Alternative Technology for Stormwater Management

Sustainable Drainage Systems – Report and South African Case Studies

Report to the
Water Research Commission

by

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This report forms part of a series of two reports. The other report is *Alternative technology for stormwater management: The South African Guidelines for Sustainable Drainage Systems* (WRC Report No. TT 558/13).

Executive summary

Background

Stormwater management in the urban areas of South Africa has, and continues to, predominantly focus on collecting runoff and channeling it to the nearest watercourse. This means that stormwater drainage currently prioritises quantity (flow) management with little or no emphasis on the preservation of the environment. The result has been a significant impact on the environment through the resulting erosion, siltation and pollution. An alternative approach is to consider stormwater as part of the urban water cycle, a strategy which is being increasingly known as Water Sensitive Urban Design (WSUD) with the stormwater management component being known as Sustainable Drainage Systems (SuDS).

SuDS attempts to manage surface water drainage systems holistically in line with the ideals of sustainable development. It aims to design for water quantity management, water quality treatment, enhanced amenity, and the maintenance of biodiversity. In so doing many of the negative environmental impacts of stormwater are mitigated and some benefits may in fact be realised.

Objectives and aims

This study had the following three aims:

i) To identify and develop new and appropriate, practical and affordable alternative stormwater management technologies for South Africa in line with Water Sensitive Urban Design (WSUD) principles.

ii) To evaluate the identified technology options in terms of their ability to improve stormwater management in urban areas; i.e. reduce the impacts on receiving watercourses resulting from increased velocities and volumes of runoff and the deterioration of runoff quality.

iii) To develop practical and user-friendly guidelines for the implementation of WSUD for both retrofit and greenfield scenarios in both the economic and sub-economic sectors of South African society.

Methodology

Literature review

An extensive search was undertaken to uncover all that had been published on Sustainable Drainage Systems since 2000. The information obtained (which included books, journal papers, conference proceedings, reports and manuals) was used to compile a 405-page bibliography. The bibliography was in turn used to compile the Literature Review presented here (Chapter 2) as well as the South African Guidelines for Sustainable Drainage Systems hereafter referred to as the South African SuDS Guidelines, or simply “the Guidelines” (separate document).

South African case studies

At the beginning of the research, a number of exploratory field trips were undertaken to assess what had been planned and implemented in South Africa with respect to SuDS. Although the case studies were limited to only three provinces (Western Cape, Gauteng, KwaZulu-Natal), these three provinces account for approximately half the population and the majority of the economic activity of South Africa. They also experience different climatic conditions from each other that roughly represent much of the country. The identified case studies were then monitored over a two year period. The eight most promising case studies were selected for further study and reporting. The wetlands and associated SuDS at Century City in Cape Town were studied in particular detail. The monitoring of these case studies did not include instrumentation or measurements of the quality or quantity outcomes of the systems, except in the case of Century City where monitoring had been undertaken by the landowner association.

The development of the South African SuDS Guidelines

In the course of the search for source material, 27 SuDS design manuals from Australia, the United Kingdom and the United States were reviewed. The South African SuDS Guidelines were then compiled by summarising the key material from these manuals in such a way as to be relevant to all professionals working with stormwater – and not just engineers. The Guidelines are not intended to be a design manual but a way of highlighting potential opportunities for better stormwater management. Initially the draft Guidelines – together with supplementary material – was compiled on a DVD and given out to delegates attending workshops in Cape Town, Johannesburg, Centurion, George and Durban. The feedback from these workshops was incorporated into the final SuDS Guidelines along with a number of further refinements.

The SuDS Economic Model (SEM)

The SuDS Economic Model (SEM) comprises Excel macro-enabled software that was developed to assist in the economic analysis of alternative approaches to stormwater management. The functioning of the model is described in Appendices D-F in the SuDS Guidelines.

The SuDS / WSUD Website

Initially it was envisaged that the output from this research project would be distributed on a DVD. This approach initially proved successful, but a number of shortcomings became evident including the fact that: it was not possible to get copyright clearance for all resources;

a DVD is difficult to update; and it requires practitioners to have a DVD drive to access the information.

As a result a decision was made to develop a website which could in time be expanded to cover other issues associated with WSUD. This approach has a number of advantages: it is possible to link references to their sources; it is possible to continuously update material and correct any errors; and it is possible to collect data on new SuDS projects from the professionals involved. The resulting website can be found at the following address: www.wsud.co.za

Project deliverables

This study set out to identify and develop new and appropriate guidelines for the use of alternative stormwater technology in South Africa. The project resulted in the development of the following deliverables:

- Sustainable Drainage Systems – report and South African case studies (this document).
- The South African Guidelines for Sustainable Drainage Systems (The South African SuDS Guidelines).
- The 'SuDS Economic Model (SEM)'.
- The 'SuDS Conceptual Design' poster.
- The 'Working Sustainable Drainage Systems into the City' poster.
- The 'Water Sensitive Urban Design: South Africa' website (www.wsud.co.za).

Review of South African case studies

A number of South African case studies were reviewed as part of the research. A summary of the findings follows:

Permeable pavements

Permeable paving is the most commonly implemented SuDS option in South Africa. This is most likely due to its promotion by the Concrete Manufacturers Association (CMA). Three case studies from across South Africa were investigated in detail. These were:

- **The Cape Town Grand Parade –** situated next to the Town Hall in the centre of Cape Town, this was the first major permeable paving scheme in the Western Cape.
- **A University of Witwatersrand parking area –** two multi-use sports fields were converted into parking areas using permeable paving to manage the stormwater runoff.
- **The Pietermaritzburg Anglican Cathedral –** the parking area was upgraded making use of permeable paving to manage the stormwater runoff.

Permeable paving systems can manage stormwater without the need to install catchpits and stormwater pipes. Sand, silt and other fine material have a destructive effect on the drainage capacity and detention volume of a permeable paving system however and should be carefully controlled.

Green roofs

Green roofs are vegetated roofs which act as excellent source controls. They are relatively easy to retrofit onto many commercial buildings in high density areas where other SuDS options would be inappropriate. Two interesting retrofit projects in Cape Town (DEADP Green Roof) and eThekwini (Green Roof Pilot Project) have been undertaken in South Africa.

The case studies highlighted the fact that people are generally drawn to well vegetated and pleasant environments as provided by green roofs. There is however a need for further research into the selection of plant types for the different regions of South Africa.

SuDS treatment trains

SuDS options should not be isolated but should be connected to form a treatment train in order to increase the resilience of the system. Two new developments in South Africa, Cotswold Downs and Hawaan forest estate, have implemented SuDS treatment trains and present interesting case studies.

The Cotswold Downs Golf Estate is situated between Hillcrest and Waterfall on the western outskirts of eThekwini. Although the development was modelled on SuDS principles from the outset, the consultants had not initially considered source controls for private properties within the development. The developers then revised and issued a second stormwater management plan focusing specifically on the provision of these type of SuDS.

Hawaan Forest Estate is an upmarket residential development, situated to the north of Stratton-on-Sea in eThekwini. Rain falling on the estate is initially detained in source controls such as roof gardens and soakaways which ‘polish’ and attenuate it before the runoff is directed over lawn into adjoining vegetated swales. The swales link to fourteen detention ponds distributed around the lower-lying eastern side of the estate and showcased by an ‘ornamental’ pond at the entrance

A number of lessons were learnt through these two case studies, including: that a SuDS approach has the potential to enhance the investment potential of a development; but operation and maintenance requires expertise which may be expensive.

Century City wetlands

First conceptualised in 1995, the last decade has seen Century City established as an upmarket development with the largest shopping centre in the Southern Hemisphere and containing Cape Town's only theme park. Current land use zoning includes commercial and residential uses supported by large corridors of office park buildings. Century City offered one of the most integrated systems to be reviewed, with the longest management history, and thus provided an ideal case study.

This system collects stormwater runoff from Century City and neighbouring Summer Greens developments, and channels it into the adjoining Tygerhof detention pond. The Wingfield outfall, located at the north-eastern end of Century City's bounds, is the stormwater outfall for the development.

A number of lessons were learnt through this case study; most importantly that the use of treated sewage effluent to supplement water in the wetland during dry periods needs to be carefully considered and monitored; and that a wetland system of this magnitude requires on-going maintenance and monitoring.

Conclusions and recommendations for future research

Conventional stormwater management focuses largely on quantity (flow) management by collecting runoff and channeling it to the closest watercourse. This has resulted in the erosion of natural channels and pollution resulting in environmental degradation. SuDS offers an alternative approach through designing for water quantity management, water quality treatment, enhanced amenity, and the maintenance of biodiversity. The approach has been widely adopted overseas, however it was clear from the national workshops that there is still some degree of scepticism as to its effectiveness in South Africa.

During the course of this study several areas for further research were identified, including: *inter alia*; the need to determine local SuDS maintenance requirements; the development of technical decision support systems (DSSs) for South African conditions; the need to undertake long term monitoring SuDS systems in South African conditions; and the need to promote the results of this project to smaller municipalities through a series of workshops.

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Glossary of Terms

The definitions below refer to the use of terms in these guidelines only and care should be taken when applying these definitions outside of these guidelines.

Abstraction here refers to the portion of rainfall that does not contribute to runoff through such processes as: interception, infiltration and storage in local depressions.

Absorption here refers to the taking up of one substance into the body of another, e.g. rainwater taken up into a plant.

Aerobic is the state requiring or allowing the presence of free essential oxygen.

Anaerobic is the absence of free elemental oxygen, or a state not requiring or damaged by the absence of free elemental oxygen.

Annual probability of exceedance is the statistical probability of a flood or rainfall event of a given magnitude being exceeded in any given year.

Aquifer is a porous, water-logged sub-surface geological formation. The description is generally restricted to media capable of yielding a substantial supply of water.

Attenuation means the reduction of peak stormwater flow.

Berm is a ridge designed to reduce erosion.

Bio-degradation here refers to the degradation of organic pollutants in stormwater runoff by microbes.

Bio-retention area here refers to a depressed landscaped area that collects stormwater runoff and infiltrates it into the soil below through the root zone thus prompting pollutant removal.

Block paver here is a precast concrete or clay brick sized flexible modular unit.

Brown-field here refers to a site that is or was occupied by a permanent structure which is now being considered for redevelopment.

Buffer strip here refers to a vegetated area ordinarily situated on gently sloping ground designed to filter out insoluble pollutants in runoff. It is also known as a filter strip.

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.

Channel Protection Volume (*CPV*) refers to the volume and rate of flow required for management to reduce the potential for degradation in natural channels. It is usually achieved through the detention of runoff onsite. The critical storm event typically has a recurrence interval (RI) of around 2 years.

Check dam is a low weir or dam that lies across a drainage channel to retard or re-route flow from a channel, ditch or canal for the purpose of erosion or scour reduction.

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.

Confined aquifer is an aquifer which is enclosed by formations that are substantially less permeable.

Contamination here refers to the introduction of microorganisms, factory produced chemicals or wastewater in concentrations that render water unsuitable for most uses.

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

Critical duration is the length of rainfall event that typically results in the greatest rate of flow, flood volume or flood zone level at a specified location.

Degradation here refers to the general and progressive alteration of stream or channel profiles due to long-term periods of water-induced erosion / scour.

Depression storage refers to precipitation stored in surface depressions.

Design probability of exceedance is the selected probability of exceedance of a particular event for the design of a drainage system or a component thereof.

Design period here is either the expected useful lifespan of a structure or asset, or sometimes the amortisation period if loans have been procured to finance its construction.

Design storm encompasses the properties of a selected storm which may include the depth, spread and duration of the rainfall as well as variations in rainfall intensity in space and time over the catchment area for the purposes of sizing infrastructure.

Detention pond here refers to a pond that is normally dry except following large storm events when it temporarily stores stormwater to attenuate flows. It may also allow infiltration of stormwater into the ground.

Development here refers to any man-made change to property including, but not limited to, the construction or upgrading of buildings or other structures, paving, municipal services, etc.

Don't Do Damage (D^3) here refers to the importance of ensuring that extreme storm events does not cause significant damage to property and pose significant risks to life.

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.

Drainage area is that part of a catchment that contributes to the runoff at a specified point.

Drainage corridor refers to the area usually extending on either side of the centreline of a watercourse along its longitudinal length but also including: vleis, wetlands, dams or lakes that can be linked to the conveyance of runoff.

Drainage system refers to the network of channels, drains, hydraulic control structures, levees, and pumping mechanisms that drain land or protect it from potential flooding.

Drawdown is the lowering of the surface level of a water body as a result of the withdrawal of water, most commonly in the case of groundwater tables, ponds or wells.

Dry pond is a detention pond that remains dry during dry weather flow conditions.

Dry weather flow means flow occurring in a water course not attributable to a storm rainfall event. Dry weather flows do not fluctuate rapidly.

Effluent here refers to wastewater that flows from a process or confined space that has been partially or completely treated.

Evapotranspiration means the evaporation from all water, soil, snow, ice, vegetation and other surfaces plus transpiration of moisture from the surface membranes of leaves and other plant surfaces.

Event probability is the probability of a particular threshold being equalled or exceeded by a selected rainfall event.

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

Filtration, also referred to as bio-filtration, means the filtering out 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.

Floodplain means the area susceptible to inundation by floods.

Floodplain fringe is that area in a river defined as being below the level reached by the Regional Maximum Flood (RMF) or Probable Maximum Flood (PMF) and above the level reached by normal flow.

Flood zone or floodway means the area inundated by the Regional Maximum Flood (RMF) or Probable Maximum Flood (PMF).

Flow Control (minor storms) (FC_m) here refers to the reduction of peak storm flow rate (m^3/s) to the equivalent of pre-development scenario. This is typically for storm events with a recurrence interval of between 2 and 10 years.

Flow Control (FC_D) here refers to the reduction of peak storm flow rate (m^3/s) to the equivalent of the pre-development situation – or accepted alternative – while simultaneously ensuring that risks to property and human life are mitigated. This is typically for storm events with a recurrence interval greater than 10 years.

Freeboard means the vertical distance from the water surface to the top of a confining structure, usually a wall and/or gate.

Gabion is a rectangular shaped steel wire basket that is generally filled with rock for embankment protection and flood control.

Geotextile is a textile or plastic fabric designed to separate different fill materials. It is normally permeable.

Green-field here 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.

Gross pollutants are waste items generally larger than 10 mm in diameter and typically include: plastics, cardboard packaging, metals, bottles and paper products.

Hydrograph is a plot of discharge or runoff relative to time.

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.

Hyetograph is a plot of rainfall relative to time.

Hydraulic roughness is a composite of the physical characteristics that influence the flow of water across the ground, whether natural or channelized.

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 here refers to the process of penetration of rainwater into the ground.

Infiltration device is a SuDS element designed to aid the infiltration of surface water into the ground.

Infiltration trench is a trench that is usually filled with granular material designed to promote infiltration of surface water to the ground.

Interception refers to precipitation stored on vegetation as opposed to rain stored in surface depressions (termed depression storage).

Lag time is defined as the time from the centroid of the excess rainfall to the peak of the associated runoff hydrograph.

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

Major drainage system is a stormwater drainage system which caters for severe, infrequent storm events, to prevent fatalities and minimise damage to property.

Minor drainage system is a stormwater drainage system which caters for frequent storms of a minor nature, to minimise inconveniences.

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

Non-structural measures here refer to planning, institutional and pollution prevention practices designed to prevent or minimise pollutants from entering stormwater runoff and/or reduce the volume of stormwater requiring management.

Overland flood escape route is an area over which stormwater in excess of the capacity of a stormwater system will flow to safeguard property from flooding.

Perennial stream is a watercourse that flows continuously.

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

Peak discharge (also known as 'peak flow') is the maximum rate of flow of water passing a given point during or immediately after a rainfall event.

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

Polish here refers to the additional treatment of runoff by any physical or biological process.

Porous asphalt is an asphalt surface that is pervious with open voids to allow water to pass through.

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

Rainfall excess is the additional water that produces runoff after interception storage, depression storage and infiltration have been satisfied.

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

Receiving waters are natural or man-made aquatic systems which receive stormwater runoff, e.g. watercourses, wetlands, canals, estuaries, groundwater and coastal areas.

Recharge Volume (*ReV*) is the proportion of the Water Quality Volume (*WQV)* that needs to be infiltrated on site to make up for the reduction of natural infiltration.

Recurrence interval (RI) or return period is the average interval between events exceeding a stated benchmark. The recurrence interval is usually expressed in years and is the reciprocal of the annual probability – that is, the event having an annual probability of occurrence of 2% (0.02) has a recurrence interval of 50 years. This does not imply that such an event will occur after every 50 years, or even that there will necessarily be one such event in every 50 years, but rather that over a very long period (e.g. 1000 years), assuming no climate change, there will be approximately 20 events of greater magnitude (1000/20 = 50 years). See Return period.

Retention pond is a pond-like structure where runoff is retained for a sufficient time to allow settlement and possibly biological treatment of some pollutants.

Retrofitting here 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.

Return period is the average time interval of hydrological event occurences of a given or greater magnitude. The interval is normally expressed in years. See Recurrence Interval.

Riparian refers to anything adjoining a watercourse or other water body.

Riprap refers to stone or blocks which are intentionally placed along the embankment of watercourses to minimise the potential for erosion.

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

Scour here refers to the movement of solid material due to the forces of flowing water.

Sedimentation is the deposition of soil particles that have been carried by flowing waters, typically during flood peaks as a consequence of a decrease in the velocity of flow below the minimum transportation velocity.

Sheet flow is runoff over a relatively flat or flattened surface. It has no defined channel.

Soakaway is a subsurface structure that is designed to promote infiltration into the ground.

Source controls are non-structural or structural best management practices to minimise the generation of excessive strormwater runoff and/or pollution of stormwater at or near the source.

Spillway is a waterway adjoining ponding areas or other hydraulic structures used for the routing of excess water.

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

Stormwater attenuation pond is a facility which temporarily stores excess stormwater runoff with the intention of reducing the flood peak.

Stormwater outfall is the point at which runoff discharges from a conduit.

Stormwater runoff refers to the portion of rainfall which flows to the surface drainage system.

Stormwater system is constituted by both constructed and natural facilities including: stormwater pipes, canals, culverts, overland escape routes, ‘vleis’, wetlands, dams, lakes, and other watercourses, whether over or under public or privately owned land, used or required for the management, collection, conveyance, temporary storage, control, monitoring, treatment, use and disposal of stormwater.

Structural measures/controls are permanent engineered devices implemented to control, treat or prevent stormwater pollution and/or reduce the volume of stormwater that requires management.

Sub-drain is a porous conduit that is installed below the ground surface to manage ground-water flows thereby mitigating potential damage to property.

Sub-surface runoff is the flow derived from water infiltrating the soil and flowing laterally in the upper soil strata. It usually reaches the receiving streams or bodies of water fairly soon after a rainfall event without joining the main body of groundwater.

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.

Sustainable development means "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Bruntland *et al.,* 1986).

Swale is a shallow vegetated channel designed to convey stormwater, but may also permit infiltration. The vegetation assists in filtering particulate matter.

Time of concentration is the time required for water to flow from the most hydraulically remote point of the basin to the point/location of analysis.

Treatment train is a combination of different methods implemented in sequence or concurrently to achieve best management of stormwater. These methods include both structural and non-structural measures.

Volatilisation is the conversion of stormwater runoff compounds to gas or vapour typically as a result of heat, chemical reaction, a reduction of pressure or a combination of these.

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.

Watercourse edge means the top of a discernable bank or canal in the case of natural and constructed watercourses respectively. Where an edge is not readily discernable, the extremity of the area susceptible to inundation by the 1:2 year storm is often deemed the watercourse edge.

Watershed is the upper boundary of a specified catchment area for rainfall that contributes to a given drainage area.

Water pollution incident means an occurrence that has the potential of prejudicing the quality of water in the stormwater management system or threatening public health or safety.

Water quality volume (*WQV*) is the design volume of runoff which requires water quality treatment in order to reduce/remove a specified percentage of pollutants.

Water table is the upper most level of the zone of saturation below the Earth's surface, except where this surface is formed by an impermeable body.

Weir is a relatively small dam-type structure across a waterway used to divert flow, reduce erosion and/or measure flow volumes.

Wetland refers to any land translational between terrestrial and aquatic systems where the water table is usually at or near the surface, or is periodically covered with shallow water, and which in normal circumstances supports or would support vegetation typically adapted to life in saturated soil. This includes water bodies such as lakes, salt marshes, coastal lakes, estuaries, marshes, swamps, ‘vleis’, pools, ponds, pans and artificial impoundments.

Whole Life Cycle Cost refers to the present day value of the total costs of a structure throughout its likely operating life.

List of Acronyms

ASCE	American Society of Civil Engineers
Aus	Australia
BCA	Benefit Cost Analysis
CBD	Central Business District
CCA	Capital Cost Analysis
CoCT	City of Cape Town
CPAF	Cost Price Adjustment Factor
CPI	Consumer Price Index
D^3	Don’t Do Damage
DAC	Damage Avoidance Cost
DEADP	Department of Environmental Affairs and Planning
DoCGTA	Department of Cooperative Governance and Traditional Affairs
DPLG	Department of Provincial and Local Government
EGS	Ecosystem Goods & Services
EU	European Union
EUL	Expected Useful Life
FC_D	Flow Control (Don’t Do Damage)
FC_M	Flow Control (minor storms)
GIS	Geographic Information System
LCCA	Life Cycle Cost Analysis
LID	Low Impact Development
P&G	Preliminary & General
PMF	Probable Maximum Flood
ReV	Recharge Volume
RI	Recurrence Interval
RMF	Regional Maximum Flood
SEM	SuDS Economic Model
SuDS	Sustainable Drainage Systems
TN	Total Nitrogen
TP	Total Phosphorus

TSS	Total Suspended Solids
UK	United Kingdom
USA	United States of America
USEPA	United States Environmental Protection Agency
WQV	Water Quality Volume
WTP	Willingness To Pay

1. Introduction

Currently, stormwater planning and design in the urban areas of South Africa focuses on collecting runoff and channelling it to the closest watercourse – frequently having a significant impact on the environment through the resulting erosion, siltation and pollution. Whilst some local authorities have gone to considerable lengths to reduce runoff peaks through the use of retention and detention ponds, very little attempt has been made to improve stormwater quality and almost no attempt has been made to treat stormwater as a resource. Indeed, local authorities frequently consider stormwater management together with road maintenance as though it was not part of water services at all.

Internationally numerous alternatives to the traditional stormwater management approach have in recent years been developed to manage the quantity and quality impacts associated with urban runoff – generally by dealing with stormwater as close to its source as possible. Various terms have been applied to these alternative approaches including *inter alia*, Best Management Practices (BMPs), Low Impact Development (LID) and Sustainable Drainage Systems (SuDS). Increasingly, however, it has become obvious that stormwater is but one part of the urban water cycle and should be treated as such. Furthermore, the management of stormwater needs to be integrated into urban design so that stormwater can be transformed from a waste to be disposed of as quickly as possible into an asset that can enhance the urban environment and increase water security. The integration of the entire urban water cycle – including stormwater – with urban design is increasingly being called Water Sensitive Urban Design (WSUD) in line with Australian practice.

In South Africa it is convenient to regard SuDS as the stormwater management component of WSUD. SuDS attempts to manage surface water drainage systems holistically in line with the ideals of sustainable development by mimicking the natural hydrological cycle, often through a number of sequential interventions in the form of a "treatment train". To this end, the key objectives of the SuDS approach are the effective management of stormwater runoff quantity, quality, associated amenity and biodiversity of the urban drainage system. Much of the work on SuDS has recently been summarised in documents such as: *Sustainability in Urban Storm Drainage* (Stahre, 2006); *Australian Runoff Quality: A Guide to Water Sensitive Urban Design* (Engineers Australia, 2006); and *The SUDS Manual* from UK CIRIA, as well as the associated construction manual (Woods-Ballard *et al.*, 2006). It is however recognised that all of this work has been carried out in affluent countries (Sweden, Australia and the UK respectively), often under quite different climatic and economic conditions to South Africa. Whilst these documents provide an excellent starting point for this research, and in particular the Australian document owing to similarities in the geography between Australia and South Africa, there is still a need for research on the specific application of these technologies to local conditions. In developing countries such as South Africa, a far larger proportion of stormwater runoff in urban areas emanates from low-income areas or areas that are poorly served by reliable sanitation systems. Such runoff contains much higher levels of sewage pollution and in particular carries an increased risk of spreading disease-causing organisms. This should be kept in mind when such systems are designed.

SuDS offer an opportunity to promote natural drainage systems through the use of a number of key unit processes. These unit processes are linked to elementary focal points of the binding philosophy of SuDS, namely:

i) Quantity – e.g. rainwater harvesting, infiltration, detention, conveyance and retention of stormwater runoff to protect receiving waters;

ii) Quality – e.g. reducing removal of sediment by reducing flow velocities; bio-filtration of runoff pollutants; adsorption, biodegradation, volatilisation, and the breakdown of organic pollutants in stormwater runoff;

iii) Amenity – e.g. protecting, shaping and creating open spaces and enhancing the visual appearances of the specified systems; enhancing physical, mental and social well-being as well as improving cultural, educational, aesthetic and spiritual experiences through interactions with nature;

iv) Biodiversity – ensuring that habitats remain undisturbed to preserve both their diversity as well as that of the creatures they support; and

v) Ecosystem services – the removal and reduction of pollutants; the retention of soil to protect against damage from erosion and siltation processes; the reduction of the likelihood of and vulnerability to damage from extreme events; the decomposition of waste compounds and the recycling of associated nutrients.

This study set out to identify and develop new and appropriate, practical and affordable alternative stormwater technology for South Africa. It has achieved this by: reviewing current overseas SuDS practice; evaluating the limited examples of SuDS implementation in South Africa; developing what is hoped to be practical and user-friendly guidelines to guide professionals in the implementation of SuDS in South Africa; and making practical information available on a dedicated website, www.wsud.co.za. Due to time and resource constraints it was not possible to undertake a detailed assessment of the different sites where SuDS had been implemented in South Africa, most of which have only recently been implemented with no history of in-service experience to draw on.

This report is set out as follows: **Chapter 2** presents a review of the literature on SuDS and presents key legislation impacting on stormwater management; **Chapter 3** describes how the research was carried out; **Chapter 4** summarises examples of SuDS implementation in South Africa; and **Chapter 5** makes some conclusions and recommendations for further research.

2. Literature review

The urban landscape is changing more rapidly in the 21st Century than ever before. According to Martine *et al.* (2008), many scholars argue that the world is experiencing a 'second wave of urbanisation' which is having significant effects on the shaping of cities in the global South and the environmental challenges they face. This 'second wave' of urbanisation is defined as the period from 1950 until present, in contrast to the 'first wave' of urbanisation that took place in Europe and North America between 1750 and 1950 (Pieterse, 2008). In South Africa, the urban population roughly doubled between 1950 and 2004 to constitute approximately 62% of the total population (United Nations, 2005). This has had a profound effect on stormwater drainage (Lems, 2008; Beall & Fox, 2009; Todes, 2009). Historically stormwater drainage has prioritised quantity (flow) management with little or no emphasis on the preservation of the environment (Parkinson *et al.*, 2007). This is no longer acceptable; there is a need to move to a more sustainable approach. This chapter looks at the link between sustainability and urban drainage, gives a short history of stormwater management, presents the SuDS paradigm and finishes off with a discussion on the economics of stormwater systems.

2.1 Sustainability and urban drainage

'Sustainability' and 'sustainable development' have become recognised 'buzzwords' in the 21st Century, especially in the urban infrastructure design and management sector. These are often misconceived as 'end states' and perceived as rigid project targets that are hoped to be achieved in an allotted time-frame (Hjorth & Bagheri, 2006). However, sustainable development is neither the state of the system nor an attainable target, but rather an on-going process which inter-relates aspects of economy, environment, society and other technicalities (Donovan & Naji, 2003; Hjorth & Bagheri, 2006). Hjorth & Bagheri (2006) state that *"sustainable development must, then, be seen as an unending process defined neither by fixed goals nor the specific means of achieving them, but by an approach to create change."*

O'Regan & Moles (1997) suggest that conventional drainage practices have failed to manage the complexities of environmental systems largely because decision-makers often fail to understand the underlying structure of urban systems. The design and management of urban drainage infrastructure in South Africa require a shift from the current fragmented 'sectoral' approach – where drains are seen as merely a way of reducing flood risk and protecting the road surfaces – to a more 'holistic' approach where stormwater management is seen as merely one component of a greater whole. According to Hjorth & Bagheri (2006) and Senge *et al.* (2000), such a shift requires the yielding of linear and mechanistic thinking to non-linear, organic thinking – or 'systems thinking'. This will require management to understand the relationships between the components of urban drainage systems, as opposed to merely the components in isolation (Field & Sullivan, 2003; Hjorth & Bagheri, 2006). This is best achieved through the formation of interdisciplinary partnerships (Ellis *et al.*, 2006; Woods-Ballard *et al.*, 2007).

2.2 A short history of stormwater management

Debo & Reese (2003) describe a stormwater management paradigm as follows:

> "*We each have a stormwater management paradigm. A paradigm is what we think is true and right about a certain subject. It is the grid through which we put all information and input into a subject. In fact, it is everything we think is true about something. Whether our paradigm is, in fact, true and effective, is not the point. We believe it is. And, we only reluctantly change our ways and agree to agree with someone else's paradigm. Knowing your own paradigm is the first step in understanding stormwater management. The second is seeing how far you have to go, and fearlessly setting out.*"

They then go on to suggest that stormwater management has evolved through nine paradigms to the present. These may be summarised – with additional references – as follows:

i) ***"Run it in ditches"*** – at the outset of the 'first wave' of urbanisation commencing at the end of the 18th Century, rural practices were prevalent in urban areas which led to the first stormwater paradigm – everything of liquid form and any objects generally transported by those liquids were designed to run into ditches similar to those on a farm or small-holding.

ii) ***"Run it in pipes"*** – piped infrastructure was increasingly used from the middle of the 19th Century. Liquid waste from streets, flush toilets and kitchens was piped to the nearest watercourse (Lems, 2008).

iii) ***"Run it in stormwater pipes"*** – this was the first of many 'urban' based stormwater design paradigms which came into existence after the Second World War. At this time, the Rational Method became the design method of choice (Kuichling, 1889; Thompson, 2007).

iv) ***"Keep it from stormwater pipes"*** **–** the use of detention ponds became prevalent from the early 1970s to attenuate high flood peaks. The effective implementation of detention ponds however requires: the availability of hydrological criteria, volume and peak flow calculations, geographic assessments downstream, realistic hydrograph routing, sufficient space, detailed plan reviews, health and safety certification, as-built certification, long-term maintenance agreements, and strict environmental enforcement. These are however, complex and time-consuming and are rarely met (Novotny & Brown, 2007).

v) ***"Do not allow flooding"*** – The first mainframe hydraulics and hydrology models were geared for use on computers in the late 1970s and became commonly available in the 1980s. This software became increasingly easy to use and was relatively effective for large scale stormwater quantity master-planning with a focus on the prevention of flooding.

vi) ***"Do not pollute" –*** From the 1980's stormwater software which placed more emphasis on pollution control became available (Water Research Commission, 1999a,b).

vii) ***"It is the ecology"*** – Programmes to improve river health became popular from early 1990 (Water Research Commission, 1999b). This concept utilised macro-invertebrates and fish in the receiving waters as indicators of the quality of stormwater runoff.

viii) ***"Water is Watershed"*** – In the USA a recent organisational convergence has seen federal agencies reorganised to be watershed-focused. Local governments have begun to operate in terms of holistic watershed planning. A critical setback to this approach is that it is too complex for most citizens to understand and relate to.

ix) ***"Green and bear it"*** – there has been growing interest in the promotion of sustainable development amongst governments and local municipalities throughout the world – and this includes the control of stormwater runoff (Ellis *et al.*, 2006). Novotny & Brown (2007) comment, *"A new paradigm is emerging from the successes and failures of efforts to control pollution that offers the promise of adequate amounts of clean water for all beneficial uses. Urban waterways are the historic core of our cities' economies and have the potential to be rich sources of biological diversity, contributing to the quality, economy and health of urban life."* Brown (2007) suggests that urban elements such as 'environment' and 'energy' are moving speedily ahead of elements such as 'mobility' and 'economic growth' in respect of their importance to the global public.

Until recently South African authorities have been mainly concerned with the management of flood risk, however an increasing numbers of local authorities are adopting more advanced stormwater management approaches with Cape Town arguably the most advanced with their *Management of Stormwater Impacts Policy* (CoCT, 2009).

This document promotes Sustainable Drainage Systems (SuDS) as a holistic approach to urban drainage synonymous with the stormwater management component of Water Sensitive Urban Design (WSUD) in Australia, and Low-Impact Development (LID) in the USA (SEMCOG, 2008; Woods-Ballard *et al.*, 2007; MBWCP, 2006). This paradigm focuses on the management of stormwater runoff at or near the source (Furumai, 2009; Claytor & Flicker, 2005).

2.3 The SuDS paradigm

2.3.1 The impacts of urbanisation

> "*The water cycle is one of the most critical processes to supporting life on this planet, and fresh waters are central to all aspects of our lives. Historically, urbanisation has led to the loss and degradation of wetlands, rivers and groundwater resources through pollution, resource depletion and construction within natural flood plains*" (Woods-Ballard, *et al*. 2007).

Urban development typically reduces the natural permeability characteristics of land by replacing free draining surfaces with impermeable surfaces such as roofs, roads and paved areas that are drained by 'hard' infrastructure (i.e. pipes and lined channels) – here referred to as 'conventional drainage systems' (ASLA, 2008; Armitage, 2009). Development also results in the removal of vegetation, often indigenous, which removes many of the natural stormwater buffering processes and reduces evapotranspiration. Furthermore, subsoil strata are usually compacted during development altering the local infiltration characteristics of the soil media (Wilson *et al.*, 2004; Maine Department of Environmental Protection, 2006). Conventional drainage systems tend to neglect water quality management, water resources management, and the vibrancy of biomass and biodiversity (CSIR, 2000a,b; Woods-Ballard *et al.*, 2007). The impact of development and the associated change in stormwater hydrographs are depicted in Figures 2-1 and 2-2.

Under pre-development conditions there is generally minimal runoff. Precipitation is mainly infiltrated, evaporated and/or transpired. Under post-development conditions, however, there is generally a significant increase of runoff as a result of hardened surfaces and fast conveyance infrastructure. This significantly increases the likelihood of flooding and channel erosion downstream. In addition less stormwater infiltration into the soil strata reduces aquifer recharge and decreases baseflow discharges into receiving watercourses (Minton, 2002; Taylor, 2003; Field & Sullivan, 2003).

2.3.2 Overview of Sustainable Drainage Systems (SuDS)

Sustainable Drainage Systems (SuDS) offer an alternative approach to conventional drainage practices in line with the ideals of sustainable development (Wilson *et al.*, 2004; Woods-Ballard *et al.*, 2007). They attempt to mimic the natural hydrological cycle within urban environments by passing the stormwater through a sequence of interventions – a 'treatment train' – to manage urban stormwater runoff at its source, on a local scale, or region-wide in order to reduce the likelihood of flash flooding, improve water quality and enhance amenity and promote biodiversity (Semple, 2004; Melbourne Water, 2005; SEMCOG, 2008). Wilson *et al.* (2004) illustrate the inter-relationship between water quality, water quantity and amenity & diversity in the form of a Venn diagram (Figure 2-3).

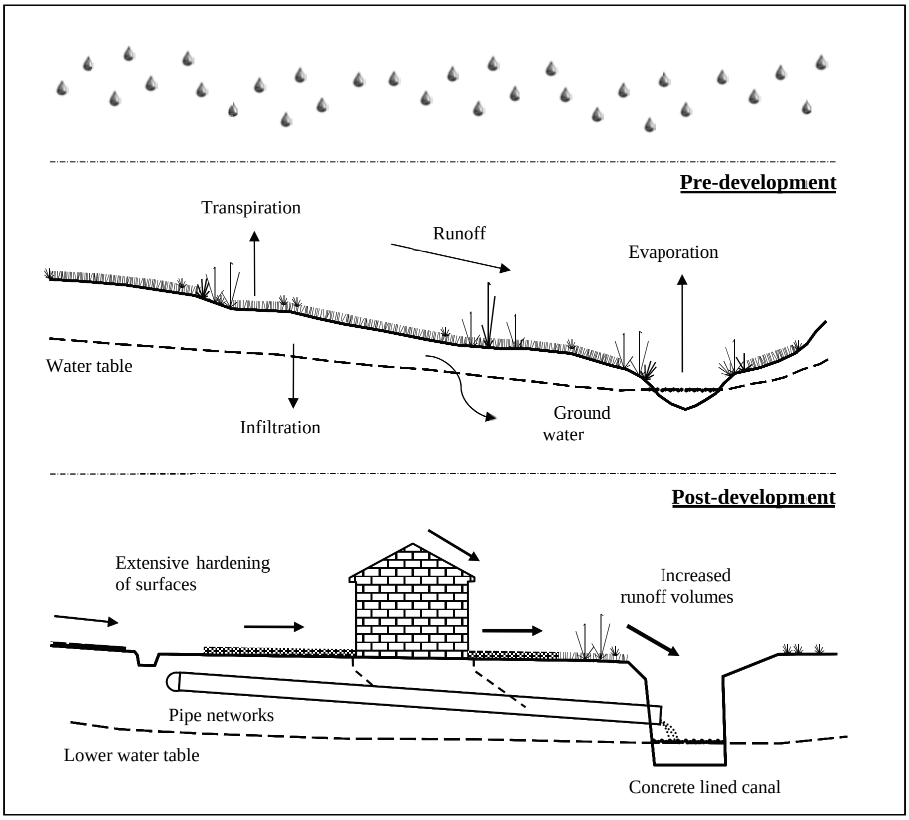

Figure 2-1: General pre- and post-development runoff characteristics
(Woods-Ballard *et al.*, 2007; Van Wieringen, 2010)

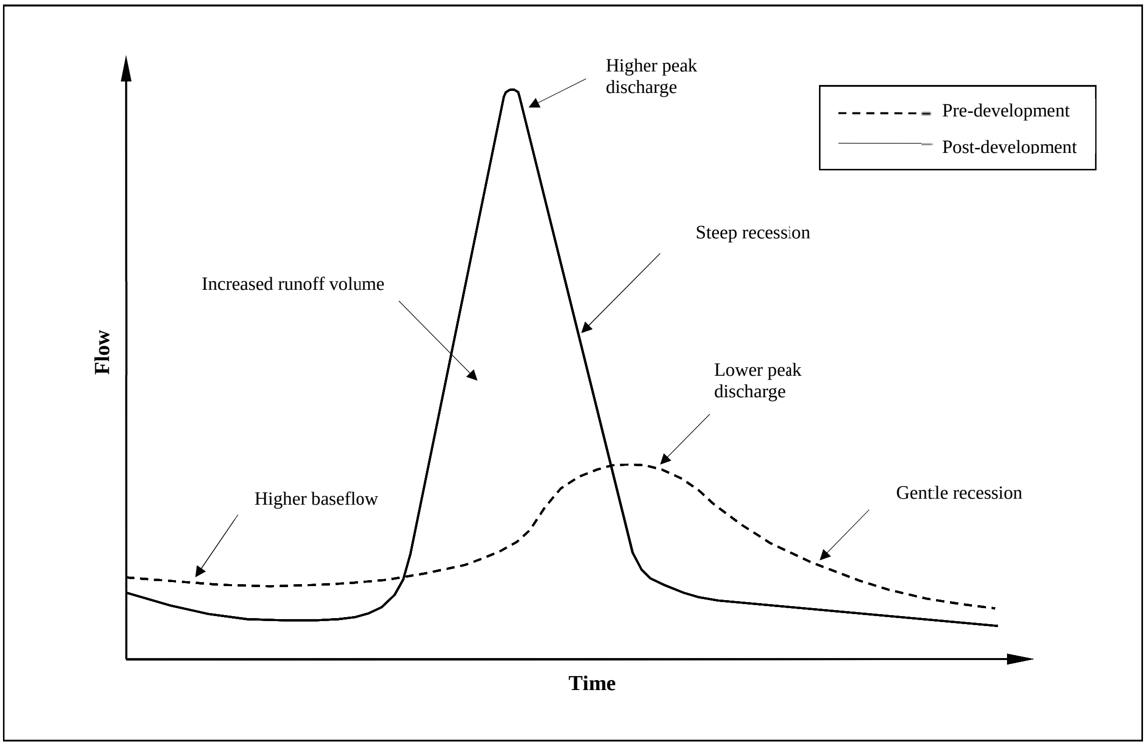

Figure 2-2: General pre- and post-development stormwater runoff hydrographs
(after Reed, 2000; Wilson *et al.*, 2004)

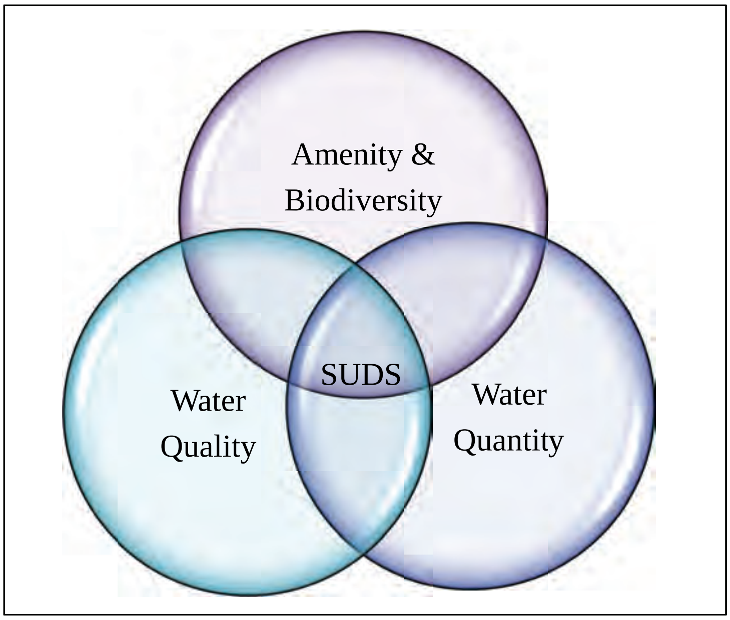

Figure 2-3: Relationship between elementary focal points of SuDS (Wilson *et al.*, 2004)

2.3.3 Overview of SuDS options

There are many different SuDS options that can be used to manage stormwater runoff on a specified site (Urban Water Technology Centre, 2009). It is unlikely that they will all be applicable and effective on any one site. Idaho Department of Environmental Quality (2005) and Taylor (2003) suggest that the selection of these drainage components should thus be guided by characteristics of the development. The following five basic selection criteria should be considered (Field & Sullivan, 2003; Woods-Ballard *et al.*, 2007):

i) Current and future land use characteristics;

ii) Site characteristics and utilisation requirements;

iii) Catchment characteristics;

iv) Stormwater runoff quantity and quality performance requirements;

v) Amenity; and

vi) Biodiversity

It is important to recognise that certain SuDS may be inappropriate in certain conditions found in South Africa. The advantages and limitations of each alternative system should be identified during the planning and design phases (Donovan & Naji, 2003; Melbourne Water Corporation, 1999). For example the use of vegetated systems with public access in high pollution catchments, or catchments where stormwater is contaminated with sewage such as informal settlements, will pose a public health risk. Also the creation of new permanent water bodies may have unintended consequences – such as providing areas for mosquitoes to breed. It is important to establish the variation in levels of both microbiological and chemical pollutants in a stormwater source before decisions are made on the most appropriate SuDS to install.

SuDS are not meant to be standalone interventions. For any given development, a number of SuDS options are usually grouped together in the form of a treatment or management train. A good SuDS treatment train has four components / stages, as discussed in the following sections.

2.3.3.1 Good house-keeping

While not always reflected in published treatment train descriptions, 'good-housekeeping', is a group of important preliminary activities which are effective SuDS options in their own right (Melbourne Water Corporation, 1999). They include various preventative measures in order to minimise pollution in the runoff (Taylor, 2003; Wilson *et al.*, 2004) such as: litter control; the removal of particulates from streets; the use of environmentally friendly soaps, fertilisers, herbicides, pesticides and fungicides; the management of construction sites to reduce sedimentation and soil erosion; and educating the public with respect to the use of detergents for washing cars (Wilson *et al.*, 2004).

2.3.3.2 Source controls

Source controls are used to manage stormwater runoff as close to its source as possible – generally within the boundaries of the property. Some examples are:

i) ***Green roofs*** – are vegetated roofs (Stahre, 2006; Wanielista *et al.*, 2008). *Sedum* (small flowering plants) is the most common plant species used for green roofs; however, other vegetation types can be used in a strategic manner to increase resilience during extreme climatic conditions. A survey conducted on the green roof established on the eThekwini Engineering Services building (Greenstone, 2010), as well as extensive international surveys, have indicated that green roofs are capable of absorbing light to moderate rainfall events with ease (Dallmer *et al.*, 2008; Stovin, 2009). The most common types of green roofs include: extensive green roofs, intensive green roofs (Figure 2-4), simple intensive green roofs, green walls, and blue roofs.

ii) **Stormwater collection and reuse** – also known as 'rainwater harvesting' (Figure 2-5) – refers to the temporary storage and successive reuse of rooftop and/or surface runoff (Melbourne Water Corporation, 1999). It aids in reducing stormwater flood peaks and provides extended detention (Parkinson & Mark, 2005; Scholz, 2006). It may be configured as either direct supply systems or gravity systems (Woods-Ballard *et al.*, 2007; Garcia Maldonado, 2009). In areas where the dry season is prolonged, the effect of removing significant volumes of runoff water from rivers by means of rainwater harvesting should be kept in mind. If rainwater harvesting is widespread, significantly less water will reach such rivers and the ecological reserve needed for their healthy functioning may be seriously impaired.

Figure 2-4: Intensive green roof, CBD, Cape Town

Figure 2-5: Rainwater harvesting tank, Selborne Estate, East London

iii) ***Soakaways* –** are excavated pits that are packed with course aggregate and other porous media and used to temporarily store stormwater runoff from a single property which is then infiltrated into the soil to recharge the groundwater (Stahre, 2006; Livingston & McCarron, 2008). They are effective in removing particulate and suspended stormwater runoff pollutants (Melbourne Water, 2005). Common technology derivatives of soakaways include: oil and grit separators, and modular plastic geocellular structures.

iv) ***Permeable pavements* –** are load-bearing, durable and pervious surfaces such as concrete block pavers (CBPs) laid on top of granular or stone base that can temporarily store stormwater runoff (Concrete Manufacturers Association, 2003). From there the runoff either infiltrates into the underlying strata or is drained through the use of permeable pipes (Taylor, 2003; Woods-Ballard, *et al.* 2007). Stored water can be collected, screened and reused for several non-potable, domestic purposes (Parkinson & Mark, 2005). Common technology derivatives include: gravel pavement systems, porous asphalt and concrete systems, and modular pavements.

2.3.3.3 Local controls

Local controls are used to manage stormwater runoff as a third ‘line of defence’ typically in public areas such as roadway reserves and parks. Some examples:

i) **Filter strips –** are grassed areas of land that are used to manage shallow overland stormwater runoff through infiltration. These grassed areas are densely vegetated and generally uniformly graded (Debo & Reese, 2003). Filter strips are most effective as pre-treatment options in treatment trains, especially to aid the stormwater management processes of bio-retention areas, infiltration trenches and swales (Melbourne Water Corporation, 1999). Filter strips can also be used to intercept and redirect stormwater runoff in order to spread it as sheet flow, thus attenuating flood peaks (Field & Sullivan, 2003; Melbourne Water, 2005). They are designed to use bio-filtration as a primary means of stormwater runoff pollutant removal.

ii) **Swales** – are shallow grass-lined channels with flat bases and sloped sides that typically remain dry between rainfall events (Mays, 2001; Parkinson & Mark, 2005). Alternative materials can be used to suit the on-site drainage characteristics (Woods-Ballard *et al.*, 2007). They serve as an alternative drainage option to roadside kerbs and gutters in low and medium density residential areas (Field & Sullivan, 2003; Jefferies, 2010). Swales use partial infiltration and bio-infiltration to remove pollutants in stormwater runoff. The most common types of swales include: enhanced dry swales, wet swales, and vegetated buffers.

iii) **Infiltration trenches** – are excavated trenches which are backfilled with rock or other relatively large granular material, and wrapped in geotextile (Hobart City Council, 2006). They are typically designed to receive stormwater runoff from adjoining residential properties and transportation links such as asphalt roads and footpaths (Debo & Reese, 2003; Taylor, 2003). They increase stormwater infiltration and groundwater recharge, which decreases the frequency of flooding (SEMCOG, 2008) and may remove as much as 90% of sediment, heavy-metals, coliform bacteria and organic matter for stormwater runoff (Field & Sullivan, 2003) (Figure 2-6).

iv) **Bio-retention areas** – also known as 'rain gardens' or 'bio-retention filters', are landscaped depressions used to manage stormwater runoff through several natural processes, such as filtration, adsorption, biological uptake and sedimentation (Debo & Reese, 2003). They typically reduce stormwater runoff quantities and rates, and improve the quality of stormwater discharging into downstream watercourses (Woods-Ballard *et al.*, 2007). Bio-retention areas normally incorporate a series of small stormwater management interventions such as grassed strips for infiltration, temporary ponding areas, sand beds, mulch layers and a wide variety of plant species (Endicott & Walker, 2003) (Figure 2-7).

Figure 2-6: Infiltration trench servicing a gated village

Figure 2-7: Bio-retention area underlying footbridge, Evergreen Retirement Village, Cape Town

v) **Sand filters –** also known as 'perimeter sand filters', usually comprise an underground sedimentation chamber and a filtration chamber through which stormwater runoff is temporarily stored before being percolated through a sand filter and then released to a receiving waterbody, e.g. a river, lake or wetland (Debo & Reese, 2003). Sand filters generally operate most effectively when serving impervious areas less than 8000 m^2, however large sand filters have the capacity to manage stormwater runoff from areas as large as 100,000 m^2 (Endicott & Walker, 2003).

2.3.3.4 Regional controls

Regional controls are used to manage stormwater runoff as a last 'line of defence'. They are generally large-scale interventions which are constructed on municipal land. Examples include:

i) **Detention ponds** – also known as 'detention basins', are relatively large depressions that temporarily store stormwater runoff in order to reduce the downstream flood peak. This is particularly useful in preventing downstream scour and soil erosion (Semple, 2004; MBWCP, 2006). They are usually unlined and vegetated, but lined ponds can be used if there are soil stability or land use issues (Melbourne Water Corporation, 1999; Jefferies, 2010). Some of the stormwater runoff may infiltrate into the underlying soil stratum in the case of unlined ponds (Field & Sullivan, 2003).

ii) **Retention ponds** – also known as 'retention basins' are formed by excavating below the natural ground water level and/or lining the base to retain stormwater runoff (Mays, 2001; Debo & Reese, 2003) (Figure 2-8). The maximum storage capacity of retention ponds is typically greater than their permanent pond volume which makes them effective in reducing downstream stormwater flood peaks (Field & Sullivan, 2003; NCDWQ, 2007). They use a combination of sedimentation, filtration, infiltration and biological uptake processes to remove pollutants from stormwater runoff (Woods-Ballard *et al.*, 2007). If the stormwater is polluted with sewage, such ponds may experience biofilm formation in the upper layers of the soil at the bottom over time, gradually reducing the absorption.

iii) **Constructed wetlands** – attempt to mimic the characteristics of natural wetlands through the use of marshy areas and aquatic-resilient plants (NCDWQ, 2007; Woods-Ballard *et al.*, 2007) (Figure 2-9). They can be aesthetically pleasing and provide a vibrant habitat for fish, birds, rare and endangered species, and other wildlife. They can be very effective in the removal of particulates and dissolved nutrients as well as noxious substances such as heavy metals (Debo & Reese, 2003). Meandering flows are ideal as they encourage extended detention time that typically increases the removal of pollutants (Melbourne Water Corporation, 1999). It should however be kept in mind that channelling polluted water through a pristine natural wetland can irreparably harm the wetland itself. Even lightly polluted stormwater can cause slow build-up of pollution in the wetland, leaving the functioning of constructed or natural wetlands impaired over time.

Figure 2-8: Retention pond, eThekwini

Figure 2-9: Densely-vegetated constructed wetland, eThekwini

2.3.4 SuDS treatment trains

The effectiveness of a SuDS system depends on the treatment train (Minton, 2002; Wilson *et al.*, 2004) where each successive intervention acts to further treat the stormwater runoff (Figure 2-10).

SuDS treatment trains prioritise water quality treatment for low flows, and attenuation and volume control for high flows. The number of elements and the scale of the treatment train components depend on (Woods-Ballard *et al.* 2007):

i) The sensitivity of the receiving watercourses and related environments;

ii) The size of the contributing catchments upstream;

iii) The composition of the stormwater – i.e. what pollutants are present in the stormwater, and their expected concentrations.

When designing a SuDS treatment train it is important to have a clear understanding of the catchment and what pollutants may be found in the catchment in order to manage risks to public health. This will have an impact on the types of SuDS options implemented, or in certain cases prevent the use of SuDS altogether. Table 2-1 highlights what pollutants may be found in stormwater. The potential risks of each pollutant, if present at a site, needs to be assessed. This is especially important in the case of pathogens where stormwater facilities are open to the general public (NWQMS, 2006).

SuDS treatment train options / components may be combined in any order, although they may be conveniently categorised into: good housekeeping, source controls, local controls and regional controls. Each SuDS option can be scaled to meet the drainage requirements of any specified site in a unique manner (Taylor, 2003; Semple, 2004; Urbanwater Technology Centre, 2009).

Wilson et al. (2004) suggest that the performance of treatment trains is typically proportional to the number of SuDS options utilised. This is because the treatment efficacy of a multi-component treatment train can be maximised to remove a wide range of pollutants by utilising a range of processes (Woods-Ballard et al., 2007). Furthermore, the greater the number of sequential options used, the lower the risk of system failure (Taylor, 2003).

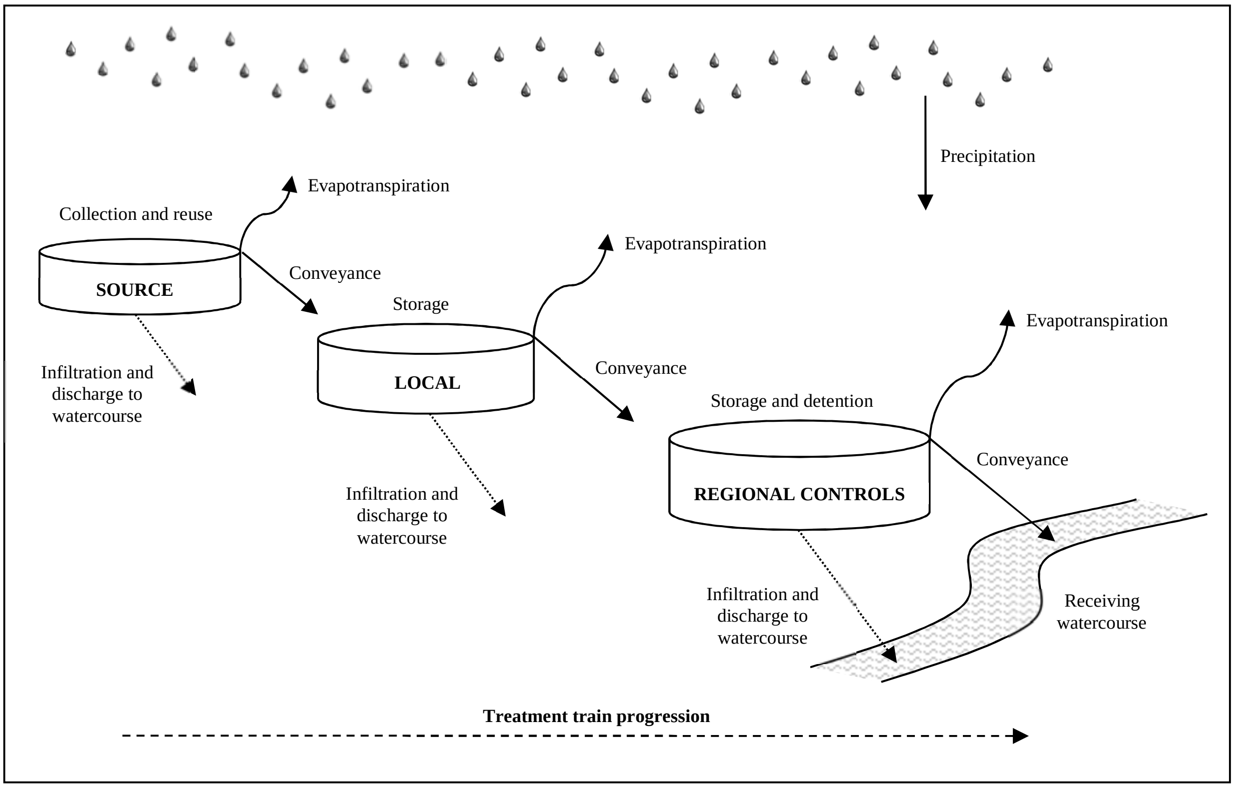

Figure 2-10: The SuDS treatment-train (Woods-Ballard *et al.*, 2007)

Three different treatment trains are presented in Figure 2-11 (Berwick, 2011). Assuming that all potentially meet the local pollutant removal criteria for a hypothetical catchment, it might be expected that Treatment Train 1 is the 'best' option as the lower level of complexity would generally translate into lower capital costs and a smaller land take, however:

- In Treatment Train 1, all the runoff with associated pollutants is piped directly into the wetland. This implies that all the suspended solids will collect in the wetland which will require frequent removal with consequent disturbance and risk to the functioning thereof.
- In Treatment Train 2, the swales convey the runoff to the wetland. During this process the swales will filter the runoff and remove a large portion of the sediment, lessening the quantity entering the wetland.
- In Treatment Train 3, the runoff is further detained in a dry detention pond before it is released to the wetland. This allows for almost all sediment to potentially settle out thus preventing it from entering into the wetland.

Table 2-1: Stormwater pollutants (Krypo, 2004; Minton, 2002; Opher & Freidler, 2010)

Pollutant Group	Pollutant	Source	Associated Land-use	Impacts
Nutrients	Nitrogen & Phosphorus	Fertilisers	Urban gardens/agriculture	Excessive nutrients result in eutrophication. They are commonly associated with algal plumes, reduced clarity resulting in decreased bio-diversity.
		Animal waste	Urban, residential	
		Organic matter	Urban, residential	
		Septic tanks	Urban, residential & rural	
Sediments	Suspended & settleable solids	Erosion of landscaping	Urban, commercial, residential, industrial	Increased turbidity, sedimentation, smothering of aquatic plant and animal life.
		Erosion of construction sites	Urban, commercial, residential, industrial	
Organic material	Plant litter	Landscaping	Urban, commercial, residential, industrial	Increased nutrients & sediment.
Pathogens	Bacteria, viruses and protozoa	Failing sewer/sewage systems Contaminated solid waste	Urban, commercial, residential, industrial	Public health risk. Contaminated recreational areas. Threat to downstream irrigation water and edible crops. Decreased economic value of natural recreational areas.
		Animal waste	Urban, residential	
Hydrocarbons	Oils & grease	Motor vehicle emissions	Roadways	
		Industrial processes & waste	Urban, industrial	
Metals	Lead, copper, zinc and others	Motor vehicle wear	Roadways	
		Industrial leaks	Urban, industrial	
		Construction materials	Urban, commercial, residential, industrial	
Toxic chemicals	Pesticides and herbicides	Agriculture	Rural, agriculture	
		Landscaping	Urban, commercial, residential	
Solids	Debris & rubbish	Littering	Urban, commercial, residential	Threat to wildlife. Aesthetic appeal decreased.
		Dumping	Urban, industrial	

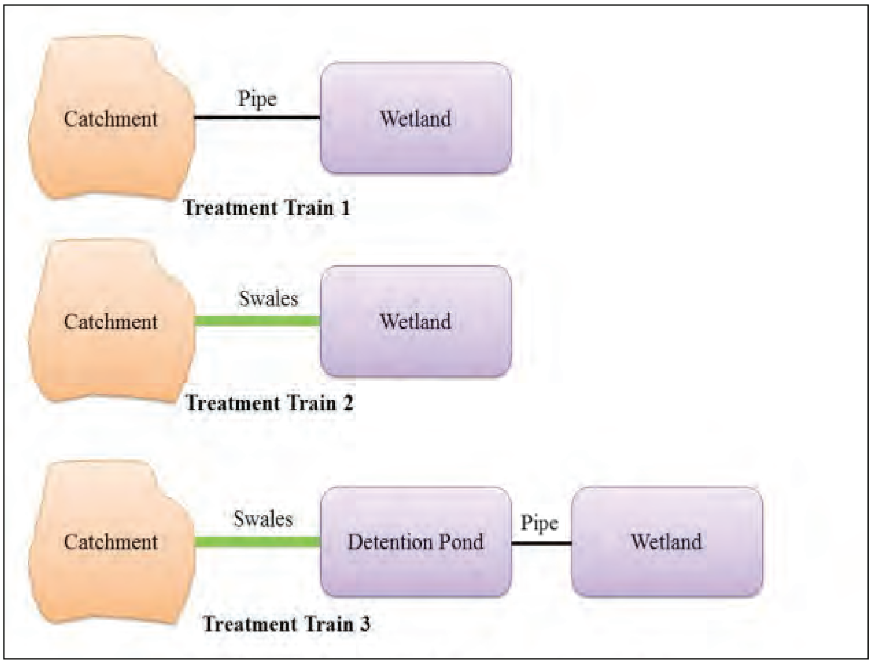

Figure 2-11: Three treatment trains (adapted from Berwick, 2010)

Seeing that it is generally more cost effective to remove sediments in dry rather than wet environments, both Treatment Trains 2 and 3 might well prove to be more cost effective than Treatment Train 1 in the long term as a consequence of reduced maintenance, an increased life span and better water treatment.

2.4 The economics of stormwater management

SuDS are relatively new to South Africa. As with many new technologies of this type there is a degree of scepticism about local applicability (CIWEM Conference 2005, 2005). Partly this is due to a concern about maintenance and associated costs for which there is a general lack of data worldwide (Taylor & Fletcher, 2006) and, furthermore, local conditions will influence costs. On the other hand, there are also 'hidden' externalised costs associated with conventional drainage systems which need to be taken into account. This section reviews the international experience with respect to SuDS and discusses the value of Ecosystem Goods and Services (EGS) which are provided by this approach.

2.4.1 International experience

SuDS technologies have been extensively implemented in a number of developed countries and various studies have been undertaken to assess the economic implications. A summary of some of the conclusions is presented in Table 2-2.

Table 2-2: Studies comparing SUDS and Conventional systems

Study	Conclusions on the relative costs between SuDS and conventional systems
Boubli *et al.*, 2003	"*Based on the above discussion it appears that a WSUD can be delivered on most projects without imposing a cost burden. In fact a balanced WSUD may be cost neutral on smaller projects but is likely to deliver increasing savings on larger projects.*"
Lloyd, 2004	"*Bio-filtration systems provide a 25% saving to the community compared to treating runoff conventionally at a downstream constructed wetland. Additionally research found 85% of homebuyers supported the introduction of this technology in their neighbourhoods.*"
Sidek *et al.*, 2004	The finding of the study was that MSMA (environmentally friendly drainage) was 5% less than that of conventional systems.
Coombes *et al.*, 2004	"*The benefits of WSUD source control approaches arise from reduced mains water use and reduced stormwater infrastructure…In addition, the case study demonstrates that use of WSUD source controls including rainwater tanks in new urban development's offers the economically most efficient infrastructure solution providing benefits to the community of up to $6B in the Lower Hunter Region and up to $5B in the Central Coast Region.*"
Narayanan & Pitt, 2006	In a comparison of conventional systems and grass swales system, grass swales appeared to cost approximately a fifth of the cost over the life cycle.
USEPA, 2007	"*The 17 case studies presented in this report show that LID practices can reduce project costs and improve environmental performance. In most cases, the case studies indicate that the use of LID practices can be both fiscally and environmentally beneficial to communities.*"
ECO NW, 2007	In a review of the economics of LID's in the USA, it generally found, with some notable exceptions that LID's were more economical.

Note that LID (Low Impact Development) and WSUD (Water Sensitive Urban Design) are broadly equivalent to SuDS in the USA and Australia respectively. Overall Table 2-2 appears to indicate that SuDS are usually, but not always, 5-25% more economical than conventional systems on the basis of Life Cycle Cost Analysis (LCCA). In some cases, conventional systems potentially cost twice that of the SuDS equivalent over the lifetime of the project. It is however important to identify 'who pays for what'. SuDS require on-going, regular maintenance so a relatively higher proportion of the LCCA cost is contained within this activity. It is also important to recognise that these studies are not a case of two identical sites being developed; rather they usually consider a hypothetical alternative to design actually being implemented. Consequently there is uncertainty in some of the contingency values which could make a difference of 10-30% either way. Furthermore the experience of both designers and contractors will influence the economics of a design (Lampe *et al.*, 2005) – which is of particular relevance in South Africa where there is little experience with SuDS.

A significant issue that is raised by some of the studies relates to the fairness of the comparison. For an example, the study by Narayanan & Pitt (2008) detailed alternative designs for a particular site – each one raising a significant concern:

i) The cost of maintenance of the conventional system was 'estimated' without details as to how this was determined; and

ii) The SuDS (LID) design made use of a 1700 ft (520 m) long by 50 ft (15 m) wide swale with natural buffers of 50 ft (15 m) on either side. No reputable guidelines would suggest that such a wide swale and associated buffer strips – 45 m in all – is reasonable under most circumstances. The large land-take would significantly reduce the amount of developable land and hence the income of the developer which was not accounted for. Swales are generally a ‘cheap’ SuDS option but the ‘exploitative’ use of swales in this design suggests an option more economical than likely to be achieved in practice.

The discount rate is also an issue that is seldom considered in any of the studies. Varying the discount rate alters the economic viability of each alternative (Sidek *et al.*,2004). The credibility of some of the international studies is thus questionable. For this reason, unless independent verification is possible, these sorts of studies can only give an indication of typical ranges of values. Meanwhile, few studies take into consideration that conventional systems and SuDS can only be truly compared if the value of Ecosystem Goods and Services (EGS) preserved by SuDS but largely destroyed by conventional systems are taken into account. Incorrect conclusions will be reached if a LCCA is conducted without considering the significant costs that are externalized onto the environment by conventional systems.

2.4.2 Ecosystem Goods & Service (EGS)

Ecosystem Goods and Services (EGS) refer to all the benefits to human livelihoods provided by ecosystem processes involving the interaction of living environmental elements (ASLA, 2008). The motivation behind SuDS and their practical application can be linked to the way they preserve these benefits – which can also be monitored as performance criteria to indicate whether a SuDS treatment train is functioning properly. The objective of the SuDS approach is to protect, restore and improve the immediate environment through efficient and effective stormwater management (MBWCP, 2006).

The difference between Natural Assets (NA) and EGS requires clarification. NA are “*the stocks of environmental resources owned by”* an individual or institution, whereas EGS “*are the flows of benefits derived from these assets (the interest or services generated by the natural capital*” (de Wit *et al.*, 2009). A SuDS design effectively reinvests in natural capital which results in increased ‘interest’ in the form of EGS. Unfortunately, in comparing stormwater systems, the focus is commonly on the costs to stakeholders and not necessarily about the balance sheet or the different forms of capital. This is evident in the studies presented in Table 2-2 which all considered monetary costs over the life cycle but failed to consider the EGS.

There are a number of ways of understanding different ecosystem services. The Millenium Ecosystem Assessment (2005) provides a simple representation of the different ecosystem goods and services such as: provisioning, regulating, cultural and supporting goods or services (Figure 2-12). Consideration of the ecosystems goods and services in these four groups assists in identifying possible valuation techniques and ensures that a service is not valued more than once when conducting an economic analysis. Most of the EGS provided by SuDS are classified as regulating services as these are most directly associated with stormwater management. The more important ones are highlighted in the descriptions that follows.

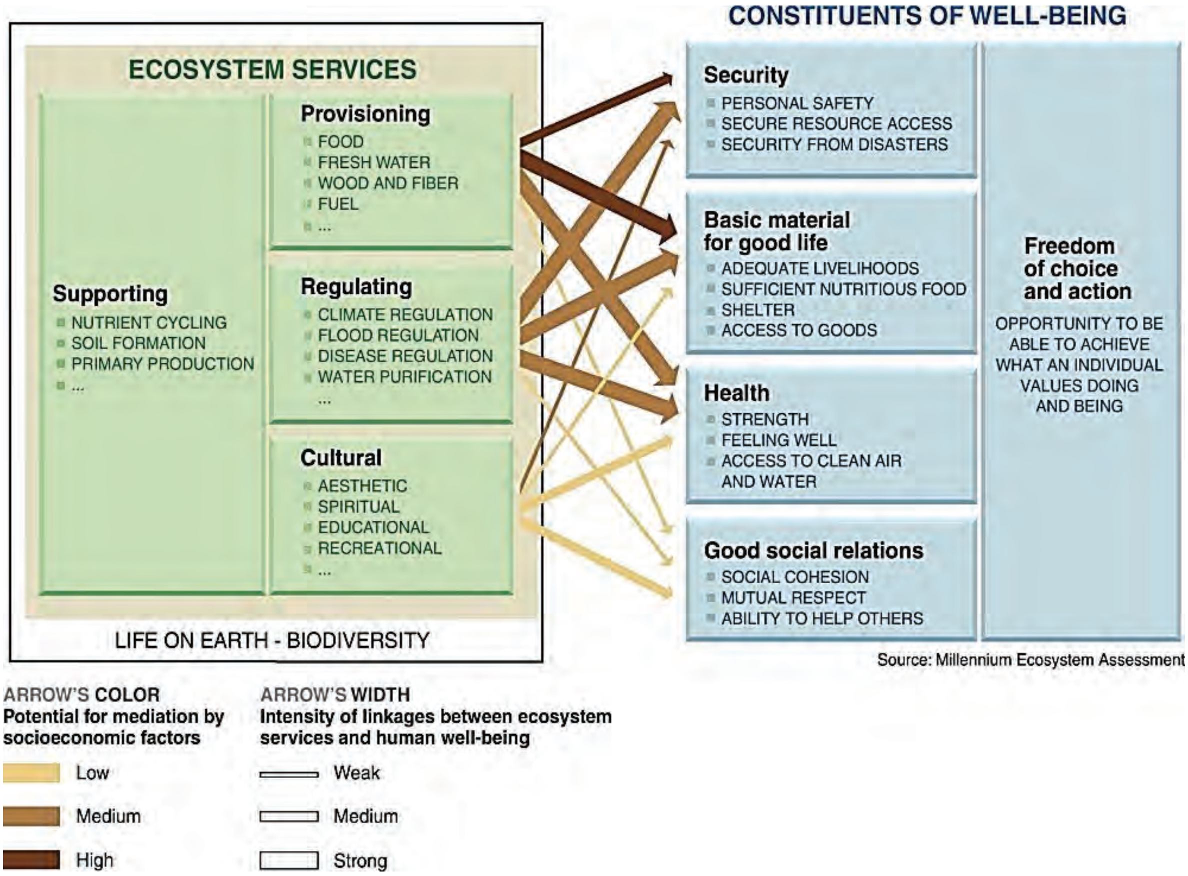

Figure 2-12: Ecosystem Services (Millenium Ecosystem Assessment, 2005)

2.4.2.1 Reduced flooding

It is widely recognized that urban development is generally resulting in increased runoff volumes and peak flows. Urbanisation can increase the runoff rate by 20-50% compared with natural conditions. In the extreme, the peak flow can be as much as 6.8 times that before development. This typically causes flash floods in streams and rivers and an increased number of ‘bankfull’ flows. (SANRAL, 2007; Haubner *et al*., 2001; Brown *et al*., 2005). The SuDS philosophy of on-site treatment both promotes the retention of water on site and the reduction of runoff velocities. This reduces the costs and impacts on downstream infrastructure, e.g. bridges (ECONorthwest, 2007).

2.4.2.2 Improved water quality

Buys & Aldous (2009) noted that stormwater is a major contributor to deteriorating water quality in urban water systems. It is widely accepted that SuDS have the ability to treat stormwater and thereby improving water quality (ECONorthwest, 2007; Minton, 2002) by capturing pollutants and treating them through physical, chemical, and biological processes depending on the technology implemented. This improved water quality is an environmental service that is essentially provided for free. All 'natural' systems take time to break down microbiological pollution and if the inflow into such systems brings more pollution than the system can treat, build-up will inevitably occur. It should therefore be borne in mind that the more polluted the stormwater, the higher the potential for the system to become overloaded which will result in significantly lower pollutant removal being realised.

2.4.2.3 Increased ground water recharge

The South African Government has identified ground water as an increasingly important resource for supplying coastal cities as almost all surface water resources have been accounted for (Gosling, 2010). Urbanisation generally results in reduced infiltration which results in the lowering of the water table – which in turn results in increasing extraction costs and the potential for environmental damage. In Atlanta, USA, research carried out by Otto *et al.* (2002) suggest that impervious surfaces there have reduced ground water infiltration by 132 billion (500 billion litres) gallons a year – the equivalent of 3.6 million people’s water usage (ECONorthwest, 2007). Almost all SuDS promote infiltration.

2.4.2.4 Enhanced aesthetics & property values

Water frontage and the preservation of natural features can add to the aesthetics of an area and consequently to the value of local properties (US Department of Defence, 2004; ECONorthwest, 2007). ‘Properly designed’ drainage systems may have the ‘waterfront effect’ that is commonly associated with natural water bodies. The value of this typically ranges between 5-30% – averaging at a 10% increase in the value of those properties with a view of the water bodies (Buys & Aldous, 2009). In Cape Town the rehabilitation of the Kuils River elevated property prices adjacent to the river by an average 10-12% (Van Zyl & Leiman 2001 in de Wit, 2009). A recently updated study by the US Department of Defence (2010) concludes that: “*In a variety of completed projects, micro-scale runoff management features have provided architectural interest in various forms...*”

This does not apply to all SuDS technologies as some may in fact cause depreciation in adjacent property values. Buys & Aldous (2009) found that dry ponds had the opposite effect to wet ponds and that property values were 4-10% lower. Detention ponds are frequently not properly maintained, collecting solid waste. Mosquitoes can present a health risk in wet ponds. Additionally, certain options take up more land than conventional systems, and this land also has value (Buys & Aldous, 2009). On the other hand, some options like green roofs manage stormwater without requiring additional land (USEPA, 2000), an advantage for developers who are concerned about losing developable area. Table 2-3 is compiled from USEPA (1995) and indicates which factors related to drainage tend to lead to an increase or a decrease in property values.

Table 2-3: Factors affecting property values (USEPA, 1995)

Factors affecting property values near open water bodies	
Increase	**Decrease**
Naturally designed water bodies (Wet ponds)	Open, unprotected water is a concern to residential owners with young children – drowning hazard
Ponds & lakes create ideal scenery for business parks	Poor design / aesthetic appeal (particularly dry ponds)
Positioning water features near entrances increase sale and value of properties	Safety concerns are the main negative effect of stormwater controls
Property with water views or other amenities can be charged premiums	Poor maintenance leads to unsightly wet / dry ponds due to excessive algal growth or garbage build-up
New recreational facilities (paddling, open areas etc.)	Health concerns (mosquito breeding grounds)

2.4.2.5 Reduced energy consumption

"*Vegetated roof covers in urban areas offer a variety of benefits, such as extending the life of roofs, reducing energy costs ….*" (USEPA, 2000). The reduction in energy costs is related to the reduction in ambient temperature as a consequence of the insulation offered by green roofs. The ability to reduce ambient temperatures has recently been confirmed in a study for the eThekwini Municipality. The study showed that the use of green roofs decreases the air temperatures and insulates the roof (Greenstone, 2010). This insulation effect can reduce energy requirements of entire buildings (ECONorthwest, 2007) while concurrently reducing pollution and improving aesthetics (US Department of Defense, 2010).

2.4.3 Payment for the destruction of EGS

It is not always appreciated by stormwater system designers that the destruction of EGS by conventional systems could be considered unconstitutional. Section 24 of Chapter 2: Bill of Rights of the South African Constitution, Act 108 of 1996 (RSA, 1996) states that: "*Everyone has the right… (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that – (i) prevent pollution and environmental degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development*". By showing little concern for the unnecessary ecological damage that they cause both within the catchment and in the receiving waters, conventional drainage systems break the law. Hunter City Council (2007) summarizes the basic principles in relation to EGS threatened by development:

i) the "***polluter pays***—*that is, those who generate pollution and waste should bear the cost of containment, avoidance or abatement;*

ii) ***the users of goods and services*** *should pay prices based on the full life cycle of costs of providing the goods and services, including the use of natural resources and assets and the ultimate disposal of any waste; and*

iii) ***environmental goals****, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms, that enable those best placed to maximise benefits or minimise costs to develop their own solutions and responses to environmental problems."*

These views are widely supported in the literature. Lampe *et al*. (2005) emphasize the need to consider EGS as part of any analysis. In conventional systems, these costs are generally externalized onto the environment resulting in the potential for the loss of natural capital. The whole life cycle of drainage designs are not usually considered.

2.5 Legislation

"*The regulatory backdrop provides a clear responsibility for the control of storm water, placing this responsibility in the hands of the local authority..."* (Buys & Aldous, 2009). South Africa's municipalities are beginning to develop their own policies to maintain and protect their watercourses along with the expectation that landowners take reasonable steps to treat stormwater. A failure to take 'reasonable means' and thus to prevent pollution may conceivably result in the landowner being held legally liable. The legislation pertaining to stormwater must be taken into consideration when conducting an economic comparison of stormwater technologies, even if the liability cannot be directly assessed.

2.5.1 National legislation

The following national legislation is relevant to stormwater management, and should be considered when selecting, and implementing stormwater management options.

2.5.1.1 Constitution

The Constitution of the Republic of South Africa, Act No. 108 of 1996 (RSA, 1996), as noted in Section 2.4.3, guarantees citizens the right to an environment that is not harmful to their health or wellbeing (Clause 24 (b); Act No. 108 of 1996). This is reiterated in Clause 146 (conflicts between national and provincial legislation), and Clause 152 (the objectives of local government).

2.5.1.2 National Water Act

The National Water Act, Act 36 of 1998 (RSA, 1998a; RSA, 1999) places considerable responsibility on local authorities for the protection of water resource. Part 4, Section 19(1), states that, *"An owner of land, a person in control of land or a person who occupies or uses the land on which – (a) any activity or process is or was performed or undertaken; or (b) any other situation exists; which causes, has caused or is likely to cause pollution of a water resource, must take all reasonable measures to prevent any such pollution from occurring, continuing or recurring."* Stormwater is a potential water resource, and hence should fall under the above provisions. It is implies that during construction precautions need to be undertaken to prevent pollution of stormwater. This could potentially be interpreted to prescribe the need for stormwater 'quality' control on private and public land, which is the responsibility of the land owner.

2.5.1.3 National Environmental Management Act

The National Environmental Management Act (NEMA), Act 107 of 1998 (RSA, 1998b) acknowledges that many South African citizens reside in environments that are harmful to their health and wellbeing. In response to this challenge of widespread impoverished development, it is stated in the Act that, *"everyone has the right to an environment that is not harmful to his or her health or well-being; sustainable development requires the integration of social, economic and environmental factors in the planning, implementation and evaluation of decisions to ensure that development serves present and future generations."* According to Buys and Aldous (2009) NEMA also places a responsibility on developers to prevent destructive practices that have deleterious effects on the environment.

NEMA places significant emphasis on the importance of sustainable forms of development. Several principles for 'national environmental management' are listed, including Section 2 states that, *"(3) Development must be socially, environmentally and economically sustainable. (4)(a) Sustainable development requires the consideration of all relevant factors including the following: (i) That the disturbance of ecosystems and loss of biological diversity are avoided, or, where they cannot be altogether avoided, are minimized and remedied; (ii) that pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied; (vii) that a risk-averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions; and (viii) that negative impacts on the environment and on people's environmental rights be anticipated and prevented, and where they cannot be altogether prevented, are minimised and remedied."* These principles of sustainable development, as well as many others, largely underpin the fundamental philosophy of SuDS and environmental wellbeing.

2.5.1.4 National Health Act

The National Health Act, Act 61 of 2003 (RSA, 2004a) states that, "*every local authority is required to take all necessary, reasonable and practical measures to maintain a hygienic and clean district at all times and to prevent the occurrence of any nuisance or hygienic condition.*" This is becoming increasingly relevant in stormwater management, particularly with the recent inception of SuDS in many cities countrywide. Several SuDS options maintain open water bodies temporarily or permanently that could potentially spread disease-causing organisms to the population or attract nuisances such as mosquitoes and other disease vectors. It is likely that municipalities will shift responsibility for compliance to developers whilst they take on the responsibility for monitoring compliance in order to maintain this health requirement. The legal consequences of disease outbreaks spreading from stormwater systems have not been tested in court, but it is unlikely that local authorities will be able to exonerate themselves from this duty completely.

2.5.1.5 National Building Regulations and Building Standards Act

The National Building Regulations and Building Standards Act, Act 103 of 1977 (RSA, 1985), issued by the Department of Trade and Industry in June 1977, provides support for local environmental policies. It states that local municipalities have the authority for approval of all types of developments. Section 4(1) states that, "*No person shall, without the prior approval in writing of the local authority in question, erect any building in respect of which plans and specifications are to be drawn and submitted in terms of this Act.*" This clause is supported by similar clauses in Sections 7, 8 and 9 of the Act. As part of the definition of the '*erection of buildings*' stated in the Act, infrastructure for the management of stormwater runoff are included. This is what gave the City of Cape Town the authority to pass policies and compliance-related benchmarks for stormwater management.

2.5.1.6 Supplementary national legislation

The following Acts also have an indirect bearing on the management of stormwater in South Africa:

i) National Water Services Act, Act 108 of 1997 (RSA, 1997)

ii) Municipal Systems Act, Act 32 of 2000 (RSA, 2000);

iii) Disaster Management Act, Act 57 of 2002 (RSA, 2003);

iv) National Environmental Management: Biodiversity Act, Act 10 of 2004 (RSA, 2004b); and

v) National Environmental Management: Protected Areas Act, Act 57 of 2004 (RSA, 2004c).

2.5.2 National Policies and Guidelines

2.5.2.1 SANS 10400-R: Stormwater Disposal

In April 2010, the South African National Standards (SANS) released a draft publication of national regulations that pertain to stormwater management, entitled, 'SANS 10400-R: The Application of the National Building Regulations – Part R: Stormwater Disposal' (SABS Construction Standards, 2010). At the time of writing a draft was being circulated for public comment. The document is heavily premised on 'hard', conventional urban drainage practices and there is no consideration given to SuDS options that are effective in the disposal of stormwater runoff from properties. Section 4.2.1.1 states that, *"Stormwater emanating from the roof, paving area in the immediate vicinity of a building shall not cause damage to the building interior, structure, or structural elements, or accumulate in a manner that unduly inconveniences the occupant."* Little significance is placed on the utility of rainwater as a valuable resource which can be used by land owners for many non-potable domestic requirements. Instead, emphasis is placed on the correct disposal of stormwater at 'source' in order to minimise or prevent damage to property.

2.5.2.2 Human Settlement Planning and Design

The latest guidelines for Human Settlement Planning and Design (CSIR, 2000a,b) were compiled by the CSIR's Building and Construction Technology Sector in 2000, in support of the National Department of Housing. The guidelines follow '*three rules*' of stormwater management which are stated as *"applicable throughout the world today as far as the drainage of surface runoff is concerned."* These rules are: (1) the 'common enemy' concept; (2) natural flows; and (3) reasonable use (CSIR, 2000b). It is stated in the guidelines that, *"stormwater runoff is considered a common enemy and each property owner may fight it off or control it by retention, diversion, repulsion or altered transmission. The focus of the common enemy rule has two focal points: (1) the need to make improvements to property, with the acknowledgement that some damage results from even minor improvements; and (2) the principle of granting each landowner as much freedom as possible to deal with his land essentially as he sees fit."* It is disturbing that no thought has been given to the possibility of stormwater being a valuable resource and thus treating it as 'a common friend'.

2.5.2.3 Drainage Manual

The 5th edition of the Drainage Manual was published by the South African National Roads Agency Limited (SANRAL) in 2006 (SANRAL, 2006). The manual was published as a guide to both students and practitioners to assist in meeting the challenges of stormwater drainage in urban environments. The manual is also premised on 'hard', conventional drainage practices, but provides useful equations and 'tools' that can be used to calculate drainage volume and flow characteristics for more sustainable forms of urban drainage.

2.5.3 Provincial legislation

There is limited provincial authority for stormwater management. Care should be taken to ensure provincial regulations, where they exist, are observed.

2.5.4 Local legislation

It is relatively difficult to set national stormwater legislation, beyond simply emphasizing the need for water quality and quantity management. This is due to the wide range of environmental factors. For example, it would be difficult to set infiltration requirements nationally as in certain areas, e.g. dolomitic areas, infiltration of stormwater could pose a significant threat. Additionally the enforcement of national policies which affect municipal decisions such as land rezoning and development rights is problematic. Therefore the development and adoption of local policies and bylaws is of utmost importance. Three Metros have or are developing new stormwater policies as shown in Table 2-4.

It is important to note that while some municipalities are moving towards SuDS, and implementing or drafting by-laws to this effect, a number of municipalities may still have by laws in force which are counter to SuDS, e.g. bylaws which enforce the channelling of runoff from properties to the road.

2.6 Summary

Stormwater management in the urban areas of South Africa has and continues to predominantly focus on collecting runoff and channelling it to the nearest watercourse. This means that stormwater drainage currently prioritises quantity (flow) management with little or no emphasis on the preservation of the environment. The result has been and continues to be a significant impact on the environment through the resulting erosion, siltation and pollution.

An alternative approach is to consider stormwater as part of the urban water cycle, a strategy which is being increasingly known as Water Sensitive Urban Design (WSUD) with the stormwater management component being known as Sustainable Drainage Systems (SuDS). SuDS attempts to manage surface water drainage systems holistically in line with the ideals of sustainable development. It aims to design for water quantity management, water quality treatment, enhanced amenity, and the maintenance of biodiversity. In so doing many of the negative environmental impacts of stormwater are mitigated and some benefits may in fact be realised.

A review of South African legislation – including national policies and guidelines – reveals that whilst very little has been published to directly promote SuDS, the need for such an approach is implicitly suggested.

Table 2-4: Local SuDS oriented stormwater legislation

Local Authority	Policy/Bylaw	Status	Overview
City of Cape Town	Stormwater Management By-Law	Gazetted (PG6300:2005; Provincial Gazette, 2005)	The purpose of the by-law, as stated in the opening abstract of the by-law is to, "*provide for the regulation of stormwater management in the area of the City of Cape Town, and to regulate activities which may have a detrimental effect on the development, operation and maintenance of the stormwater system.*"
	Management of Urban Stormwater Impacts Policy	Adopted (May 2009; CoCT, 2009a)	This was the first policy to place value on stormwater in the context of the national water crisis and 'climate change'. The following is stated in the preamble; "*Well-managed urban water bodies are valuable resources providing environmental and recreational services which require protection and enhancement. This is particularly important in the context of changing weather patterns and the associated local, national and international strategies targeting sustainability, climate and energy issues.*"
	Floodplain and River Corridor Management Policy	Adopted (CoCT, 2009b).	The Floodplain and River Corridor Management Policy (May 2009) is not directly associated with stormwater management; however it necessitates the importance of well managed and sustainable watercourses, and places significant value on the utility of stormwater runoff (Roads and Stormwater Department, 2009b).
City of Johannesburg	Draft by-laws relating to stormwater management	Draft (City of Johannesburg Council, 2009-01-29)	The Draft by law is in response to the need to better manage stormwater.
eThekwini Municipality	Design manual: Guidelines and policy for the design of stormwater drainage and stormwater management systems.	Current guidelines for stormwater designs submitted to eThekwini Municipality	*".. stormwater systems designed on the basis that not more than 40% of the area of residential properties would be hardened. As such, any development in such areas in excess of a 40% limitation naturally implies that the developer must be held responsible to manage the excess runoff from such a site for the proportion of hardening in excess of 40%...."*

3. Research methods

This chapter details the development of the South African Guidelines for Sustainable Drainage Systems and associated tools and supporting documents. These include, *inter alia*, the literature review; the review of case studies – in particular South African case studies; the development of the SuDS Economic Model; and the setting up of the website.

3.1 Literature review

An extensive search was undertaken to uncover all literature that had been published on Sustainable Drainage Systems since 2000. The information so obtained, which included books, journal papers, conference proceedings, reports and manuals, was used to compile a 405-page bibliography. The bibliography was in turn used to inform both the Literature review in the previous chapter as well as the South African SuDS Guidelines (a separate document).

3.2 South African case studies

At the beginning of the research, a number of exploratory field trips were undertaken to assess what had been planned and implemented in South Africa in the line of SuDS. Apart from the Western Cape, these included visits to KwaZulu-Natal (20-22 January 2009) and Gauteng (27-29 January 2009). Although the case studies were limited to only three of the nine provinces, these three provinces account for approximately half the population and the majority of the economic activity of South Africa. They also experience different climatic conditions from each other that in turn roughly represent much of the country. As a consequence of these initial visits, several projects were identified as potentially useful as case studies for inclusion in this report. These were then monitored over the period 2009-2011 and an attempt made to determine the effectiveness of their SuDS.

3.2.1 Case study selection

A total of 19 potential case studies were initially identified. The eight most promising were then selected for further study and reporting whilst one, the wetlands at Century City in Cape Town, were studied in particular detail. The eight selected case studies and their associated SuDS are listed below:

- *Grand Parade, Cape Town*: permeable paving and bio-retention ruts.
- *University of Witwatersrand, Johannesburg*: permeable paving.
- *Anglican Cathedral, Pietermaritzburg*: small permeable paving.
- *Department of Environmental Affairs and Development Planning, Cape Town*: roof garden.

- *eThekwini Green Roof Pilot Project, eThekwini:* green roof initiative in city centre.
- *Cotswold Downs Golf Estate, Hillcrest, eThekwini*: incorporation of numerous SuDS principles.
- *Hawaan Forest Estate, Umhlanga, eThekwini*: incorporation of numerous SuDS principles.
- *Century City, Cape Town*: rocky swales, bio-retention areas, infiltration trenches, silt traps, large retention ponds, large constructed wetland.

3.2.2 Collection and analysis of data

Contact details were sourced for the various clients, consultants and contractors who were personally involved in case studies and interviews were conducted with as many as possible. In some instances, the interviewees were reluctant to divulge critical information. As a result of time and financial constraints it was not possible to instrument any of the sites. As a result the case studies reflect an evaluation of the information that was available. The experience gained by these professionals was documented – wherever possible – according to the following three developmental phases:

i) **Planning phase**;

ii) **Implementation phase**; and

iii) **Operation & maintenance phase**.

A framework (Figure 3-1) was developed to assist in the gathering of critical data with a view to establishing the likely sustainability of the various SuDS interventions. The following data was collected:

- **Background information:** Site location; general site conditions; basic purpose; and noteworthy history.
- **Technical information:** Type of intervention; master plan; review of ground conditions; critical design elements; challenges faced and outcomes; programme summary (preliminary planning to completion); operation and maintenance (O&M); and photographs of chief components.
- **Environmental information:** Noteworthy criteria relating to flora; and fauna; and details of any environmental impact assessment (EIA).
- **Economic information:** Breakdown of major costs; unit costs; analysis of alternatives.
- **Social, legal & institutional information:** engagement with interested and affected parties (I&AP’s); social tolerability; significant legal; and institutional issues.
- **Discussions & conclusions:** Relative success rating; significant challenges and outcomes; lessons learnt; and recommendations.

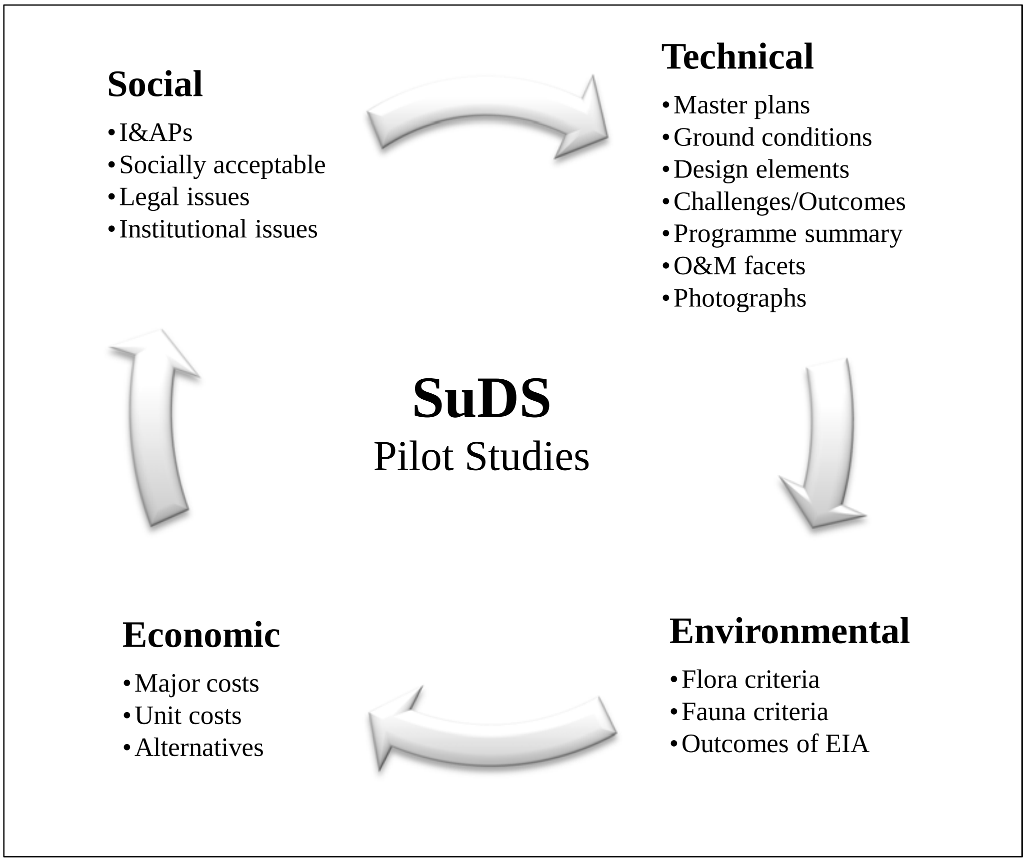

Figure 3-1: Framework showing the circular relationship linking the sustainability components

There is some inter-dependence between the various aspects of sustainability as illustrated in Figure 3-1. In the case of the project costs, attempts were made to assess the 'design life costs' including: capital costs; operating and maintenance costs; risk; environmental costs; costs of refurbishment and replacement; and disposal costs.

3.2.3 Observations

The case studies are structured in Chapter 4 so that it is possible to observe and identify 'lessons learnt', which may be useful to future SuDS projects. These highlight the successes and failures of the various initiatives examined.

3.3 The development of the South African SuDS Guidelines

In the course of the search for source material, 27 SuDS design manuals from Australia, the United Kingdom and the United States were located and acquired. The new South African SuDS Guidelines were then compiled through summarising the key material from these manuals in such a way as to be relevant to all professionals working with stormwater. Jargon was kept to a minimum and defined if necessary. Equations were also limited. The Guidelines are not intended to be a design manual but a way of pointing attention to potential solutions. Useful source material is referenced so that designers can readily get more detailed advice.

The Guidelines are divided into five chapters:

Chapter 1 – Introduction to SuDS: provides an overview of the basic SuDS principles;

Chapter 2 – Design criteria and methods: provides an overview of the SuDS design approach;

Chapter 3 – Source Controls: Green roofs, rainwater harvesting and reuse, soakaways and permeable pavements;

Chapter 4 – Local Controls: Filter strips, swales, infiltration trenches, bio-retention areas and sand filters; and

Chapter 5 – Regional Controls: Detention ponds, retention ponds and constructed wetlands.

Each of the twelve SuDS families is described under the following eight headings:

i) General description

ii) General design guidelines

iii) Advantages

iv) Limitations

v) Operation and maintenance

vi) Technology derivative(s)

vii) Case studies

viii) Further reading

The Guidelines are supplemented by the addition of six Appendices. Appendices A-C cover various design aspects including:

Appendix A: SuDS conceptual design framework

Appendix B: SuDS pollutant removal capabilities

Appendix C: General designs for SuDS options

One of the biggest concerns of developers is the cost of implementing SuDS. A SuDS Economic Model was developed to estimate the various costs – and compare them with those associated with the conventional approach. This model is described in some more detail in Section 3.4, but in the Guidelines the costing of stormwater systems is summarised in Appendices D-F as follows:

Appendix D: Life cycle costing of stormwater management

Appendix E: Overview of the 'SuDS Economic Model (SEM)'

Appendix F: Stormwater management costing fact sheets

A draft of the Guidelines – together with supplementary material comprising:

- The SEM software;
- The City of Cape Town policy documents on *Floodplain and River Corridor Management* and the *Management of Urban Stormwater Impacts* plus their *SUDS Landscape and Indigenous Plant Species Guideline V1.0*;
- The 27 SuDS manuals;
- Conference proceedings from many of the recent international stormwater conferences;
- Case studies from Australia, the United Kingdom and the United States;
- A list of informative websites;
- Additional information on the design of permeable paving;
- Additional material on the management of urban litter in stormwater systems

was compiled on a DVD and presented to delegates attending workshops in the following cities:

i) Cape Town (10 March 2011);

ii) Johannesburg (23 March 2011);

iii) Centurion (24 March 2011);

iv) George (16 May 2011); and

v) Durban (25 May 2011).

The feedback from these workshops was incorporated into the final SuDS Guidelines along with a number of further refinements.

3.4 The SuDS Economic Model (SEM)

The Simple Economic Model (SEM) comprises Excel macro-enabled software that assists in the economic analysis of alternative approaches to stormwater management. The functioning of the model is described in Appendices D-G in the SuDS Guidelines. In order to be able to undertake a complete analysis over the whole life cycle of a system or compare systems it was necessary to collect data for:

- The capital costs;
- The maintenance costs and frequencies;
- The disposal costs; and
- The Expected Useful Life (EUL) of the various components.

There is very limited experience with respect to SuDS in South Africa. Numerous firms including: contractors, consultants, quantity surveyors, landscaping, nurseries and garden services were contacted in connection with typical rates for construction. Most were unable or unwilling to be of assistance as they felt that divulging this information might undermine their competitive edge. A number of builder's pricing manuals were out of date or had restrictions on the distribution of data. Fortunately the Department of Local and Co-operative Governance's Municipal Infrastructure Grant (MIG) manuals have detailed unit rates for a wide variety of tasks. For the purposes of the version of the SEM attached to this report, the prices were adjusted to October 2010 making use of the Contract Price Adjustment Formulae (CPAF) (GCC, 2010). To ensure that the rates would be consistent, those from the MIG manual were compared with those from all available sources, and unless deemed unreasonable, were used. Where they were deemed unreasonable the rates from the next most available and reliable source was used.

Similar problems applied to identifying typical maintenance rates. The City of Cape Town has recently undertaken a survey into the costs of maintenance for their systems. This was updated using the relevant CPAF and Consumer Price Index (CPI) where appropriate. Where information was missing, further sources were sought including international literature in some instances.

Identifying typical frequencies for maintenance tasks also proved troublesome – complicated by the lack of experience with SuDS in South Africa. Where data was provided, there was often little indication as to how they were obtained. The Water, Environment Research Foundation (WERF) report: *Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems* (Lampe *et al*., 2005) was identified as the most reliable source of maintenance frequencies for the following reasons:

- It sought to determine maintenance requirements based on experience, not judgements or estimates;
- It covered a wide variety of climates (both UK and USA); and
- It was developed through an international project combining the experiences and knowledge of some of the top drainage experts in the world.

Surprisingly, Lampe *et al*. (2005) fail to identify the Expected Useful Lives (EUL) of the different technologies and simply compared all technologies over 50 years. While expert judgment may indicate many SuDS options could last this long, this is seldom the case.

All of the above data was collected and compiled into a number of fact sheets that are presented in Appendix F of the South African SuDS Guidelines. It is important to stress that the data presented in these 'fact sheets' is meant as a guide – a starting point for the economic analysis. Where better, more recent, data is available this should be used instead.

3.5 The SuDS / WSUD Website

Initially it was envisaged that the outputs of this research project would be distributed on a DVD. This approach initially proved successful, but there were a number of shortcomings:

- It was not possible to get copyright clearance for all resources;
- It is difficult to update and monitor the links to useful websites; and
- It requires practitioners to have a DVD drive to access the information.

As a result the decision was made to develop a website which could in time be expanded to cover the broader topic of Water Sensitive Urban Design (WSUD). This approach has a number of advantages:

- It is possible to link references to their source which obviates the need for copyright clearance;
- It is possible to continuously update material and correct any errors;
- It is possible to collect data on new SuDS projects from the professionals involved; and
- It aids in promoting SuDS to the wider public.

The resulting website, www.wsud.co.za was developed using Wordpress.org software. An 'off-the-shelf' design theme "The Station" was used to improve the appearance of the webpage. The website is currently being hosted for free by typo.net.

4. South African case studies

The following section details the South African case studies. The method of investigation is described in Section 3.2. For the purposes of comparison, case studies of a similar nature have been grouped together.

4.1 Permeable pavements

4.1.1 Introduction

Permeable paving is the most commonly implemented SuDS option in South Africa. This is likely due to its promotion by the Concrete Manufacturers Association (CMA). Three case studies from across South Africa are described here to demonstrate its use. An overview of these is presented in Table 4-1 and described in the next three sections. An alternative approach implemented in Bishops Court Business Park is then described before some observations are made about all four systems.

Table 4-1: Overview of three South African permeable paving case studies

	CoCT Grand Parade	Wits parking lot	Cathedral parking lot
Location	Central Business District, Cape Town	University of Witwatersrand northern parking lot, Braamfontein, Johannesburg	Anglican Cathedral, Central Business District, Pietermaritzburg
Review focus	Implementation and Operation phases	Implementation phase	Planning and implementation phases
SuDS pioneers	Iliso Engineers and Project Managers; Kaulani Civils South and Engineers; Inca Concrete Products	Arup (Pty) Ltd; Concor Technicrete	Partners in Development Consulting Engineers and Project Managers
Pollution control	Compliance with the regulations set out by the CoCT for developers	Fine pollution particles are trapped in the sub-base layers of the permeable paving	Fine particles and a small percentage of nutrients will be removed from stormwater
Flow management	Runoff flows to a low lying portion of the site where it infiltrates into permeable surfaces, is collected and discharged by a perforated drainage pipe	Runoff spreads over the two flattened paving areas and infiltrates into the sub-base layers and soil, the remainder is discharged by a minor perforated pipe network	Runoff flows across an impermeable area onto permeable pavers. The runoff is filtered through the permeable paving structure. The filtered runoff is discharged into the municipal stormwater system

4.1.2 CoCT Grand Parade

The historic rectangular-shaped Grand Parade situated next to the Town Hall in the centre of Cape Town was the first major permeable paving scheme in the Western Cape (Figure 4-1). It was used as an official public viewing site for the 2010 World Cup soccer tournament by the Federation of International Football Associations (FIFA). Apart from needing to meet the City of Cape Town stormwater objectives, the consultant, Iliso Consulting Engineers and Project Managers, and the contractors, Kaulani Civils South and Engineers, needed to satisfy FIFA certified expectations whilst preserving the historical legacy of the site. *Aquaflow* permeable concrete block paving (PCBP) was selected. The paving blocks were supplied by Inca Concrete Products who manufactures these and other permeable paving blocks under license from the British concrete block paving (CBP) manufacturer and SuDS design company, Formpave.

Figure 4-1 Cape Town Grand Parade

The implementation phase comprised the removal of the previous asphalt surface and the subsequent laying of the concrete block pavers. Approximately 22,500 m^2 of paving was laid of which only 3500 m^2 in the north-eastern portion is permeable paving. This relatively small area of PCBP has more than adequate capacity to handle the stormwater runoff for the entire parade surface.

The pavers were designed to support light vehicle traffic. Their mean compressive strength is stated to be 38 Nmm^{-2}, with an absolute minimum strength of 30 Nmm^{-2} (British Board of Agreement, 2009a,b). They have been designed to have sufficient impact resistance to prevent their cracking during the handling and laying stages. Furthermore, they were manufactured from C40 concrete to resist the corrosive effects of chemicals, oils and flammable fuels that may spill on them.

The design of the PCBP system is shown in Figure 4-2, and comprises: 80 mm thick PCBP surface layer; a 50 mm thick layer of 5 mm clean stone placed on an *inbetex* geotextile membrane; a 100 mm thick layer of 5-20 mm stone; a 250 mm thick layer of 10-63 mm stone; and an SC membrane of low permeability. Perforated drainage pipes have been placed on the lower geotextile layer spanning the entire length of the Grand Parade from the south-east to the north-west to drain the base layer.

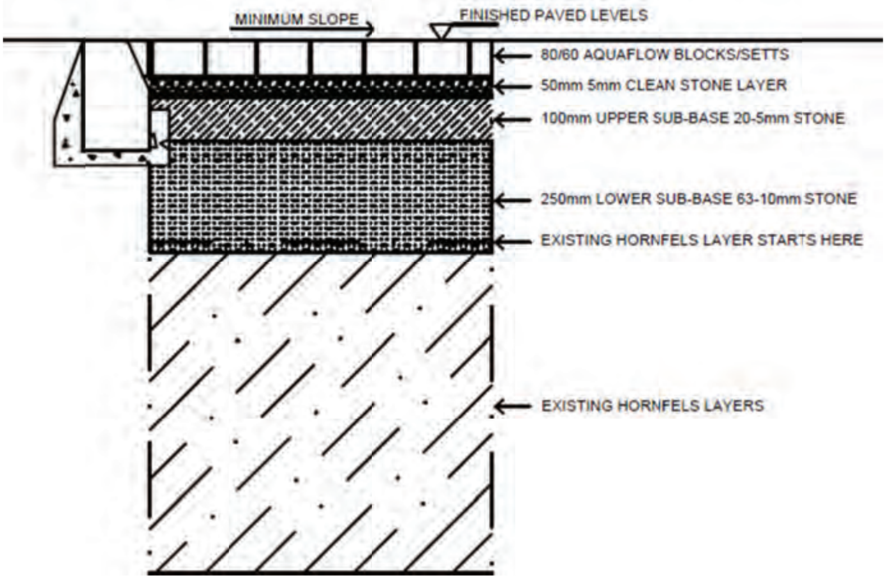

Figure 4-2: A Typical cross section of the permeable paving area (Iliso Consulting Engineers, 2009)

The British Board of Agreement (2009a,b) document various infiltration tests performed on the *Aquaflow* PCBP product. The pavers are able to absorb 9 mm of rainwater over a storm duration of 30 minutes, which is subsequently released via evaporation and exfiltration into the underlying layer. Tests performed on 1 m^2 of the laid pavers indicated that during high intensity rainfall, stormwater can drain through the pavement surface and into the base course material at a rate of up to 4500 mm/h, greatly reducing the likelihood of surface ponding (British Board of Agreement, 2009a,b). The difference in performance between the permeable pavers and standard paving is illustrated by Figures 4-3 and 4-4 which show the PCBP and ordinary (non-permeable) pavers on the Grand Parade after wet weather conditions. PCBP are also resistant to most common forms of weathering such as freeze thawing and excessive heat. Properly maintained, they have a nominal design life of 20 years.

Proper maintenance is essential for the long term success of permeable pavements. In the case of the Grand Parade, a general inspection of the paving is scheduled to take place preferably once a month or no longer than once every three months. A standardised inspection form is used to document important aspects.

During the World Cup, the construction of a temporary stage and entertainment area resulted in a number of pegs being driven through the permeable pavers causing considerable damage to them which was repaired. Long term monitoring of the system will indicate what impact the stage and pegs have had on the pavement.

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4.1.3 University of Witwatersrand northern parking lot

In 2007, two multi-use sports fields at the University of Witwatersrand (Wits) in Johannesburg were converted into parking areas. The parking areas are situated to the north of the main campus, south of Empire Road and west of the M1 north-bound. The fields had been under-utilised during consecutive summer sports seasons whilst there was a need for additional parking for students. The consultants for the project were Arup (Pty) Ltd, and the manufacturers of the PCBP were Concor Technicrete.

The PCBP system was designed as a Concor Technicrete '*Typical Infiltration System*' suitable for use by light motor vehicles only (< 2.5 tonnes)", shown in Figure 4-5. The '*Typical Infiltration System'* comprises: '*AquaTrojan Slab*' concrete paver; a 50 mm thick layer of 2-6 mm sized clean stone; a 100 mm thick layer (upper sub-base) of 5-20 mm stone; and a 250 mm thick layer (Lower sub-base) of 10-63 mm stone. The clean stone and upper sub-base layers are separated by an *Inbitex*® geotextile layer.

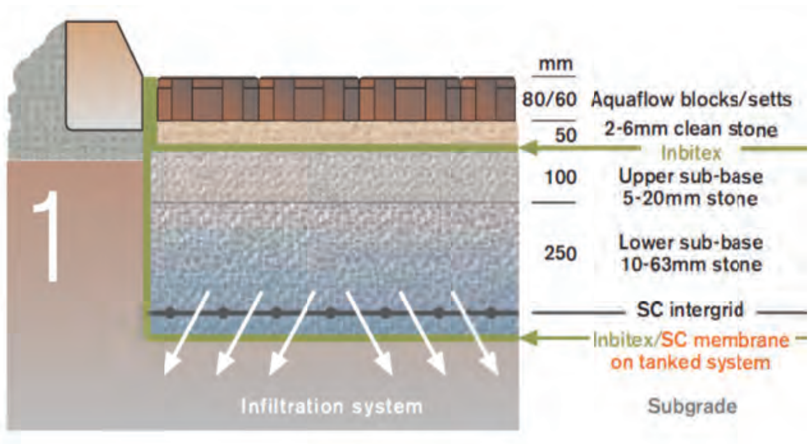

Figure 4-5: A schematic of the 'Typical Infiltration System' permeable paving (Concor Technicrete, 2009)

Each parking area has a separate entrance and exit which are raised above the connecting asphalt road surface to prevent stormwater flowing onto them from this source. The lower parking area to the west (Figure 4-6) is approximately 3.5 m below the upper parking area to the east (Figure 4-7). In total, the two parking areas can accommodate 550 vehicles. A thin underground concrete curtain wall was constructed along one side of the parking area to prevent stored stormwater in the base layers from seeping into that of the asphalt road that runs alongside.

Figure 4-6: Lower west Wits parking area

Figure 4-7: Upper east Wits parking area

Whilst the implemented permeable paving system appears to be handling the stormwater runoff, there were a few errors in the design and construction. The first and most visible error is with the design of the chute located on the embankment discharging the overflow from the top parking area onto the lower one (Figure 4-8). The stormwater flows down the chute at a high velocity until it is slowed down by the energy dissipating blocks at the bottom of the embankment (Figure 4-9). During high-intensity storm events, however, stormwater spills over the sides of the chutes and washes sand and silt material onto the permeable paving on the lower parking area. This is supplemented by loose sand blown off the embankment (Voogt, 2009). This material has clogged the paving blocks in the vicinity of the embankment Figures 4-10 and 4-11). Similarly, topsoil that was dropped – or washed – onto the paving blocks from the various planters located throughout the parking areas has also led to local clogging.

Whilst it is clearly a concern that a portion of the infiltration capacity of the PCBP surface has been lost through lack of attention to detail, it should be noted that the parking areas as a whole are still able to cope with the stormwater runoff as the permeable pavers have been designed with an enormous factor of safety. Stormwater merely infiltrates through the non-clogged sections and spreads throughout the sub-base of the system. This is typical of permeable paving systems; a considerable degree of clogging is required before they eventually fail to cope with the flow.

Figure 4-8: Embankment separating the two Wits parking areas (above)

Figure 4-9: Chute and energy dissipater on the Wits embankment (right)

Figure 4-10: Sand and silt covering the permeable paving in the lower Wits parking area

Figure 4-11: Stone fines and crusher dust covering the permeable paving in the Wits parking area

Another error which occurred during the construction of the paving system is the irregular placement of concrete pavers. Overly wide joints are subject to both faster clogging by finer materials as well as dislodging through point loading. As a consequence, several concrete pavers on the upper parking area have come loose exposing the underlying layers.

4.1.4 Anglican Cathedral parking lot

In Mid-2009 the Diocese of Natal approached Partners in Development (Pty) Ltd (PID) to upgrade the Cathedral parking-lot at 169 Langalibalele Street in Pietermaritzburg. The parking-lot was primarily surfaced with asphalt (Figure 4-12), but there were areas with grass, gravel and even concrete grass block pavers (Figure 4-13). Although the grassed and gravel areas were all potentially permeable, a densely compacted underlying clayey soil inhibited infiltration and consequently sections of the parking lot were readily flooded during rainfall events. The situation was exacerbated by surrounding hardened surfaces that were linked to the parking area (Figure 4-14). Roof runoff from the cathedral complex was, however, drained to a 375 mm diameter municipal stormwater pipe in Langalibalele Street.

Figure 4-12: Anglican Cathedral parking lot prior to redevelopment

Figure 4-13: Unattractive concrete grass block paving with dead grass

Figure 4-14: Hardened surfaces covering most open areas

PID opted for a paving system that is a combination of asphalt pavement and PCBP. The total drainage area is approximately 3000 m^2 with a permeable paving area of 350 m^2. The paving system was designed using the Permpave and Lockpave software packages and assuming that the parking lot is normally used by light vehicles with only the occasional emergency and service vehicles. The 2 year RI design rainfall (15 minute duration) was used for the hydrological analysis. A target of 62% peak outflow reduction was required with a 50 mm/hr rainfall intensity. The hydrological modelling gave the following output values (Partners in Development, 2009):

i)	Peak runoff flow to paver system:	62.5 ℓ/s
ii)	Peak runoff flow leaving paver system:	37.7 ℓ/s
iii)	Storage volume required:	23.8 kℓ
iv)	Minimum thickness of base course:	170 mm
v)	Minimum discharge pipe diameter:	90 mm

PID followed a standard permeable paving design shown in Figure 4-15. They assumed a surface infiltration rate of 900 ℓ/s·ha for the 80 mm thick permeable pavers. The design, shown in Figure 4-15 comprises: 80 mm thick Unidecor concrete blocks; 25 mm river sand bedding; a 200 mm deep layer of single sized uniform granular material with 40% voids; and a network of 100 mm cordrain draining a sump connected to the municipal stormwater pipe. Negligible infiltration was expected into the sub-grade, instead the stormwater is temporarily stored in the base course prior to being discharged into the 375 mm diameter municipal stormwater pipe in the adjoining Langalibalele Street. This storage results in considerable attenuation of the peak flow.

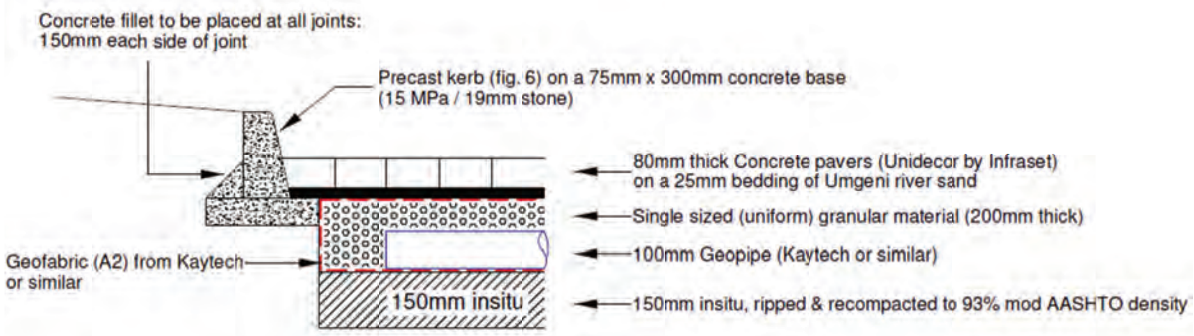

Figure 4-15: A schematic of the 'Typical Infiltration System' permeable paving (Partners in Development, 2009)

At the time of writing the pavement had managed to cope with a number of significant storms, and while there are signs of a build-up of sediment, this is not expected to be a problem in the next ten years, at which stage the pavement may require rehabilitation to ensure it operates as it is designed to.

The capital costs of the system as designed are compared with those of a similarly sized conventional system in Table 4-2. They include: ripping up the existing system, other general earthworks, trenching, the product costs, resurfacing the area and the connection to the outfall drain.

Table 4-2: Capital Cost comparison for the Pietermaritzburg Cathedral parking lot
(Partners in Development, 2009)

Capital costs	Conventional (R)	Permeable paving (R)
Preliminary and General	44 500.00	54 500.00
Parking Area	208 837.50	255 865.00
Outfall drain	12 050.00	12 050.00
Contingencies (5%)	13 269.38	16 120.75
Subtotal	278 656.88	338 535.75
VAT (14%)	39 011.96	47 395.01
Total Cost (R)	**317 668.84**	**385 930.76**

It can be seen that the conventional system has a lower capital cost than the sustainable system with the biggest difference being in the cost of the paving surfacing materials. On the other hand, the costing for the conventional asphalt solution ignores the potential increase in municipal stormwater pipes and the impact of poorer quality water downstream.

4.1.5 Bishops Court Business Park parking area

A cheaper alternative to the PCBP systems selected for the previous three sites is to replace the pavers with a 19 mm clean stone aggregate surface such as that used in the Bishops Court Business Park (Figures 4-16 & 4-17). The stone surface potentially allows rapid infiltration of stormwater into the underlying material while still being reasonably attractive. Such systems do however require on-going maintenance as the surface is continually being disturbed by vehicular traffic. At Bishops Court Business Park, a labourer periodically rakes the surface to inhibit the development of ruts as a consequence of wheels running over the surface.

Apart from the danger of stones being kicked up by vehicular traffic and causing damage, another disadvantage to the use of loose stone surfaces is that children may be tempted to throw the stones around. The latter is a good reason for not using them, for example, in the parking lot of the Anglican Cathedral in Pietermaritzburg.

4.1.6 Observations concerning permeable paving in South Africa

i) Permeable paving systems can manage stormwater without the need to install catchpits and stormwater pipes. Even when provided with under-drains, permeable paving systems markedly reduce the peak discharge from the site in question. Urban litter cannot easily enter the stormwater drainage system as there are no catchpits.

ii) Sand, silt and other fine material have a destructive effect on the drainage capacity and detention volume of a permeable paving system.

iii) There is potential for the harvesting and reuse of stormwater that is temporarily stored in the sub-base layers of the PCBP system.

Figure 4-16: Multi-coloured aggregate used for parking bays

Figure 4-17: Stone-surfaced driveways for light vehicle use

iv) PCBP systems are best constructed with small surface slopes – even flat. This ensures that stormwater does not run off, but sinks into the surface. On the other hand, the base of the excavation should be graded to assist the flow towards the outlet to ensure the pavement system empties during storm events.

v) The performance of PCBP systems relies on adequate maintenance to reduce / remove clogging.

vi) Permeable paving areas should be designed with particular consideration given to local landscaping to prevent fine material from embankments or planters washing onto the pavers and causing premature clogging. Ideally the paving should be higher than the abutting vegetated areas. Particular care needs to be taken during the establishment of the vegetation as this is when the risk is greatest.

vii) The many different colours and textures available in PCBP allow for more aesthetically pleasing environments.

viii) PCBP is, under many urban conditions, more resistant to general wear from applied loads than most asphalt surfaces (Concrete Manufacturers Association, 2003). This typically increases the longevity of a paving system and lowers the maintenance costs.

ix) Concrete grass block pavers are ineffective SuDS technologies in clayey soils. Furthermore, they tend to get very hot in warm climates which can inhibit the growth of the grass.

x) It is currently difficult to source suitable material for filling the joints between permeable concrete blocks e.g. 1-3 mm stone. This to likely increase construction cost as a result of additional transportation expenses.

4.2 Green Roofs

4.2.1 Introduction

Green roofs are vegetated roofs which act as excellent source controls. They are relatively easy to retrofit onto many commercial buildings in high density areas where other SuDS options would be inappropriate. Two interesting retrofit projects have been undertaken in South Africa and are presented in this section; an overview is given in Table 4-3.

Table 4-3: Overview of green roof case studies in South Africa

	Western Cape DEADP	**eThekwini Municipal**
Location	Central Business District; Cape Town	Central Business District; Durban
Review focus	Implementation phase; Operation & maintenance phase	Implementation phase; Operation & maintenance phase
SuDS pioneers	Department of Environmental Affairs and Development Planning (Western Cape DEADP); Eco Logic	KwaZulu-Natal’s DEADP; Municipal Climate Protection Programme (MCPP)
Pollution control	Compliance with the regulations set out by the CoCT for developers, and trash collection devices.	No requirements
Flow management	Roof collects and effectively attenuates stormwater over its surface area	Roof collects and effectively attenuates stormwater over its surface area

4.2.2 Western Cape DEADP

On 5 December 2006, Minister Essop officially opened the garden on the roof of the Dorp Street offices of the Western Cape Department of Environmental Affairs and Development Planning (DEADP) in the CBD of Cape Town. DEADP staff claim that the implementation of the roof garden is an attempt to addresses several key global issues, including: sustainable development, the effective management of the environment, combating ‘climate change’ and the efficient usage of natural resources. The roof garden does this through:

i) Effective stormwater attenuation; and

ii) The regulation of temperatures in the building.

Figure 4-18 is an aerial view of the roof prior to the development of the roof garden. The developers were faced with a number of challenges, mainly due to the high density nature of the site. The main focus was the aesthetics whilst stormwater management was only a secondary concern. No data concerning the effectiveness of the stormwater management were collected.

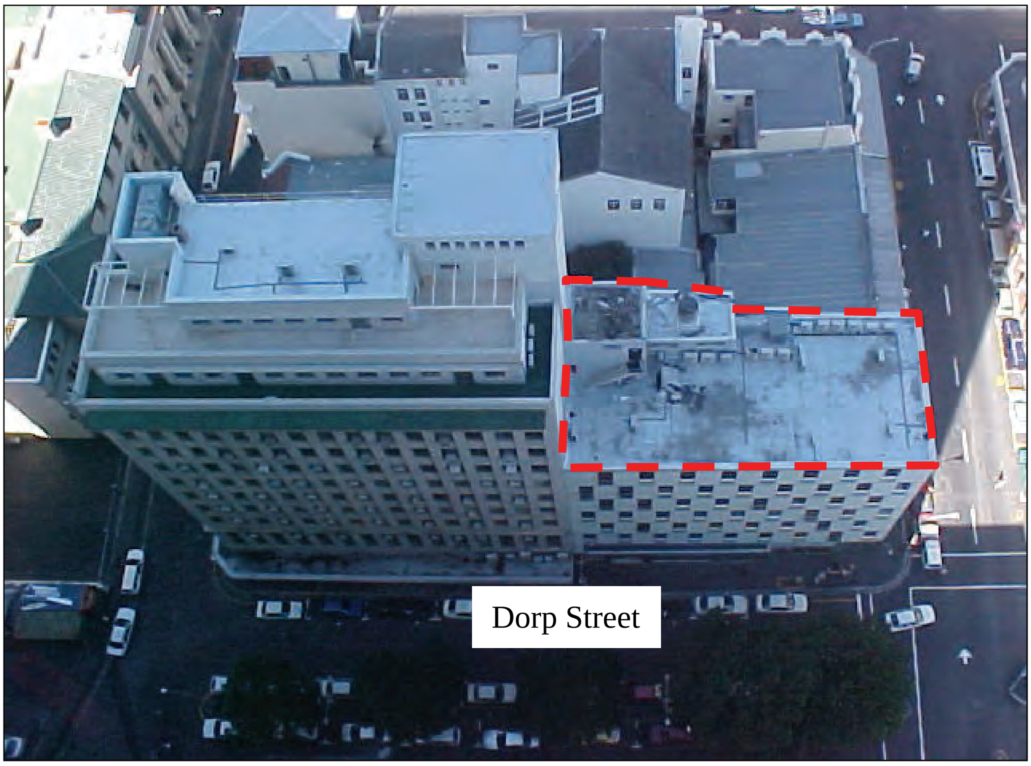

Figure 4-18: Aerial view of predevelopment conditions (Western Cape DEADP)

The top of any building in the CBD of Cape Town will be exposed to climatic extremes including: long hot dry summers, strong winds, and lengthy periods of cold damp weather. In the case of the DEADP building, a drip irrigation system was installed to irrigate the vegetation during dry periods whilst conserving water. This system requires regular monitoring and maintenance, which is performed by ecological specialists. The garden was landscaped to display four indigenous biomes: Costal Thicket, Mountain Fynbos, Strandveld and Succulent Karoo, which are kept separate from each other and clearly marked for the benefit of staff and visitors.

It is worthwhile summarising the steps taken in the creation of the roof garden:

i) Predevelopment conditions were assessed. The roof was found to be characteristically ‘lifeless’ and an unutilised space. Air-conditioning units were randomly scattered over the surface of the roof (Figure 4-19).

ii) The old roof cladding and the air-conditioning units were removed.

iii) Following this, the roof was waterproofed using a corrosion-protected steel composite material, which was heated and rolled over the surface of the roof. A mobile crane was positioned to transport construction materials.

iv) Air-conditioning units were grouped under a prefabricated steel housing unit to save space. Bricks were laid to form the skeletal structure of the roof garden layout, and steel railings were placed around the perimeter of the roof.

Figure 4-19: Roof garden predevelopment conditions (Source: Western Cape DEADP)

v) Roof garden elements were then added which included: a "*Polytimber*" boardwalk, *polytimber* seating units, drainage layer piping, screening for the air-conditioning housing units, steel plant support structures and additional cladding in areas vulnerable to leakage.

vi) The roof was lined with impermeable geotextile materials (*Bidim*® and *Dorken*®) of varying grades, and topsoil was spread over the surface of the bare brickwork design (Figure 4-20).

vii) Plants from the four Western Cape biomes were craned onto the roof and planted by botanical specialists (Figure 4-21).

As previously mentioned, drip irrigation was chosen for the roof garden. Two clear benefits of drip irrigation motivated its use on this roof garden: the efficient use of water resources, and a more effective application of plant food. Other benefits of drip irrigation include:

- Drip systems may be adapted to suit oddly shaped beds or those with uneven topography or soil texture;
- Drip irrigation can be made very water efficient which is important if water is scarce or expensive;
- Drip irrigation systems can be divided into different watering zones to cater for the water requirements of different plant groups;
- A drip irrigation system can be automated to distribute fertilizers, herbicides, nematodes and fungicides; and
- Drip irrigation helps with weed control in an arid climate by keeping much of the soil surface dry.

Figure 4-20: Basic layout of DEADP roof garden showing different sections (Source: Western Cape DEADP)

Figure 4-21: View of completed roof garden (Source: Western Cape DEADP)

The drip irrigation system at the DEADP offices uses flexible polyethylene tubing. Two wind sculptures pump water through the system using mechanisms similar to standard windmills.

The system does require regular attention and maintenance. This has partly been contracted out through the appointment of a contractor to carry out monthly monitoring tasks on all components of the garden and present an annual report of their findings with corresponding recommendations to the DEADP. Four general maintenance areas are addressed: plant health, garden appearance, equipment monitoring and institutional requirements. In addition weekly upkeep is performed by DEADP cleaning staff. General upkeep includes: weeding, additional water (if necessary), and the clearance and disposal of litter. Information and training sessions are also conducted during regular maintenance slots which aim to teach DEADP employees about: indigenous vegetation, roof garden technology, and more significantly, principles of sustainable development.

Records show that the roof garden has reduced the need for air-conditioning. Unfortunately no records have been kept regarding its performance with respect to stormwater management. It is however safe to assume that the thick drainage layer beneath the vegetative mass has a significant stormwater retention capacity which will ensure peak flow attenuation. Furthermore, any surplus water that is discharged off the roof would, to some extent, have been 'polished' by its movement through the vegetation and the drainage layers. All in all, the roof garden has provided DEADP staff with anaesthetically pleasing and tranquil facility.

4.2.3 The eThekwini Green Roof Pilot Project

Research into the effectiveness of green roof technology in South Africa is being carried out in Durban through the KwaZulu-Natal DEADP in conjunction with the Municipal Climate Protection Programme (MCPP). They have initiated the Green Roof Pilot Project which aims to achieve the following:

i) A reduction in building temperatures and stormwater runoff;

ii) Mitigation and adaption to climate change; and

iii) Promotion of inner city biodiversity.

Two adjoining flat topped roofs at eThekwini Engineering Services have been planted with twelve different varieties of vegetation in small, tailor-made planting trays (Figure 4-22). The performance of the green roofs is monitored through: the placing of thermometers on the surfaces of and within the concrete layers; the placing of flow gauges to facilitate the calculation of the flow and volume of stormwater that runs off each; and the use of ecologists to monitor the growth patterns of the various vegetation types throughout the year, concentrating on the effects of extreme temperatures and the changing of seasons.

The Green Roof Pilot Project is a potentially valuable attempt to test the effectiveness of green roof systems in the subtropical conditions of KwaZulu-Natal.

Figure 4-22: Views of the eThekwini Green Roof Pilot Project

4.2.4 Observations concerning green roofs in South Africa

Green roofs can offer a range of ecosystem services and increase the amenity value of a roof by allowing staff to conduct informal meetings and enjoy lunch breaks without any traffic threat. Some observations from the limited experience in South Africa include:

i) Irrigation may be required in certain cases. Drip irrigation systems are initially more expensive than conventional spray systems, but savings in water and energy – and hence operational costs – are typically evident after around three years.

ii) Staff and visitors to the Western Cape DEADP green roof have shown an interest in this innovative SuDS technology. People are generally drawn to well vegetated and pleasant environments.

iii) There is a need for further research into the selection of plant types for the different regions of South Africa.

4.3 SuDS treatment trains

Ideally SuDS options should not be isolated but should be connected to form a treatment train to increase the resilience of the system. The following sections review the planning and implementation phases of two new developments in South Africa. An overview of each development is provided in Table 4-4.

Table 4-4: Overview of SuDS treatment trains in South Africa

	Cotswold Downs	**Hawaan Forest Estate**
Location	Hillcrest, eThekwini	Umhlanga Rocks, eThekwini
Review focus	Planning phase; Implementation phase	Implementation phase
SuDS pioneers	Davies Lynn & Partners (Pty) Ltd; Metro Stormwater Management Unit	Stemele Bosch Africa Consulting Engineers and Project Managers; Ndebele Kirby Planners
Water conservation	Three forms of water conservation are used to supplement the high irrigation demands of the champion golf course	Garden reticulation is occasionally performed using water from the feature retention pond at the entrance of the development
Pollution control	BMP litter traps collect floatable objects; retention and detention ponds allow for the settlement of the insoluble pollutants and sediment	Trash racks prevent pollution from entering the downstream forest, and treatment trains remove significant amounts of nutrients from the stormwater
Flow management	Stormwater is collected in sub-catchments on-site and flows through a series of regional attenuation measures	The development maintains upstream conditions using SuDS treatment trains prior to the discharge of stormwater into the Hawaan Forest downstream

4.3.1 Cotswold Downs Golf Estate

The Cotswold Downs Golf Estate is situated between Hillcrest and Waterfall on the western outskirts of eThekwini (Figure 4-24). The Estate accommodates over 700 residential plots on 232 ha development, which includes a championship-standard golf course. Public open spaces and wetlands are abundant throughout the development. The Nkutu River passes through the low lying central section of the site from the west to east before passing through the suburb of Waterfall and joining with the Molweni River (Torr, 2003). The development adjoins the Kranzkloof Nature Reserve to the East. Due to the undulating slopes on the development, the stormwater consultants, Davies Lynn & Partners (Pty) Ltd, were reluctant to design conventional stormwater management infrastructure. With an expected increase in runoff flows and volumes from the proposed development, conventional systems would have had destructive effects on the low-lying parts of the development and especially the nature reserve downstream. In response to these concerns, a SuDS approach was used to mitigate stormwater flood peaks and improve the quality of water discharged to the Nkutu River.

In November 2003, Davies Lynn & Partners (Pty) Ltd issued a master plan report on water and environmental issues for the then proposed Cotswold Downs development. One of the key issues noted in this report was the concern regarding adequate water provision for the irrigation of the golf course. It suggested that this water could come from two main sources. The first source was treated effluent from neighbouring developments. It could be piped to a control station in the development and pumped to parts of the golf course. This system would require a high level of supervision and considerable energy. The second option was the harvesting of local water resources from groundwater, stormwater harvesting and some use of surface water from the Nkutu River. This option attempted to integrate the natural environment with the infrastructure requirements.

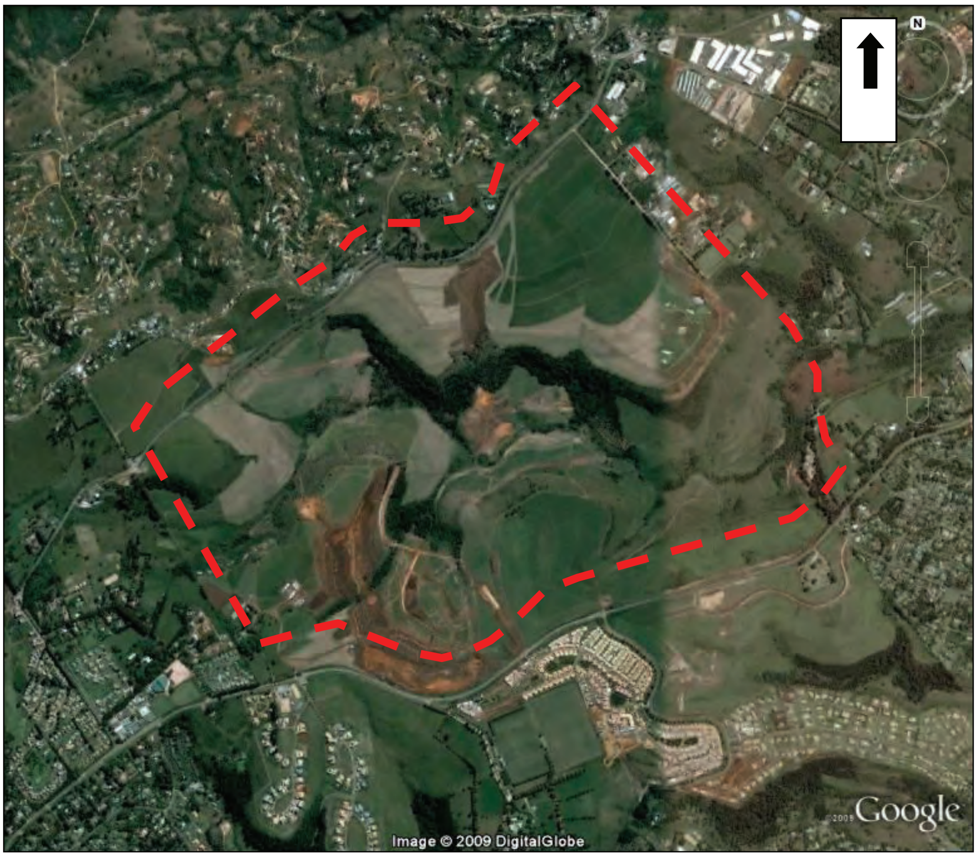

Figure 4-24: Aerial view of the Cotswold Downs Golf Estate prior to development

The mean annual precipitation (MAP) over the development is approximately 930 mm. For the purpose of groundwater supplementation and stormwater harvesting, much of this rainwater needed to be retained on site. Groundwater was expected to provide some 200 k*l*/day or 6000 k*l*/month. Combined with an expected 1300 k*l*/day or 39,000 k*l*/month from treated effluent this could supply the golf course with adequate water resources for irrigation purposes. The water could be stored in reservoirs along the Nkutu River (Figure 4-25). The consultants estimated that approximately 7000 m^3 storage capacity was required.

The effectiveness of stormwater harvesting depends on the development pattern. Generally the construction of housing units and their associated 'hard infrastructure' would be expected to significantly increase the local stormwater runoff which could then be harvested and reused (Torr, 2003). The Nkutu River catchment is approximately 8.6 km^2 in area and has an estimated Mean Annual Runoff (MAR) of $1.1x10^6$ m^3. The Rational and US Soil Conservation Service (SCS) methods were used to estimate runoff volumes over the development whilst the hydraulic program HEC RAS was subsequently used to predict the 1, 50 and 100 year flood-lines. Two reservoirs were then constructed on the Nkutu River within the estate for both water supply purposes as well as flow attenuation (Figure 4-25). The ponds were initially positioned to allow two years of temporary abstraction to supplement the relatively high irrigation demands. They were also designed to capture the full 24-hr storm volume for these return periods. The reservoir design made allowances for erosion management during construction to prevent silt causing damage downstream. Stormwater harvesting began in 2006 when up to 100 kl of stormwater was harvested daily. A trash rack was installed across the river as it exits the development (Figure 4-26).

Figure 4-25: Reservoirs along the Nkutu River

Figure 4-26: Large trash rack on the Nkutu River

A team of specialists, supervised by Professor Fred Ellery of the University of KwaZulu-Natal, conducted an independent assessment on the status quo of the wetlands in the Cotswold Downs development. Development boundaries and several golf course greens were moved to accommodate existing wetlands. Where it was impossible to avoid or create detours around wetlands, sections of these were filled and they were reconstructed nearby. In particular, the design made allowances for seepage water to pass under road structures and enter the wetland edges to prevent possible drying. Earthworks were limited near to wetlands to prevent the local raising or lowering of the groundwater table which could be critical to the health of the affected wetlands. Newly constructed wetlands were carefully designed to ensure they maintained their ability to effectively ‘polish’ stormwater runoff. Access roads within the Estate have asphalt surfaces with a straight cross-fall (Figure 4-27). Channels on the lower side of the road direct the stormwater runoff into a swale catchpit that helps to guide it into the nearest swale (Figure 4-28).

Figure 4-27: Typical road cross-section in Cotswold Downs

Figure 4-28: Road swale catchpit in Cotswold Downs

Although the development was modelled on SuDS principles from the outset, the consultants had not initially considered source controls at private properties within the development. By 2008, some 40 housing units had been built or were being constructed, the golf course irrigation system had been in operation for three years and had proven to be effective, whilst most local and regional controls were complete and were in the operation and maintenance phase. Then, in September 2008, Davies Lynn & Partners (Pty) Ltd issued a second stormwater management plan focusing specifically on the provision of source control SuDS in private properties in the estate. The responsibility of source control drainage was handed to the property owners. The sites were divided into two categories (Torr, 2008):

- *Blue Sites* – These were sites identified as suitable for the infiltration of stormwater on the site with little risk of negative effect on down-slope roads or other buildings. Infiltration was generally achieved through the use of underground soakaways linked to the roof downpipes; and
- *White Sites* – These were sites identified as 'risky' in terms of infiltration of stormwater on site, and therefore more suited to construction of attenuation tanks on site, with discharge to the adjacent surface water control system (i.e. into roads or piped / open drains in the overall estate system).

There have to date been no reported problems with the stormwater system. The site will however require on-going monitoring to evaluate the system's ability to manage stormwater quantity and quality.

4.3.2 Hawaan Forest Estate

Hawaan Forest Estate is an upmarket residential development privately owned by Hawaan Investments (Pty) Ltd situated to the north of Stratton-on-Sea in eThekwini. The Hawaan Forest lies to the east of the estate and separates it from the coastline. This forest is one of the last remaining group of dry coastal forests in the region. The Ohlanga River and Lagoon are located to the north-east (Figure 4-29). It was a requirement by eThekwini's Catchment Management Department that any drainage routes through the forest should be kept as natural as possible given the history of relatively large floods in the immediate area (Knox, 2003).

Figure 4-29: Aerial view of Hawaan Forest Estate

The US Soil Conservation Service (SCS) method was used to calculate peak flows and runoff hydrographs. In the planning phase of the development, six individual catchments 3-15 ha in area were identified upstream of the proposed estate (Knox, 2003). All except one southern catchment directed stormwater runoff through the site. In order to satisfy the requirements of the City, three rectangular drainage openings were left in the bottom of the boundary wall (Figure 4-30). A steel grid prevents unauthorised access to the estate – as well as intercepting any large debris. Smaller objects that enter the development are stopped by wooden trash racks that lie across all vegetated swales (Figure 4-31). The implemented stormwater management scheme was designed to optimise stormwater infiltration for a 5-year recurrence interval storm and operate at maximum capacity for a 20-year recurrence interval storm. Buffer strips and infiltration zones with average widths of 6 m were prescribed on non-developable areas. A further 5 m of the allotted 12 m road reserves, which form the access network of the development, were allocated for the use of swales. The roads were designed to usher stormwater runoff into the adjacent vegetated swales (Figure 4-32), the operation and maintenance of which is performed by the estate manager.

Figure 4-30: Rectangular drainage opening in the boundary wall at Hawaan Estate

Figure 4-31: Wooden weir to capture smaller objects in Hawaan Estate

Figure 4-32: Access road linked to a vegetated swale in Hawaan Estate

Figure 4-33: Small retention pond at the end of an access road in Hawaan Estate

Rain landing on the estate is initially detained in source controls such as roof gardens and soakaways which 'polish' and attenuate it before it is directed over the lawn into adjoining vegetated swales. The swales link to fourteen detention ponds distributed around the lower-lying eastern side of the estate (Figure 4-33) and showcased by an 'ornamental' pond at the entrance (Figure 4-34) (Knox, 2003). The volume of these detention areas ranges between 100 and 2500 m^3. They are connected to a large infiltration trench that runs north to south along the boundary of the development (Figure 4-35). This ensures that any overflow is evenly spread into the Hawaan Forest downstream. Records show that the overland flows have not changed subsequent to the development which illustrates the potential of a SuDS treatment train to manage the runoff in an aesthetically pleasing manner.

Figure 4-34: Ornamental pond at the entrance to Hawaan Estate

Figure 4-35: Large connecting infiltration trench in Hawaan Estate

4.3.3 Observations concerning SuDS treatment trains in South Africa

A number of lessons have been learnt through the two case studies:

i) A SuDS approach has the potential to enhance the investment potential of the development. People are naturally drawn to aesthetically pleasing and environmentally friendly surroundings.

ii) Developers should promote source control SuDS on private developments to ensure some primary attenuation and treatment of stormwater runoff prior to discharge into the road reserves.

iii) Ponds can perform a number of roles: attenuation, infiltration, silt control, water supply and amenity.

iv) Operation and maintenance requires a certain level of expertise which can be expensive.

4.4 Wetland System – Century City

The upmarket, multi-use Century City development in the suburb of Milnerton in the City of Cape Town was originally conceived in 1995 and is now well established (Figure 4-36). It is approximately 250 ha in area and was initially covered largely by invasive alien vegetation and degraded wetlands and salt pans. Currently the development includes: medium-high density residential, medium-high density commercial, public transport interchanges, educational facilities, internal private open spaces, as well as Africa’s largest shopping mall, a theme park and a multi-purpose constructed wetland totalling R16 billion in property investment (Century City Life, 2011). To date, 69% of the developable land has been utilised, with the remaining 31% (R11 billion at 2010 values) set to be developed by 2020 – most of which will be medium-high density commercial (CCPOA, 2011c; Century City Life, 2011).

The slogan, *"Live, Work, Play"* coined by the Century City Property Owners' Association (CCPOA) markets Century City as a relatively 'self-sufficient' environment.

Century City is situated on a natural low lying area of Cape Town known as the *Blouvlei*. The 'vlei' has been replaced by a constructed wetland is situated in the heart of the Century City development, and featuring as a natural locale. The wetland has been built around 'Intaka Island', *intaka* meaning 'bird' in the isiXhosa language. It is sixteen hectares in area, is home to 177 indigenous plant species and 120 bird species, has seven different natural habitats, and was awarded conservation status for its educational, self-guided nature trails for visitors in 2010. The multi-purpose constructed wetland aims to, *inter alia*, conserve a rare type of wetland and *Fynbos* habitat, preserve the breeding heronries of waterbirds, and naturally filter and purify water from the development's canals (CCPOA, 2011a,b,c; Liebenberg & Ralph, 2009).

4.4.1 Design of Century City wetlands

The wetland is comprised of four main treatment cells, two large seasonal salt pans, and an adjoining canal network (Figure 4-37). During the wetter half of the year – typically April to September – rainwater and resultant baseflows supplement the wetland through the canal network and underlying aquifer. Over the drier and hotter half of the year – typically October to March – treated sewage effluent from the nearby Potsdam wastewater treatment works (WWTW) was originally used to maintain the water levels in the wetland. The treated effluent was implemented with effect from December 2008, but needed to be halted early in 2010 due to a rapid increase in phosphorous levels throughout the wetland (Day & Ross-Gillespie, 2008). Instead, water from the canal is now pumped into the wetland in the summer season. Figure 4-38 illustrates the direction of the flow within the wetland.

The stormwater runoff entering the wetland is designed to pass through all four treatment cells every 72 days on average. Water from the canal is pumped into Cell 1 (Figure 4-39). It is then gravity fed through to the other three cells and treated through: sedimentation, filtration and biofiltration, adsorption, biodegradation, volatilisation, precipitation, plant-uptake, nitrification, and photosynthesis. The clean stormwater is subsequently discharged back into the canal where it can be used by residents and visitors for recreational purposes. The processes within each of the constructed wetland's treatment cells including the environmental benefits of the seasonal salt pans are described as follows:

i) **Cells 1 and 2** (Figure 4-39 & 4-40) – The first two cells in the wetland are partly covered with *P. australis* reedbeds and *Typha capensis* (*T. capensis*) bulrushes. These vegetation types grow relatively fast and are capable of absorbing significant quantities of phosphate, which is an essential nutrient for plant growth. They do, however, generate endogenous respiration and die off rapidly (Ekama *et al.*, 2007), which adds to the nutrient load in these cells. The clearing of dead biomass is therefore a critical maintenance procedure in these cells. Generally, stormwater that is discharged from Cells 1 and 2 has significantly lower phosphorous counts.

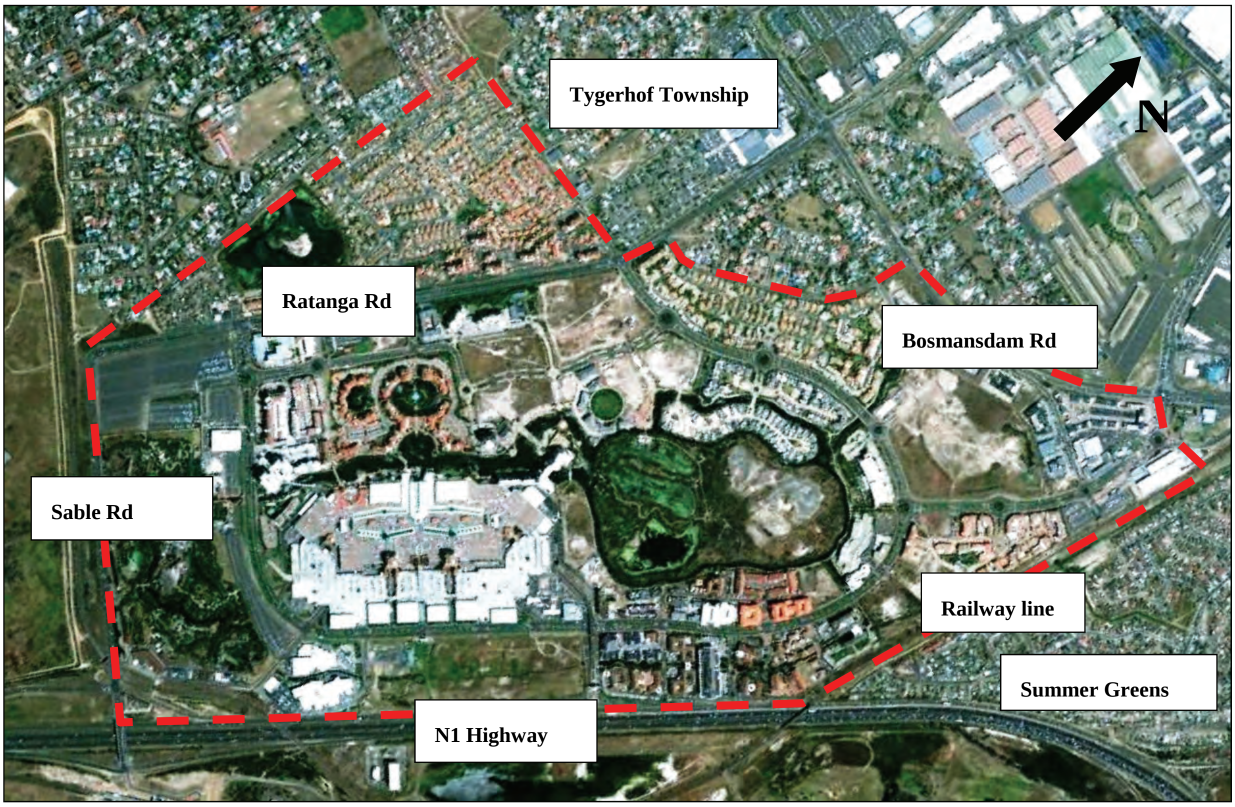

Figure 4-36: Aerial view of Century City development (Source: Google Earth, 2011)

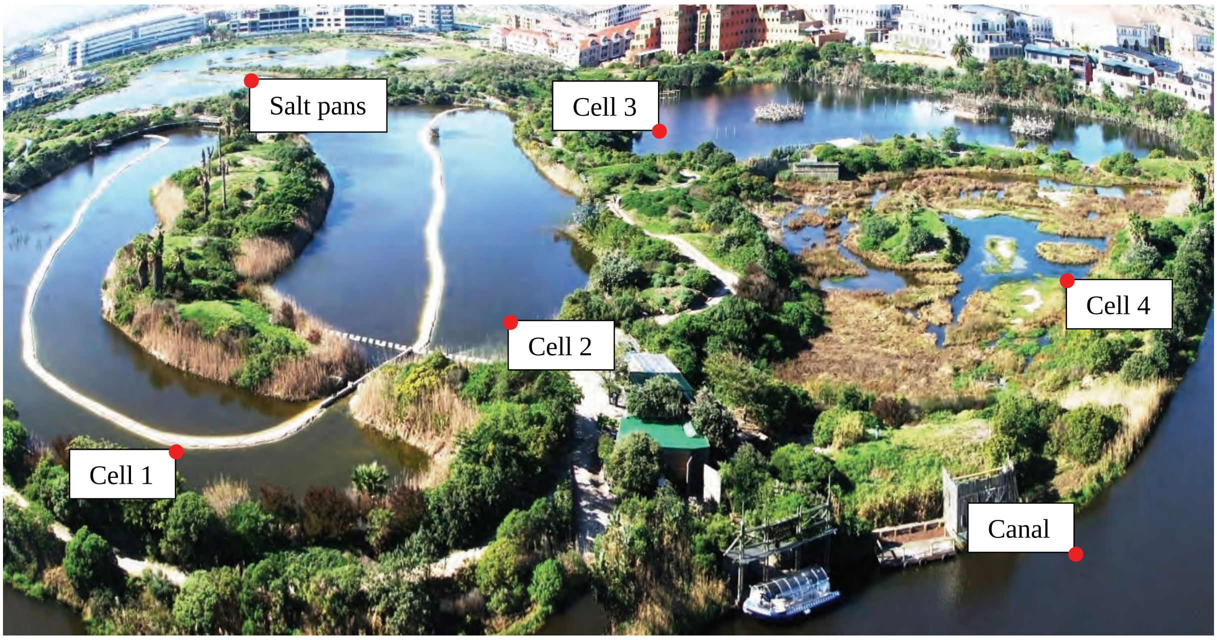

Figure 4-37: Panoramic view of the Century City constructed wetland

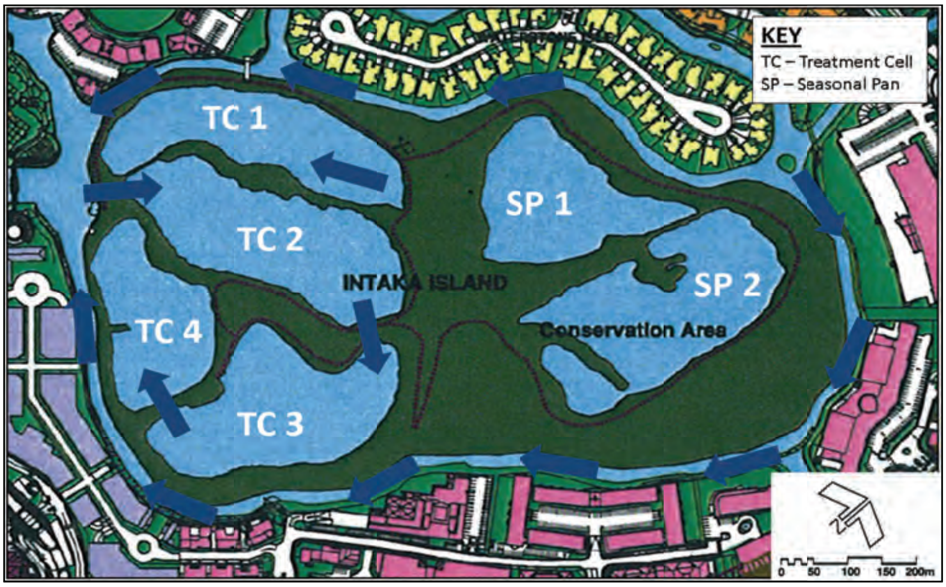

Figure 4-38: A plan view schematic of the Century City constructed wetland and treatment flow paths (CCPOA, 2009)

Figure 4-39: Cell 1 after routine dredging

Figure 4-40: Cell 2 during the wetland's construction phase

ii) **Cell 3 –** This cell has the characteristics of a retention pond, and is larger and deeper than the other treatment cells (Figure 4-41). Its relatively large surface area allows important aeration processes over the surface of the retained stormwater. The bacteria that break down nitrogenous compounds generally flourish in the aerobic zone of this environment, thus eradicating most nitrogenous compounds that enter this cell from Cells 1 and 2.

iii) **Cell 4 –** The fourth and final cell (Figure 4-42) is shallower than the other cells and is the most densely vegetated. Lower water levels in the cell ensure that stormwater is adequately aerated to encourage aerobic treatment processes. The vegetation provides the last remaining biological treatment targeting residual phosphates and nitrates that escaped the previous three treatment cells. Stormwater discharging from this final cell into the canal network is safe for recreational uses such as canoeing and punting, but not clean enough for potable purposes.

iv) **Seasonal Salt Pans:** The two seasonal pans are situated to the north-east of the four retention ponds on Intaka Island (Figure 4-41 and Figure 4-42). They are natural systems that were originally part of the pre-development low-lying Blouvlei area. They are sensitive to the relatively extreme climatic changes that are typical of the prevailing climate conditions. A mandate was therefore drafted by the CCPOA as part of the development's EMP to protect and preserve the seasonal salt pans as they were (CCPOA, 2011a,b). The pans dry out completely during the dry summer season, and fill with water to no more than 0.5 m during the wetter winter season. In the event of long rainfall durations and increased stormwater runoff volumes, excess stormwater is discharged into the canal network adjacent to both seasonal pans. The seasonal pans do not contribute substantially to the treatment of stormwater runoff, but control the salinity of underground aquifers, and benefit the development's amenity and biodiversity – also key elements of effective SuDS schemes.

Figure 4-41: Overlooking Cell 3, Canal Walk shopping centre and Table

Figure 4-42: Overlooking Cell 4 and the Knightsbridge residential quarters

4.4.2 Management of Century City wetlands

Two aspects of management in Century City have been prioritised higher than others, namely; (1) the safety and security of residents and daily users, and (2), and more pertinent for this study, the development's urban water system, referred to by the CCPOA as the *"bloodline"* of the development and called 'Canal Walk' – after which the shopping centre is aptly named.

By 2010, the urban water system in Century City had been operating for approximately fifteen years. The CCPOA coordinate a number of operation, monitoring and maintenance activities that are required to ensure the effective functioning of the urban water system, especially the vegetated systems such as SuDS options. These typically including three main components, namely: (1) routine operation and maintenance procedures, (2) a response-oriented task force to remedy irregular situations, and (3) *ad hoc* management interventions. Furthermore, there are four key management objectives stated in the development's EMP, to:

i) Provide a habitat for birds, particularly breeding water birds;

ii) Provide an aesthetically pleasing constructed wetland that symbolises a 'green lung';

iii) Cleanse stormwater in the constructed wetland, which can then be used throughout the canal network and for numerous irrigation requirements; and

iv) Provide the public with high quality recreational facilities and educational amenity (Blouvlei Environmental Committee, 2003).

In order to help them satisfy these environmental requirements, the CCPOA have employed the ecological specialists, the Freshwater Consulting Group (FCG), to monitor and review the performance of the constructed wetland and adjoining water bodies on a monthly basis, with focus predominantly given to the quality of water in the development, sediment data acquisitioning, and remedial measures linked to organism growth. The FCG also provide detailed monitoring reports of ecological activity in and adjoining the wetland system which is useful literature for future development planning. Each report focuses on the basic amenity and system dynamics of biomass and biodiversity in the constructed wetland and canal network. By 2011, nine reports written by the FCG had specified several environmental issues in the development and have resulted in major technical interventions throughout the development since 2008.

Water quality has been an on-going problem. In part this was because of the use of poorly treated sewage effluent to supplement water volumes during the dry summer months – now discontinued. Meanwhile human intervention led to the introduction of alien vegetation and fish species that required innovative removal measures to prevent widespread ecological destruction. Six of the more 'regular' maintenance procedures that are required for the wetland's treatment cells and adjoining canal network include:

i) Annual draining and dredging of wetland Cells 1, 2 and 3, followed by periodic re-design (minor and irregular) to allow improved flow distribution between cells;

ii) Annual removal of fish, typically Carp (*Cyprinus carpio*) as well as large numbers of Tilapia species and indigenous Cape Kurper (*Sandelia capensis*) from the artificial canals and treatment wetland system, using the pesticide 'Rotenone';

iii) Monthly addition of barley straw bales to selected areas of the urban water system which minimises the algal blooms and prevents sedimentation (Figure 4-43);

iv) Biweekly removal of invasive aquatic weeds and alga from water bodies, including: *Azolla filiculoides*, *Lemma gibba*, and *Cladophora sp*.;

v) Weekly cutting and removal of *Potamogeton pectinatus* from the beds and surface of the canal network; and

vi) Bimonthly pumping and removal of bird faeces (high in Ortho-phosphate and Total phosphate) from sludge sumps installed beneath the heronries (Figure 4-44) (CCPOA, 2011c, Day, 2008a,b).

Figure 4-43: Barley straw bales at canal network inlet in Century City

Figure 4-44: High phosphate producing heronries in Century City constructed wetland

Water quality data is typically collected on a monthly basis with additional *ad hoc* collections on a weekly basis if a particular aspect of water quality has been 'red-flagged' and requires more intensive monitoring (Liebenberg, 2011). The following key water quality criteria and general criteria are monitored monthly:

- Dissolved and total phosphorous concentrations;
- Chlorophyll-*a*;
- Turbidity (measured as Nephelometric Turbidity Units or NTUs, but also represented by Secchi depth and total suspended sediment values);
- Oxygen concentration;
- Ammonia concentrations;
- The presence of disease-causing bacteria (key indicator organisms are *Escherichia coli* and faecal coliforms);
- Phaeophytin analysis;
- Taxonomic identification and enumeration of phytoplankton;

- Rate of recovery of aquatic macroinvertebrate communities after Rotenone application; and
- Measurement of sediment quality and depth in the treatment wetland cells prior to and after draining of the cells (CCPOA, 2011c).

At the time of writing, the water quality appeared to be under control.

4.4.3 Major remedial interventions

There have been two major remedial measures carried out in the wetland over the past two years. Firstly, in order to manage the increase in Phosphorous throughout the constructed wetland, the inflow of treated effluent from the Potsdam WWTW was discontinued (Century City Life, 2011). The decision to stop the inflow was informed by the results of annual maintenance procedures that were carried out at the development's 1 Mℓ reservoir and pump system. The treated effluent input was effectively supplementing the constructed wetland with approximately 100-150 mm of additional water depth. This input was seen to be most essential during the dry summer seasons. However a water table study (Day, 2011) revealed that ceasing the input of treated effluent would have no drastic effects on water level fluctuations in the wetland and the adjoining urban water system. The impact of this decision has been reviewed over the past two summer seasons, but the results are inconclusive as a result of two major leakages in the system. Having remedied those problems, the first test for the fluctuation in the water level in the wetland will come in the summer season of 2011/12.

The second major remedial measure was the targeting of bird faeces in Cell 3. There have been no studies performed on the exact increase of phosphorous in the water bodies due to bird faeces but there is sound international evidence to suggest that bird faeces cause undesirably high levels of phosphorous in water (Day, 2011; Day, 2010a,b). This problem has been addressed by decreasing the number of heronries from five to three and by placing the newly constructed heronries on sludge collection sumps. Two heronries sit on 20,000 ℓ uPVC tanks that are submerged in the water; whilst the third rests on a square reinforced concrete wall that is also submerged. According to the Senior Environmental Manager of the wetland, this specific measure has decreased phosphorous concentrations throughout the wetland by hydraulically isolating bird faeces in the third treatment cell which can then be removed by pumping them out of the sumps every three months (Liebenberg, pers comm). Water quality measurements and visual evidence (Figure 4-45 and Figure 4-46) suggests that the wetland is functioning far better in 2011 than it had been in 2008 (Century City Life, 2011). Figure 4-45 and Figure 4-46 illustrate the extent to which the *A. filiculoides* (which flourished as a result of high nutrient levels) spread across the constructed wetland's treatment cells in 2008 (Figure 4-45), and the efficacy of improving water quality input (Figure 4-46).

Figure 4-45: The prevalence of *A. filiculoides* in the constructed wetland, 2008

Figure 4-46: The efficacy of fundamental management interventions, 2009

4.4.4 Observations concerning wetland systems in South Africa

A number of lessons have been learnt through this case study:

i) The use of treated sewerage effluent to supplement water in the wetland during dry periods needs to be carefully considered and monitored.

ii) A wetlands system of this magnitude requires on-going maintenance and monitoring.

iii) If correctly implemented and maintained a wetland system of this nature can make a major improvement to the amenity and biodiversity whilst simultaneously managing stormwater.

4.5 Summary

SuDS is a new approach to stormwater management in South Africa. As a result there are only a few sites in the country that have implemented a SuDS approach to stormwater management. Through monitoring these sites, a number of important lessons have been learnt. These lessons were used to inform the guidelines and helped to ensure that international experience and literature was appropriately translated for the South African context. There is however a need to identify sites to undertake detailed studies to further understand how best to implement SuDS in South Africa. This will require the monitoring of sites, both qualitatively and quantitatively, from inception to the end of operation – i.e. in perpetuity. This will help to develop a better understanding of: the local maintenance requirements; the water quality treatment efficiency of different SuDS options; local risk factors; the social context; and how each aspect affects the implementation of SuDS as a stormwater management technique in South Africa.

5. Conclusions & recommendations

Conventional stormwater management focuses largely on quantity (flow) management, by collecting runoff and channeling it to the closest watercourse. This has had a significant impact on the environment through the erosion of natural channels, siltation of water bodies and pollution resulting in environmental degradation. Sustainable Drainage Systems (SuDS) offers an alternative approach through designing for water quantity management; water quality treatment; enhanced amenity; and the maintenance of biodiversity. The approach has been widely adopted internationally with some good results.

While SuDS are starting to be implemented across South Africa, it was clear from the national workshops that there is still some degree of skepticism as to their effectiveness – particularly their performance during high intensity storms. Another restriction arises from the fact that a number of local authorities may still have by-laws in place which prevent their implementation. During the course of this study several research needs have been identified:

- The determination of local SuDS maintenance requirements. The development of an online SuDS database that captures information for different SuDS options from around South Africa would provide the basis for this research. While this is a relatively simple task, the upkeep and maintenance of this database is crucial to ensuring relevant information is collected so that in future detailed research may be conducted. This would go a long way towards informing and reducing the uncertainty that negatively impacts on and acts as a barrier to the wider use of SuDS locally.
- The development of simple tools which allow consultants from all disciplines to quickly and fairly value the environmental goods and services they will be providing or removing on their projects.
- An assessment of the risks associated with SuDS – and how these can be reduced.
- The determination of vegetation planting combinations for different conditions which has an impact on the maintenance requirements of a system as well as the goods and services which might be derived.
- The development of suitable technical decision support systems (DSSs) for South African conditions. This would need to include the identification of appropriate parameters for undertaking appropriate assessment/risk assessments to determine whether SuDS should and should not be used.
- The need to undertake long term monitoring of SuDS systems to test their efficacy in South African conditions. This will require the identification, instrumentation and ongoing monitoring of typical examples across South Africa.
- The results of this project should be promoted to smaller municipalities through a series of workshops.

- The Council for Scientific and Industrial Research (CSIR) should be engaged when they revise their Guidelines for Human Settlement planning and design to ensure that cognizance is taken of this new stormwater management paradigm.

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