K5/1826: Alternative technology for stormwater management

The South African Guidelines for Sustainable Drainage Systems

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Executive summary

Background

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 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 a summary Literature Review (in the research report) as well as these South African Guidelines for Sustainable Drainage

Systems – hereafter referred to as the South African SuDS Guidelines, or simply “the Guidelines”

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, Kwa-Zulu 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-G in the SuDS Guidelines.

The SuDS / WSUD Website

Initially it was envisaged that the outputs 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; it is difficult to update; and a DVD 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.
- The South African Guidelines for Sustainable Drainage Systems (The South African SuDS Guidelines) (this document).
- 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).

The South African Guidelines for Sustainable Drainage Systems

As previously mentioned, the South African SuDS Guidelines were compiled through summarising and translating for South African conditions the key material from over 27 international manuals, numerous conference and journal papers, and a number of books. These guidelines were designed to assist practitioners with the design, operation and maintenance of SuDS in South Africa. There is unfortunately limited experience and data available locally; therefore the parameters quoted in this guideline have all been collected from international literature. These parameters are dependent on a variety of factors including, *inter alia*, climate, pollution composition and concentration, technical design, and maintenance. Local conditions should thus be carefully considered before the use of these values.

Chapter 1: Introduction to SuDS

Chapter 1 provides an overview of SuDS. The chapter details how and why there has been a shift internationally in the management of stormwater. The chapter also briefly highlights: the design principles of SuDS, the importance of the ecosystem and the services it provides. The chapter ends by noting that designing stormwater management systems using SuDS ideally requires an interdisciplinary approach which could, but does not always, require a vast range of professionals.

Chapter 2: Design criteria and methods

Chapter 2 provides guidance on the design criteria and methods. The chapter provides guidance as to what designers should consider for different design storms. It highlights a number of simple formulae that may be used in developing conceptual designs, however stormwater experts would be expected to use more sophisticated models.

Chapters 3-5: SuDS options

Chapters 3–5 detail each of the twelve 'families' of SuDS options. For ease of reference they are grouped as follows:

- ***Source Controls*** **(Chapter 3)** are used to manage stormwater runoff as close to its source as possible – generally within the boundaries of the property.
- ***Local Controls*** **(Chapter 4)** are used to manage stormwater runoff as a second 'line of defence' typically in public areas such as roadway reserves and parks.
- ***Regional Controls*** **(Chapter 5)** are used to manage stormwater runoff as a last 'line of defence'. They are generally large-scale interventions which are constructed on municipal land.

The grouping of the options is not meant to be prescriptive and it is possible that most could be used at a different control level, e.g. wetlands could be a source, local or regional control. The overview includes, *inter alia*: general overview, design guidance, guidance on operational and maintenance requirements, and a list of advantages and disadvantages of the SuDS option. The twelve SuDS 'families' are:

Source Controls

- ***Green roofs*** are vegetated roofs (Wanielista *et al.*, 2008; Stahre, 2006).
- ***Rainwater Harvesting*** refers to the temporary storage and reuse of rooftop and/or surface runoff (Melbourne Water Corporation, 1999).

- ***Soakaways*** are usually excavated pits that are packed with course aggregate and other porous media and are used to detain and infiltrate stormwater runoff from a single source.
- ***Permeable pavements*** comprise 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.

Local controls

- ***Filter strips*** are vegetated areas of land that are used to manage shallow overland stormwater runoff through filtration (Debo & Reese, 2003).
- ***Swales*** are shallow grass-lined channels with flat and sloped sides that are used to convey stormwater from one place to another. They typically remain dry between rainfall events (Mays, 2001; Parkinson & Mark, 2005).
- ***Infiltration trenches*** are excavated trenches which are lined with a geotextile and backfilled with rock or other relatively large granular material (Hobart City Council, 2006). They are typically designed to receive stormwater runoff from adjoining residential properties**.**
- ***Bio-retention areas*** are landscaped depressions used to manage stormwater runoff through several natural processes such as filtration, adsorption, biological uptake and sedimentation (Debo & Reese, 2003).
- ***Sand filters*** usually comprise of an underground sedimentation chamber connected to a filtration chamber in which stormwater runoff is temporarily stored before being filtered through a sand filter (Woods-Ballard *et al.*, 2007).

Regional controls

- ***Detention ponds*** are relatively large depressions that temporarily store stormwater runoff in order to reduce the downstream flood peak (Woods-Ballard *et al.,* 2007).
- ***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 (Debo & Reese, 2003; Mays 2001).
- ***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). They can be aesthetically pleasing and provide a vibrant wildlife habitat.

Appendices

- ***Appendix A*** presents a SuDS site design framework.

- ***Appendix B*** is a table summarising the estimated pollutant removal capacities of selected SuDS options from international literature.
- ***Appendix C*** comprises a series of standard design drawings for each of the SuDS options presented in the guidelines.
- ***Appendix D*** provides an overview of the need for, and the way of, determining the life cycle costs of stormwater management.
- ***Appendix E*** describes the SuDS Economic Model (SEM) and its appropriate use.
- ***Appendix F*** supplies users of the SEM with basic life cycle costing and maintenance data for both SuDS and conventional systems.
- ***Appendix G*** is the SuDS Conceptual Design poster.
- ***Appendix H*** is the 'Working SuDS into the city' poster.

Conclusions

Conventional stormwater management focuses largely on quantity (flow) management, by collecting runoff and channelling 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 internationally, however there is still some resistance to their use in South Africa. These guidelines are is intended to assist practitioners to identify and flag opportunities where the use of SuDS is appropriate and may add to the value of the urban environment.

Cape Town
June 2012

Appropriate use of the guidelines

These guidelines are designed to assist practitioners with the design, operation and maintenance of Sustainable Drainage Systems (SuDS) in South Africa. They are not meant to be prescriptive but rather to assist practitioners identify and implement opportunities for improving the management of stormwater in South Africa.

There is very little data available locally as to the efficacy of SuDS in South Africa. As a result a number of parameters quoted in this guideline have been collected from international literature. These parameters are dependent on a variety of factors including, *inter alia*, climate, pollution composition and concentration, technical design, and maintenance. As a result they should be considered only a guide to the relative performance of selected SuDS options. Where local data is available it should be used instead.

Neither the Water Research Commission (WRC) nor the authors take any responsibility for any loss of life or damage to property that might result from the use of these guidelines.

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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 scenario – 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 to SuDS

There has been growing interest in the promotion of sustainable development amongst local and national governments throughout the world – and this includes the control of stormwater runoff (Ellis, *et al.* 2006). Sustainable Drainage Systems (SuDS) offer an alternative approach to conventional drainage practices by attempting to manage surface water drainage systems holistically in line with the ideals of sustainable development. They achieve this by mimicking the natural hydrological cycle, often through a number of sequential interventions in the form of a 'treatment train' as will be discussed in Section 1.1. The key objectives of the SuDS approach are the effective management of: stormwater runoff quantity, quality and the associated amenity and biodiversity which may be described in the form of a hierarchy (Figure 1.1) where each level contributes to an improved, more sustainable drainage system. Simply put, there is no point focusing on biodiversity if life and property have not already been protected.

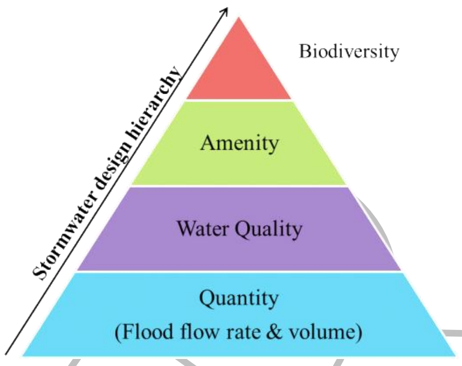


Figure 1.1: The stormwater design hierarchy

Prior to the design of any stormwater system there are a number of important considerations including:

- The local hydrological cycle;
- The local ground conditions – including unusual geological formations;
- The different challenges of development on green-field versus brown-field / retro-fitted sites;
- The impact of different types of development;
- Compliance with the law – particularly local by-laws which are often quite specific with respect to allowable development.

Whilst each of these will be mentioned in these guidelines they are largely outside the scope of the document which is focused more on the available technology options. Chapter 1 (this one) introduces the notion of sustainable drainage and describes important design and management concepts associated with SuDS. Chapter 2 describes the basic design approach. Chapters 3, 4 and 5 present twelve 'families' of SuDS options / technologies in the categories of 'Source Controls', 'Local Controls', and 'Regional Controls' respectively. Appendix A presents a SuDS conceptual design framework. Appendix B presents the expected pollutant removal for various SuDS options. Appendix C presents typical design details for various SuDS options. Appendix D gives a brief introduction to life cycle costing for stormwater management. Appendix E describes a costing model that is available as part of the guidelines. Appendix F provides supplementary data for the aforementioned model. Appendix G is the 'SuDS conceptual design poster'. These SuDS Guidelines are intended for use by all practitioners working in the field of stormwater management and promote the notion of interdisciplinary partnerships at all levels and phases of development where applicable.

1.1 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)

Development normally reduces the natural permeability characteristics of land by replacing free draining surfaces with impermeable surfaces such as roofs, roads and paved areas that are typically drained by 'hard' infrastructure (i.e. pipes and lined channels).

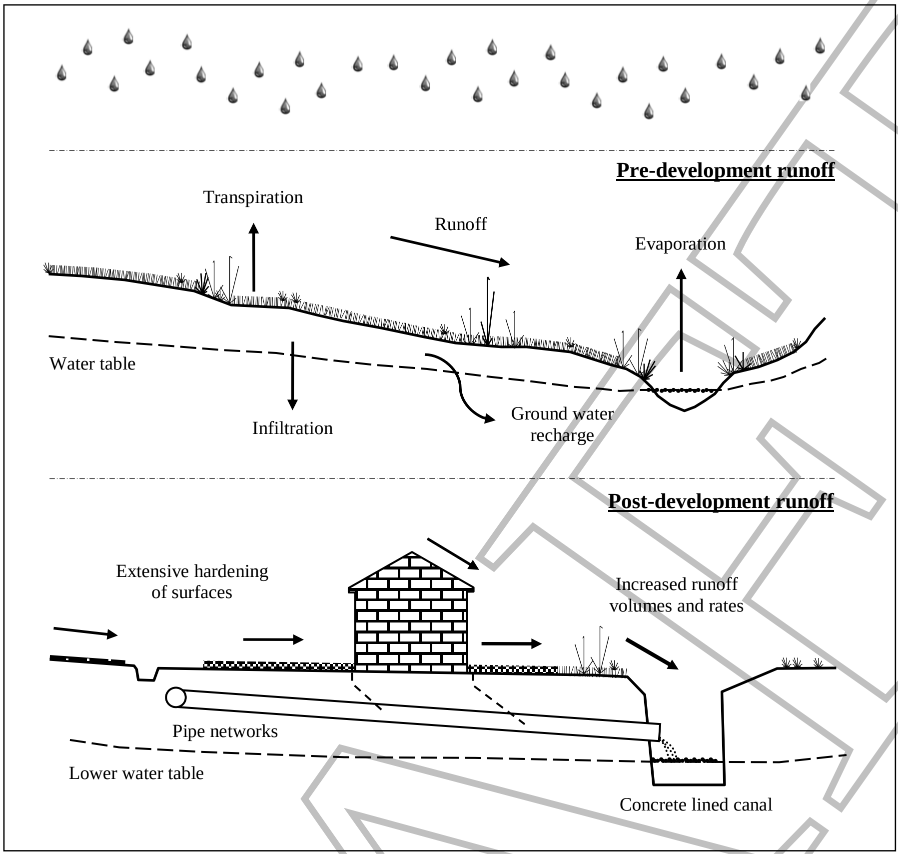


Figure 1.2: Typical pre- and post-development runoff scenarios with the conventional approach to stormwater management (after Wilson *et al.*, 2004; Haskins, 2010; Van Wieringen, 2010)

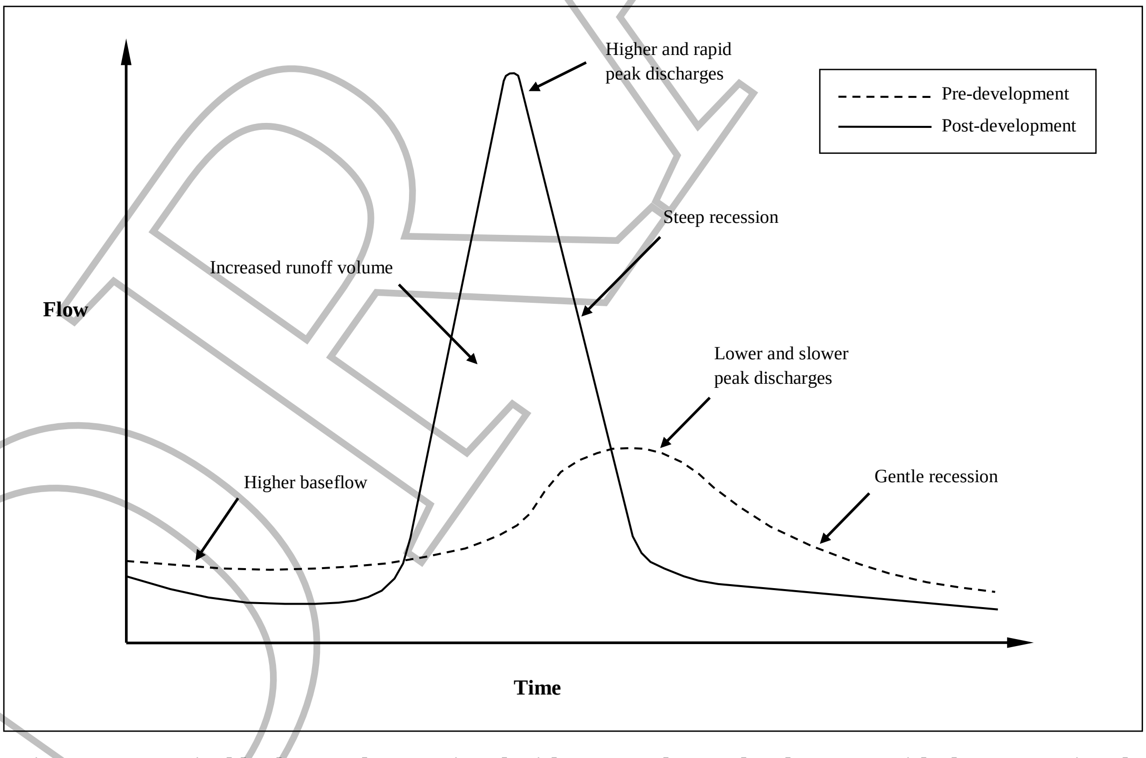


Figure 1.3: Typical hydrographs associated with pre- and post-development with the conventional approach to stormwater management (after Reed, 2000; Wilson, *et al.*, 2004)

Development also leads to a general loss of vegetation, often indigenous, which reduces stormwater buffering through ponding, interception storage, as well as evapotranspiration. Subsoil strata are often compacted during development thereby reducing their infiltration potential.

Conventional drainage systems are generally focused on eliminating local flood nuisances and largely ignore the need to preserve or improve water quality and the associated aspects of amenity and biodiversity. They frequently have an adverse impact on flooding within the wider catchment and ignore the potential for the use of stormwater as a water resource. Figure 1.2 is a simplified schematic that illustrates typical pre- and post-development scenarios with the conventional approach to stormwater management. The associated hydrographs are illustrated in Figure 1.3. Under post-development conditions the likelihood of extreme flooding and channel erosion downstream of developments is significantly increased. Less stormwater infiltration into the soil strata decreases the recharge of the underlying aquifers and hence baseflow discharge into receiving watercourses. Overland discharge is also generally considerably more polluted than baseflow discharge. The overall outcome is damage to the receiving waters and loss of biodiversity. The situation may be exacerbated by the heat-island effect associated with many large cities which may result in more intense stormwater runoff over those areas.

1.2 SuDS processes

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

i) Quantity (flow and volume);

ii) Quality;

iii) Amenity; and

iv) Biodiversity.

Each of these unit processes is briefly described in the following sections (after Wilson *et al.*, 2004 and Woods-Ballard *et al.*, 2007):

1.2.1 Stormwater quantity management

- **Rainwater harvesting** – the direct capture of stormwater runoff, typically from rooftops, for supplementary water uses on-site;
- **Infiltration** – the soaking of stormwater runoff into the ground thereby physically reducing the volume of stormwater runoff on the surface;
- **Detention** – the slowing down of stormwater runoff before subsequent transfer downstream;
- **Conveyance** – the transfer of stormwater runoff from one location to another;
- **Long-term storage** – the volumetric control of stormwater runoff in a specified infiltrating area that will drain very slowly; and
- **Extended attenuation storage** – the retention of stormwater runoff to protect receiving watercourses in the event of flooding if long-term storage and additional infiltration are not feasible on site.

1.2.2 Stormwater quality management

- **Sedimentation** – the removal of sediment particles attached to pollution in stormwater runoff by reducing flow velocities to ensure sediment particles fall out of suspension;
- **Filtration and biofiltration** – the filtering of stormwater runoff pollutants that are conveyed with sediment by trapping these constituents on vegetative species, in the soil matrix or on geotextiles;
- **Adsorption** – the process whereby stormwater runoff pollutants bind to the surface of aggregate particles. Types of adsorption include cation exchange, chemisorption and absorption;
- **Biodegradation** – the degradation of organic pollutants in stormwater runoff by microbes;
- **Volatilisation** – the conversion of stormwater runoff compounds to gas or vapour typically as a result of heat, chemical

reaction, a reduction of pressure or a combination of these;

- **Precipitation** – the removal of soluble metals in stormwater runoff through chemical reactions between pollutant constituents and aggregate in the control structure to form a suspension of insoluble precipitates;
- **Plant-uptake** – the removal of stormwater runoff nutrients and metals through uptake by plants;
- **Nitrification** – the oxidisation of ammonia and ammonium ions in stormwater runoff by microbial factions to form nitrite and nitrate; and
- **Photosynthesis** – the breakdown of organic pollutants in stormwater runoff through extended exposure to ultra-violet light.

1.2.3 Amenity management

- **Health and safety** – the planning and implementation of control measures to prevent the injury or death of people including, *inter alia*, safe design practices, alert medical aid teams, and cooperative communities;
- **Environmental risk assessment and management** – the assessment and management of the various environmental sub-components to ensure their longevity;
- **Recreation and aesthetics** – the provision of interactive and attractive structural and non-structural components by protecting, shaping and creating open spaces and enhancing the visual appearances of the specified systems; and
- **Education and awareness** – the dissemination of knowledge about stormwater management amongst interested and affected parties, through proactive campaigns, field trips and interactive stakeholder agreements.

1.2.4 Biodiversity management

- **Protection** – the identification and preservation of indigenous flora and associated fauna;
- **Maintenance of habitat** – the removal of invasive species; and
- **Monitoring –** the monitoring of the fauna and flora, to ensure early intervention when problems arise.

1.3 SuDS selection

1.3.1 Selection basics

It is important to understand that SuDS generally embrace a number of options that are arranged in a treatment train. In other words, stormwater is managed through a series of unit processes (see Section 1.2) in much the same way as, for example, wastewater is treated in a treatment works. Twelve families of SuDS options are presented here. They each incorporate a variety of treatment processes with considerable overlap. The linking of these together in the form of a treatment trains is the subject of Section 2.1. The selection of any particular option is determined by the unique characteristics of the site. It is unlikely that all options will be applicable and / or effective on any one site. It is thus important that the advantages and limitations of each option should be identified during the planning and design phases. Wilson, *et al.* (2004) and Woods-Ballard *et al.,* (2007), identify seven basic selection criteria:

i) Current and future land use characteristics;

ii) Site characteristics and utilisation requirements;

iii) Catchment characteristics;

iv) Stormwater runoff quantity (peak flow and flood volume) requirements;

v) Stormwater quality requirements;

vi) Amenity requirements; and

vii) Biodiversity requirements.

Appendix G provides a '*SuDS Conceptual Design*´ matrix that may be used in the design process to identify the most appropriate technology based on the following criteria: site suitability; life cycle cost; amenity and biodiversity value; ability to manage quantity; and ability to improve water quality. Further guidance is supplied in Chapter 2.

There are four key intervention points ('coaches') in the treatment train, each having slightly different combinations of SuDS options to control the stormwater:

i) **'Good housekeeping'** to ensure that as much as possible is done to minimise the release of pollutants – such as solid waste – into the environment where it may subsequently be transported by stormwater.

ii) **Source Controls** manage stormwater runoff as close to its source as possible, usually on site. Typical SuDS options include: green roofs, rainwater harvesting, permeable pavements and soakaways.

iii) **Local Controls** manage stormwater runoff in the local area, typically within the road reserves. Typical SuDS options include: bio-retention areas, filter strips, infiltration trenches, sand filters and swales.

iv) **Regional Controls** manage the combined stormwater runoff from several developments. Typical SuDS options include: constructed wetlands, detention ponds and retention ponds.

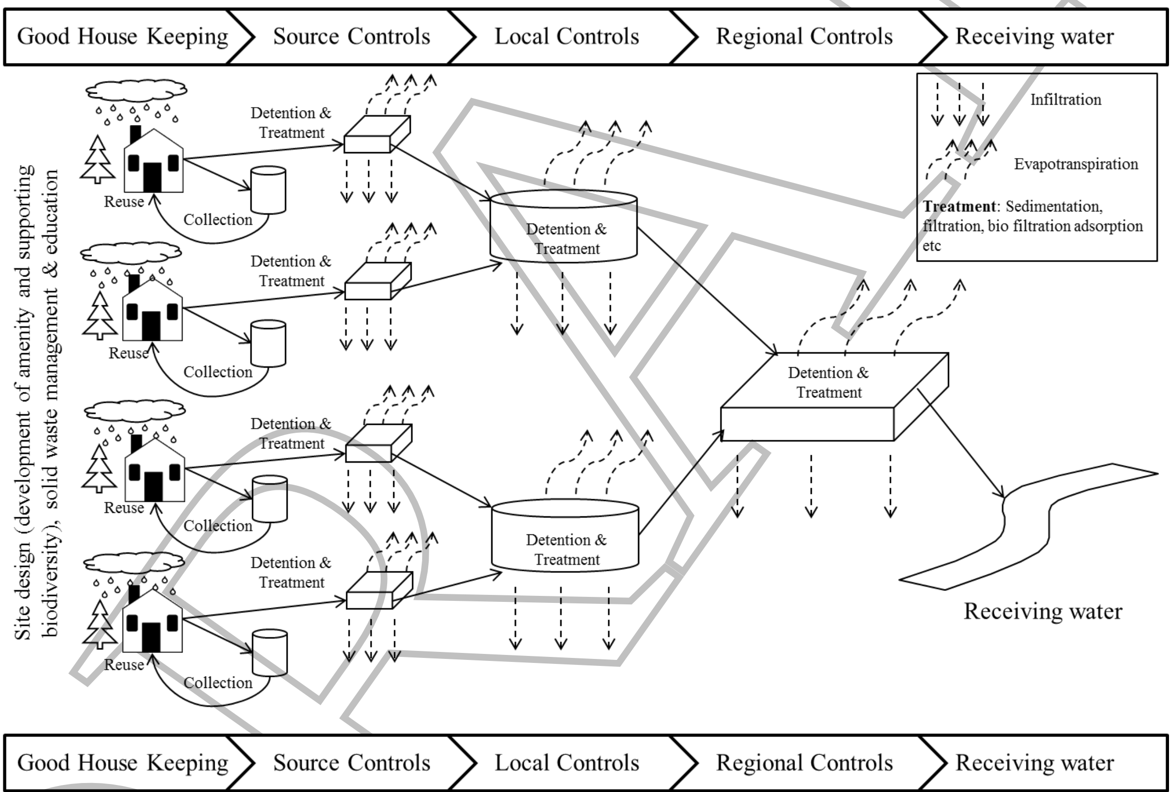


Figure 1.4: SuDS treatment train schematic

Figure 1.4 depicts a SuDS treatment train schematic illustrating the relationship between the four SuDS interventions. SuDS treatment trains should prioritise: (1) water quality treatment for low flows; and (2) attenuation and volume control for high flows. Furthermore, the number and size of the SuDS treatment train components depends on: (1) the sensitivity of receiving watercourses or other environments; (2) the size of contributing catchments upstream; and (3) the expected pollutant concentrations in stormwater runoff inflows (Woods-Ballard *et al.*, 2007). Whilst the different SuDS options tend to be associated with a particular point in the treatment train, it is often possible to utilise them elsewhere depending on the site. For example, constructed wetlands are generally regarded as a regional control but they may also be used as an effective source control, as in the form of a pocket wetland in a residential complex. A more comprehensive review of the theory of SuDS treatment trains and their application is included in Section 2.4.

1.3.2 Ecosystem services

According to the American Society of Landscape Architects (2008), 'ecosystem services' are defined as "*all possible goods and services that benefit human livelihoods, which are produced by ecosystem processes involving the interaction of living environmental elements"*. The link between the philosophy of the SuDS approach and its practical application is related to the promotion of ecosystem services. These services can be monitored as performance criteria to indicate whether a SuDS treatment train is functioning in a sustainable manner. The objective should be to protect, restore and improve pertinent ecosystem services on site. The following eight ecosystem services are the ones most likely to be promoted through the use of SuDS (after American Society of Landscape Architects, 2008):

i) **Regulating the climate** – maintaining an acceptable balance of atmospheric gases at historic levels and eliminating or minimising greenhouse gases in order to regulate local temperatures, precipitation and humidity;

ii) **Water and air purification** – the removal and reduction of pollutants in water and in the air;

iii) **Regulating water supply** – the storing and provision of water within artificial storage facilities, watersheds and aquifers;

iv) **Erosion and sediment control** – retaining soil within a specified environment through structural protection against damage from erosion and siltation processes;

v) **Hazard mitigation** – reducing the likelihood of and vulnerability to damage from extreme rainfall events, flash floods and storm surges;

vi) **Habitat functions** – providing a suitable habitat for refuge and reproduction of vegetative species and wildlife, thereby contributing to nature conservation;

vii) **Waste treatment** – the decomposition of waste compounds and the recycling of associated nutrients; and

viii) **Human health, well-being and cultural benefits** – enhancing physical, mental and social well-being as well as improving cultural, educational, aesthetic and spiritual experiences through interactions with nature.

1.3.3 Risk assessment

While SuDS may offer a range of valuable ecosystem services it is important to consider the risks of implementing a SuDS system. This is especially important in South Africa where stormwater in both formal and informal areas may be contaminated by sewage. It is therefore important that practitioners consider the composition of the stormwater in their area, including all chemical and biological pollutants, and ensure that their designs do not unduly increase the risk to public health and safety.

In line with conventional stormwater design, a risk assessment based on the hydraulic design should also be undertaken.

1.4 Interdisciplinary partnerships

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

1.4.1 Role players in SuDS

The ideals of sustainability dictate that a successful design team should incorporate many disciplines, of which the 'stormwater engineer' is simply one member. Different projects will require different combinations of professionals to be successful. The bigger and more complicated the project, the bigger and more diverse the team should be. Urban practitioners are thus encouraged to establish interdisciplinary partnerships to add value to the various aspects of stormwater design and management (Ellis *et al.*, 2006). Such an interdisciplinary partnership may be comprised of any or all of the urban design and management professionals listed in Table 1.1 (listed alphabetically).

Table 1.1: Potential human capital for SuDS interdisciplinary partnerships

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

1.4.2 'Sustainable development' and SuDS

'Sustainability' and 'Sustainable development' have become buzzwords in the 21st Century, especially in the urban infrastructure design and management sector. Brundtland *et al.* (1987) define sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". According to Hjorth & Bagheri (2006), it is often misconceived as an 'end state' and perceived as a rigid project target to be achieved in an allotted time-frame. Sustainable development, however, should not be viewed as a project that has an end state. It is neither the state of the system nor an attainable target, rather an ideal. It is an ongoing process which inter-relates aspects of economy, environment, society and other technicalities. O'Regan & Moles (1997) suggest that conventional practices in environmental management for one, fail to manage the complexities of environmental systems which has resulted in a surplus of misguided paradigm shifts. They suggest that common errors and undesirable side effects in urban management are often a result of the inability of decision-makers to understand the underlying structure of the system of which they are a part. The design and management of urban infrastructure in South Africa, and urban drainage practices in particular, require a shift from fragmented 'service provision' to 'holism'. According to Hjorth & Bagheri (2006) and Senge, *et al.* (2000), such a shift requires the yielding of linear and mechanistic thinking to non-linear and organic thinking – or 'systems thinking'. This places emphasis on management seeking to understand the relationships between the various components of the urban drainage system.

2. Design criteria and methods

This section introduces a framework for effective drainage design and management. Underlying this framework is (CSIR, 2000a,b):

- The need to protect the health, welfare and safety of the public, and to protect property from flood hazards by safely routing and discharging stormwater from developments;
- The quest to improve the quality of life of affected communities;
- The opportunity to conserve water and make it available to the public for beneficial uses;
- The responsibility to preserve the natural environment;
- The need to strive for a sustainable environment while pursuing economic development; and
- The desire to provide the optimum methods of controlling runoff in such a way that the main beneficiaries pay in accordance with their potential benefits.

The management of stormwater is a complex task and practitioners need to carefully consider all the associated risks in the light of:

- The goals of the design (what it aims to achieve)
- The maintenance level (Appendix D);
- Costs (Appendix F); and
- The sustainability of the proposed drainage design.

Subsequent sections will look at the various SuDS options and give guidance as to their likely performance against these three criteria. A SuDS Conceptual Design Framework (Appendix A) is included as an addendum to help guide the design process.

2.1 Treatment train design

SuDS design includes all the various aspects that link together to control and manage stormwater with the greatest efficiency possible. The purpose of this section is to briefly describe how a SuDS treatment train is developed for any particular situation.

In Section 1.3 it was mentioned that the management of stormwater cannot be accomplished using a single SuDS option, it requires a treatment train – also called a 'management' train. This 'train' can have any number of 'coaches', but it is convenient to conceive of four main groups which may be called: Good Housekeeping, Source Controls (Section 3), Local Controls (Section 4) and Regional Controls (Section 5). These are schematically illustrated in Figure 1.4. A first estimate of the typical number of 'coaches' (components) required to provide sufficient treatment is provided in Table 2.1.

Table 2.1 Typical numbers of treatment train components (Woods-Ballard *et al.*, 2007)

Receiving water sensitivity / **Catchment Characteristic**	**Low**	**Med**	**High**
Roofs only	1	1	1
Residential, roads, parking areas and commercial zones	2	2	3
Refuse collection areas, industrial areas, highways, loading areas, truck stops	3	3	4

In an attempt to maintain pre-development conditions, stormwater runoff should be controlled and treated as close to its source as possible. The collection, storage, use, infiltration and evapotranspiration processes inherent in many source SuDS controls (Section 3) are particularly useful in mimicking natural drainage characteristics. If the stormwater cannot be handled on site, the next link in the management train local SuDS controls (Section 4) which attempt to manage all the stormwater generated in a local area. Where stormwater is to be conveyed from one place to another, more 'natural' channels such as filter strips or swales are preferred to pipes and concrete-lined canals which speed up the flow and provide little water quality benefit. Regional SuDS controls (Section 5) represent the last 'line of defence' for the management of the stormwater before it is discharged to the receiving waters. The basic design process may be summarised as follows:

i) Carry out a preliminary analysis of the amount (volume and flow) and the quality of stormwater to be treated.

ii) Map out the preferred flow path/s – with preference being given to overland routes. This may differ between the minor system and the major system (Section 2.2).

iii) Determine the number, type and location of the various SuDS options in a treatment train. Generally, the performance of the treatment train is related to the number of SuDS options that the stormwater passes through. Multi-component treatment trains can be more readily designed to remove a wide range of pollutants by utilising different treatment processes. Furthermore, the greater the number of SuDS interventions, the smaller the risk of a total system failure.

iv) Determine the performance of each of the different SuDS options in the treatment train for each of a variety of design scenarios ranging from the smaller, more frequent storms to the larger, less frequent storms. The SuDS treatment train would be expected to treat the entire pollution load from the small, very frequent storms; handle the peak flow and possibly volume for a designated 'design storm'; and survive the very largest infrequent storms without significant damage.

v) Aggregate the contributions from each of the elements in the SuDS treatment train and compare with the stormwater management objectives. These should ideally be the pre-development conditions but it is possible that the objectives may have been relaxed by an agreed performance standard determined by the local authority. If the design meets the objectives and is agreed to by all parties, detailed design follows, otherwise the designer needs to return to step iii) and try out other treatment train options.

vi) Once a number of potential treatment train solutions have been found, they must be costed to determine the relative life-cycle costs (Appendix D); and

vii) The team needs to make a decision!

It is also important to recognise that the design of any SuDS treatment train is directly linked to the anticipated long-term management plan. This aspect is covered in more detail in Appendix D.

The following four international design manuals give considerable detailed guidance for the design of treatment trains and the associated SuDS options (listed alphabetically). Links have been provided at www.wsud.co.za. The various SuDS options are summarised in Chapters 3-5 of this document:

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

ii) North Carolina Division of Water Quality, (2007). *Stormwater Best Management Practices Manual*, NCDWQ, North Carolina, United States of America

iii) Southeast Michigan Council of Governments, (2008). *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers*, SEMCOG, Michigan, United States of America

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

2.2 Design events

A common – but not the only – way of designing SuDS systems is through the consideration of a number of 'design storms'. The design objective is different for each storm frequency. For example, small storms should be fully infiltrated on site where possible, whilst very large storms should be managed in such a way to minimise damage.

Figure 2.1 gives a conceptual SuDS design framework. It is a plot of peak flow rate versus the storm recurrence interval, RI (the reciprocal of frequency of exceedance). Two curves are indicated: the first is labelled 'Pre-development' and refers to an idealised relation between peak flow rate and storm recurrence interval for a theoretical catchment that is still in its natural state. As can be seen, no flow is anticipated for low-recurrence interval, i.e. very small storms. Precipitation is totally absorbed through a combination of interception storage and infiltration. A point is reached however where the rainfall becomes sufficient – through a combination of intensity and duration – to result in runoff. Larger storms will generally result in larger peak runoffs trending to a theoretical maximum as defined by the Regional Maximum Flood (RMF) or Probable Maximum Flood (PMF). The second curve is labelled 'Post-development' and refers to the situation associated with most current development. Hardening of surfaces and improving the conveyance of drainage channels results in flow for smaller storms compared with the pre-development situation, and higher flows for almost all larger storms. It is only in the case of extreme events that the difference between peak flow rates emanating from the pre-development and post-development situations becomes insignificant as the surface becomes completely saturated – thereby reducing intervention storage and infiltration to zero – whilst the flow paths become very similar. One of the objectives of the SuDS approach is to bring the peak flow rates (and associated volumes) back to the pre-development situation. It simultaneously attempts to meet the objectives of water quality, provide for amenity and preserve bio-diversity. This makes it inherently more complex than conventional design which typically has only two primary objectives: minimising inconvenience through the minor – usually piped – system, and minimising damage to property and potential loss of life through the major – usually overland flow – system.

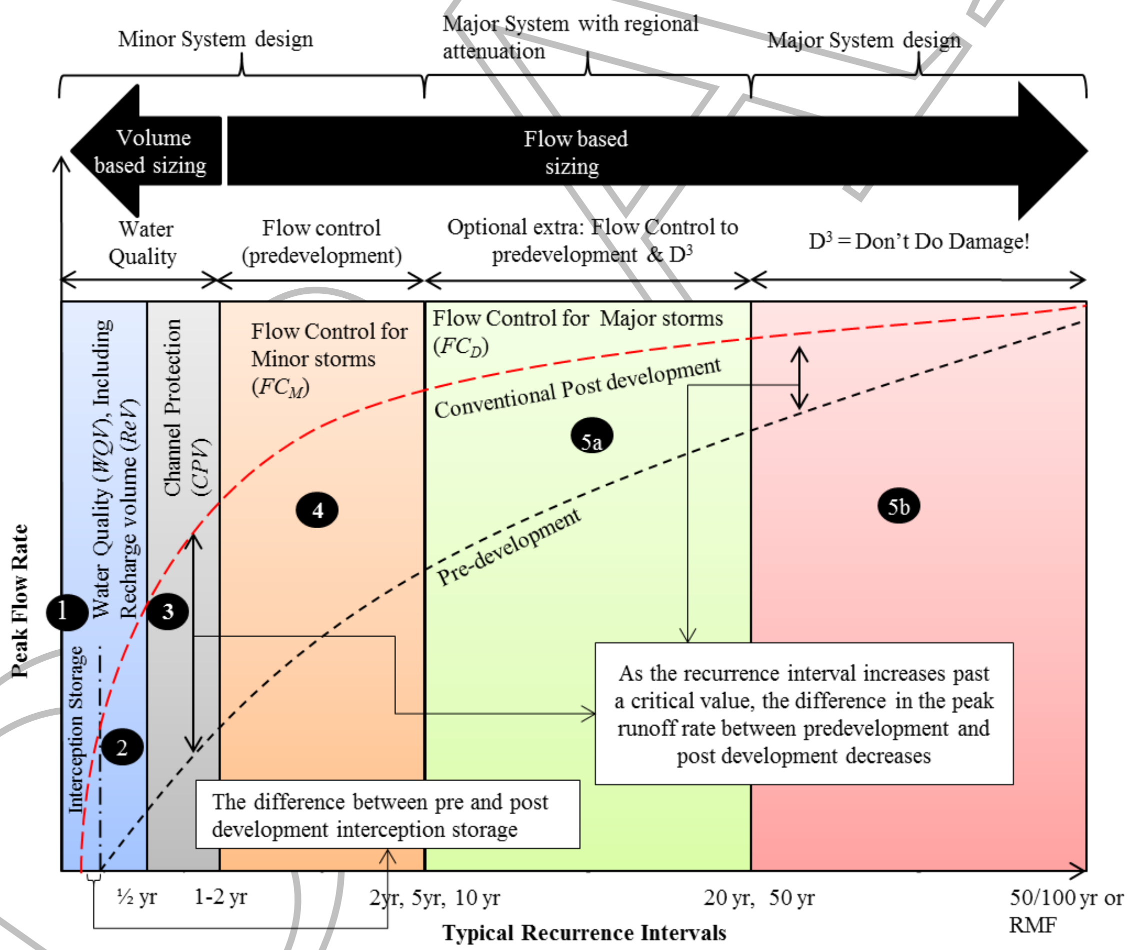


Figure 2.1: Conceptual stormwater design framework

Figure 2.1 indicates five distinct design 'zones' that need to be considered for SuDS design:

i) All precipitation is absorbed through interception storage and infiltration in Zone 1.

ii) As the storm intensity increases, the focus (in Zone 2) moves to the management of runoff quality and quantity.

iii) It is often very difficult to handle water quality issues for all but small storms; past a certain threshold the emphasis starts to move to one of channel bed protection (Zone 3).

iv) There is still a need to minimise inconvenience so SuDS must give the equivalent peak overland flow protection offered by conventional systems beyond that achieved in Zones 1-3. This is covered in Zone 4.

v) SuDS need to be designed for major events just like conventional systems. Zone 5 may be divided into two: Zone 5a where peak flows may be reduced to pre-development, and Zone 5b where the emphasis moves to minimising damage to property and potential loss of life (D^3 = "Don't Do Damage"!)

Overall, Zones 1-4 cover the equivalent of conventional 'minor' system design whilst Zone 5 covers 'major' system design. In Zones 1 and 2 the focus is on the improvement of water quality through volume-based sizing of SuDS options. Zones 3-5 focus on flow control. Table 2.2 defines some key terms that appear in Figure 2.1. In Table 2.3, these are linked up with the different zones and types of management. Additional explanation follows.

2.2.1 Recharge Volume (*ReV*)

The increase in imperviousness associated with most urban areas results in a significant decrease in infiltration and consequential dropping of groundwater tables. SuDS promote the infiltration of stormwater. The Recharge Volume is the amount that should be infiltrated to ensure adequate groundwater recharge.

2.2.2 Water Quality design (*WQV*)

The main principle in water quality design is the effective implementation of a SuDS treatment train to prevent and alleviate the risk of pollution associated with the site in question.

The amount of pollution discharging from any site during a specific rainfall event is dependent on the following three main factors:

i) The duration and intensity of the rainfall event;

ii) The land use characteristics of the site, with industrial areas normally yielding more polluted discharges than residential and commercial areas except where sanitation provision is not adequate; and

iii) The time interval between rainfall events, with longer periods normally resulting in higher levels of pollution (Wilson *et al.*, 2004; Woods-Ballard *et al.*, 2007).

Table 2.2: Key design terms

Term (units)	Definition
WQV (m^3)	The Water Quality Volume is the volume of water from small storm events where the focus is on treating for water quality. The storm events typically have a RI of less than 1 year; be less than the 90 percentile storm or have less than a set depth of precipitation.
ReV (m^3)	Recharge Volume is the proportion of the *WQV* that should be infiltrated on site to make up for the reduction of natural infiltration.
CPV (m^3)	The Channel Protection Volume 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 RI of around 2 years
FC_M (m^3/s)	Flow Control (minor storms) here refers to the reduction of peak storm flow to the pre-development scenario typically for storm events with a RI of between 2 and 10 years depending on the type of development.
FC_D (m^3/s)	Flow Control is also required for maintaining pre-development flows, prevent damage to property, and risks to life for storm events with a RI of greater than, say, 10 years.
D^3	Don't Do Damage refers to the importance of ensuring that extreme storm events does not cause significant damage to property and pose significant risks to life.

Table 2.3: Links between zones, design objectives and associated treatment / management

Zone	Objective	Treatment / management type	Management level
1	Interception storage	None required	None required
2a	Environmental (Quality)	Total Volume treatment of Water Quality Volume (*WQV*)	Good housekeeping and Source controls
2b	Environmental (Groundwater)	Total Volume treatment (infiltration) of Recharge Volume (*ReV*)	Source and Local Controls
3	Environmental (Flow rate)	Total Volume treatment of Channel Protection Volume (*CPV*)	Source and Local Controls
4	Environmental (Flow rate) & Inconvenience	Peak flow control reduced to predevelopment levels (FC_M)	Local and regional Controls
5a	Environmental, Health & Safety, Inconvenience	Peak flow control reduced to pre-development levels (FC_D) and prevent damage to property, and risks to life	Road ways and regional attenuation
5b	Inconvenience, Health & Safety	Prevent damage to property, and risks to life	Major design: Road ways etc.

The Water Quality volume (*WQV*) is used to determine the volume of each storm that should be fully treated for water quality. The use of a treatment train enhances the pollutant removal capabilities of each of the various SuDS over the course of the drainage system. The estimated pollutant removal capabilities of a number of SuDS options and/or technologies are listed in Appendix B. The pollutant removal capabilities are dependent on a number of variables such as: rainfall event characteristics, soil characteristics – and their associated infiltration capacities, vegetation type and the geological lie of the land.

Currently there are no national or provincial standards for pollutant removal from stormwater – although this will surely come within the next few years. The City of Cape Town has, however, released interim criteria that specify required performance standards for the management of stormwater impacts in that city (CCT, 2009). These may be utilised as acceptable pollutant removal standards until such time as more appropriate performance standards are published.

Pollution concentrations during rainfall events are neither constant nor proportional relative to the rainfall duration and intensity. Instead, they are relatively higher during the early stages of a rainfall event. This phenomenon is known as the first flush and is normally attributed to the following rainfall induced characteristics:

- The build-up of sediment and other pollutants on surfaces between rainfall events;
- Relatively higher erosion potential after an extended dry period; and
- Relatively higher rainfall intensities towards the beginning of many rainfall events.

It is particularly important that the capture and treatment of the first flush is prioritised in the design process to ensure that the initial stormwater runoff that is discharged into the receiving watercourse is of an improved quality (Jefferies, 2010, Woods-Ballard *et al.*, 2007). Interception storage is a particularly useful way of dealing with this phenomenon as it provides considerable water quality benefits.

2.2.3 Flood protection for receiving watercourses (FC_M & FC_D)

The Flow Control (minor storms – FC_M; and major storms – FC_D) is required for the protection of the receiving water bodies. Typically this is determined for pre-determined design storms representing minor and major storms respectively.

The protection of the receiving watercourse is a critical aspect in the design of SuDS. According to Woods-Ballard *et al.*, (2007), there are two general principles with respect to the protection of receiving watercourses from the threat of increased flood risk:

i) To ensure, wherever possible, that the frequency of discharge **rates** from the new or proposed development is similar to that of the equivalent green-field conditions; and

ii) To ensure, wherever possible, the frequency of **volumes** of runoff from the new development is similar to that of the equivalent green-field conditions.

Each of these is briefly discussed here to illustrate the necessity of these drainage characteristics in the proposed SUDS design.

2.2.3.1 Assessment of runoff rates

According to the SANRAL '*Road Drainage Manual*' (2006), urbanisation typically increases 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 pertaining before development. This typically causes flash floods in streams and rivers and an increased number of 'bankfull' flows. Excessive scour and erosion that could negatively affect the ecology of these watercourses is likely to follow. This is mitigated by ensuring that the post-development runoff rates are limited to the green-field runoff rate through local storage and/or infiltration. It is not essential that the post-development runoff rates from individual storms should be identical to the green-field runoff rate, only the frequency of these rates should be matched as closely as possible.

2.2.3.2 Assessment of runoff volume

The frequency of runoff volumes from a new or proposed development should also be designed to be similar to those of the equivalent green-field conditions. Particular consideration should be given to the following (after Woods-Ballard *et al.*, 2007):

- Increased runoff volumes from developed areas associated with the reduction in pervious area usually results in less groundwater recharge and thus reduced base-flow in the receiving watercourses; and
- The relatively smaller, more frequent rainfall events from developed areas contribute the largest total pollutant load to the receiving watercourse. In most green-field situations, small rainfall events do not generate runoff. Runoff volumes from these events should thus be minimised which will in turn significantly reduce the pollutant loads.

For small events, infiltration devices and interception storage are easily capable of trapping the first 5-10 mm of rainfall. Much larger storage capacity will be required for the more extreme rainfall events which can, in the extreme, cause total runoff volumes from developed areas to be up to 10 times the runoff volume from the equivalent green-field conditions (SANRAL, 2006).

2.2.4 Flood protection for developments

An important objective of stormwater management is the protection of people and property from flooding. According to Clause 144 of the South African National Water Act, No. 36 of 1998 (RSA, 1998), "*no person may establish a township unless the layout plan shows, in a form acceptable to the local authority concerned, lines indicating the maximum level likely to be reached by floodwaters on average once in every 100 years*." Development should be discouraged within the 1 in 100 year flood-lines – particularly on functional floodplains. Developments should also not raise the risk of flooding in neighbouring areas. As with conventional design, SuDS should cater for the more common storms without causing major inconvenience (the minor system). Typical design flood frequencies for different types of development are reproduced from "*The Red Book*" (CSIR, 2000b) in Table 2.4.

Table 2.4: Design flood frequencies for minor systems (CSIR, 2000b)

Land use	Design flood RI
Residential	1 – 5 years
Institutional (e.g. school)	2 – 5 years
General commercial and industrial	5 years
High value central business districts	5 – 10 years

The impact of more severe storms needs to be assessed to ensure that they do not pose a serious risk to life and property (the major system). Some form of storage may be prescribed to reduce this risk. It is assumed that the majority – if not all – flow will be overland flow as there is always a danger that any underground stormwater infrastructure will be overwhelmed and/or the inlets potentially blocked during severe storms. If necessary, flow paths must be established to direct the surplus water safely away from any development to the nearest receiving water. The following additional issues should also be considered for severe storms:

- Potential blockages in the system need to be identified and removed or significantly reduced;
- The intensified flooding impacts of potential blockages, interferences or system failures need to be assessed and catered for;
- The impact of the structural failure of any relatively large storage facility in the system needs to be considered;
- Potentially unstable or vulnerable structures and properties need to be positioned away from overland flood routes;
- Basements and other low-lying human settlement structures should be assessed for flood risk and appropriate action taken; and
- Unhindered access to key municipal and government buildings should be ensured.

Minimum floor levels should ideally be above the maximum anticipated flood level anticipated – with allowance for freeboard and the potential impacts of climate change. All calculations should be inspected and verified by the appropriate local catchment management authority prior to development approval.

According to Woods-Ballard *et al.* (2007), the consequences in the event of exceedance are normally significantly less with SuDS than conventional drainage systems.

2.2.5 Summary of SuDS design

In order to account for all the aims it is necessary to design for a number of different scenarios. In general, SuDS target the shorter RI storms and manage water quality and quantity for environmental reasons. With storms of intermediate RI, the focus shifts to managing quantity only. With extreme events the focus is on preventing damage to property and loss of life. Further design guidance is supplied in Appendix G.

2.3 Hydraulic design

Stormwater flows are impossible to model accurately. To begin with, rainfall characteristics are highly variable and may be affected by climate change. Secondly, the physical layout of the catchment is both complex and is being continuously altered. Attempts have been made to model flow using a wide variety of empirical, deterministic and stochastic models – with many commercial software packages available. None of them are particularly accurate. All rely – to at least some extent – on the experience of the modeller.

Stormwater design commences with the development of a conceptual drainage layout. The 'SuDS conceptual design framework' in Appendix A can be used to assist practitioners in both the development process and the conceptual process. It may be necessary to employ an environmental expert to monitor the proposed interventions.

Some simple models are introduced below. This does not preclude the use of more sophisticated – and potentially more accurate – methods including software such as SWMM, which are recommended for higher value / more complex developments. See Section 2.3.5 for further guidance on available software for advanced design.

2.3.1 Runoff rates and volumes

The runoff rates and volumes for the pre-developed conditions should be estimated to determine the acceptable maximum discharge from the designated site. Runoff from most urban developments is almost instantaneous when compared to greenfield sites. Normally, the runoff is modelled using one of the many commercial software packages available. Alternatively a number of simple methods are offered in the *Drainage Manual* (SANRAL, 2006). A quick assessment of the expected runoff rates from small catchments – typically less than 15 km^2 – may be obtained with the aid of the Rational Method:

$$Q = \frac{C\,i\,A}{3.6}$$

Where:

Q = design peak runoff rate (m^3/s)
C = runoff coefficient (0 – 1)
i = rainfall intensity (mm/hr)
A = catchment area (km^2)

The biggest challenge is the determination of the runoff coefficient *C*. Guidance in the use of the Rational Method in South Africa is given in Section 3.1 of the *Drainage Manual* (SANRAL, 2006).

The runoff volume may be estimated from (Woods-Ballard *et al.*, 2007):

$$RV = PR \times A \times d$$

Where:

RV = runoff volume (m^3)
PR = coefficient of runoff (0 – 1)
A = catchment area (km^2)
d = rainfall depth (mm)

In this equation, the biggest challenge is the estimation of an appropriate percentage runoff. Section 4.2.2 of Woods-Ballard *et al*. (2007) makes some recommendations for the UK in this respect, but these may not be applicable to South Africa.

2.3.2 Simplified conveyance design

Although SuDS are conceived as an alternative to conventional stormwater management, this does not preclude the use of pipes and channels. The flow through such components is readily described by the Manning equation:

$$Q = \frac{A^{5/3} \times S^{1/2}}{n \times P^{2/3}}$$

Where:

Q = design peak flow rate (m^3/s)
A = cross-sectional area of flow (m^2)
S = slope of water surface (m/m)
n = Manning roughness coefficient (s/m$^{1/3}$)

2.3.3 Storage design

The storage of stormwater runoff from a development is an important unit process in SuDS. There are two primary objectives:

- Adequate water quality treatment by the provision of extended residence (treatment storage); and
- Flood protection downstream of the site by attenuation of the peak flows (attenuation storage).

The water storage capacity of a structure is readily estimated as follows:

$$V = \sum_{i=0}^{n} \frac{(A_i + A_{i+1})}{2} \times d_i$$

Where:

V = storage volume (m^3)
A_i = surface area at elevation *i* (m^2)
A_{i+1} = surface area at elevation *i*+1 (m^2)
d_i = vertical height difference (m)
n = number of vertical sections
i = integer variable

According to Debo & Reese (2003), storage facilities designed for water quality treatment may be sized according to the specified Water Quality Volume (*WQV*) computed as follows:

$$WQV = \frac{P\,R_V\,A}{1000}$$

Where:

WQV = Water Quality Volume (m^3)
P = total rainfall depth to be included (mm)

R_V = volumetric runoff coefficient (0.05 – 0.95)
A = total drainage area (m^2)

with

$$R_V = 0.05 + 0.009 \times I$$

and: I = percentage of impermeable cover (%)

There are three alternative methods that could be used to determine the total rainfall depth, *P*, for the determination of the *WQV*:

i) A predetermined rainfall depth, typically in the region of 10-25 mm. Wilson *et al.* (2004) suggest that rainfall depths of 10, 15 and 20 mm are adequate to wash off: fine dust and / or soluble pollutants; oils and greases; and pollutants on pervious surfaces.

ii) *P* can be determined with the aid of a rainfall event analysis over the specific area in question. According to Wilson *et al.* (2004) and Debo & Reese (2003), the 90th percentile of the daily rainfall can be used; determined by plotting a 24–hour rainfall exceedance curve. The percentage of days where a specific rainfall depth was exceeded should be plotted against the total number of rainfall days.

iii) Alternatively the rainfall depth generated by the half-year 24-hour rainfall event could be used.

Whatever method is chosen, the rainfall depth should not be less than 10 mm.

Debo & Reese (2003) also recommend a water balance calculation. This assists designers in determining whether the specified stormwater drainage area is large enough and has the necessary characteristics to support a permanent pool of water during more extreme conditions. This calculation is particularly useful in the design of constructed wetlands and retention ponds (Section 5). A water balance calculation accounts for the change in volume of permanent pools of water resulting from the difference between the inflows and outflows over a given period of time:

$$\Delta V = P + Ro + Bf - I - E - Et - Of$$

Where:

ΔV = change in permanent pool volume (m^3)
P = precipitation on surface of pool (m^3)
Ro = runoff volume (m^3)
Bf = baseflow volume (m^3)
I = infiltration component (m^3)
E = evaporation component (m^3)
Et = evapotranspiration component (m^3)
Of = overflow volume (m^3)

2.3.4 Infiltration design

Infiltration is a critical design characteristic in most SuDS. It serves two primary objectives:

- Reducing the attenuation storage volume requirements; and
- Replenishing the groundwater.

Infiltration is an acceptable and feasible means of stormwater disposal in most locations although the structural stability of adjoining soils, structures, services and slopes should be rigorously assessed and suitable remedial action taken if infiltration systems are to be implemented. Care must also be taken to ensure that groundwater resources are protected against contamination by polluted stormwater runoff. This might require the pre-treatment of the stormwater prior to infiltration.

The suitability of a site for infiltration is dependent on a number of variables, notably the permeability and saturation-state of the surface and sub-surface soil media. These soil properties usually dictate the performance of infiltration systems. In the first instance, a soil's capacity to infiltrate water is limited by the coefficient of permeability. Table 2.5 lists typical permeability coefficients categorised in terms of their general suitability for infiltration. The soil texture may be determined from the sand, silt and clay percentages using the United States Department of Agriculture (USDA, 1938) Soil Texture Triangle (Figure 2.3).

The coefficient of permeability is one of the greatest uncertainties in the design of infiltration-type SuDS, the efficiency of which also are likely to reduce over time due to clogging and compaction. A geotechnical investigation should be performed prior to the design to ensure that infiltration-type SUDS are capable of performing the task that they have been assigned. Since infiltration-type SuDS are prone to significant changes in infiltration performance due to the changes in the state of infiltration media over their specified design lives, a factor of safety (FOS) should be used in their design. Table 2.6 lists typical FOS.

2.3.5 SuDS sizing and modelling

Various modelling tools are available to assist with SuDS design. Some of these are profiled in Tables 2.7 and 2.8.

Table 2.5: Typical soil texture permeability coefficients (after Jefferies, 2010)

Soil texture	Permeability coefficients (mm/h)	Adequacy
Gravel	10,000 – 1,000,000	**Generally inadequate treatment**
Sand	100 – 100000	
Loamy sand	10 – 1000	**Yes**
Sandy loam	50 – 500	
Loam	1 – 100	
Silt loam	0.5 – 50	
Sandy clay loam	1 – 100	
Silty clay loam	0.05 – 5	**No**
Clay	< 0.1	
Unstratified soil	0.01 – 10	
Rock	0.01 – 100	

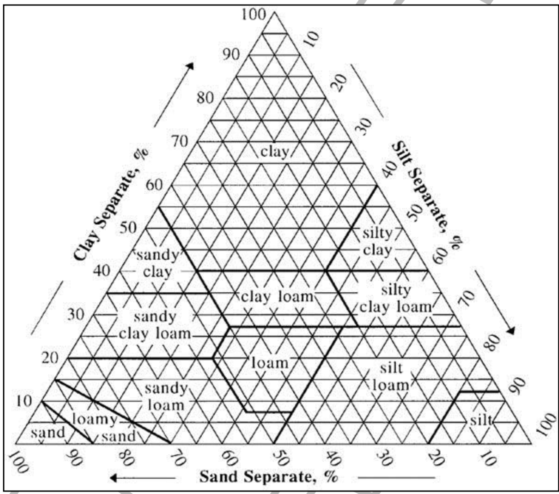


Figure 2.2: **Soil Texture Triangle** (USDA, 1938)

Table 2.6: Factors of safety for infiltration-type SuDS (Woods-Ballard *et al.*, 2007)

Risk Level	Factor of Safety
Low risk	1.5
Moderate risk	2
Major risk	10

Table 2.7: Potential models for design criteria computation (after Elliot & Trowsdale, 2005)

	Public Education	Research	Developing Sizing rules for devices	Planning of land use in catchments/cities	Preliminary design of regional controls	Preliminary design of a subdivision or site	Detailed design of regional drainage system	Detailed design of subdivision or site	Site Layout and materials selection
MOUSE		Suitable	Suitable	Suitable	Suitable	Suitable	Marginal	Marginal	Marginal
MUSIC			Suitable	Suitable	Suitable	Suitable			
P8			Suitable	Suitable	Suitable	Marginal			
SLAMM			Suitable	Suitable	Suitable	Marginal			
StormTac				Suitable	Suitable				
SWMM		Suitable	Suitable	Suitable	Suitable	Suitable	Marginal	Marginal	Marginal
PCSWMM		Suitable	Suitable	Suitable	Suitable	Suitable	Marginal	Marginal	Marginal
UVQ		Suitable	Marginal	Marginal	Marginal	Suitable			
WinDes (Quant. only)			Marginal		Suitable	Suitable	Suitable	Suitable	Marginal

Key: Black = Model is suitable for use; Grey = Model is marginally suited for use; White = Model is not suited for use

Table 2.8: SuDS component capabilities for selected design models (after Elliot & Trowsdale, 2005)

	Imperviousness reduction	Ponds and wetlands	Soil protection	Reduction of contaminant generation	Infiltration trenches/bores	On-site detention tanks	Swales	Run on	Rain tanks	Bioretention, rain gardens filtration devices	Permeable paving	Green roofs
MOUSE	■	■	▒	▒	▒	■	■	□	▒	▒	▒	□
MUSIC	■	■	▒	▒	■	■	■	▒	■	■	▒	▒
P8	■	■	▒	▒	■	■	■	□	▒	□	□	□
WinSLAMM	■	■	▒	▒	■	□	■	□	□	■	□	□
StormTac	■	■	▒	▒	□	□	■	□	□	□	□	□
SWMM	■	■	▒	▒	▒	■	■	■	■	■	■	■
UVQ	■	■	▒	▒	■	▒	□	■	■	▒	□	□
WinDes (Quant. only)	■	▒	□	□	▒	▒	▒	□	▒	▒	▒	▒

Key: ■ Model explicitly addresses the use of the approach; ▒ Model may be used for the approach; □ Cannot be used for device the approach

A key input is rainfall data. This is often available from the local authority; alternatively the *South Africa Rainfall Atlas* (Zucchini & Nenadic, 2006) includes image and site specific databases in addition to a rainfall simulator. Daily, monthly and annual rainfall data and information can be extracted – as well as storm percentage and percentile data.

Before utilising any form of modelling, users should be aware of the model assumptions and limitations. The greatest uncertainties in the prediction of the performance of SuDS are as a result of the complexities associated with the vegetated and amenity components (Woods-Ballard, *et al.*, 2007).

2.4 Amenity and biodiversity

The Collins English Dictionary defines amenity as, "*a useful or pleasant facility; or the fact or condition of being agreeable*." The New Penguin English dictionary defines biodiversity as, "*the number and diversity of distinct living species within the world or a particular environment*." Unlike with conventional urban drainage practices, the adequate provision of amenity and protection of biodiversity are primary objectives of SuDS. The three key principles for the effective provision of amenity and biodiversity benefits in SuDS schemes are discussed as follows.

2.4.1 Environment, health and safety

There are a number of circumstances where some SuDS options are unsafe; for example where there is a serious risk of drowning in the case of ponds and wetlands, or of damage to motor vehicles in ditches. These risks should be taken into consideration in the design and, if necessary, precautions taken. Areas of particular concern include:

- Transportation nodes and links;
- Pre-primary and primary schools; and
- Informal dwelling areas.

Examples of precautions that could be taken with ponds include: the provision of gentler side slopes (e.g. less than 1 in 3), shallower depths around the edges, or the strategic placement of vegetation to act as a barrier to unsupervised children.

It is also important to consider the risks associated with the pollutants in the stormwater. It is necessary when designing a SuDS treatment train to have a clear understanding of the catchment and what pollutants may be found in the catchment. This may have an impact on the types of SuDS options implemented, or in certain cases prevent the use of SuDS altogether. Table 2.9 highlights

Table 2.9: Stormwater pollutants (Krypo, 2004; Minton,2002; Opher & Freidler, 2010)

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

what pollutants are typically found in stormwater. The potential risks of each pollutant that may be present at a site, need to be assessed. This is especially important in the case of pathogens where stormwater facilities are open to the general public (NWQMS, 2006).

Another significant health and safety concern relates to breeding of mosquitoes and other vectors and the associated risk of transmission of various diseases. In these circumstances, ponds could be designed to drain within, say, three days of the specified rainfall event to prevent the stagnation of water. Other natural controls, such as the introduction of selected fish species, could be introduced into permanent bodies of water. The expertise of an appropriately qualified scientist will be useful in these circumstances.

According to Wilson *et al.*, (2004) and Woods-Ballard *et al.* (2007), the following four risk management questions need to be answered:

i) What are the possible hazards?

ii) Who is at risk?

iii) How can these possible hazards be avoided or mitigated?

iv) What is the associated residual risk?

2.4.2 Aesthetic impact and amenity benefit

Many SuDS have a visual impact, therefore public acceptability needs to be addressed through activities such as (Woods-Ballard *et al.,* 2007):

- Education and awareness campaigns;
- Landscaping the area to maximise the aesthetic appeal of the specified system;
- Ensuring that an appropriate maintenance plan is developed and adhered to so as to ensure that the SuDS have a positive visual impact all year round; and
- Adjoining open water areas to recreation sites where` the health and safety risks can be properly managed.

Landscaping and planting procedures may require the expertise of a Landscape Architect and Botanist, respectively.

2.4.3 Ecological services

According to the American Society of Landscape Architects (2008) and Woods-Ballard *et al.,* (2007), the maximization of the ecological services of SuDS is important for two main reasons:

i) To provide the necessary amenity and biodiversity enhancements at the specified development site; and

ii) To adequately facilitate the natural movement of wildlife species through the 'green' corridors within the development.

Ecological diversity can be maximised, *inter alia*, in the following manner:

- The planting of indigenous vegetation;
- Pre-treatment before polluted water is discharged into open water bodies;
- Retaining, protecting and enhancing existing natural drainage systems;
- Creating a range of diverse habitat types; and
- Including a relatively shallow aquatic bench zone in wetland and pond design.

It is important to recognise that implementing certain SuDS options may have unintended consequences. For example wetlands may attract water birds, such as herons, whose faeces cause an increase in phosphorous concentrations.

2.4.4 Education and awareness

Education and awareness campaigns are often an effective means of developing community acceptance and reducing concerns over perceived risks associated with various SuDS options. They also have an important role to play in ensuring that SuDS structures are not adversely affected during general landscaping maintenance. Opportunities may include:

- Public participation during the design process;
- The dissemination of information on the proposed SuDS and its role in supporting and/or enhancing the environment;
- The placing of signs at each SuDS structure informing the community and maintenance teams about its purpose and its functioning.

3. Source controls

3.1 Green roofs

3.1.1 General description

A roof that is deliberately covered in vegetation may be described as a 'green roof' (Semple *et al.*, 2004; Stahre, 2006; Figure 3.1). The use of vegetative roof covers and roof gardens is an important source control for stormwater runoff. They provide great benefits in densely urbanised areas where there is less space for other SuDS options (NCDWQ, 2007; Semple *et al.*, 2004). *Sedum* (a type of small shrub) is the most common vegetation type used for green roofs, however, many other vegetation types can be used depending on the conditions. Generally, green roofs that contain moss-*sedum* mixtures are able to endure longer periods of drought (Stahre, 2006). Flat roofs often incorporate a thicker layer of vegetation or roof gardens that promote general rooftop accessibility and other forms of outdoor recreation.

Figure 3.1: Ethekwini Green Roof Pilot Project, Durban CBD

A study on the efficacy of a green roof constructed in the Durban CBD by eThekwini Municipality (Greenstone, 2010; Figure 3.1), as well as many international studies, indicate that green roofs are capable of completely absorbing light to moderate rainfalls (up to the 80 or 90 percentile storm). They also provide some minor stormwater detention which increases the 'time of concentration', significantly delaying runoff peaks and decreasing runoff volumes. Vegetative roof covers and roof gardens are usually at their most effective with respect to pollution removal in the summer and spring growing seasons, with reduced efficiencies in autumn and winter seasons. According to Stovin (2009), structural appraisal of a variety of flat roof types suggests that retrofitting green roofs is a feasible option in many instances, particularly for concrete roof slabs. Typical pollution control characteristics for green roofs are included in Appendix B.

3.1.2 General design guidelines

Post 2000 advances in synthetic drainage materials now allow green roofs to be built on flat and gently sloped roofs, typically between 0° and 20°. On roof slopes greater than 20°, support systems such as horizontal strapping should be used to prevent slipping or slumping of the growing vegetation. The vegetative layer is typically 30-40 mm thick and sits upon a drainage layer approximately half this thickness. The drainage layer in turn lies on a waterproof membrane to prevent leakage into the building below (Figure 3.2). Green roofs constructed using these dimensional characteristics generally have specific weights of 40-60 kg/m^2 (Stahre, 2006; Wanielista *et al.*, 2008). The structural design of the roof needs to account for the additional weight of the green roof component materials and expected water detention volumes – including any possible snow accumulation (NCDWQ, 2007).

Figure 3.2: Waterproofing a roof in preparation for the construction of a green roof

The detention volume available in a green roof is a function of the depth and porosity of the vegetation bedding that is added to the new or existing roof structure (Semple *et al.*, 2004). Green roofs are especially effective when implemented on roofs with large surface areas, such as industrial and commercial buildings, and blocks of flats. If a green roof is retrofitted on an existing rooftop particular care should be taken to ensure that the stormwater can freely flow into the various components of the roof drainage system (NCDWQ, 2007). Irrigation may be required to keep the roof green during dry periods. The general design for green roofs and the adjoining inspection compartment is given in Figure C1.

3.1.3 Advantages

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

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

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

iv) Green roofs can be designed to closely mimic the pre-development state of the buildings (Greenstone, 2010; Woods-Ballard *et al.*, 2007); and

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

3.1.4 Limitations

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

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

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

iv) Green roofs may only be used on steep roofs (>20°) if additional support systems such as horizontal strapping are provided; and

v) Plant varieties for green roofs may be quite limited; indigenous vegetation is generally best (Wilson *et al.*, 2007).

3.1.5 Operation and maintenance

Maintenance cycles should generally include three to four inspections per year to search for vegetation related problems such as weeds and bare patches, and any stress related damages to the roof and building structure (Hobart City Council, 2006). General plant maintenance is also required. It may be necessary to irrigate during the establishment of the vegetation and dry periods. The application of fertilizers can be periodically performed; however, it is preferable that fertilizers are not used as this will impact the quality of the stormwater runoff (NCDWQ, 2007).

3.1.6 Technology derivatives

There are three main types of green roofs, namely: extensive green roofs (Figure 3.1), intensive green roofs (Figure 3.3), and simple intensive green roofs (Woods-Ballard *et al.*, 2007). Two other derivatives – which are not strictly green roofs but placed here for convenience – are also applicable for urban drainage namely green walls and blue roofs. Each of these is briefly described as follows.

3.1.6.1 Extensive green roofs

Extensive green roofs incorporate low growing and low maintenance vegetation that cover the entire roof surface. They are typically accessed for maintenance purposes only, and can be implemented on both flat and sloped surfaces. Extensive green roofs usually comprise a growing vegetation medium 25-125 mm in thickness, covered with hardy and drought tolerant flora. Indigenous mosses, herbs and grasses are commonly used – which are intended to be reasonably self-sustaining.

3.1.6.2 Intensive green roofs

Intensive green roofs incorporate planters and trees that have a high level of accessibility (Figure 3.3). It is recommended that rainwater harvesting (Section 3.2) is used as the primary irrigation source for intensive green roof flora. This system generally places higher dead and live loads on the roof and building structures than extensive systems, and will undoubtedly require more intensive ongoing maintenance.

3.1.6.3 Simple intensive green roofs

Simple intensive green roofs have elements in common with both extensive and intensive green roofs; having both larger plants as well as low growing and/or ground covering plants such as lawns. They often require a lot of maintenance, such as cutting, fertilizing and watering, as well as increased accessibility. There are fewer demands on the strength of the roof structure than intensive green roofs, which may lower roof system costs.

Figure 3.3: Intensive green roof, Department of Environmental Affairs and Development Planning, Cape Town

3.1.6.4 Green walls

Green walls are vegetated walls that may be implemented as elements of a building or as free-standing partitions. They significantly attenuate first-flush flows from buildings by detaining rainwater on the surfaces of leaves and other parts of the vegetation. The vegetation is usually grown in an inorganic stratum. Green walls require high frequency maintenance especially if they are located in dense urban areas such as central business districts (CBDs). The construction of green walls is quite complex and should be carried out by experts.

3.1.6.5 Blue roofs

Blue roofs are typically flat roofs with kerbed peripheries that serve to store and/or detain rainwater. The roof structure must be waterproofed and able to carry the additional load. Blue roofs require regular maintenance checks to ensure that there is no build up of debris and sediment. An annual structural maintenance check should be carried out by certified professionals.

3.1.7 Case studies

The following case studies are good examples of where green roofs have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Greenstone, C, (2009). *Rooftop Gardens and the Greening of Cities – A case Study of University of KwaZulu-Natal*, University of KwaZulu-Natal, eThekwini: A case study of the feasibility and performance of a variety of green roof vegetation to treat and control stormwater and provide internal temperature control in KwaZulu-Natal.

ii) Rickards, B, (2006) *Low Impact Development Case Study: City Hall Green Roof*, Coastal Smart Growth Program, City of Boston: A concise case study of the project scope, timeline and budget as well as design and implementation phases of the Boston City Hall green roof.

iii) USEPA, (2007). 'Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices', *Toronto Green Roofs, Toronto, Ontario (A Modelling Study)*, Washington: A brief case study that evaluates the benefits of greatly expanded green roofs in Toronto using a geographic information system (GIS).

3.1.8 Further reading

The following documents are considered useful references when designing green roofs. Where possible download links to the documents have been provided at www.wsud.co.za.

i) Feller, M, Traver, R, Wadzuk, B, (2010) *Estimation of Green Roof Evaptranspiration: Experimental Results*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

ii) Hopkins, G, (2009). Green Infrastructure: *Re-interpreting natural systems (WSUD) from ground to green walls and roofs within the urban form*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

iii) Kasmin, H, Stovin, VR, Hathway, EA, (2009). *Towards a generic rainfall-runoff model for green roofs*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

3.2 Rainwater harvesting

3.2.1 General description

"Water resources sustainability is the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-cause disasters" (Mays, 2007).

Rainwater harvesting is an essential element of effective water conservation where stormwater is utilised as a water supply. Conventional stormwater infrastructure results in pollution and the addition of millions of cubic metres of water into watercourses and oceans each year. With minimal treatment this water could be used to supplement the potable water supply for secondary water uses such as toilet flushing and garden irrigation. Storage of runoff from roofs and other elevated impervious surfaces is provided by rainwater tanks, barrels and other storage structures until the water is required (Figure 3.4) (Hobart City Council, 2006; Stahre, 2006). It is very common in developing countries where it is often the primary water supply.

The utilisation of stormwater as a water source not only saves potable water, it also reduces stormwater discharge from roofs. Stormwater storage facilities may also be connected to other SuDS options such as infiltration trenches or soakaways. Parkinson & Mark (2005) and Scholz (2006) suggest that rainwater harvesting systems are particularly useful during extreme rainfall events as they help protect receiving watercourses by reducing the initial runoff volumes and the associated pollutants (McAlister, 2007). Pollution control characteristics for stormwater collection and reuse are included in Appendix B.

Figure 3.4: Roof runoff storage tanks for household purposes

3.2.2 General design guidelines

Many different stormwater collection and reuse systems are commercially available. According to Donovan & Naji (2003), the principal element requirements for an effective stormwater collection and reuse system are:

- The strategic placement of roof gutters;
- A first-flush trap and/or filter sock to catch leaves and other debris;
- A rainwater storage facility (tank, barrel or sump);
- Leaf and organic debris diverters;
- A means of getting the water to its point of use, preferably by gravity or otherwise a pump and pipeline;

- An in-line filter and/or UV disinfection device if there is any risk of human contact; and
- An overflow system – preferably linked to another option in a SuDS treatment train.

Taylor (2003) and Stahre (2006) suggest that a minimum of two rainwater storage facilities with a storage capacity of 1000*l* should be implemented for single residential households. There is no upper limit; 25,000*l* rainwater tanks and 40,000*l* underground sumps have been installed on single-unit properties. There are five main considerations when selecting a storage facility (Hobart City Council, 2006):

i) Budgetary constraints;

ii) Local rainfall characteristics;

iii) On-site and off-site space availability;

iv) Impervious catchment areas (including, but not limited to roof areas);

v) Future rainwater uses; and

vi) Constraints on amounts harvested due to ecological needs of the environment.

The network of gutters contributing to the storage units should preferably be partially covered in a high permeability filter screen to reduce debris, animal contaminants and other likely pollutants from entering the collected stormwater runoff system – whilst ensuring adequate capacity. Furthermore, a small pollutant trap or bypass filter should be installed to prevent debris and/or contaminants from entering the collected stormwater system. Storage facilities that are childproof as well as insect and vector proof should be given preference in the selection process. In the event of extreme rainfall, stormwater runoff that cannot be contained in the available rainwater storage facilities should be channelled to other SuDS options to minimise damage to property and potential fatalities. 'Stormwater' signs should be placed above the outlet of the specified rainwater storage facility in an effort to prevent people, especially children, from drinking the water or utilising it for other potable demands (Hobart City Council, 2006). Designers may use the following simple water balance equation to calculate the volume of usable rainfall – also referred to as the annual collectable rainfall (after Wilson *et al.*, 2004; Woods-Ballard *et al.*, 2007):

$$V = R \times A \times C \times FE$$

Where:

V	= Volume of usable rainwater (ℓ)
R	= Average rainfall over period (mm)
A	= Area contributing to runoff (m^2)
C	= Run-off coefficient (0-1)
FE	= Filter Efficiency (0-1)

The runoff coefficient is the realistic proportion of rainfall runoff that enters the specified storage facility. Table 3.1 indicates commonly used runoff coefficients.

Table 3.1: Typical runoff coefficients for rainwater harvesting off roofs

Roof classification	Runoff coefficient C
Pitched roof, tiled	0.85
Flat roof, tiled	0.6
Flat roof, gravel	0.4
Extensive green roof	0.3
Intensive green roof	0.2

The filter efficiency refers to the proportion of water post filtration available for use. Generally manufacturers recommend a conservative 0.9. The rainfall period selected for the calculation depends on the climate but monthly values are generally the most appropriate. The available water is determined from the volume of usable rainwater and the filter efficiency.

3.2.3 Advantages

i) The optimal utilisation of stormwater collection and reuse systems in residential, commercial and industrial units can significantly reduce potable water consumption;

ii) The collection of stormwater runoff reduces the pollutant loads that enter nearby watercourses;

iii) The collection and reuse of stormwater runoff attenuates flood peaks; and

iv) There is a wide variety of rainwater storage containers commercially available in South Africa which are generally easy to install.

3.2.4 Limitations

i) Roof collection systems tend to be ineffective for water supply in areas that have hot and dry climatic conditions for a significant part of the year;

ii) The water quality needs to be monitored and is generally such that the water can only be used for supplementary purposes;

iii) Rainwater storage facilities that are implemented above the ground level may be unattractive; and

iv) Currently, rainwater reuse on a domestic scale is relatively expensive, with the rainwater tanks constituting the most significant cost of the system.

3.2.5 Operation and maintenance

Households that utilise harvested rainwater for potable purposes should be aware of the potential health risks and take the necessary operational and maintenance precautions. Harvested rainwater should be filtered as well as boiled or chlorinated if it is to be used for potable purposes (Hobart City Council, 2006; Parkinson & Mark, 2005). Untreated rainwater is generally safe to use for flushing toilets and irrigating gardens.

General maintenance includes: the monitoring of the first flush diverter; the cleaning of roof gutters; and monitoring and removal of sediment in the storage tank.

3.2.6 Technology derivatives

There are two types of stormwater collection and reuse systems that are generally applicable to residential, commercial and industrial uses, namely pumped supply systems and gravity supply systems. Each approach has a different performance with respect to their water supply efficiency, electrical consumption, noise pollution, maintenance intensity, operation requirements, and space requirements (Woods-Ballard *et al.*, 2007). The main elements of each approach are briefly described below.

3.2.6.1 Pumped supply systems

Stormwater runoff from impervious surfaces (typically rooftops) passes through a coarse filter and is collected in a storage facility (rainwater barrel, tank or sump). Water is then pumped by a booster pump directly into the specified application points in and around the connected building/s when required. Once the specified storage facility runs dry, allowance should be made for water from the main reticulation to be fed into the system. If this is done manually, it will require regular checks on the water level in the storage facility (Woods-Ballard *et al.*, 2007).

3.2.6.2 Gravity supply systems

Stormwater runoff from impervious surfaces (typically rooftops) passes through a coarse filter and is collected in a storage facility (rainwater barrel, tank or sump). This water is then gravity fed into the specified application points in and around the connected building. Once the specified storage facility runs dry, there should be a water main back-up supply (Wilson *et al.*, 2004; Woods-Ballard *et al.*, 2007). Unlike direct supply systems, gravity supply systems do not generally require electrical energy which saves on costs and means that supply can be maintained during power outages.

3.2.7 Case studies

The following case studies are good examples of where rainwater harvesting systems have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Angelis, G, Shaw, M, (2004). *Barnwell Golf Course Stormwater Treatment and Reuse*, Sustainable Water Challenge Project, Canada Bay: A case study of the treatment and reuse of stormwater pollution entering Canada Bay using, *inter alia*, a sand filter and gross pollutant trap for treatment and collection purposes.

ii) Butterworth, J, (2006). *Showcasing Sustainability North Sydney Community Centre*, NSW Sustainable Water Challenge Awards 2006, New South Wales: A case study discussing the water sensitive urban design principles used in the design and construction of a community centre, including an innovative rainwater harvesting system.

iii) Chanan, A, (2003). *Low Flow Filtration & Reuse Project*, Kogarah Municipal Council, Kogarah: A case study of the designs, construction, installation and costs of a low flow sand filtration and reuse system for treating and reusing stormwater from a roadway arterial.

3.2.8 Further reading

The following documents are considered useful references when designing rainwater harvesting systems. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Gold, A, Goo, R, Hair, L, Arazan, N, (2010). *Rainwater Harvesting: Policies, Programs, and Practices for Water Supply Sustainability*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

ii) Lesjean, B, Schmidt, M, Schroeder, K, Huau, MC, (2009). *International Review of Rainwater Harvesting Management: Practices, Market and Current Developments*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

iii) Rodrigo, S, Sinclair, M, Leder, K, (2009). *Urban Tanks – Are they properly maintained?*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

3.3 Soakaways

3.3.1 General description

Soakaways usually comprise an underground storage area packed with course aggregate or other porous media that gradually discharges stormwater to the surrounding soil. They are similar to infiltration trenches (Section 4.3) in operation, but usually have a smaller plan area (MBWCP, 2006). They are often used to handle roof runoff from a single building (Figure 3.5).

Multiple soakaways can be linked to drain larger areas such as parking lots and motor highways. In such instances, modular geocellular structures can be used as a more suitable 'backfill material'. The cross-section of the soakaway and the type of material utilised determines the infiltration characteristics of the device. Modular geocellular structures provide relatively high stormwater treatment and rates of groundwater recharge. On the negative side, the rapid movement of water through soakaways leads to an increased risk of groundwater contamination. It is thus important to ensure that adequate stormwater pre-treatment is implemented upstream of the soakaway if necessary. The pollutant removal processes associated with soakaways include: volatilisation, sedimentation, bio-degradation and filtration (Wilson *et al.*, 2004; Woods-Ballard *et al.*, 2007). Pollution control characteristics for soakaways are included in Appendix B.

Figure 3.5: Groundwater recharge of runoff from a single residential dwelling, Cotswold Downs Estate, Hillcrest

3.3.2 General design guidelines

The soakaway size is dependent on the porosity of the course aggregate or geocellular material that is used to fill the excavated pit. It is emptied either by the percolation of the stormwater directly into the underlying soil or via perforated drainage sub-drains installed near the base of the structure. Measures should be taken to prevent fine-grained material from entering the backfill portion of the structure, especially during the construction and maintenance phases. Soakaways that are situated in fine-grained soils should be lined with a geo-textile to prevent the migration of fines into the coarser porous media (Stahre, 2006). A custom designed oil and sediment collection compartment may also be constructed as a simple and effective pre-treatment device if required (Woods-Ballard *et al.*, 2007).

Soakaways are usually designed to store the entire volume from the design storm and be able to infiltrate at least half of this within 24 hrs to create additional capacity for the runoff from subsequent rainfall events. They normally serve areas less than 1000 m^2, but groups of soakaways can serve areas as large as 100,000 m^2 (MBWCP, 2006). They can be between one and four metres in depth although soakaways serving single residences are seldom more than 1.5 m in depth. They are often constructed using preformed polyethylene or precast concrete rings, 1-2.5 m in diameter. The lined excavation can be kept hollow, but a high voids fill material reduces the turbulence associated with high flow rates into the structure (Woods-Ballard *et al.*, 2007). To prevent groundwater contamination, soakaways should be constructed at least 1.5 m above the groundwater table to allow for additional filtration (Livingston & McCarron, 2008). The general design for soakaways with the adjoining oil and sediment collection compartment is given in Figure C2.

3.3.3 Advantages

i) Soakaways that are operated and maintained regularly may have design lives of up to 20 years, after which the fill should be replaced (Stahre, 2006);

ii) Soakaways significantly decrease both the runoff volume and rate; and

iii) Soakaways are particularly effective in removing particulate and suspended stormwater runoff pollutants.

3.3.4 Limitations

i) Soakaways are not suitable in areas where infiltrating water would negatively impact on adjacent structural foundations or adversely affect existing drainage characteristics;

ii) Soakaways are normally limited to relatively small connected areas (Woods-Ballard *et al*., 2007);

iii) Soakaways do not function well when constructed on steep slopes and in loose or unstable areas;

iv) Sub-drain piping systems must be utilised when soakaways are implemented in very fine silt and clay stratum because of the low infiltration rates; and

v) Sedimentation within the collection chambers will cause a gradual reduction in the storage capacity (Stahre, 2006).

3.3.5 Operation and maintenance

As with most SuDS options, the design life of soakaways is directly related to the frequency and quality of inspection and maintenance cycles. Soakaways situated in fine soils, such as silts and clays, require a more detailed inspection and maintenance routine than those in more porous stratum (Melbourne Water, 2005). An inspection opening makes routine inspections easier and allows greater accessibility to the backfill material. The flow entrance into the soakaway should be visible through the inspection opening. Such accessibility also makes it easier to manually clear out debris and sediment build-up. Adjoining stormwater runoff contributing areas, such as parking lots and roadways, should be regularly swept to prevent the intrusion of silt into the soakaway. Clogged soakaways may attract mosquitoes and other associated vectors as well as foul odours as a result of standing water (Taylor, 2003). In this instance, the replacement of the 'backfill material' will most likely be necessary (Woods-Ballard *et al.,* 2007).

3.3.6 Technology derivatives

Soakaways are similar to infiltration trenches (Section 4.3) and infiltration basins (Section 5.1.6). Pre-treatment can be effected through the use of oil and grit separators. Modular plastic geocellular structures can be used to improve their performance. Each is briefly described as follows.

3.3.6.1 Oil and grit separators

Oil and grit separators are often included in SuDS treatment trains to provide pre-treatment of stormwater runoff where necessary. They are most applicable in areas where stormwater runoff from commercial or industrial areas may be polluted with high levels of hydrocarbons, heavy metals and/or Total Suspended Solids (TSS) (Wilson *et al.*, 2004). They require frequent maintenance to prevent the build-up of fine grained and oil-based pollutants. One advantage is that they do not require much space as they are typically implemented underground.

3.3.6.2 Modular plastic geocellular structures

Modular plastic geocellular structures are geometric structures with high void ratios that are used to increase storage capacity without significant loss of structural strength. Due to the modular nature of these geocellular structures, they can be made to suit the specific requirements of a wide variety of sites (Woods-Ballard *et al.*, 2007). They normally have a high load capacity relative to their light weight which allows for their use beneath heavily trafficked areas such as parking bays. They are also commonly used in retrofitted systems. According to Woods-Ballard *et al.*, (2007), modular plastic geocellular structures generally have long-term physical and chemical stability when utilised below ground.

3.3.7 Case studies

The following case studies are good examples of where soakaways have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Atlantis, (2010). *Case studies: Infiltration/Soakaway systems*, Atlantis Water Management, New South Wales: Eight concise case studies of large infiltration devices and soakaways implemented in Australia, the USA, the UAE, Malaysia and Chile.

ii) Environment Agency, (1999). *Case Study: Soakaways help reduce run-off*, The environmental issues: Managing surface water, Ipswich: A concise case study that highlights several benefits of the uses of soakaways to manage stormwater runoff.

3.3.8 Further reading

The following documents are considered useful references when designing soakaways. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Bergman, M, Binning, P, Kuczera, G, Mikkelsen, PS, Mark, O, (2009). *Integrating soakaway infiltration devices in distributed urban drainage models – from allotment to neighbourhood scale*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

ii) Hewa, GA, Argue, JR, Pezzaniti, D, (2009). *Setting Criteria for Channel-Forming, Environmental and Flood Flows for Waterways in Urbanising Catchments*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth

iii) Hossain, MA, Furumai, H, Nakajima, F, Kasuga, I, (2008). *Accumulated sediments within soakaways in an old infiltration facility: source or sink for heavy metals?*, 11th International Conference on Urban Drainage, Endinburgh

3.4 Permeable pavements

3.4.1 General description

Permeable pavements refer to pavements that are constructed in such a manner that they promote the infiltration of stormwater runoff through the surface into the sub-layers and/or underlying strata (Figures 3.6 and 3.7). There are many alternatives for the load-bearing surface material including: permeable concrete block pavers (PCBP), brick pavers, stone chip, gravel, porous concrete and porous asphalt. The latter two are also referred to as porous pavements. In places with suitable climates and low traffic loading even grass can be used with or without reinforcement as the situation demands. Patented open celled concrete grass pavers or cellular plastic grids are often used for the reinforcement of the grass surface layer. Permeable paving surfaces are suitable for pedestrian and vehicular use, and can be modified to carry heavier loadings (Taylor, 2003; Woods-Ballard *et al.*, 2007). Design software is widely available.

Permeable paving is generally constructed on a coarse gravel sub-base which creates temporary storage facilities and allows stormwater runoff to infiltrate into the underlying stratum, promoting the recharge of the groundwater table (Semple *et al.* 2004; Stahre, 2006). Stored rainwater can be reused for several domestic purposes (Section 3.1) – typically gardens and lawns (Hobart City Council, 2006). Sub-drains can be utilised to improve collection. Permeable pavements generally do not remove litter and other debris from stormwater runoff as this is left on the surface; however this provides an opportunity for it to be collected through street-sweeping. Soluble pollutants tend to pass through the permeable pavement structures owing to the lack of extended detention. Pollution control characteristics for permeable pavements are listed in Appendix B.

Figure 3.6: Permeable concrete block pavers with open joints and slotted ends filled with pea-sized gravel

3.4.2 General design guidelines

The most important considerations are to ensure:

i) The entire minor design storm – which includes the specified Water Quality Volume (*WQV*) – is captured. Additional flow should be discharged into the specified drainage system or outfall in a controlled manner; and

ii) The provision of adequate structural support to withstand the expected loadings from pedestrian, vehicles, plant or other machinery (Woods-Ballard *et al.*, 2007).

Permeable pavement technologies can be designed to suit most loading specifications. Typical installations include (Debo & Reese, 2003):

- Residential driveways;
- Parking bays;
- Private roads, public service roads and fire-engine lanes;
- Industrial storage and loading areas; and
- Bike pathways, walkways, terraces and around swimming pools.

Heavily polluted stormwater containing large quantities of sediment should not be discharged onto permeable paving as it inevitably results in clogging throughout the system (Stahre, 2006). Particular care should be taken to protect the pavements from sediment deposition during construction (Hobart City Council, 2006) as permeable pavements are prone to clogging by particulate matter. Another concern is structural failure from high wheel loadings (Debo & Reese, 2003; Minton, 2002). The use of permeable pavements should be restricted to slopes less than 5% – ideally flat – as the high velocity stormwater from steep slopes is not readily able to penetrate the pavement surface (Stahre, 2006; Debo & Reese, 2003). The base layers are typically constructed of compacted stone that is able to support the required vehicle loadings (Figure 3.7). These layers must be designed for immersion in water for extended periods of time (Taylor, 2003).

Permeable concrete block pavers (PCBPs) are commonly used for heavily trafficked areas. They are normally placed on a layer of nominal 5 mm clean stone that sits on a geotextile membrane. The membrane is laid on a layer of stone aggregate which may in turn be placed on other base layers with or without geomembranes separating the layers (Figure 3.7). Note that there is some controversy concerning the use of geotextiles to separate the layers, with some researchers claiming that they are subject to blockage over time from fine material as well as impermeable organic films. If the permeable pavements can be designed to obviate the need for geotextiles with the aid of a graded filter, this would be preferable. The operation of permeable pavements is highly dependent on good workmanship – particularly with the laying of pavers (Woods-Ballard *et al.*, 2007). PCBPs should be laid with even spaces between each paver and no protruding blocks.

If there is any concern about the ability of the in-situ material being able to absorb the total volume of stormwater in the base-layers of the permeable pavement after the design rainfall event, perforated drainage pipes should be provided. These pipes typically lie on the bottom-most layer of geofabric and span the whole area of the permeable pavement system.

Figure 3.7: Section through the base layers that will support permeable concrete block pavers

According to the British Board of Agreement (2009), the mean compressive strength of PCBPs is approximately 30-40 N/mm^2, with an absolute minimum strength of 30 N/mm^2. PCBPs are generally designed with impact resistance sufficient to prevent the cracking of pavers during the handling and laying implementation phases. Furthermore, they are usually manufactured from C40 concrete which is able to resist the corrosive effects of chemicals, oils and flammable fuels that could potentially spill onto these pavers over their lifetime. PCBPs are normally placed by hand; however, there are several placement devices that can be used to speed up the laying process over larger areas. The general design for permeable pavements is given in Figure C3.

3.4.3 Advantages

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

ii) Permeable pavements increase the ‘usable’ area on specified developments by utilising, *inter alia*, roadways, driveways and parking lots as stormwater drainage areas;

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

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

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

3.4.4 Limitations

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

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

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

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

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

3.4.5 Operation and maintenance

The maintenance requirements should be clearly specified and reviewed during the planning and design phases (Taylor, 2003). Regular inspection and maintenance are recommended for ensuring the long-term effectiveness of permeable pavements. The fine stone aggregate in the joints and slots of PCBPs should be replaced from time to time to prevent blockage. Research has shown that this area is the one most prone to blockage; it also tends to trap the most pollutants – including particulate heavy metals which adhere to the fine-grained soil. A typical maintenance procedure includes vacuum-sweeping and/or high pressure jet-washing of the surface every three months or four times per year (Donovan & Naji, 2003; Field & Sullivan, 2003; Melbourne Water, 2005). In the event of failure throughout the specified permeable pavement system, Woods-Ballard *et al.*, (2007) suggest that the following procedures should be followed for reconstruction:

i) Remove the surface layering and laying courses;

ii) Remove the geotextile filtering layers;

iii) Inspect, remove, wash and replace sub-base if required;

iv) Renew or replace the geotextile layering; and

v) Renew the laying course and/or PCBPs.

Having said all of the above, there are many examples around the world of permeable pavement systems that are still operating successfully after many years with minimal maintenance. In many cases, the enormous infiltration capacity of the permeable pavement system – they are frequently designed for an infiltration capacity some ten times greater than theoretically required for the design storm – means that considerable clogging can be tolerated before the system fails.

3.4.6 Technology derivatives

According to Wilson *et al.*, (2004) and Woods-Ballard *et al.*, (2007), permeable pavements are one sub-type of pervious pavements; the other being porous pavements. There are numerous permutations of the basic systems, some of which are described below.

3.4.6.1 Gravel pavement systems

Gravel pavement systems are generally comprised of single-sized aggregate without the addition of a binding product (Figure 3.8). These systems are the simplest and least expensive permeable pavement available. Gravel pavement systems may require daily maintenance procedures, including the raking, sorting and re-levelling of their specified aggregate surfaces. They are most effectively used for parking lots and driveways where traffic volumes and speeds are relatively low. Geosynthetic materials and plastic grid structures can be utilised beneath the gravel surfacing to provide structural reinforcement. Local crushed aggregate should be used for the surface to avoid excessive transportation costs.

Figure 3.8: Gravel pavement system, Bishops Court Office Park, Hillcrest

3.2.6.2 Porous asphalt and concrete systems

Porous asphalt and concrete systems are generally made from a specially formulated mixture of asphalt or Portland cement and a uniformly graded coarse stone and water. The end result is a material that has a very high permeability; usually several times more permeable than the underlying soil layer. It is then placed on a suitable base course. Porous paving should be avoided in areas where large quantities of sediment, windblown sand and debris may block the porous paving surface. Care must also be taken near shallow aquifers as the system has poor pollution removal characteristics and hence the aquifers could easily be contaminated unless the some barrier is put in place (Debo & Reese, 2003; Hobart City Council, 2006). Under these circumstances, water percolating through the porous paving should be trapped and safely removed from the underlying layers. Porous paving does have the aesthetic advantage that it can be designed to 'blend' into the surrounding urban landscape. It is particularly effective in the removal of suspended solids and sediment from stormwater runoff. On the other hand, it requires regular maintenance to ensure on-going efficiency (Wilson *et al.*, 2004). Cleaning is generally carried out with the aid of specially designed vacuum cleaners.

3.2.6.3 Modular pavements

Modular pavements typically comprise modular paving blocks (MPBs) with large openings filled with pervious materials such as stone, sand and grass (Figure 3.9). These blocks interlink to form a pavement surface that is able to support relatively heavy loads. A gravel base course provides storage space for the stormwater runoff that infiltrates through the modular block surface (Stahre, 2006).

Figure 3.9: Modular pavement system planted with grass, Clifton Hill Estate, Hillcrest

There are many modular paving materials commercially available including: flexible plastic cellular confinement systems, moulded plastic materials, interlocking concrete blocks and cast-in-place concrete blocks (Debo & Reese, 2003; Hobart City Council, 2006). Modular block paving is only suited to areas that have low traffic volumes (Debo & Reese, 2003; Minton, 2002).

3.4.7 Case studies

The following case studies are good examples of where permeable pavements have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Dourehi, A, Moore, J, (2006). *Raleigh Street stormwater capture and re-use, Cammeray*, 2006 Sustainable Water Challenge, Sydney: A case study on the installation of a permeable paving system that receives stormwater runoff from a shopping centre complex, laden with litter and oil.

ii) Still, D, (2009). *Diocese of Natal: Upgrade of Cathedral Centre parking Area*, Partners in Development, Pietermaritzburg: A brief pictorial case study on the upgrade of aging asphalt parking area surfacing with permeable concrete block pavers (PCBP).

3.4.8 Further reading

The following documents are considered useful references when designing permeable pavements. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Kevern, J, (2010). *Maintenance and Repair Options for Pervious Concrete*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

ii) Myers, B, van Leeuwen, J, Beecham, SC, (2009). *An Experimental Study on the Long-Term Water Quality Impacts of Gravel Media in Storage Underlying Permeable Pavements*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

iii) Smith, DR, Hunt, WF, (2010). *Structural/Hydrologic Design and Maintenance of Permeable Interlocking Concrete Pavement*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

4. Local controls

4.1 Filter strips

4.1.1 General description

Filter strips are maintained grassed areas of land that are used to manage shallow overland stormwater runoff through several filtration processes in a similar manner to buffer strips. They can be as simple as uniformly graded strips of lawn alongside a drain (Field & Sullivan, 2003; Melbourne Water, 2005). They 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 (Sections 4.2, 4.3 and 4.4). They are also effective as stormwater runoff mitigation options in low-density developments (Debo & Reese, 2003; Environment Protection Authority – Melbourne Water Corporation, 1999). They intercept and spread out stormwater runoff thus helping to attenuate flood peaks. Filter strips are commonly used along stream banks as vegetated buffer systems (Figure 4.1), but are also used downstream of agricultural land to intercept and infiltrate stormwater runoff. They are particularly useful for providing a first line of defence against sheet flows from large paved areas such as parking lots and arterial roadways (Debo & Reese, 2003).

Figure 4.1: Vegetated filter strips adjoining a meandering stream

Filter strips use vegetative filtering as a primary means of stormwater runoff pollutant removal. Properly designed filter strips remove most sediment and other settleable solids such as hydrocarbons; however, soluble nutrients and heavy metals are often not adequately removed. Soluble pollutants generally pass through filter strips although some infiltrate into the underlying soil. There, additional removal is effected when pollutants are bound to organic matter and removed through biological processes (Debo & Reese, 2003 Field & Sullivan, 2003; Melbourne Water, 2005). With the use of appropriate indigenous vegetation, filter strips have the potential to provide a habitat corridor for wildlife (Environment Protection Authority – Melbourne Water Corporation, 1999). Pollution control characteristics for filter strips are included in Appendix B.

4.1.2 General design guidelines

Filter strips are generally sized against the 6 or 12 month, 24-hour recurrence interval storm. As with other bio-retention and infiltration options, the pollutant removal characteristics of filter strips are determined by the relationship between their length, width, slope and soil permeability compared to the stormwater runoff rate and its associate velocity (Field & Sullivan, 2003). Filter strips must be designed to provide sufficient contact time for the adequate functioning of the water quality treatment processes. They normally serve areas smaller than 20,000 m^2 with slopes between 2% and 6% (Debo & Reese, 2003). As a rule of thumb, the initial sizing of the specified filter strip should allow for an infiltration area approximately twice that of the contributing impervious stormwater runoff surface, or be at least be as long and wide (Field & Sullivan, 2003; Woods-Ballard *et al.*, 2007). Excess water running off the infiltration area should be carefully managed to ensure that it does not run onto adjoining developments or create stagnant pools of water in local surface depressions, which could potentially attract mosquito breeding and other nuisances (Stahre, 2006).

The primary treatment process of filter strips is filtration – with limited pollutant uptake. The main design and management objective should therefore be to develop a dense and sustainable vegetation growth in order the maximise the filtration processes and reduce to potential for erosion (Environment Protection Authority – Melbourne Water Corporation, 1999). To promote the settling of pollutants, stormwater runoff velocities should not exceed 0.3 m/s (Woods-Ballard *et al.*, 2007). The provision of dense vegetation, preferably indigenous, potentially improves the runoff attenuation in addition to boosting amenity and biodiversity in the immediate vicinity (NCDWQ, 2007). Vegetation selection is linked to the soil and climatic conditions for the specified site; however the height of the chosen vegetation should exceed the expected depth of the overland flow to ensure that the entire flow volume is filtered. Small flow distribution structures can be used to spread the flow more uniformly over the filter area if necessary. Some examples of distribution structures include shallow weirs, check dams, perforated pipes, rip-rap mattresses and stilling basins. Ideally, filter strips should not receive any overland flow until the specified vegetation media has been established (Environment Protection Authority – Melbourne Water Corporation, 1999). The general design for filter strips is presented in Figure C4.

4.1.3 Advantages

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

ii) The layout of filter strips is quite flexible;

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

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

v) Filter strips normally integrate well within the natural landscape to provide open spaces for uses such as recreation.

4.1.4 Limitations

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

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

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

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

v) Because filter strips are not able to manage high velocity stormwater runoff flows, they are not effective on steeply sloping landscapes.

4.1.5 Operation and maintenance

Filter strips are relatively low maintenance stormwater management options. Maintenance largely comprises regular inspection and cutting. In addition, they need to be periodically checked for signs of erosion and cleared of litter. From time to time, sediment may have to be removed which might require re-levelling and the planting of new vegetation (Woods-Ballard *et al.*, 2007). Filter strips should also be occasionally inspected during rainfall events to ensure that the flow distribution is relatively uniform over the infiltration area. According to Debo & Reese (2003), clogging of the underlying soil media accounts for the failure of as many as 30% of all infiltration-type SuDS. Vegetation should be kept in a healthy condition, especially in areas of abnormally high or low rainfall. In order to achieve this, weeding and fertilizing, if required, should be carried out on a regular basis in addition to routine watering. Vegetation replacement will be necessary from time to time in areas that have died-off or have been subject to excess sediment build-up (Field & Sullivan, 2003; Debo & Reese, 2003).

4.1.6 Technology derivative

Vegetated buffers work in a similar manner to filter strips.

4.1.7 Case studies

The following case studies are good examples of where filter strips have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Belan, G, Otto, B (2004). *Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management, American Rivers*, Washington D.C. 40 pp. A brief case study of a vegetated filter strip used to protect a stream from the stormwater runoff from an adjoining building.

ii) Stabenfeldt, L, (1996). Forest *& Riparian Buffer Conservation*, Forestry Workgroup of the Nutrient Subcommittee, Washington: Several case studies on the implementation and conservation of vegetated filter strips and riparian buffers, used for primarily for sustainable stormwater management.

4.1.8 Further reading

The following documents are considered valuable references when designing filter strips. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Endo, J, Fujiwara, H, Tamoto, N, Sakakibara, T, (2009). *Deterioration of rainwater infiltration facilities with time*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

ii) Hathaway, JM, Hunt, WF, 2008, *Field Evaluation of Level Spreaders in the Piedmont of North Carolina, USA*, 11th International Conference on Urban Drainage, Endinburgh.

iii) Schooler, PLS, 2010, *An alternate approach to size vegetative filter strips as elements of a highway LID stormwater management strategy*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

iv) Winston, RJ, Hunt, WF, 2010, *Low Impact Development Benefits of Level Spreader – Vegetative Filter Strip Systems*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

4.2 Swales

4.2.1 General description

Swales are shallow grass-lined channels with flat and sloped sides (Mays, 2001; Parkinson & Mark, 2005). Although they are normally lined with grass (Figure 4.2), alternative linings can be used to suit the characteristics of the specified site (Section 4.2.6) (Field & Sullivan, 2003). They serve as an alternative option to roadside kerbs and gutters in low density residential areas but because they generally have a larger stormwater storage capacity, they help to reduce runoff volumes and peak stormwater flows. They require relatively large surface areas to function effectively.

For more sustainable stormwater management efficacy, swales are commonly combined with buffer and bio-retention systems in a treatment train (Figure 4.3). Swales use a combination of infiltration and bio-infiltration to remove dissolved pollutants in stormwater runoff. The larger particles are filtered by the vegetation (Debo & Reese, 2003; Field & Sullivan, 2003; McAlister, 2007). Pollution removal characteristics for swales are listed in Appendix B.

Figure 4.2: Roadside swale, Cotswold Downs Golf Estate, Hillcrest

Apart from serving as open drainage systems for stormwater runoff and providing some minor infiltration area, swales also serve as stormwater pre-treatment facilities for larger SuDS options in the treatment train (Hobart City Council, 2006; Melbourne Water, 2005). A well-designed swale system should provide (Debo & Reese, 2003):

i) Reduction of impervious cover;

ii) Pronouncement of the surrounding natural landscape; and

iii) Multiple aesthetic enhancements.

4.2.2 General design guidelines

Swales are generally suitable for road medians and verges, car parking runoff areas, parks and recreation areas (Environment Protection Authority

– Melbourne Water Corporation, 1999). They should be designed to meet two chief stormwater management processes, namely, (1) flow conveyance requirements, and (2) effective stormwater pre-treatment (Debo & Reese, 2003). According to the MBWCP (2006), the following five steps are typically required for design:

i) Determine the likely treatment performance of the conceptual design, and specify associated plant species and planting densities;

ii) Determine the design flows and resultant dimensions of the swale(s), cognisant of site constraints;

iii) Estimate and optimise the design inflow of the system, verifying the design with scour velocity and treatment performance checks;

iv) Size the overflow area(s) making allowance for traffic; and

v) Draft a maintenance plan.

Figure 4.3: Swale combined with bioretention areas, Hawaan Estate, Umhlanga

Swales generally form part of the minor flood design and should be sized accordingly. Design recurrence intervals vary from two to ten years. Care must be taken to ensure that the flow velocities are not too high and that there is sufficient freeboard level to prevent flooding (Section 2.1.3). Grassed swales are gently sloped in the flow direction, whilst the side slopes are kept gentle enough – typically less than 30° – for the grass to be easily cut using mechanical grass-cutters (Stahre, 2006). In flatter areas, swales may be designed to act as small detention basins with very small flow velocities. If the in-situ soil has a low permeability the base of the swale can be underlain with a granular stone material drained with the aid of perforated pipes. If standing water is a problem, the longitudinal slope of swales should exceed 2.5% (Hobart City Council, 2006; Taylor, 2003). Swales that are long and wide with gentle longitudinal slopes (< 5%) typically perform better than short and narrow configurations (Field & Sullivan, 2003; Debo & Reese, 2003; Melbourne Water, 2005).

The grass covering on and around swales should be kept healthy to assist in the removal of pollutants. Grassed swales remove pollutants by binding them to soil particles and other organic matter. The extent to which soluble pollutants are removed depends on the density of the grass and the exposure of the soil to the stormwater. If the grass is too dense, very little soil will be in contact with the stormwater and the soil may not be very effective in removing contaminants (Minton, 2002; Hobart City Council, 2006; Parkinson & Mark, 2005). Studies have shown swales to be very effective in the removal of heavy metals and suspended solids but not so effective in the long-term removal of nutrients (Debo & Reese, 2003). The MBWCP (2006) list the following four vegetation types for use in and around swales to enhance pollutant removal:

i) Groundcovers for sedimentation removal and erosion protection;

ii) Shrubs for screening, glare reduction and aesthetic value;

iii) Trees for shading and character; and

iv) Indigenous and existing vegetation for ecological stability.

The general design for swales is depicted in Figure C5.

4.2.3 Advantages

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

ii) Runoff from adjacent impermeable areas is often completely infiltrated *in-situ* using swales;

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

iv) Swales generally reduce stormwater runoff volumes and delay runoff peak flows.

4.2.4 Limitations

i) Swales normally require a larger land area than conventional kerb and channel drainage systems;

ii) Swales have very limited removal capabilities for soluble pollutants and fine sediment;

iii) Swales are impractical on properties that have a relatively steep topography;

iv) Standing water in swales has the potential to result in the breeding of mosquitoes and the generation of foul odours; and

v) If they are not properly maintained, failure is likely to occur more quickly with swales than with most other SuDS options.

4.2.5 Operation and maintenance

The effective design life of swales is directly related to the standard of maintenance. Swales have the potential to manage stormwater indefinitely if properly maintained. Maintenance activities generally include, *inter alia*, the regular mowing of grassed surfaces, weed control, watering during extended dry periods, re-seeding of uncovered areas, and the frequent clearing of litter, debris and visible blockages (Melbourne Water, 2005). The most important maintenance period is the first two years during the 'plant establishment period' when frequent weed control and replanting may be required. The flow inlet and outlet areas require particular attention at the establishment of the specified swale as they may be subject to erosion (MBWCP, 2006). Accumulated sediment should be removed once it exceeds about 100 mm in depth or starts to overwhelm the vegetation cover (Endicott & Walker, 2003; Field & Sullivan, 2003). The swale should be inspected at least twice year, generally at the beginning and end of the wet season, to check for areas of erosion and channelization (Taylor, 2003).

4.2.6 Technology derivatives

There are several variations which can be considered for stormwater management. Two are described below.

4.2.6.1 Enhanced dry swales

Enhanced dry swales are vegetated conveyance systems that include a bed of prepared soil to enhance the filtration of the stormwater runoff volume that passes through it (Figure 4.4). The filter soil overlies an under-drain system. They are designed to treat the entire volume of water that passes through.

Figure 4.4: Gabion-lined dry swale, Hawaan Estate, Umhlanga

4.2.6.2 Wet swales

Wet swales are vegetated conveyance systems designed to retain stormwater and to create marshy conditions that are ideal for wetlands. They require a high water table and/or poorly drained soils if they are to remain wet. Wet swales are generally not used in residential areas as the presence of standing and stagnant water can create foul odours and increase the likelihood of mosquito breeding (Debo & Reese, 2003; NCDWQ, 2007).

4.2.7 Case studies

The following case studies are good examples of where swales have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Chanan, A, Woods, P, Ghetti, I, Singh, G, Spyrakis, (2006). *Connells Point Drainage Project*, NSW Sustainable Water Challenge Awards 2006, Kogarah: A case study on the diversion of stormwater runoff flows through a grassed swale that offered adequate flood protection and environmental benefits.

ii) Melbourne Water, (2005). *Altona Green Park*, Melbourne Water, Hobsons Bay: A case study on the provision of a safe and active recreational area for public use through the implementation of a swale and stormwater collection and reuse system.

iii) Owen, R, Butler, P, Cullan, P, Herd, D, Happold, B, Fisher, N, (2008). *Wessex Water Operations Centre, Claverton Down*, Wessex Water Operations Centre, Bath: A brief case study of use of permeable paving, soakaways, swales and rainwater harvesting to mange stormwater runoff from residential developments.

4.2.8 Further reading

The following documents are considered valuable references when designing swales. Where possible download, links to the documents have been provided at www.wsud.co.za.

i) Backstrom, M, (2001). *Particle trapping in grassed swales*, NOVATECH 2001, Lyon-Villeurbanne.

ii) Brown, T, Berg, J, Underwood, K, (2010). *Replacing Incised Headwater Channels and Failing Stormwater Infrastructure with Regenerative Stormwater Conveyance*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

iii) Robert Bray Associates, (2007). *A Sustainable Drainage Design Strategy For Urban Development: Creating A Suds Landscape To Replace The Storm Sewer*, SUDSnet National Conference, Coventry University.

4.3 Infiltration trenches

4.3.1 General description

Infiltration trenches are excavated trenches that are filled with rock, or other relatively large granular material, or commercial void forming products. A geotextile is used to provide separation between the trench media and the surrounding soil. They normally have a rectangular vertical cross-section and are usually designed to receive stormwater runoff from adjacent properties and transportation links such as asphalt roads and footpaths (Debo & Reese, 2003, Melbourne Water, 2005, Taylor, 2003). Stormwater permeates through the voids in the trench and is temporarily stored. Over a period of time this water infiltrates into the underlying soil and replenishes the groundwater (Hobart City Council, 2006). Unlike soakaways (Section 3.3), infiltration trenches are usually designed without piped outlets (Endicott & Walker, 2003), however, the installation of perforated pipes in the trenches provides for the outflow of surplus stormwater when infiltration into the surrounding soil is inadequate (Field & Sullivan, 2003; Mays 2001).

Pollution control characteristics for infiltration trenches are presented in Appendix B. Studies have shown that infiltration trenches can be effective in removing sediment, metals, coliform bacteria and organic matter (Taylor, 2003; Field & Sullivan, 2003). Infiltration trenches are most effective in pollutant removal when provided with an appropriately designed pre-treatment system that removes gross pollutants (Morton Bay Waterways and Catchments Partnership, 2006; Woods-Ballard *et al*., 2007).

4.3.2 General design guidelines

Figure C6 shows typical trench dimensions. The inner perimeter of the trench, which is usually rectangular in cross section, is normally lined with a geotextile fabric to prevent soil and other fine materials from migrating into the rock and/or aggregate fill. The coarse fill material may be capped with the geotextile and covered with a layer of top soil or other growth medium (Melbourne Water, 2005). The aggregate used to fill the infiltration trench is typically 6-40 mm in diameter (Taylor, 2003). When operating optimally, the trench is designed to infiltrate or discharge the design runoff within 24 hours after a moderate rainfall event (up to the 80 or 90 percentile storm). Berms may be constructed down-slope of infiltration trenches to encourage further groundwater recharge (Endicott & Walker, 2003; Field & Sullivan, 2003). According to Field & Sullivan (2003), there are four aspects to consider in the design:

i) The infiltration rates in the surrounding soil stratum;

ii) The required stormwater treatment flow rates;

iii) The type of porous media to be used for backfilling the trench; and

iv) The clogging potential of the trench.

Infiltration trenches are most effective when implemented adjacent to impervious areas such as roads, footpaths, parking lots and other hardened areas (Mays, 2001; Woods-Ballard *et al.*, 2007). They are most commonly implemented in residential areas; however, if properly designed, infiltration trenches have been used in industrial areas as well (NCDWQ, 2007). It is important that attention is given to the control of sediment as this can lead to premature clogging (Environment Protection Authority – Melbourne Water Corporation, 1999). As a consequence, consideration should be given to the addition of vegetated swales and buffers and/or small detention ponds to reduce the quantity of sediment reaching the trench. The pollutant removal ability of infiltration trenches can also be enhanced by utilising washed aggregate and layering the subsoil with organic matter and top soil (Taylor, 2003).

4.3.3 Advantages

i) Infiltration trenches increase stormwater infiltration and corresponding groundwater recharge;

ii) Infiltration trenches decrease the frequency and extent of flooding;

iii) Infiltration trenches are particularly effective in removing suspended particulates from stormwater;

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

v) Infiltration trenches have negligible visual impact as they are generally below ground.

4.3.4 Limitations

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

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

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

iv) They are restricted to areas with permeable soils.

4.3.5 Operation and maintenance

For the first year after the trench has been constructed, it should be inspected after every large rainfall event for sediment and debris build up, and the quality and quantity of stormwater. It can be checked quarterly thereafter. The construction costs of infiltration trenches are relatively low compared with other infiltration based SuDS options; however, the cost of maintaining infiltration trenches is relatively higher, especially if they are implemented in areas with fine-grained soils (Taylor, 2003). The top layers of the trench should be periodically cleaned to prevent undesirable sediment build up (Debo & Reese, 2003; Melbourne Water, 2005). If the infiltration trench is clogged by sediment and/or debris, there is also a greater likelihood that mosquito and other vector breeding will occur. If it takes longer than 72 hours for the trench to drain, then the backfilled aggregate infiltration media should be removed and all dimensions of the trench should be increased to improve infiltration into the underlying soil (Taylor, 2003).

4.3.6 Technology derivatives

Soakaways (Section 3.3) and infiltration basins (Section 5.1.6) are both similar to infiltration trenches.

4.3.7 Case studies

The following case studies are good examples of where infiltration trenches have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Carpenter, V, Littleboy, R, Hoyland, J, (2001). *Bognor Regis Sports Centre*, West Sussex County Council, West Sussex: A concise case study on the implementation of an infiltration trench which receives excess stormwater runoff from a porous parking lot and sports pitch.

ii) Melbourne Water, (2003). *Riviera Street Reconstruction*, Melbourne Water, City of Kingston: A case study discussing the alleviation of the problem of stormwater runoff from roads in a suburban neighbourhood, by incorporating vegetated inlet zones and infiltration trenches.

iii) USEPA, (2008). *Case Studies for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*, USEPA: A case study briefly describing the use of infiltration trenches as part of a larger stormwater management system.

4.3.8 Further reading

The following documents are considered valuable references when designing infiltration trenches. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Browne, D, Deletic, A, Mudd, GM, Fletcher, TD, (2009). *A 2D Stormwater Infiltration Trench Model*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

ii) Watanabe, A, Ishikawa, Y, Yoshida, K, (2008). *Reduction of non-point source pollutants using infiltration facilities and model analysis of the reduction effects*, 11th International Conference on Urban Drainage, Endinburgh.

4.4 Bio-retention areas

4.4.1 General description

Bio-retention areas, also referred to as 'rain gardens' or 'bio-retention filters', are landscaped depressions typically employed to manage the runoff from the first 25 mm of rainfall by passing the runoff through several natural processes (Figure 4.5). These processes include, *inter alia*, filtration, adsorption, biological uptake, sedimentation, infiltration and detention. 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). They are particularly effective in managing stormwater runoff from minor and more frequent rainfall events. Excess stormwater runoff generated during major rainfall events is routed to other structural stormwater controls. Bio-retention areas are applicable for managing stormwater runoff on many sites, such as: between residential plots, parking lots, adjoining roadways, and within large landscaped impervious areas. The concept of 'bio-retention' can be incorporated into most other SuDS options and/or technologies, such as swales and detention ponds (Sections 4.5 and 5.2), to improve pollutant removal potential and enhance the amenity and biodiversity of the immediate environment (Woods-Ballard *et al.*, 2007).

Bio-retention areas maximise the management potential of engineered soil media and the associated vegetation to capture and treat the specified Water Quality Volume (*WQV*) of stormwater runoff. A portion of the stormwater runoff is generally removed through infiltration and evapotranspiration within the ponded area. The outflow, at least partially cleaned through the various processes in operation in the bio-retention area, is directed to the next link in the SuDS treatment train (Debo & Reese, 2003). In this manner, bio-retention areas are able to reduce stormwater runoff quantities and rates whilst improving the quality of stormwater entering watercourses further downstream (Woods-Ballard *et al.*, 2007). They are particularly effective in removing nutrients, heavy metals, pathogens and various suspended solids (Endicott & Walker, 2003, NCDWQ, 2007). Pollution control characteristics for bio-retention areas are included in Appendix B.

Figure 4.5: Bio-retention area situated between housing units, Evergreen Retirement Village, Cape Town

4.4.2 General design guidelines

The use of bio-retention areas is appropriate in relatively small catchments, typically in the region of 1000-4000 m^2. Several smaller bio-retention areas can be linked together for larger catchments (Endicott & Walker, 2003; Woods-Ballard *et al.*, 2007). The base and sides of the infiltration pit may require lining in areas where infiltration is deemed unsuitable due to groundwater contamination. Bio-retention areas may also need to be lined in areas where slope stability is of concern or where the infiltration of stormwater runoff may result in foundation or other structural issues. In these instances, an under-drain network should be installed. In addition, suitable flow routes should be identified to convey any excess stormwater runoff towards more appropriate stormwater controls (Woods-Ballard *et al.*, 2007). Small energy dissipating structures can be used to prevent high flows from adversely affecting the management capacity of the specified bio-retention area. These can be designed to spread piped flow over the infiltration areas. Flow dissipaters and spreaders typically include shallow weirs, check dams, perforated pipes, rip-rap mattresses and stilling basins (Environment Protection Authority – Melbourne Water Corporation, 1999).

Bio-retention areas are generally designed to ensure that the acceptable Water Quality Volume (WQV) depth does not exceed 150 mm. Ideally they should empty over a period of about 48 hours after a storm event – up to a maximum of 72 hours. Ultimately it is a trade-off between allowing sufficient contact time between stormwater runoff and the specified vegetation for effective pollutant removal whilst ensuring that the system is able to receive subsequent rainfall events (Endicott & Walker, 2003; Woods-Ballard *et al.*, 2007). Plants selected for bio-retention areas should not only be hardy in order to withstand the quantity and quality of stormwater runoff that may be expected, but also the potentially long, hot and dry periods in between rain events. They should preferably be indigenous as they will not only be adapted to the local climate, but will assist in preserving the natural biodiversity of the area. An herbaceous cover should be grown to protect the topsoil or upper mulch layers from erosion (NCDWQ, 2007). The use of a diverse range of trees and shrubs is advised to provide adequate protection against insects and / or disease. According to Woods-Ballard *et al.*, (2007) trees and large shrubs are often included for the following reasons:

- Interception of precipitation and the improvement of evaporation processes;
- Dissipation of runoff forces from rainfall events;
- Facilitation of surface water infiltration and the associated groundwater recharge processes; and
- Boosting of the amenity and biodiversity through, *inter alia*, the provision of shade and the reduction of potential runoff temperatures.

The general design for bio-retention areas is displayed in Figure C7.

4.4.3 Advantages

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

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

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

iv) Bio-retention areas are generally satisfactory as retrofit options; and

v) Bio-retention areas can be made aesthetically pleasing.

4.4.4 Limitations

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

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

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

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

v) The construction costs incurred for bio-retention areas are generally higher than most other SuDS options (Wilson *et al.*, 2004).

4.4.5 Operation and maintenance

To ensure that bio-retention areas function effectively, routine inspection and maintenance needs to be performed on a roughly monthly and annual basis. As with most other SuDS options, the design life of bio-retention areas is related to the frequency and quality of the maintenance. If bio-retention areas are correctly designed and maintained, they have the potential to manage stormwater indefinitely. The most important maintenance procedures include: monthly debris and litter removal, annual weeding, annual replacement of the topsoil or upper mulch layers, annual replacement of damaged vegetation, regular pruning and treatment of diseased trees and plants, and sediment removal whenever there is considerable build-up (Endicott & Walker, 2003; Woods-Ballard *et al.*, 2007). According to Woods-Ballard *et al.*, (2007), there should be no need to use fertilisers as the nutrients remaining in the bioretention areas are normally elevated, especially with the use of an upper mulch layer. The inappropriate application of fertilisers has the potential to increase the stormwater runoff pollutant content downstream of the bio-retention area.

4.4.6 Technology derivative

Bio-retention ruts are often an effective type of bio-retention area.

4.4.6.1 Bioretention ruts

Bio-retention ruts, also referred to as 'bio-retention allotments' or 'bio-retention gullies', are small pits filled with vegetation. They are commonly established at low points in the surface of, plazas otherwise impervious areas such as parking lots or open public spaces (Figure 4.6).

Figure 4.6: Bio-retention rut filled with a coarse aggregate and planted with a tree, Grand Parade, Cape Town

Bio-retention ruts can be any shape in plan, and are typically 1-10 m^2 in area. Normally they are filled with sand or coarse aggregate, covered with a selected soil media in which a selection of vegetation is planted. Runoff passing through these layers is infiltrated into the underlying strata. If the local infiltration rate is inadequate, a subsurface pipe drainage network may be provided.

4.4.7 Case studies

The following case studies are good examples of where bio-retention areas have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Alderete, D, Scharff, M, (2005). *Case Study: The Design of a Bioretention Area to Treat Highway Runoff and Control Sediment*, International Erosion Control Association (IECA) Conference, Dallas: A case study that describes the design, construction and investigation of a bioretention area, and assesses the water quality performance thereof.

ii) City Projects, (2006). *Barcom Avenue Park Upgrade – Water transfer & Bioretention*, 2006 Sustainable Water Challenge Project, Sydney: A case study of a bioretention retrofit to improve the stormwater quality in a catchment by limiting the quantity of pollution and reducing the peak flow running into stormwater drains.

iii) Melbourne Water, (2004). *Stawell Street Reconstruction*, Melbourne Water, City of Kingston: A case study of the aims, maintenance requirements and costs of bioretention basins that collect stormwater runoff from roads and properties before it is discharged into the conventional drainage system.

4.4.8 Further reading

The following documents are considered valuable references when designing bio-retention areas. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Howard, DJ, Roberts, AG, Symes, P, Somes, N, (2009). *Royal Botanic Gardens Melbourne: Lessons Learnt in Transforming an Existing Garden Bed Feature into a Functioning Rain Garden*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

ii) Hunt, WF, Passeport, E, Brown, RA, (2008). *Water Quality and Hydrologic Benefits of Five Bioretention Cells in North Carolina, USA*, 11th International Conference on Urban Drainage, Endinburgh.

iii) LeFevre, GH, Novak, PJ, Hozalski, R, (2010). *Quantification of Petroleum Hydrocarbon Residual and Biodegradation Functional Genes in Rain Garden Field Sites*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

iv) O'Neill, SW, Davis, AP, (2010). *Analysis of Bioretention Media Specifications and Relationships to Overall Performance*, ASCE Low Impact Development 2010: Redefining Water in the City, Los Angeles.

4.5 Sand filters

4.5.1 General description

Sand filters come in many forms. They normally comprise of a sedimentation chamber linked to an underground filtration chamber comprising sand or other filtration media through which stormwater runoff passes (Debo & Reese, 2003). The sedimentation chamber facilitates the removal of suspended particulates and heavy metals, whilst the filtration chamber removes smaller particulate pollutants that pass through the sedimentation chamber. The removal mechanism is partly through filtration by the sand bed and partly through microbial action within the media. (Melbourne Water, 2005; MBWCP, 2006). Once the treatment process is completed, the stormwater either percolates into the surrounding stratum or is returned to the conveyance system (Woods-Ballard *et al.*, 2007). According to Field & Sullivan (2003), sand filters have been used in France since the 1820's, however they have only recently become popular for the treatment of stormwater runoff elsewhere. They are usually installed in conjunction with land uses having relatively large percentages of impervious surfaces.

Sand filters are generally used for impervious areas less than 8000 $m^{2;}$ however, sand filters may be designed to manage stormwater runoff from areas as large as 100,000 m^2 (Endicott & Walker, 2003). The operation of sand filters is similar to that of bio-retention areas (Section 4.4) and other bio-retention systems, with the exception that stormwater runoff passes through a linear filter medium without vegetation (MBWCP, 2006). The primary control component of stormwater management for sand filters is water quality improvement. They are particularly effective in the removal of hydrocarbons; this function may be enhanced by adjusting the filter media (Debo & Reese, 2003). They are also used extensively to remove sediment and other particulate pollutants from the first flush (Section 2.2.2) from adjoining impervious areas (Semple *et al.*, 2004). Pre-treatment is required for the removal of coarse sand and gravel from stormwater (Field & Sullivan, 2003; Environment Protection Authority – Melbourne Water Corporation, 1999). Pollution control characteristics for sand filters are included in Appendix B.

4.5.2 General design guidelines

Sand filters may be used in a variety of situations and can function for an indefinite period if designed and maintained correctly (Field & Sullivan, 2003; Woods-Ballard *et al.,* 2007). According to Field & Sullivan (2003), sand filters are most commonly used:

- In areas of fine soils and relatively low associated infiltration rates;
- In arid regions with high evaporation rates where limited rainfall and high evaporation rates preclude the utilisation of retention ponds or wetlands for stormwater management (Sections 5.2 and 5.3);
- In areas where there is limited open ground, sand filter systems can be implemented beneath impervious surfaces; and
- When there is a significant requirement to protect groundwater resources.

Sand filters are prone to clogging, especially from sediment-carrying runoff from construction sites and areas with open soil patches. In light of this, it is often useful to pre-screen out litter, coarse sediment and larger debris (MBWCP, 2006).

The most common filter media used in sand filters is sand – often in layers. Other filter media include peat, limestone and topsoil (Environment Protection Authority – Melbourne Water Corporation; 1999, Woods-Ballard *et al.*, 2007). For optimal efficiency, they generally require a hydraulic head of 1-1.5 m. Filtered effluent from sand filters is typically used for:

i) Recharging groundwater resources;

ii) Adding polished runoff into the treatment train waterway; and

iii) Non-potable domestic water uses.

If the sand filter effluent is to be used for domestic water uses, periodic water quality checks should be carried out to determine possible health risks. A typical sand filter design is given in Figure C8.

4.5.3 Advantages

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

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

iii) They manage stormwater runoff effectively on relatively flat terrains with high ground water tables where bio-retention systems are inappropriate (NCDWQ, 2007);

iv) The filtered effluent can be reused for most non-potable domestic water uses including: toilet flushing, dish washing and garden watering; and

v) Sand filters may be retrofitted with relative ease into existing impervious developments, constrained urban locations or in series with conventional stormwater management systems (Melbourne Water, 2005).

4.5.4 Limitations

i) Premature clogging is likely to occur in sand filters if they receive excessive sediment-carrying runoff, especially from construction sites and areas with open soil patches;

ii) Large sand filters are not generally attractive, especially if they are not covered with grass or other vegetation;

iii) Sand filters are generally ineffective in controlling stormwater peak discharges (NCDWQ, 2007);

iv) Sand filters are expensive to implement and maintain relative to most other SuDS options and/or technologies (NCDWQ, 2007; Taylor, 2003); and

v) Some sand filters, especially if designed and/or implemented incorrectly, may fail, resulting in standing pools of water which have the potential to attract nuisances such as mosquitoes and midges.

4.5.5 Operation and maintenance

To ensure their longevity, sand filters require a higher frequency of maintenance than most other SuDS options (Field & Sullivan, 2003; McAlister, 2007). Regular maintenance should thus be a top priority in the management plans of sand filters at the design stage of their application. The surface material should be periodically screened to minimise larger quantities of litter and debris, especially in dense urban areas. Designers should take care in the selection and implementation of the filtration media. The utilisation of silty or clayey filtration media tends to increase the probability of clogging (Debo & Reese, 2003; MBWCP, 2006; Taylor, 2003).

The frequency of cleaning required for sand filters can be determined by performing weekly filter inspections, especially during the dominant wet season (Melbourne Water, 2005; Taylor, 2003). Sand filters should be inspected at least once after a relatively large rainfall event to clear sediment, litter and debris, and to ensure all stormwater has been drained within 72 hours of the specified rainfall event. According to Taylor (2003), 50-100 mm of filtration media should be removed from the filtration surface and be replaced with fresh filter media if stormwater is taking longer than 72 hrs. to drain. Sand filters which are not properly maintained tend to form a crust-like layer of finer material on the filtration surface after six months or so which inhibits their performance (Debo & Reese, 2003; MBWCP, 2006; Taylor, 2003).

4.5.6 Technology derivatives

Wilson *et al.*, (2004) and Woods-Ballard *et al.*, (2007) make particular reference to two sand filter derivatives: underground sand filters and surface sand filters. Each of these is briefly described as follows.

4.5.6.1 Underground sand filters

Underground sand filters are very similar in design, performance, operation and maintenance to perimeter sand filters. They may receive stormwater runoff from single or multiple pipe inlets. They are particularly effective in areas with extremely limited space. Unfortunately, limited space usually means limited accessibility which can make maintenance difficult (Woods-Ballard *et al.*, 2007).

4.5.6.2 Surface sand filters

A surface sand filter generally consists of a forebay for the removal of sediment followed by the infiltration basin. It often receives stormwater runoff from other SuDS options in a treatment train. (Woods-Ballard *et al.*, 2007).

4.5.7 Case studies

The following case studies are good examples of where sand filters have been implemented. Where possible download, links to the documents have been provided at www.wsud.co.za.

i) Angelis, G, Shaw, M, (2004). *Barnwell Golf Course Stormwater Treatment and Reuse*, Sustainable Water Challenge Project, Canada Bay: A case study of the treatment and reuse of stormwater pollution entering Canada Bay using, *inter alia*, a sand filters and gross pollutant trap for treatment and collection purposes.

ii) Chanan, A, (2003). *Low Flow Filtration & Reuse Project*, Kogarah Municipal Council, Kogarah: A case study of the designs, construction, installation and costs of a low flow sand filtration and reuse system for treating and reusing stormwater from a roadway arterial.

iii) Jones, C, (2005). *Hindmarsh Park Sand filter*, A Sustainable Water Challenge 2005 Project, Kiama: A comprehensive case study of a stormwater treatment train comprising of gully pits, litter traps and a 'state of the art' sand filter that incorporate *HydroCon* permeable concrete pipes.

4.5.8 Further reading

The following documents are considered valuable references when designing sand filters. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Howard, DJ, Roberts, AG, Symes, P, Somes, N, (2009). *Royal Botanic Gardens Melbourne: Lessons Learnt in Transforming an Existing Garden Bed Feature into a Functioning Rain Garden*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

ii) Mladenovski, I, Dalton, S, Jayasuriya, N, (2009). *The effectiveness of University Hill constructed wetland in treating stormwater*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

iii) Sansalone, J, Pathapati, S, Becciu, G, (2008). *Simulation of Particulate Matter Fate and Head Loss in a Passive Urban Drainage Radial Filter*, 11th International Conference on Urban Drainage, Endinburgh.

5. Regional Controls

5.1 Detention ponds

5.1.1 General description

Detention ponds or detention basins are temporary storage facilities that are ordinarily dry but are designed in such a manner that they are able to store stormwater runoff for short periods of time (Figure 5.1). The captured stormwater runoff either infiltrates into the underlying soil layers or, more usually, is drained into the downstream watercourse at a predetermined rate. This means that detention ponds are particularly effective at regulating the flow in the downstream watercourses and/or supplementary treatment systems. They are usually grass lined, but concrete lined ponds can be used if there are soil stability or land use issues (Environment Protection Authority – Melbourne Water Corporation, 1999; Field & Sullivan, 2003; Parkinson & Mark, 2005). The use of detention ponds depends on the availability of adequate space.

Figure 5.1: Large roadside detention pond, Hillcrest

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

5.1.2 General design guidelines

In general, detention ponds are designed to temporarily store as much water as possible for 24 to 72 hours whilst aiming to provide a safe and secure public environment (Field & Sullivan, 2003). According to the Environment Protection Authority – Melbourne Water Corporation (1999) and Woods-Ballard *et al.*, (2007), the following four factors should be considered at the planning and design phase:

i) The local catchment hydraulics and hydrology;

ii) The implementation of appropriate safety structures including pest and vector controls;

iii) The prevention of dangerously steep ground slopes around the pond perimeter; and

iv) Upstream treatment systems and outlet structures.

Detention ponds are vulnerable to erosion from high speed flows at the inlet so particular care must be taken to ensure that this does not happen. This can be accomplished in a number of ways, from the construction of an entrance structure that spreads the inflow, to the planting of hardy vegetation in and around the entrance. Detention ponds generally include ‘hard’ engineered outlet structures that regulate the discharge of stormwater (Debo & Reese, 2003; Endicott & Walker, 2003). An emergency spillway should also be provided if there is a risk of damage from an overflowing point (Figure 5.2). In arid regions, any vegetation should be drought tolerant (Debo & Reese, 2003; NCDWQ, 2007). Detention ponds may also be integrated with sports facilities such as tennis courts and skate parks, which are flooded during the storm.

The pollutant removal performance of detention ponds can be improved through the construction of upstream pre-treatment SuDS options and/or the construction of a sediment trap at the entrance. The addition of a sediment trap at the inlet to the pond potentially reduces the long-term operation and maintenance requirements. For best performance in pollution removal, detention ponds typically require a surface area of at least 2% of the contributing impervious area (Field & Sullivan, 2003; MBWCP, 2006). In industrial areas, they should be designed to trap common and potentially hazardous pollutants. For safety purposes, detention ponds should be fenced. It should also be possible to rapidly drain them if urgently required (Stahre, 2006). Typical design details for detention ponds are given in Figure C9.

Figure 5.2: Detention pond emergency overflow structure, New Heritage Market, Hillcrest

5.1.3 Advantages

i) They are able to temporarily store large volumes of stormwater thus attenuating downstream flood peaks;

ii) Detention ponds are relatively inexpensive to construct and easy to maintain;

iii) Detention ponds may serve multiple purposes during drier seasons, particularly as sports fields, play parks or commons. Care should though be taken where stormwater may be contaminated with sewage as this will pose health and environmental risks; and

iv) If managed regularly, detention ponds can add aesthetic value to adjoining residential properties as well as presenting fewer safety hazards than wet ponds due to the absence of a permanent pool of water.

5.1.4 Limitations

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

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

iii) Siltation can be a problem;

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

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

vi) Detention ponds are not very suitable in areas with a relatively high water table, or where the soil is very coarse and there is a risk of groundwater contamination (Hobart City Council, 2006; Taylor, 2003).

5.1.5 Operation and maintenance

The hydraulic and pollution removal performance of detention ponds depends on good maintenance. Regular inspections should be carried out to check whether the clearing of accumulated sediment is necessary. This is particularly important if the pond serves a dual purpose such as a sports field, play area or commons (NCDWQ, 2007). The management of vegetation (e.g. mowing the grass) should also be carried out when appropriate (Woods-Ballard *et al.*, 2007). Inspections should be carried out after larger rainfall events (normally greater than the 80 or 90 percentile storm) to ensure that the pond is performing as designed and that the inlet and outlet structures are free of debris and litter (Environment Protection Authority – Melbourne Water Corporation, 1999). Detention ponds may require de-silting from time to time (typically every 5 years).

5.1.6 Technology derivative

SEMCOG (2008), Wilson *et al.*, (2004) and Woods-Ballard, *et al.* (2007) describe an infiltration basin as follows.

5.1.6.1 Infiltration basins

Infiltration basins are very similar to detention ponds in design, construction and maintenance except that they do not ordinarily discharge into a downstream watercourse. Instead, stormwater runoff is infiltrated into the ground where it recharges the underlying aquifers. The quality of the water is improved through filtration through the sand medium. This can be enhanced through the use of vegetation in the same manner as a bio-retention device. They are usually designed to handle small rainfall events from catchment areas of less than 4 ha.

5.1.7 Case studies

The following case study is a good example of where a detention pond has been implemented.

i) Hussain, CF, Brand, J, Erickson, AJ, Gulliver, JS, Weiss, PT, (2010). *Case Study #1: Monitoring a dry detention pond with under-drains*, University of Minnesota, A case study on a dry detention pond designed to provide on-site storage up to a 100 year, 24 hour rainfall event.

5.1.8 Further reading

The following documents are considered valuable references when designing detention ponds. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Bentzen, TR, Larsen, T, Thorndahl, S, Rasmussen, MR, (2005). *Removal of heavy metals and PAH in highway detention ponds*, 10th International Conference on Urban Drainage, Copenhagen.

ii) Massoudieh, A, Leatherbarrow, JE, Kayhanian, M, Abrishamchi, A, Young, TM, (2008). *Numerical Model for Suspended Particles Removal within a Detention Basin*, 11th International Conference on Urban Drainage, Endinburgh.

iii) Vollertsen, J, Lange, KH, Pedersen, J, Hallanger, P, Bruus, A, Laustsen, A, Bundesen, VW, Brix, H, Nielsen, AH, Nielsen, NH, Wium-Andersen, T, Hvitved-Jacobsen, T, (2008). *Removal of soluble and colloidal pollutants from stormwater in full-scale detention ponds*, 11th International Conference on Urban Drainage, Endinburgh.

5.2 Retention ponds

5.2.1 General description

Retention ponds, also referred to as 'retention basins', have a permanent pool of water in them (Debo & Reese, 2003; Mays 2001). They are generally formed through the construction of a dam wall (or walls) equipped with a weir outlet structure (Figure 5.3). The maximum storage capacity of retention ponds is larger than their permanent pond volume. Stormwater coming into the pond is mixed with the permanent pond water and released over the weir at a reduced rate (Field & Sullivan, 2003; NCDWQ, 2007). Retention ponds are usually capable of handling relatively large quantities of stormwater runoff (Woods-Ballard *et al.*, 2007). The permanent pond volume can be utilised as a source of water for various non-potable purposes.

Figure 5.3: Large retention pond, Cotswold Downs Golf Estate, Hillcrest

Retention ponds generally provide a medium to high pollutant removal capacity (Woods-Ballard *et al.*, 2007). They normally utilize a combination of sedimentation, filtration, infiltration and biological uptake processes to remove pollutants from stormwater runoff (Stahre, 2006). Generally, retention ponds are less problematic to maintain than detention ponds (Field & Sullivan, 2003), although care must be taken to ensure that they are not a drowning hazard. If the inflow water is severely polluted (e.g. as emanating from areas with poor sanitation) then contact with the pond by the public should be limited. Pollution control characteristics for retention ponds are listed in Appendix B.

5.2.2 General design guidelines

Retention ponds can be used for a wide variety of land uses – provided that sufficient space is available. They are also effective as a retrofit option (NCDWQ, 2007, Woods-Ballard *et al.*, 2007). Water loss through the floor and sides of the ponds can be reduced by installing clay or plastic liners below the permanent water level (Debo & Reese, 2003). It is important to address various concerns associated with the open water characteristics of retention ponds at the design stage. These typically include: the mitigation of health and safety risks, aesthetic appeal, and the eradication of potential mosquito breeding and other nuisances (Field & Sullivan, 2003; Endicott & Walker, 2003). Safety can be improved by designing the pond with moderate side slopes and relatively shallow depths, as well as providing a barrier – which could be vegetation – around its perimeter (Stahre, 2006).

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

Flood control is provided with the addition of extended storage volume above the permanent water line. Floodwater typically spills onto a minimum 3 m wide vegetated buffer surrounding the pond. The addition of a shallow 'bench' along the perimeter can provide an aquatic habitat that has the potential to enhance biological pollutant removal for the influent stormwater runoff, and reduce the likelihood of algal mat formation (Field & Sullivan, 2003). Vegetation can also be used to stabilise adjoining side slopes and prevent soil erosion (NCDWQ, 2007; Woods-Ballard *et al.*, 2007). The use of appropriate indigenous vegetation is recommended in order to maintain local biodiversity and to ensure that the vegetation grows with ease and can tolerate the conditions in the pond (Debo & Reese, 2003). The general design for retention ponds may be found in Figure C10.

5.2.3 Advantages

i) The incorporation of retention ponds into the natural landscape promotes biodiversity; they can also be used for recreational purposes where adequate supervision is available;

ii) Retention ponds generally have the capacity to remove a wide range of common stormwater runoff pollutants;

iii) Retention ponds are one of the most cost-effective SuDS options; and

iv) Stormwater runoff that is captured in retention ponds can be reused for irrigation or secondary domestic purposes where the water quality is acceptable.

5.2.4 Limitations

i) The permanent open pool of water creates health and safety concerns and therefore requires social impact considerations at the design stage;

ii) If maintained infrequently or irregularly the permanent open pool of water could display unsightly floating debris and scum. Other nuisances include foul odours and mosquitoes;

iii) Retention ponds are normally restricted to sites with shallow slopes;

iv) Retention ponds require a baseflow or the addition of supplementary water to maintain a specified permanent water line;

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

vi) Retention ponds are generally not as effective in removing pathogens as constructed wetlands.

5.2.5 Operation and maintenance

Retention ponds and detention ponds share similar operation and maintenance requirements, the most important being sediment and litter removal cycles, especially if the pond is situated in an area of high visibility (Parkinson & Mark, 2005). Other requirements typically include the mitigation and eradication of nuisances such as foul odours and mosquito breeding, and the stringent implementation of weed control (Field & Sullivan, 2003). Taylor (2003) suggests that appropriately chosen fish could be introduced into retention ponds to improve natural mosquito and midge control. The outlet structure must be designed in such a way that it can be opened and the pond drained so that it can be cleaned in the event of excessive pest populations or rapid algae growth. Inlet and outlet structures are prone to clogging from accumulating floating debris and litter, and should thus be inspected and cleared frequently, especially after large rainfall events (Endicott & Walker, 2003; Woods-Ballard *et al.*, 2007). Any damaged structural components that are identified should be repaired as quickly as possible to prevent major structural collapse (Hobart City Council, 2006).

5.2.6 Technology derivative

According to Van Duzer (2004) and Haskins (2010), the stormwater runoff pollutant removal capabilities of retention ponds can be improved with the addition of floating islands. This retention pond derivative is briefly described as follows.

5.2.6.1 Floating islands

Floating islands, also referred to as 'managed aquatic plant systems' (MAPS) or 'floating treatment wetlands' (FTW), are floating material structures packed with aquatic plants and other aquatic vegetation types, which are released to meander on the surface of retention ponds or other open water sources. The specially selected aquatic plants and vegetation are supported on floating material and rooted in matrix-like soil media. They are particularly useful in the uptake of dissolved nutrients suspended in the water column. The root structures are able to hang freely in the water and are naturally covered with a biofilm that supports nutrient uptake (Haskins, 2010). To ensure this intervention remains a permanent means of stormwater runoff pollutant removal, the aquatic plants and vegetation should be frequently harvested and replaced when necessary.

5.2.7 Case studies

The following case studies are good examples of where retention ponds have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Campbell, N, Maxwell, J, Berry, C, Homes, W, (2001). *Dunfermline Eastern Expansion*, Dunfermline: A concise case study that describes the uses of ponds to achieve maximum attenuation of stormwater flows.

ii) Hague, W, Gunasekara, R, (2007). *Lamb Drove – SUDS residential scheme*, Cambridgeshire County Council, Cambridge: A case study that briefly describes the uses of a retention pond as part of a SUDS scheme.

5.2.8 Further reading

The following documents are considered valuable references when designing retention ponds. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Apperson, CS, Hunt, WF, Kennedy, S, Harrison, BA, Lord, WG, (2005). *Occurrence and relative abundance of mosquitoes in stormwater retention facilities in North Carolina, USA.*

ii) Kazuhiro, IDO, (2009). *Method of evaluating water retention measures in a runoff control plan*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

iii) Vopicka, K, (2008). *Sediment Assessment of Stormwater Retention Ponds within the Urban Environment of Calgary, Canada*, 11th International Conference on Urban Drainage, Endinburgh.

5.3 Constructed wetlands

5.3.1 General description

Wetlands generally refer to marshy areas of shallow water partially or completely covered in aquatic vegetation (Figure 5.4). They may be categorised into: natural, modified natural, or constructed wetlands. They can provide a vibrant habitat for fish, birds and other wildlife – potentially offering a sanctuary for rare and endangered species. Their aesthetic appeal encourages their recreational use. Constructed wetlands are man-made systems designed to mimic the natural systems in areas where they would not usually be found. They are most often to be found serving catchments larger than 10 ha, and are particularly useful in attenuating stormwater flood peaks and 'polishing' the runoff from residential areas (Endicott & Walker, 2003). The most common stormwater runoff pollutant treatment processes that occur in constructed wetlands are: sedimentation, fine particle filtration and biological nutrient and pathogen removal (Field & Sullivan, 2003; Parkinson & Mark, 2005). Wetlands cannot remove all pathogens. The percentage removal depends *inter alia* on the pollution concentration of the inflow, the rate of flow-through, the pollution saturation level of the wetland and the degree to which the pathogens clump or adhere to settleable particles.

Figure 5.4: Constructed wetland, Century City, Cape Town

Constructed wetlands are generally considered to be effective ecosystem filters as they can be very efficient in the removal of particulates and dissolved nutrients as well as noxious substances such as heavy metals (Debo & Reese, 2003; Parkinson & Mark, 2005). Constructed wetlands typically include four zones:

i) The **inlet zone**, which includes a sediment forebay for the removal of coarse sediments;

ii) The **macrophyte zone** (Figure 5.5), which is a shallow and heavily vegetated area that facilitates the removal of fine particles and the uptake of soluble nutrients;

iii) The **macrophyte outlet zone**, which channels cleaner stormwater runoff into adjoining structures downstream; and

iv) The **high flow bypass channel**, which protects the inlet, outlet and macrophyte zones from vegetation damage and structural scour during periods of abnormally high flow (MBWCP, 2006).

Figure 5.5: The macrophyte zone in a constructed wetland, Century City, Cape Town

Where a base flow is not present, constructed wetlands may require a supplementary water supply to support the relatively dense aquatic vegetation with their micro-organisms during dry periods (Woods-Ballard *et al.*, 2007). Pollution control characteristics for constructed wetlands are included in Appendix B.

5.3.2 General design guidelines

The successful implementation of a wetland requires its effective incorporation into the landscape design and management (MBWCP, 2006). Local conditions should be taken into account in design. Access – both public and for maintenance – should be prioritised at the planning and design phases, and the involvement of local interest groups such as wildlife associations and nurseries should be encouraged (Stahre, 2006).

It is critical that a suitable sediment forebay should be provided in the inlet zone to prevent litter, debris, coarse sediment and other gross pollutants from entering the macrophyte zone. The design should also facilitate the easy access to, and removal of, the accumulated material (Field & Sullivan, 2003). Consideration should be given to the installation of trash racks on the inlet to prevent floating litter or debris polluting the wetland or being carried downstream (Debo & Reese, 2003; Stahre, 2006).

The water level in the wetland needs to be carefully regulated; this is usually carried out with the aid of a suitable level control structure. The establishment of an even flow distribution throughout the constructed wetland system is important to avoid the 'short-circuiting' of flow and stagnation in areas. Meandering flows are ideal as they encourage extended detention times and hence increase the removal of pollutants. In general, pollution removal is related to the time spent in the macrophyte zone. The use of appropriate indigenous vegetation aids in protecting biodiversity (Environment Protection Authority – Melbourne Water Corporation, 1999; Field & Sullivan, 2003; Woods-Ballard, *et al.* 2007). Vegetation also promotes the settlement of suspended matter and facilitates nutrient uptake processes. Bacteria associated with wetland vegetation assist in the reduction of nitrogen. According to Scholz (2006), the following aspects should be considered in the selection of appropriate vegetation:

i) Rapid establishment and growth;

ii) Minimum disease or weed risk;

iii) Suitability for the local climate;

iv) Tolerance of hypertrophic water-logged conditions; and

v) Stormwater runoff pollutant removal capacity.

Care must be taken to ensure that the wetland vegetation does not act as a source of pollution itself (Minton, 2002). For example, birds roost in certain types of vegetation which can lead to high nutrient loads from their droppings. This should be taken into account in the design of the macrophyte zone(s). The congregation of water birds may facilitate avian influenza (a notable risk to poultry) and other diseases and this should be monitored. The general design for constructed wetlands is given in Figure C11.

5.3.3 Advantages

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

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

iii) Small aquaculture wetlands have the ability to produce various kinds of food (Hobart City Council, 2006); and

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

5.3.4 Limitations

i) Constructed wetlands could potentially attract mosquitoes;

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

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

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

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

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

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

5.3.5 Operation and maintenance

Constructed wetlands require relatively frequent and detailed inspections. The maintenance frequency can however be reduced through effective pre-treatment; e.g. by removing silt, trash and debris. A typical inspection would check for the accumulation of sediment, organic debris, litter, oils, weed growth, nuisances, algal blooms and scour (Environment Protection Authority – Melbourne Water Corporation, 1999). Maintaining healthy vegetation and adequate flow conditions is essential to the functioning of a constructed wetland (Taylor, 2003). From time to time the vegetation will need to be harvested. Harvested organic matter can often be composted and re-used (Endicott & Walker, 2003; Parkinson & Mark, 2005). Weeds tend to spread rapidly after periods of heavy rainfall and should be removed as soon as is practical. During some seasons, for example in winter, plants naturally 'die-off'. The resultant dense litter layer can enhance stormwater runoff pollutant removal (NCDWQ, 2007) but can also reintroduce nutrients into the water column.When a constructed wetland receives a much higher volume of water than it can accommodate and becomes stagnant, plants in the wetland can become waterlogged and die off. This can create bad smells and species changes in the remaining vegetation after drainage. It can also significantly affect the ability of the wetland to remove pollution.

The breeding of mosquitoes and other disease vectors is a common problem in constructed wetlands. This should be avoided particularly in areas where, for example, malaria is endemic. There are several natural methods for controlling mosquitoes including: the introduction of predators such as fish and deliberately varying the water levels through the breeding season to disturb breeding cycles (MBWCP, 2006). Poorly maintained wetlands are vulnerable to invasive plant species that threaten indigenous wetland vegetation. The removal of invasive vegetation is critical to the sustainability of constructed wetlands (NCDWQ, 2007; Woods-Ballard *et al.*, 2007).

5.3.6 Technology derivatives

Wetlands are complex entities which should be planned and designed for incorporation into natural surroundings. Wilson *et al.,* (2004) and Woods-Ballard *et al.,* (2007) give reference to three constructed wetland derivatives, namely: extended detention shallow wetlands, pocket wetlands and submerged gravel wetlands. Each is briefly described as follows.

5.3.6.1 Extended detention shallow wetlands

Extended detention shallow wetlands store most of the stormwater 'Water Quality Volume' (*WQV*) above the normally relatively shallow marshy depths within the macrophyte zone(s). This allows for the storage and treatment of a greater volume of stormwater runoff than in a simple shallow wetland. The selection of plants that can tolerate irregular wet and dry periods is essential (Woods-Ballard *et al.,* 2007).

5.3.6.2 Pocket wetlands

Pocket wetlands are typically less than 400 m^2, and serve developments no greater than 40,000 m^2. The water depth in pocket wetlands should not exceed 1.5 m. They generally require excavation down to the water table or a consistent baseflow to support the immediate ecosystem (Woods-Ballard *et al.,* 2007). The outlets often comprise a broad-crested weir which may be equipped with a trash rack and/or drain pipe and valve which can be used to empty the pond for maintenance purposes. Owing to their small size and generally limited stormwater retention period they are not as effective as the larger constructed wetlands. Despite this, they can be an attractive SuDS option for smaller developments (Debo & Reese, 2003).

5.3.6.3 Submerged gravel wetlands

Submerged gravel wetlands are designed with one or more treatment cells backfilled with rock or coarse gravel. The outlet is designed in such a way that the surface of the water remains below the top of the rock/gravel layer during small to medium rainfall events (up to the 80 or 90 percentile storm). Algae and microbes thrive on the surface area of the backfill material and the anaerobic conditions near the base of the backfill material promote the removal of nitrogen. This is a technique that is used extensively for the treatment of municipal wastewater; however, it is a relatively new practice in the management of stormwater runoff (Woods-Ballard *et al.,* 2007). For increased pollutant removal efficiency, suitable vegetation may be established elsewhere in the wetland.

5.3.7 Case studies

The following case studies are good examples of where constructed wetlands have been implemented. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Mladenovski, I, Dalton, S, Jayasuriya, N, 2009, *The effectiveness of University Hill constructed wetland in treating stormwater*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth: A comprehensive case study on the effectiveness of a constructed wetland in treating stormwater runoff from industrial, commercial and residential areas.

ii) Robert Bray Associates, 2007, *Matchborough First School*, Robert Bray Associates, Worcestershire: A concise case study on the implementation of swales, detention basins and constructed wetlands at a school development.

iii) Smith, G, Mortensen, S, Williams, T, Hundy, B, Dixon, B, 2006, *Magdala Creek Riparian Restoration*, 2006 Sustainable Water Challenge, Blue Mountains: A case study on the application of, *inter alia*, a constructed wetland, to improve water quality and restore natural environmental flows.

5.3.8 Further reading

The following documents are considered valuable references when designing constructed wetlands. Where possible, download links to the documents have been provided at www.wsud.co.za.

i) Cook, A, Boer, S, Breen, P, 2009, *Adapting Best Practice Design of Constructed Stormwater Wetlands for Application in the Coastal Dry Tropics*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

ii) Frame, M, D'Aspromonte, D, Crawford, D, 2009, *Techniques for Inflow Control to Constructed Wetlands*, The 6th International Water Sensitive Urban Design Conference and Hydropolis #3, Perth.

iii) Higgins, NMP, Johnston, PM, Gill, LW, 2008, *The Integration of a Constructed Wetland into a Major Road Network*, 11th International Conference on Urban Drainage, Endinburgh.

iv) Wu, CY, Kao, CM, Lin, CE, Chen, CW, Dong, CD, 2009, *Application of constructed wetland for river water quality improvement and non-point source pollution control: a case study in Taiwan*, 8th Urban Drainage Modelling and 2nd Rainwater Harvesting Conference, Tokyo.

References

American Society of Landscape Architects (ASLA). (2008). *The Sustainable Sites Initiative: Guidelines and Performance Benchmarks*. The Sustainable Sites Initiative. Texas.

Austin, D. (2010). *Personal communication*.

Berwick, N. (2011). SUDS Online Operations & Maintenance Course Notes. Scotland: University of Abertay.

Bester, B. (2010). *Personal Communication*.

Bester, A., Jacobs, H., van der Merwe, J., & Fuamba, M. (2010). *Unit cost-functions for value estimation of waterborne sewer infrastructure*. Retrieved 18 October 2010, Available at: http://www.ewisa.co.za/literature/

Blockley, D. (2005). *The New Penguin Dictionary of Civil Engineering*. Penguin Books, Michigan. ISBN 014051526.

British Board of Agreement. (2009a). *Aquaflow permeable paving – Q24 Storm water source control system.* Formpave Specification sheet. Watford, Herts, UK.

British Board of Agreement. (2009b). *Formpave Porous Rectuangular Paving Blocks*. Formpave detail Sheet 2. Watford, Herts, UK.

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

Brown, R., Sharp L., & Ashley R. (2008). *Implementation impediments to institutionalising the practice of sustainable urban water management.* Proceedings of the 11th International Conference on Urban Drainage. 11th International Conference on Urban Drainage. 1-10.

Brundtland, G. (1987). *Our Common Future*, World Commission on Environment and Development (WCED), Oxford University Press, Oxford. ISBN: 9780192820808.

Buys, F. & Aldous, M. (2009). The perceived economic impact of the City of Johannesburg's storm water attenuation policy on private property developers. *Acta Structilia* , *16*(2), pp 18-45.

City of Cape Town (CoCT). (2009a). *Floodplain Management Policy – Balancing flood risk, ecological and social considerations adjacent to watercourses and wetlands.* Catchment, Stormwater and River Management Branch. City of Cape Town.

City of Cape Town (CoCT) .(2009b). *Management of Urban Stormwater Impacts Policy.* Catchment, Stormwater and River Management Branch. City of Cape Town.

Clift, M. & Bourke, K. (1999). *Study on Whole Life Cycle costing*. Building Research Establishment (BRE LTD) in : Lampe, L., Barrett, M., Woods-Ballard, B., Andrews, A., Martin, P., & Kellagher, R. (2005). *Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems*. Water Environment Research Foundation Project 01-CTS-21T, Water Environment Research Foundation.

Coombes, P. (2004). Water Sensitive Urban Design in the Sydney Area: *Rainwater tanks*. Practise Note 4. Available at: http://www.indiawaterportal.org/sites/indiawaterportal.org/files/04-Rainwater%20tanks_0.pdf

Council for Scientific and Industrial Research (CSIR). (2000a). *Guidelines for Human Settlement Planning and Design: Vol. 1*. CSIR. Pretoria. ISBN: 0798854987.

Council for Scientific and Industrial Research (CSIR). (2000b). *Guidelines for Human Settlement Planning and Design: Vol. 2*. CSIR. Pretoria. ISBN: 0798854987.

Catchment, Stormwater and River Management branch (CSRM). (2005). *Maintenance Cost Frequency Study.* Unpublished. Catchment Stormwater and River Management Branch, Roads and Stormwater Department, City of Cape Town.

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

Department of Co-operative go.vernance and Traditional Affairs (DoCGTA). (2010). *An Industry Guide To Infrastructure Guide To*

Service Levels And Unit Costs. Department of Cooperative Governance & Traditional Affairs. Available at: http://www.thedplg.gov.za/subwebsites/mig/docs/Industry%20Guide%20-%20Infrastructure%20Service%20Delivery%20Level%20and%20Unit%20Cost%20Final.pdf

Donovan, I. & Naji, F. (2003). *Water Sensitive Planning Guide for the Sydney Region.* Upper Parramatta River Catchment Trust. Sydney. ISBN: 0734761120.

Department of Provincial & Local Governmrnt (DPLG) (2006). *Guidelines for Infrastructure Asset Management (2006-2009).* Department of Provincial and Local Governement. Available at: http://www.cogta.gov.za/subwebsites/mig/docs/7.pdf

ECONorthwest. (2007). *The Economics of Low Impact Development - A Literature review.* ECONorthwest. Available at: http://www.econw.com/reports/2008_ECONorthwest_NEMO_Low-Impact-Development.pdf/

Elliott, A. & Trowsdale, S. (2005). *A review of models for low impact urban stormwater drainage*. Environmental Modelling & Software, Vol. 22, No. 3, pp. 394 – 405. Available at: http://www.sciencedirect.com/science/article/pii/S1364815206000053

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

Ellis, R. & Callaghan, P., (2009). *Infrastructure Asset Useful Lives - SA Councils Current Practises.* Tonkin Engineering Science. Available at: http://www.lga.sa.gov.au/webdata/resources/files/Infrastructure_Asset_Useful_Lives_SA_Councils__Current_Practices_-_Final_Report.pdf

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

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

Field, R. & Sullivan, D. (2003). *Wet-weather flow in the urban watershed*. Lewis Publishers. Florida. ISBN 1566769167.

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

Haskins, C. (2010) 'Planting to Enhance Cape Town's Stormwater Management' lecture series, *Introducing Sustainable Urban Drainage Systems and the role of Landscaping*. Catchment, Stormwater and River Management Branch. City of Cape Town.

Haubner, S. Reese, A., Brown, T., Claytor, R. & Debo, T. (2001). *Georgia Stormwater Management Manual*. Georgia. Available at: http://www.georgiastormwater.com/

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

Hjorth, P & Bagheri, A, (2006). *Navigating towards sustainable development: A system dynamics approach*, Futures, Vol. 38, pp. 74-92.

Jefferies, C. (2005). *SUDS Online - Design Concepts & Principles - Course Notes*. Scotland.

Jefferies, C. (2010). *SUDS Concepts and Design Principles: Information and lessons to support the course*. University of Abertay. Dundee.

Klein, R. (2003) Development Issues, A Citizens Guide to preserving and enhancing quality of life in developing areas. Community and Environmental Defense services Available online : http://ceds.org/pdfdocs/TOC.pdf

Krpo, A. (2004). GIS Model for Assessment of Land Use and Urban Development Effects on Stormwater Runoff: Puhinui Catchment Case Study , 1-242. Auckland University.

Lampe, L., Barrett, M., Woods-Ballard, B., Andrews, A., Martin, P., & Kellagher, R. (2005). *Performance and Whole Life Costs of Best Management Practices and Sustainable Urban Drainage Systems*. Water Environment

Research Foundation Project 01-CTS-21T, Water Environment Research Foundation.

Livingston, E. & McCarron, E., (2008). *Stormwater Management – A guide for Floridians*. Florida Department of Environmental Regulation. Florida.

Lloyd, S. (2004). Quantifying environmental benefits, economic outcomes and community support for water sensitive urban design. CRC for Catchment Hydrology, Civil Engineering Monash University.

Matt, C. (2009). *Green-Roof Maintenance: Irrigation, Weeding, Fertilizing*. Available at: http://www.facilitiesnet.com/roofing/article/GreenRoof-Maintenance-Irrigation-Weeding-Fertilizing--10651

Mays, L. (2001). *Water Resources Engineering*. John Wiley & Sons. New York. ISBN 0-471-29783-6. DOI: 10.1002/ep.670200306.

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

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

McAlister, T. (2007). *National Guidelines for Evaluating Water Sensitive Urban Design (WSUD).* BMT WBM Pty Ltd. Brisbane.

Melbourne Water (2005). *WSUD Engineering Procedures: Stormwater.* CSIRO Publishing. Collingwood. Victoria. Available from: http://www.publish.csiro.au/pid/4974.htm

Minton, G. (2002). *Stormwater Treatment*. Resource Planning Associates. Amica International Inc. Seattle. Available from: http://www.stormwaterbook.com/

Narayanan, A. & Pitt, R. (2005). *Costs of Urban Stormwater Control Practices.* Stormwater Management Authority of Jefferson County. Available at: http://unix.eng.ua.edu/~rpitt/Class/StormWaterManagement/M4%20Stromwater%20controls/e%20costs/M4e%20Internet%20material/Microsoft%20Word%20-%20M4e2%20Costs%20of%20Urban%20Stormwater%20Control%20Practices%20Aug%2031%20200.pdf

North Carolina Division of Water Quality (NCDWQ), (2007). Stormwater Best Management Practices Manual, North Carolina Division of Water Quality, North Carolina. Available at: http://portal.ncdenr.org/

Novotny V. & Brown P. (2007). 'Cities of the Future': *The fifth paradigm of urbanization*. IWA Publishing. London.

National Water Quality Management Strategy (NWQMS). (2006). *National Water Quality Management Strategy: Australian Guidelines For Water Recycling: Managing Health And Environmental Risks (Phase1).* Environment Protection and Heritage Council, the Natural Resource Management Ministerial Council and the Australian Health Ministers' Conference.

Opher, T. & Friedler, E. (2010). Factors affecting highway runoff quality. *Urban Water Journal*, 7(3), 155-172.

Otto, B., Ransel, K. & Todd, J. (2002). *Paving Our Way to Water Shortages: How Sprawl Aggravates the Effects of Drought. American Rivers, Natural Resources Defense Council, and Smart Growth America. August. Available at* http://www.americanrivers.org/library/reports-publications/paving-our-way-to-water.html

O'Regan, B. & Moles, R. (1997). Comments and Debates: Applying a Systems Perspective to Environmental Policy. *Journal of Environmental Planning and Management.* Vol. 40, pp. 535-8.

Pagiola, S., von Ritter, K. & Bishop, J. (2004). Assessing the Economic Value of Ecosystem Conservation. *Environment Department Paper No.101*. The World Bank Environment Department. Available at: http://www.cbd.int/doc/case-studies/inc/cs-inc-iucn-nc-wb-en.pdf

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

Penguin Books (2000). *The New Penguin English Dictionary*. Finland.

Reed, D. (2000). 'Book Reviews', Flood Estimation Handbook (Procedures for Flood Frequency Estimation), *Hydrological Sciences Journal*, Vol. 45, No. 6, pp. 629.

South African National Roads Agency LTD (SANRAL). (2006). *Drainage Manual 5th Edition*. The South African Roads Agency Ltd. Pretoria. ISBN 1868443280. Available at: http://www.nra.co.za/content/Drain5.pdf

Schmidt, E. & Schulze, R. (1987). *Flood Volume and Peak Discharge from small catchments in Southern Africa, based on the SCS technique*. University of Natal, Department of Agricultural Engineering. Pietermaritzburg, South Africa: Agricultural Catchments Research Unit.

Scholz, M. (2006). *Wetland Systems to Control Urban Runoff*. Elsevier. Amsterdam.

South East Michigan Council Of Governments (SEMCOG). (2008). *Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers*, Southeast Michigan Council of Governments, Michigan. Available at: http://www.semcog.org/lowimpactdevelopment.aspx

Semple, E. (2004). *New Jersey Stormwater Best Management Practices Manual*. New Jersey Department of Environmental Protection. New Jersey.

Senge, P., Seville, D., Lovins, A. & Lotspeich, C. (2000). *Systems Thinking Primer for Natural Capitalism: The Four Basic Shifts*, Society for Organisational Learning.

Southeast Michigan Council of Governments (2008). *Low Impact Development Manual for Michigan: A Design Guide for Implementors and Reviewers*. SEMCOG. Michigan. Available at: http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf

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

Stovin, V. (2009). The potential of green roofs to manage Urban Stormwater. *Water and Environmental Journal*. University of Sheffield, Sheffield.

Taylor, S. (2003). New Development and Redevelopment: *Stormwater Best Management Practice Handbook*. California Stormwater Quality Association. California. Available at: http://www.cabmphandbooks.com/development.asp

United States Department of Agriculture (1938). *Soil Texture Triangle*. Accessed at : www.usda.gov [Accessed: 02/10/2010].

US Department of Defense, (2010). *Unified Facilities Criteria (Ufc)*. US Department of Defense. Naval Facilities Engineering Command. Us Department Of Defense. Available at: http://www.lowimpactdevelopment.org/lid%20articles/ufc_3_210_10.pdf

United States Environmental Protection Agency (USEPA), (2000). *Low impact development(LID): A Literature Review*. USEPA. Available at: http://www.epa.gov/owow/NPS/lid/lid.pdf

Van Weiringen. (2010). Presentation to IUWM course, University of Cape Town.

Van Duzer, C. (2004). *Floating Islands: A Global Bibliography*. Cantor Press. Los Altos Hills. California.

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

Wilson, S., Bray, R. & Cooper, P. (2004) *Sustainable drainage systems: Hydraulic, structural and water quality advice*. CIRIA C609. London. ISBN 0860176096. Available from: http://www.ciria.org.uk/suds/publications.htm

Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R. & Shaffer, P. (2007). *The SUDS Manual*. CIRIA 697. London. Available at: http://www.ciria.org.uk/suds/publications

Zucchini, W. & Nenadic, O. (2006). *Environmetrics: A Web-based rainfall atlas for Southern Africa*, Wiley InterScience, Vol. 17, pp. 269-283. DOI: 10.1002/env.748.

Appendix A

SuDS conceptual design framework

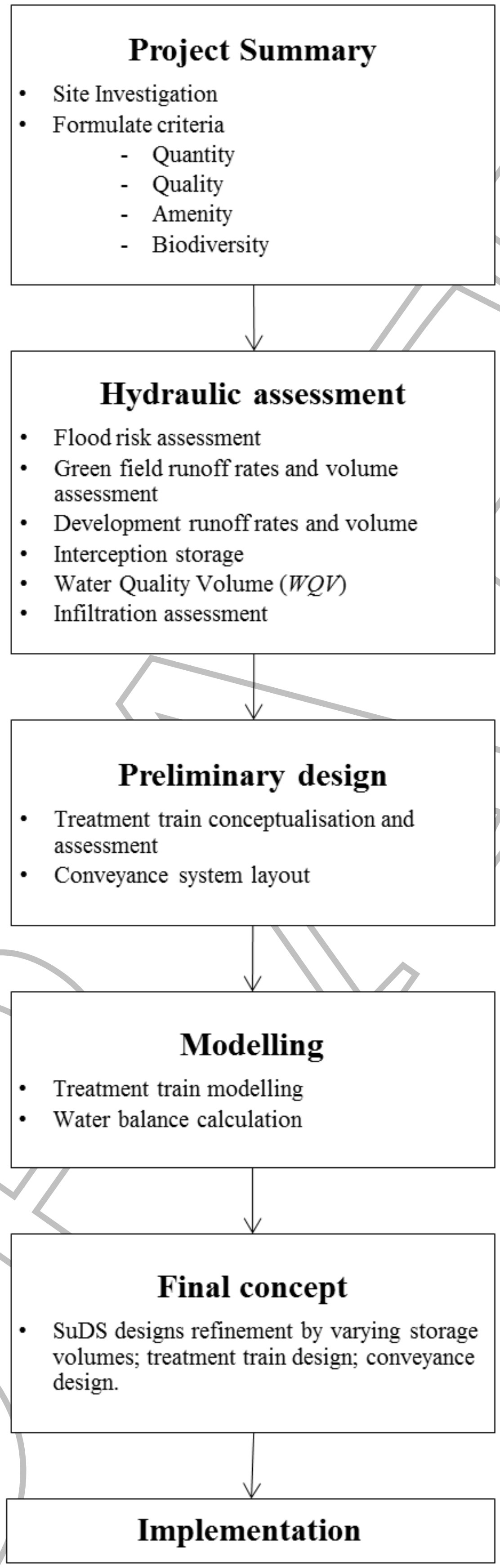


Figure A1: SuDS Conceptual Design Framework (CDF)

Appendix B

Pollutant removal capacities

Measured pollutant removal capacities of selected SuDS options and technologies
(after Debo & Reese, 2003; Minton, 2002; NCDWQ, 2007; Wilson *et al.*, 2004, Woods-Ballard *et al.*, 2007)

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

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

Disclaimer

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

Appendix C

General designs for SuDS options

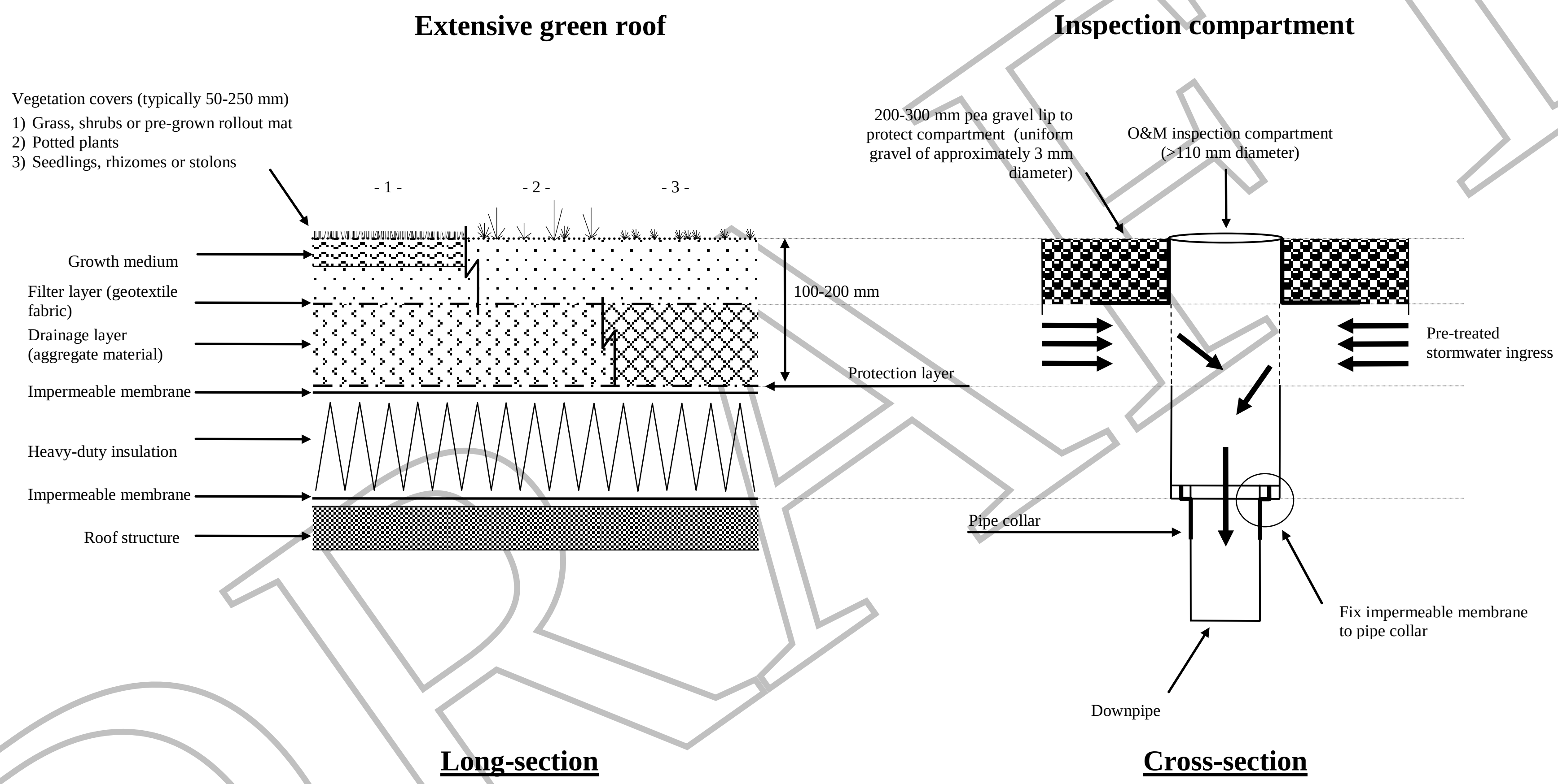


Figure C1: General design for green roofs and adjoining inspection compartment
[after Wilson *et al.*, (2004); Woods-Ballard *et al.*, (2007)]

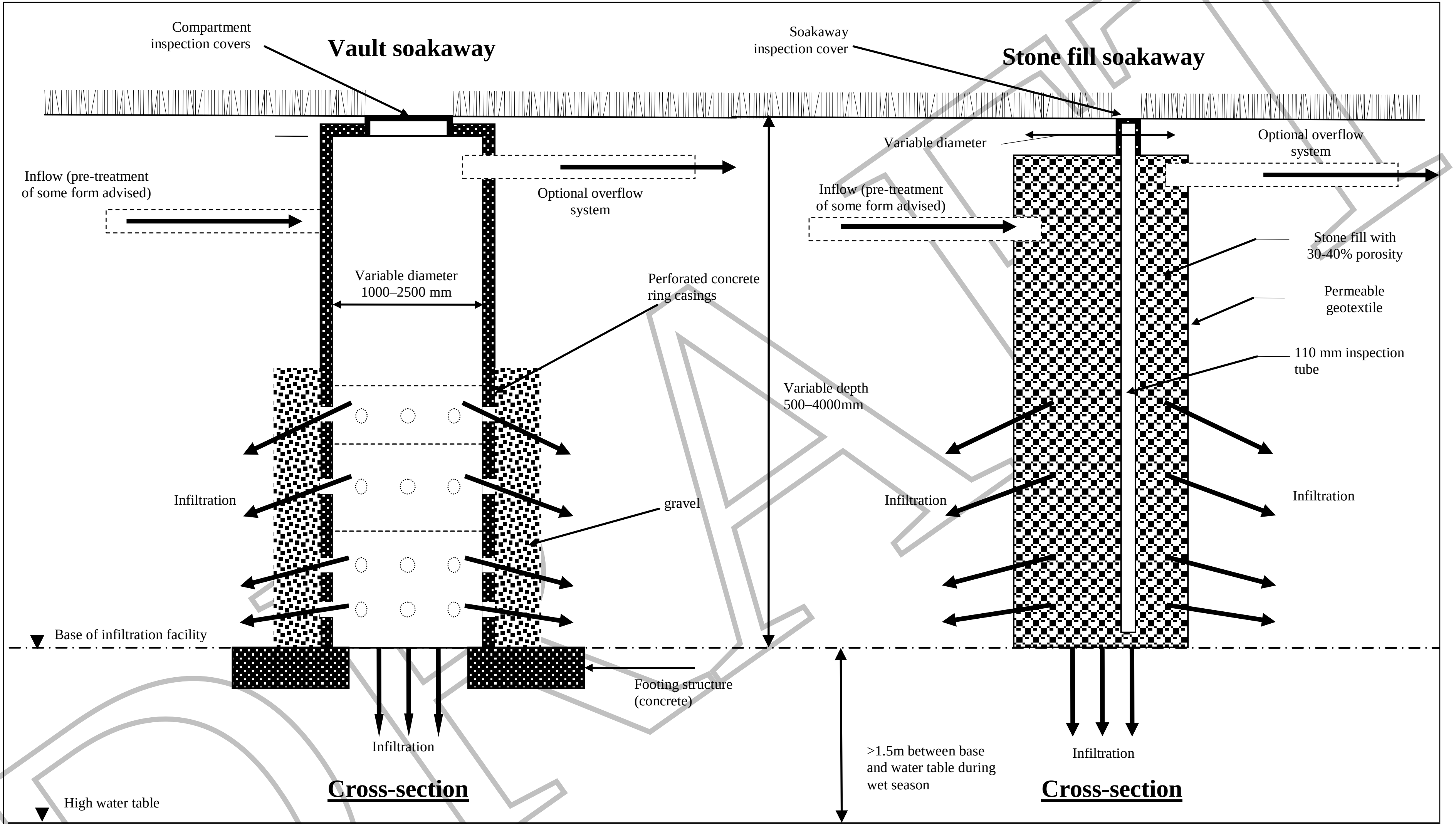
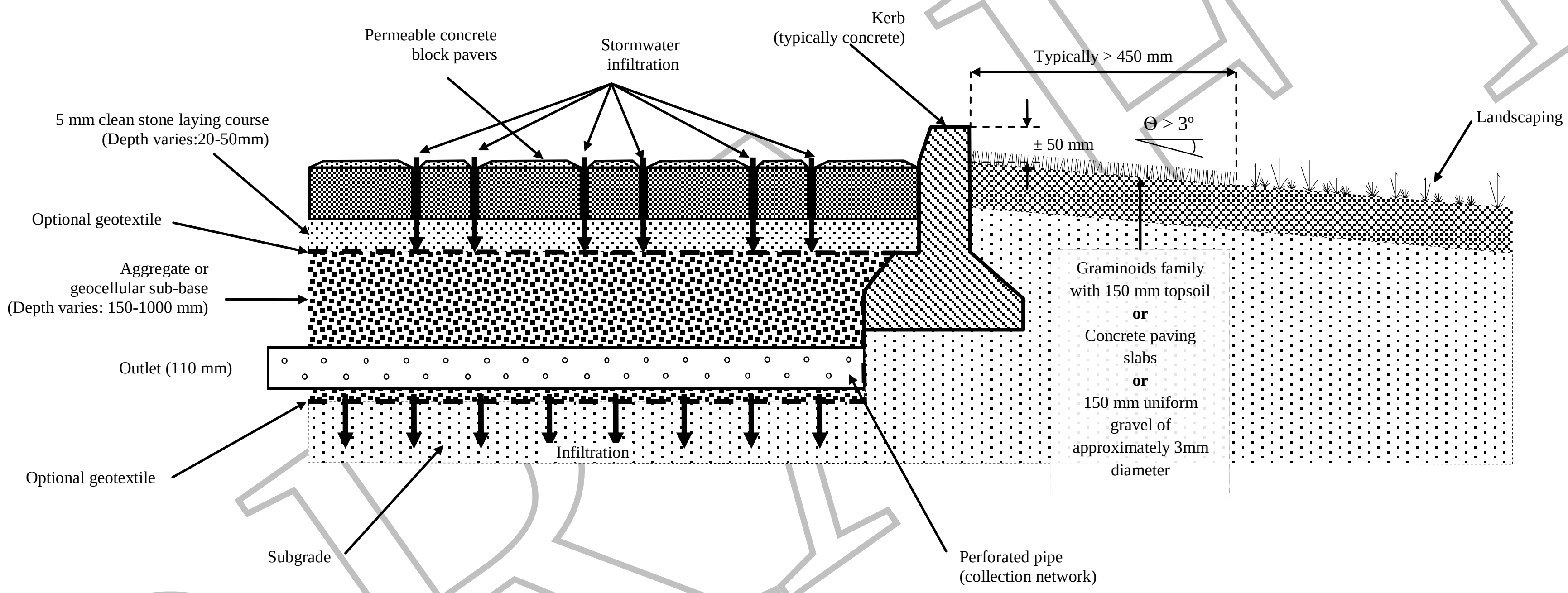


Figure C2: General designs for soakaways

[after Woods-Ballard et al., (2007); Haubner *et al.*, (2001)]



Cross-section

Figure C3: General design for permeable pavements and adjoining landscaped areas
[after Wilson *et al.*, (2004); Woods-Ballard *et al*., (2007)]

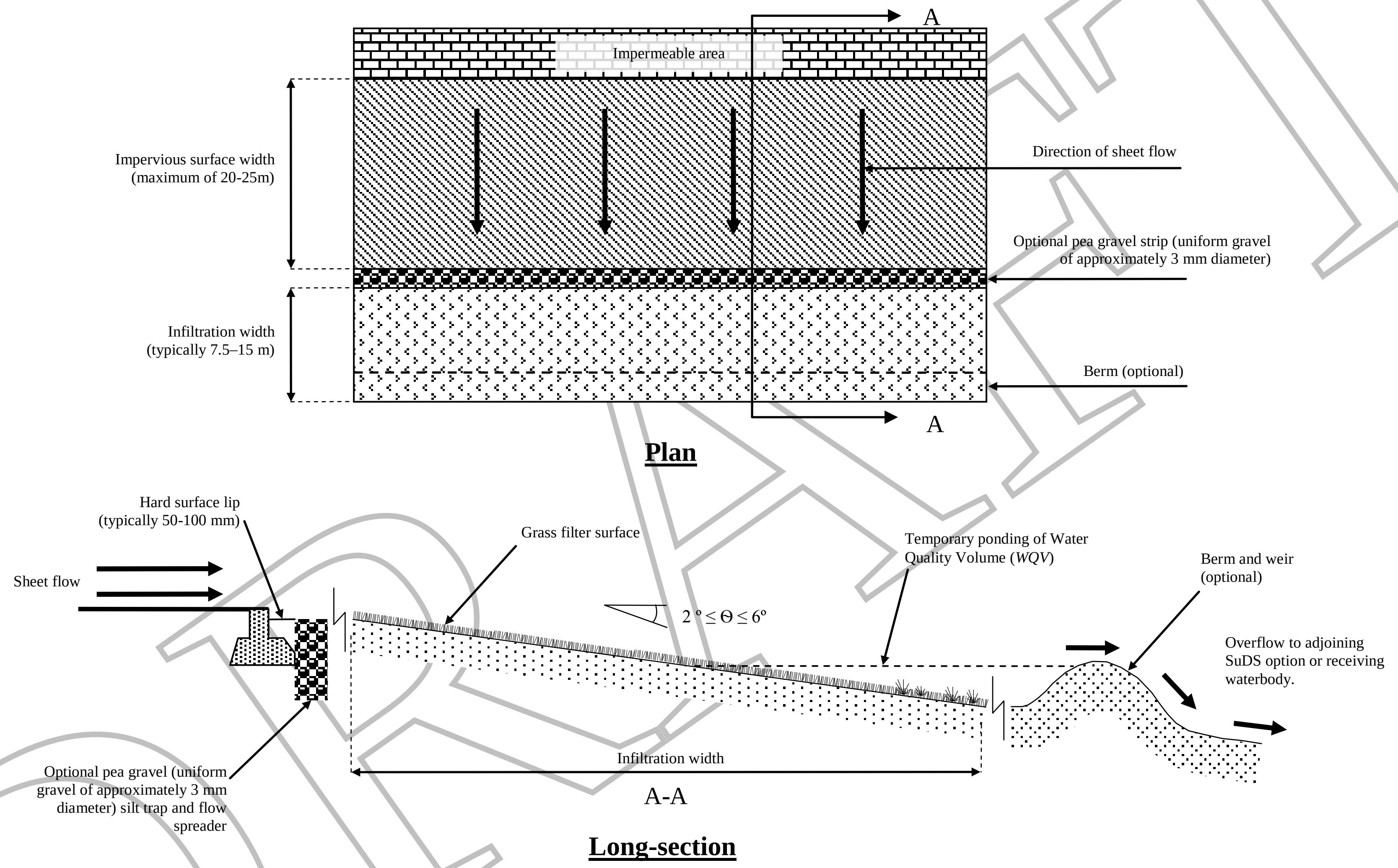


Figure C4: General design for filter strips and adjoining silt trap and berm

[after Wilson *et al.*, (2004); Woods-Ballard *et al.*, (2007); Haubner *et al.*, (2001)]

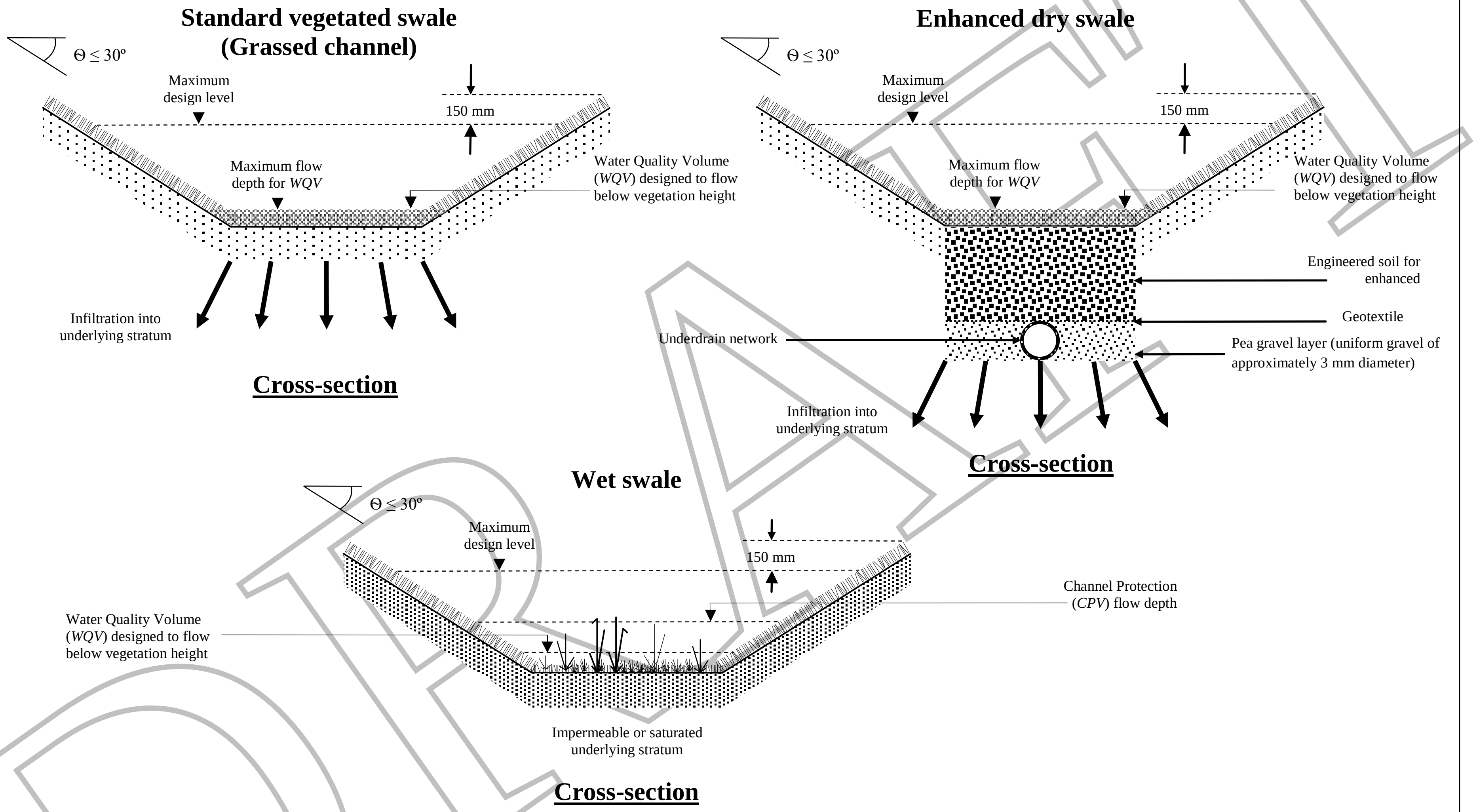


Figure C5: General design for swales

[after Wilson *et al.*, (2004); Woods-Ballard *et al.*, (2007); Haubner *et al.*, (2001)]

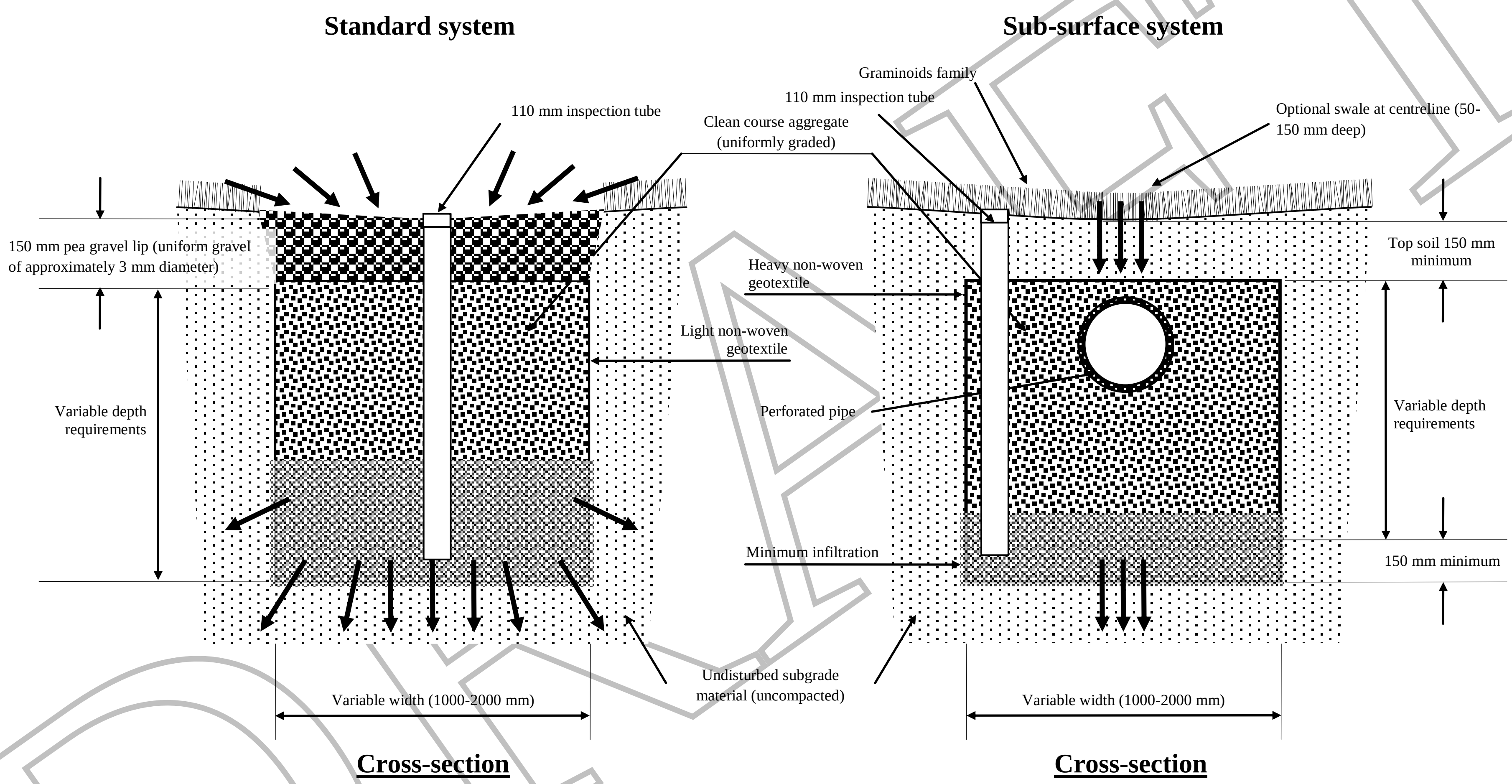
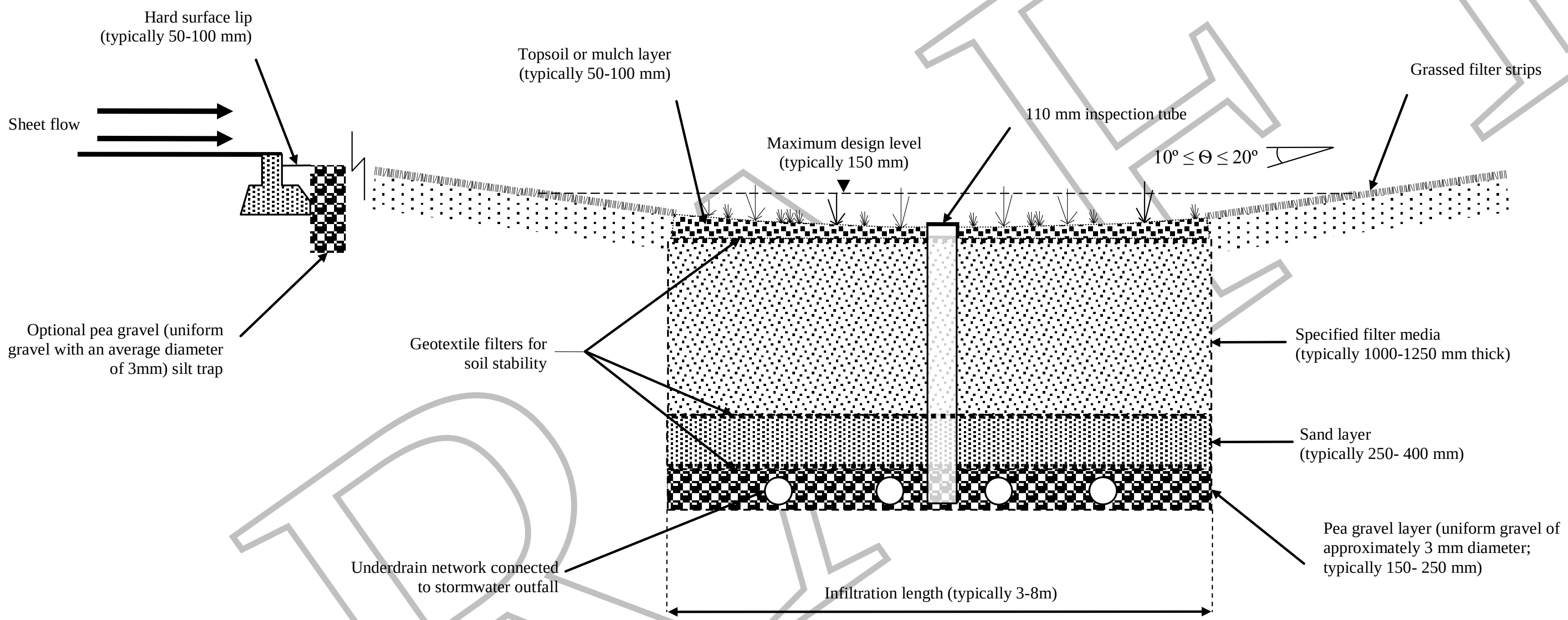


Figure C6: General design for dual system infiltration trenches
[after SEMCOG (2008)]



Long-section

Figure C7: General design for bio-retention areas

[after Wilson et al., (2004); Woods-Ballard *et al.*, (2007); Haubner *et al.*, (2001)]

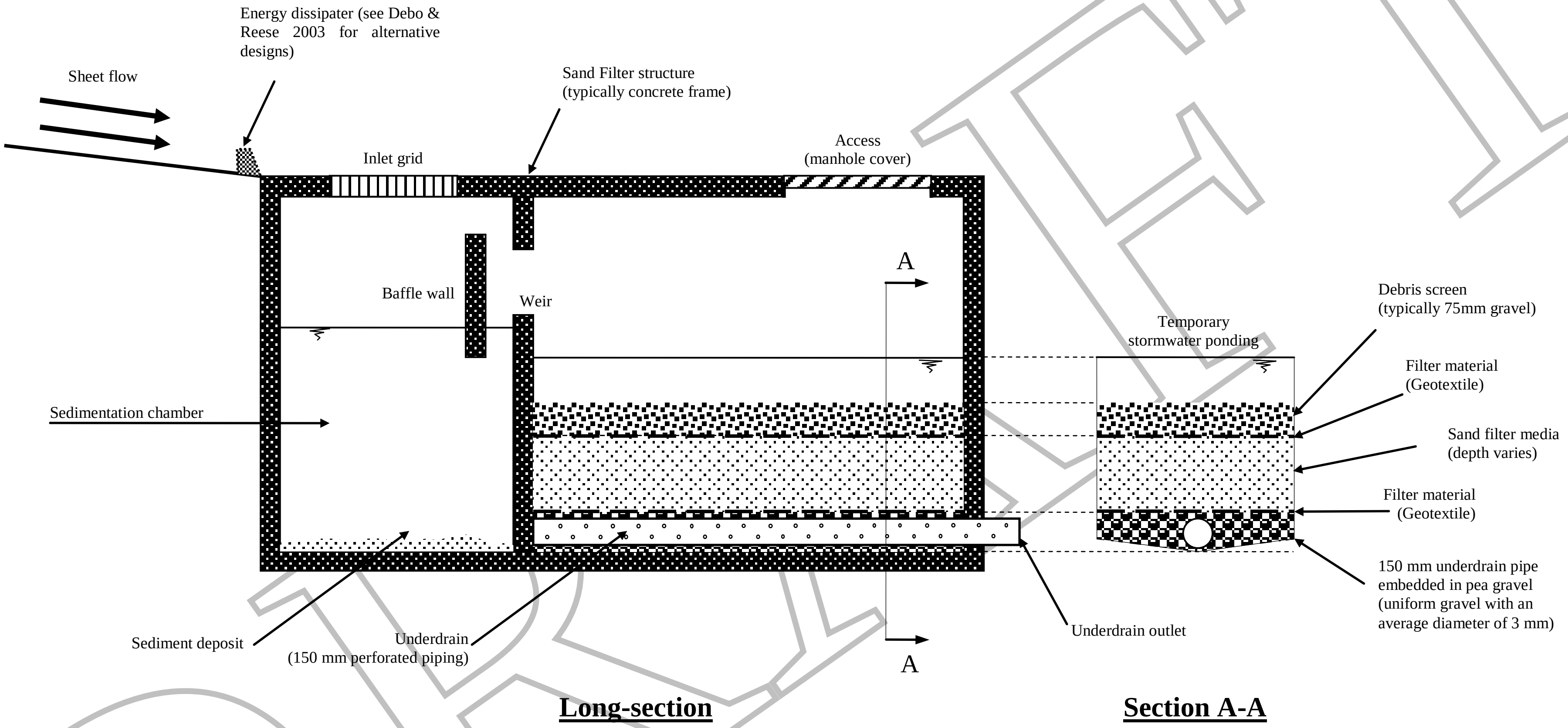


Figure C8: General design for sand filters with pre-treatment chamber
[after Debo & Reese (2003); Wilson *et al.*, (2004); Woods-Ballard *et al.*, (2007)]

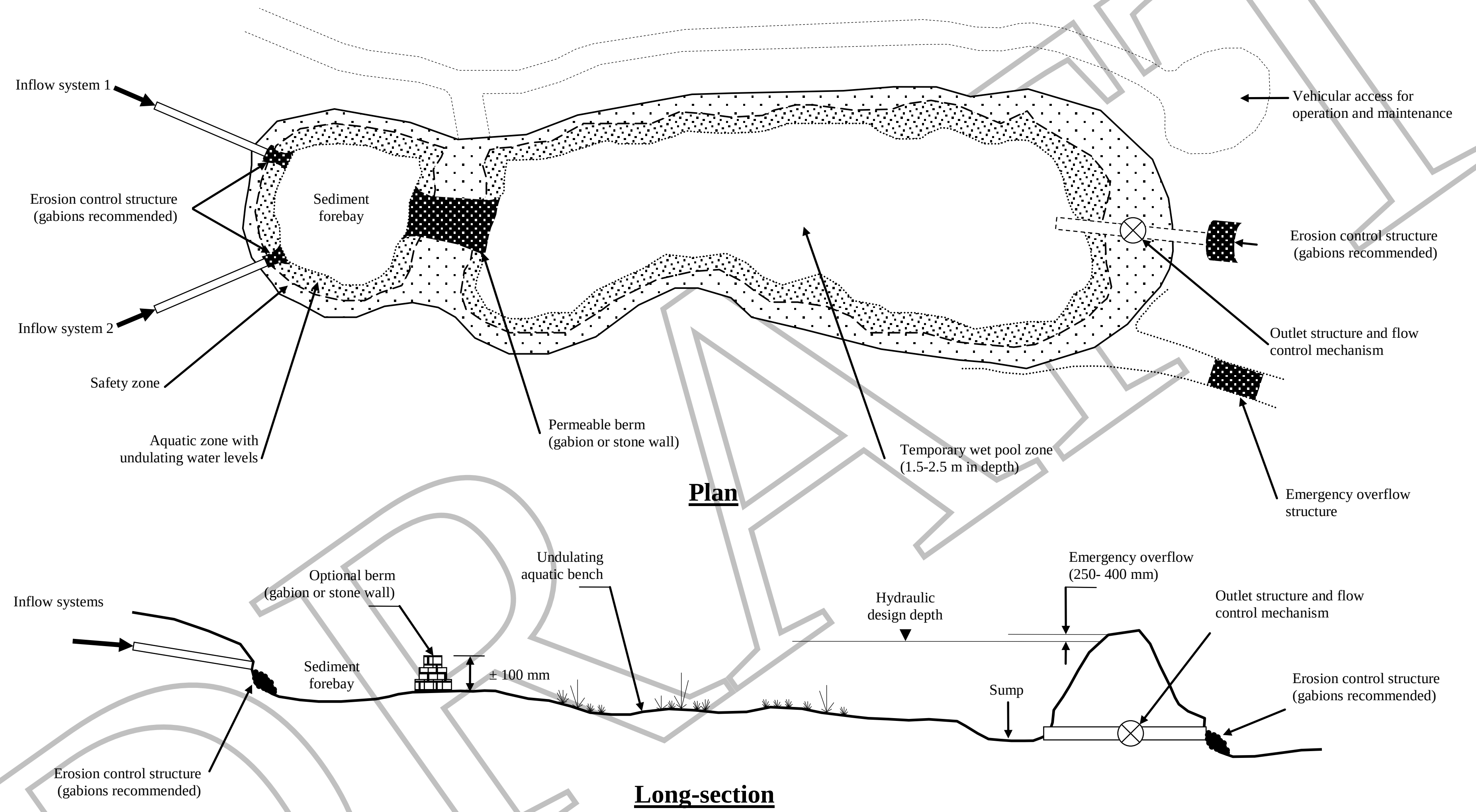


Figure C9: General design for detention ponds

[after Wilson *et al.*, (2004); Woods-Ballard *et al.*, (2007) and Others]

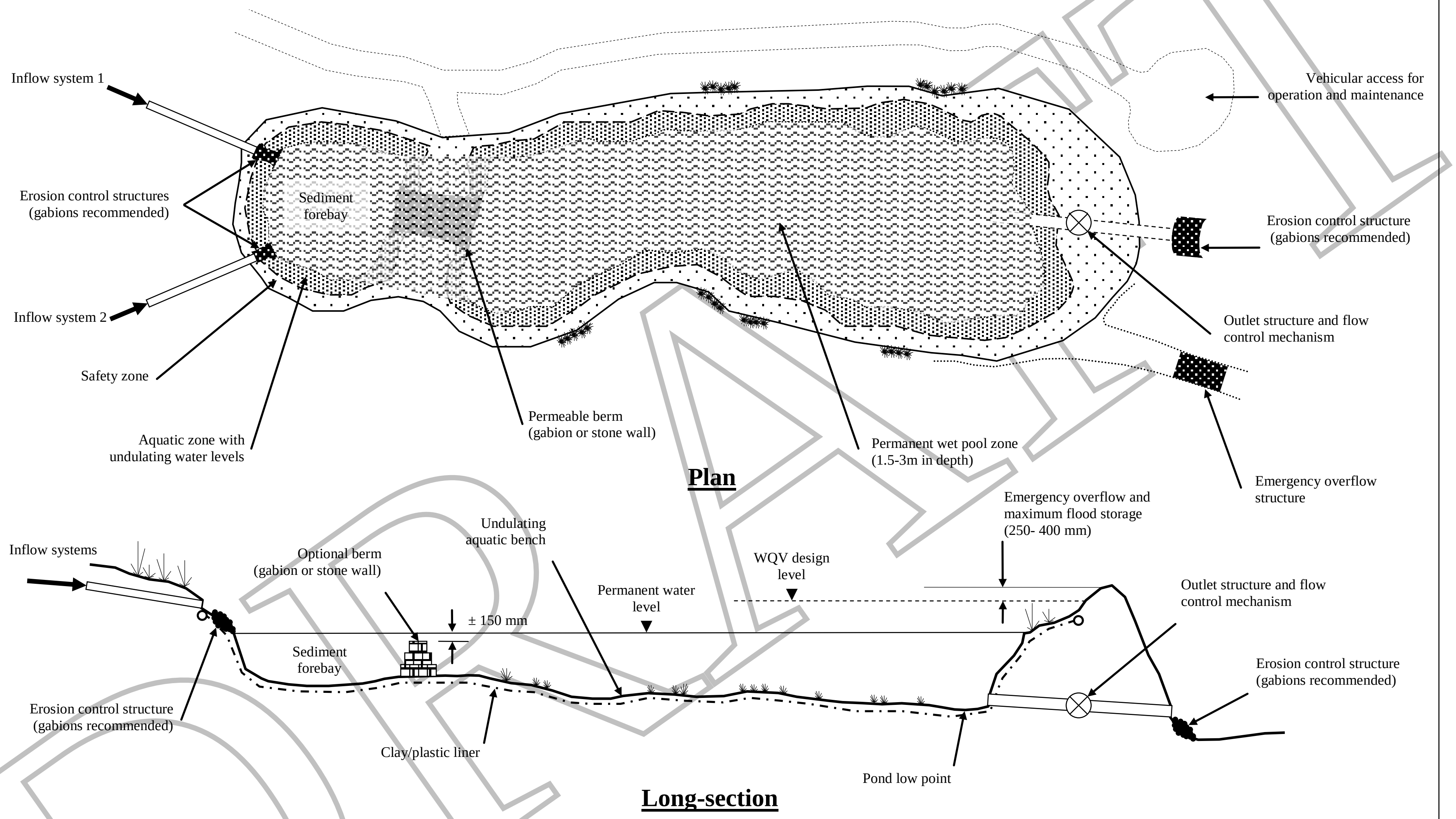


Figure C10: General design for retention ponds
[after Wilson *et al.,* (2004); Woods-Ballard *et al.,* (2007)]

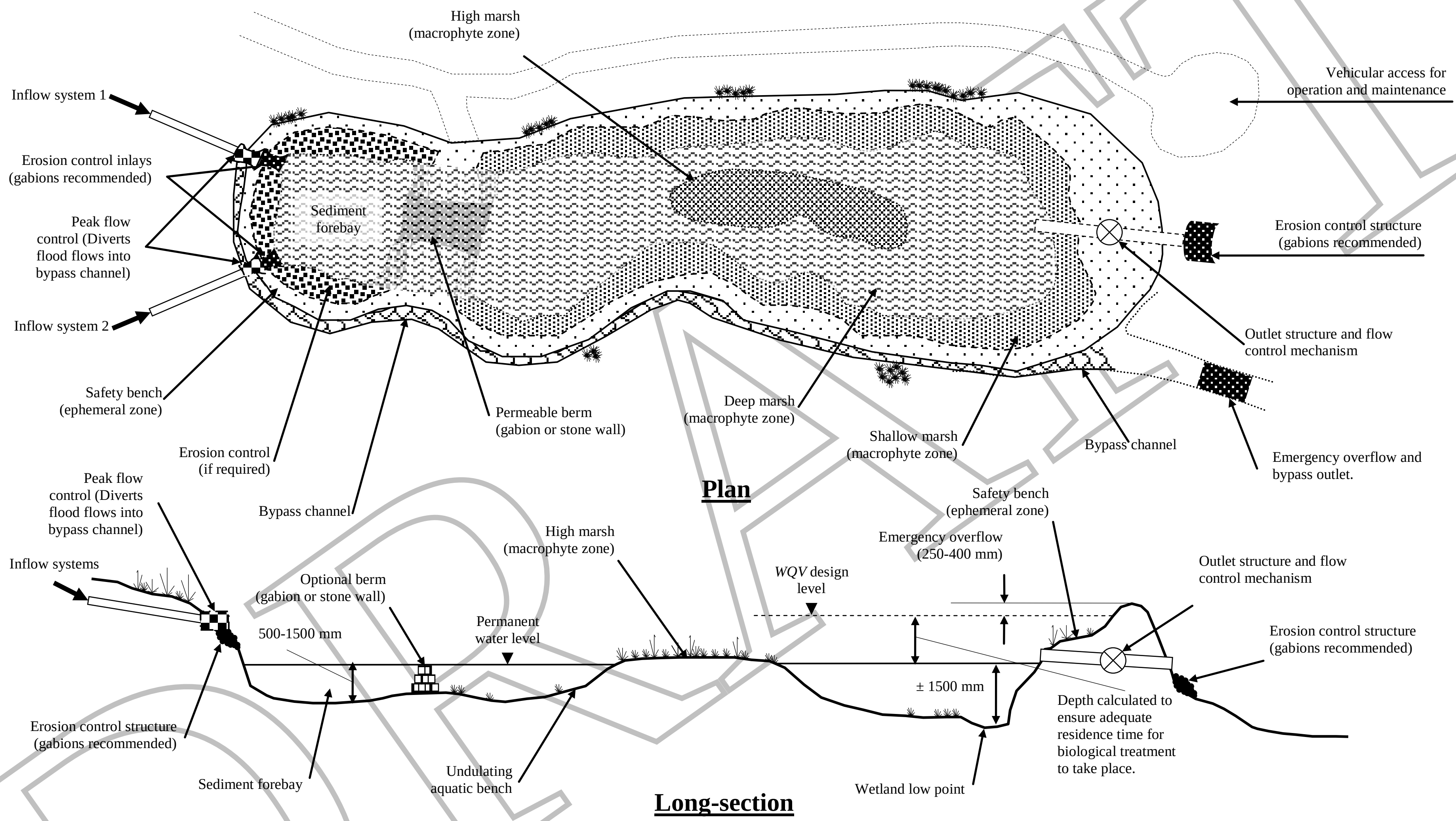


Figure C11: General design for constructed wetlands

[after Wilson *et al.*, (2004); Woods-Ballard *et al.*, (2007) & others]

Appendix D

Life cycle costing of stormwater management

D1 Introduction to document

Appendix D is intended to give a brief introduction to the most important aspects of costing SuDS. Appendix E describes a costing tool that is available as part of these guidelines. Appendix F provides useful data for the costing tool. Appendix D is not aimed as a detailed guide to costing, rather it is aimed and structured to specifically highlight aspects relevant to SuDS and identify relevant literature sources to aid those currently working with, designing, tendering or promoting the use of SuDS.

- Section D2 highlights the importance of designing using a treatment train approach;
- Sections D3-D5 cover the basics of estimation for different phases of the systems life cycle;
- Section D6 discusses international comparisons of SuDS and conventional designs citing studies from the UK, USA and Australia; and
- Section D7 discusses techniques for calculating and analysing life cycle costs of stormwater systems.

D2 Principles affecting costs

SuDS are fundamentally different to conventional systems and therefore the factors that influence their costs, both capital and operating are different. This section highlights how the principles of SuDS and design decisions impact on the costs of the system.

In the process of selecting stormwater components for new developments, it is crucial that the SuDS philosophy be considered. SuDS, unlike conventional piped systems, are not solely a stormwater quantity management solution – stormwater quality, amenity and bio-diversity are also considered. It is important to recognize that these other aspects are often ignored in a conventional system – effectively externalising them to the long-term detriment of the environment. The costs need to be considered from a holistic perspective.

The effectiveness of a SuDS system is based on the use of a treatment train, where each successive unit process acts to further treat the runoff, as illustrated in Figure D1.

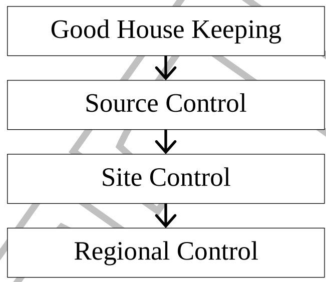


Figure D1: SUDS Treatment Train

By way of example, the three treatment trains shown in Figure D2 could all potentially meet the local pollutant removal criteria in the short term for a certain hypothetical catchment. The capital costs increase from Treatment Train 1 through to Treatment Train 3. It may therefore seem logical to use Treatment Train 1 as it has the lowest capital cost, however:

i) 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.

ii) In Treatment Train 2, 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.

iii) 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 settle out thus preventing it from entering the wetland.

Treatment Train 1 may have the lowest capital cost, but since it is generally more cost effective to remove sediments from dry above-ground SuDS (Berwick, 2011), both Treatment Trains 2 and 3 might well prove to be more cost effective in the long term. Treatment Train 3 might be over-designed, although this depends on the catchment, pollutant load, and receiving water body. This shows that it is vital that the long term functioning of the SuDS technology and treatment train is considered as part of the design and costing process.

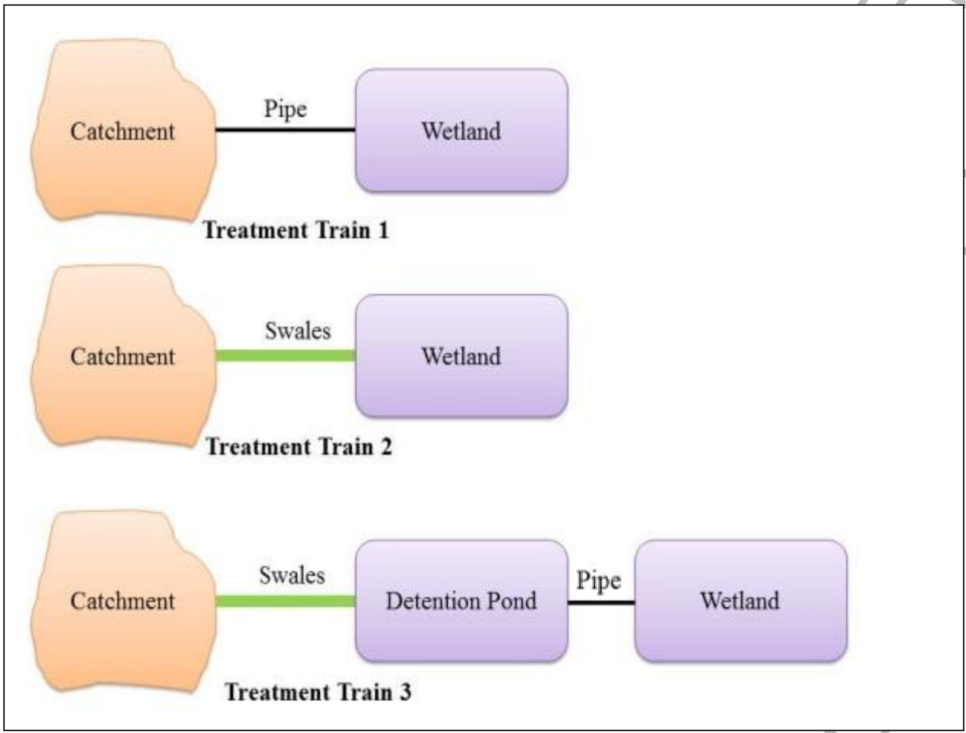


Figure D2: Three treatment trains (adapted from Berwick, 2011)

D3 Capital costs

Section D2 explained the importance of considering a SuDS system as a treatment train and not just as individual components. The following section outlines the factors that need to be considered when designing and costing SuDS. Unlike a conventional system, each SuDS option has a range of performance variables. Each of these variables has potential impacts on the costs of implementing the specific SuDS option, as well as on the cost of the future maintenance requirements of the system as a whole. It is therefore important that when optimizing the system a range of performance variables and their impacts on maintenance costs be considered.

The majority of expenditure in SuDS is related to earthworks and landscaping. Estimating accurate unit rates is quite difficult due to the variation in the rates, especially within the landscaping profession. Apart from inflation, the following aspects of a development will additionally impact on the costs of the system:

- Project scale and unit costs;
- Retrofits *vs*. green fields;
- Regulatory requirements;
- Public *vs*. private design and construction;
- Contractor *vs*. public works crew;
- Flexibility in site selection, site suitability; and
- Levels of experience with the technologies, by both designers and contractors (Lampe *et al.*, 2005).

The last point is of particular relevance in South Africa where the 'SuDS approach' is relatively new.

An important aspect that should be considered as part of the capital costs is the cost of establishing vegetation where it is required, e.g. swales, wetlands and green roofs. These SuDS options require irrigation and possible replanting until the vegetation is fully established. These costs may be difficult to accurately determine.

Developers may be concerned that SuDS options may decrease the developable area (Buys & Aldous, 2009; ECONorthwest, 2007). This concern is real as many SuDS options require a larger land take than conventional options. On the other hand, if SuDS are correctly implemented – considering quantity, quality and amenity – they may add considerable value to the properties.

D4 Operation & maintenance

The design process must fully consider the maintenance requirements. Facilities should be designed to be as maintenance free as possible; however competent designers should "*recognise that all structures require periodic maintenance, inspection and repair*" (Debo & Reese, 2003).

"*The question is not whether stormwater management system maintenance is necessary in a community. Rather, the question is how a community's maintenance programs will be budgeted, staffed, and administered, and who has responsibility for managing inspections, scheduling periodic required maintenance, and funding remedial work.*" (Haubner *et al*., 2001). Many SuDS require constant maintenance to ensure proper functioning; failure to do so may result in the system needing to be prematurely overhauled which may have significant cost implications. Designs should therefore allow for the frequency and types of maintenance that the system will require and all associated cost should be considered as part of the design process.

All SuDS require regular inspection to ensure that potential problems are identified and dealt with timeously. SuDS also require the following tasks on a regular basis to ensure proper functioning (Woods-Ballard *et al*., 2007; Berwick, 2011; Lampe *et al.*, 2005):

- Litter/debris removal;
- Grass & vegetation management including cutting, pruning, invasive species removal, weeding; and
- Minor sediment removal, erosion management, etc.

From time to time, more substantial intervention will be required, including:

- Sediment management;
- Vegetation replacement;
- Minor overhauls; and
- Repair of failed components

Maintenance may be considered at five different levels, as detailed in Table D1. It is important to recognise that amenity is a central SuDS principle and therefore this may require particular attention. In certain circumstances, for example where a detention pond is out of sight and has no amenity value, a low level of maintenance would be appropriate (performance functioning). Conversely, upmarket gated communities may emphasise the aesthetic aspects of SuDS and hence Level 5, focusing on amenity aspects would be important. Normally a medium level of maintenance would be acceptable. It is highly unlikely that there will be many situations where no maintenance would be required.

Table D1: Levels of maintenance for SUDS

Maintenance Level	Description
1. None	No maintenance is undertaken.
2. Low	Basic maintenance ensuring functioning of the SuDS options
3. Medium	Intermediate maintenance ensuring functionality and reasonable level of amenity
4. High	High maintenance ensuring both the functioning of the SuDS and ensuring a high amenity level (appearance). Additional maintenance is for amenity value only and does not impact on functioning
5. Extreme	Maintenance exceeding level 4.

Unlike with conventional systems, SuDS treatment trains are fairly complex when it comes to determining both the system's life cycle and the life cycle costs. Appendix F details estimated maintenance rates and frequencies for the SuDS options. Certain costs such as the impacts of storms or heat waves on the cultivation of vegetation are difficult to predict. Extremes of either may require extensive replanting. There are also climate and site specific considerations to be addressed by the project team.

D5 Environmental goods & services (EGS)

SuDS mimic natural processes. Consequently they have the potential to supply a number of environmental goods and services to stakeholders. These include but are not limited to: flood mitigation, improved water quality, increased ground water recharge, and improved aesthetics resulting in increasing property values. This section discusses the environmental goods and services which SuDS potentially offer.

Increasing urban development generally results in increased runoff volumes and peak flows. The cumulative effects of these impacts on flood peaks typically ranges between 20-50% in residential areas and up to 100% – or more – in heavily industrialized areas (SANRAL, 2007; Brown *et al.,* 2008). The SuDS philosophy of on-site treatment results in both the detention and infiltration of stormwater on site, as well as reducing runoff velocities. This not only reduces flooding but also reduces the costs of downstream infrastructure, e.g. bridges (ECONorthwest, 2007)

SuDS have the ability to treat stormwater, and thus improve water quality (ECONorthwest, 2007). This is important as stormwater is a major contributor to the deteriorating water quality in cities (Buys & Aldous, 2009). SuDS improve water quality by capturing pollutants and treating them through physical, chemical, and biological processes depending on the technology implemented (Minton, 2002).

The use of infiltration in SuDS increases ground water recharge, a source of water identified by the South African government as a potential resource for supplying coastal towns and cities in particular. Research in Atlanta, USA by Otto *et al*. (2002) suggests that impervious surfaces have reduced ground water infiltration in Atlanta by 132 billion gallons (500 billion litres) a year, the equivalent water usage of 3.6 million people (ECONorthwest, 2007).

Increased urbanization generally leads to increased impervious surfaces, e.g. pavements, sidewalks, roofs, driveways. These have the ability to increase runoff by up to a factor of 10 (Haubner *et al.*, 2001; Brown *et al.*, 2008). Conventionally piped systems are designed to remove runoff from an area as quickly as possible. This ignores the aesthetics of the stormwater system. Water frontage (in upper income areas) and natural features can add to the aesthetics of an area and consequently to the value of the properties in that area. 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...*" The value of the benefit is typically 5-30% averaging at a 10% increase in property values with a suitable view of the water bodies (Buys & Aldous, 2009). This is however not the case for all SuDS technologies; some in fact can cause depreciation in adjacent property values. For example, Klein (2003) found that dry ponds had the opposite effect of wet ponds and that property values were 4-10% lower than when they were not present. This perspective is supported by research in Illinois, which also indicated a perceived negative effect related to their construction (Buys & Aldous, 2009). Common factors impacting on property values are highlighted in Table D2.

Certain technologies take up more land that conventional systems, and this land also has value (Buys & Aldous, 2009). There is a need to consider and to balance this aspect through the combination of technologies used.

On the other hand, vegetated roofs for example take no additional land. "*Vegetated roof covers in urban areas offer a variety of benefits, such as extending the life of roofs, reducing energy costs….*" (USEPA, 2000). Greenstone (2010) showed that the use of green roofs decreases the air temperatures and insulates the roofs. This insulation effect can reduce an entire building's energy requirements (ECONorthwest, 2007), while concurrently reducing pollution and improving aesthetics (US Department of Defence, 2010)

Table D2: The effect of open bodies of water on property values (USEPA, 1995)

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

D6 International case studies

A number of studies have been undertaken around the world in order to determine the financial and economic implications of implementing SuDS type technologies. Different regions define SuDS, LID's, BMP's etc. slightly differently, but in general, the results are comparable. Table D3 summarises the conclusions from a selection of international studies. Overall it appears that SuDS are usually, but not always, more economical than conventional systems. In the extreme, conventional systems can cost twice that of SuDS over the lifetime of the project. It is however important to identify 'who pays for what'. SuDS require on-going, regular maintenance. A relatively higher proportion of the costs might be contained within this particular item.

The ECONorth West (2007) report: *The Economics of Low Impact Development - A Literature review* supplies a very good overview of a wide range of studies into the economics of Low Impact Development (equivalent to SuDS) in the USA.

Table D3: Studies comparing SuDS and conventional systems

Study	Country	Year	Report's economic conclusions
Lloyd *et al*	Aus.	2002	"*Analysis of the capital costs of the bio-filtration systems showed only a 0.5% increase to the developer. This small increase in cost was offset by the increased marketability of the estate to the consumer. The success of the project has been widely acknowledged and the Lynbrook Estate demonstration project has helped to encourage the adoption of WSUD principles and practice by others elsewhere in Australia.*"
Boubli & Kassim	Aus.	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.*"
Coombes *et al*	UK	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	USA	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.

D7 Life cycle costing

When considering the costs of a drainage system, whether it is a SuDS or conventional system, it is important to understand what type of analysis is being undertaken. The three main techniques commonly used internationally to evaluate the costs – both financial and economic – of stormwater drainage systems are as follows

- **Capital Cost Analysis** (CCA) is the calculation and comparison of the capital costs of projects.
- **Benefit Cost Analysis** (BCA) is the process of calculating and comparing the benefits and costs of a project via the computation of the benefits: costs ratio.
- **Life Cycle Cost Analysis** (LCCA) is the calculation and comparison of all costs from acquisition to disposal of an asset.

Each of these techniques has different advantages and short comings. Table D5 outlines the differences between each approach. CCA is the simplest to calculate where there is limited life cycle costing data. Section D1 however emphasised the need to consider the whole life cycle of the SuDS system. It is therefore vital that the interests of all stakeholders be considered as part of the design process, especially when considering the economic arguments. Should the system's owners, either city councils or private land owners, not be able to maintain and operate the system, the system will potentially fail. Therefore a simple CCA analysis may be inappropriate.

The BCA is the most comprehensive approach, however it is difficult to undertake. The more complicated and detailed the studies required, the less attractive SuDS may appear to developers.

The LCCA analysis, on the other hand, is commonly used internationally and would generally be the most appropriate in South Africa. By considering all expenditure over the system's life cycle it ensures all stakeholders have an understanding of their total commitments. It is however important to recognise that there are a number of non-financial benefits to SuDS. These may be accounted for in a simplified economic life cycle cost analysis (Appendix E).

Table D5: Techniques for analysing drainage economics

Techniques for analysing urban drainage economics	
Advantages	**Disadvantages**
Capital Cost Analysis (CCA)	
One of the most common studies	Considers only capital costs
Requires the least number of inputs	Ignores benefits
	Ignores goods & services
Can be easily completed	Does not take account of effectiveness of system
Benefit Cost Analysis (BCA)	
More comprehensive analysis	Requires more data and time, and costs more to produce
Considers all economic benefits and costs	
Life Cycle Costing (LCCA)	
Considers whole life cycle costs from design to decommissioning	Does not consider the value of all ecosystem goods and services

Life Cycle Costing is "*the systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset*." (Clift & Bourke, 1999). Life cycle costing essentially considers all the costs associated with an asset. In terms of SuDS, this would include: design, construction, establishment of vegetation (SuDS option dependent), maintenance (inspections, regular, irregular, and corrective), and disposal. These costs (and any benefits) are all discounted to their present value. There are two possible Life Cycle Costing analyses that may be undertaken, viz. an economic or a financial analysis, as indicated in Figure D4. Both environmental costs and benefits may be economically appraised and included in the analysis.

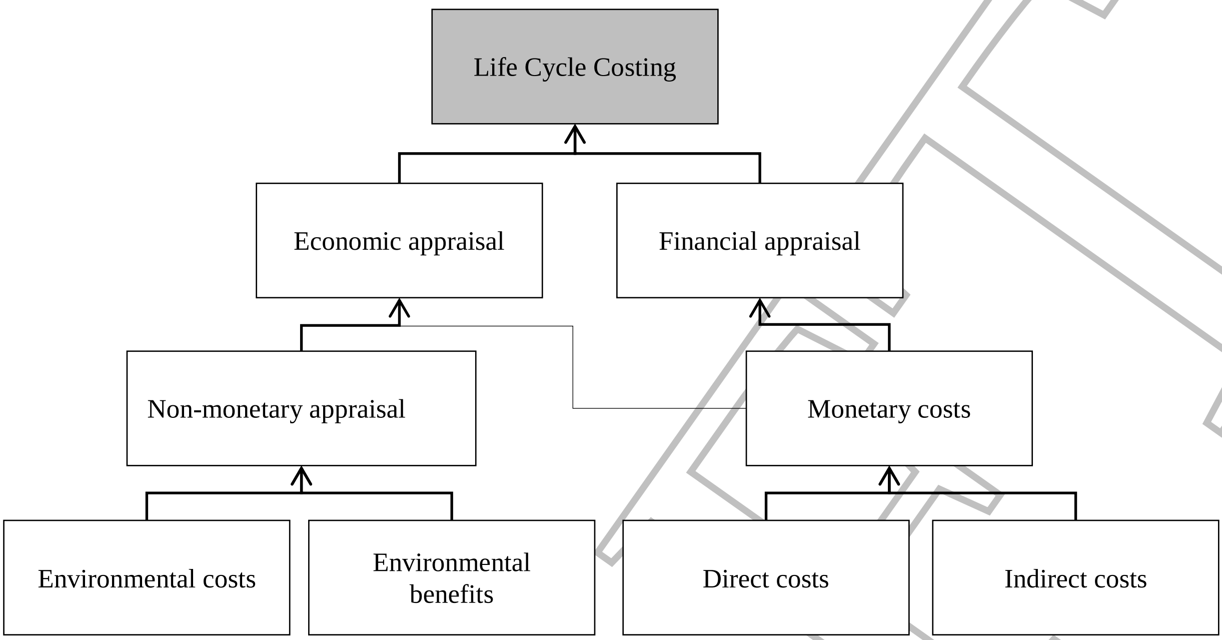


Figure D4: Economic and financial appraisals (Lampe *et al.*, 2005)

In order to undertake economic analyses it is necessary to bring future expenditure to Present Value. To do this the expenditure is multiplied by the relevant discount factor:

$$DF = \frac{1}{(1+i)^n}$$

Where:

DF = Discount Factor
i = Interest rate
n = Period/year from present

The Total Life Cycle Costs is the sum of all future costs reduced to present value, as expressed in the following equation:

$$PV = DF_0(EX_0) + DF_1(EX_1) + \ldots\ldots + DF_n(EX_n)$$

Where:

PV = Present Value
DF = Discount Factor
EX = Expenditure
i = Interest rate
0 = Base year
1,2… =Years from base year
n = Period/year from present

Benefits may be calculated in the same manner and subtracted from the present value costs; the result would be considered the 'Net Present Value'.

D8 Further reading

i) Debo, T & Reese, AJ, 2003, *Municipal Stormwater Management*, Lewis Publishers, Florida. 1141 pp.

ii) DoCGTA (2010). *An Industry Guide to service levels and unit costs Department of Cooperative Governance and Traditional Affair.*

iii) Narayanan, A. and R. Pitt. (2005). *Costs of Urban Stormwater Control Practices*. Stormwater Management Authority of Jefferson County, AL.

iv) SANRAL (2006). Drainage Manual 5th Edition. The South African Roads Agency Ltd. Pretoria. ISBN 1868443280.

v) Woods-Ballard, B, Kellagher, R, Martin, P, Jefferies, C, Bray, R & Shaffer, P, 2007, *The SUDS Manual*, CIRIA 697, London.

Appendix E

Overview of the 'SuDS Economic Model'

E1 Introduction

It is important that the selection of an alternative stormwater strategy is done in a fair manner. Appendix E lays out the procedure to undertake such an analysis using a 'SuDS economic model' (SEM) available at www.wsud.co.za. The SEM was developed with four aims:

i) To establish the life cycle costs of alternative drainage designs.

ii) To account for the differences in environmental impacts on an 'equivalent and fair basis'.

iii) To provide a simple method that may be applied to different sites within South Africa.

iv) To present results in a manner that is accessible and understandable to the stakeholders.

E2 Overview of the SEM

The SEM is a macro-enabled Excel workbook that can consider up to 12 groups of SuDS and conventional components. For each technology the SEM considers: the total capital cost per technology / component including establishment costs for up to the first three years; the inspection costs; routine maintenance costs; and irregular and corrective maintenance costs. It is possible to enter data for three different maintenance scenarios from either a maintenance plan or through the use of Appendix F to estimate the frequency of different tasks where there is a lack of local data. Additionally – and critically – the value of Environmental Goods and Services (EGS) are accounted for through the use of a 'Damage Avoidance Cost (DAC)' in the case of conventional systems. The DAC is an estimate of the minimum cost of treating the stormwater discharge to the receiving waters to a level equivalent to that provided by SuDS through the device of a virtual stormwater treatment works (the treatment works does not exist, it is merely a means to estimate the value of EGS expected from the receiving waters). The SEM can analyse stormwater management systems over any period up to a maximum of 100 years, although shorter analysis periods are generally more appropriate. The program ensures that the maintenance schedule is 'reset' when a technology / component is replaced. With the aid of this SEM it is possible to quickly and fairly complete a comparative analysis of two very different drainage systems. The output of the SEM is a number of user-friendly comparative charts and tables.

E3 Computational stages in the SEM

The model has three distinct computational stages as indicated in Figure 1. The model may be applied in a number of ways: to compare a SuDS and a conventional design; to compare two SuDS designs (in which case Step 2a may be skipped) or to consider the costs and benefits of a single SuDS design (in which case Step 2b may also be skipped, resulting in a standard LCCA).

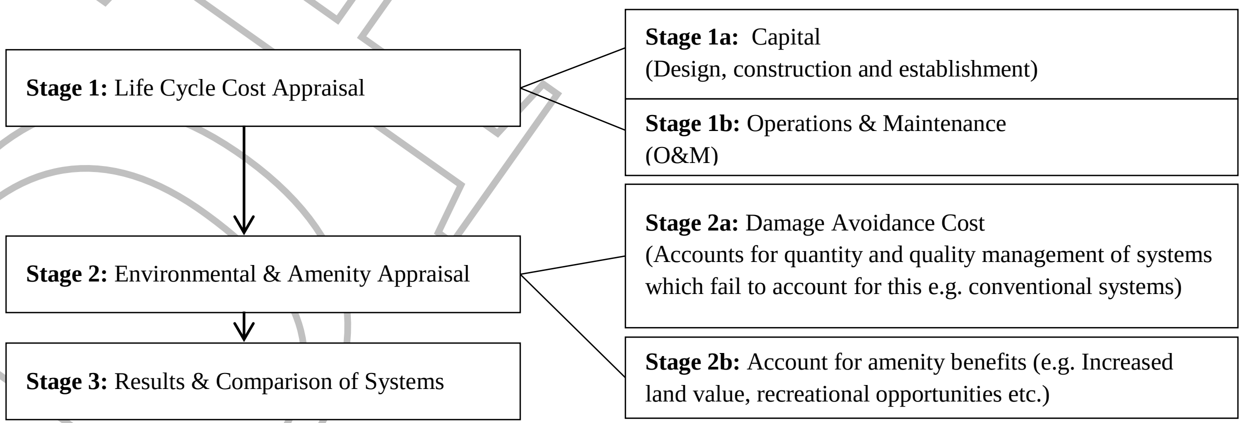


Figure E1: Computational stages in the SEM

E3.1 Stage 1 – Life Cycle Cost Appraisal

A design for the site is developed. All costs over a common life cycle are reduced to their present value. The life cycle analysis considers different maintenance regimes, i.e. High, Medium and Low maintenance for both SuDS and conventional designs, as different maintenance regimes may result in different outcomes. It is possible to enter data for three different maintenance scenarios either from a maintenance plan or by making use of Appendix F to estimate the frequency of different tasks where there is a lack of local data. It is also important to recognize that different drainage systems cannot be compared at component level as, for example, a green roof cannot be directly compared with a conduit which would convey an equivalent roofs runoff to the municipal storm sewer, because the value of the municipal storm sewer would also need to be considered. Proposals need to be considered as whole systems and not individual components.

E3.2 Stage 2 – Environmental & Amenity Appraisal

Stage 1 provides LCCAs of the monetary aspects. Stage 2 considers the non-monetary aspects. For comparison with conventional systems the EGS supplied by SuDS, but not conventional systems, need to be considered. The EGS are valued using the DAC tool described in Section E4. The DAC tool calculates an annual environmental cost to substitute for the fact that the environment is continuously treating and managing runoff from conventional systems. The SEM then reduces the costs to their present value. One shortcoming is that SuDS cater for water quality, quantity and amenity whilst the DAC tool only considers water quality and quantity. Where local data is available for the valuation of the amenity this can be entered into the model. All systems are now being considered on a 'fair and equivalent basis'.

E3.3 Stage 3 – Results & Comparison of Systems

The process outlined in Figure E1 should be completed for each proposed design, ensuring that all designs are developed to manage the same design storm. The SEM aims to compare the systems in a transparent manner and thus the different cost elements are presented separately as indicated in Table E1. This also allows for a comparison of the two systems from a number of different perspectives, i.e. the capital costs – which are of particular interest for developers, the environmental costs – which are of particular interest for environmental lobby, and the maintenance costs – which are of particular interest for the property owners. Sensitivity analyses may also be undertaken, for example by varying the discount rate and/or level of maintenance.

Table E1: Comparing a SuDS system with a conventional system

Stage		Item	Proposal 1 (e.g. SuDS)	Proposal 2 (e.g. Conventional)
1	a)	Capital Costs	R XXXX	R XXXX
	b)	O&M (PV)	R XXXX	R XXXX
		Sub Total 1	**R XXXX**	**R XXXX**
2	a)	Quantity & Quality management (Damage Avoidance Cost) (PV)	R 0,00 (meets set criteria therefore no externalized environmental costs)	R XXXX
	b)	Amenity (local /site specific data) (PV)	R XXXX	R XXXX
3		**Total "Cost" (PV)**	**R XXXX**	**R XXXX**

E4 The Damage Avoidance Cost (DAC) tool

The valuation of EGS is the most significant feature of the SEM as it allows for SuDS and conventional stormwater management systems to be fairly compared. While many tools are available for completing Stage 1, few are available for completing Stage 2. The DAC tool provides a quick, conceptual estimate of the EGS. This tool applies the 'Substitute Cost Principle' in valuing the EGS in the form of the quantity management and quality treatment supplied by SuDS system. The assumption is then made that conventional systems externalize the equivalent value, in the form of EGS, onto the environment at large. The value of the goods and services supplied by SuDS is calculated by considering the cost of acquiring and managing a virtual treatment facility for stormwater from the conventional system that would produce equivalent water quality treatment and quantity management. Typical treatment objectives considered achievable by the CoCT (2009) for SuDS are presented in Table E2.

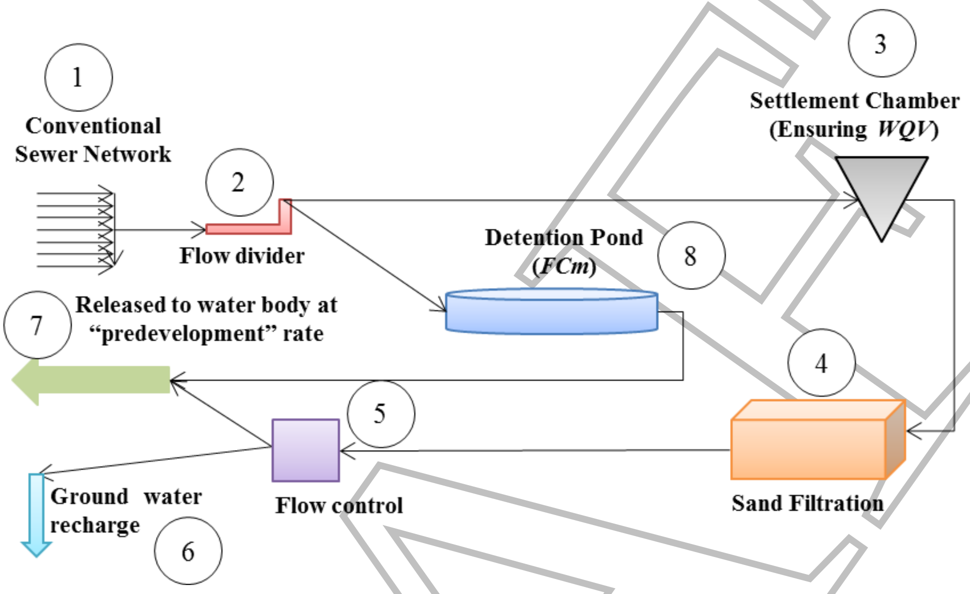


Figure E2: Schematic treatment train for virtual treatment works used to estimate the DAC

Figure E2 presents a schematic treatment train for the virtual treatment works assumed by the SEM to be the most cost-effective way of treating stormwater discharge from a conventional drainage system in order to meet the objectives described in Table E2. The treatment train operates as follows:

1. The stormwater iscollected in the municipal stormwater network.
2. The stormwater passes through a flow divider which is designed to divert flows to the detention pond (8) when the treatment facility is filled to capacity.
3. The stormwater enters the settlement chamber where settleable solids and gross pollutants are removed.
4. The stormwater then passes through a sand filter to remove suspended pollutants.
5. The stormwater then passes through a flow control which diverts a portion for ground water recharge.
6. A portion of the stormwater equivalent to the natural recharge volume is then infiltrated to supplement ground water.
7. The remaining stormwater is released to the receiving water course.
8. In event of a storm requiring peak flow attenuation (decreasing of peak flows) the stormwater which exceeds the capacity of the treatment facility is diverted (Step 2) to the detention pond. It is then released to the receiving waterbody at a predevelopment rate.

The water released to the receiving waters from such a facility is of a similar quality to that expected from a SuDS system designed to meet the same objectives, hence the hypothetical cost of treating conventional cost in this way may be termed the 'Damage Avoidance Cost (DAC)'. Note that the virtual facility also allows for groundwater recharge, an important additional service offered by SuDS.

The DAC needs to account for both water quality and quantity (total volume and flow rate). In South Africa the climatic conditions vary greatly from region to region. The model accounts for this by allowing the user to choose between one of five standard 24-hour design storms as appropriate for the sizing of the virtual treatment works. These include the four South African SCS storms (Southern African adaptations of the United States Soil Conservation Service design storms as described in Schmidt & Schulze, 1987), and a 24 hour constant precipitation storm. For the same storm volume, higher intensity storms require larger and more costly treatment facilities than lower intensity storms – therefore the constant precipitation design storm is the least costly and the SA SCS Type 4 the most costly. Other parameters that may be varied include: the depth of runoff; the lag time and the discount rate.

Table E2: Treatment objectives considered achievable using SuDS (CoCT, 2009)

Objectives	**Pollutant**	**Modelling Parameters**
Quantity control	Increased peak flows	Management of the Quantity Control volume (*FCm*) storm
Quality of run-off	Litter/Rubbish	100% Removal for Water Quality Volume (*WQV*)
	SS	80% reduction for *WQV*
	TP	45% reduction for *WQV*

In the computation of the DAC by the SEM, care is taken at all times to ensure the 'least cost principle' is adhered to. Over-estimation of the value of EGS is a criticism frequently levelled at the Substitute Cost Method. Optimal performance of each unit process is thus assumed. For simplicity sake, the model does assume a number of parameters that influence the valuation of EGS. These are presented in Table E3. The three criteria that should be met to ensure the appropriate use of the Substitute Cost Method according to Pagiola *et al.* (2004) are listed in Table E4 as well as the justification as to how the approach adopted in the DAC meets each one.

The Water Quality Volume (*WQV*) and Flow Control (minor system) (*FCm* – as defined in Section 2of the Guidelines) storms are modelled. The treatment facility is sized to ensure that it has sufficient capacity based on the

Table E3: Fixed input parameters in the DAC

Component	**Parameter**	**Value**
Flow diversion	Capacity	Equals peak *WQV* Runoff
Sedimentation chamber	Area	20% of *WQV*
	Depth	2 m (max)
Filtration chamber	*K* (m/s)	0.6 m/day
	Depth of filter	0.5 m
	Head over filter	2 m
Detention basin	Area	Sufficient to ensure detention of FC_M
	Depth	Max depth = 2 m; Average Depth = 1m
	Outlet	Orifice
Effective impervious area	15 ha	Sets the optimum size of sand filter

Table E4: DAC Justification

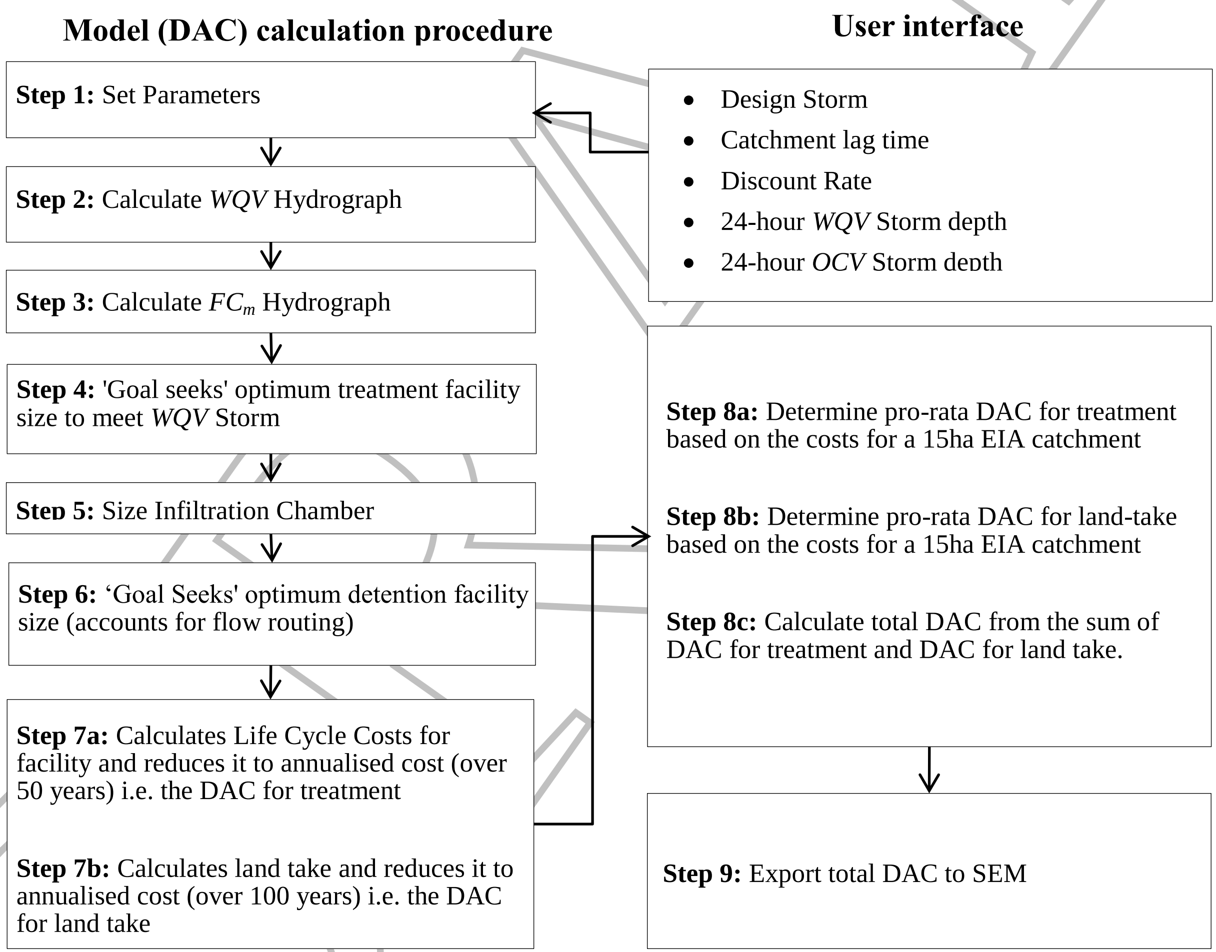
Criteria	**Justification**
Equivalent Service:	The facility ensures equal treatment to a SuDS system as per Table E2
Least Cost:	The DAC attempts to calculate the least cost of treating runoff from conventional systems using the most appropriate treatment works – in this case an on-line sand filter connected to an off-line detention pond.
Willingness to Pay:	The "polluter pays" principle is widely accepted in law and therefore it is appropriate that the cost of treatment is accounted for. In conventional systems these costs are externalised onto the environment resulting in the potential loss of natural capital. It is likely that there will be resistance to service charges being levied for stormwater treatment measures but this is not an excuse for not doing so.

WQV Storm. The FC_M Storm is routed through the facility and excess runoff that the quality treatment facility cannot manage is routed through a quantity control pond which releases runoff at a reduced rate (30% of post development).

The calculation procedure for the DAC follows the process outlined in Figure E3. The initial parameters for the analysis are entered by the user in Step 1. The model then automatically completes Steps 2-6. The order of the model's calculation procedure is significant as it ensures that the facility's use is optimized, i.e. the treatment facility is fully utilized before the detention facility is required, ensuring it is a 'least cost alternative'. The hydrographs for the Water Quality volume generated. Step 7 involves the separate calculation of the costs for treatment and the 'land-take'. The land-take accounts for the fact that real treatment facilities would have to be located somewhere in the city and land will have to be acquired at some cost. The SEM allows for this cost to be included if so desired.

The user calculates the final DAC in Step 8. The final DAC includes an amount for treatment and an amount for land-take (if desired). The virtual facility initially assumes a catchment with an effective impervious area (EIA) equal to 15 ha – an estimate of the area that will require a sand filter of roughly optimal size. This is to ensure that the

Figure E3: DAC tool calculation procedure



cost of developing and operating the facility is based on the 'least cost principle'. The costs (treatment and land-take) associated with EIAs larger or smaller than 15 ha are then determined pro-rata. The final DAC is then exported to the main SEM spread-sheet in Step 9.

E5 Conclusion

The failure to consider the impact of externalizing stormwater pollution from conventional systems is a common criticism of most commonly used economic tools as this unfairly distorts the benefit to cost ratio away from SuDS. LCCAs in particular have failed to fairly consider alternative designs through not accounting for the EGS supplied by SuDS systems. The SEM presented above does not consider all aspects, but it considers those most relevant to ensuring that the costs and benefits of different stormwater management systems may be compared in a fair manner and in a way which may be understood by a variety of stakeholders.

Appendix F

Stormwater management costing fact sheets

F1 Overview of fact sheets

Each fact sheet included herein contains a summary of the information required to conduct a preliminary 'life cycle costing' analysis for a stormwater management system. The fact sheets include:

- An overview of the SuDS option;
- Summary of capital costs;
- Summary of routine maintenance frequencies and costs;
- Summary of corrective maintenance predicted frequencies and costs;
- Predicted life cycle duration; and
- Conceptual value of environmental goods and services.

Although the focus of this document is not conventional stormwater drainage systems, components of conventional systems are often used as part of a SuDS system. A section detailing the cost relating to conventional systems has therefore been included. Table F1 lists the available fact sheets corresponding to the primary SuDS options included in the main text of the guidelines.

Table F1: Fact sheets for stormwater management

Option	Section
Conventional design: inlets, outlets etc.	F2
Green roofs	F3
Rainwater harvesting	F4
Permeable pavements	F5
Buffer and filter strips	F6
Swales (dry, wet, enhanced)	F7
Infiltration trenches and soakaways	F8
Bio-retention	F9
Dry stormwater ponds	F10
Wetlands and wet ponds	F11

F1.1 Summary of capital costs

The 'capital costs' section details factors that need to be considered when implementing the SuDS option. Typical unit rates for construction are also presented.

F1.2 Summary of maintenance costs

The inspection, routine maintenance and corrective maintenance frequencies that have been presented in this section are largely based on work done by Lampe *et al* (2005). The results are presented for the USA and UK separately, and based on the USA format. This study is available on the WERF website (www.werf.org) along with a set of MS Excel based costing tool that makes use of data from the USA. These frequencies reflect typical frequencies for individual SuDS. It is important to note that:

- The frequencies and typical rates for inspections refer to having a professional inspection and the completion of a report; and
- The routine maintenance frequencies and typical rates refer to specific maintenance tasks undertaken and exclude inspection tasks.

In reality, frequencies and associated costs will be dependent on a number of factors including: land use, climate, treatment train, component design etc. In addition, typical routine and corrective maintenance costs have been sourced from builders pricing guides, discussions with members of industry, the City of Cape Town and a range of recent tenders from across South Africa.

F1.3 Predicted Life Cycle costs

Lampe *et al.* (2005) failed to identify potential Expected Useful Life (EUL) cycles for individual SuDS, rather leaving this to the individual to assess. Due to the relative inexperience in South Africa, this appendix presents a number of EUL sourced from international literature. These could be applied after considerations of the local conditions versus those found in the country of origin. Explanations of possible maintenance activities for each SuDS option are included in the main body of the guidelines.

F1.4 Typical rates

The typical rates for capital costs presented in the fact sheets are estimates that are largely based on DoCGTA (2010), and checked against recent tenders, and industry pricing manuals (Merkels & Buildaid). The 'Gauteng prices' used can be adjusted in line with the MIG Guidelines for other provinces. With respect to landscaping costs, identifying typical unit rates is difficult as it is dependent on the contractors and how they determine their rates. Additionally the cost of vegetation varies significantly. Grass is a prime example. 'Buffalo' sometimes cost more than R50 per square meter in 2010, whereas 'Kikuyu' was typically less than half that at R20 a square meter. For swales and buffer strips this could have major cost implications as grassing is a significant cost factor. It was decided that the MIG guidelines should guide the typical rates, as these was based on an extensive research and stakeholder input. All rates exclude VAT, P&G's, and consulting / design fees. The typical rates presented for operations and maintenance have been collected from the City of Cape Town's Catchment, Stormwater and River Management Branch and adjusted to 2010 values.

F2 Conventional drainage

F2.1 Municipal Infrastructure Grant (MIG) Manual

DoCGTA (2010) provides estimates of capital construction costs for a range of infrastructural development, including a number of stormwater components, Table F2.1. The estimates are built up from typical unit rates. The estimates are deficient in that there are no estimates for pipes smaller than 600 mm diameter. The manual does however supply a detailed breakdown of the typical rates on which the cost estimates were based. This database was used to estimate typical unit rates build up estimates for constructing infrastructure. The data and the detail that it is supplied in the DoCGTA (2010) manual allows for this data to be used for determining estimates of capital costs.

The DPLG (2006) presented a set of operating and maintenance estimates as a percentage of the Current Replacement Cost (CRC) of the infrastructure. The CRC's supplied in DPLG (2006) however seem to be poor estimates when compared to the costs of the tasks required to maintain such systems. No information or reference is given for the origin of these estimates. Hence, while simple to use, there is the potential that these estimates underestimate the costs of maintaining a conventional system. The estimates supplied in DPLG (2006) should not, if at all possible, be used to estimate the life cycle costs of a conventional system. Instead estimates should be made by estimating the costs for cleaning, minor repairs and inspections separately. This can either be undertaken by sourcing typical rates from local companies or using the fact sheets below. Where data is not available and the fact sheets are not suitable so that using the DPLG (2006) estimates for operating and maintenance costs cannot be avoided, the uncertainty in these values should be clearly noted.

Table F2.1: Typical Capital costs for conventional drainage design – Aug 2009
(DoCGTA, 2010)

Asset	Unit	Average cost R's (Gauteng)
Unlined channel	m	230
Lined channel	m	770
Pipe culverts (600 mm diameter; Class 100D)	m	3,600
Box culverts (1500 mm x 1500 mm)	m	17,000
Low level stream crossings	m	59,000
Dewatering (subsoil)	m	5,100
Gabions	m^3	1,300
Reno mattresses	m^3	1,600

F2.2 Capital costs

Bester *et al.* (2010) present a set of simple-to-apply algorithms for estimating the capital costs of a gravity piped network. The algorithms consider all the components involved in the construction of the pipe line only. The algorithms do not consider aspects such as kerbs, catch pits and connections into the trunk line. The study effectively averaged the values of many successful tenders (Bester, 2010).

The alternative to making use of algorithms such as these is to build up the costs considering all the individual aspects. Narayanan & Pitt (2005) presented a simple model for this purpose. Alternatively a Quantity Surveyor should be consulted.

F2.3 Operations & maintenance

F2.3.1 Inspections

Conventional stormwater systems require regular inspections to ensure that they are being optimally managed and to identify potential failures before they occur. Table F2.3 contains the recommended intervals between inspections for conventional designs.

Table F2.3: Inspection frequencies for conventional components (CSRM, 2005)

Asset	Months between Inspections
Catch pits	6-12
Lined channels	12
Unlined channels	6-12
Maintained watercourses	12
Intakes / headwalls	6-12
Vleis and wetlands	12
Ponds	12

F2.3.2 Routine maintenance

Routine maintenance comprises the cleaning of the infrastructure and, where necessary, the management of vegetation and the removal of sediment. The frequencies contained in Table F2.4 are guides and are dependent on a number of factors including the pollution potential of the catchment. It should be noted that the different levels of maintenance in a conventional system relate only to hydraulic functioning and public health concerns. They do not consider amenity aspects.

F2.3.3 Corrective maintenance

Estimating the cost of corrective maintenance is difficult as it is affected by the age of the system and the standards and levels of service to which the local authority aspires. The City of Cape Town spends approximately 10% of its annual maintenance budget on 'repairs' (Austin, 2010). This is a rough guide and is based on a sub-optimal routine maintenance operation related to budgetary constraints.

Table F2.4: Routine maintenance frequencies (after CSRM, 2005)

Asset description	Months between maintenance		
	High	Avrg.	Low
Connections	6	9	12
Catch pits	6	8	12
≤300 mm diameter	3	16	24
375 mm diameter	12	22	24
450 mm diameter	24	24	24
525 mm diameter	36	46	48
600 mm diameter	48	48	48
>600 mm diameter and box culverts	60	60	60
Lined channels	1	6	12
Unlined channels	1	6	12
Maintained watercourses	4	9	12
Intakes / headwalls	1	5	12
Vleis and wetlands	6	10	12
Ponds	6	10	12

F2.3.4 Expected Useful Lives (EUL)

There are no generally agreed upon 'expected useful lives' (EUL) for different components of a conventional stormwater system. Few municipal asset management plans will define the EUL, and where they do, the EUL's vary or are questionable. This is especially evident in South Africa where available Municipal Asset Management Plans will estimate the EUL of a concrete pipe to be 40 years. International literature is also limited on EUL of conventional systems. For this reason only one set of EUL is in Table F2.5. These are from a recent study in South Australia by Tonkin Engineering Science. The study looked at the current Asset Management strategies. It is worth noting that where assets are not actively managed, their EUL may be reduced (Narayanan & Pitt, 2005).

Table F2.5: EUL of stormwater network components (Ellis & Callaghan, 2009)

Asset	No. Councils surveyed	Min	Max
		EUL in years	
Reinforced concrete pipe	8	50	100
uPVC	5	20	100
Box culvert	6	50	100
Side entry pit	4	50	80
Junction box	4	50	80
Headwall	5	50	80
Lined channel	4	50	100
Unlined channel	4	10	100

F2.3.5 Typical unit rates

Tables F2.6 & F2.7 present typical unit rates for inspections and routine maintenance. They have been sourced from recent tenders and budgeting documents compiled by the City of Cape Town's stormwater department. Where applicable the rates have been adjusted to 2010 Rand values.

F2.3.6 Further reading

The following documents are considered valuable references when calculating the costs of conventional systems. Where possible download links to the documents have been provided at www.wsud.co.za.

i) Debo, T & Reese, AJ (2003) *Municipal Stormwater Management*, Lewis Publishers, Boca Raton.

ii) Drainage Manual. (2007). Pretoria, South Africa: The South African National Roads Agency.

Table F2.6: Inspection rates for conventional systems (2010) (see Section F1.4)

Asset	Inspection costs	
	Units	Rate (R)
Catch pits	No.	130
Conduits/pipes	m	20-25
Lined channels	monitoring point inspection	130
Unlined channels	monitoring point inspection	130
Maintained watercourses	monitoring point inspection	160
Intakes / headwalls	No.	130
Vleis and wetlands	No.	210
Ponds	No.	180

Table F2.7: Cleaning rates for conventional systems (2010) (see Section F1.4)

Asset	Cleaning rates	
	Units	Rate (R)
Connections	No.	63
Catch pits	No.	60
≤300 mm diameter	m	55
375 mm diameter	m	60
450 mm diameter	m	60
525 mm diameter	m	80
600 mm diameter	m	80
>600 mm diameter and box culverts	m	150
Box culvert	m	350
Lined channels	m	37
Unlined channels	m	47
Maintained watercourses	m	280
Intakes / headwalls	No.	200
Vleis and wetlands	ha	5,800
Ponds	m^2	1.3

iii) DoCGTA. (2010). *An Industry Guide To Infrastructure Guide To Service Levels And Unit Costs.* Department of Cooperative Governance and Traditional Affairs.

iv) Ellis, R., & Callaghan, P. (2009). *Infrastructure Asset Useful Lives - SA Councils Current Practises.* Tonkin Engineering Science.

v) Woods-Ballard, B, Kellagher, R, Martin, P, Jefferies, C, Bray, R & Shaffer, P (2007). *The SUDS Manual*, CIRIA 697, London

F3 Green roofs

Green roofs are roofs designed to carry a vegetated layer. For further information see Section 3.1.

F3.1 Capital costs

The capital costs for a green roof vary depending on the specific design, for example if the design includes or excludes insulation, and the height above the ground at which it is to be constructed. Such factors may impact on the maintenance of the system and need to be taken into account when analysing the capital costs of a design.

F3.2 Inspections

Green roofs are effectively elevated bio-retention areas, and although Lampe *et al.* (2005) do not specify an inspection schedule for them a reasonable approximation is that of the bio-retention SuDS option, as has been used in Table F3.1. Additionally after big storm events it is advisable to ensure the system drains within the design period by checking the inspection chambers. Table F3.1 displays typical inspection frequencies for green roofs in the USA and UK.

Table F3.1: Inspection frequencies (months) (Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	N/A	36	12
USA	36	6	1

F3.3 Routine maintenance

"The different vegetative roofing system manufacturers have different maintenance recommendations, so it depends on the system you're installing…it depends on intensive versus extensive. It depends on built in place versus modular" (Matt, 2009). Routine maintenance is primarily about vegetation management, and the replacement of soil that is lost due to 'erosion', be it water or wind erosion. While the system is being established it may also include the replacement of plants that do not survive. Table F3.2 displays typical routine maintenance frequencies for green roofs in the USA and UK.

Table F3.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Litter management	UK	12	4	1
Management of vegetation	UK	6	4	1
Vegetation management	USA	36	6	1

F3.4 Irregular & corrective maintenance

Corrective maintenance is generally concerned with the management of the roof's water proofing layers and management / unblocking of the drainage layer. Table F3.3 displays typical irregular maintenance tasks for green roofs and highlights the problems with estimating irregular maintenance requirements.

Table F3.3: Irregular maintenance frequencies (months)

Task	Low	Med.	High
Repair waterproof layer	Dependent on quality of construction, and site factors		
Replace soil	Site specific		

F3.5 Expected Useful Life (EUL)

The expected useful life of a system is determined in the design phase. It is dependent on the type of system and the type of vegetation. Narayanan & Pitt (2005) showed how three different green roofs had varying EUL's of between 10 and 40 years simply due to the design selected. Narayanan *et al.* (2005) estimate a EUL ranging between 10-40 years, although EUL's up to 90 years have been noted.

F3.6 Typical unit rates

Maintenance costs, as with construction costs, will vary depending on the accessibility of the roof, the function of the roof, and the scale of the project. Households with easy accessibility could potentially be managed by the homeowner at no additional cost. Table F3.4 displays typical construction rates for green roofs. Table F3.5 displays typical maintenance rates for green roofs.

Table F3.4: Typical maintenance rates (2010)
(see Section F1.4)

Description	Unit	Rate (R)
Inspections	No.	210
Litter & vegetation management	visit.m^2	2.00-2.40
Soil replacement	m^3	161
Repair of water proof layer	Dependent on damage	

Table F3.5: Typical construction rates (2010)
(see Section F1.4)

Description	Units	Rate (R)
Derbigum SP4 waterproof layer	m^2	174
Aggregate	m^3	215
Geotextile (Filter Fabric - Bidim)	m^2	21
Inspection eyes	No.	102
Plant layer / vegetation	m^2	46
Top soil supplied by contractor, spread in 100-200 mm thick layers	m^3	161
Plants supplied & planted	m^2	46
Supply and add mulch to shrub areas (20 mm)	m^2	62
Grassing per m^2	m^2	20-50
Crane hire – all terrain hydraulic crane, 18 ton	day	4584
Green roof estimate (without consideration for height)	m^2	444
Green roof estimate – direct application (without consideration for height)	m^2	400
Green roof estimate – modular application (without consideration for height)	m^2	480

F4 Rainwater harvesting

Rainwater harvesting is the collection, storage and reuse of stormwater runoff. For further information see Section 3.2.

F4.1 Capital costs

The capital costs are comprised of the storage unit, the additional piping and guttering required to convey the water to the storage unit. Additionally a 'first flush filter' is recommended to prevent the storage unit becoming filled with sediments and debris. Where gravity flow to the point of reuse is not possible a booster pump may be required.

F4.2 Inspections

The system should be inspected regularly to ensure that the first flush diverter is emptied. This will protect the rest of system from sediments and debris. The storage unit should be checked to ensure sediments have not built up. These tasks can be undertaken quickly and simultaneously. Table F4.1 displays typical inspection frequencies for rainwater harvesting systems.

Table F4.1: Inspection frequencies (months)
(Coombes, 2004)

Task	Low	Med.	High
Inspection	6	4.5	3

F4.3 Routine maintenance

In order to protect the system from a build-up of sediments the gutters upstream need to be cleaned, as well as the 'First Flush' device. The roof catchment area should also be maintained and kept free of a build-up of pollutants.

F4.4 Irregular & corrective maintenance

Sediment will build up, albeit slowly, even if the rest of the rainwater harvesting system is maintained properly. Where maintenance is poor the rate at which sediment will need to be removed will increase for the system to function properly. The frequency of irregular maintenance is highly variable and dependant on the level of regular maintenance.

F4.5 Expected useful life (EUL)

The EUL of the system is determined by the EUL of the rainwater tank. Therefore with proper maintenance and no unforeseen damage the system should last beyond the EUL's shown below. Narayanan *et al.*, (2005) suggest a EUL of 20 years or more.

F4.6 Typical unit rates

The costs of constructing a rainwater harvesting system are based upon those of a 'yard tank' connected to the gutters of a house (DoCGTA, 2010), with the addition of a first flush filter. While it may not be necessary to raise the rain water harvesting tank, by elevating the tank it is possible to negate the need for a pumping system. Table F4.2 displays typical construction rates for rainwater harvesting systems.

Maintenance costs reflect estimates of the costs should a contractor be responsible for the maintenance of a system. Rainwater harvesting can easily be maintained by the home owner at no additional cost. Table F4.3 displays typical rates for maintenance of rainwater harvesting systems.

Table F4.2: Typical construction rates (2010) (see Section F1.4)

Description	Units	Rate (R)
Supply and install 5000 litre Tank/Water Butt (Including 15% P&G's)	No	14,200
Supply and install 5000 litre Tank/Water Butt (no Stand) (Including 15% P&G's)	No	7,600
Supply & Install First Flush Device	No	1,800

Table F4.3: Typical rates for maintenance (2010) (see Section F1.4)

Description	Unit	Rate (R)
Inspections	No.	160
First flush – cleaning requires inspection	No.	150
Gutter cleaning	m	Included in roof clean
Roof cleaning	m^2	0.75 (excl. water used)
Sediment removal	m^3	70

F5 Permeable pavements

Permeable pavements allow water to percolate through them. Often the runoff is then detained in a storage unit from where it either infiltrates into the ground or is released at a reduced flow rate to a receiving water body. For further information see Section 3.4.

F5.1 Capital costs

Capital costs are dependent on the design – whether it is a full infiltration, partial infiltration or fully contained system. For partial or full infiltration systems it is important that the outlet be sized correctly. The connection of the outlet into the municipal sewer will result in an additional cost.

F5.2 Inspections

Permeable pavements require regular inspections to ensure that they are being optimally managed. Additional inspections should be carried out after large storm events to ensure the permeable paving system is operating within design limits. Table F5.1 displays typical inspection frequencies for permeable pavements in the UK and USA.

Table F5.1: Inspection frequencies (months) (Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	12	6	1
USA	36	6	1

F5.3 Routine maintenance

The routine management of litter, solid waste and vegetation is required to prevent the system clogging. Sweeping has been shown to dramatically increase the permeability of the system. Table F5.2 displays typical routine maintenance frequencies for permeable pavements in the UK and USA.

Table F5.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Litter management	UK	60	12	2
Sweeping	UK	12	6	4
Sweeping and litter management	USA	36	6-12	1

F5.4 Irregular & corrective maintenance

Corrective maintenance for permeable block paving is no different to conventional block paving and entails fixing any local pavement failures. Due to the wide variation resulting from different uses and quality of construction it is difficult to estimate corrective maintenance frequencies. Another task is the removal of sediment collected in the pavement. Sediment should ideally be managed through routine sweeping. Once clogged, the system may need to be cleaned using a vacuum cleaner – not readily available in RSA – or partially overhauled. Current evidence from Australia indicates the majority of sediments are collected in the top 25mm of the paving layer works – hence this could be removed and replaced. Irregular maintenance frequencies for permeable pavements are highly variable and typically range between 10-15 years (Lampe *et al.*, 2005).

F5.5 Expected Useful Life (EUL)

The design lives listed below relate to system clogging. Evidence from Australia indicates only the top 25 mm of the system would need to be overhauled for the system to function properly again. Table F5.3 displays typical EUL for permeable pavements.

Table F5.3: EUL of a permeable pavement

	Jefferies, 2005	Shackel, 2011
Design Life	15-20 years before clogging	>10 years based on current research at 10 years

F5.6 Typical unit rates

Table F5.4 displays typical construction rates for permeable pavements. Table F5.5 displays typical maintenance rates for permeable pavements.

Table F5.4: Typical maintenance rates (2010) (see Section F1.4)

Description	Unit	Rate (R)
Inspections	visit	180
Sweeping	visit.m^2	0.05-0.10
Structural repairs	m^2	190
Overhaul of top 25mm	m^2	40

Table F5.5: Typical construction rates (2010)
(see Section F1.4)

Description	Units	Rate (R)
Cut to fill	m^3	39
Cut to spoil	m^3	79
Overhaul to dumpsite	m^3.km	0.10 - 8.00
Layer Works:		
Supply, install and compact 250 mm thick, 10-63 mm course aggregate, no fine	m^3	240
Supply, install and compact 100 mm thick, 5-20 mm course aggregate, no fines.	m^3	290
Supply, install and compact 50 mm thick, 5 mm course aggregates, no fines.	m^3	280
Supply and install 50 kN/m Rock Grid geosynthetic mesh (PC Range 2.6 mm thick)	m^2	50
Supply and lay 160 mm diameter Geopipe – Subsurface drainage	m	65
Aquaflow permeable paving blocks 200 x 110 x 80 mm, 50 MPa	m^2	155
Connection for sub-surface drainage into existing stormwater network	No	50
Kerbing:		
Kerbing and channelling straight	m	160
Kerbing and channelling curves	m	180
Permeable Paving unit rate (P&G's = 15%)	m^2	450

F6 Buffer & filter strips

Buffer & filter strips are grassed slopes that are designed to filter runoff. The design can be modified to aid infiltration through the use of a berm. For further information see Section 4.1.

F6.1 Capital costs

The construction of buffer and filter strips require the grading and cultivation of open land.

F6.2 Inspections

Buffer and filter strips should be regularly inspected to monitor damage due to erosion and sediment build up. Table F6.1 displays typical inspection frequencies for buffer and filter strips used in the USA and UK.

Table F6.1: Inspection frequencies (months)
(Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	24	6	1
USA	36	6	1

F6.3 Routine maintenance

Routine maintenance comprises litter and vegetation management. Typical routine maintenance frequencies are supplied in Table F6.2.

Table F6.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Litter management	UK	12	4	1
Grass cutting	UK	6	4	1
Grass cutting, weeding and litter management	USA	36	6-12	1

F6.4 Irregular & corrective maintenance

Corrective maintenance is largely sediment removal (especially when a berm is used) and erosion management. It is ideal if the buffer / filter strip is designed with a flow spreader to minimise the chances of concentrated flow that result in erosion. Maintenance is similar to that required for swales (Lampe *et al*, 2005). Table F6.3 supplies typical irregular maintenance frequencies for buffers and filter strips in the USA.

Table F6.3: Irregular maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Low	Med.	High
Sediment removal and erosion	1200	78	18

F6.5 Expected Useful Life (EUL)

A Buffer or filter strip has the potential to last indefinitely. Literature indicates buffers & filter strips may have service lives ranging from 20-50 years. Table F.9.4 displays typical EUL for buffers and filter strips.

Table F6.4: EUL of buffer and filter strips

	Jefferies, 2005	Narayanan *et al.*, 2005
Design life	20-50 years	20 used in LCC

F6.6 Typical unit rates

The construction rates given in Table F6.5 are based on the MIG Guidelines (DoCGTA, 2010). If extensive cut and/or fill are required these rates will be inappropriate. Table F6.5 displays typical construction rates for buffers & filter strips. Table F6.6 displays typical maintenance rates for buffers and filter strips.

Table F6.5: Typical construction rates (2010) (see Section F1.4)

Description	Units	Rate (R)
Earthworks	m^2	4.50
Grassing	m^2	20
Buffer/Filter Strip unit rate (Includes 15% P&G)	%	28
Irrigation	m^2	20

Table F6.6: Typical maintenance rates (2010) (see Section F1.4)

Description	Unit	Cost
Inspections	visit	180
Litter & vegetation management (monthly)	visit. m^2	1.50-2.40
Erosion	m^2	35
Sediment management	m^3	71

F7 Swales

A swale is a grass channel designed to filter stormwater as it is conveyed. The design can be modified to aid infiltration by adding check dams and through additional layer works (e.g. enhanced dry swale – see Section 4.2.).

Swales can additionally be designed to ensure biological treatment e.g. wet swales which do not drain entirely.

F7.1 Capital costs

A grass swale is relatively simple to construct as it is effectively a trapezoidal earth channel lined with grass. Check dams may also be included and can be constructed from wood, earth, or small 'gabion' walls.

F7.2 Inspections

The swale should be inspected regularly to monitor damage resulting from erosion and / or sediment build up. Swales are commonly used to remove sediment before it enters wet or underground SuDS, and thus sediment build up is an important aspect of the inspection. Table F7.1 displays typical inspection frequencies for grass swales.

Table F7.1: Inspection frequencies (months) (Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	24	6	1
USA	36	6	1

F7.3 Routine maintenance

Routine maintenance tasks comprise the removal of litter and cutting grass. Table F7.2 displays typical routine maintenance frequencies for grass swales.

Table F7.2: Routine maintenance (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Litter management	UK	12	4	1
Grass cutting	UK	6	4	1
Grass cutting, weeding and litter management	USA	36	6-12	1

F7.4 Irregular & corrective maintenance

Corrective maintenance is limited to sediment removal. When the build-up of sediment begins to impact on the hydraulic capacity of the swale then sediment will need to be removed i.e. when 10% of the swale depth or according to design specifications. Erosion management is also vital and any signs of erosion should be dealt with to prevent compounding the damage in future storm events. Table F7.3 displays typical irregular maintenance frequencies for grass swales.

Table F7.3: Irregular maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Low	Med.	High
Erosion and sediment management	1200	78	18

F7.5 Expected Useful Life (EUL)

A well maintained swale has the potential to last indefinitely. However as shown in Table 7.4 literature indicates swales normally have service lives ranging from 10-50 years. Enhanced swales especially may require extensive layer works to reinstate. Table F7.4 displays typical EUL's of grass swales.

Table F7.4: EUL of a Swale

	Jefferies, 2005	FHWA, 2005 in Jefferies, 2005
Design life	10 years	20-50 years

F7.6 Typical unit rates

Table F7.5 displays typical construction rates for swales. Table F7.6 displays typical maintenance rates for swales.

Table F7.5: Typical construction rates (2010) (see Section F1.4)

Description	Units	Rate (R)
Clear and grub	m^2	4
Strip and remove topsoil	m^3	27
Cut to spoil	m^3	82
Trimming side drains to profile, compact	m	27
Levelling verges	m	19
Grassing	m^2	20-50
Swale per m (P&G's = 15%)	m	305
Construct scour protection (steep sections)	No.	440

Table F7.6: Typical maintenance rates (2010) (see Section F1.4)

Description	Unit	Cost (R)
Inspections	visit	160
Litter & vegetation management	visit.m^2	1.50-2.40
Erosion	m^2	35
Sediment management	m^3	71

F8 Infiltration trenches / soakaways

Infiltration trenches (Section 4.3) and soakaways (Section 3.3) operate in a similar manner. The purpose of these SuDS options is to collect, store and infiltrate stormwater. They are commonly constructed as trenches filled with void forming media – e.g. stone.

F8.1 Capital costs

Infiltration trenches are excavated trenches that are filled with rock, or other relatively large granular material, or commercial void forming products. The 'void former' – be it aggregate or geo-cellular units – may impact on the cost and efficiency of the design. Sub surface trenches (generally soakaways) need to include an overflow.

F8.2 Inspections

Inspections should be undertaken to ensure the system is draining within the design period. This is accomplished through regular inspections as well as inspections after large storm events. Once it is no longer draining effectively corrective maintenance should be undertaken. Table F8.1 displays typical inspection frequencies for infiltration trenches and soakaways in the UK and USA.

Table F8.1: Inspection frequencies (months) (Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	36	12	3
USA	>36	12	1

F8.3 Routine maintenance

As these systems are predominantly if not entirely below ground, it is often difficult to access them for maintenance. Routine maintenance therefore considers the immediate surroundings and comprises litter and vegetation management. Vegetation management is important to prevent the geo-synthetic layer being breached which could lead to the clogging of the system. Pre-treatment is advisable (e.g. swale/filter strip) as pre-treatment will decrease the sediment loads entering the SuDS option thereby increasing its useful life SuDS option. Table F8.2 displays typical routine maintenance frequencies for infiltration trenches and soakaways in the USA and UK.

Table F8.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Litter, vegetation & surface management	UK	36	6	2
Litter, vegetation & surface management	USA	36	6-12	1

F8.4 Irregular & corrective maintenance

Corrective maintenance is undertaken when the system is no longer operating within design limits, e.g. when no longer emptying within 24 hours. This can be done in one of two ways, either the entire system is replaced, or the top layer (gravel and geo-synthetic) are removed and replaced. This assumes that the rest of the system is not clogged. The WERF (2005) UK maintenance report states that it does not expect climate to affect the maintenance of this SuDS option. Table F8.3 displays the typical irregular maintenance frequencies for infiltration trenches and soakaways. As is evident from the typical EUL's in Table F8.4 the UK estimates seem to be overly optimistic.

Table F8.3: Irregular maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med.	High
Routine scarifying of top layer	UK	480	240	120
Overhaul system	USA	60	48	18

F8.5 Expected Useful Life (EUL)

The EUL of infiltration trenches and soakaways vary. This is mainly due to the poor reputation of the system, a direct result of poor maintenance internationally which leads to these systems failing prematurely. Table F8.4 displays the EUL for infiltration trenches and soakaways.

Table F8.4: EUL of an infiltration trench

	EPA in Jefferies, 2005	FHWA in Jefferies, 2005
Design life	5-15	10

F8.6 Typical unit rates

Table F8.5 displays typical maintenance rates for infiltration trenches and soakaways. Table F8.6 displays typical construction rates for infiltration trenches and soakaways.

Table F8.5: Typical maintenance rates (2010)
(see Section F1.4)

Description	Unit	Rate(R)
Inspections	visit	180
Litter & vegetation management	visit$\cdot$m^2	2
Overhaul top layer	m^3	40
Complete overhaul of system is equivalent to construction cost		

Table F8.6: Typical construction rates (2010)
(see Section F1.4)

Description	Units	Rate (R)
Clear and remove topsoil	m^2	7
Cut to spoil	m^3	80
Surface bed preparation	m^2	35
Geotextile (Filter Fabric - Bidim)	m^2	20
"Chamber"	-	-
Stone fill (Different diameters: see permeable paving)	m^3	270
Building sand	m^3	340
Supply & lay 160 mm slotted pipe	m	65
"Sub surface"/Soakaways	-	-
Top soiling of verge areas	m^2	6
Grassing	m^2	20 - 50
Standard surface infiltration Trench (30% Voids ratio)	m^3	570

F9 Bio-retention

Bio-retention areas are engineered gardens that detain, treat and infiltrate stormwater. They may include an under drain connecting into the municipal stormwater pipe. For further information see Section 4.4.

F9.1 Capital costs

The capital costs are comprised of excavation, layer works, and landscaping. When an under-drain is included, the costs of connecting to the municipal sewer must be added.

F9.2 Inspections

As with all SuDS options, regular inspections are necessary, both to ensure that litter, sedimentation and excessive vegetation do not impact on the functioning of the bio-retention system, and to ensure that the system is functioning properly during and after large storm events. Table F9.1 displays typical inspection frequencies for bio-retention areas in the USA and UK.

Table F9.1: Inspection frequencies (months)
(Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	24	6	1
USA	36	6	1

F9.3 Routine maintenance

Routine maintenance is considered to be equivalent to any other small SuDS options, and comprises litter and vegetation management. The position in the treatment train is important – where possible, pre-treatment should be included to remove sediment. Table F9.2 displays routine maintenance frequencies for bio-retention systems.

Table F9.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Litter management	UK	12	4	1
Vegetation management	UK	6	4	1
Vegetation and Litter management	UK	36	6-12	1

F9.4 Irregular & corrective maintenance

Corrective maintenance which predominantly comprises the management of sediment, is dependent on upstream sediment management. If the bio-retention unit does not drain within the design period (24-36 hours) it will be necessary to either cultivate / scarify the top soil layers or overhaul the system. Table F9.3 displays typical irregular maintenance frequencies for bio-retention systems in the USA.

Table F9.3: Irregular maintenance frequencies (months) (Lampe *et al.*, 2005)

Source	Low	Med.	High
USA	n/a	78	18

F9.5 Expected Useful Life (EUL)

As with other SuDS options there is a wide variation in the EULs of bio-retention systems. Soil conditions, catchment areas, and treatment train design and maintenance schedule will all impact the EUL of a bio-retention area. If possible the bio-retention area should be preceded by a small swale, filter strip, or sediment bay. Table F9.4 displays typical EULs for bio-retention areas.

Table F9.4: EUL of a bio-retention area

Subject	MUSIC, 2009	Narayanan & Pitt, 2005
Design life	25-50 years	20 years

F9.6 Typical Unit Rates

Table F9.5 displays typical construction rates for green roofs. Table F9.6 displays typical maintenance rates for bio-retention areas.

Table F9.5: Typical construction rates (2010) (see Section F1.4)

Description	Units	Rate (R)
Clear and remove topsoil	m^2	7
Cut to spoil	m^3	82
300x300 stone drain covered in Geofabric (110 mm drainex pipe)	m	160
Backfilling with selected material	m^3	120
Top soil supplied by contractor, Spread in 100-200 mm thick layers	m^3	160
Plants supplied & planted	m^2	45
Supply and add mulch to shrub areas (20 mm)	m^2	60
Surrounding areas:		
Top soiling of verge areas	m^2	6
Grassing	m^2	20 - 50
Unit rate for bio-retention area	m^2	410
Irrigation	m^2	20

Table F9.6: Typical maintenance rates (2010) (see Section F1.4)

Task	Unit	Rate (R)
Inspections	visit	210
Litter & vegetation management (based on quarterly visits)	visit.m^2	2.00-2.40
Sediment removal	m^3	71

F10 Detention ponds

Detention ponds are areas designed to temporarily detain runoff. They drain within a specified period of time, usually 24-48 hours. For further information see Section 5.1.

F10.1 Capital costs

Detention ponds may be constructed using a range of techniques, from simple excavation to retaining walls. Designs may include sediment forebays to reduce sediment entering the rest of the detention pond, and making routine and irregular maintenance simpler and cheaper. It is also important that the type of outlet is carefully considered.

F10.2 Inspections

The inspections of detention ponds should consider the general state of the detention pond, including the impact of sedimentation, vegetation growth, the state of the inlets and outlets etc. Table F10.1 displays typical inspection frequencies for detention ponds in the UK and USA.

Table F10.1: Inspection frequencies (months) (Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	>12	<4	<1
USA	>36	36	12 + large storm events

F10.3 Routine maintenance

Routine maintenance of detention ponds includes the removal of litter, mowing of grass banks and general management of vegetation. Additionally routine maintenance should ensure the sediment forebay / basin, inlets and outlets are operational and clear of gross pollutants. Table F10.2 displays typical routine maintenance frequencies for detention ponds in the USA and UK.

F10.4 Irregular & corrective maintenance

Irregular maintenance of stormwater ponds includes vector control (ensuring the detention pond empties within the design period), algae removal (sediment bay) and sediment management. These tasks are climate and site specific and difficult to predict. Sediment removal requirements will be dependent on the treatment train design and general maintenance of the system. Table F10.3 displays irregular maintenance frequencies for detention ponds.

Table F10.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med.	High
Litter & vegetation management	USA	36	6 -12	1
Litter removal	UK	12	6	1
Grass cutting	UK	36	3	1
Clean sediment in forebay	UK	12	12	12

Table F10.3: Irregular maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med	High
Sediment removal	USA	240	96	36
Sediment removal & dewatering	UK	600	300	120

F10.5 Expected useful life (EUL)

The EUL of a stormwater management pond is largely dependent on the design of the whole system. If the stormwater pond is not protected from sediment by upstream controls it will inevitably have a much reduced EUL. Table F10.4 displays the EUL for detention ponds.

Table F10.4: Expected Useful Life

	Jefferies, 2005	FHWA (Jefferies, 2005)
Design life	Dependent on maint.	20-50 years

F10.6 Typical Unit Rates

Table F10.5 displays typical construction rates for green roofs. Table F10.6 displays typical maintenance rates for detention ponds.

Table F10.5: Typical construction rates (2010)
(see Section F1.4)

Description	Units	Rate (R)
Earthworks:		
Cut to fill	m^3	40
Excavate detention ponds 1-2m deep	m^3	18
Overhaul	m^3.km	0.10 – 8.00
Excavate material	m^3	100
Surface bed preparation for bedding of gabions	m^2	70
Gabions (2.0 x 1.0 x 1.0) PVC coated gabion boxes 2,7mmm diameter galvanised wire, to SANS 1580, including rock infill	m^3	1300
Geotextile (Filter Fabric - Bidim)	m^2	20
Reno mattresses (3.0 x 1.0 x 0.3 PVC boxes)	m^3	1590
Gabions, reno mattress, stone Pitching	m^2	330
Pond inlet/outlet	No	23,500
Attenuation pond outlet (2006 includes P&G, VAT)	No	550,000
Grassing	m^2	20

F11 Wetlands & retention ponds

Wetlands and retention ponds are controls which maintain a permanent pool of water. The major difference from a design point of view is that a retention pond has 25 to 50 per cent of the pond surface area covered with vegetation, whereas a wetland has 75 to 100 per cent coverage (Jefferies, 2010). For further information see Section 5.2 and Section 5.3.

Table F10.6: Typical maintenance rates (2010)
(see Section F1.4)

Description	Unit	Rate (R)
Inspections	visit	180
Litter & vegetation management	visit.m^2	0.60 - 2.20
Sediment Removal	m^3	157

F11.1 Capital costs

Wetlands and retention ponds require extensive landscaping works. The outlet would need to be designed to ensure that the system retains runoff for sufficient time in order to ensure biological treatment.

F11.2 Inspections

Inspections include checking and monitoring for mosquitoes (vector control), monitoring algae, and monitoring sediment build-up etc. Table F11.1 displays typical inspection frequencies for wetlands and retention ponds.

Table F11.1: Inspection frequencies (months)
(Lampe *et al.*, 2005)

Country	Low	Med.	High
UK	>12	<4	<1
USA	>36	36	12 + Events

F11.3 Routine maintenance

The routine maintenance of wetlands includes: removal of litter, mowing of grass banks and general management of vegetation. Routine maintenance should include the inspection and cleaning of inlets and outlets. Table F11.2 displays typical routine maintenance frequencies for wetlands and retention systems in the USA.

Table F11.2: Routine maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Low	Med.	High
Litter and general vegetation management	36	6 - 12	1

F11.4 Irregular & corrective maintenance

Irregular maintenance includes tasks such as vector control, algae removal and management. These tasks are climate and site specific and difficult to predict. Sediment removal requirements will be dependent on the treatment train design and general maintenance of the whole drainage system. Table F11.3 displays typical irregular maintenance frequencies for wetlands and retention systems in the USA and UK.

Table F11.3: Irregular maintenance frequencies (months) (Lampe *et al.*, 2005)

Task	Country	Low	Med.	High
Sediment removal	UK	600	300	120
Sediment removal main pool	USA	480	360	240
Sediment removal forebay	USA	240	60-120	12-24

F11.5 Expected useful life (EUL)

The EUL of wetlands and retention ponds will be dependent on the system design. Expert opinion suggests that they should last for 50 years, although poor design and maintenance will result in premature failure. Table F11.4 displays the typical EUL's for wetlands and retention ponds.

Table F11.4: Expected useful life

	USEPA (Jefferies, 2005)	FHWA (Jefferies, 2005)
Design life	>20	20-50

F11.6 Typical unit rates

Currently no estimates for the construction of wetlands are available. Table F11.5 displays typical maintenance rates for wetlands and retention ponds.

Table F11.5: Typical maintenance rates (2010) (see Section F1.4)

Description	Unit	Rate (R)
Inspections	Visit	210
Vegetation management (large)	visit.m^2	0.60
Vegetation management (pocket wetlands)	visit.m^2	2.00-2.40
Sediment removal (Standard wetland)	m^3	Site dependant >160
Sediment removal (Submerged gravel)	Capital Cost	

Appendix G

SuDS Conceptual Design Chart