools relating to SuDS. An emphasis is placed on the SuDS facilities which have been selected as solutions within the DSS since it represents the fundamental attribute of the research project.

Chapter 3 discusses the processes undertaken to complete the research project.

Chapter 4 focuses on the selection chart developed to support the efforts of the SuDS guidelines for SA. This section provides a detailed guideline on the use of the DSS developed. A description on the components of the DSS and an overview of the research effort is included.

Chapter 5 concludes the research conducted. The functionality of the DSS developed and the context of SuDS in terms of the research is addressed.

Chapter 6 suggests recommendations for further research into the improvement of the DSS developed.

Appendices include the DSS selection charts developed, tables of additional SuDS information and the required ECSA level outcomes compliance.

2. Literature review

In order to develop a decision support system, it is necessary to review the concept of Water Sensitive Urban Design (WSUD) within a South African context, Sustainable Urban Drainage Systems as a component of WSUD and suitable existing stormwater decision support systems (DSS). A literature review compiled from a range of published works is required to further the understanding of SuDS and DSSs, their role and relevance to urban water management. The sections within this chapter Sections of this chapter provide brief overviews of such topics.

2.1 Water Sensitive Urban Design

Water Sensitive Urban Design is a modern concept which has been implemented internationally. The concept of WSUD as well as the drivers for WSUD in South Africa have been reviewed in order to understand the concept as well as its context and relevance in South Africa

2.1.1 Concept of Water Sensitive Urban Design

The term Water Sensitive Urban Design (WSUD) was first used during the early 1990s, as specialists started to explore and formalise approaches for integrated water management (Lloyd, 2001). Myers et al. (2013), states that it is only in recent years that water policy makers recognised the need to manage the urban water cycle in a way that minimises changes to natural catchment hydrology and move towards achieving the objectives of ecologically sustainable development.

WSUD fundamentally involves maintaining the water balance and water quality of an urbanised environment in the same state as prior to urbanisation, (Davies, 1996). As defined by Wong and others (Lloyd, 2001; Wong, 2000, 2001, 2002), WSUD is a "*philosophical approach to urban planning and design that aims to minimise the hydrological impacts of urban development on the surrounding environment*".

Wong & Eadie (2000) add that WSUD is multi-disciplined and aims to holistically consider the environmental, social and economic consequences of water management infrastructure. An Australian Intergovernmental Agreement on a National Water Initiative defines WSUD as the integration of urban planning with management, protection and conservation of the urban water cycle so to ensure urban water management sensitivity to natural hydrological and ecological processes (NWC, 2004). The above definitions demonstrate that the concept of WSUD is constantly evolving as research improves.

WSUD is based on the premise that urban development and redevelopment must address the sustainability of water (Engineers Australia, 2006). Armitage et al. (2014) adds that WSUD includes the protection of natural water reservoirs, courses and ecosystems; attenuating stormwater runoff; promoting re-use of both storm and wastewater; and reducing the demand on potable water through more efficient use of existing supplies.

Wong (2013) reiterates that the WSUD concept has evolved from stormwater management to a focus on integrating the urban water cycle therefore including potable water, wastewater and stormwater into built and natural urban landscape. There has been realisation that all forms of water in the urban environment have a resource value and provide many benefits to society. In alignment with this description, Myers (2013) states that WSUD encompasses the integrated management of all water sources in the urban environment and includes their efficient utilisation, storage, treatment and reuse in order to maximises the economic, environmental, recreational and cultural value of water (Government of South Australia, 2010).

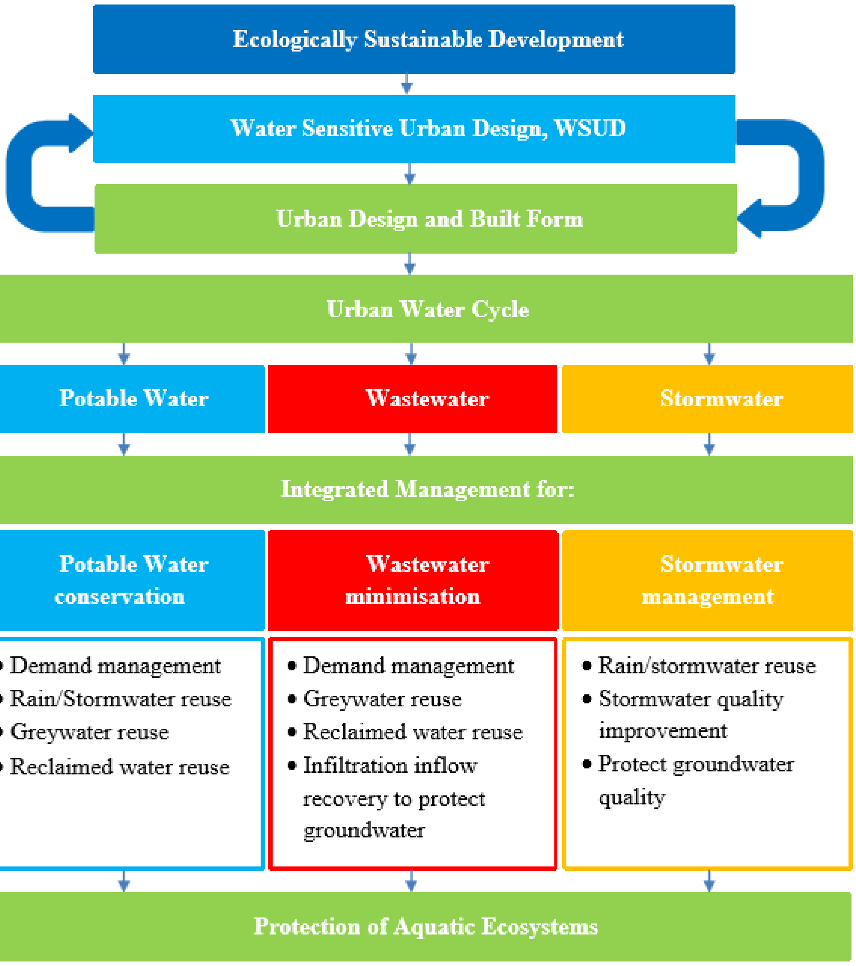

Figure 2-1: Summary of WSUD framework (Armitage et al., 2014)

WSUD is a contemporary approach to the planning and design of urban environments that is 'sensitive' to the issues of water sustainability, resilience and environmental protection. It represents a significant shift in the way water and related environmental resources and water infrastructure are considered in the planning and design of cities, according to Armitage et al. (2014).

WSUD, ecologically sustainable development and integrated water cycle management are intrinsically linked and complementary. A framework for WSUD developed by Wong (2006) captures the interactions of the built urban form, material and energy flows and urban water cycle management in delivering an integrated approach to water conservation and aquatic ecosystem protection.

Wong (2013) elaborates on the holistic water sensitive approach to planning and design as being a new paradigm in integrated water cycle management since it brings together the social, physical and environmental sciences with various engineering disciplines. WSUD aims to ensure water is given due prominence within the urban design process for an effective transition into Water Sensitive Cities (WSC).

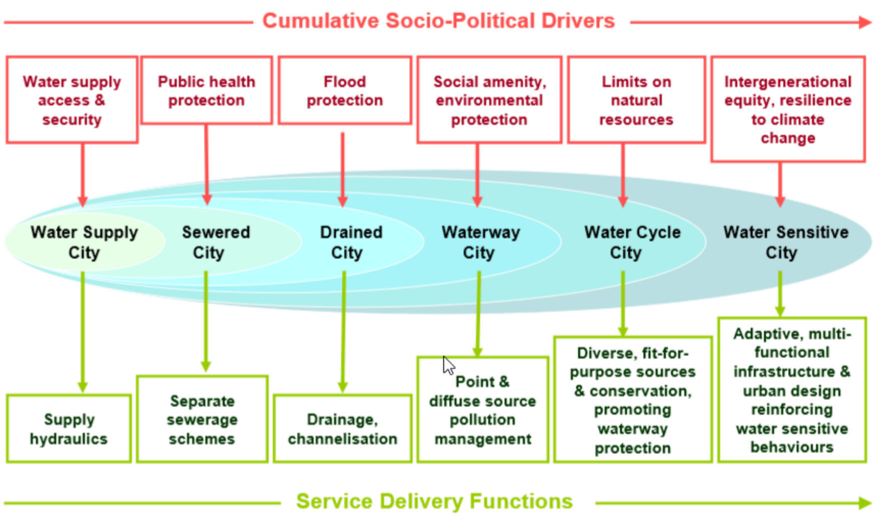

Figure 2-2: Urban Water Management Transitions Framework (Wong & Brown, 2008)

Implementation of WSUD will contribute towards attaining sustainable urban environments; this involves development that does not deplete natural resources nor degrades the amenity and biodiversity value of land and water environments (Wong, 2013). Through considering all aspects of the urban water cycle and their interaction with urban design, WSUD aims to be the medium through which sustainable development occurs in settlements.

2.1.2 Drivers for WSUD in South Africa

There are various motivations for the need to alter the current, conventional approach to Urban Water Management in South Africa through Water Sensitive Urban Design initiatives.

South Africa (SA) is a developing nation which faces issues such as water scarcity and rapid urbanisation as well as the challenge of providing an adequate supply of water for its citizens (Armitage et al., 2014). According to the National Development Plan for South Africa, greater attention will have to be paid to the management and use of water; WSUD is an alternative approach to enhancing the quality, quantity as well as the amenity and biodiversity value of water through holistic UWM.

Water scarcity and climate change are major concerns which drive the need to a more integrated approach to managing urban water systems. South Africa is no exception compared to other countries, as excessive pressure is placed on natural catchments which results in settlements being faced with the challenges of accommodating growing populations with finite freshwater resources and adapting to the potential impacts of climate change (Moglia et al., 2012). The NDP (2012) states that South Africa needs an enhancement of the people and economy's resilience to climate change.

Water security is increasingly a matter of major concern, with most surface water resources fully accounted for and poor water quality within and downstream of urban areas (Armitage et al., 2014). Rapid urbanisation attribute to the decline in water quantity and quality since more people require access to an adequate water services and urban development hinders the natural water cycle.

WSUD has the potential to: mitigate the negative effects of water scarcity; manage and reverse water pollution, develop social and intergenerational equity, increase sustainability; and develop resilience within water systems (Wong, 2013). In RSA, the need for WSUD is more pertinent as well as the consideration of settlements in an alternative way. According to Armitage et al. (2014), a major challenge in RSA is the promotion of economic and social equity whilst simultaneously ensuring environmental sustainability. From a water management perspective, implementation of WSUD would be necessary in an attempt to achieve the goals of water sensitivity.

Myers et al. (2013) mentions that drivers for the implementation of WSUD range from the need for management of stormwater flows, improvement in water quality, the desire for reducing mains water consumption, reduction in financial costs and the need for preservation of vegetation or amenity.

As adapted from Wong (2013), RSA require WSUD for the protection of the biodiversity of urban waterways and estuarine environments as well as the proper management of natural systems. Enhancement of the sustainability and liveability of settlements can be achieved through WSUD implementation.

Movement of RSA municipalities towards better managing the natural and urban systems as well as address challenges such as urban heat islands, cleaning waterways and sustainable building is necessary for RSA to transform and adapt. Planning and policies which progress towards strategies to develop new urban forms supporting the transition to water sensitive cities such as the WSUD: Framework and Guidelines for South Africa is a significant driver which has the potential to bring about change in UWM.

WSUD encapsulates the overall idea of IUWM and consists of various aspects, of which SuDS is the stormwater management component. Particular emphasis has been placed on SuDS in this literature review since it is the focus of the research project. The concept of SuDS and the various technologies suitable for implementation has been discussed in the following section.

2.2 SuDS

Scholz (2015) mentions that UWM has transformed from building traditional conventional systems to implementing SuDS, which are part of the best management practice techniques used in the USA and seen as contributing to WSUD in Australia. According to Ellis et al. (2006), there has been a growing interest in the promotion of sustainable development amongst local and national governments throughout the world - this includes the control of stormwater runoff.

SuDS offer an alternative approach to conventional drainage practices by attempting to manage surface water drainage systems holistically, in line with the ideals of sustainable development. SuDS could be considered as an approach which highlight potential opportunities for better stormwater management and have the potential to address key issues caused due to urbanisation. (Armitage et al, 2014). SuDS, as a component of WSUD, has been identified as a means to control flows and filter stormwater therefore removing a large portion of pollutants. The activities of WSUD are shown in figure 2-3.

The term SuDS is generally used to describe an urban intervention that can manage stormwater through detention, harvesting, infiltration, evaporation or conveyance while contributing added functionalities such as recreational benefits, urban heat island effect reduction. (Lerer et al, 2015). Attenuation of stormwater is a considerable attribute of SuDS.

Wong (2013) states that SuDS technologies attempt to mimicking the natural system and do so effectively. Lerer et al. (2015) adds that SuDS incorporate components of the urban water cycle in addition to stormwater, such which is not considered by conventional approaches such as the groundwater.

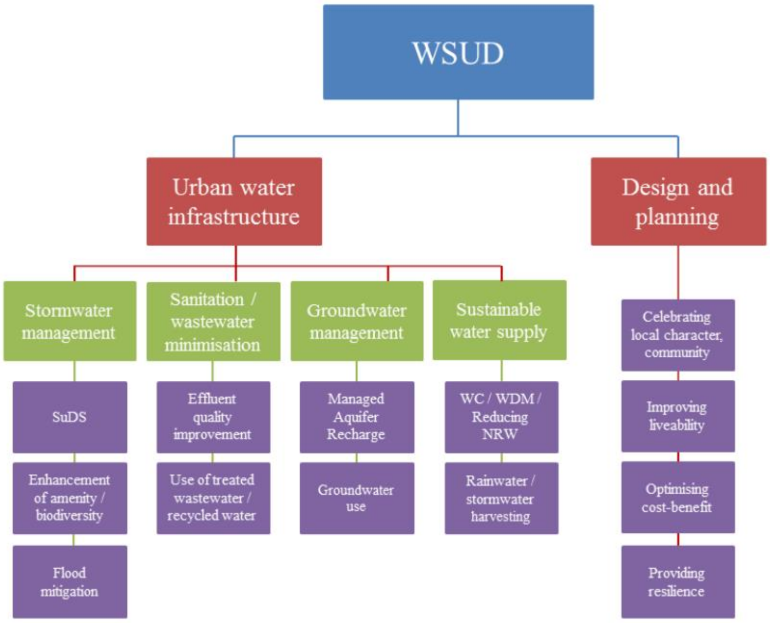

Figure 2-3: WSUD activities (Armitage et al., 2014)

Development within urban regions generally results in the replacement of free draining surfaces with impermeable surfaces that are typically drained by conventional drainage systems therefore reducing the natural permeability characteristics of land (Armitage et al. 2013).

Conventional; drainage systems are generally focused on eliminating local flood inconveniences and largely ignore the need to preserve or improve water quality and the associated aspects of amenity and biodiversity. Unlike SuDS, conventional drainage ignore the potential for the use of stormwater as a water resource and minimise infiltration therefore decreased recharge of the underlying aquifers. Under post-development conditions the likelihood of extreme flooding and channel erosion downstream of developments is significantly increased (Armitage et al., 2014).

Stormwater has been identified as a major contributor towards the pollution and deteriorating health of waterways. Increases in urban development causes an increase in the proportion of impervious surfaces in catchments. The velocity and volume of water disposed into waterways creates problems of erosion, flooding and changing of natural flow regimes along with associated ecological damage. More pollutants are washed into streams, affecting river health (Wong, 2013).

SuDS technologies aim to address water quality and quantity challenges, and enhance the local biodiversity while being acceptable aesthetically to the public (Scholz, 2015). In so doing many of the negative environmental impacts of stormwater are mitigated and some benefits may in fact be realised (Armitage et al, 2014) SuDS promote natural drainage through the use of key unit processes linked to the four focal points of SuDS philosophy arranged in a hierarchy shown in figure 2-4.

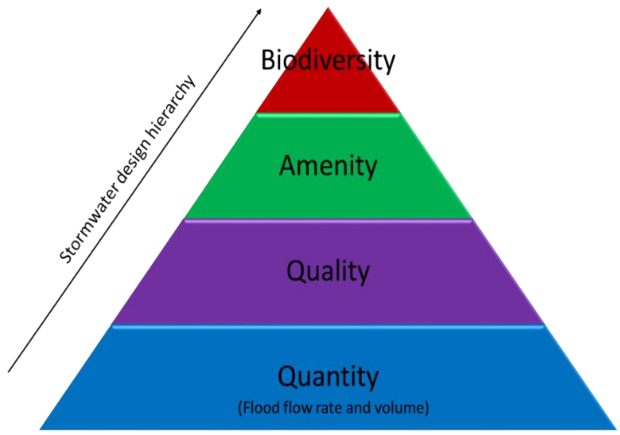

Figure 2-4: The stormwater design hierarchy (Armitage et al, 2013)

According to Armitage et al. (2014), there are a number of important considerations which need to be taken into account prior to SuDS implementation and therefore, stormwater design. Considerations mentioned are, the local hydrological cycle, local ground conditions; the different challenges of development on green-fields versus retro-fitted sites and the impacts of different types of developments.

Critical issues facing planners and policy makers, are ensuring the protection of source waters and the management of stormwater through SuDS implementation (Shoemaker et al, 2009). According to Scholz (2015), barriers to the implementation of SuDS include adoption problems, flood and diffuse pollution control challenges, negative public perception, and a lack of decision support tools and reduced space in urban areas.

Practical experience with implementing SuDS is rare in many regions, compared to that of conventional systems. This requires the need for knowledge gaps to be filled before large scale implementation of SuDS may be expected. Lehere et al. (2015) adds that another factor inhibiting the implementation of SuDS is its complexity since the technology becomes a part of the urban landscape therefore moving away from being a distinct hidden functionality.

Typical objectives of SuDS are the consideration of new options and practices in the management of water supply. efforts to ensure that surface water flow and groundwater infiltration rates return to predevelopment conditions; provision of functional services within the threshold of water resources; and protection of biodiversity and ecological systems (Armitage et al., 2013).

Basic selection criteria for SuDS depend on the current and future land use characteristics, site and catchment characteristics as well as utilisation requirements. Stormwater run-off quantity, quality, amenity and biodiversity are further considerations for SuDS selection identified by Wilson, et al, (2004) and Woods-Ballard et al, (2007). It is important that the advantages and limitations of SuDS options be identified during the planning and design phases.

SuDS technologies are categorised into source, local or regional controls according to its stormwater management capabilities.

2.2.1 Source controls

Source controls are facilities which manage stormwater runoff as close to its source as possible and may provide the first processes stormwater would encounter in the treatment train. SuDS technologies which have been placed in this category are green roofs, rainwater harvesting, permeable pavements and soakaways. Such technologies generally collect, treat and store stormwater emanating from within the boundaries of the site. Such facilities are suitable for implementation in residential and commercial areas (Armitage et al., 2013).

Green roofs

A roof designed to host vegetation may be referred to as a 'green roof' (Semple et al., 2004; Stahre, 2006). They provide great benefits in densely urbanised areas where space is limited (NCDQ, 2007; Semple et al., 2004).

Green roofs are considered an important source control for stormwater runoff; studies have indicated that green roofs are capable of completely absorbing light to moderate rainfalls. They are able to provide minor stormwater detention, delay runoff peaks and decrease runoff volumes therefore closely mimicking the pre-development state of the site. Pollution removal capabilities are usually at their most effective during the vegetation growth seasons (Armitage et al., 2013).

Vegetative roof gardens may be established on new buildings and according to Stovin (2009), retrofitting is a feasible option in many instances, particularly for flat concrete roof slabs. Industrial, commercial or high rise residential buildings with large roof surface area are identified to be suitable locations for vegetative gardens.

Leakage into the building is prevented through a waterproof membrane. Structural design of the roof needs to account for the additional imposed weight (NCDWQ, 2007).Indigenous vegetation is considered the best option (Wilson et al., 2007). Roof garden promote rooftop accessibility and outdoor recreation; they can significantly improve the amenity and biodiversity of the area. Irrigation would be required during dry periods, rainwater harvesting is a recommended water source alternative. Green roofs are generally more expensive to implement compared to conventional roof runoff. (Armitage et al., 2013).

Soakaways

Soakaways significantly decrease runoff volume and rate and is effective in removing particulate and suspended stormwater runoff pollutants. They generally comprise of an underground storage area with course aggregate or other porous media that gradually discharges stormwater to the surrounding soil. They are similar to infiltration trenches in operation but have smaller plan area (MBWCP, 2006). They are often used to handle roof runoff from a single building.

Multiple soakaways can be linked to drain larger areas such as parking lots and vehicle highways. The cross section of the soakaway and the type of material utilised determines the infiltration characteristics of the device. Though rapid movement of water through soakaways leads to increased risk of groundwater contamination. It is important to ensure adequate stormwater pre-treatment is implemented upstream.

Soakaway size is dependent on the porosity of the aggregate or material that is used to fill the excavated pit. It is emptied by percolation of stormwater directly into the underlying soil or via perforated drainage sub-drains near the base of the structure. Geotextile lining is required for soakaways in fine-grained soils to prevent migration of fines into the coarser porous media. Soakaways are designed to store the entire volume from the design storm and should be able to infiltrate at least half of the volume within 24hours. They normally serve smaller areas however, groups of soakaways can serve larger areas (MBWCP, 2006). To prevent groundwater contamination. Soakaways should be constructed 1.5m above the groundwater table to allow for additional filtration (Livingston & McCarron, 2008).

Soakaways are not suitable where water would impact on structural foundations or affect existing drainage characteristics. They not function well on steep slopes or unstable areas. Sub-drain piping systems must be utilised when implemented in soil with low infiltration rates. Sedimentation in the collection chamber gradually reduces the storage capacity therefore regular operation and maintenance is required for efficiency (Stahre, 2006).

Rainwater harvesting

An essential element of effective water conservation where stormwater is utilised as a water supply. The optimal utilisation of stormwater collection and reuse systems in residential, commercial and industrial units can significantly reduce potable water consumption.

Storage of runoff from roofs and other elevated impervious surfaces is provided by rainwater tanks until the water is required (Stahre, 2006). The collection of stormwater runoff reduces the pollutant loads that enter nearby watercourses; collection along with the reuse of stormwater attenuates flood peaks. Systems are useful during extreme rainfall events since it helps protect receiving watercourses through reducing initial runoff volumes and associated pollutants.

Utilisation of stormwater as a water source saves potable water and reduces stormwater discharge from roofs. Storage facilities may be connected to other SuDS technologies such as infiltration trenches or soakaways. Many different stormwater collection and reuse system are commercially available and generally easy to install. Requirements for effective stormwater connection is a means of getting the water to its point of use, preferably by gravity or a pump and pipeline (Armitage et al., 2013).

The main consideration when selecting a storage facility (Hobart City Council, 2006) include budget constraints; local rainfall characteristics space availability; impervious catchment areas and future rainwater uses. (Armitage et al., 2013). A small pollutant trap or bypass filter should be installed to prevent debris and/or contaminants from entering the collected stormwater system. Storage facilities that are childproof as well as insect and vector proof should be given preference in the selection process.

Roof collection systems tend to be ineffective for water supply in areas that have hot and dry climatic conditions for a significant part of the year. Harvested rainwater should be filtered as well as boiled or chlorinated if it is to be used for potable purposes (Hobart City Council, 2006). Untreated rainwater is generally safe to use for supplementary purposes such as flushing toilets and irrigating gardens.

Permeable pavements

This stormwater control is effective in flood peak reductions providing surface detention storage (Debo & Reece, 2003). Permeable pavements reduce stormwater discharge rates and volumes from impervious areas. Stormwater runoff stored in permeable pavements can be infiltrated to recharge the groundwater table or re-used for several secondary domestic purposes. (Semple et al., 2004; Stahre, 2006; Hobart City Council, 2006).

Sub-drains can be utilised to improve collection. Permeable pavements generally do not remove litter and other debris from stormwater runoff. Soluble pollutants tend to pass through the permeable pavement structures owing to the lack of extended detention. It can be very effective in removing pollutants if the majority of the pollution is infiltrated to the groundwater (Debo & Reece, 2003). The pollutant removal ability of permeable pavements is lower than most other SuDS options.

The most important considerations are to ensure: The entire minor design storm is captured. Additional flow should be discharged into the specified drainage system or outfall in a controlled manner. The provision of adequate structural support to withstand the expected loadings from pedestrian, vehicles, plant or other machinery (Woods-Ballard et al., 2007).

Lined permeable pavement systems can be utilised where foundation or soil conditions limit infiltration processes. Permeable pavements have multiple uses of the space area on specified developments by utilising, inter alia, roadways, driveways and parking lots as stormwater drainage areas. Permeable paving surfaces are suitable for pedestrian and vehicular use (Woods-Ballard et al., 2007).

Polluted stormwater containing large quantities of sediment should not be discharged onto permeable paving as it results in clogging (Stahre, 2006). The use of permeable pavements should be restricted to slopes less than 5% grade as high velocity stormwater is not able to penetrate the pavement surface (Stahre, 2006; Debo & Reese, 2003).

Permeable pavements are not normally suitable for high traffic volumes and speeds greater than about 50 km/hr, or for usage by heavy vehicles and/or high point loads due to potential structural failure (Woods-Ballard et al., 2007; Debo & Reese, 2003). The base layers are typically constructed of compacted stone that is able to support the required vehicle loadings (Taylor, 2003).

Regular inspection and maintenance are recommended for ensuring the long-term effectiveness of permeable pavements. (Field & Sullivan, 2003; Melbourne Water, 2005). If managed incorrectly, there is great potential for clogging by fine sediment, which significantly reduces the effectiveness of the specified system.

2.2.2 Local controls

As a 'second line of defence', local controls are implemented (Armitage et al., 2013). As the name suggests, the control typically manages stormwater runoff in the local, possibly public, area. SuDS technologies placed in this category may convey, detain, and/or infiltrate as well as treat stormwater from upstream which may originate from surrounding sites and roadway reserves falling within the 'drainage area'. Filter strips, infiltration trenches, sand filters, swales and bio-retention areas are SuDS which typically function on a local control level.

Filter strips

Filter strips are uniformly graded and densely vegetated land used to manage shallow overland stormwater runoff , treat runoff from and remove pollutants several filtration processes and infiltration (Field & Sullivan, 2003; Melbourne Water, 2005).

Filter strips help attenuate flood peaks. They are particularly useful for providing a first line of defence against sheet flows from large paved areas such as parking lots and arterial roadways (Debo & Reese, 2003).Filter strips have minimal stormwater runoff storage capacity and are not very good at treating high velocity flows therefore are not recommended to be located on steeply sloping landscapes.

They are most effective as pre-treatment options in treatment trains, especially to aid stormwater management. They are also effective as stormwater runoff mitigation options in low-density developments (Debo & Reese, 2003; Environment Protection Authority – Melbourne Water Corporation, 1999).

Filter strips use vegetative filtering as a primary means of stormwater runoff pollutant removal. Properly designed filter strips remove most sediment and other settleable solids. (Debo & Reese, 2003 Field & Sullivan, 2003; Melbourne Water, 2005).The main design and management objective should therefore be to develop a dense and sustainable vegetation growth in order to maximise the filtration processes and reduce potential for erosion (Environment Protection Authority – Melbourne Water Corporation, 1999).

Provision of dense vegetation, preferably indigenous, potentially improves the runoff attenuation in addition to boosting amenity and biodiversity in the immediate vicinity (NCDWQ, 2007).

Appropriate use of indigenous vegetation increase the potential to provide a habitat corridor for wildlife (Environment Protection Authority – Melbourne Water Corporation, 1999). Filter strips are relatively low maintenance stormwater management options with low installation and maintenance costs. Filter strips are usually able integrate well within the natural landscape and can provide open spaces for uses such as recreation.

Swale

Swales are shallow grass-lined channels with flat and sloped sides (Parkinson & Mark, 2005). Swales are designed to meet stormwater management processes such as flow conveyance requirements and effective stormwater pre-treatment (Debo & Reese, 2003).Swales generally have a larger stormwater storage capacity; they help to reduce runoff volumes and peak stormwater flows. They require relatively large surface areas to function effectively.

For more sustainable stormwater management efficacy, swales are commonly combined with buffer and bio-retention systems in a treatment train Swales use a combination of infiltration and bio-infiltration to remove dissolved pollutants in stormwater runoff. The larger particles are filtered by the vegetation (Debo & Reese, 2003; Field & Sullivan, 2003).

They serve as an alternative option to roadside kerbs and gutters in low density residential areas. Swales are generally suitable for road medians and verges, car parking runoff areas, parks and recreation areas (Environment Protection Authority – Melbourne Water Corporation, 1999).Apart from serving as open drainage systems for stormwater runoff and providing some minor infiltration area, swales serve as stormwater pre-treatment facilities for larger SuDS options in the treatment train (Hobart City Council, 2006; Melbourne Water, 2005).

Grassed swales are gently sloped in the flow direction, (Stahre, 2006). In flatter areas, swales may be designed to act as small detention basins with very small flow velocities. If the in-situ soil has a low permeability the base of the swale can be underlain with a granular stone material drained with the aid of perforated pipes.

Vegetated swales are normally less expensive and more aesthetically pleasing compared to conventional kerbs and concrete channels. Pronouncement of the surrounding natural landscape; and multiple aesthetic enhancements are additional amenity benefits. (Armitage et al., 2013). The effective design life of swales is directly related to the standard of maintenance. Failure is likely to occur more quickly with swales than with most other SuDS options if not properly maintained.

Infiltration trench

Infiltration trenches are excavated trenches filled with relatively large granular material. A geotextile is used to provide separation between the trench media and the surrounding soil. Infiltration trenches increase stormwater infiltration and corresponding groundwater recharge therefore decreasing the frequency and extent of flooding (Armitage et al. 2013).

They are usually designed to receive stormwater runoff from adjacent properties and transportation links (Debo & Reese, 2003, Melbourne Water, 2005, Taylor, 2003). Stormwater permeates through the voids in the trench and is temporarily stored. Over a period of time this water infiltrates into the underlying soil and replenishes the groundwater (Hobart City Council, 2006). Installation of perforated pipes in the trenches provides for the outflow of surplus stormwater when infiltration into the surrounding soil is inadequate (Field & Sullivan, 2003; Mays 2001).

Infiltration trenches are particularly effective in removing suspended particulates from stormwater such as sediment, metals, coliform bacteria and organic matter (Taylor, 2003; Field & Sullivan, 2003). Pollutant removal ability of infiltration trenches can be enhanced by utilising washed aggregate and layering the subsoil with organic matter and top soil (Taylor, 2003).

When operating optimally, the trench is designed to infiltrate or discharge the design runoff within 24 hours after a moderate rainfall event (up to the 80 or 90 percentile storm). Infiltration trenches are most effective when implemented adjacent to impervious areas such as roads, footpaths, parking lots and other hardened areas (Woods-Ballard et al., 2007). They are most commonly implemented in residential areas; however, if properly designed, may be suitable in industrial areas (NCDWQ, 2007).

As a consequence, consideration should be given to pre-treatment or implementation of upstream SuDS facilities to reduce the quantity of gross pollutants and sediment reaching the trench in order to reduce clogging. Infiltration trenches are prone to failure if sediment, debris and other pollutants clog the facility.

Due to their relatively narrow cross section, infiltration trenches can be utilised in retrofit sites. Infiltration trenches have negligible visual impact as they are generally below ground. This SuDS technology is not appropriate on unstable or uneven land, or on steep slopes; Infiltration trenches situated in coarse soil strata, could possibly cause groundwater contamination therefore would ideally be located in places with permeable soils. The construction costs of infiltration trenches are relatively low compared with other infiltration based SuDS options; however, the cost of maintenance is relatively higher (Taylor, 2003).

Sand filter

Sand filters normally comprise of a sedimentation chamber linked to an underground filtration chamber comprising filtration media through which stormwater runoff passes (Debo & Reese, 2003). Once the treatment process is completed, the stormwater either percolates into the surrounding stratum or is returned to the conveyance system (Woods-Ballard et al., 2007). Sand filters are generally ineffective in controlling stormwater peak discharges (NCDWQ, 2007);

The primary control component of stormwater management for sand filters is water quality improvement. Suspended particulates, sediment heavy metals, smaller particulate pollutants are removed (Melbourne Water, 2005; MBWCP, 2006). Pre-treatment is required for the removal of coarse sand and gravel from stormwater (Field & Sullivan, 2003; Environment Protection Authority – Melbourne Water Corporation, 1999).

They are usually installed on smaller developments in conjunction with land uses having relatively large percentages of impervious surfaces; however, sand filters may be designed to manage stormwater runoff from significantly larger areas (Endicott & Walker, 2003).

According to Field & Sullivan (2003), sand filters are most commonly used in areas of fine soils and relatively low associated infiltration rates as well as arid regions with high evaporation rates where limited rainfall and high evaporation rates are expected. This SuDS facility contributes to biodiversity through adding polished runoff into the treatment train waterway. Non-potable domestic water uses. When there is a significant requirement to protect groundwater resources, the facility is appropriate and can therefore be used for recharging resources.

Sand filters are efficient offline stormwater management technologies in areas with limited space as they can be implemented beneath impervious surfaces. The filtered effluent can be reused for most non-potable domestic water uses. Sand filters may be retrofitted with relative ease into existing impervious developments, constrained urban locations or in series with conventional stormwater management systems (Melbourne Water, 2005 They manage stormwater runoff effectively on relatively flat terrains with high ground water tables (NCDWQ, 2007). Ultra-urban developments, small commercial establishments, parking lots, and industrial applications are deemed suitable.

To ensure their longevity, sand filters require a higher frequency of maintenance than most other SuDS options (Field & Sullivan, 2003). The utilisation of silty or clayey filtration media tends to increase the probability of clogging (Debo & Reese, 2003; MBWCP, 2006; Taylor, 2003).

Sand filters may be used in a variety of situations and can function for an indefinite period if designed and maintained correctly (Field & Sullivan, 2003; Woods-Ballard et al., 2007).Sand filters are prone to clogging, hence those which are not properly maintained tend to have inhibited performance (Debo & Reese, 2003; MBWCP, 2006; Taylor, 2003). Sand filters are expensive to implement and maintain, relative to most other SuDS options (NCDWQ, 2007; Taylor, 2003).

Bio-retention area

Bio-retention areas are landscaped structural stormwater controls which capture and temporarily store the water quality volume employed. The facility uses soils and vegetation in shallow basins or landscaped areas to remove pollutants from stormwater runoff. (Debo & Reece. 2003). Natural processes undergone by stormwater through the facility include filtration, adsorption, biological uptake, sedimentation, infiltration and detention. The facility incorporates a series of small stormwater management intervention and each of the components of the bio-retention area is designed to perform a specific function.

The grass channel reduces incoming runoff velocity and filters particulates from the runoff. The ponding area provides temporary storage of stormwater runoff prior to its evaporation, infiltration, or uptake and provides additional setline capacity. The mulch layer provides filtration as well as an environment conductive to the growth of microorganisms that degrade hydrocarbons and organic material. The planting soil in the bio-retention facility acts as a filtration system, adsorption of hydrocarbons, heavy metals, nutrients, and other pollutants. Plants in the ponding area provide vegetative uptake of runoff and pollutants and also serve to stabilize the surrounding soils. Finally, a sand bed provides for positive drainage and aerobic conditions in the planting soil and provides a final polishing treatment media (Debo & Reece, 2003).

The use of bio-retention areas is appropriate in small catchments, several can be linked together for larger catchments (Endicott & Walker, 2003; Woods-Ballard et al. 2007). Base and side sf the bio-retention area may require lining where infiltration is unsuitable due to groundwater contamination as well as in areas where slope stability is of concern or infiltration of stormwater may cause structural issues – an underdrain should be installed in such situations. Treated water may be conveyed for re-use for secondary domestic purposes. Suitable flow routes should be identified to convey any excess stormwater runoff towards more appropriate controls.

This facility is an excellent stormwater treatment practice since it is effective at the removal of most stormwater runoff pollutants In a situation where a removal rate is not deemed sufficient, additional controls may be put in place at the given site in a series or treatment train approach. (Debo & Reece, 2003).

Bio-retention systems are designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events (Debo & Reece, 2003). Routine inspection and maintenance needs to be performed to ensure effective functionality and maintain aesthetic appeal, this impacts the design life. Bio-retention facilities are normally impractical in areas with steep slopes, construction costs are higher than most SuDS options (Wilson et al., 2004).

Bio-retention areas are suitable for many types of developments from residential to high-density commercial projects. They are satisfactory retrofit options in a wide variety of landscapes where stormwater runoff rates, volumes and flood peaks are effectively attenuated with the correct implementation. Bio-retention is an ideal stormwater management facility for median strips, parking lot islands, and swales. There are numerous design applications, both on- and offline, in impervious or high-density environments (Debo & Reece, 2003).

2.2.3 Regional controls

SuDS technologies such as detention ponds, retention ponds and constructed wetlands are generally implemented on a large scale and have been categorised as regional controls. This level of control often manages stormwater runoff as a last 'line of defence' prior to its release into receiving waters (Armitage et al, 2013) Regional control facilities may convey, detain, store and/or infiltrate as well as treat large volumes of stormwater emanating from several surrounding developments, which means that the drainage area feeding the technology may be of a considerable size.

Detention pond

Detention ponds are temporary storage facilities for large volumes of stormwater. These facilities are ordinarily dry but are designed in such a manner that they are able to store stormwater runoff for short periods of time. The captured stormwater runoff either infiltrates into the underlying soil layers or is drained into the downstream watercourse.

Particularly effective at attenuating downstream flood peaks as well as regulating the flow in the downstream watercourses and supplementary treatment systems. In general, detention ponds are designed to temporarily store as much water as possible for 24 to 72 hours while aiming to provide a safe public environment (Field & Sullivan, 2003).

Insoluble pollutants are typically removed through sedimentation. Therefore, the detention time and volume of stormwater runoff govern the pollutant removal efficacy of the system. When it comes to these pollutants, the larger detention ponds with greater surface areas and volumes tend to have better pollutant removal capabilities than smaller ponds. Detention ponds are most effective with small magnitude, high frequency storms (Debo & Reese, 2003; Environment Protection Authority – Melbourne Water Corporation, 1999; Field & Sullivan, 2003).

The pollutant removal performance of detention ponds can be improved through the construction of upstream pre-treatment SuDS options and/or the construction of a sediment trap at the entrance. Reduce risk of siltation. .. For safety purposes, detention ponds should be fenced. It should also be possible to rapidly drain them if urgently required through appropriate outlets (Stahre, 2006). The implementation of appropriate safety structures including pest and vector controls; Detention ponds are not very good at removing dissolved pollutants and fine material and generally not as effective in removing pathogens compared to constructed wetlands.

Detention ponds are relatively inexpensive to construct and easy to maintain; Detention ponds may serve multiple purposes during drier seasons, particularly integrated as sports fields, play parks or commons. (Armitage et al., 2013) If maintained regularly, detention ponds can add aesthetic value to adjoining residential properties as well as presenting fewer safety hazards than wet ponds due to the absence of a permanent pool of water.

To achieve the best possible results, detention ponds should have a large plan area. Detention ponds are not very suitable in areas with a relatively high water table, or where the soil is very coarse since there is a risk of groundwater contamination (Hobart City Council, 2006; Taylor, 2003). The hydraulic and pollution removal performance of detention ponds depends on good maintenance. (NCDWQ, 2007)

Retention pond

A retention pond is designed as a permanent pool of water, often with additional flood control and extended detention storage volume available. Retention ponds generally hold water for release only through evapotranspiration and infiltration (Debo & Reese, 2003). Run-off from each rain event is detained and treated in the pool primarily through settling and biological uptake mechanisms (Armitage et al., 2013). Retention ponds require the addition of supplementary water to maintain a specified permanent water line; maximum storage capacity of retention ponds is larger than their permanent pond volume.

Stormwater ponds are designed to control both stormwater quantity and quality. Stormwater coming into the pond is mixed with the permanent pond water and released over the weir at a reduced rate (Field & Sullivan, 2003; NCDWQ, 2007). Retention ponds are usually capable of handling relatively large quantities of stormwater runoff (Woods-Ballard et al., 2007). The permanent pond volume can be utilised as a source of water for various non-potable purposes.

Retention ponds generally have the capacity to remove a wide range of common stormwater runoff pollutants; they generally provide a medium to high pollutant removal capacity (Woods-Ballard et al., 2007). They normally utilize a combination of sedimentation, filtration, infiltration and biological uptake processes to remove pollutants from stormwater runoff (Stahre, 2006). Retention ponds are generally not as effective in removing pathogens compared to constructed wetlands.

Retention ponds are normally restricted to sites with shallow slopes; these facilities are generally large continuous area required. Retention ponds can be used for a wide variety of land uses – provided that sufficient space is available. (NCDWQ, 2007, Woods-Ballard et al., 2007). Retention ponds are generally applicable to most types of new developments and redevelopment therefore suitable to retrofit situations.

The performance of retention ponds is significantly improved with the construction of a sediment forebay at the inlet. The outlet structure should typically enable the temporary storage of the runoff from the design storm; releasing the volume over a 24-hour period. (Endicott & Walker, 2003; Woods-Ballard et al., 2007). Effective pollutant removal is enabled by increasing the time the stormwater resides in the pond (Debo & Reese, 2003; Field & Sullivan, 2003).

Incorporation of retention ponds into the natural landscape and the use of appropriate indigenous vegetation is recommended in order to maintain local biodiversity (Debo & Reese, 2003). They can also be used for recreational purposes. The permanent open pool of water creates health and safety concerns and therefore requires social impact considerations at the design stage. Concerns typically include: the mitigation of health and safety risks, aesthetic appeal, and the eradication of foul odours potential mosquito breeding and other nuisances (Field & Sullivan, 2003; Endicott & Walker, 2003).

Retention ponds operation and maintenance requirements, the most important being sediment and litter removal, especially if the pond is situated in an area of high visibility (Parkinson & Mark, 2005; Debo & Reese, 2003).

This SuDS facility has multi-objective uses such as for amenities as well as flood control. flood control Retention ponds have proven to be the most effective SuDS options when considering all aspects of cost, performance, and maintenance. (Debo & Reese, 2003).

Constructed wetland

Wetlands refer to marshlands of shallow water, stored over a long-term, covered in aquatic vegetation. Constructed wetlands are man-made systems designed to mimic the natural systems in areas where they would not usually be found. They are most often found on large catchments, are useful in attenuating stormwater flood peaks and improving the quality of run-off from residential areas (Endicott & Walker, 2003).

The most common stormwater runoff pollutant treatment processes that occur in constructed wetlands are: sedimentation, fine particle filtration and biological nutrient and pathogen removal (Field & Sullivan, 2003; Parkinson & Mark, 2005). Constructed wetlands are generally considered to be effective ecosystem filters as they can be very efficient in the removal of particulates and dissolved nutrients as well as noxious substances such as heavy metals (Debo & Reese, 2003; Parkinson & Mark, 2005).

The successful implementation of a wetland requires its effective incorporation into the landscape design and management (MBWCP, 2006). Local conditions should be taken into account in design. Their aesthetic appeal encourages their recreational use.

Constructed wetlands can provide a habitat for fish, birds and other wildlife. The use of appropriate indigenous vegetation aids in protecting biodiversity (Environment Protection Authority – Melbourne Water Corporation, 1999; Field & Sullivan, 2003; Woods-Ballard, et al. 2007).

Vegetation also promotes the settlement of suspended matter and facilitates nutrient uptake processes. Bacteria associated with wetland vegetation assist in the reduction of nitrogen. Constructed wetlands that are effectively incorporated into the urban landscape of neighbouring residences have the potential to add great aesthetic value to those properties.

Constructed wetlands are limited to application on relatively flat land as they become costly to incorporate on steep and potentially unstable slopes. The water level in the wetland needs to be carefully regulated; this is usually carried out with the aid of a suitable level control structure.

Constructed wetlands require relatively frequent and detailed inspections. The maintenance frequency can however be reduced through effective pre-treatment. Maintaining healthy vegetation and adequate flow conditions is essential to the functioning of a constructed wetland (Taylor, 2003).

2.3 Treatment train

A treatment train is a combination of different methods implemented in sequence or concurrently to achieve best management of stormwater. SuDS manage surface water drainage systems holistically by mimicking the natural hydrological cycle, through a number of sequential interventions and a series of unit processes in the form of a 'treatment train'(Armitage et al, 2013).

SuDS embrace a number of options arranged in treatment train. Stormwater is managed through a series of unit processes. The SuDS options presented incorporate a variety of treatment processes with considerable overlap. Through linking these together appropriately, form an effective system. Figures 2-5 and 2-6 are schematics of treatment trains.

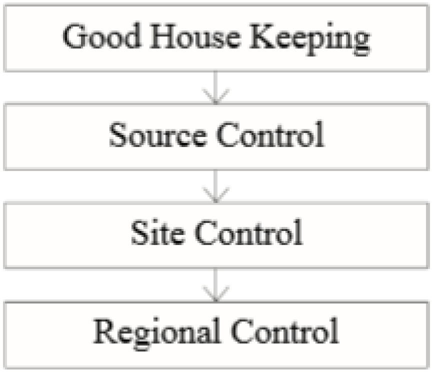

Figure 2-5: SuDS treatment train (Armitage et al., 2014)

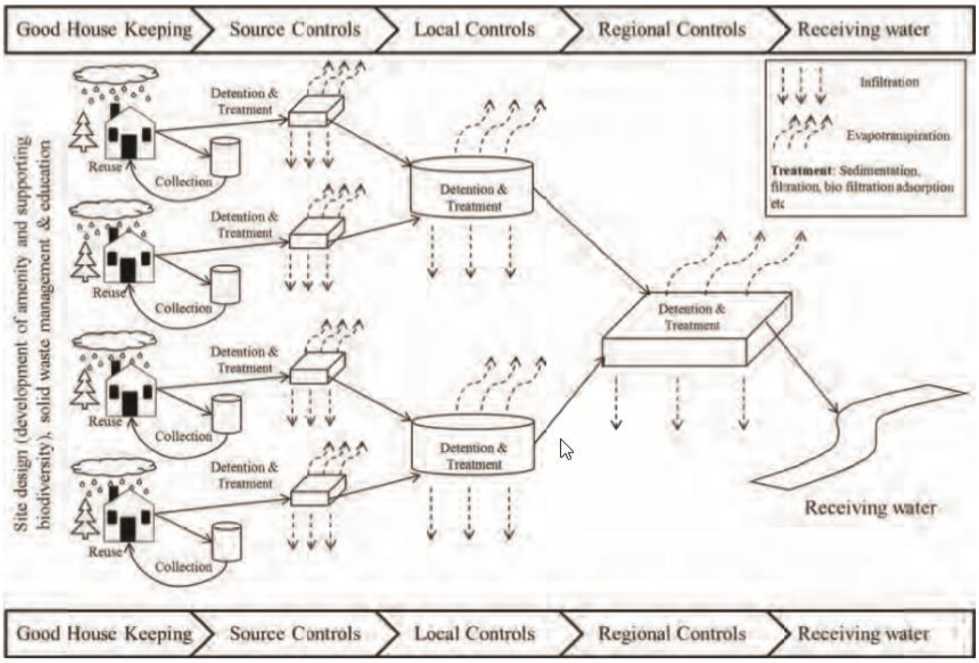

Figure 2-6: SuDS treatment train schematic (Armitage et al., 2013)

A challenge faced by decision-makers is how to select the best combination of practices to implement among the many options available that result in the most cost-effective, achievable, and practical management strategy possible for the location of interest. Informing the decision-maker on the possibility of implementing an integrated series of facilities which work together in order to attenuate and translate stormwater as well as improve the quality. Will satisfy the water quantity and quality objectives (Shoemaker et al, 2009).

Where the pollutant removal capabilities of an individual structural stormwater control are not deemed sufficient for a given site application, additional controls may be used in series in a treatment train. Many combinations of structural controls in series may exist for a site. The combinations of structural stormwater controls are limited only by the need to employ measures of proven effectiveness and meet local regulatory and physical site requirements.

It is considered worthwhile to discuss the purpose and functions of a DSS and its relation to SuDS since the development of a SuDS decision support chart is a fundamental attribute of the research project

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2.4 Decision Support Systems

Decision Support Systems (DSS) are regarded as tools for making better decisions within an organisation, as mentioned in the title of the journal paper compiled by Tripathi (2011). Just as the success of an organisation depends on the quality of information it generates which form the basis for the decisions made, so too would a DSS have the capacity to suggest suitable alternative stormwater practices. A DSS is considered as one of many types of information systems supporting decision-making, directly or indirectly.

According to Jewitt and Görgens (2000), a DSS is generally a computer based information system with integrated decision support tools useful for managers and stakeholders. Computer based information systems are proven to make selection processes more effective and efficient when large amounts of data or complexities are involved (Tripathi, 2011). Computer based models are useful tools to establish the effectiveness of stormwater management techniques and the degree to which they conform to water quality requirements (Zoppou, 2001).

The interface of the DSS should be interactive, flexible and adaptable for the user. Insights of the decision-maker are required, along with the models and databases of the DSS in order to be led to specific, implementable decisions which may solve the problem at hand. (Tripathi, 2011) A DSS would combine several sources of information, represent more than one problem and/or model a multifaceted problem (DWAF, 2001).

DSS have evolved significantly over recent years.in terms of its definition and the underlying technologies it uses. Its purpose has remained consistent, to offer the appropriate technology that will enable the cognitive process of a decision-maker. DSS are able to facilitate individual decision-making and aid research as well as managerial activities in an attempt to increase organisational performance through monitoring and analytics (Wessels, 2014).

Computer modelling requires expertise and experience as well as input data that are appropriate and relevant. The process requires calibration and verification of the chosen parameters in order to produce useful results. Computer modelling requires expertise and experience as well as input data that are appropriate and relevant. The process requires calibration and verification of the chosen parameters in order to produce useful results (Butler & Schultz, 2005).

Wessels (2014) adds that DSS aims to be responsive to the needs of user in order to promote fact-driven decision-making through the generation of individual knowledge. These objectives should ultimately improve the quality of organisational decision-making. DSS are aimed to facilitate organisational decision-making.

DSS is specifically designed to provide the decision maker with a set of information that will enhance their decision-making capabilities. Most DSSs are therefore designed around the problem they are trying to solve, the concern they are attempting to address or the question they wish to answer and only represent a small subsection of the overall generic decision-making process (DWAF, 2001).

The success of a specific DSS is therefore dependent on its ability to solve the problem it is being used to address at the required scale and the extent to which it can support the decision making process. It is crucial when designing and DSS to define the needs that the user is trying to fulfil at the required scale. The tools developed need to offer means of entering, accessing and interpreting the information for the purpose of sound decision making (DWAF, 2001). Stewart et al. (2000) have suggested that the following stages, processes and activities represent the generic decision-making process in figure 2-7.

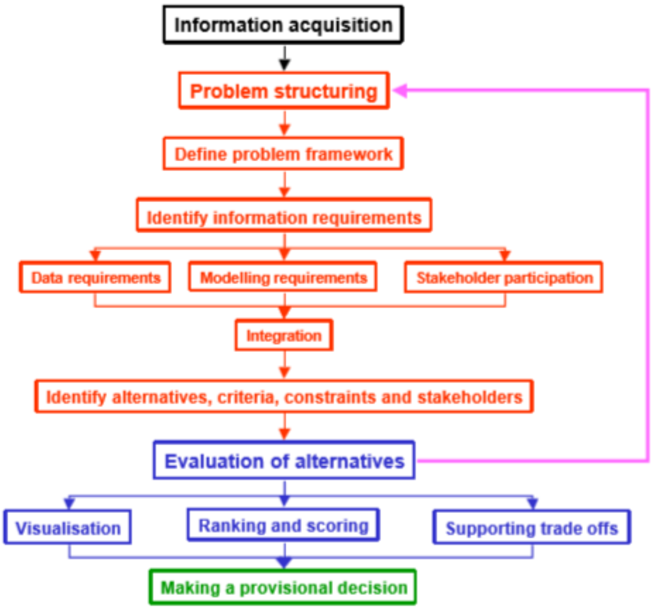

Figure 2-7: The generic decision-making process (Stewart et al., 2000)

Many tools have been developed to assist making decisions regarding the implementation of SuDS. A decision tool for the purpose of the considered to be nay software tool that can answer a question a decision-maker asks. A decision support tool may focus on already visualising existing information or on producing information based on an analysis of input information. All tools are considered to inherently have a logical structure, as the definition of a DSS suggests, and step application, based on cause-and-effect. (Lerer et al. 2015)

New challenges for decision makers have motivated the development of many decision support tools for the modelling of SuDS. This is because SuDS offers a larger selection of, often multi-functional measures, compared to conventional stormwater management (Lerer et al, 2015).

Critical assessments deal comprehensively not only with the design, operation, maintenance, and water quality monitoring of traditional and SuDS, but also with the analysis of asset performance and modelling of treatment processes and performances of existing infrastructure predominantly in developed but also developing countries, and the sustainability and economic issues involved. (Scholz, 2015)

A review by Lerer et al. (2015) has identified decision-support tools and they differ in in terms of how many aspects of water they address. Many of the identified tools used to make informed decisions are ineffective, leading to poorly designed systems. There is a need for more awareness among tool developers and users on the significance of context to SuDS planning decisions.

Armitage et al., 2014 suggests that variability among the tools can partly be explained by variability in local context including conditions such as type of existing stormwater systems, groundwater conditions and legislative frameworks. There are clear influences of local context on the development of tools which has implications for the transparency of tools and the potential for using them outside their original context

Existing decision support systems analysed based on the user manuals available in order to attempt to determine standard procedures a user would follow and the information the user requires. The user is assumed to be one with a technical knowledge background on SuDS. There is a wide range of stormwater models available for use in South Africa. The purpose, spatial and temporal scale, cost, usability and data requirements for each model vary. Each system has a different purpose and intended outcome which would assist the user in evaluating SuDS facilitates. (Armitage et al, 2014).

The literature review discusses the concept of WSUD and SuDS as the stormwater component. Further insight is shared on SuDS technologies appropriate for implementation in South Africa as well as the significance of a treatment train approach to stormwater management. Lastly, a background to DSS and stormwater modelling tools have been provided.

3. Research method

The research process involved the collection, sorting and reading of literature in order to compose a comprehensive literature review. Research has been related to WSUD, DSS with a focus placed on SuDS, therefore urban stormwater management.

A DSS in the form of a selection chart has been developed for the purpose of this research project. The DSS is based on and supports the efforts of the SuDS and WSUD guidelines. Additional research into SuDS implementation and management was necessary to gain further insight. Relevant deciding factors relating to SuDS selection have been identified for the development of the DSS.

A series of related diagnostic questions have been developed for the DSS, based on significant factors identified. The components of the DSS have been grouped strategically according to the stormwater design hierarchy to formulate a DSS which aims to provide suitable SuDS technologies as solutions for selection. Solutions are based on SuDS information provided in the literature, which relate the quantity, quality, amenity and biodiversity of stormwater.

Guidelines on the use of the DSS have been developed to guide the user through the selection process. Insight into the DSS has been discussed, providing additional information on the content and criteria of the DSS. Conclusions on the outcomes of the research project have been drawn on the DSS and the context of SuDS. Recommendations have been made for further research on the improvement of the DSS.

4. Decision support system discussion

A Decision Support System (DSS) has been developed for the purpose of this research project. It is intended that the DSS be used as a general guide for decision-makers and stakeholders concerned with the stormwater management of a development. The DSS is presented in the form of a selection chart. There is potential for the chart to assist the user in making informed decisions regarding SuDS technology selection.

It has been intended for the DSS to be used from the conceptual design phase of a development so to incorporate SuDS technologies into the stormwater management planning. The DSS could potentially be used at various levels of decision-making as well as include various professionals involved with the development – this could encourage interdisciplinary partnerships.

The DSS developed, facilitates the decision-making process through a series of diagnostic questions. Each question provides a limited, suitable selection of answers which the user has the option to choose from. Each diagnostic question has intended to trigger a decision which seek to extract information on the site conditions and the intentions of the decision-maker in order to lead the user to suitable SuDS technologies for the development. The questions and answers provided are perceived to be uncomplicated and insightful since they closely relate to facts pertaining to SuDS technologies and could possibly be understood by a user who may not be knowledgeable on the topic of SuDS

The selection chart addresses specific site characteristics and requirements for SuDS technologies therefore allowing the user to make decisions based on relevant criteria. The selection chart diagnostic questions have been categorised and intentionally ordered into sections according to the stormwater design hierarchy i.e. water quantity, quality, amenity and biodiversity management. Additional information perceived as benefits which may influence SuDS technology selection have been added.

For each control stage of the stormwater treatment train, i.e. source, local and regional, a DSS has been developed. It would be the choice of decision-maker as to which stages of stormwater would be most suitable to incorporate into the development. The decision-makers are not limited to any one of the control stages since the stages could be sequentially implemented with one another for improved stormwater quantity and quality management.

Basic information pertaining to the conditions of the site where development would occur, should be established prior to the SuDS selection process. Information required in order to progress through the selection process, would be whether the site is greenfields or if retrofitting infrastructure would be necessary. Area of the site or available open land for SuDS implementation would be addressed thereafter. Presence of an underlying aquifer, infiltration conditions of the ground and maximum water table depths would be questioned further down the diagnostic sequence.

It would be the intentions the decision-maker has for stormwater management which have great influence over the outcome after having progressed through the DSS. The user has the option to reuse the stormwater or dispose of it through infiltration, conveyance, detention or long-term storage, where appropriate.

The series of diagnostic questions which relate to management of stormwater quantity on the site lead to one or various SuDS technologies as solutions. The diagnostic questions relating to quality, amenity biodiversity and additional information follow and help to refine the selection therefore the user can check the suitability of their choices of SuDS.

The user is not restricted to any one specific solution, nor are they limited to the solutions available. Table 4-1 shows each SuDS technology, which forms part of the selection chart solutions, which have been categorised according to their function. Appendix B provides an extended range of solutions and suggests that SuDS within the same categories are possible technological variants.

Table 4-1: SuDS solution guide and relevant classification (Ellis, 2015)

SuDS solution	Category
Green roof	Bio-retention systems (BR)
Rainwater harvesting	Alternative Supplies (AS)
Soakaway	Infiltration systems (IN)
Permeable pavement	Porous surfaces (PS)
Filter strip	Bio-filter systems (BF)
Swale	Enhanced swales (SW)
Infiltration trench	Infiltration systems (IN)
Bio-retention area	Bio-retention systems (BR)
Sand filter	Sand filter systems (SF)
Detention pond	Detention systems (DS)
Retention pond	Retention systems (SP)
Constructed wetland	Wetland system (SW)

A selection of SuDS options have been chosen from that which have been outlined in the SuDS guidelines. The SuDS options are deemed “appropriate, practical and affordable alternative stormwater management technologies for South Africa in line with Water Sensitive Urban Design (WSUD) principles” (Armitage et al, 2013).

There exists a range of stormwater modelling tools which could be referred to as Decision Support Systems for SuDS selection and would be appropriate for use in South Africa. These software systems are more complex when compared to the DSS selected since the DSS is presented in a format that could be more easily understood. The DSS could be used prior to use of the systems discussed in the literature review to assist with making informed decisions prior to modelling the technologies.

It would be the responsibility of the user to make informed decisions after having worked through the diagnostic questions of the chart and to base their choice of technologies on that which is perceived to be most suitable, depending on the criteria selected. The DSS has been developed as a guide to SuDS technology selection; it is strongly recommended for professional experience and judgement to be applied when designing facilities regarding stormwater management.

The selection chart is intended to be a convenient tool for guiding selection and providing practical support to help users make more informed decisions without having to work through the SuDS guidelines prior to use. The chart may be used as a simple reference tool the user could work through quickly since it is a manual interpretation of information which may be understood by decision –makers regardless of their profession or academic background. The DSS could possibly be useful in making information relating to SuDS easier to understand therefore useful for the selection process.

4.1 Guide to using the decision support system

The DSS selection chart has been sub-divided into sections according to the stormwater design hierarchy, i.e. quantity, quality, amenity and biodiversity, along with additional aspects. Each section comprises of a set of strategic diagnostic questions. It is intended for the user to progress through the chart in the order of the diagnostic questions which are in accordance with the stormwater management ranking established in the design hierarchy.

The decision-maker would be required to choose a selection chart based on the suitable stormwater control level the user intends to implement. The first set of diagnostic questions have been categorised into and presumed to impact aspects related to stormwater quantity management. Outcomes of the diagnostic questions which have been chosen, form decision paths which lead to SuDS technologies suggested for selection.

In order to enhance the selection process, diagnostic questions addressing quality management of stormwater have been added. Pollutant removal capabilities of the SuDS technologies have been the focus for determining stormwater quality. Amenity and biodiversity management aspects have been added to highlight characteristics and potential benefits of SuDS technologies. Additional aspects relating to each SuDS technologies included in the DSS are relative potential costs as well as the levels of operation and maintenance required. Quality, amenity and biodiversity, additional aspects as well as the SuDS design suggestions are sections which have been included into the DSS in order to assist the user in refining their selection and potentially make the selection process easier.

A step-by step guide through the DSS sections and categorised diagnostic questions with the possible solutions to choose from, has been provided.

4.1.1 Quantity

i) The user is required to choose a selection chart based on the level of stormwater control required for the development.

Diagnostic question	**Diagnostic solutions**		
Is the stormwater control required at a source, local or regional stage?	Source	Local	Regional

ii) The user is required to stipulate whether the site is a greenfields or retrofit development.

Diagnostic question	**Diagnostic solutions**	
Is the site for development greenfields or retrofit?	Greenfields	Retrofit

iii) Should the site be greenfields, the size of the site would be taken into account by the user.

Diagnostic question	**Diagnostic solutions**	
Is the site for development considered small ($<4000m^2$) or large ($\geq 4000m^2$)?	Small	Large

iv) Should the site be retrofit, the user would be required to estimate the area of open land available for development on the site.

Diagnostic question	**Diagnostic solutions**	
Is the open land available on site limited ($<200m^2$) or excessive ($\geq 200m^2$)?	Limited	Excessive

v) The user should decide whether they intend on re-using or disposing of the stormwater on the site for development.

Diagnostic question	Diagnostic solutions	
Does one intend to re-use or dispose of the stormwater on the site?	Re-use	Dispose

vi) The user should decide whether the stormwater for re-use is required to be of potable quality or if the water will be used for secondary purposes.

Diagnostic question	Diagnostic solutions	
Is the water for re-use required to be of a potable or secondary standard?	Potable	Secondary

Should potable water be required, the stormwater could follow the same processes as the water which would be of secondary quality, however, additional tertiary treatment, such as chlorination or disinfection, would be required. Purposes for collected, treated and stored secondary stormwater are limited to domestic activities which do not require human contact with the water such as irrigation and toilet flushing. Selection of the secondary option would lead the user to the stormwater harvesting options and appropriate SuDS technologies.

vii) The decision-maker is required to select the most suitable quantity management process for the disposed stormwater.

Diagnostic question	Diagnostic solutions			
Is the conveyance, detention, long-term storage or infiltration of stormwater appropriate quantity management for the development?	Conveyance	Detention	Long-term storage	Infiltration

The options of conveyance, detention and long-term storage would lead the user directly to appropriate SuDS technologies which the user has the option to select from.

viii) Ground conditions of the site would need to be established if infiltration is selected as the most suitable quantity management process.

Diagnostic question	Diagnostic solutions	
Is there an aquifer underlying the site?	Yes	No
Is the infiltration rate of the in-situ ground material perceived to be of low (≤3.8mm/h) or high (>3.8mm/h) hydraulic conductivity?	Low	High
Is the water table level during the high rainfall season the 1.5m below the ground surface?	Yes	No
Is the available location for a stormwater control facilities in close proximity to buildings and infrastructure such that infiltration is of concern with regard to the structural integrity of the ground and building foundations.	Yes	No

Suitable SuDS technologies would be the endpoint to the decision path which follows the selected diagnostic answers. The following conditions would suggest that infiltration may not be suitable on the site for development: an aquifer underlies the site, the in-situ soil has a low infiltration rate, the water table is close to the ground surface or infiltration threatens the structural integrity of buildings or may cause erosion. Provided the mentioned conditions do not hold true, the user would be directed to suitable SuDS technologies which support infiltration.

At this stage of the DSS, the user would have been directed to SuDS technologies which may be appropriate according to the decision path followed by the user. The following diagnostic questions seek to extract information, related to stormwater quantity management, from the user in order to assist with the selection process.

ix) The user has the option to decide whether they intend on increasing the permeability of the site after development. The DSS would stipulate which SuDS technologies have the potential to increase permeability when incorporated into external landscaping and paving features.

Diagnostic question	Diagnostic solutions	
Would one consider increasing the permeability of the site through landscaping or paving?	Yes	No

x) The user has the option to specify whether they may consider implementing a SuDS technologies which may be incorporated into the building itself or landscaping or paved areas.

Diagnostic question	Diagnostic solutions		
Would one prefer incorporating the SuDS technology into the building, landscaping or paved areas of the site?	Building	Landscaping	Paving

xi) Provided the user prefers incorporating a SuDS technology into exposed parts of a building, it would be necessary to be aware of certain significant design conditions.

Diagnostic question	Diagnostic solutions	
Would the building have a relatively flat roof and be able to support additional loading?	Yes	No

The options selected by the decision-maker, based of the series of diagnostic questions included in the quantity management section of the DSS, form the decision path which leads to appropriate SuDS technologies. Diagnostic questions following the suggested technologies have been included to enhance the decision-making process for the user and incorporate various aspects significant for stormwater design.

4.1.2 Quality

As outlined in the stormwater design hierarchy, management of the quality of the water follows the quantity. Within the quality section of the DSS, the diagnostic questions specifically address the pollutant removal capabilities of the SuDS technologies. It has been indicated by a ‘yes’ or a ‘no’ whether each technology has the potential to treat stormwater satisfactorily.

Diagnostic questions included in the DSS and related to the treatment capabilities of SuDS technologies are as follows:

i) Does the facility have the potential to satisfactorily remove the required 80% of TSS and 45% of TP from the stormwater prior to release into a waterway or conventional drainage network?

ii) Is the removal of a satisfactory percentage of TSS content in stormwater a required function of the facility?

iii) Is the removal of a satisfactory percentage of TP content in stormwater a required function of the facility?

iv) Is the removal of a satisfactory percentage of TN content in stormwater a required function of the facility?

v) Is the removal of a satisfactory percentage of hydrocarbon content in stormwater a required function of the facility?

vi) Is the removal of a satisfactory percentage of heavy metal content in stormwater a required function of the facility?

vii) Is the removal of a satisfactory percentage of faecal coliform content in stormwater a required function of the facility?

The stormwater design hierarchy ranks the components of stormwater management, hence quality is followed by amenity and biodiversity diagnostic questions.

4.1.3 Amenity and biodiversity

Management of amenity and biodiversity aspects are perceived as less significant components of the stormwater design hierarchy, therefore, possibly have less influence as selection criteria for decision-making. The diagnostic questions address aspects of amenity and biodiversity such as vegetation incorporation, habitat provision, aesthetic appeal, recreational benefit and potential of multi-functionality.

Answers to the diagnostic questions are a ‘yes’ or a ‘no’ in order to indicate that the SuDS technology has the potential to meet the criteria of preference to the user. Diagnostic questions included in the DSS which relate to amenity and biodiversity management are as follows:

i) Would one seek to or be required to incorporate vegetation into the development?

ii) Would one prefer the technology provide a natural habitat for organisms?

iii) Would one prefer the technology provide aesthetic enhancement to the surroundings?

iv) Would one prefer the technology offer recreational benefit?

v) Would one prefer the technology offer additional purposes other than the intended stormwater management capabilities?

4.1.4 Additional attributes

In order to provide a general overview of potential implications of SuDS technologies, the diagnostic highlights those which could possibly be less expensive to implement and maintain, relative to one another. Costs and responsibilities associated with stormwater infrastructure are often pivotal deciding factors on their implementation; for this reason, relevant diagnostic questions have been included in the DSS.

i) Would one seek a technology which may potentially have lower capital costs?

ii) Would one seek a technology which requires lower operation and maintenance in terms of the upkeep activities and related costs?

In summary, the user is required to decide which stormwater control stage is suitable for the development and systematically progress through the series of quantity diagnostic questions by offering a response. The responses selected determine the decision flow path. It would be the decision-flow path determined by the user which connects the quantity management responses to each other and ultimately leads to suitable SuDS technologies as stormwater management solutions. The quality, amenity and biodiversity as well as the additional factors outlined, have been included to enhance and possibly refine the SuDS selection, therefore facilitating the decision-making process. Finally, the user may refer to the technology specific criteria which provides further information thus allowing for more informed decisions to be made.

4.2 Stormwater level of control

Control levels largely depend on the size of the site and the drainage area contributing to the stormwater flow. Three broad control scales have been identified for ease of reference according to those outlined in the South African SuDS guidelines. Each SuDS technology suggested as solutions have been grouped into a stormwater control category. The grouping of the options is not necessarily prescriptive and it is possible that most could be used at a different control levels therefore at various stages of a treatment train.

As mentioned, specific SuDS technologies have been categorised according to the most suitable level they may fall within. For this reason, a DSS has been devised for each level of control since it allows for the each chart to appear more organised and manageable when used. The user of the DSS is required to select a chart based on the level of controls deemed most appropriate for the development.

Source controls are facilities which manage stormwater runoff as close to its source as possible and may provide the first processes stormwater would encounter in the treatment train. SuDS technologies which have been placed in this category are green roofs, rainwater harvesting, permeable pavements and soakaways. Such technologies generally collect, treat and store stormwater emanating from within the boundaries of the site. Such facilities are suitable for implementation in residential and commercial areas.

As a ‘second line of defence’, local controls are implemented. As the name suggests, the control typically manages stormwater runoff in the local, possibly public, area. SuDS technologies placed in this category may convey, detain, and/or infiltrate as well as treat stormwater from upstream which may originate from surrounding sites and roadway reserves falling within the ‘drainage area’. Filter strips, infiltration trenches, sand filters, swales and bio-retention areas are SuDS which typically function on a local control level.

SuDS technologies such as detention ponds, retention ponds and constructed wetlands are generally implemented on a large scale and have been categorised as regional controls. This level of control often manages stormwater runoff as a last 'line of defence' prior to its release into receiving waters. Regional control facilities may convey, detain, store and/or infiltrate as well as treat large volumes of stormwater emanating from several surrounding developments, which means that the drainage area feeding the technology may be of a considerable size.

In terms of source and local controls, the SuDS technologies are often most suitable for accepting stormwater when the drainage area and size of the site for development are reasonably small. Therefore when larger volumes of stormwater may be expected, multiple linked technologies placed in suitable locations may be required for efficient management. For larger lots and drainage areas, regional stormwater control may be more suitable.

The size of the drainage area contributes towards the anticipated volumes expected to enter the SuDS technologies on the site. It is the choice of the decision-makers as to whether the stormwater management facilities developed on the site would accept stormwater emanating off the site since considerable increases in stormwater volume would require larger, often local and regional control measures.

The levels of control form the stages of the treatment train concept, it has been considered important to initiate the idea of a stormwater treatment train from a conceptual design phase through the DSS by suggesting various SuDS technologies categorised into the levels of control for stormwater management. It is presumed that the categorisation may be a necessary initial criteria which may simplify and aid the selection process for the decision-maker.

It is recommended that the user of the DSS work though each chart with levels of control and attempt to initiate technologies from each level of control. By implementing a combination of technologies in series, the stormwater undergoes several processes which allows for improved management of stormwater especially in terms of quantity and quality.

4.3 Stormwater quantity management

Quantity is the most significant factor with regard to stormwater management, as described in the stormwater hierarchy. Stormwater control selection is considered to have a major impact on the scale at which stormwater management is required. Conditions which relate to and follow on from the site conditions is the management of the stormwater quantity on site.

Reduction of stormwater flood flow rate and volume through attenuation is the fundamental purpose of stormwater management as well as ensuring that surface water flow and groundwater infiltration rates return to predevelopment conditions. Effective management of stormwater on site is essential to prevent inconvenience to the users of the development, as well as possible flood and erosion damage.

Diagnostic questions in this section signal responses related to the location of the development, size of the site and open land available. The intention of the decision-maker to re-use through harvesting or dispose of the stormwater have also been examined through the DSS.

According to the SuDS guidelines, quantity management encompasses the conveyance, detention, long-term storage and infiltration of stormwater – these are regarded as means of handling stormwater on a development, in the DSS.

Decision paths are developed when the user progresses though the diagnostic questions and would eventually be directed to one or multiple SuDS technologies. These solutions may be suitable initiatives which could be selected since they possibly address the stormwater management requirements for the development.

4.3.1 Development location

For the purpose of the selection chard developed, location to whether the development would be situated on a greenfields site or if retrofitting is required. Greenfields is a site with open space which has not been used for buildings and other structures on the surface. The site may be earmarked development and be underlain with infrastructure. Installation of additional or alternative stormwater management approaches on a site which has been developed is referred to as retrofitting.

In both cases, it has been intended to achieve an improved management of stormwater which leads to the possibility of SuDS incorporation in conjunction with, however, reducing reliance on a conventional system. Through implementation of SuDS technologies, it is an intention to reduce impervious land area while encouraging development. Keeping the post-development runoff less than or equal to the predevelopment flow can be achieved on greenfields and retrofitted sites through SuDS initiatives.

It appears that it may be possible for all SuDS facilities to be retrofitted to an existing site according to the selection chart; however, open land availability would be limited therefore the facilities requiring greater expanse of land would be less suitable options. The perceived area of open land available precedes the site location. Though it may not be suitable for all and therefore options which may be most suitable in retrofit situations.

4.3.2 Land area

A greenfields site for development has been categorised as either small ($<4000m^2$) or large ($\geq 4000m^2$) within the DSS. The deciding value of $4000m^2$ has been interpreted from the CoCT Management of Urban Stormwater Impacts Policy (2009).

The size of the site is expected to have an influence over the volume of stormwater which may be managed within the development. This could determine the potential drainage area which would feed the SuDS technologies selected for implementation and dictate the level of stormwater control required. The number of SuDS technologies the user would consider implementing in a sequence, arranged as a treatment train would be determined by the site area.

Larger sites are likely to receive an increased flow and volume of stormwater and may possibly be collecting stormwater from several surrounding developments upstream of the stormwater course. The diagnostic question indirectly addresses stormwater quantity since land area affects the peak flow of stormwater on the site as well as control suitability. There are greater opportunities for improved stormwater attenuation on larger sites through SuDS implementation.

In the case of large areas for source and local controls in the DSS, the same procedure would be followed as though the site were small. Most SuDS technologies have been designed to service smaller areas; therefore, servicing the entire area would require the implementation of multiple technologies for effective stormwater management. It is critical for the technologies to be designed and sized correctly in order to manage the stormwater inflow of certain design storms.

For larger areas, it is recommended that the decision-maker implement a range of source, local and regional controls in order to attain suitable quantity and quality management objectives Treatment trains become a greater possibility since there is potential to place a range of SuDS technologies on the site.

Size differentiation has been deemed necessary for the DSS. There is potential for larger greenfields sites to have an increased area of open land available for the implementation of SuDS initiatives and the size may influence the volume of water chosen to be managed on the site for development.

4.3.3 Open land availability

In a retrofit development situation, it is considered necessary for the user to establish the area of open land available. According to the Debo & Reece Structural Control Screening Matrix (2003), a SuDS technology, may potentially require 5% of the land area. With the exception of swales which require a minimum of 10% of the site area.

Limited area available on the site has been selected to be less than 5% of the total land area therefore an area of $200m^2$ has been chosen as the quantitative limit. Open land exceeding the $200m^2$ has been perceived as excessive, in the context of the DSS. Challenges may exist for designers attempting to retrofit SuDS technologies within areas termed as ‘limited’, since the site may be densely developed. It is, however, possible to incorporate certain technologies into a minimal area of land and remain effective.

4.3.4 Stormwater intentions

The user of the DSS has been given the option in the form of a diagnostic question, to re-use or dispose of the stormwater existing on the site. The implementation of SuDS technologies which allow for the re-use of stormwater through harvesting is strongly suggested since this aligns with the goals of WSUD, contributes towards water supply and reduces the volume of run-off in an urban environment.

Stormwater intended to be re-used on the site could be harvested using the various SuDS technology options suggested. Certain technologies or a combination of SuDS in series, are capable of treating stormwater to a secondary quality. Domestic uses of stormwater treated to a secondary quality, are irrigation and toilet flushing. Both of which require large volumes of water and could reduce demands on potable water.

When it would be intended to re-use the stormwater, regardless of the quality required, SuDS technologies chosen which allow for infiltration require underdrain piping to convey the stormwater to a storage facility. It would be necessary to treat the stormwater, possibly through filtration prior to storage. SuDS technologies such as green roofs and rainwater harvesting which would require the re-use of stormwater, the water would require collection, treatment and conveyance to a storage facility before it could be used.

In the case where the user of the DSS would select potable water as a requirement, the stormwater could undergo the same treatment processes and therefore be of secondary quality. Tertiary treatment would be necessary before the water would be suitable and safe enough for human contact.

Disposal, in the context of the DSS, would be the release of water from the development. Whether stormwater is released directly into a waterway or off the site via the conventional system, attenuation and treatment is required. The water is likely to land up in a natural waterway and therefore the process of sedimentation and slow release of the stormwater is necessary for the health of the management of urban waterways.

Methods in which stormwater can be manged prior to harvesting or disposal, will be discussed in the following section.

4.3.5 Stormwater handling procedures

It would be the decision of the DSS user on the manner in which they would prefer stormwater be handled on site, either as a process prior to release or harvesting. The methods which have been identified according to the SuDS guidelines as quantity management processes and have been incorporated into the DSS are conveyance, detention, long-term storage and infiltration. A range of diagnostic questions has been developed in order to interpret the process requirements of the user.

Conveyance involves the movement of stormwater from one point to another, typically in a channelised section. There are SuDS technologies such as filter strips and swales whose primary function would be the effective transporting of stormwater for the prevention of flooding along with the reduction of run-off flows and volumes.

Detention of stormwater would occur when the peak flow rate of stormwater on site is required to be reduced to pre-development levels. Peak flows due to high rainfall events would require attenuation prior to release into and for the protection of watercourses or conventional drainage systems. All of the SuDS technologies suggested in the DSS have the capability of attenuating stormwater as well as sedimentation and other pollutant removal potential.

The user may be likely to select the long-term storage of stormwater when it would be intended to have a waterbody on the site or if stormwater would be collected for harvesting. The chosen SuDS technology may contain a permanent pool of water. After having collected and conveyed stormwater to a specific, suitable location, the technology may accept additional stormwater which may undergo several processes before it would be slowly drained out. Storage of water for extended periods would occur for rainwater harvesting prior to use and regional control facilities such as retention ponds and constructed wetlands.

In the context of the DSS, extended attenuation storage has also been referred to as long-term storage. This would be because the protection of receiving watercourses during extreme storm events, especially when long-term storage and infiltration are not feasible on the site has been considered as a necessary function for the retention of stormwater (Armitage et al., 2013).

Infiltration is an important process forming part of the urban water cycle. Volume and flow rate of run-off would be decreased due to infiltration therefore reducing negative impacts on waterways as a result. Increasing ground infiltration would allow for replenishment of underground water sources, provided the water is of an acceptable quality.

Diagnostic questions addressing possible concerns with infiltration have been related to the ground soil, water and stability conditions. The presence of an underlying aquifer requires a response since it would be unethical to pollute potential water supply resources with what may be contaminated stormwater. Treatment of stormwater prior to infiltration would be necessary or no infiltration should occur in this case therefore requiring lining for prevention.

Ground infiltration rates vary, depending on the type of soils. In-situ soil materials with low infiltration rates are often unsuitable for the infiltration of stormwater. SuDS technologies which promote infiltration are typically constructed with engineered soils. Hydraulic conductivity would be a value which indicates the rate at which water is predicted to infiltrate through the saturated soil medium. Table 4-2 shows grouping of soils according to a description along with potential hydraulic conductivity.

Table 4-2: Table showing hydraulic soil groupings

(Gironás et al, 2010; Debo & Reece, 2003)

Soil group	Description	Saturated hydraulic conductivity (mm/h)	DSS grouping
A	Soils having a low runoff potential due to high infiltration rates (These soils consist primarily of deep, well-drained sands and gravels.)	≥ 11.4	High
B	Soils having a moderately low runoff potential due to moderate infiltration rates (These soils consist primarily of moderately-deep to deep, moderately well- to well-drained soils, with moderately fine to moderately coarse textures.)	3.8 – 7.6	High
C	Soils having a moderately high runoff potential due to slow infiltration rates (These soils consist primarily of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately-fine to fine texture.)	1.3 – 3.8	Low
D	Soils having a high runoff potential due to very slow infiltration rates (These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.)	0.0 – 1.3	Low

According to Debo & Reece (2003), SuDS technologies whose main functionality involves treatment of stormwater through infiltration should not be saturated with underground water. Such technologies are typically implemented below the ground surface, hence having a water table within 1.5m of the surface may prevent the technology performance.

Structural integrity of the ground and surrounding infrastructure may be threatened by the presence of water in the soil. For this reason, a diagnostic question addressing a concern over the perceived proximity of a SuDS technology to adjacent buildings has been included. Erosion and failure of foundations is a possible occurrence when the surrounding soil conditions may be dynamic due to an increase in infiltration nearby. Should this be the case, the base of the technologies should be lined and an underdrain included.

Urban development generally results in an increased volume and flow rate of run-off during storm events. This would be due to the replacement of natural free-draining surfaces with impermeable surfaces. Detention, storage and infiltration, promoted by SuDS technologies mimic processes of the natural water cycle. Quantity management is necessary to reduce the risk of flooding, through the conveyance and attenuation of stormwater for the protection of people, infrastructure and waterways in the urban environment.

4.3.6 Further quantity management criteria

Developments in urban regions, especially those which require retrofitting, are generally dense with buildings and infrastructure. Replacement of naturally free-draining surfaces are usually replaced with impermeable surface which increase the volume and flow-rate of stormwater run-off from the development.

In the DSS, a diagnostic question has been included which specifically addresses whether a user intends on developing or keeping permeable area on the site in excess of the required minimum. It is encouraged that a portion of the land area be permeable surfaces and exceed the 15% minimum, as outlined in the CoCT Management of Urban Stormwater Impacts Policy (2009).

It would be possible for all the suggested SuDS technologies to increase surface permeability for improved stormwater management since this allows for infiltration, attenuation therefore reduced run-off flow rates and volumes. An increase in permeability of the site surface would be suggested and has been brought to the attention of the DSS user. Through the implementation of SuDS technologies, criteria such as an increase in surface permeability could influence the decision of the user who would have the option to decide if they intend on increasing the permeability of the development.

The user would have the option in the DSS to establish whether the SuDS technologies directed to, have potential to be incorporated into a building, the landscaping or paved areas.Where open land is limited, the decision-maker could potentially have the option of incorporation a SuDS technology into the roof of a building, the landscaping or paved areas of the development. Paved areas such as walkways and low-traffic parking or roadway facilities could be altered to become permeable surfaces.

Provided the user prefers incorporating a SuDS technology into exposed parts of a building, it would be necessary to be aware of certain significant design conditions such as the building having a flat roof and structurally able to support additional loading. Stormwater harvesting and green roofs, are SuDS technologies which could potentially be installed on the roof of a building. If the roof would be unable to support the storage rainwater harvesting tanks, then it would be suggested to place the tanks on the ground surface instead. It would generally be preferred if the roof were to be that of a multi-story building, concrete and as flat as possible for ease of construction, operation and maintenance.

It has been considered imperative to note and is an integrated assumption of the DSS that stormwater would be released off the site directly into natural waterways or into a conventional municipal drainage system. In both cases, the stormwater would eventually reach a waterbody, therefore, it would be necessary for the stormwater to be attenuated treated prior to its release.

Appropriate sizing of SuDS technologies for stipulated storm return intervals would be vital during the design process. Risks associated with inefficient technologies would be great, especially during rainfall events. Source and local control are generally considered as minor systems and larger regional; controls as major systems in terms of their capacities to function effectively when accepting certain storm return interval volumes and flow rates. Certain technical design aspects such as the storm return intervals for which SuDS technologies should be sized, have not been included in the DSS as it has been deemed as specific technical information. The designer is required to compare the land area available to the rainfall event and during design, ensure that there would be sufficient are for the SuDS technology selected.

In practice, the land use of the development plays a significant role in stormwater management planning, however, is not influential criteria in the selection chart. Though it would impact the SuDS facilities selection, the options suitable for particular land uses overlap and many facilities could be adapted to suit the land use. Typically, land use is associated with an increase in impervious area, resulting in both an increase in stormwater runoff and pollutants.

It has been considered necessary to note that all of the SuDS technologies suggested, when designed appropriately, could be used in conjunction with existing or future conventional drainage systems on the site for development. The incorporation of SuDS technologies, especially in the form of a treatment train, could reduce the burdens of increased stormwater volumes and flow rates imposed on conventional drainage systems and waterways.

Having a series of technologies reduces flood risk and damage potential. Conventional drainage infrastructure developed in future could potentially be reduced in size should it be implemented in conjunction with SuDS technologies. An intention of the DSS would be to encourage a reduction in the dependency on conventional municipal drainage system and demand for potable water though the incorporation of SuDS technologies.

Quantity management is considered the most significant aspect of stormwater, according to the hierarchy as it focuses on the reduction of stormwater flow rates and volumes. . There are various aspects which have been incorporated into the DSS which address and could have influence over stormwater quantity concerns, either directly or indirectly. Site location, land area availability, stormwater intentions and handling thereof, as well as various other conditions have been considered as criteria which have influence over stormwater quantities; these criteria have been incorporated into the DSS quantity diagnostic section.

4.4 Stormwater quality management

This section of the DSS seeks to encourage decision-makers to consider the treatment of stormwater on sites for development in order to improve the quality of water released into natural waterways and conventional drainage systems.

It is a requirement, according to the CoCT Management of Urban Stormwater Impacts Policy (2009), to improve the quality of water exiting a site most significantly through the removal of sediment. It has been stipulated that 80% of TSS and 45% of TN be removed from stormwater prior to its release into waterways or municipal conventional system.

In the DSS, it has been indicated by a ‘yes’ or a ‘no’ if the SuDS technology has the potential to remove a satisfactory percentage of the stormwater pollutant. The removal of pollutants by each SuDS technology is based on the information provided in Appendix C; the values specify the potential pollutant removal. If the maximum removal capability exceeds 50% then the technology would be considered more appropriate since it may be more efficient. In the case of TN, where the minimum removal should be 45%, the standard has been slightly adjusted.

Pollutants typically found in urban stormwater whose content may possibly be reduced through processes facilitated by SuDS technologies, have been highlighted. The pollutants are as follows: Total suspended solids (TSS), Total Phosphorus (TP), Total Nitrogen (TN), hydrocarbons, heavy metals and faecal coliforms. Table 4-3, adapted from the SuDS guidelines (2013), Appendix G, groups and highlight the pollutants and briefly discusses the potential impacts of the contaminants.

Table 4-3: Table of stormwater pollutants and their impacts (SuDS guidelines, 2013)

Pollutant group	Pollutants	Impacts
Solids	Debris and rubbish	Threat to wildlife. Aesthetic appeal decreased.
Organic material	Plant litter	Increased nutrients & sediment.
Sediments	Suspended and settable solids (TSS)	Increased turbidity, sedimentation, smothering of aquatic plant and animal life.
Nutrients	Nitrogen and phosphorus (TN and TP)	Excessive nutrients result in eutrophication. It is commonly associated with algal plumes, reduced clarity resulting in decreased bio-diversity.
Hydrocarbons	Oils, grease and others	Polluted water may become toxic. Aquatic life becomes toxic due to bioaccumulation. Decrease of biodiversity.
Metals	Lead, copper, zinc and others	Polluted water may become toxic. Aquatic life becomes toxic due to bioaccumulation. Decrease of biodiversity
Pathogens (Faecal coliforms included)	Bacteria, viruses and protozoa.	Public health risk. Contaminated recreational areas. Decreased economic value of natural recreational areas
Toxic chemicals	Pesticides and insecticides.	Polluted water may become toxic. Aquatic life becomes toxic due to bioaccumulation. Decrease of biodiversity

SuDS technologies involve several processes. It is through the mimicking of natural processes that the stormwater may undergo treatment. The processes considered for stormwater quality management in the SuDS guidelines are: sedimentation, filtration, adsorption, biodegradation, plant-uptake and nitrification. Table 4-4 shows the processes which each SuDS technology may facilitate.

Table 4-4: Table of the stormwater quality management capabilities of SuDS technologies (SuDS guidelines, 2013)

	SuDS technology	**Sedimentation**	**Filtration,**	**, Adsorption**	**Biodegradation**	**Plant uptake**	**Nitrification**
Source control	Green roof	P	P	P	P	P	P
	Rainwater harvesting	PR	X	X	X	X	X
	Soakaway	PR	P	P	P	X	X
	Permeable pavement	x	P	P	S	X	X
Local control	Filter strip	P	P	P	P	S	S
	Swale	S	P	P	S	S	S
	Infiltration trench	PR	P	P	S	X	S
	Bio-retention area	P	P	P	P	P	P
	Sand filter	S	P	P	S	X	X
Regional control	Detention pond	P	X	X	X	X	X
	Retention pond	S	S	S	P	P	P
	Constructed wetland	S	S	P	P	P	P

*Key: P – primary process; S – secondary process, PR – pre-treatment required and X – not applicable.

Placing a series of SuDS interventions in the form of a treatment train has potential to increase treatment of the stormwater therefore improving the overall stormwater quality. In the case where a SuDS technology has been selected however, it does not have the potential to treat the stormwater satisfactorily, the decision-maker should consider implementing other technologies upstream or downstream of the stormwater flow path. Incorporation of additional SuDS technologies relieve the reliance on one facility for quantity and quality management which may prove to be beneficial for the development.

Stormwater pollutants pose health risks on humans and the natural environment, when in contact. Therefore, it is important for decision-makers to consider the treatment of stormwater and be aware of the implications of pollutants. Pollutants have detrimental effects on the natural environment by negatively affecting the health of waterways, the ecology and aesthetics of the region.

4.5 Amenity and biodiversity

The value of this section within the DSS is often undermined when compared to quantity and quality management according to the stormwater design hierarchy. The possibility of enhancing amenity and biodiversity on the site for development through SuDS technology interventions is an additional facet the decision-maker may consider including.

The DSS has incorporated amenity and biodiversity management through various diagnostic questions which are intended to influence the SuDS selection made by the user. It should be noted that the criteria do not form part of a decision flow path established, leading to suitable SuDS technologies. The aspects simply highlight the potential of the various technologies in order to enhance the options for selection and intend to promote that more informed decisions be made.

According to Armitage et al. (2013), amenity management incorporates the health and safety of people and the environment as well as environmental risk assessment and management. Education and awareness, too, form part of amenity. All of which are important aspects which need to be taken into consideration by a decision-maker when selecting and designing SuDS technologies.

The DSS, however, addresses the recreational benefit, aesthetic enhancement and multi-purpose potential of SuDS technologies. Such aspects are considered to impact the amenity of a site, hence the reason for having been included.

Recreational benefits of a SuDS technology in the context of the DSS would be the addition of a feature of attraction to the site within an open space where recreational activities could take place around the technology. Aesthetic enhancement would be the capacity of the SuDS technology to improve the visual appearance of the site in such a manner that it may be attractive to most people.

A multi-use facility would be one which offers an additional service to the site other than its stormwater management capabilities. For example, permeable pavements may be incorporated into a parking facility or walkways and detention ponds may be utilised for various recreational activities during dry periods. Implementing facilities with increased functionality into a building, landscaping or paved areas on the site, allows for making better use of the space and resources available. The capability of a SuDS technology to possess the mentioned benefits has the potential to influence the selection of a decision-maker.

It has been considered essential to note that the DSS itself is a tool which promotes education and awareness on the significance and benefits of SuDS implementation. Since the DSS has been developed to be used by any individual, there would be the possibility that the interested and affected parties impacted by the development may have the opportunity to make use of the DSS and further their understanding. This could potentially assist with the development of community acceptance, increase participatory involvement in the conceptual design process and may reduce concerns associated with SuDS options.

Biodiversity management incorporates the protection and monitoring of indigenous flora and fauna as well as the maintenance of the habitat through the removal of invasive species (Armitage et al, 2013). Within the context of the DSS, the incorporation of indigenous vegetation has the potential to preserve and increase the biodiversity on site.

Vegetation forming a part of the SuDS technology, whether it has been incorporated into a building or the landscaping on the site, enhances the aesthetic appeal and possible functionality for stormwater quantity and quality management. Further benefits of vegetation would be conservation of the natural environment without the hindrance of development as well as assisting with maintaining stormwater run-off its pre-development state.

Habitat provision by a SuDS technology would entail it being a sanctuary for flora and fauna species which contributes towards nature conservation (Environment Protection Authority – Melbourne Water Corporation, 1999). It has been considered a positive attribute for SuDS technology and has been included in the DSS to highlight this feature to the decision-maker.

Amenity and biodiversity form part of the stormwater design hierarchy. It has been deemed necessary to emphasise the capacity of SuDS technologies to fulfil stormwater management requirements other than the quantity and quality aspects. Within the DSS, the ability of SuDS to possess certain attributes has been indicated by a ‘yes’ or a ’no’. Technologies with additional capabilities have the potential to be more attractive for selection by a decision-maker.

There are additional factors which have the potential to influence the SuDS selection made by the decision-maker and are discussed in the following section.

4.6 Additional deciding factors

Costs vary significantly and depend on a multitude of design and economic considerations. A definite value has not been imposed in terms of costs related to the construction, operation and maintenance of the SuDS technologies. The rating of a 'low' cost technology in the DSS would be a general relative indication which has been included for comparison purposes.

Input for the maintenance of SuDS technologies incorporated into a development, vary in the procedures and regularity required. The more specialised the material, methods and effort required to construct, operate and maintain the technology, the higher the costs would be. Costs and responsibilities associated with stormwater infrastructure are often pivotal deciding factors on their implementation; hence diagnostic questions with responses perceived as suitable, have been inserted.

Stormwater quantity, quality, amenity and biodiversity management requirements have been addressed by the DSS along with additional factors which may influence the decisions of the DSS user. Conclusions based on the development of a DSS for SuDS selection have been drawn in the following chapter.

5. Research conclusions

Numerous tools have been designed for the purpose of selection and modelling of alternative urban drainage systems; The DSS selection chart developed is the first of its kind which intends to support the efforts of the recent WRC publications. Initiation of SuDS technology implementation from a conceptual design phase has been intended by offering guidance through a specific stormwater management selection process.

After having progressed through the selection chart, the understanding and awareness of SuDS to the user of the DSS, may possibly increase. The DSS is a tool which aims to assist decision-makers identify and implement opportunities for improved change in the approach to stormwater management. This could be a valuable contribution, though small, for progression towards the idea of having sustainable urban environments which encapsulate the principles of WSUD. Content of this research project closely correspond to the SuDS guidelines which users of the DSS have the option to refer to for additional information and further guidance on SuDS implementation.

Conclusions based on the research have been drawn and categorised into distinct sections. The concluding sections pertain to the DSS and SuDS - the most significant aspects of the research project.

5.1 Decision support chart

The DSS has been developed as the main component of and represents the outcomes of this research project. Promoting informed decision-making and streamlining the process of SuDS selection has been attempted though the DSS selection chart. Considering the potential complexity of alternative stormwater management decision-making, the DSS developed could be practical to use in order to make a suitable selection.

The selection chart has fulfilled certain requirements of a DSS, in terms of the broad definition – a tool which could assist with making more informed decisions. Despite the format of the decision support tool, the chart could be referred to as a DSS as it has been throughout this research project.

Formulation of the selection chart required a general understanding of SuDS technologies and their requirements in order to develop a process of guiding users through a diagnostic process of decision-making. Users of the system have been provided with an overview of alternative stormwater management technologies appropriate for implementation in South Africa.

Those who may be unfamiliar with the concept and implementation of SuDS, could be adequately introduced to a range of SuDS facilities through the use of the DSS. Through a rational diagnostic procedure, the user would be directed to SuDS options. The options could be suitable for their development since it has been reached through a decision flow-path decided by the user. Since the DSS asks pertinent questions, particular determining factors are realised for the decision path which affects the options for selection.

It has been proposed for the chart to be used from a conceptual design through to an operational phase, in order to initiate improved integration of SuDS into a development. A means to assist selection and facilitate the decision-making process would be an anticipated function of the DSS as opposed to a detailed technical design tool. Information provided in the research project and the selection chart diagnostic refers to and has not replaced existing literature on SuDS. Use of the DSS would not substitute knowledge and experience required for the detailed design and construction of SuDS facilities.

The user of the DSS would not be required to have an in-depth knowledge of SuDS when selecting suggested technologies. Though, particular details regarding the site for development would be necessary. Content within the DSS and research project should provide sufficient information on which a user could base their decision. After having progressed through the DSS, users should have a general understanding of the SuDS facilities directed to and the requirements thereof. SuDS technologies incorporated as solutions are not intended to be prescriptive. Selection of stormwater facilities and appropriate treatment train options based on the outcomes of the DSS, remains the responsibility of the decision-maker. The selection chart has been developed as a guide; it is strongly recommended that professional experience and judgement be applied when designing facilities for stormwater management.

Regardless of their role or profession, decision-makers and stakeholders are those who are in a position to determine the infrastructure and practices on a development. All people involved in stormwater management would be informed on, relate and refer to the particular process of selection outlined in the DSS. For this reason, it is intended that the DSS be an inclusive tool which promotes interdisciplinary collaborations at all levels and applicable phases of development. Supplying relevant information to decision-makers may broaden their knowledge and design potential.

The DSS has covered a range of aspects such as site location, site scale, on-site re-use of stormwater and level of stormwater control i.e. source, local and regional. There are many more factors that have an impact on shaping the content of the chart which have not been included in order to keep the chart as simple and general as possible. Through the DSS, the implementation of SuDS and intentional improved urban water cycle management could be encouraged. Drawing decision-makers towards choosing SuDS technologies to be used in conjunction with or in place of conventional drainage infrastructure has been attempted to be addressed.

As a tool, the DSS has been based on implicit information which may not be considered valid or applicable to all users. Though, the criteria of the DSS have been considered necessary for the selection of suitable SuDS technologies. It would not be expected that the decision-maker experience difficulties using the tool or interpreting the results, unlike the stormwater modelling tools described in the literature review.

There could be the possibility of incorporating the DSS as a marketing tool for SuDS promotion and a means of presenting alternative stormwater management ideas. The chart has intended to help select technologies which have potential to enhance the marketability of a development through increased amenity and biodiversity, despite the additional maintenance required. SuDS technologies could be valuable assets to a development which produce evident stormwater management results.

There is a wide range of stormwater models available which vary in functionality. It is important for developers and users of SuDS decision support tools to acknowledge that there is not one tool or system in existence which sufficiently addresses every concept within IUWM, holistically. Along with the DSS developed, stormwater decision systems and models in existence could be used in conjunction, with the DSS as an initial selection step prior to modelling the SuDS technologies.

Based on the content of the research project, defined expectations have been supported. However, it cannot be confirmed whether the DSS has the ability to make the SuDS selection process more effective and efficient for decision-makers. However, the SuDS concepts addressed may be more easily understood though using the DSS.

In supporting the SuDS guidelines, the DSS may be the first of its kind to guide decision-makers through a SuDS selection process. The selection chart as a tool, has been developed within however, may not necessarily be limited to, the South African context. SuDS requirements are the basis upon which the DSS framework has been composed since SuDS facilities are alternative solutions to stormwater management. The DSS ultimately seeks to recommend suitable SuDS options for various developments.

5.2 Context of SuDS

In South Africa, a holistic approach to UWM is in its early stages of acceptance and implementation. The concept of SuDS, a component of WSUD practices, provide alternative approaches to stormwater management when compared to conventional drainage systems. SuDS align with the ideals of sustainable development and contribute towards the vision of developing water sensitive cities.

It has been noted that other components of the urban water network such as water supply and sanitation are important in progressing the objectives for WSUD, however, have not been covered by this research project. The DSS developed considers the stormwater component of UWM therefore cannot be regarded as an integrated tool. Additional components touched on in the DSS and advocated for in the research, have been groundwater recharge and water supply through the re-use of stormwater for secondary domestic purposes.

SuDS have been the focus of this research project; there is minimal data with regards to SuDS efficacy, hence the need for informed selection, design, implementation and maintenance. There are, however, key issues relating to the current social and economic capacities of implementing SuDS technologies in SA.

The established hierarchy for stormwater management has been abided by in this research project. The levels of the SuDS hierarchy contribute towards improved stormwater systems, with runoff quantity and quality of most significant concern. Additional levels of amenity and biodiversity encourage further progress towards the enhancement of the urban environment and effective management of stormwater runoff.

The overarching quantity level of stormwater management encompasses processes such as infiltration, conveyance, detention and/or storage which allow for attenuation and flood protection. Relative pollutant removal capabilities of SuDS technologies have been shown in the DSS. Stormwater can be treated through various natural processes, therefore, improving the quality of water released into surface waterways and groundwater.

Amenity and biodiversity are aspects of the stormwater hierarchy which have been addressed in this research project. Though they have not been regarded as decisive criteria which lie along a decision flow-path, they provide additional benefits which enhance selection. According to Armitage et al, (2013), these stormwater management aspects incorporate the following attributes: protection of ecological systems and the environment; health and safety of people; recreation and aesthetics. This research project itself, has the potential to promote education and awareness of SuDS technologies and their benefits.

SuDS technologies, as in the SuDS guidelines, have been categorised as source, local or regional controls according to the scale of stormwater management and general intervention stages within a treatment train. A combination of SuDS technologies implemented sequentially or concurrently, is referred to as a treatment train and has been stated to achieve better management of stormwater. Implementation of SuDS facilities in an urban area contribute towards the mimicking of the natural hydrological cycle, necessary for sustainable UWM.

Criteria influencing SuDS selection are dependent on a variety of factors which may or may not have been included in the DSS. Factors include, but are not limited to, climate, site location, scale of development, pollution removal capability, technical design complexity, and maintenance. Those which have been included in the DSS selection chart have been considered as fundamental concepts pertaining to relevant aspects of SuDS design. It has been noted that significant aspects which have not been incorporated into the DSS such social, political, financial and economic criteria, are bases upon which development decisions are most often made.

It can therefore be concluded that the research project, including the DSS, would be able to simply inform users and offer convenient decision support within UWM, for appropriate SuDS selection. Recommendations which follow relate to possible means of improvement on that which has been developed.

6. Recommendations for further research

The following recommendations have been made for further study and research, regarding Decision Support Systems for IUWM in South Africa:

i.) Improve on the selection chart developed through expanding on the stormwater aspect as well as integrating other components of WSUD such as water supply and sanitation. This would give the DSS a holistic approach to UWM. Additional social, political, financial and economic aspects could be incorporated into the DSS since these factors have significant influence over UWM decisions.

ii.) Develop the selection chart into a DSS program interface which allows for the selection process to be more user-friendly and convenient. This requires further investigation into how decision support tools can assist in making more complex IUWM decisions.

iii.) Investigate the efficiency and effectiveness of the DSS selection chart developed after having been used by decision-makers through a trial and feedback process. The DSS developed is open to further investigation and improvement by other researchers in order to enhance the field of and potentially change IUWM practices.

The development of DSS and other selection tools are necessary for improved IUWM, especially in South Africa where the concept is fairly new. These tools are a means of encouraging interdisciplinary partnerships through informing various professionals and creating an awareness of possible technologies. Making information more readily accessible and understandable, increases the chances of a positive shift in development practices. A change in approach to UWM is necessary for progression towards sustainable development and protection of water resources.

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Appendix A – DSS SuDS selection charts

A-1 DSS - SuDS selection chart for source stormwater control

A-2 DSS - SuDS selection chart for local stormwater control

A-3 DSS - SuDS selection chart for regional stormwater control

Appendix B – SuDS classification

Table B-1: SuDS classification table (Ellis. 2015)

SuDS category	**Retention systems (SP)**	**Detention systems (DS)**	**Porous surfaces (PS)**
Category subtype	Wet pond Wet ED pond Micro pool ED pond Multiple ponds Floating islands	Dry detention basin (ED) Multi-purpose detention area Underground detention	Permeable paving Porous concrete Gravel media Grass block paving
SuDS category	**Enhanced swales (SW)**	**Infiltration systems (IN)**	**Chemical systems (CH)**
Category subtype	Dry enhanced swale Wet enhanced swale	Infiltration trench Infiltration basin	Alum treatment Chlorine treatment
SuDS category	**Bio-retention systems (BR)**	**Gross pollution trap (OT)**	**Proprietary systems (PP)**
Category subtype	Bio-retention area Green roof Rain gardens	Oil-grit separator Gross pollution trap Litter silt trap	Proprietary systems
SuDS category	**Sand filter systems (SF)**	**Wetland system (SW)**	**Bio-filter systems (BF)**
Category subtype	Surface sand filter Perimeter sand filter Austin sand filter Underground sand filter Organic filter	Shallow wetland Shallow ED wetland Pond/Wetland Pocket wetland Submerged gravel wetland	Filter strip / Bio-strip Grassed channel Bio-bag Bio-swale Trickling filter
SuDS category	**Alternative Supplies (AS)**		
Category subtype	Rainwater harvesting (RWH) Stormwater harvesting (SWH) Greywater recycling	Blackwater recycling Groundwater use WWTP effluent use	Surface abstraction Blue roofs

Appendix C - SuDS pollutant removal

Table C-1: Measures pollutant removal capacities of selected SuDS options and technologies (Armitage, et al. 2013)

Option/ Technology	Pollutant removal %					
	TSS	Hydro carbons	TP	TN	Faecal Coli Forms	Heavy Metals
Source controls						
Green roofs	60 - 95	-	-	-	-	60 - 90
Soakaways	70 - 80	-	60 -80	25 – 60	60 - 90	60 - 90
Stormwater collection and reuse	PS	PS	PS	PS	PS	PS
Permeable pavements	60 - 95	70 - 90	50 - 80	65 - 80	-	60 - 95
Local controls						
Bio-retention areas	50 - 80	50 - 80	50 60	40 - 50	-	50 - 90
Filter strips	50 - 85	70 -90	10 - 20	10 - 20	-	25 - 40
Sand filters	80 - 90	50 -80	50 -80	25 - 40	40 -50	50 -80
Infiltration trenches	70 - 80	-	60 - 80	25 - 60	60 - 90	60 - 90
Swales	60 - 90	70 - 90	25 - 80	30 - 90	-	40 - 90
Regional controls						
Constructed wetlands	80 - 90	50 - 80	30 - 40	30 - 60	50 - 70	50 - 60
Detention ponds	45 - 90	30 - 60	20 - 70	20 - 60	50 - 70	40 - 90
Retention ponds	75 - 90	30 - 60	30 - 50	30 - 50	30 - 70	50 – 80
PS – Product specific; TSS – Total Suspended Solids; TP – Total Phosphorous; TN – Total Nitrogen						

ECSA level outcomes compliance

ECSA Outcome 1: Problem solving

Through compiling the research project independently in the specialised field of Urban Water Management of Civil Engineering, the knowledge of the researcher has been extended. The researcher aimed to refine the broad research topic, follow a systematic approach to record and critically evaluate the findings, analyse the problem and present the solutions appropriately. Creativity and innovation has been encouraged and have been key in the approach adopted to solving the identified problem. In the final document, the appropriate goals and objectives of the research project have been clearly defined and the implications of the findings discussed.

ECSA Outcome 2: Application of scientific and engineering knowledge

Content of the research project outcomes have been relevant to engineering sciences, appropriately conceptualised and diagnosed problems related to urban stormwater run-off which could be resolved with Sustainable Urban Drainage Systems, a specialised area of Civil Engineering.

ECSA Outcome 4: Investigations, experiments and data analysis

The research project has been presented as an investigation designed and conducted to solve the identified issue relating to urban stormwater management. The purpose, process and outcomes of the research have been presented in a technical report with appropriate graphical information. A literature search has been conducted and the material found, evaluated. An analysis of existing decision support systems for urban stormwater management and conceptualisation of SuDS initiatives as solutions have been communicated. Conclusions have been discussed based on evidence found in literature and findings.

ECSA Outcome 5: Engineering methods, skills and tools

Competence to use relevant and appropriate engineering methods and skills in order to solve the identified problems within urban stormwater management have been demonstrated through this research project. Critical assessment of findings in the literature and the outcomes of the research project are evident in the documentation. There has been scope for computer applications to be developed for the purpose of this research project.

ECSA Outcome 6: Professional and technical communication

The technical aspects of the research project have been clearly conveyed to both a technical and non-technical audience through presenting the information in a report and e-portfolio format. The writing is considered to be of an appropriate style, structure and language; graphics have been used effectively to communicate the decision support system so that it could be user-friendly.

ECSA Outcome 8: Individual, team and multi-disciplinary working

Competence to work individually has been demonstrated through the identification of focussed objectives and evidence of adopting a systematic approach in order to solve the selected problem. Results of the research project have been attained through effective task execution and time management.

ECSA Outcome 9: Independent learning ability

Independent learning through developed skills have been demonstrated through the compilation of documents showing an effective strategy followed to learn about Sustainable Urban Drainage Systems and its applications in engineering. In addition, the gathering and critical evaluation of relevant information have shown an understanding of the focussed research topic.

ECSA Outcome 10: Engineering professionalism

The researcher has been critically aware of the need to make use of personal judgement and has taken responsibility for their own decisions when compiling the research project. During the decision making, problem solving and research design processes, an understanding of own capabilities and research conducted within an area of current competence, has been required. All course requirements have been complied with in order for the research project to be acceptable.

The research project document has been compiled to fulfil all the ECSA level outcomes required and to the satisfaction of the supervisor and external examiner, according to the guidelines and feedback provided prior to submission.