STORMWATER DESIGN MANUAL FOR THE CITY OF JOHANNESBURG

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STORMWATER DESIGN MANUAL

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REPORT TO

CITY OF JOHANNESBURG

BY

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EXECUTIVE SUMMARY

Urban stormwater management is no longer about efficient drainage and flood management. It is about the protection of a resource. Storm drains are no longer wastewater networks but a means of conveying water resources to control points for treatment and reuse to enhance the urban environment. These new values and principles of stormwater management underpin the By-laws of the City of Johannesburg as published in the Provincial Gazette in 2010. The intention, at the time of publishing these By-laws, was that they would be accompanied by a Manual that would offer guidance to public and private sector participants in the design and management of stormwater facilities who will need to use these new approaches.

This Manual presents a set of principles that planners and designers need to apply, to ensure that their stormwater plans meet the requirements of good stormwater management. Furthermore, these principles are intended to provide support to consultants, developers and municipal officers considering plans for the development and management of the City, from spatial development frameworks through to site development plans.

The intention of the By-laws is to ensure the use of the best available methodology to mitigate the impacts of urban development on stormwater runoff. Specifically, the interventions to mitigate these impacts must address: peak discharge, volume, frequency, duration of runoff and quality of runoff, and these mitigation measures must be considered for all stages of the project including:

- Planning to ensure that sufficient space is made available for the required stormwater management measures;
- Design to achieve the desired result;
- Construction to ensure that no contaminated stormwater discharges from the site (including sediment) or enters the drainage or riparian system;
- Operation, maintenance and education to ensure that the constructed stormwater management measures continue to function as designed for the life of the project;
- Decommissioning to ensure that the drainage system is restored to its natural functionality at the end of the project life.

In addition to the use of the latest and best technology, new developments should adhere to best practice by understanding the context of the development in terms of the application of Green Infrastructure principles, as presented in Appendix C.

The Manual presents the principles enshrined in the 2010 By-laws in Section 1, followed by a clause-by-clause commentary on the By-laws in Section 2. This section also gives guidelines on aspects relevant to each chapter of the By-laws. The appendices present additional information, including methods of calculating and modelling stormwater loads and runoff.

PREFACE

This Stormwater Design Manual is intended to act as a guide to the City of Johannesburg stormwater by-laws of 2010. It is intended as a living document, subject to revisions and expansion as data becomes available through performance monitoring and in response to climate change. Sections in the Appendices that will be supplemented in the next edition of the Manual are indicated with titles only.

The notes contained in grey boxes are not intended to have legal effect or to restrict the ambit of the bylaws but rather as clarifications, explanations and amplifications thereof as the case may be with the intention being to provide practical guidance to lay readers of the Manual. In the event of a conflict between the notes and the Manual or Bylaws, the Manual and Bylaws will prevail.

Users of the Manual are encouraged to contact the authors with ideas, data and suggestions for improvement.

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DISCLAIMER

The material contained in this publication is intended to assist the practitioner to comply with the requirements of the City of Johannesburg's Stormwater Bylaws. It is not intended as professional advice on specific applications. It is the responsibility of the user to determine the suitability and appropriateness of the material contained in this publication to specific applications. No person should act or fail to act on the basis of any material contained in this publication without first obtaining specific independent professional advice. The City of Johannesburg, its employees and agents, and the authors of this document expressly disclaim any and all liability to any person in respect of anything done by any such person in reliance, whether in whole or in part, on this publication.

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DEFINITIONS, TERMINOLOGY AND ACRONYMS

BMP **B**est **M**anagement **P**ractice is a term used in the United States of America and Canada to describe a type of water pollution control measure. Historically the term has referred to auxiliary pollution controls in the fields of industrial wastewater control and municipal sewage control, while in stormwater management (both urban and rural) and wetland management, BMPs may refer to a principal control or treatment technique as well.

ESCP **E**rosion and **S**ediment **C**ontrol **P**lan, to be compiled as part of the Stormwater Drainage Plan, that address the risk of sediment yield from a development site, the potential impacts on the receiving environment, the intended measures to address the risk and a demonstration of the expected performance. The intended measures will be a combination of planning to minimise exposed areas as well as BMPs to contain the sediment yield from those exposed areas.

GI **G**reen **I**nfrastructure refers to “the interconnected set of natural and man-made ecological systems, green spaces and other landscape features that together form an infrastructure network providing services and strategic functions in the same way as traditional ‘hard’ infrastructure” (GCRO, 2013). It is not specific to urban stormwater infrastructure though stormwater networks are a common focus of Green Infrastructure design. Importantly, Green Infrastructure aims to provide multiple services of which stormwater functions could be one (others may be public amenity (parks) and biodiversity, for example). This usually involves multiple municipal departmental stakeholders and (currently) institutional and administrative problems. Nevertheless, Green Infrastructure is increasingly being seen as critical to sustainable cities and as a climate adaptation initiative; therefore, stormwater planning and design will inherently be central to it. A distinction is to be made between this term and GSI, though in practice many drainage solutions may be both.

GSI **G**reen **S**tormwater **I**nfrastructure maximises the use of infiltration, evapotranspiration, storage and reuse to control and treat stormwater runoff. GSI practices are generally small in scale and distributed in a decentralized manner throughout the landscape. GSI is intended to manage stormwater runoff as close to the source as possible in an effort to maintain pre-development hydrology.

LID **L**ow **I**mpact **D**evelopment is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, and minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. There are many practices that have been used to adhere to these principles such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. Applied on a broad scale, this approach can maintain or restore a watershed's hydrologic and ecological functions. (EPA, 1993)

LIDS **L**ow **I**mpact **D**rainage **S**ystems, synonymous with GSI.

SDP **S**tormwater **D**rainage **P**lan is a drawing or drawings of the site showing the spatial relationship, capacities, flow directions, and all other characteristics of the stormwater management system for the site and its receiving system. It forms part of the Stormwater Management Report (SWMR).

SQID **S**tormwater **Q**uality **I**mprovement **D**evice is an intervention with the primary function of improving the quality of the stormwater runoff. This can include structures such as gross pollutant traps or proprietary devices for separating sediment, floating debris and non-emulsified oil from the stormwater flow. The can also include interventions with multiple functions, such as wetlands or sediment traps

SUDS **S**ustainable **U**rban **D**rainage **S**ystems recognise the value of rainwater, seeking to capture, use, delay, or absorb it, rather than reject it as a nuisance or problem. Sustainable drainage delivers multiple benefits. As well as delivering high quality drainage whilst supporting areas to cope better with severe rainfall, SUDS can also improve the quality of life in developments and urban spaces by making them more vibrant, visually attractive, sustainable and resilient to change by improving urban air quality, regulating building temperatures, reducing noise and delivering recreation and education opportunities.

SWMR **S**torm**w**ater **M**anagement **R**eport, needs to contain minimum content as outlined in Chapter 2 of the Manual. The SWMR shall include the Stormwater Drainage Plan (SDP) and the Erosion and Sediment Control Plan (ESCP).

WSUD **W**ater **S**ensitive **U**rban **D**esign integrates water cycle management into urban planning and design to manage the impacts of stormwater from development. It is applied at all scales, from the individual property to the regional catchment. It aims to protect and improve waterway health by replicating the natural water cycle as closely as possible.

Definitions used in the By-laws can be found on p16-22 of this Manual.

INTRODUCTION

Urban stormwater management is no longer about efficient drainage and flood management: it is about the protection of a resource. Storm drains are no longer wastewater networks but a means of conveying water resources to control points for treatment and reuse to enhance the urban environment. In addition to protecting water resources, a sustainable drainage system can improve the quality of life in urban spaces by making them more vibrant, visually attractive, sustainable and more resilient to change, by improving urban air quality, regulating building temperatures, reducing noise and delivering recreation and education opportunities.

These new values and principles of stormwater management underpin the By-laws of the City of Johannesburg as published in the Provincial Gazette in 2010. The intention, at the time of publishing these By-laws, was that they would be accompanied by a Manual that would offer guidance to public and private sector participants in the design and management of stormwater facilities who will need to use these new approaches. Therefore, this Manual provides guidance to:

- Catchment planners
- Project team designing stormwater management systems
- Authorities designing surface water management systems
- Authorities reviewing site development plans

THE CITY OF JOHANNESBURG BY-LAWS

Densification, pollution, degradation of natural water resources

One of the key drivers of the new approach to stormwater is the increasing densification of urban areas, with associated increase in the percentage of impervious surfaces. This is coupled with increasing pollution, including heat build-up through the use of dense and dark coloured materials. These factors combine to cause rapid degradation of natural water courses, as well as preventing the natural recharge of sub-surface water bodies.

At the time of writing, the City of Johannesburg was the fastest growing metropolitan municipality in South Africa. The population has grown at an average 3.2% pa since 2001 and in 2011 stood at just over 4.4 million (StatsSA, 2011). The proportion of the population living in informal settlements has decreased over that time from 23% to 19% (HDA, 2013), but both formal land development and informal areas continue to expand. Plans for urban densification and likely growth of informal settlements require proactive management and planning to ensure recovery and protection of the City's water resources.

Current thinking on stormwater

Increasingly, stormwater is viewed as a component of broader water resource management in a holistic system; stormwater is regarded as a valued resource, rather than a waste product to be disposed of as quickly and efficiently as possible. This new thinking places more emphasis on catchment planning, catchment recovery, and flood/hazard risk management.

Stormwater management problems present themselves in the form of severe pollution, erosion and river bank damage, and increasing reports of flooding every summer, with property damage, traffic disruption and loss of life. All the streams in the metropolitan area are in a poor state (State of Rivers Report, 2011); yet there remains a high demand for more development. The management of urban runoff, along with protection of the environment and provision for public amenity needs urgent attention.

Sustainable stormwater management is central to the initiative of Green Infrastructure investment (GCRO, 2016). High quality drainage systems that are integrated into the overall design of a development will automatically provide many other services and become features themselves, attracting tourism and investment, driving local economic growth. Where such systems are designed to make efficient use of the space available, they can often cost less to implement than underground piped systems (Woods-Ballard, et al., 2015).

Underpinning current thinking on stormwater management is the concept of 'zero impact targets' that aim to match the parameters characterising the stormwater regime prior to human impacts. Zero impact targets are often best achieved through the support from facilities planned at a catchment scale. Catchment stormwater planning is critical to achieving an effective balance between water resource management, environmental sustainability and optimal land use. Urban planners and engineers planning at catchment scale must be aware of the contents of this Manual to make provision for the inclusion of surface water management principles and facilities described here to enable the target of zero negative impact to be achieved.

These guidelines are applicable to all projects and changes of land use that will affect runoff or infiltration, irrespective of property size. Different standards and evaluation criteria are applied to projects of different scales. They also apply to site redevelopments, where retrofitting of Green Infrastructure facilities can be introduced.

Climate change

The mean annual amount, frequency, spatial distribution, and seasonality of precipitation has changed gradually over the past century, and is projected to change more rapidly in the coming century, due to the impacts of climate change (Kruger, 2006). Unlike mean temperatures, which are projected to increase globally, the changes in precipitation are more complex, and highly location specific (Sylla et al., 2013). Where one small region may be projected to experience an increase in mean precipitation, an adjacent location may be modelled to experience a decrease. The severity of single events, and the timing of onset and termination of the rainy season is even more difficult to project over long periods (decadal to century scale).

The most recent climate change projections for South Africa indicate a shift to drier conditions for the Gauteng Province, including Johannesburg, for the period 2036-2065 (SAWS, 2017). However, with continual improvements to both global and regional climate models, and developments in the capacity to downscale these models for the varied topography and biogeography of South Africa, these projections are constantly being improved and updated (James et al., 2018).

Of central importance to the management of stormwater in the City of Johannesburg is that the frequency and severity of extreme climatic events is projected to increase under climate change (Abiodun et al., 2017). These impacts of climate change on precipitation patterns are further compounded by cyclical climatic forcing, including ENSO, which has measured impact on South Africa (Meque & Abiodun, 2015).

THE MANUAL

> ***"manual"*** *means the stormwater design manual contemplated in section 3(3)(a), adopted by the Council, as amended or substituted from time to time*

This Design Manual seeks to achieve two main aims:

1. To modernise the management of urban runoff as a resource and to ensure that it is given early consideration in both urban planning and the development of site plans; and
2. To set out methodologies and data relevant to the management of storm runoff under Highveld weather conditions specific to Johannesburg.

The guidelines given in this document are the minimum applicable standard. Property owners, developers and design teams are encouraged to apply more stringent criteria and to strive for zero negative impact.

The role of land-owners and professionals

The 2010 By-laws place specific responsibilities on land-owners, and those professionals appointed to act on their behalf. The By-laws are explicit in requiring any new development or re-development to match the pre-development conditions, taken to mean prior to 1886 with the discovery of gold on the Witwatersrand. This Manual provides guidelines for professionals to be able to meet this requirement, as well as giving guidance in Best Management Practices to achieve stormwater designs that are aligned with the spirit of the By-laws.

The responsibility for compliance with the By-laws lies jointly with the developer, the engineer, the contractor and the owner of the property. Moreover, the owner is required to provide any subsequent owner with an operation and maintenance manual to ensure that the stormwater management system continues to function in accordance with the By-laws and the design intention for the entire life of the project.

Reference manual for green infrastructure and interpretation of By-laws

Many of the principles discussed in this Manual are drawn from current thinking on best international practice. These include SUDS (Sustainable Urban Drainage Systems) adopted in the UK, LID (Low Impact Development) principles adopted in the US, and WSUDS (Water Sensitive Urban Design) adopted in Australia. They all seek to minimise the impact of urban development on local water resources, and have been adopted in other developing countries such as Brazil and China, which have experienced similar rapid growth of their metropolitan areas to South Africa.

SUDS are designed to maximize the opportunities and benefits obtained from surface water management, specifically by improving the way we manage water quantity, water quality, amenity, and biodiversity. In this section, some broad planning principles derived from *The SUDS Manual* (Woods-Ballard, et al., 2015) will be discussed. More specific principles as they apply to water quantity and water quality will be elaborated upon.

The SUDS approach involves slowing down and reducing the quantity of surface water runoff from a developed area to manage downstream flood risk, and to reduce the risk of that runoff causing pollution. This is achieved by harvesting, infiltrating, slowing, storing, conveying, and treating runoff on site and, where possible, on the surface rather than underground.

By adopting this approach, SUDS can enhance the green space within developments and link wider green networks, supporting the provision of habitats and places for wildlife to live and flourish. The benefits to the community of using this approach are also numerous, including improvements in health, wellbeing, and quality of life for individuals and communities. (Woods-Ballard, et al., 2015).

To maximise these benefits, surface water management should be considered from the beginning of the development planning process, influencing site layout and design, and the characteristics of urban spaces. So it is important that, where appropriate, an interdisciplinary team (including planners, landscape architects, architects, and drainage and environmental engineers) should work together from the outset.

There are many different ways that these systems can be applied to deliver effective surface water management and the apparent lack of space should never be a reason for not using SUDS. Designing drainage systems so that the space performs multiple functions is particularly important in dense urban areas where space is at a premium (Woods-Ballard, et al., 2015).

In order to maximise benefits, managing surface water runoff should, as far as possible:

- Use surface water runoff as a resource
- Manage rainwater close to where it falls (at source)
- Manage runoff on the surface (above ground)
- Allow rainwater to soak into the ground (infiltration)
- Slow and store runoff to mimic natural runoff rates and volumes
- Reduce contamination of runoff through pollution prevention and by controlling the runoff at source
- Treat runoff to reduce the risk of urban contaminants causing environmental pollution.

Depending on the characteristics of the site and local requirements, these may be used in combination and to varying degrees (Woods-Ballard, et al., 2015).

Structure of the Manual

The Manual is divided into three sections. The first presents the principles that underpin the City of Johannesburg Stormwater By-laws. For ease of reference, each of the principles is summarised in a text-box. Section 2 is divided into nine Chapters, each of which presents the By-laws verbatim in italics. This is followed, in most chapters, with guidelines associated with that Chapter. The third section of the Manual provides Appendices with detailed information and examples of calculations.

SECTION 1: PRINCIPLES

The cumulative impact of ever-increasing areas of development and hard pavement in metropolitan areas suggests that a "one size fits all" standard for stormwater management does not assure optimum design and management. This is especially the case where site specific decisions are made without an understanding of the constraints and requirements of the wider catchment, and the engineer or planner is limited to a set of potentially unsuitable standards that may be applied to obtain sign-off of a site development plan.

A set of principles has therefore been prepared which is intended to provide a backdrop against which decisions on stormwater planning and design may be applied. Planners and designers need to refer to these principles to ensure that their stormwater plans meet the requirements of good stormwater management. Furthermore, these principles are intended to provide support to consultants, developers and municipal officers considering plans for the development and management of the City, from spatial development frameworks through to site development plans.

How to apply the principles:

i. If in doubt, adopt the precautionary principle.

ii. If there is no catchment surface water management plan to guide site development stormwater requirements, adopt the precautionary approach.

iii. Manage stormwater volume and not just peak discharge.

iv. Stormwater designs must address all the principles in this Manual.

v. Make space for stormwater management.

1.1 PURPOSE OF STORMWATER MANAGEMENT

Surface water should be managed for maximum benefit, now and in the future. By understanding context and the Departments responsible for the planning and design of urban areas working together, surface water management can be integrated into the design of our urban areas, to protect our environment and to create high quality places for future generations (Woods-Ballard, et al., 2015).

1.2 PRESERVATION AND ENHANCEMENT

1.2.1 Protection and enhancement of water quality

It is estimated that runoff from Johannesburg's paved surfaces, less what would have run off in its pre-development greenfield state, is close to 45% of the annual purchase of potable water (as at 2011, including non-revenue water), and as much as 70% of the billed water. Water for the City of Johannesburg is imported from as far afield as KwaZulu-Natal and Lesotho through inter-basin transfer schemes and international agreements. In addition, along with Ekurhuleni, the City of Johannesburg pollutes the local streams to such an extent that Rand Water and the Department of Water & Sanitation are required to use some of this imported water to flush the Vaal River to protect downstream users. Similar impacts are experienced in the Crocodile River and Hartebeespoort Dam. In drought years these impacts are severe and at a regional scale. This is clearly an unsustainable situation and the City of Johannesburg will, at some point, need to play a significant role in the management and preservation of water resources.

Principle: Stormwater is a water resource. The effects of urbanisation resulting in flash flooding, sediment, and pollution loads, surcharging sewer systems, watercourse erosion, etc., substantially increase the cost of capture, storage, and treatment of the water. Urban planning and all development should support the protection and preservation of this resource. Furthermore, new development should not compromise the potential for rehabilitation and enhancement of pre-existing urban areas.

The protection and enhancement of water quality is one of the core principles of sustainable urban drainage. Runoff from urban surfaces in Johannesburg is polluted with sediments, hydrocarbons, phosphates, potentially pathogenic organisms, and a range of organic and inorganic compounds. Litter is a constant presence and threatens the design capacity of stormwater systems. Furthermore, rainfall-runoff in Johannesburg can be acidic, with pH levels as low as 4 (Mphepya, et al., 2004), particularly for first flush events after a dry period.

Principle: A Stormwater Management Plan, whether at catchment scale or for a specific site, must describe the pollution risks and how these may affect the quality of the runoff and stream flow. They must also describe the potential impacts on the receiving systems and identify Best Practice measures to mitigate the risks as far as reasonably possible. Where the potential for mitigation is limited or reasonably beyond the means of the site to achieve, this should be clearly stated and motivated.

1.2.2 Protection of ecological resources

Protection and enhancement of ecological systems is a central theme of source control, green infrastructure, and sustainable drainage. Ecological systems form part of the Urban Natural Capital that plays an integral role in contributing to the environmental and economic health of cities. In addition they provide cost effective benefits to stormwater quality and flood management.

Policy-makers now recognise the important contribution that designing for biodiversity can make to ecosystem services and improved community 'living' space. The benefits of creating new habitats and rehabilitating or enhancing existing habitats through sustainable drainage system design go far beyond the contribution that planting makes to the functionality and performance of the drainage system. Landscape features that support diverse habitats and associated ecosystems provide a healthy and stimulating environment that can add significant value to urban living. Biodiversity value can be delivered by even very small, isolated schemes, but the greatest value is achieved where the drainage systems are planned as part of wider green landscapes, as they can then help to provide important habitat and wildlife connectivity.

A fundamental aspect of ecological health is heterogeneity. Structural heterogeneity is a crucial component of this. In terms of wetlands, this includes micro-topography, wetland shape, vegetation community, macro and micro-invertebrate communities. For lotic systems such as streams, structure is important for both riparian and instream aspects of the stream. Using the South African Scoring System Version 5 (SASS5) as a guideline (Dickens & Graham, 2002), instream habitat is partitioned into overhanging vegetation (including submerged plants), sand, stones and bedrock. All are important although stones in-current usually provide the most species rich biotope on the Highveld. A mix of these habitat types is healthy, and imparts a degree of ecological resilience to the stream. Riparian habitat also benefits from structural heterogeneity, and a good mix of species both creates this and enhances faunal species richness simultaneously. These factors play a role in the design of channel morphology and materials used in channel construction.

Not all parts of urban drainage networks can be maintained or converted to green infrastructure, and hard surface grey infrastructure will continue to perform important stormwater drainage functions in Johannesburg. There should, however, be consistent effort to maximise the ecological potential of drainage management systems in new development (and land re-development), coupled with a programme of retrofitting green infrastructure in existing networks. Watercourses, natural drainage lines, wetlands, attenuation and retention dams, and sediment traps are ideally suited for ecological engineering design.

The following criteria should be used to guide design proposals around biodiversity and ecosystem services:

- support and protect natural local habitat and species
- contribute to the delivery of local biodiversity objectives
- contribute to habitat connectivity
- create diverse, self-sustaining, and resilient ecosystems

Detailed design criterial can be derived from this Manual or from the literature, for example *The SuDs Manual* (Woods-Ballard, et al., 2015).

Principle:

Green infrastructure, with defined targets for habitat creation, should be addressed as part of the drainage alternatives considered for all new development sites, and presented as part of the SDP submission.

As part of catchment master planning, existing networks should be assessed for sections of the network that may be converted to green infrastructure. A programme of retrofitting green infrastructure should be drawn up and implemented. Such programmes in established metropolitan areas such as the City of Johannesburg could extend to 50 years or more.

1.2.3 Protection of open space networks

Good urban design aims to deliver attractive, pleasant, useful and above all 'liveable' urban environments that support and enhance local communities. Water is a valuable natural resource, and the management of rainfall and runoff can form a key part of an urban vision. Designs using surface water management systems to help structure the urban landscape can enrich its aesthetic and recreational value, promoting health and well-being. Water managed on the surface, rather than underground, can help reduce summer temperatures, provide habitat for flora and fauna, act as a resource for local environmental education programmes and working groups and directly influence the sense of community and prosperity of an area. SUDS can provide opportunities for water to be visible and audible as it travels through the landscape – places where water flows, stills, trickles or splashes are often where it is experienced and valued most. Amenity and biodiversity are often considered together, but they are each important in their own right, and the overlaps and linkages should be recognised by designers (Woods-Ballard, et al., 2015).

The benefits of integrated networks of public open space to community health and wellbeing are well documented (cf. Fletcher, et al., 2015; Lawson, et al., 2015; Mguni, et al., 2016). Watercourses, drainage lines and urban streams provide important corridors of open space suitable for public access, and therefore an important contribution to Urban Natural Capital. A good example in Johannesburg is the river corridor of the Braamfontein Spruit and its tributary streams that link numerous public parks providing an almost continuous 25km open space corridor, which is used for recreational purposes from Braamfontein to Sunninghill. Even though it is not in pristine condition and issues of security along the route are a concern, it is used daily by communities along its length.

Not all parts of an open space network will be public, and private open space areas still contribute to the wider health and wellbeing of the municipal area, particularly where watercourses and drainage lines offer corridors of open space continuity across public and private areas. Where private open space breaks the continuity of the public open space corridor, alternative public pathways should be provided.

1.3 CATCHMENT MASTER PLANNING

Stormwater management is optimised through the identification of objectives and performance targets on a catchment basis. These are presented as Catchment Master Plans that should reflect both baseline conditions and long-term land development plans, and will then set out stormwater targets to achieve this. These may include “catchment recovery” or “runoff harvesting” targets as outlined in the sections below. The Catchment Master Plans should include stormwater control targets for new development, retrofitting source control and SUDS facilities in established catchments, and the development of Green Infrastructure. Site design requirements, including attenuation or retention and water quality requirements, are best set in the context of Catchment Master Plan requirements.

Principle:

Catchment Master Plans shall be established, reviewed, and updated for all major drainage networks in the City of Johannesburg. They will acknowledge downstream risks and requirements, and set stormwater targets for the catchment as a whole. Stormwater management criteria for site development will be defined in the Catchment Master Plan and these criteria may vary across the catchment.

Site development plans should refer to the relevant Catchment Master Plan, and demonstrate how the site drainage will support the aims of the master plan. In the absence of a Catchment Master Plan, on-site drainage management should default to frequency of runoff and volume control with parameters equivalent to greenfield site conditions for a range of storm return periods and durations.

1.4 CATCHMENT RECOVERY

An integral part of Catchment Master Planning is the theme of catchment recovery (or catchment repair). This considers the long-term recovery of the hydrological response of the urban catchment to pre-development conditions. It is the foundation for the application of WSUDS in Australia (Argue, 2004), or the "sponge city" concept being implemented on a grandiose scale in China, that guides both the development of greenfield sites and the re-development of sites within established urban areas. This concept encourages the Catchment Master Plan to consider the potential for retrofitting WSUDS in established areas and even setting standards for greenfield development that compensates for older development upstream.

> Principle:
>
> All stormwater design shall consider the return of the urban catchment to greenfield conditions.
>
> All Catchment Master Plans should plan toward catchment recovery.

1.5 RUNOFF HARVESTING

Runoff harvesting is a viable means of stormwater management, and offers the added value of providing a water source. At a site scale, the efficacy of the harvesting systems can be affected by storage capacity and use. Harvesting runoff at a catchment scale, utilising facilities in the public space (e.g. floodplains) with potentially larger storage volumes has the potential to optimise the water balance and therefore the efficacy of the system.

> Principle:
>
> Runoff harvesting is a form of SUDS that is encouraged in the City of Johannesburg. At catchment scale, this should be represented in the Catchment Master Plan. On-site drainage design in the upstream areas should demonstrate support for this, but must not compromise the flood risk of properties or potential damage to natural water courses downstream.

Runoff harvesting at catchment scale (and therefore represented in the Catchment Master Plan) could require the promotion of storm runoff to maximise the yield from upstream catchments. On a site scale this would encourage impermeability and attenuation rather than permeability and retention in support of the principle of on-site volume control. At catchment scale, the principle of volume control is preserved by the runoff harvesting facility. This approach would require extreme care to ensure protection of the drainage system upstream of the regional harvesting facilities.

> Principle:
>
> Rainwater should be treated as a resource and its harvesting should be the default design intention.

1.6 FLOOD AND HAZARD RISK

1.6.1 Flood management

Flood Volume

Flood hazard and the changing risk with incremental upstream development and climate change is one of the founding themes of stormwater management. The principle of flood peak flow attenuation via detention systems is embedded in current practice in Johannesburg. Some authorities believe that the combined performance of these systems on a catchment scale or metro scale is uncertain and could even be detrimental to the flood risk of properties further downstream, but this concern has not been demonstrated in practice (Boyd 1993). Internationally, volume control has superseded attenuation as Best Practice, requiring the implementation of retention and infiltration systems.

Infiltration systems appropriate for Johannesburg will need further research. Given the steep terrain and the quartz and granite geology over much of the metropolitan area, deep groundwater recharge will be limited. Infiltration may therefore be restricted to the relatively flatter slopes along natural drainage lines where soil depths are greater.

Runoff harvesting may instead offer greater potential for volume control, particularly if used in conjunction with retention systems.

Principle:

Precautionary Principle: On-site retention (instead of attenuation) is the default condition in the absence of a catchment management plan.

Whether at catchment scale or site scale, development should seek to limit storm runoff to no greater than a greenfield state condition under all storm conditions up to the 1:100 year event. Measures to manage volume fall into two categories; retention for reuse, and infiltration and evapotranspiration. All developments must address either one or a combination of these measures.

However, attenuation measures may be considered where there is a Catchment Master Plan providing for retention and reuse in other parts of the catchment.

Flood Conveyance and Disaster Management

Planning, providing for, and maintaining flood conveyance paths and corridors is an important part of stormwater management at both catchment scale and site scale. It is an integral part of flood hazard management and a key service provided by the stormwater network.

Flood conveyance is designed as part of the stormwater drainage network for effective disaster management. This essentially provides flood capacity exceeding the design capacity of the primary asset (for example, the culvert or storm drain along a road). Hence flood conveyance may include streets and roads that will convey the 100 year flood when the 5 year design capacity of the culvert is exceeded. These systems need to be specifically planned and designed for, with capacity and performance clearly stated. Flood conveyance systems need to be included in the municipal infrastructure asset register and communicated to the City's emergency services.

Whilst the 100 year flood is enshrined in law in Section 144 of the Water Act (Act 36 of 1998) it cannot be regarded as the limit of risk. There is a significant probability that the 100 year event will be exceeded during the lifetime of a development, and the system should be designed to minimise the consequences of flood events with recurrence intervals exceeding 100 years.

> Principle:
>
> The design capacity of the different components of the stormwater network will be defined according to Catchment Master Plan requirements and within the guidelines set out in this Design Manual. However, all sites will analyse the 100 year flood event, clearly setting out the intended conveyance of the storm runoff through the site by means of flood lines, and indicating the safe height of threshold levels for buildings above the flood line.
>
> The consequences of flood events with recurrence intervals exceeding 100 years should be assessed and minimised

Floodplain Management

Floodplains are a specific component of the flood conveyance network of a city. They typically form part of major drainage networks and include a natural channel and riparian open space that is inundated in extreme events. Section 144 of the National Water Act (Act 36 of 1998) requires the 100 year flood line to be represented on planning and site design drawings, implying that this is the defined extreme event to be used. The CSIR (2000) “Red Book” instead suggests the Regional Maximum Flood (RMF) should determine the extent of the floodplain.

In many developing cities, the stream morphology will have been altered by the storm runoff responses from the upstream catchment under development. In Johannesburg the river corridors are mostly degraded environments where flash flooding is readily recognised in the steeper north-flowing streams by the steep, unstable, eroded river banks and the river bed eroded to bedrock. Similar features appear in the upper sections of the south-flowing streams but then present as wide, heavily sedimented, and often unstable, wetland areas as the gradients flatten out. Many sections of these floodplains are security risk areas and have become dumping grounds for building rubble and general waste.

Yet even in severely degraded conditions, these floodplains still provide flood management, open space, recreation, and habitat services, albeit to an extent well below their potential. They perform an important hazard management function as they convey the largest portion of the storm runoff and still offer some attenuation of flash floods. They can, however, also be a source of hazard risk when they overflow bridges or inundate property as their capacity is exceeded by uncontrolled runoff from catchment development or debris build-up, or both.

The benefits of streams and rivers, and their floodplains, to urban communities and their environments are well documented. A central principle of this Design Manual is therefore to preserve and rehabilitate the municipality’s watercourses and floodplains, and to convert them from hazard zones and dumping grounds to assets that contribute to community wellbeing and improve land values along their corridors. This involves bringing the floodplains into the community environment and developing them as functioning parts of the stormwater system whilst supporting other services such as open space and recreational areas and opportunities for ecological enhancement.

The primary function of floodplains and their watercourses should remain the safe conveyance of flood flows, yet they have the capacity for multiple functions well beyond this, particularly in the urban environment. To achieve this, they need to be developed and utilised. Therefore, the intention is <u>not</u> to prohibit development adjacent to, or into, the floodplain. Instead development is encouraged to incorporate the floodplain, and its watercourse, as part of urban rehabilitation and development. This approach is best supported by catchment plans that set out the flood management performance of the watercourses to ensure that flood hazard is controlled.

> Principle:
>
> The primary function of floodplains is to convey extreme flood events safely. The municipality shall determine the magnitude and recurrence interval of the design event, which may vary according to location, catchment size, land use and sensitivity to flood hazard.
>
> In addition, in accordance with a Catchment Master Plan, floodplains may also provide features that perform other functions such as flood peak attenuation, retention and runoff harvesting, water quality treatment, parkland and recreation, and ecological services.
>
> It is also possible to include development feature as extensions to the floodplain to perform flood management functions; for example, using streets as part of the flood conveyance, utilising car parks and sports fields for flood storage and attenuation. The inclusion and design of such features will need to show that flood risk to adjacent areas upstream and downstream is not increased, that the targets set by Catchment Master Plans are not compromised, and that the facilities are manageable and sustainable.
>
> Floodplains should be developed as assets providing multiple services to the municipality and its communities. They should be integrated with the rest of the municipal network of Green Infrastructure and captured on the municipal asset register with a full description of their respective functions, services to the community, ecological status, flood capacity status and flood lines. Individual assets within the floodplain, such as attenuation dams, wetlands, bridges, etc. should also be captured in the asset register, with similar detail. The asset register should present the long-term objectives of each floodplain, reflecting the potential for both flood conveyance and provision of multiple other services to the communities along their length.
>
> Development in the floodplain should always seek to enhance the value of the asset by improving the functionality of one or more of the services, or adding to the services. Compromise of any of the services should be avoided unless there is offset provided to the net benefit of the community.

Adaptation to climate and weather change

As the urban footprint of the City of Johannesburg expands and changes over time, there are potential changes in weather and climate that need to be considered in stormwater management.

Climate change predictions for the Highveld currently show a trend of decreasing number of rainfall events in combination with larger storm events. Fatti & Vogel (2011) analysed storm data at OR Tambo with results suggesting this trend is already in effect. Climate model simulations at municipal scale are still poor, but recent research for the Ekurhuleni area offers an indication of the potential change in intensities in the near future.

Weather patterns over the developed metropolitan area may also change the nature of storm events. Research in Beijing, China linked heightened storm intensities to the heat island effect of the expansive city. Indeed it is not clear whether the trend identified by Fatti & Vogel (2011) may be linked to the rate of expansion of the metropolitan areas of Johannesburg and Ekurhuleni.

Further research on these topics relevant to Johannesburg and the Highveld area is required, but there are at least some data at the municipal scale that can be applied to storm design analysis to test for sensitivity of systems to changing storm conditions.

Principle:

The Stormwater Management Report should indicate how changing climatic conditions have been taken into account in the stormwater management plan. For example, this could include:

- Application of a climate change design curve for Highveld conditions
- Application of a percentage increase to design rainfall depth (e.g. 20% as done in UK),
- A combination of these two.

Densification and brownfields development

Retrofitting stormwater systems with sustainable drainage facilities provides an important opportunity for catchment recovery when previously developed sites are re-developed. All re-development sites will be assessed in relation to pre-development runoff conditions. Planning for open space in urban densification plans remains as important as it does in all other urban development plans. SUDS, WSUDS, LID and Green Infrastructure are a requirement in densification programmes.

Principle:

The principles of catchment recovery shall apply.

Site re-development shall be considered against Greenfield site runoff conditions. Make space for surface water management facilities.

The drainage solutions need to be integrated as part of the overall Catchment Master Plan where available.

Informal settlements and informal densification

Informal settlements and densification in low-income areas through the building of 'backyard shacks' pose particular concerns for stormwater management. While design and management of these settlements often resides with urban planners and city administration, international experience shows that stormwater managers, often in a close association with wastewater managers, should be active participants in any decision-making associated with these areas.

Informal settlements can be broadly defined as opportunistic developments which take advantage of vacant land. The land is either unused because it is unsuitable for development due to geological reasons or it has been earmarked for future development (Huchzermeyer, 2009). Due to the location of these settlements, they are often subject to increased risk factors from the environmental conditions and flooding (Parkinson et al. 2007). The impacts from insufficient stormwater infrastructure not only impacts the lives of these residents but also the quality of effluent reaching receiving waters due to sewerage leaks and increased sediments from unpaved areas (Jagals 1997 and Parkinson et al. 2007). When it comes to the upgrading of informal settlements, stormwater infrastructure is usually one of the last agenda items (Huchzermeyer 2009). Due to the nature of informal settlement upgrade and low-cost housing scheme implementation approaches, stormwater infrastructure often falls with city administration and planners instead of stormwater managers. International experience however shows that stormwater managers, often in a close association with wastewater managers, should be active participants in any "urbanisation" plan of formal areas.

While informal areas are typically diverse, research shows they tend to share common characteristics; illegality in land tenure, precariousness of dwelling conditions, lack of urban infrastructure and segregation from the formal town centres or city hubs (Fitchett, 2017). Addressing these issues requires an effective combination of social understanding and community support, institutional structures and capacity, and technical support (engineering, planning, architectural). The principles and design guidelines in this Manual will support the stormwater managers in their role in participating in an urbanisation plan for informal settlement areas, but in advance of such plans, there are several conditions that the stormwater manager can assume in dealing with stormwater from these areas.

a. Informal settlements and low-cost-housing areas need to be included in Catchment Management Plans. The baseline hydrological and hydraulic parameters need to be carefully considered, with site inspection, consultation and monitoring central to establishing these parameters.

b. The formalisation of informal settlements should always be assumed as part of the future scenario land use in the Catchment Master Plan. This is because relocation of inhabitants is usually undesirable.

c. The stormwater management of informal settlement areas should be catchment based rather than according to municipal boundaries (e.g. wards).

d. Due to typically high population densities in urban slums, it is reasonable to assume an urbanisation plan to be equivalent to any other urban densification plan

e. Examples of successful urbanisation plans show that public open space is central to a viable and healthy urban landscape. Therefore, SUDS, WSUDS, LID and Green Infrastructure are as applicable to the upgrading of informal settlements as any other part of the municipal environment.

f. Provision of effective stormwater and sewer infrastructure is shown to be central to the success of any urbanisation plan. However, the separation of these systems in informal settlements is not always assured. With the very strong trend of developing backyard shacks in established low-cost-housing schemes in Gauteng, it is common, for example, for stormwater downpipes to be connected directly to the sewer lines by the new owners. This leads to surcharging sewers that then pollute the surface water drainage network. In places such as Brazil, where similar storm conditions encourage separate stormwater and sewer networks, combined sewer systems in slum urbanisation programmes are actively considered. This approach needs careful consideration in Johannesburg, but may require a review of treatment facilities for these specific applications.

While the above provides for long-term catchment planning scenarios, the stormwater manager should still be active and proactive for current situations where informal settlements and low-cost-housing areas are established and potentially expanding. Initiatives should include the encouragement of compliance with By-laws (a requirement in the case of low-cost-housing), regular monitoring programmes (water quality in receiving streams, spread and configuration of settlement), and hazard management, such as flooding.

Parkinson et al. (2007) identify potential problems of drainage upgrading in informal settlements from case studies of interventions in developing counties. He also provides some solutions to some of the expected challenges. The box below sets out the lessons from Parkinson et al. (2007) from his case studies for consideration.

Informal settlement potential challenges & tips

- Hap-hazard layout of streets are not conducive to conventional stormwater infrastructure.
- Informal settlements usually have fewer paved areas, which makes the rational method of stormwater quantity estimations more difficult.
- The capacity of stormwater systems needs to allow for more frequent flooding because of the location of some informal settlements under flood lines.
- The settlement's lack of capacity results in solid waste and sedimentation in drainage systems.
- Open drainage systems allow for easier maintenance and removal of blockages.
- Open drains are often closed off by residents to increase land area and to address safety issues for children. as a result, these drains become breeding grounds for mosquitoes.
- Closed drains are difficult to install because levels are influenced by the lack of hard surfaces.
- Heavily-engineered systems in this context fail more often.
- Community involvement in the planning process increase the acceptance of interventions.
- It is advised that community small enterprises are employed for the construction and maintenance of systems.
- Site visits are crucial to determine whether an implementation plan is feasible at street scale.

The potential challenges provided are motivation to consider GI solutions when compiling catchment management plans. Table 1.1 rates the different GI systems according to cost and ease of construction and maintenance operations. This can aid in making decisions on the most appropriate system. The important aspects to consider is available space due to the high densities in these settlements and the ease on construction when local businesses will be contracted.

Principle:

Catchment Master Plans should represent informal settlements and low-cost-housing areas in detail, allowing an assessment of stormwater internal conditions and influences on downstream areas. The Master Plans should be used to mitigate stormwater problems, highlight the plight of residents in these communities, and help to point the way for the ultimate formalisation and upgrade of these areas. Monitoring programmes will help to refine the Catchment Master Plans over time, and should prove valuable in disaster management.

Table 1.1: SuDS for informal settlements (H = Highly appropriate, M = Medium, L = Low)

WSUD treatment measure	Indicative capital cost	Relative maintenance cost	Effectiveness in improving water quality	Area required for installation	Skill level required for installation
Roof gardens	H	M	H	M	H
Bioswales	L	L	H	L	M
Extended detention basins	M	L	H	H	L
Sand filters	M	M	M	L	L
Infiltration trenches	M	M	M	L	L
Infiltration basins	M	M	M	H	L
Porous pavements	H	M	M	H	H
Constructed wetlands	H	L	H	H	H

Source: Adapted from NSWEPA, cited in Burke and Mayer (2009).

1.7 STORMWATER NETWORK AND ASSET REGISTER

A stormwater system will comprise a network of facilities designed to perform a function in the management of stormwater. This will include all grey and green infrastructure, floodplains, and flood conveyances (including street conveyance), attenuation facilities (whether concrete ponds or wetlands), treatment facilities (trash racks or vegetated sediment traps), and runoff harvesting systems.

For the effective planning and maintenance of the stormwater network, all components of the functional system must be captured on the municipal asset register. Whereas this was historically undertaken for grey infrastructure components only, it should now include all green infrastructure, infiltration, runoff harvesting and vegetated systems where these have been presented as active components of a site or a catchment stormwater management system.

The intended function (service) of each component must be clearly described and include capacity and performance criteria. Some assets may provide multiple services, which should be stated. In the case of green infrastructure components, these services may include open space, recreation and/or habitat services.

Assets under private ownership should also be recorded where they have formed part of the approved Site Development Plan, as they contribute to the overall performance of the municipal system and become part of the baseline on which future catchment plans are developed.

Principle:

All components of the functional stormwater network will be captured on the municipal asset register with records such as description, function, location, size, capacity, permits, monitoring and maintenance requirements, ownership, and responsibilities.

Facilities on private property shall be included, particularly where these facilities are compliant with catchment stormwater strategies, or where they are important for overall catchment water resource or stormwater performance

SECTION 2: INTERPRETATION AND APPLICATION OF BY-LAWS

2.1: CHAPTER 1: INTERPRETATION, PURPOSE AND APPLICATION AND RESPONSIBILITY FOR COMPLYING WITH BY-LAWS

2.1.1 Chapter 1 By-laws

Definitions

1. In these By-laws, unless the context otherwise indicates –

"adjacent property" *means a property which has one or more common boundaries with another property regardless of whether such properties have separate owners, were acquired in ownership at different times, are situated in different catchment areas or municipal areas or are separated from each other by a private road or private right-of-way;*

"Agency" *means the Johannesburg Roads Agency (Pty) Ltd., established by the Council as a service provider fulfilling a responsibility under these By-laws which responsibility has been assigned to it in terms of section 81(2) of the Local Government : Municipal Systems Act, 2000 (Act No 32 of 2000),and in relation to a situation where there is no Agency or other service provider contemplated in that section, means the Council;*

"attenuation facility" *means any drainage facility designed to store stormwater for gradual release of that stormwater by infiltration into the soil or into an existing drainage system;*

"authorised official" *means any official of the Council or the Agency who has been authorised by the Council or the Agency, as the case may be, to administer, implement and enforce the provisions of these By-laws, acting within the scope of such authorisation;*

"best management practice" *means any physical, structural or managerial practice that, when used singly or in combination with any other such practice, prevents or reduces pollution of stormwater, erosion or sedimentation which may be caused by stormwater, and which has been approved by the Council;*

"bio-filtration facility" *means a stormwater filtration system based on an appropriate best management practice which treats stormwater by filtration through vegetation, and includes any grassed or vegetated marshy area and any land through which stormwater is filtered by means of vegetation;*

"buffer" *means an area or strip of land on a development site or property which is to be or is utilised for the management of stormwater or conservation of the riparian habitat as defined in section 1 of the National Water Act, 1998 (Act No 36 of 1998);*

"catchment area" *means an area of land in its natural state, from which stormwater runoff originates;*

"catchment area plan" *means a plan and all implementing rules and procedures relating to such plan, including land use management for managing surface water and stormwater quality, any facility for managing the quantity of such water and any drainage feature within a catchment area;*

"certificate of occupancy" *means a certificate issued in terms of section 14 of the National Building and Building Standards Act, 1977 (Act No 103 of 1977);*

"clearing" *means the removal of vegetation from the surface of any property or a portion of a property;*

*"**closed depression**" means any low-lying area of land, either natural or man-made, which receives stormwater;*

*"**completion certificate**" means the written acknowledgement by the Agency of the satisfactory completion of all work on a construction site approved by the Council, including any work shown on the approved building plans or approved plans of a township concerning the provision of municipal infrastructure, and any revision of such plans and field change approved by the Council;*

*"**comprehensive drainage plan**" means a plan for a catchment area adopted by the Agency containing a detailed analysis which deals with-*

(a) the capacity of any stormwater drainage system and the need to embellish that capacity due to various combinations of development, land use and available structural and non-structural stormwater management possibilities;

(b) the form, location and extent of stormwater quantity and

quality control measures which would satisfy the requirements of the National Water Act, 1998, and any other applicable law;

(c) stormwater quality standards; and (d) the funding requirements for the implementation of such plan.

"construction" means –

(a) in relation to a township, the construction or provision by the developer of a township of any municipal infrastructure or service; and

(b) in relation to a property, other than a township, the erection of any immovable structure on a property, excluding the erection of a boundary wall, and "construct" has a corresponding meaning;

"Council" means –

(a) the Metropolitan Municipal of the City of Johannesburg established by Provincial Notice No 6766 of 2000 dated 1 October 2000, as amended, exercising its legislative and executive authority through its municipal Council; or (b) its successor in title; or

(c) a structure or person exercising a delegated power or carrying out an instruction, where any power in these By-laws has been delegated or sub-delegated, or an instruction given, as contemplated in section 59 of the Local Government : Municipal

Systems Act, 2000 (Act No 32 of 2000), as the case may be;

"critical drainage area" *means an area contemplated in Chapter 7;*

"design storm event" *means a theoretical storm event which generates stormwater, of a given frequency interval and duration, used in the analysis and design of a stormwater facility;*

"detention facility" *means a stormwater facility designed to store stormwater, gradually releasing it at a pre-determined controlled rate, and includes any appurtenance associated with its designed function, maintenance or security;*

"developed property" *means the condition of a property following completion of a development, or if a property is developed in phases, any phase of development on that property;*

"developer" *means any person undertaking or proposing to undertake a development and includes a developer of a township;*

"development" *means any construction or proposed construction as contemplated in paragraph (a) and (b) of the definition of "construction" and "develop" has a corresponding meaning;*

"development site" *means the whole or a portion of any property or township which it is proposed to develop or is in the process of being developed;*

"diversion" *means the routing of stormwater in a direction other than its natural discharge direction and "divert" has a corresponding meaning;*

"floodplain" *means an area of land adjacent to a watercourse, or water body, with a catchment area exceeding 30 ha that will be inundated by floodwater on average once in a 100 years as determined by a professional engineer, on the basis that the minimum width of a floodplain is 32m on each side of the centre line of the water course or water body;*

"geotechnical engineer" *means a practising professional engineer who has at least four years of professional experience in geotechnical and landslide evaluation;*

"geotechnical report" *means a written report prepared by a geotechnical engineer based on a study of the effects of stormwater drainage and drainage facilities on soil characteristics, geology and groundwater;*

"grading" *means any excavation, filling or embankment building with earth materials on any property;*

"grubbing" *means the removal from any property, or portion of a property, of subsurface vegetative matter including sods, stumps, roots, buried logs, or other debris, and the incidental removal of topsoil to a depth not exceeding 300 mm;*

"hydrograph" *means a graph indicating stormwater runoff rate, inflow rate and discharge rate of stormwater, past a specific point over a time period;*

"hydrograph method" *means a method of estimating a hydrograph, using a mathematical simulation;*

"impervious surface" *means –*

(a) a hard surface area on a property which prevents or retards the entry of stormwater into the soil; and

(b) a hard surface area on a property which causes stormwater to run off its surface in a greater quantity or at an increased rate of flow, compared to the pre-development condition of that property, and includes any roof, walkway, patio, driveway, parking lot, storage area, concrete or asphalt paving, gravel road with compacted subgrade, compacted earth material, naturally compacted earth surface such as a path or swept garden, an oiled or macadamised surface and any other surface which may similarly impede the natural infiltration of stormwater, and any open uncovered attenuation or detention facility;

***"land disturbing activity"** means any activity on a property that results in a change in the existing soil cover, vegetative or nonvegetative, or both, or the existing soil topography and includes demolition, construction, paving, clearing, grading and grubbing;*

***"maintenance"** means any activity which is necessary to keep a stormwater facility in good working order so as to function as designed and includes –*

(a) complete reconstruction of a stormwater facility if reconstruction is needed in order to return the facility to good working order; and

(b) the correction of any problem on the property concerned which may directly impair the functioning of a stormwater facility;

***"maintenance manual"** means a manual adopted by the Agency in terms of section 51;*

***"major development"** means any development which results in –*

(a) the creation or cumulative addition of 500 m^2 or greater of impervious surface; or

(b) land disturbing activity of 4000 m^2 and greater; or

(c) grading involving the movement of 5,000 m^3 or more of earth material;

***"manual"** means the stormwater design manual contemplated in section 3(3)(a), adopted by the Council, as amended or substituted from time to time;*

***"minor development"** means any development which results in –*

(a) the creation or addition of less than 500 m^2 of new impervious surface area; or

(b) land disturbing activity of less than 4 000 m^2; or

(c) grading involving the movement of less than 5 000 m^3 of earth material;

***"oil/water separator"** means a structure or device used to remove suspended, floating or dispersed oil and greasy solids from stormwater;*

***"operation and maintenance manual"** means a written manual contemplated in section 49(f), containing a description of operation and maintenance procedures for a specific stormwater facility, for use by operation and maintenance personnel of the Agency;*

***"owner"** means in relation to –*

(a) immovable property, subject to paragraph (b), the person registered as the owner or holder thereof and includes the trustee in an insolvent estate, or judicial manager of a company or a close corporation which is an owner, and the executor of any owner who has died or the representative recognised by law of any owner who is a minor or of unsound mind or is otherwise under disability, provided such trustee, liquidator, executor or legal representative is acting within the authority conferred on him or her by law;

(b) immovable property -

(i) which is in the name of both spouses in a marriage in community of property, either one or both of the spouses;

(ii) which is registered in the name of only one spouse and which forms part of the joint estate of both spouses in a marriage in community of property, either one or both of the spouses;

(iii) which is registered under section 17 of the Deeds Registries Act, 1937 (Act No 47 of 1937), in the name of both spouses in a marriage in community of property to which the provisions of Chapter III of the Matrimonial Property Act, 1984 (Act No 88 of 1984), are not applicable, the husband;

(iv) which is registered in the name of only one spouse and which form part of the joint estate of both spouses in a marriage in community of property to which the provisions of Chapter III of the Matrimonial Property Act, 1984, are not applicable, the husband; and

(c) a township, the township owner, and includes an owner of land or a unit under a sectional title deed or a deed of transfer as contemplated in the Sectional Titles Act, 1986 (Act No 95 of 1986);

***"permit"** means a site development activity permit contemplated in sections 7 and 8(4);*

***"pollution"** means contamination, or other alteration of the physical, chemical, or biological properties, of surface water or stormwater and includes any change in temperature, taste, colour, turbidity or odour of the water and the discharge of any liquid, gaseous, solid, radioactive or other substance into any watercourse or stormwater system, and "pollute" and "pollutant" have corresponding meanings;*

***"post-development condition"** means the condition of any property after the conclusion of development thereon and "post development" has a corresponding meaning;*

***"pre-development condition"** means the condition of any property or portion of a property as it existed in its unaltered natural state prior to any development on that property and "pre-development" has a corresponding meaning;*

***"professional engineer"** means any person who is registered with the Engineering Council of South Africa as a professional engineer or a professional engineering technologist, who is qualified in the engineering field concerned and who is considered competent by the Agency and who has been approved by it;*

The **professional engineer** responsible for the preparation and submission of stormwater management plans to the Agency shall be required to prove competence in the field concerned. The definition of "professional engineer" in the By-laws requires that the person shall be considered competent by the Agency and shall have been approved by it. Moreover, the professional engineer is required to have the appropriate PI insurance cover. The application for approval submitted by the Engineer to the Agency shall include his or her CV highlighting previous work in stormwater management projects, a short (maximum 500 word) outline of the work done and the education received in the field, and a recommendation by at least one peer not employed by the same organisation. The peer submitting the recommendation shall have proven competence in the field of stormwater management. Note that this is consistent with the approach of "specialist lists" currently under consideration by the SA Institution of Civil Engineering (Watermeyer & Smith 2016).

Stormwater planning and design is now a specialist line of engineering. It is, however, crucial to the successful implementation of an effective stormwater management system, that the professional engineer assemble consultants with the required multi-disciplinary expertise from the outset of the project and that they be briefed to operate as a team. In order to meet the objectives in designing an effective stormwater management system, the developer is urged to adopt a multi-disciplinary approach to the project from inception through to completion and acceptance by the City of Johannesburg. This will enable the developer to maximise opportunities. The core members of the group would provide expertise in civil engineering, town planning and environmental consulting. Closely allied disciplines of freshwater ecology and landscape architecture should be added, if required, on the advice of the other professionals (SAWE, 2002).

"property" *means any land registered as a separate entity of land in the Deeds Office and includes any township and any land or unit contemplated in the Sectional Titles Act, 1986;*

"public road" *means a road, street or thoroughfare or any other right of way to which the public or a section of the public has a right of access or which is commonly used by the public or a section of the public and includes any portion of a public road between the road edge and the boundary of the land reserved for such road including a sidewalk;*

"retention facility" *means a stormwater facility designed to store stormwater runoff for an indefinite period with the volume of stored water being reduced by evaporation, infiltration or pumped out for the irrigation of land, and which may be combined with a detention facility;*

"site development activity" *means any land disturbing activity associated with the preparation of a property or portion of a property, for development;*

"site development activity plan" *means a plan contemplated in section 10, depicting all site development activities which it is proposed to implement on a development site;*

"stabilise" *means the application of a best management practice, sufficient to protect soil from the erosive force of raindrop impact and flowing stormwater and includes the establishment of vegetation, mulching, plastic covering, the application of a compacted gravel base and the protection of any channel or ditch conveying stormwater or outlet for stormwater so as to prevent any sedimentation resulting from stormwater from leaving a development site and "stabilisation" has a corresponding meaning;*

"stormwater" *means the surface stormwater runoff that results from any natural form of precipitation of water or moisture in any form;*

"stormwater drainage facility" *means any facility installed or constructed for the purpose of the conveyance or retention of stormwater;*

"stormwater drainage feature" *means any natural or man-made structure, facility, conveyance or topographic feature which has the potential to concentrate, convey, detain, retain, infiltrate or affect the flow rate of stormwater;*

"stormwater drainage system" *means every stormwater drainage facility and stormwater drainage feature forming part of a system that combines to lead stormwater from a higher lying area;*

"stormwater facility" *means a component of a man-made drainage feature for dealing with stormwater, designed or constructed to perform a particular function or multiple functions, and includes any pipe, marshy area, ditch, culvert, street gutter, detention facility, attenuation facility, wetpond, constructed wetland, infiltration device, catch basin, oil/water separator and sediment basin, but excludes any building gutter, downspout and stormwater drain serving one single family residence, or such residence and one or two additional residential units permitted by an applicable town planning scheme or other applicable law, on the same property;*

*"**stormwater quality control**" means the control of the introduction of any pollutant into stormwater and the process of separating any pollutant from stormwater, and includes any source control, biofiltration facility, wetpond, wetland, litter trap, oil/water separator, constructed wetland and any facility to control erosion or sedimentation;*

*"**stormwater quantity control**" means the control of the rate and volume of stormwater released from a development site, and includes any attenuation, detention and retention facility;*

*"**stormwater system**" means any natural or man-made system which functions independently or together with another such system to collect, convey, store, purify, infiltrate and discharge stormwater, including any stormwater facility and water course;*

*"**township**" means a township approved in terms of the Town-planning and Townships Ordinance, 1986 (Ordinance No 15 of 1986) or any other law;*

*"**watercourse**" means –*

(a) a river or spring;

(b) a natural channel in which water flows regularly or intermittently;

(c) a wetland, lake or dam into which, or from which, water flows; and

(d) any collection of water which the Minister concerned may, in terms of the National Water Act, 1998 by notice in the Government Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks;

*"**water quality sensitive area**" means any area that is sensitive to a change in water quality and includes any lake, ground water management area, aquifer as defined in the National Water Act, 1998, and a closed depression;*

*" **wetland**" means land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil, and any area where the soil shows evidence of water-logging, and includes the flood plain of any watercourse and any area which is defined as a wetland by any law, irrespective of whether such conditions exist naturally or are manmade;*

*"**wetpond**" means a natural or man-made basin for the receipt of stormwater with the intention of maintaining a permanent quantity of stormwater.*

Purpose of By-laws

2. The purpose of these By-laws is to manage, control and regulate the quantity, quality, flow and velocity of stormwater runoff from any property which it is proposed to develop or is in the process of being developed or is fully developed, in order to prevent or mitigate –

(a) erosion and degradation of watercourses;

(b) sedimentation in ponds and watercourses;

(c) degradation of water quality and fish habitat; and

(d) excess stormwater runoff onto a public road which may pose a danger to life or property or both.

Application of By-laws and manual

3. (1) Subject to the provisions of subsection 2, these By-laws do not apply in respect of any activity, structure, matter or thing on a property which has been authorised by the approval of building plans in terms of the National Building Regulations and Building Standards Act, 1977, or authorised under the National Water Act, 1998;

(2) The provisions of subsection (1) are not applicable in respect of any structure, matter or thing appearing on an approved building plan, if that structure, matter or thing did not require approval under the National Building Regulations and Building Standards Act, 1977, and any regulations made thereunder.

(3)(a) In order to ensure that the latest and best technology is utilised in the area of jurisdiction of the Council, these By-laws must be read with the manual, the provisions of which must be complied with.

The By-laws, read in conjunction with the Manual, require the use of the latest and best technology. It is clear from the definitions in Clause 3(3)(a) that the intention of the By-laws is to ensure the use of the best available methodology to mitigate the impacts of urban development on stormwater runoff.

Specifically, the interventions to mitigate these impacts must address:

- Peak discharge,
- Volume of runoff,
- Frequency of runoff,
- Duration of runoff,
- Quality of runoff,

and these mitigation measures must be considered for all stages of the project including:

- Planning to ensure that sufficient space is made available for the required stormwater management measures;
- Design to achieve the desired result;
- Construction to ensure that no contaminated stormwater discharges from the site (including sediment) or enters the drainage or riparian system;
- Operation, maintenance and education to ensure that the constructed stormwater management measures continue to function as designed for the life of the project;
- Decommissioning to ensure that the drainage system is restored to its natural functionality at the end of the project life.

In addition to the use of the latest and best technology, new developments should adhere to best practice by understanding the context of the development in terms of the application of Green Infrastructure principles (see Appendix C). This approach is equally applicable to stormwater management upgrading and rehabilitation projects. By taking greater cognisance of natural hydrological patterns and processes, it is possible to develop stormwater management systems in a manner that reduces potentially negative impacts and mimics the pre-development regime.

(b) If an irreconcilable conflict arises between any provision of these By-laws and any provision of the manual, the provision of the By-laws prevails.

Responsibility for complying with By-laws

4. (1) A developer who proposes to undertake or undertakes any work or action contemplated in these By-laws, is responsible for compliance, and for ensuring compliance, with any provision of these By-laws relating to such work or action.

(2) A contractor or agent appointed by a developer to carry out any work or action contemplated in these By-laws, is jointly and severally responsible with that developer for compliance, and for ensuring compliance, with any provision of these By-laws relating to such work or action.

(3) An owner of property which has been developed, is responsible for compliance, and for ensuring compliance, with any provision of these By-laws which is applicable in respect of that property after conclusion of that development.

Section 4 of the By-laws places the responsibility for compliance jointly on the developer, the agent or contractor appointed by the developer (which includes the responsible professional engineer and his/her team of consultants) and the owner of the property. The owner is therefore required to provide any subsequent owner with an operation and maintenance manual to ensure that the stormwater management system continues to function in accordance with the By-laws and the design intention for the entire life of the project.

2.2 CHAPTER 2: SITE DEVELOPMENT ACTIVITY PERMITS

2.2.1 Chapter 2 By-laws

Permits required

5. A permit is required for any of the following site development activities :

(a) Any site development activity in respect of a major development;

(b) any site development activity that will require connection to the Council's stormwater drainage system;

(c) any grading activity that will result in the movement of 100m³ or more of earth;

(d) any grading activity that will result in a temporary or permanent slope with a steepness exceeding 3m horizontal to 1m vertical and with a total slope height, measured vertically from bottom to top of the slope, exceeding 1,5 m;

(e) any grading activity that will include the construction of an embankment or berm which will result in the impoundment of water to a depth exceeding 450 mm or with a maximum volume exceeding 50 m³ of water;

(f) any grading activity that will result in the diversion of any existing stormwater drainage feature from its natural point of entry to or exit from a development site;

(g) any clearing or grading on a slope steeper than 3 m horizontal to 1m vertical; and

(h) any clearing within a floodplain.

Exceptions to permit requirements

6. (1) The provisions of section 5 do not apply -

(a) in respect of any property used for commercial agriculture unless it is wholly or partially situated in a floodplain;

(b) to any of the following grading activities :

(i) The excavation for any Council services or tunnel authorised under any law;

(ii) any excavation for a basement or footing for a building, retaining wall or other structure authorised by an excavation permit issued under the National Building Regulations made under the National Building Regulations, and Building Standards Act, 1977, or any other law : Provided that the provisions of this paragraph do not apply in respect of –

(aa) the placement of any fill material removed from such excavation; or

(bb) any excavation beyond the limits of a basement or footing for a building;

(iii) agricultural crop management outside any critical drainage area but limited to the preparation of soil by turning, discing, or other means approved by the Agency ;

(iv) excavation for graves, provided the excavated material is placed on the uphill side of the grave on any slope exceeding 100 m horizontal and 3 m vertical;

(v) landscape installation if fill is confined to less than 250 mm of topsoil and land disturbing activity is limited to less than 500 m²; and

(vi) any exploratory excavation for soil investigation or for determining the location of any service relating to infrastructure for the public benefit.

Applications for permits

7. (1) No person may commence any site development activity specified in section 5, on any property unless a site development activity permit has been issued for that activity by the Agency.

(2) Application for the issue of a permit must be made by the developer concerned on a form prescribed by the Agency.

(3) An application in terms of subsection (2) must be accompanied by –

(a) if the developer is not the owner of the property concerned, an authorisation in writing by the owner to the developer to lodge the application;

(b) a site development activity plan prepared in terms of section 10;

(c) a stormwater drainage plan prepared in terms of section 11;

(d) the documents required by sections 11, 12, 13, 14, 31 and 37(3) to the extent that those sections are applicable to the application concerned; and

(e) the fee prescribed by the Council.

(4) The Agency must within a reasonable time, consider an application in terms of subsection (2) and may refuse or grant it and the applicant must forthwith in writing be notified of the decision and be furnished with reasons for a refusal of an application.

(5) Upon the granting of a permit in terms of subsection (4), a permit must be issued by the Agency subject to site development standards specified in the manual and applicable at the time of the issue of a permit.

> The overriding site development requirement applicable to a permit being granted for site development, is that the site development plan must illustrate how the stormwater management system ensures that the characteristics of stormwater runoff from the site during and after development will not differ from those of the runoff from the site in its natural condition prior to the commencement of any site development activity (Section 32(2)).

(6) Approval for the issue of a permit in terms of this section also signifies approval by the Agency of all plans and other documentation submitted in terms of subsection (3).

(7) A developer must at all times display and maintain an easily legible permit notice in a form prescribed by the Agency at a conspicuous place on the development site concerned, until completion of the site development activities contemplated in the permit concerned.

Expiry of permits

8. (1) An expiry date, not exceeding three years, or in the case of a permit for grading not exceeding six months, from the date of issue of a permit, must be specified in every permit.

(2) A permit expires upon the issue of a certificate contemplated in section 82(1)(b)(ii)(cc) of the Town-planning and Townships Ordinance, 1986, or a certificate of occupancy, as the case may be, in respect of the development concerned or upon the expiry date specified in terms of subsection (1), whichever is the earlier.

(3) If a permit expires prior to the completion of construction on the development site concerned, all site development activities contemplated in that permit, must, subject to the provisions of subsection (6), cease immediately until such permit is renewed.

(4) Application for the renewal of a permit may be made by a developer on a form prescribed by the Agency, at any time from a date 30 days prior to the expiry of the permit and must be accompanied by a new stormwater drainage plan as contemplated in section 11 and such other documentation and information as may be required in writing by an authorised official.

(5) The Agency must within 30 days of receipt of an application in terms of subsection (3) consider the application and may either refuse or grant it and the applicant must forthwith in writing be notified of the decision and be furnished with reasons for a refusal of an application.

(6) If construction on a development site concerned has commenced but is not completed when a permit expires, the developer must, within seven days after such expiry submit a plan for approval by the Agency, temporarily to stabilise the site from stormwater damage or sediment runoff until the permit is renewed and must within seven days of the approval of the plan by the Agency, implement that plan.

Professional engineer required

9. Any document contemplated in section 7(3)(b), (c) and (d) must be prepared by a professional engineer, if any of the following conditions exists :

(a) The proposed development on the property concerned constitutes a major development;

(b) if the site development activity incorporates any stormwater facility or other improvement relating to stormwater in a public road for which facility or improvement the Agency will assume responsibility for maintenance;

(c) if a site development activity is to take place within a floodplain or within 100 m from the centre line of any water course;

(d) if a site develop[ment] activity is to take place on a property shown by a 15 000 scale geological map to be underlain by, or within 500m of, dolomitic geology; or

(e) in respect of any other site development activity, if the Agency considers it to be in the public interest to require that the documents concerned be prepared by a professional engineer.

Site development activity plan

10. A developer must in respect of any development site in respect of which a permit is required in terms of section 7, prepare a site development activity plan.

Stormwater drainage plan

11. (1) A developer must in respect of any development site for which a permit is required in terms of section 7, prepare a stormwater drainage plan.

(2)` A plan contemplated in subsection (1), must relate to the collection, transportation, treatment and discharge of stormwater from the development site concerned and must include a profile view of the property concerned and construction details and notes relevant to such plan.

(3) (a) A plan contemplated in subsection (1) must contain an analysis of the impact of stormwater up to 500 m or a greater distance required by a notice in writing by an authorised official served on the developer concerned, downstream from the property on which the development site concerned is situated, which may result from the proposed development on that site and must contain features to mitigate such impact.

(b) For the purposes of paragraph (a), any existing and potential impact of stormwater, including –

(i) increased sedimentation and streambank erosion and discharge;

(ii) flooding;

(iii) overcharging of any existing closed stormwater conveyance facility;

(iv) discharge to a closed depression;

(v) discharge to an existing off-site stormwater runoff control facility;

(vi) infiltration to groundwater or any area of land with the ability to contribute to, or recharge, ground water;

(vii) deterioration of stormwater quality; and

(viii) any spill and discharge of a pollutant into stormwater, must be evaluated and mitigated.

The SWMR must contain a discussion on the evaluation and mitigation of existing and potential stormwater impacts as listed, namely: stream sedimentation, erosion, and discharge; flooding; overcharging of existing stormwater conduit; discharge to a closed depression; discharge to an off-site stormwater control facility; infiltration to groundwater; deterioration of stormwater quality, pollutant discharge.

Off-site stormwater drainage analyses

12. (1) For the purposes of an application for a permit in terms of section 7 a written off-site stormwater drainage analysis must be prepared by a professional engineer, based on a study of the existing and predicted impact of stormwater runoff from the development site concerned on to any property and on a field investigation at the development site concerned, relating to any drainage area from which stormwater is received from any adjacent property and any other area contributing to stormwater being discharged on to any such property.

(2) The extent of the analysis contemplated in subsection (1), is limited to information that can be supplied by the Agency or can be obtained from ground level by opening manhole covers giving access to any stormwater drainage system, which can be opened manually, other than such covers that can only be opened by using mechanical lifting equipment.

Geotechnical reports

13. (1) The Agency may require a geotechnical report prepared by an geotechnical engineer, to accompany an application for a permit in terms of section 7 in respect of a development if –

(a) grading or the provision of any attenuation facility, detention facility or other stormwater facility is proposed within 50 m of a slope steeper than 3 m horizontal to 1 m vertical; or

(b) the development site is underlain by, or within 500 m of dolomitic geology shown on a 1:50 000 scale geological map; or

(c) an authorised official considers that the proposed development on the property concerned poses a potential stormwater hazard due to its proximity to a slope in the topography on that property either natural or man-made.

(2) The report required in terms of subsection (1) must include the effects of groundwater interception and infiltration, seepage, potential slip planes, changes in soil bearing strength and any other factor required by an authorised official.

Soils investigations reports

14. For the purposes of an application for a permit in terms of section 7, if section 9 applies in respect of that application, a soils investigation report must be prepared by a geotechnical engineer or an employee employed and supervised by such engineer, if -

(a) the soils underlying the proposed development have not been mapped;

(b) existing soils maps of soils contemplated in paragraph (a), are inconsistent; or

(c) an authorised official considers that existing soils maps are not of sufficient resolution to allow proper engineering analysis.

Permit modifications

15. (1) A developer may on a form prescribed by the Agency, apply for a modification of a permit contemplated in sections 7 or 8(5), issued to him or her.

(2) An application in terms of subsection (1) must be accompanied by the fee prescribed by the Council.

(3) For the purpose of considering an application in terms of subsection (1), an authorised official may require the applicant to furnish any document and information.

(4) The Agency must consider an application in terms of subsection (1) and may refuse or grant it and the applicant must forthwith in writing be notified of the decision and be furnished with reasons for a refusal of an application.

2.2.2 Stormwater Management Report

Deemed to Satisfy

Implementation of Green Stormwater Infrastructure (GSI) is required even where application for a permit is not required in terms of Clause 5 of the By-laws. A combination of the following will be deemed to satisfy the requirements when a permit is not specifically required:

1. A rainwater harvesting system or rain barrels with a capacity of at least 1 m^3 of storage per 100 m^2 of impervious area.
2. At least 50% of the impervious area on the site should discharge to pervious area. The pervious area accepting run-on shall be at least 2m wide and generally vegetated during the summer, e.g. a flower or vegetable garden.
3. The first few millimetres of runoff should be attenuated in a depression such as a rain garden with a capacity of at least 0.5 m^3 per 100 m^2 of impervious area draining to it.
4. Where possible paving should be flagstones interspersed with vegetation or gravel rather than impermeable concrete, asphalt, or closely interlocked bricks.

Minimum Content

As a minimum, a stormwater management report shall include:

1. Site location and description
    a. Site description, including area, bounding properties, drainage systems
    b. Topography,
    c. Geology and soils
    d. Existing land use and proposed future land use
    e. Existing vegetation and proposed future vegetation
    f. Watercourses and wetlands
    g. A locality plan
2. Pre-Development Runoff

The pre-development condition is defined as the state of the site prior to the discovery of gold on the Witwatersrand.

    a. Peak discharges and storm runoff volume for all applicable storm recurrence intervals and durations
    b. Frequency of surface runoff
    c. Quality of runoff
    d. Water balance, i.e. proportions of surface runoff, evapotranspiration, deep infiltration, and delayed runoff via shallow groundwater paths

3. Stormwater Management Interventions (GSI) Evaluated and Selected with reasons for selection
    a. Opportunities for harvesting of rainfall or runoff
    b. Peak discharge control methods
    c. Volume control methods
    d. Frequency of runoff control methods
    e. Water quality management methods

f. Multiple benefits, including those not related to stormwater such as recreational, aesthetic, wildlife habitat, carbon sequestration etc.

g. Diagrams or working drawings of all proposed GSI

h. Evaluation of risk including:

i. Uncertainties in results of calculations

ii. Uncertainties parameters

iii. Potential impacts of climate change

4. Neighbouring Properties and Receiving Systems

a. Expected flow onto the site

b. Description and capacity of the receiving system

c. Remedial measures if the receiving system does not have adequate capacity

5. Hydrograph and Water Balance Analyses

a. Calculation methods

b. Parameters selected, with reasons

c. Results of calculations, peak discharges, volume of runoff, frequency of runoff

d. Water balance, i.e. proportions of surface runoff, evapotranspiration, deep infiltration, and delayed runoff via shallow groundwater or highly throttled outlets.

e. Uncertainty of results

6. Measures to Address Runoff Water Quality

a. Construction phase

i. Erosion & Sediment Control Plan (ESCP),

ii. Pollution control plan (hydrocarbons, cement, camp sewage, etc.)

b. Operational Phase

i. Gross solids (litter)

ii. Sediment

iii. Nutrients

iv. Toxins, metals, organics

v. Pathogens and sewage spills

As a general rule, quality of water stored or discharged should meet the standards for its particular use as set out in the appropriate volume of The South African Water Quality Guidelines, Second Edition 1996 (see https://www.dwa.gov.za/iwqs/wq_guide/index.asp).

7. Safety of Selected Interventions

a. Rate of rise and fall of water, and velocity hazard

b. Embankment stability (possible rapid drawdown conditions)

c. Protection, maintenance and public awareness of extreme flood zones

d. Escape routes and prevention of entrapment, including orifices and weirs

e. Public access and hazard risk

f. Security and access, hiding places for criminals, etc.

g. Suitability of stored water for human contact

8. Maintenance, Monitoring and Expected Lifespan of the GSI

a. Management of sediment and debris
b. Cleaning regime
c. Weed, reed and alien vegetation eradication
d. Monitoring regime and acceptability criteria
e. Suggested remedial measures if failure occurs

9. Operation and Maintenance Manual
    a. For current and future owners

Credentials of Author

The author of the stormwater management report shall be a Professional Engineer as defined in Section 2.1 of this Manual

2.2.3 Site Planning and Design Guidelines

The overriding standard is that the stormwater management system must take cognisance of natural hydrological patterns and processes and be designed to reduce potentially negative impacts and mimic nature (i.e. the pre-development – before the discovery of gold) and the natural conditions of the site. The Manual currently does not have a 'standard form' or 'checklist' of site development standards, but will be described in the future. During this interim period the applicant must compile a Stormwater Management Report (see notes to Section 11.(3)(b) for the structure of the report) using the guidelines (SAWE, 2002) elaborated on below which promote the following stormwater management objectives:

- Minimise threat of flooding;
- Protect receiving water bodies;
- Promote multi-functional use of stormwater management systems;
- Develop sustainable stormwater systems.

Planning Stage

The following information should be collated for each site, during the planning stage and used to feed into the more detailed site assessment:

- Catchment area in which site is located;
- Catchment or river management plans; the overall management objectives and recommend key management actions with respect to runoff quantity, quality and other associated environmental and social issues, where such plans exist for the catchment in question, must be met in the design stage;
- Existing reports relating to the sensitivity of known wetlands, rivers or other natural ecosystems on or associated with the study area.

A site analysis plan should be prepared in which the physical features of the site as well as ownership and spatial constraints, including adjacent and downstream areas, are assembled and evaluated.

Site Analysis

The physical characteristics of the site reflect the existing course of runoff and stormwater. Working with the natural environment and processes has been found to be safer, more sustainable and easier to maintain in the long term than more traditional engineering approaches aimed at controlling these processes. On sites that have been substantially disturbed, consideration should be made of what the natural drainage and runoff conditions would have been, as well as the existing situation. This will enable potential problems and opportunities to be identified.

The following are some of the main features that should be considered and collated in the form of a site analysis plan that should be used to inform the design process.

a) Topography

The following topographical factors should be considered:

- Gradients dictate the direction of flow, and runoff/drainage routes can be plotted over land, identifying areas of ponding and concentration of loads.
- In some areas that are very flat, earthworks may be required to provide sufficient grade for drainage.
- Topography influences the potential for erosion to occur.
- Topography informs the feasibility of different locations for stormwater routes, outlets and treatment areas. The main stormwater routes should be located along natural drainage routes.
- In ecological terms, different habitats, some of higher conservation value than others, are frequently associated with changes in topography.
- From an environmental and stormwater management perspective, as the slope increases, erf sizes should also increase to prevent excessive run-off and potential erosion. Road and planning layouts should also reflect the topography of an area, to enable integrated stormwater design and management.
- The commercial (and aesthetic) value of different sections of a development area is also frequently derived from different topographical characteristics.

b) Geology, Soils and Groundwater

A good understanding of the geology, soil and groundwater conditions is an important factor in assessing the infiltration potential of the site. The following factors should be considered:

- Soil types affect surface permeability and hence rate of runoff.
- The mapping of geology and soils will indicate areas of potential groundwater recharge.
- Geology and soils influence the potential for erosion to occur.
- Soil types should be identified, along with the characteristics of the different soils, such as levels of infiltration, permeability and their water-bearing capacity.
- The presence of contaminated soils, which may pose a threat to surface and groundwater quality, should be identified and plotted.
- Areas of high groundwater levels can limit the possibilities and/or desirability of groundwater recharge and filtration methods. It should be noted that large-scale removal of certain vegetation types, such as Bluegums (*Eucalyptus spp*.), that consume large volumes of water, might significantly raise groundwater levels.
- Need to determine seasonal and longer term trends in groundwater level fluctuation. In the absence of sufficient documented groundwater information, the seasonal and long-term ground water fluctuations should be projected, based on the hydrological, geological and climatic information available.
- Soil types indicate the likely occurrence of particular plant communities, some of which may play a role in the stormwater management plan.

- Assessing soils can also indicate the presence of existing and even historic wetlands.
- Seasonal variation of groundwater levels should be taken into account.
- The geology and soils of a site will inform the feasibility of different locations for stormwater treatment areas and the potential for groundwater recharge.
- Different habitats (some with high conservation value) are associated with specific geological features and soils.

c) Climate

The following climatic factors should be considered:

- Storm rainfall parameters are major design factors and must be carefully determined.
- The general climatic characteristics of an area will also impact on the site and stormwater systems implemented, i.e. whether the site is generally waterlogged or dry, and if evaporation levels are high or low.
- Microclimate conditions can inform the spatial layout of water treatment and attenuation, particularly those associated with specific planting and multifunctional uses.

d) Hydrology

For successful, sustainable and integrated stormwater management, it is essential that the existing and/or natural hydrological response and functions of the site are understood. The following factors should be considered:

- The natural drainage that was characteristic of the development area, to the extent that this is possible, should be determined: both the irreversible as well as less permanent changes that have taken place should be identified.
- The hydrology of the development area is a function of the site analysis data: tools for quantifying storm runoff quantity and quality are dealt with in this Manual and in the literature.

e) Natural Ecosystems, Flora and Fauna

The site should be assessed in terms of the natural ecosystems and habitat types that it supports. The following factors should be considered:

- Conservation (or improvement) of bio-diversity and ecosystem function must be one of the objectives of a management plan.
- Some habitats are afforded protection by existing legislation and guideline (e.g. wetlands; buffers around rivers and wetlands).
- Where the site intercepts natural corridors of movement between ecologically important areas, stormwater management should seek to retain or recreate such corridors.
- Endangered or threatened vegetation, animals and/or habitats should be identified and associated opportunities and constraints for stormwater management assessed.
- Vegetation and animals that have roles or functions that can improve water quality, amelioration and/or infiltration should be identified, and their natural status and integrity determined.
- Healthy, diverse and/or relatively undisturbed natural systems should be identified and assessed in terms of their habitat integrity and importance (environmentally, socially and culturally), and, wherever possible, be accommodated within the future planning and development of the site.
- The presence of invasive alien animals (e.g. fish, birds) or plants should be discouraged from any developments. Alien flora or fauna associated with habitats created or maintained for the

management of stormwater from a site should not be allowed to pass into any downstream or associated water bodies.

f) Ecological Characteristics of Freshwater Ecosystems

The occurrence of rivers, streams or other watercourses on the site should be identified, and the habitat integrity of each should be determined. The following ecological and ecosystem factors should be considered:

- Floodplains and ecological buffers that relate to the site should be determined at an early stage in order to establish the broad development planning, and specific stormwater implications that they have for the site.
- The presence of wetlands within the development site should be red flagged, due to their global and nationally threatened status. Protection is accorded by certain policies and legislation.
- The stormwater discharge and receiving capacity of rivers, channels and drainage courses should be determined to establish the levels of integration of the natural and proposed stormwater management systems.
- The use of these linear elements should form part of an integrated public open space and stormwater system, and promote the multifunctional use of space.
- Floodplains and ecological buffers provide open space systems within which the more space-consuming “soft technologies” of stormwater management can be accommodated, without posing a conflict with development pressures on land.
- Development sites that do not have floodplains and ecological buffers within the area should consider integrating a public open space system with an overland escape route for an extreme storm event, to maximise the opportunity for habitat corridors.
- Where ecologically important wetlands or rivers as defined in the relevant catchment plan are recipients of stormwater discharge, the quality and quantity of stormwater discharges into such systems should be regulated to minimise downstream impacts. Cognisance should be taken of cumulative impacts to water bodies occurring, as a result of discharge from several sources (Refer to the Department of Water Affairs Water Quality Guidelines, 1996).

g) Cultural and Historical Landscapes and Archaeological Sites

Areas, routes, vegetation and landmarks that have a cultural and/or historical use or significance should be identified. Development and stormwater planning should avoid disturbing these areas where possible. Where possible they should generally be incorporated within the public open space of a development. This contributes a further function to the public open space system, and should be integrated into a network of public open space.

h) Development Requirements

The public open space and pedestrian access requirements of a development should be incorporated into the stormwater management planning of the site. The integration of public open space and access requirements with the spatial requirements of stormwater management not only reduces the conflict of pressure on land, but also enables the amalgamation of maintenance requirements, and optimises the use of resources. The following factors should be considered:

- Land use planning should be done in relation to the natural context and characteristics of the site. The appropriate placement of land uses will enhance the multi-functionality of the stormwater systems and their use as an amenity by residents in the area.

- The need for a safe environment must be taken into account (e.g. avoidance of potential hiding places for criminal elements; do not create unnecessary hazards in the selection of stormwater management options).
- The cost of stormwater implementation, management and maintenance, as well as flood risk, can be greatly reduced by identifying, retaining and enhancing the natural areas along which runoff and natural habitat retain ecological integrity. The advantages of this approach are not limited to stormwater, but can increase the visual, amenity and ecological value of a development.

i) Ownership Opportunities and Constraints

A clear distinction should be made between public and privately-owned land. The following factors should be considered:

- As a principle, stormwater should as far as possible be accommodated within public open areas or spaces under common ownership.
- Servitudes should always be registered in the favour of the controlling authority to ensure effective management and access at all times.
- Public open space used in the stormwater systems should be clearly demarcated to ensure that the stormwater functions are apparent and to enable monitoring and policing.
- Early identification of land ownership in potential stormwater treatment or conveyance areas outside of the development area will assist in identifying constraints, in some cases, as well as opportunities to provide additional space for stormwater management, through *inter alia* land swaps, use of public open space and local authority land.
- Servitudes and public rights of way can also be incorporated into the stormwater systems, for example use of road reserves for conveyance and/or infiltration, but these elements should not be critical to performance, as they may be relinquished for later development purposes (road widening, etc.). The servitudes may not however be relinquished if they are embodied in the title deeds, without legally altering or deleting the servitude, which would require the local authority consent.

j) Spatial Opportunities and Constraints

The amount of appropriate public space that is available for stormwater management should be identified at an early stage in project planning, since this will largely dictate the extent to which different stormwater design elements are feasible in a development. Where site analyses show that spatial constraints are likely to dictate stormwater design, attention should focus on identification of spatial opportunities outside of the development area (e.g. areas of public open space, local authority land; schools and other areas of open space), that might lend themselves, through negotiation, to more ecologically desirable stormwater design options.

k) Surrounding Developments

Stormwater management design options should take cognisance of developments in the upstream catchment that are likely to impact on the timing, quality or quantity of stormwater generated upstream of the development area. Identification of these issues will highlight potential problem areas in stormwater management. The following factors should be considered:

- It is important that site planning be done in context with the adjacent properties to ensure effective stormwater systems and integrated stormwater corridors. Sufficient retention facilities should therefore be planned and provided on site as part of an integrated open space system.

- Clarity on the stormwater management principles employed in upstream developments should also be obtained so that anticipated stormwater runoff from these areas can be quantified.
- The rate of growth and anticipated land-use of surrounding developments and areas that discharge onto the development site should also be taken into account to determine the future pressures on the stormwater systems.
- The general capacity of the stormwater systems of surrounding developments that lie downstream of the site and the current rate of growth and pressure on these systems should be taken into account during site planning and design. Failure of systems downstream can cause failure and flooding upstream. As a principle, the post development runoff should not exceed the predevelopment runoff.

l) Maintenance Capacity

Before stormwater design options are considered in any detail, it is vital that the developer has a clear indication of the practical maintenance capacity, in terms of time, personnel and finance, of the final managing authority for the stormwater system. Aesthetically or ecologically complex designs that owe their sustainability to regular maintenance inputs on a permanent basis will fail in the medium to long term if there is no capacity for ongoing and adequate maintenance. Similarly, where public expectations centre on aesthetically pleasing design, adequate allowance must be made for basic maintenance activities, such as removal of litter or alien clearing. If this is neglected, the project as a whole may be deemed a failure in the eyes of the public. This may have ramifications for the rest of the project in question, as well as future projects requiring public support.

Conceptual Layout

A general concept plan should form part of the Stormwater Management Report for the site layout, taking into account the legal and physical aspects of the site as developed through the site analysis process. This plan should indicate the location of different land-uses. This will influence the stormwater management conditions, and reflect some of the spatial requirements of the system.

a) Conceptual Stormwater Planning

The information gathered concerning the site and relevant legislation and policy documents as derived from the site analysis and conceptual layout will then be used to draw up a Conceptual Stormwater Plan. This plan will indicate the major flow routes, natural features that will form a part of the stormwater system and areas that are to be set aside for elements of the stormwater system, such as attenuation ponds. It will then be modified and refined in the design phase.

b) Design of the Stormwater Management System

Once the planning phase process has developed a conceptual stormwater plan for the site, the design phase needs to develop site and context specific design of the stormwater management system. This section provides design guidelines to inform appropriate stormwater design for a development. The key variables to be evaluated and managed are water quantity (volume and peak flow) and water quality. Calculation methods and parameters must be justified by references to the literature and accepted practice.

c) System Design Objectives

Various stormwater management facilities and techniques must be presented and evaluated in terms of engineering, ecological, health, safety, aesthetic, social, construction and maintenance design objectives. These should form the basis for the selection of appropriate design options. The developer needs to demonstrate, through submission of appropriate stormwater designs, the extent to which the proposed development meets these system design objectives. Monitoring requirements may be imposed on the development to measure long term performance and compliance.

2.3 CHAPTER 3: EROSION AND SEDIMENT CONTROL

2.3.1 Chapter 3 By-laws

PART 1 - MINOR DEVELOPMENTS

Interpretation of Clauses 16 & 18 The focus of the By-laws is the construction phase of a site. Internationally this is seen to be the period of highest risk of sediment generation. However, this Manual seeks to widen the focus to the operational phases of a development as well.

Control for minor developments

16. In respect of any minor development, erosion and sedimentation must be controlled during construction and any soil exposed or disturbed during construction must be permanently stabilised in compliance with the provisions of section 17.

Requirements for minor developments

17. (1) Access to a development site for vehicles must, if reasonably possible, be limited to one route.

(2) Any access route contemplated in subsection (1) must be stabilised with crusher dust, quarry spall or crushed rock to minimise the depositing of soil and other debris onto any public road.

Access roads and areas of exposed soil must be stabilised to manage both dust generation and sediment load in the stormwater runoff. The period of highest risk is the wet season and stabilisation should be immediate, but stabilisation is still required in the dry season. All stabilised areas must be inspected daily, maintained, and repaired within 12 hours of damage or failure. Stabilisation methods may vary and must be approved by the Agency after consultation with the City of Johannesburg EISD.

(3) (a) Any exposed loose soil on a development site must be stabilised by utilising an appropriate best management practice and be maintained in accordance with the manual.

(b) During any period from 1 October to 30 April, no soil contemplated in paragraph (a), may remain unstabilised for more than two days and during any period from 1 May to 30 September, for more than seven days.

(c) Sufficient material, equipment and labour must at all times be available on a development site to stabilise any exposed soil within 12 hours, if continuous rainy weather or any other occurrence necessitates it.

(4) Any adjacent property must be protected from sediment deposition by the use of a vegetated buffer, sediment barrier or filter, dike or mulching, or by a combination of these measures or by utilising any other appropriate best management practice.

Interpretation of Clause 17 (4 & 5) The site boundary is usually the last point of control for stormwater and sediment runoff and measures should be in place to treat both. Methods may vary and must be approved by

the Agency after consultation with the City of Johannesburg EISD. These measures should be in place before construction starts.

(5) Any adverse effect of increased stormwater runoff resulting from any land disturbing activity or land development activity, on a development site must be controlled by the application of an appropriate best management practice.

(6) Any measure taken in terms of this section must be inspected daily and maintained to ensure continued effective performance of its intended function.

PART 2 - MAJOR DEVELOPMENTS

Provisions applicable to major developments

18. If a proposed development on any property constitutes a major development, the requirements of sections 19 to 30 inclusive, apply, in respect of the development site concerned.

Stormwater control measures for major developments

Interpretation Clause 19

Principles for minor developments (Clause 17) apply. Areas set aside from development as identified in an EIA or other regulations must be clearly marked on site for protection during construction.

19. (1)(a) Any soil which is exposed or disturbed during construction and any material stockpile on a development site must be stabilised utilising an appropriate best management practice and be maintained in accordance with the manual.

(b) During any period from 1 October to 30 April, no soil or material stockpile contemplated in paragraph (a) may remain unstabilised for more than two days and during any period from 1 May to 30 September for more than seven days.

(c) Sufficient materials, equipment and labour must at all times be available on a development site to stabilise any exposed soil or material stockpile within twelve hours, if continuous rainy weather or other occurrence necessitates it.

(2)(a) Any clearing limit, setback, buffer and other area sensitive to stormwater, such as a steep slope, wetland or riparian corridor, on a development site determined by an environmental impact assessment in terms of the National Environmental Management Act, 1998 (Act No 107 of 1998), or any regulation made thereunder, must be clearly marked on the development site by visible pegs or other effective means and may at any time be inspected by an authorised official.

(b) For the purpose of this subsection –

(i) "clearing limit" means that portion of a development site cleared from vegetation or on which any structure has been demolished to prepare the site for a proposed development; and

(ii) "setback" means any portion of a development site where the erection of a building is prohibited by the determination of building lines in terms of an applicable town planning scheme or any other law.

(3) Any property adjacent to a development site must be protected from sediment deposition by the use of a vegetated buffer, sediment barrier, or filter, dike or mulching, or by a combination of these measures or by utilising an appropriate best management practice.

As per Clause 17(4&5). On major sites it is imperative sediment control facilities are established before grading or construction starts.

(4) Any measure contemplated in subsection (3), must be effected prior to the commencement of any grading, and must be functional before any other land disturbing activity takes place, on a development site.

(5) Every structure such as a dam, dike or diversion, whether temporary or permanent, must be stabilised in terms of subsection (1).

All stormwater control structures must be stabilised before operation. Methods may vary and must be approved by the Agency after consultation with the City of Johannesburg EISD.

(6)(a) Any cut and fill slope resulting from an excavation on a development site must be stabilised in accordance with subsection (1), and must be constructed with a roughened soil surface instead of a smooth surface, in a manner that will minimise erosion.

(b) A stormwater drainage facility to regulate stormwater flow must be constructed at the top of a slope 3m horizontal to 1 m vertical or steeper, which has an area above it that contributes to stormwater runoff.

(c) Concentrated stormwater must not be allowed to flow down the face of a cut and fill slope unless contained within a channel or pipe, adequate to deal with the volume of water.

(d) If a cut and fill slope face crosses a water seepage plane, a drainage or other erosion protection facility to deal adequately with the volume of stormwater, must be provided.

Control of erosion on slopes requires particular attention, whether temporary or permanent. Hydraulic design will be critical where catchment areas will result in significant storm runoff volumes. Measures for runoff interception, downslope conveyance and seepage planes should be designed.

Control of off-site erosion

20. Any property and watercourse downstream from a development site must be protected from erosion due to an increase in the volume, velocity, and peak flow rate of stormwater from that site by the utilisation of an appropriate best management practice to minimise any adverse downstream stormwater impact.

Stormwater discharge points and outfalls from a site must be designed to avoid erosion to downstream watercourses and properties. The stormwater design must demonstrate that systems below the site will be stable. The downstream distance analysed must be determined and motivated by the stormwater engineer for the development.

Stabilisation of temporary conveyance channels and outlets

21. (1) Any temporary on-site stormwater conveyance channel on a development site must be designed, constructed and stabilised to prevent erosion from an expected flow velocity from a 2-year frequency design storm event of any duration, for the post development condition.

(2) Stabilisation in terms of subsection (1) must be adequate to prevent erosion of any outlet, adjacent stream-bank, slope and downstream area and must be provided at the outlet of every stormwater drainage system.

> Temporary outlets and conveyance facilities need to be stabilised before being put into operation. This would imply that this needs to be achieved before work starts in the catchment area. It is also recommended that the 2-year design storm standard is reviewed according to the catchment size and flood risk, and the duration that the temporary facilities are expected to operate. The stormwater engineer must consider the risk of failure during the entire duration of the various phases of the project and make a recommendation on this before the temporary works are approved.

Stormwater drain inlet protection

22. (1) Any stormwater drain inlet made operable during construction on a development site must be protected so that stormwater runoff does not enter a municipal stormwater drainage system without first being filtered, or otherwise treated effectively to remove sediment.

(2) (a) Subject to a developer lodging an application on a form prescribed by the Agency, the requirement of subsection (1) may be waived by an authorised official if any stormwater drainage system downstream of the inlet referred to in subsection (1), discharges to an on-site sediment control facility based on an appropriate best management practice, including but not limited to, a sediment pond or trap;

(b) A drainage system contemplated in paragraph (a) must be adequately cleaned at the conclusion of the development concerned so that it operates to its best potential.

> Existing municipal drainage systems should not be compromised by discharges from construction sites and should be protected by appropriate sediment control measures on site. These in turn need to be adequately maintained. This clause should also apply to the operational phase of the development, including the cleaning and maintenance of the facilities.

Trenches for municipal services

23. (1) The construction of any trench for municipal services on a development site must be limited, if practically possible, to no more than 100 m of open trench at any one time.

(2) If consistent with safety and space considerations, material excavated from a trench contemplated in subsection (1), must, if practically possible, be placed on the uphill side of the trench.
(3) Any device for pumping water out of a trench contemplated in subsection (1), must discharge to an effective sediment trap or pond, and the velocity of such water must be sufficiently lowered prior to its leaving a development site so as to prevent erosion and sedimentation.

Trenches for installation of new services can intercept and concentrate stormwater runoff. They can also become unstable if flooded. The clause gives guidelines for trench construction, but these should be reviewed in conjunction with trench slope and potential catchment area. The applicant should make a recommendation on the best construction method in each case. Discharge from trench dewatering must include treatment for sediment load.

Constructed access routes

24. (1) If any vehicle access route to a development site intersects a paved road, either public or private, steps must be taken to minimise the deposit of matter such as mud and other debris onto such road by utilising an appropriate best management practice such as a stabilised entrance to the site.

(2) If matter is deposited onto the surface of a road contemplated in subsection (1), the road must be thoroughly cleaned, at least at the end of each working day.

(3) Matter deposited on a road contemplated in subsection (1), must be removed from such road by shovelling or sweeping and be deposited in a disposal area on the development site capable of accommodating the quantity concerned, or at a municipal solid waste disposal site.

(4) Washing of a road contemplated in subsection (1), may only be done after any matter deposited thereon has been removed in the manner required in terms of subsection (3).

Tracking of mud, dust, and materials on to paved roads must be monitored and managed using appropriate mitigation measures. The applicant or stormwater engineer should make recommendations on this aspect for approval by the Agency after consultation with the City of Johannesburg EISD.

Removal of temporary facilities

25. (1) Any temporary stormwater facility for erosion and sediment control relating to a development site must be removed within 30 days after the date of issue of a completion certificate in respect of the development concerned or after any such facility is no longer required, whichever is the earlier.

(2) Sediment trapped by a facility contemplated in subsection (1), must be removed from or stabilised on the development site concerned.

(3) Any disturbed soil area resulting from the removal of any facility contemplated in subsection (1), must be permanently stabilised.

(4) An authorised official may in writing, exempt a developer from any requirement of subsection (2) in respect of a specified development site.

Site clearing after issue of a completion certificate should not leave any risk of erosion or sedimentation arising from temporary stormwater facilities.

Dewatering of development sites

26. Any stormwater facility on a development site transporting stormwater from that site, must discharge into an appropriate sediment trap or sediment pond designed to accept the discharge of *stormwater which must be preceded by a measure to reduce the velocity of stormwater to not more than 3 m per second before it leaves that site.*

> Sediment control facilities are required on all outfalls and discharge points from a site. The performance of these facilities must be stipulated in the design, including flow velocities and settlement performance. An upper limit on flow velocity is indicated, but the appropriate velocity needs to be confirmed by the stormwater engineer for each case.

Control of pollution other than sediment

27. (1) Any pollutant, other than sediment, that occurs on a development site due to construction and related activities, must be disposed of in a manner that prevents pollution of any surface water or underground stormwater system.

(2) Pollutants contemplated in subsection (1), include any lubricant, solvent, concrete by-product, construction material, and organic debris from clearing and grubbing on a development site.

> Where sediment treatment facilities are required to capture any other types of pollutant, these need to be set out in the design of each facility.

Maintenance of erosion and sediment control facilities

28. (1) Any temporary or permanent stormwater facility for erosion and sediment control must be maintained and repaired by the owner of the property concerned to ensure its continued effective performance of its intended function.

(2) Any maintenance and repair in terms of subsection (1), must be conducted in accordance with the manual.

(3) If any stormwater facility contemplated in subsection (1), is damaged during any flood, storm or other adverse weather condition, it must forthwith be returned to its normal operating condition by the owner of the property concerned.

> One of the main causes of failure of stormwater and sediment treatment facilities is poor maintenance. The monitoring and maintenance requirements of all aspects of the stormwater system need to be set out by the stormwater engineer.

Erosion control design storm event

29. Any stormwater facility designed for the control of erosion and sediment, must be designed for a 2-year recurrence interval design storm event of any duration from 0.25 hours to seven days.

> The By-laws indicate that all erosion and sediment control facilities are to be designed to a 2-year design storm. This should be reviewed on a site by site basis and in the context of the receiving environment. A recommendation on this should be made by the stormwater engineer in each case.

Installation of rain meter

30. For the purpose of ensuring compliance with the relevant provisions of this Part, an authorised official may, by notice in writing, require a developer to install and maintain a rain meter, of a kind *required by that official, on a development site and to furnish the Agency with a written statement within two days after the conclusion of every week, specifying the quantity of rainfall that fell on that site during the previous week.*

General If the applicant believes that it is not practically possible to meet the requirements of this chapter a detailed explanation of why that is the case shall be included in the application prepared in accordance with section 7. A relaxation of the requirements of this section may only be given by the Agency after consultation with the City of Johannesburg EISD.

2.3.2 Sediment Control: Management Objectives

The management objective is to control sediment loads in streams and rivers across the city to preserve water resources and to establish and protect healthy aquatic systems. The objective includes the ability to recover degraded streams as part of catchment management strategies. Therefore, new developments and any site redevelopments should comply with longer term objectives.

Water quality guidelines for sediment loads in South African rivers are given in Table 3.1. In the absence of river-specific standards, current Catchment Management Plan and river quality objectives, these guidelines may be used to set management objectives. The 2010 City of Johannesburg State of Rivers Report shows that typical turbidity of Johannesburg rivers ranges between 10 NTU and 30 NTU in normal flow conditions, well within the guidelines in Table 3.1. However, in flood conditions, sediment loads across Johannesburg are generally observed to be unacceptably high (see Appendix F).

Table 3.1: Summary of water quality guidelines for South African rivers and streams.

Source	Determinand	Unit	Limit	Comment
SA Water Quality Guidelines (DWA, 1996a)	TSS	mg/l	100 50	All aquatic ecosystems. Aquaculture, clear water fish species.
SA Water Quality Guidelines (DWA, 1996a)	Turbidity	NTU	25	Aquaculture, clear water fish species.

Sources of Sediment

The primary sources of sediment in the streams and drainage systems of the City of Johannesburg include:

i. Streambank erosion,
ii. Erosion of poorly design drainage networks,
iii. Erosion on construction sites and areas with exposed soils,
iv. Runoff from paved surfaces (containing dust, grit, tyre rubber, etc.),
v. Litter,
vi. Sewer discharge to stormwater systems.

This section of the Manual addresses the first four sources, which are directly linked to changes in kinetic energy introduced to rainfall-runoff processes brought about by land development and which are central to stormwater design procedures. In contrast, the last two are influenced by external social and municipal factors that require additional planning, design and management measures of which many are reliant on third party participation. These are not covered in this chapter. Of the first four sources of sediment, the erosion on construction sites and runoff from paved areas are typically the focus of sustainable drainage manuals, with greater attention to construction sites. Indeed, these are also the focus of the By-laws. However, in rapidly developing city environments such as Johannesburg, the erosion of receiving streams and damage to existing drainage networks is also problematic, and may indeed produce the bulk of sediment volume in storm runoff. Therefore, it is important that the sediment control measures addressed in this chapter are closely linked to the stormflow peak and volume reduction measures addressed in other sections of this Manual. This is especially the case for the protection of off-site streams and networks where energy control measures at site outfalls only have very localised effect. The By-laws also make reference to this aspect.

Setting Limits for Acceptable Sediment Discharge

Targets for discharge limits should be determined by the sensitivity of the receiving stream and any strategic objectives for the stream. These will vary with location, even within a municipality. They will also vary between normal and flood flow conditions, though the ideal conditions are not yet identified for Johannesburg streams. The SA Water Quality guidelines recommend that to maintain healthy aquatic ecology, sediment loads should not vary by more than 10%, though this may not be realistic for natural streams in flood conditions. Sediment loads during and after storms across all of Johannesburg are seen to be unacceptably high, and in the absence of identified targets, upper limits for general conditions may be adopted as per Table 3.1, but these are likely to be overly strict and difficult to achieve (see case study for the US-EPA in Appendix F). Further research specific to Johannesburg streams is required. In the interim, the sediment trap targets in Table 3.2 are proposed. It is based on trapping different grades of sediment by a combination of settlement and filtration methods. Additional background is given in Appendix F.

Trap efficiency is for the design event. This requires testing the system for the same range of design hydrographs required for testing retention and attenuation facilities. If the system design is based on peak flow only, the same targets will need to be achieved even though this will be more conservative.

Table 3.2: Interim trap efficiency of on-site sediment treatment facilities.

Particle size	Category	Treatment	Trap Efficiency (per design storm event)			
		Primary(1) Secondary(2)	1.01 yr.	5 yr.	10 yr.	20 yr.
≥0.2mm	Gravel, coarse to fine sand	Settlement(1)	100%	100%	100%	90%
≥0.075mm	Fine sand	Settlement(1), filtration(2)	100%	100%	90%	65%
≥0.04mm	Coarse silt	Settlement(1), filtration(2)	100%	55%	35%	25%
≤0.04mm	Medium to fine silt & clay	Filtration(1), settlement(2)	50%	10%	~	~

Setting Limits for Acceptable Site Discharge for Sediment Control

Setting discharge limits for the site are addressed in Section 2.3.2. The By-laws require that site runoff should not compromise neighbouring and downstream properties, and this includes the receiving stormwater networks and streams. Damage to these systems can result in severe erosion that may be the cause of the bulk of the stormwater sediment. The cost of repair can be high and experience in Johannesburg shows that the problem may persist for many years, resulting in extensive loss of river bank material and a substantial change in the state of the receiving streams.

For this reason, the process to determining the acceptable discharges from a site must include consideration of the hydraulic capacity and structural stability of the receiving formal and natural drainage systems. It should indicate the changes in stormflow in these systems due to the development of the site and it should calculate the likelihood of damage to the receiving systems. An inspection of the river bank material and erodibility, vegetation cover and flow velocities will be needed in such an assessment.

The extent of the downstream network to be considered must be determined by the stormwater engineer, and the calculations will demonstrate the effectiveness of this. Catchment management plans, where available, must be considered in this assessment. The risk of erosion will be assessed for all the design storms and durations as set out in Section 2.5.

Erosion & Sediment Control

Literature on erosion and sediment management practices is extensive and wide ranging and, in some cases, manuals run into multiple volumes. In this version of the City of Johannesburg Stormwater Design Manual the Best Management Practices are collated into three categories which may be developed over time. While the techniques are prescriptive, the methods are not and the developer and professional engineer are left to develop the most suitable approach in each case. It will be the responsibility of the professional engineer to demonstrate the performance of the practices to be employed on the development site, and to indicate the monitoring and maintenance requirements.

The three categories of Best Management practices for the control of erosion and sediment on a development site are:

- Planning,
- Erosion control,
- Sediment capture and disposal.

2.3.3 Best Management Practices: Erosion and Sediment Planning

Planning for erosion and sediment is central to successful sediment management on a development site. This is applicable to both minor and major sites. The professional engineer must, as part of the site drainage plan, prepare an Erosion and Sediment Control Plan (ESCP) that addresses the following:

- A risk assessment of sediment yield during construction, including zones of high, medium and low risk. Show separation of the drainage of clean and dirty runoff zones.
- Presentation of the post-construction erosion and sediment management facilities and the integration of these facilities into the sediment management of the construction site.
- A description of the anticipated sediment type. This will include geotechnical analysis of the soil types (particle size distribution, specific gravity, plasticity index), as well as imported materials. The risk assessment should include contamination risk, with a chemical description of the contaminant(s).
- This should also include an indication of the dates and durations when these areas will be exposed. Where possible show optimum use of dry season construction. A scheduling of

exposed areas will be required on major sites and must demonstrate that exposed areas are kept to a minimum at all times.

- Description of methods for storage of building materials and the handling of rubble, spoil, etc.
- A description of the receiving environment and aspects sensitive to erosion, sediment deposition or suspended sediment.
- A description of soil stabilisation BMPs to be applied for access roads, excavated areas and stockpiles (Clauses 17, and 19 to 30).
- A description of sediment treatment BMPs in the form of settlement and filtration, and an evaluation of the effectiveness of these measures, including a discussion on retention times compared to expected settling times of the sediment. These will be an integral part of the development site stormwater system.
- Use of vegetated systems for erosion and sediment control, and the early establishment of these before the main site clearing and construction activities begin. These may include vegetation buffers, vegetation lined channels, energy management, sediment filtration and vegetated settlement ponds.
- On major sites, the anticipated performance of the BMPs must be demonstrated using the same range of design storm tests undertaken for attenuation and retention facilities.
- Monitoring requirements must include suspended sediment sampling at off-site discharge points during storm events, logging sediment capture volumes.
- The ESCP must also set out the maintenance and monitoring requirements for the erosion and sediment control system, including frequency of renewal of soil stabilisers, methods for cleaning BMP filter systems and requirements for emptying settlement facilities.
- Disposal of sediment must be clearly stated, including expected contamination and special requirements for disposal. Testing and monitoring for contaminants in sediments should be addressed.

The ESCP must be signed off as part of the stormwater drainage plan (SDP) prior to start of construction. It will also form part of the ECO reporting where suspended sediment sampling, sediment volume monitoring and any water quality testing is reported. Adaptations to any of the erosion and sediment control facilities must be reported.

2.3.4 Best Management Practices: Erosion Control

The following measures are considered best practice. The detail and application may vary according to site conditions and season and the most appropriate design should be researched by the professional engineer.

Table 3.3: Erosion Control BMPs.

Erosion Control BMP	Description & examples	Minor Site	Major Site
Minimise exposed areas and only excavate when necessary	Scheduling during site and construction planning	✓	✓
Rainfall energy dissipation, suitable for stock piles, spoil heaps, small exposed areas, etc.	• Grass & vegetation mulching, • Shade cloth • HDPE sheeting	✓	~
Short-term revegetation	• Hydromulching, hydroseeding • Sodding • Fibre weave blankets	~	✓
Long-term revegetation	Early establishment of parts of the final landscaping and green stormwater solutions, which can perform sediment treatment functions during construction.	✓	✓
Cellular confinement systems (most suited to slope stabilisation)	• Manufactured geotextile systems	✓	✓
Interception filters	• Fibre weave or geotextile upright barrier across the slope • Manufactures products.	✓	✓
Interception drains (best suited to large exposed slopes)	• Similar to agricultural contour, installed across the slope • Interception drains set at flatter slopes to reduce flow velocity	~	✓
Riprap armouring (best suited to drain liners)	Rock, waste rubble or large gravel cladding (depending on slope)	~	✓
Fabricated liner systems	There are a range of fabricated liners available in SA that are suitable for erosion control, particularly as drain liners.	✓	✓
Vegetated lined systems	Use of grasses, sedges and similar vegetation as natural liners for storm drains. These are good for energy management and erosion control, but need early establishment.	~	✓
In-line energy control structures (structures used in the drainage network to manage velocity and depth of stormwater flow)	• Weir structures, sand bags, gabions, located along storm drains to reduce hydraulic gradient and flow velocity. • Drop structures, used for conveying stormwater down steep slopes. • Energy dissipaters & ”level spreaders” (typically used at outfalls) discharge concentrated stormflow over a wide spillway	✓	✓

Assessing stability of temporary erosion protection works

Planning is as critical for ensuring the stability and performance of temporary works as it is for permanent works. The following apply:

- Temporary erosion protection works need to be installed and stabilised before pressed into operation on a construction site. Hence the employment of vegetated systems needs to be adequately planned such that sufficient time is allowed for the establishment of vegetation. Lined systems may be required if time is too short.
- Hydraulic structures and conveyance systems for major sites need to be sized and designed for capacity and stability. Hydraulic capacity must assume worst case runoff conditions. Hydraulic resistance parameters must be clearly defined and appropriate to the lining intended.
- Hydraulic structures and conveyance systems for minor sites need to be checked for hydraulic gradient (slope) and the consequences of overtopping in a large storm event.
- Flow velocities in conveyance channels should be kept as low as possible, and may not exceed 3 m/s. Lower velocities may be needed for unlined or vegetated lined channels. Design velocities must be suitable for the lining of the channel, the erodibility of the subgrade, and the size and stability of receiving structures. Channel gradients may be flattened to reduce flow velocities by the introduction of energy breaks (e.g. small weirs) in the channel, or by increasing flow resistance (e.g. by large stone or cobble lining, or the introduction of vegetation). The latter will reduce channel hydraulic capacity and the channel size should be increased.

2.3.5 Best Management Practices: Sediment Capture and Disposal

The following measures are considered best practice. The detail and application may vary according to site conditions and season and the most appropriate design should be researched by the professional engineer.

Designing Sediment Settlement Facilities

The design of a settlement treatment facility will require knowledge of the nature of the sediment (grading and specific gravity) and the retention time in the facility (a function of the flow rate and size of storage). The samples selected for grading must demonstrate that they are representative of the material likely to be eroded. Typically, this will look at all erodible material on site, including soils, excavated areas, stock piles and spoil heaps. The flow rates will be determined from the storm runoff calculations as set out in Chapter 5. The stormwater engineer must provide the calculations demonstrating the performance of the selected settlement treatment facility.

Table 3.4: Sediment Capture BMPs.

Sediment Control BMP	Description & examples	Minor Site	Major Site
Maximise use of vegetation buffers around the construction site, and along the site boundaries. Construction site runoff may discharge directly into these buffer areas.	Grassed swales are particularly effective. Maintenance should be minimal and grass cutting is ideally avoided. However these areas need protection from construction traffic, stockpiling and dumping, and should be fenced off. Stormwater collection facilities may be required on the down slope side of these buffer areas.	✓	✓
Sediment trap and filter barriers (usually applied in locations where sheet flow will occur)	• Swales (as above) where space allows, • Fibre weave or geotextile upright barriers installed across the slope, • Hay bales across the slope (properly joined and embedded)	✓	✓
Stormwater inlet filters (for sediment trapping at kerb inlets, drop structures, etc.)	• Gravel "sausages" made from geo-fabrics, • Geo-fabric barriers	✓	✓
Sediment traps (settlement basins) These must be designed as an integral part of the stormwater network and must meet performance requirements for design storm size and trap efficiency. They are often located before off-site discharge, and upstream of key stormwater control facilities (e.g. attenuation dams), but they should be considered for use throughout the stormwater network.	• Designed and constructed for the specific sediment type and design storm event. Storage volume is critical and dimensions are important. • Wide range of options including concrete structures, excavated ponds, over-sized channel sections. • Lined, unlined and vegetated sediment traps can be considered, depending on water quality, erosion risk and maintenance requirements. • Adaptation of attenuation ponds and retention ponds may be considered. • Performance requirements (storm size and trap efficiency) must be clearly defined.	✓	✓
Litter traps	The effects of blockages on stormwater systems due to litter can be rapid and severe. Stormwater systems are therefore vulnerable to failure due to litter. Management of litter from on-site sources is best achieved through effective litter collection rather than litter traps installed within the stormwater network. However, if still required, litter trap facilities may be included in on-site stormwater systems and must be approved by the Agency or EISD. Note that monitoring and maintenance will be key considerations.	✓	✓

Designing Filtration Facilities

Design of filtration systems is dependent on each situation. Narrow filter barriers are typically applied to areas where sheet flow occurs. Spacing of the strips will be dependent on slope and area. They can be vulnerable to sediment build-up and damage in storm events and require inspection and repair after each storm event.

More effective filter strips are vegetated strips of land that can receive overland flow from large areas of the site, and even concentrated outfalls if provided with energy (velocity) dissipaters and flow spreaders. The filter strip should be on an even, shallow gradient, with a dense vegetation cover (e.g. bush grasses, sedges, etc.). The width of the strip should be a minimum of 4m, but ideally 6m or more. Sediment management on the filter strip is important, to maintain an even gradient and to avoid channels forming with risk of erosion.

Dewatering flooded areas on site (trenches, pits, etc.)

Rainwater collecting in pits and trenches on a site may contain high levels of suspended sediment. Overflow from all flooded areas of the site must be captured in the stormwater management system and associated sediment control facilities. Where dewatering takes place, the sediment discharge limits shall be as per Table 3.2 for the 1.01 year design storm event, and any of the sediment containment BMPs may be considered. Ideally, the water will be left in the pit or trench long enough for settlement of the bulk of the sediment, so that filtration is all that is required.

Control of vehicle-borne mud from the site

Sites in Johannesburg are likely to have high clay content in the soils and this will lead to tracking of mud from the site onto public roads on the wheels of construction vehicles. Access points to and from the site are generally targeted as the best locations to manage this, although on a major site the main internal roads may be treated in the same way. This is the construction of a stabilised pad that will assist in the removal of mud from vehicle tyres. The basic requirements are as follows:

Aggregate size:	G5 (50-60mm), placed on a geotextile layer where required.
Depth of layer:	150mm (minimum).
Dimensions:	Width = full width of the access point.
	Length = 20m (minimum).
Drainage:	The stabilised pad must be adequately drained to prevent submergence during storm events, and to allow washing when required.
Washing:	Provision for washing may be required in times when mud is not removed by vehicle movement alone. Drainage of the pad should discharge to a settlement pond with a pump facility for jetting the tyres and thus recycled for tyre washing.

Monitoring of the system is critical and may be combined with any weighbridge and security operations for the site. Response to mud tracking off-site should be immediate. Requirements of the By-laws (Clause 24) include the cleaning of public roads by the end of the working day.

Disposal of Sediment

Both settlement facilities and filter strips will accumulate sediment. For the facilities to continue to perform their function, sediment will need to be removed on a regular basis.

Disposal of sediment will depend on the nature of the sediment (as defined by the grading of the material and any organic content) and any contamination of the sediment. Contamination will include any detergents, hydrocarbons and cement commonly found on construction sites, or any other pollutant. Polluted sediments must be collected and disposed of at a registered waste disposal facility. All off-site disposal should be at a licensed waste disposal facility. Any alternative off-site disposal must be authorised by a manger of the Agency after consultation with EISD.

The developer and contractor may also obtain exemption from off-site disposal if the sediments are pollution free and can be recycled on site. This may include returning building material to stock piles, or mixing into the topsoil and landscaping material if suitable. Exemption will need to be obtained from the Agency after consultation with EISD before this approach can be adopted.

2.3.6 Best Management Practices: Outfall Energy Management

If the target of ensuring that post development discharge is similar to pre-development conditions, both in peak flow and volume, the requirement for energy management (i.e. velocity management) at the outfall from the site should be minimal. However, if post development discharge is significantly greater than pre-development conditions, it is likely to destabilise the receiving drainage network, rivers and streams.

The design of energy management outfall structures can vary significantly from site to site. The most appropriate design in terms of detail and application should be researched by the professional engineer. However, the following principles are considered best practice:

- It is **NOT** ideal to install energy management controls in the receiving stream or drainage line. Instead, the outfall from the site should ensure that site discharge flow rates are already at the preferred velocity **BEFORE** entering the receiving system.
- The maximum velocity of 3m/s is a guideline. Site specific conditions may require velocities lower than this. The professional engineer must assess this for each outfall and recommend appropriate maximum velocities.
- Energy reduction is achieved either by reducing the hydraulic gradient, or by increasing the flow resistance in the conveyance system. A combination of the two may also be used.
- Reducing the hydraulic gradient may be achieved by introducing a drop structure (a weir, attenuation dam, etc.), or by reducing the gradient of the conveyance channel.
- Increasing flow resistance can be achieved by introducing energy blocks into the lined systems, though this is an old approach. Alternatives include stone pitched liners, careful placement of large rocks or using vegetated channels. **Caution:** Increasing flow resistance requires larger conveyance channels, especially in the case of vegetated channels. For example, reeds are a very effective form of velocity management but can reduce the hydraulic capacity of a channel by a factor of 10.
- Vegetated filter strips may also be used as a very effective velocity control measure. Storm runoff is discharged over a length of a filter strip which then drains into the receiving watercourse or drain. This will also provide a measure of sediment trapping and water

quality treatment. **Caution:** Managing flow distribution over the filter strip will be critical to its success.

2.3.7 Monitoring and Maintenance of BMPs

Monitoring and maintenance of erosion and sediment control facilities is critical to the performance and success of the system. The developer and contractor must ensure that a person (or persons) is allocated to this task. Actual on-site monitoring and maintenance will be dependent on the site, the drainage network and the requirements in the ECSP, and will need to adapt to storm conditions. However, the following must be included:

- A rain gauge must be maintained on site, and rainfall recordings taken at least daily, typically at 08:00 each day. More frequent readings may be taken during storm events.
- Daily inspection of all erosion and sediment control facilities in the wet season (October to March), and every week in the dry season (April to September).
- Inspection of all erosion and sediment control facilities should also take place after large storms.
- Sediment removal from settlement facilities needs to be done to maintain their performance. Sediment disposed off-site needs to be taken to a licensed waste facility.
- Sediment maintenance of filter facilities is required to ensure their continued function. Filter barriers require inspection and repair after each storm event. Filter strips and vegetation buffers may need sediment build-up to be raked to maintain an even gradient.
- Water quality sampling (both TSS and Turbidity) must be undertaken at all site outfalls, and at main settlement facilities within the site. Sampling during storm events is required; approximately weekly at major sites and approximately monthly at minor sites.
- Reporting of maintenance and monitoring must be carried out in accordance with the ESCP.

2.4 CHAPTER 4: GRADING

2.4.1 Chapter 4 By-laws

Grading plans

31. (1)(a) A grading plan in respect of any proposed grading on a development site must, subject to the provisions of section 9, be prepared.

> A grading plan is required for any site activity that requires a permit in terms of section 5 of the By-laws. The application for the Grading Plan shall be in accordance with section 7 of the By-laws. The application for the Grading Plan shall be prepared by an approved professional engineer if any of the conditions stipulated in section 9 of the By-laws exist.

(b) A plan contemplated in paragraph (a), must incorporate a plan of every retaining structure which is greater than 1,5m in height which is to hold graded soil in place, if such structure has not been included in building plans approved under the National Building Regulations and Building Standards Act, 1977.

(2) A grading plan contemplated in subsection (1), must –

(a) indicate both temporary and permanent erosion and sedimentation stormwater control facilities on the development site concerned for a period from the commencement of site development activities, continuing without interruption to the completion of the development on that site;

(b) specify the construction sequence for the establishment of every such facility; and

(c) conform to every applicable requirement and standard for erosion and sedimentation control specified in Chapter 3.

Drainage

32.(1) The requirements of Chapter 5 relating to stormwater management must be complied with prior to the commencement of any grading on a development site.

(2) The characteristics of all stormwater from a development site with regard to quality, flow rate, velocity and frequency must be the same as the stormwater runoff which would have flowed from the development site in its natural condition prior to commencement of any site development activity.

> The minimum acceptable pre-development values for stormwater with respect to quality, flow rate, velocity, and frequency, are those that would have occurred if the property had been in its natural condition i.e. prior to the discovery of gold on the Witwatersrand. If the development site is in its natural state, these baseline data can be obtained by monitoring runoff from the site for at least two hydrological years prior to the commencement of construction. It is, however, unlikely that any site will be in its natural condition so baseline data can be generated by hydrological modelling using parameters applicable to the site in its natural condition. The Stormwater Management Report contemplated in section 7 shall give details of the parameters used and the results of the modelling.

(3) Any stormwater runoff which would have flowed onto a development site naturally, must be accepted onto that site, and must be discharged from that site to a natural watercourse or a municipal stormwater drainage system.

Change in topography of development site

33. (1) The maximum surface gradient resulting from any grading activity on a development site may not exceed 3 m horizontal to 1 m vertical : Provided that such gradient may be exceeded, subject to the prior approval in writing by an authorised official if he or she is satisfied on the basis of engineering calculations prepared by a professional engineer, that surface erosion on the development site concerned can be controlled to an erosion rate equal to a stabilised gradient under the same conditions as those existing on the development site in its predevelopment condition.

(2) (a) Any property, public road or other municipal infrastructure which is adjacent to a development site must be protected from stormwater damage occurring during grading operations.

(b) If any damage contemplated in paragraph (a) occurs, an authorised official may, by written notice served on the developer concerned, require him or her to take the steps specified in the notice to restore such damage within a time so specified and to prevent a recurrence of such damage.

(c) Any damage contemplated in paragraph (a), must irrespective of whether a notice has been served in terms of paragraph (b), forthwith be restored by the developer concerned at his or her own cost.

(d) If there is a failure to comply with paragraph (b) or (c), the Council may take the steps necessary to restore the damage and may recover the cost thereof from the developer concerned.

Maintenance

34. Any erosion and sediment control, and stormwater facility and drainage facility relating to grading, must be maintained in good operating condition at all times, as required by section 28.

2.5 CHAPTER 5: STORMWATER MANAGEMENT

2.5.1 Chapter 5 By-laws

PART 1: MAJOR DEVELOPMENTS

Application

35. If a proposed development on any property constitutes a major development, the requirements of this Part apply in respect of the development site concerned.

Development activities

36. (1) If one or more of the following conditions exist on a development site, the requirements of this Part apply to the maximum extent practically possible in respect of that site, and in respect of any adjacent property which is part of the development:

> If the applicant believes that it is not practically possible to meet the requirements of this section a detailed explanation of why that is the case shall be included in the application prepared in accordance with section 7. A relaxation of the requirements of this section may only be given by the Agency after consultation with the City of Johannesburg EISD.

(a) a development site greater than 4000 m^2 in area in size with 40 per cent or more impervious surface, prior to commencement of the development;

> This section shall apply to any development site greater than 4 000m^2 in area irrespective of the proportion of impervious cover either before or after completion of the development.

(b) a development site from which stormwater is discharged to a watercourse or water body which has a water quality problem documented in the records of the Council or the Agency, and includes, but is not limited to, a watercourse and water body –

(i) listed in a report required under the National Water Act, 1998, and designated as not being beneficially used; or

(ii) listed under the National Water Act, 1998, as not expected to meet water quality standards or water quality goals contemplated in that Act ; and

(c) a development site in respect of which the need for stormwater control measures additional to those applicable to that site has been identified by an authorised official.

Approved hydrological methods for design

37. (1) For the purposes of any estimation of peak stormwater runoff rate used in the design of any stormwater quantity control facility, a hydrograph method of analysis approved by the Agency must be utilised.

> A hydrograph method shall generate a continuous time series of discharge against time of sufficient duration to show the trend of the falling limb of the hydrograph after the end of rainfall. The application shall contain a description of the methodology used and a motivation as to why the chosen method is appropriate for use on the site.

(2) Any storage facility that forms a part of a stormwater quality control facility, must be designed by using a method approved by the Agency.

The design of a storage facility must use a recognised routing calculation method to compute the outflow hydrograph from the inflow hydrograph and the stage/storage and stage/discharge characteristics of the basin. If the purpose of the basin is to reduce peak discharge only, then a simple reservoir (level pool) routing calculation will be sufficient. If the basin is to be used for longer duration storage with the intention of reducing volume or frequency of discharge, or of improving water quality, then the computation method used shall take account of infiltration and evapotranspiration losses and the physical, chemical and biological processes that take place in the water body.

(3) Any calculation method used for a design contemplated in subsection (1), must be described, the value of any parameter and variable must be stated, and the reason for selecting a specific range of values must be set out in a design report for a proposed stormwater management strategy for the property concerned, prepared on behalf of a developer and such report must be submitted to the Agency for approval.

Suggested values for some parameters are given in Appendix E. Runoff and infiltration parameters are, however, highly dependent on site characteristics. The stormwater management report shall describe and give reasons for the selection of all parameters used.

Stormwater quantity control

38. (1) Subject to the provisions of subsection (2), the following requirements for stormwater quantity control apply :

(a)(i) All stormwater entering a development site in its predevelopment state from a depression or conduit, must be received on that site at a naturally occurring or otherwise legally existing location;

In accordance with the Common Law, a downhill property must accept all natural stormwater runoff from a higher lying property. If the runoff is concentrated either in time or space then the neighbours must agree on an acceptable discharge point onto the lower lying property and route that the runoff must follow across the lower property. The cost of any improvements necessary to allow the flow to cross the lower property safely and conveniently shall be borne by the higher lying property or properties in proportion to their contributing catchment areas

(ii) all stormwater leaving a development site must at all times during and after development, be discharged at a naturally occurring or otherwise legally existing discharge location so as not to be diverted onto or away from any adjacent downstream property : Provided that a diversion which will correct an existing downstream stormwater problem, may, on written application by a developer on a form prescribed by the Agency, be permitted in writing by an authorised official;

(iii) for the purpose of this paragraph "naturally occurring location" means the location of any watercourse, channel, depression or marshy area existing as an established system, identifiable on a topographic representation of the property in the records of the Council, either from a map, photograph, site inspection, decision of a court of law or other means approved in writing by the Agency;

(b) the post-development peak stormwater discharge rate from a development site for a 5- to 25-year recurrence interval design storm event of any duration from 0.25 to 24 hours, or any other design storm event stipulated by the Agency up to and including a 50-year design storm event, may not at any time exceed the pre-development peak stormwater runoff rate from that site for the same design storm event;

The maximum post-development stormwater discharge rates shall not exceed the pre-development discharge rates for the entire range of recurrence intervals for events of any duration. The pre and post development discharge rates shall be determined for a range of recurrence intervals from three (3) times per year to 100 years and for a range of durations that include 0.25h; 0.5h; 1.0h; 6.0h; 12.0h and 24.0h and curves plotted to demonstrate that the post-development peak does not exceed the pre-development peak discharge rate for any of the recurrence intervals or the durations calculated, and is unlikely to exceed the pre-development peak for any intermediate duration.

Alternatively, continuous simulation can be used to determine frequency of runoff and flow duration frequency curves. These results can then be used in the SWMR to show that characteristics of the post-development runoff do not differ from the pre-development characteristics.

This section shall be read in conjunction with section 32.(2), therefore:

- The characteristics of the runoff from the site after development must meet the target values for peak discharge, volume of discharge, frequency of runoff and quality of runoff as described later in this Section or in the applicable appendices.
- The methodology for demonstrating compliance with this clause must be described in detail in the Stormwater Management Report submitted in accordance with section 7 of the By-laws.

Although this section requires analysis for events of recurrence interval up to 50 years the Stormwater Management Report should consider at least the 100 year recurrence interval event, and consider rarer events where appropriate. The requirement for the determination of the 100 year floodline in terms of Section 144 of the Water Act (Act 36 of 1998) has been interpreted by the courts as meaning that any event with a recurrence interval of less than 100 years should be anticipated by a reasonable engineer. Only if the recurrence interval exceeds 100 years can the event be regarded as “force majeure”.

(c) any closed depression which receives stormwater discharge from a development site must be analysed using a hydrograph method for routing stormwater, and infiltration relating to such depression must be addressed, if relevant;

For a closed depression without a defined overflow the expected 100 year maximum water level should be evaluated using a water balance analysis. This analysis shall be:

Either over a period of 3 years using motivated values for evapotranspiration and infiltration as outflows and measured rainfall records to estimate inflow. The maximum time step shall be one month. The first year of the analysis shall be for a year with the average annual rainfall for the site, the second year shall be for the 100 year RI annual precipitation, and the 3rd year shall be an average year as used for year

1. If rainfall records for the 100 year RI 1 year depth are not available the monthly values can be estimated by using a Gumble plot to estimate the 100 year rainfall depth and by using the monthly values of the best available data adjusted in proportion to the ratio of the annual rainfall depths.

<u>Or</u> a long term analysis using a set of statistically generated synthetic monthly rainfall values. At least 5 analyses with different random seeds shall be done and the minimum duration for each analysis shall be 1 000 years. (Guidance for this method can be taken from water resources practice)

The report required in terms of Clause 7 shall describe in detail the methodology used and the parameters assumed.

(d) if a proposed development will result in a discharge of stormwater to a closed natural depression that has a water surface area greater than 500 m² at overflow elevation, the following requirements must be complied with for the purpose of an analysis contemplated in paragraph (c) :

(i) the stormwater runoff hydrograph from a 100-year design storm event, of any duration from 24 hours to seven days from the pre-development catchment area draining to a closed depression contemplated in paragraph (c), must be routed into that depression using only infiltration as outflow from the depression;

(ii) if a portion of such closed depression is located off the development site concerned, the impact of stormwater on any adjacent property must be taken into account;

(iii) if overflow of such closed depression occurs, the closed depression must be analysed as a detention or infiltration pond, to determine whether the depression can safely cope with the expected quantity of stormwater;

(iv) no discharge from a closed depression may exceed the discharge rate from that depression immediately prior to the development, resulting from a 2, 10, 25 and 100-year design storm event of any duration from 0.25 hours to seven days and a control structure to regulate outflow from such depression, an emergency overflow spillway and an access road must be provided and other design criteria required in writing by the Agency must be complied with;

(v) if a closed depression will be maintained by the Agency, a servitude in respect thereof must, subject to the provisions of section 43(1), be registered in favour of the Council to protect the Council's rights; and

(vi) if a development will create a stormwater runoff from the property concerned to a closed depression located off the development site, the volume of runoff discharged may not be increased beyond the effect of a 2, 10, 25 and 100-year design storm event of any duration from 0,25 hours to seven days;

(e) any stormwater quantity control facility to be provided, must be designed to meet, as a minimum performance standard, the requirements of this section, unless –

(i) stormwater from a development site will discharge to a Council stormwater system approved by an authorised official to receive stormwater from that site; or

(ii) stormwater from a development site discharges to a receiving body of water and it can be demonstrated by the developer, to the satisfaction of an authorised official, that stormwater quantity control is not warranted;

> If the developer believes that the requirements for the control of stormwater runoff from the site is not warranted, the Stormwater Management Report shall contain a detailed motivation for the complete or partial relaxation of the stormwater management requirements. The stormwater management requirements may be relaxed by an authorised official of the Agency after consultation with appropriate officials of the City of Johannesburg EISD. A relaxation of the stormwater management requirements will only be valid if specifically noted in the site development activity permit issued in terms of section 7.

(f) if the conditions downstream from a development site are determined by an authorised official to be exceptionally sensitive to potential stormwater discharges from that site compared to the situation immediately prior to the development, that official may, by notice in writing, require a factor of safety to be applied in respect of the total storage volume of any attenuation and detention facility and a reduction of the stormwater released from the site concerned;

> The decision of whether downstream conditions are sufficiently sensitive to require the application of a factor of safety shall be at the discretion of the official of the Agency after consultation with appropriate officials of the City of Johannesburg EISD.

(g) no attenuation facility or open stormwater quantity control facility may be located –

(i) in a public road;

(ii) on any land zoned as public open space under an applicable town planning scheme, without written approval of the Council ;

(iii) in any floodplain below the 50-year floodline; or

> The construction of an attenuation facility below the 100 year floodline that requires excavation or infilling of more than 5 m^3 of material is a listed activity in terms of regulations in terms of the National Environmental Management Act (NEMA) and will therefore require authorisation from the Gauteng Department of Agriculture and Rural Development (GDARD). Moreover, this is regarded as an alteration of the bed or banks of the watercourse in accordance with Section 21 of the Water Act and will therefore require a Water Use Licence from the Department of Water and Sanitation (DWS). Jane to re-word

(iv) in any wetland without approval of the Department of Water Affairs and Forestry;

(h) reasonable access to any stormwater facility to enable ease of maintenance, as determined by an authorised official, must be provided;

(i) if conditions on a development site are appropriate for infiltration of stormwater and ground water quality on that site is protected, streambank erosion control must be implemented, utilising infiltration to the fullest extent practicable; and

Retention storage, combined with infiltration and evapotranspiration, are the preferred methods for runoff volume reduction. Suitability of the site for infiltration is dependent on soil type and depth, proximity to vulnerable structures, etc. If infiltration is inappropriate for the site, the Stormwater Management Report shall explain why, and offer alternative methods for the reduction of runoff volume and frequency.

(j) any quantity control facility contemplated in paragraph (g), must be selected, designed and maintained according to the manual, and may not be built within a vegetated buffer, except for a stormwater conveyance system approved in writing by an authorised official and subject to the provisions of the National Environmental Management Act, 1998 (Act No 107 of 1998).

Quantity control facilities shall be designed to meet the target characteristics for stormwater runoff given later in this Chapter.

Impervious underground tanks intended specifically for peak discharge attenuation are not acceptable unless more than 80% of the volume of the tank is allocated to long term storage for the purpose of harvesting rainwater.

The Stormwater Management Report shall describe in detail the reasons for the selection of the various components of the management facility and give details of the design and calculation methods used. This Report shall contain details of the maintenance requirements for the facility, including arrangements for inspection of the facility from time to time by officials of the Agency. The maintenance section of the Stormwater Management Report shall contain the name and contact information of the person responsible for the maintenance of the facility.

The developer and all subsequent owners of the property shall ensure that the maintenance section of the Stormwater Management Report is passed on to each subsequent property owner. The seller of the property shall be responsible for informing the Agency of the name and contact information of the new person responsible for maintenance of the facility.

(2) The Agency may, if it considers that circumstances relating to stormwater management in respect of any development so requires, by notice in writing, require the developer concerned to comply with any additional requirement relating to control of the peak discharge or quantity of stormwater, specified in the notice.

(3) No person may do anything which may interfere with the proper functioning and the ease of maintenance of any structure or facility contemplated in this section.

Combination of quality and quantity control facilities

39. Any quality control stormwater facility may be incorporated into the design of a stormwater quantity control facility if such combination will facilitate water quality control.

Quality control requirements

40. (1) Subject to the provisions of subsection (2), the following requirements for stormwater quality control apply :

(a) A best management practice concerning stormwater quality control must be utilised in respect of any stormwater facility relating to stormwater quality in respect of a development site, to the maximum extent practically possible;

The target values for the quality of stormwater runoff are given later in this section. The Stormwater Management Report shall give details how these targets will be achieved in accordance with international best practice. If the developer believes that the target values cannot be practically achieved, then the Stormwater Management Report shall explain in detail why that is the case and contain proposals for alternative target values. Relaxation of the target values may be allowed by an authorised official of the Agency after consultation with an appropriate official of the City of Johannesburg EISD.

(b) a stormwater facility for any treatment relating to the quality of stormwater must be of a size sufficient to hold and treat stormwater runoff from a 2-year recurrence interval design storm event of any duration;

(c) no structure relating to stormwater quality control may be built within a vegetated buffer, other than a conveyance system approved in writing by an authorised official;

(d)(i) treatment of stormwater discharge must be provided by utilising a wetpond or biofiltration or both, based on a best management practice : Provided that another best management practice may be utilised subject to the granting of a deviation or exemption from the provisions of the manual in terms of section 61;

Retention basins (wet ponds) and biofiltration are the preferred methods of managing the quality of stormwater runoff. Any alternative best management practice for improvement of stormwater runoff quality shall be described in detail in the Stormwater Management Report. The description shall contain details of the calculations used to show that the practice will work and examples of its application internationally. Innovative water quality management practices may be permitted at the discretion of an authorised official of the Agency following consultation with an appropriate official of the City of Johannesburg EISD.

(ii) a wetpond is required for a development site on which an impervious surface greater than 2 ha for use by motor vehicles, will be created by the development from which stormwater will discharge –

(aa) directly to a municipal or private regional stormwater facility or closed depression without providing stormwater quantity control on the development site concerned ; or

(bb) directly or indirectly to a water course or wetland within 1 km downstream of the development site concerned;

(e) all stormwater must, prior to its discharge to a stormwater facility based on an appropriate best management practice and designed to utilise infiltration, pass through a stormwater treatment facility designed to remove suspended solids; and

For the purposes of this section the definition of suspended solids shall include floating debris. The Stormwater Management Report shall contain information on the expected particle size distribution of the likely suspended solids and information on the duration of retention required to ensure effective removal of 95% of the suspended material. The maintenance section of the Stormwater Management Report shall contain details of how the accumulated sediment will be removed from the treatment facility.

(f) all stormwater from a development site on which heavy construction equipment is used, maintained or stored or on which any petroleum product is stored or transferred to such equipment or any vehicle, and from any vehicle washing bay, must be treated by an oil/water separator of a size effectively to prevent pollution of such stormwater.

(2) The Agency may, if it considers that circumstances relating to stormwater quality control in respect of any development so require, or that the requirements of subsection (1) do not afford adequate protection for any water quality sensitive area on site or within the catchment area where the property concerned is situated, by notice in writing, require the developer concerned to comply with any additional requirement, relevant to such control, specified in that notice.

PART 2: MAJOR AND MINOR DEVELOPMENTS

Application

41. If a proposed development on any property constitutes a major or minor development, the requirements of this part apply in respect of the development site concerned.

Stormwater drainage facilities

42. (1) An on-site stormwater drainage facility must be provided on every development site and must be of sufficient capacity to convey –

(a) stormwater without flooding or otherwise damaging any existing or proposed structure;

(b) any post-development peak stormwater runoff from a development site resulting from a 5-year recurrence interval design storm event, of any duration from 0.25 to 24 hours; and

(c) any existing stormwater runoff upstream from a development site that will be conveyed through that site, taking potential development upstream from the site into account.

(2)(a) In estimating a peak stormwater runoff rate used in the design of a stormwater drainage facility contemplated in subsection (1), either the rational method as described in the manual, or a hydrograph method of analysis approved by the Agency in writing, must be used.

Comment on this clause must be read in conjunction with comment on Clause 37.(1).

The use of the Rational Method for calculations relating to the design of stormwater management facilities is discouraged. This method lumps all of the characteristics of the drainage system into a single value designated the rational "C". Such a gross lumping of parameters militates against subtleties of design and the evaluation of the benefits of distributed stormwater management interventions.

Some variations of the Rational Method allow for the generation of a simplified triangular hydrograph. It should be noted that some literature suggests that the duration of the falling limb of the hydrograph is twice duration of design storm, yielding a hydrograph with a duration of three times the storm duration. This literature is WRONG. It can easily be shown that, for higher values of C, the volume of runoff calculated this way (i.e. the area under the hydrograph) can exceed the total volume of rainfall, thereby violating the continuity principle.

Other variations, for example James (1981), of the Rational Method allow the generation of a more realistic runoff hydrograph by deducting losses from a triangular rainfall hyetograph, multiplying the resulting effective rainfall hyetograph by the area of the catchment and transforming the triangular hydrograph to a smooth curve using Muskingum routing. This smoothed hydrograph is mathematically easier to route through a storage basin.

If a calculation based on the Rational Method is used, it should be noted that the critical storm duration that yields maximum peak discharge from a detention basin is not the same as the critical storm duration that yields maximum peak discharge in the drainage system upstream of the basin, and that the value of the runoff coefficient "C" varies with rainfall intensity, i.e. with both recurrence interval and storm duration.

The use of a computer based model that allows for catchment discretisation and determination of parameters based on the physical characteristics of the drainage area combined with a continuous record of measured rainfall data is recommended.

(b) The selection method, and all parameters or variables used in an estimation in terms of paragraph (a), must be stated and explained in a design report contemplated in section 37(3).

(3)(a) Any existing stormwater facility and any other conveyance facility up to 500 m downstream from a development site that falls within the downstream portion of an off-site stormwater drainage analysis, contemplated in section 12 must have sufficient capacity to convey, without flooding or otherwise damaging any existing or proposed structure, on or off site, a post-development peak stormwater discharge contemplated in subsection (1)(b).

(b) Any pipe stormwater drainage system must have capacity to convey stormwater runoff from a 5-year recurrence interval design storm event of any duration and any such system that conveys stormwater on the surface of land must be capable of conveying the runoff from a 25-year recurrence interval design storm event of any duration.

(4) No stormwater drainage facility utilising a closed conveyance structure such as pipes, may discharge directly onto the surface of a public road.

Servitudes

43. (1) If the Agency at any time decides to accept responsibility for the maintenance of any stormwater conveyance system, on any development site or property, the owner of that site or property must, prior to commencement of such maintenance, register a servitude acceptable to and in favour of the Council for the protection of the Council's rights of inspection and maintenance of and its right of access to such system.

(2) Any stormwater facility that is to be maintained by the Agency and any vehicular access to such facility must be located in a servitude contemplated in subsection (1), in favour of the Council, or located in any open space on Council property designated by the Agency in consultation with the Council.

(3) Any conveyance pipe for stormwater that is to be maintained by the Agency must be located within a servitude contemplated in subsection (1), and an access structure to such pipe must be positioned in a public road reserve so that it can be accessed for purposes of inspection, without entering the property on which such pipe is situated.

Wetlands

44. (1) The following requirements must, in addition to the requirements of section 38, be complied with if stormwater from any development site discharges directly, or indirectly across any intervening property, into a wetland:

(a) The quantity and velocity of any stormwater discharge must be controlled and treated to the extent that such discharge attains a quality in compliance with the requirements of the National Water Act, 1998, the National Environmental Management Act, 1998 and any other applicable law;

(b) a stormwater discharge must maintain the frequency and flow of pre-development conditions, to the extent necessary to protect the characteristic functions of the wetland;

> The Stormwater Management Report shall contain an evaluation of the natural frequency and discharge into the wetland to be used as a target value for the post development runoff, and shall demonstrate how the post development discharge will be managed to meet that target distribution. The Report shall include photographs and a description of the state of the wetland prior to commencement of any construction, and a description of steps that will be taken to ensure that the wetland does not degrade as a result of the stormwater discharge directed into it. The Report shall include and the name and contact information for the person who will be responsible for the maintenance of the constructed wetland.

(c) prior to discharging to a wetland, any alternative discharge location and any natural water storage infiltration opportunity outside the wetland, must be evaluated by a professional engineer and utilised for the stormwater discharge if reasonably practically possible;

> The Stormwater Management Report shall contain a description of the investigation that was carried out to identify possible alternative discharge points.

(2) A man-made wetland which is intended to mitigate for the loss of a natural wetland area may, subject to the provisions of paragraph (e), be designed and used to treat stormwater;

(3) an authorised official may, after consideration of an evaluation in terms of subsection (1)(c) in writing allow a wetland, contemplated in subsection (2) to be constructed and utilised for the discharge of stormwater, provided it is -

(a) constructed in an area which is not designated as a wetland or wetland buffer under the National Environmental Management Act, 1998 or any other law; and

(b) utilised in an area where it will not detrimentally affect any such designated wetland or buffer;

(4) if a wetland contemplated in subsection (3), is not maintained in accordance with the manual for a period of three years, its status as a wetland terminates; and

> The Stormwater Management Report shall contain a section describing how the constructed wetland will be maintained, and the name and contact information for the person who will be responsible for the maintenance of the constructed wetland. On the first anniversary of completion of the constructed wetland, and every second anniversary thereafter, the responsible person shall submit to the Agency a brief report including photographs showing the state of the wetland and confirming that it is being maintained in accordance with the original management plan.

(5) no stormwater facility relating to the discharge of stormwater to a wetland may be constructed within a naturally vegetated buffer, unless that facility has been approved in writing by an authorised official.

(6) The Agency may, if it considers that in any particular case the provisions of subsections (1) to (5) do not afford adequate protection in respect of wetlands and buffers contemplated in that subsection, by notice in writing, require the developer concerned to comply with any additional requirement relevant to such wetland or buffer, specified in that notice.

Regional stormwater facilities

45. (1) If the Agency considers that the public would benefit by the establishment of a regional stormwater facility which would serve as an alternative to the construction of separate on-site stormwater drainage facilities on various properties, it may construct such facility to provide stormwater quantity and quality control for more than one development.

(2) A regional stormwater facility must be located outside the 50-year floodline of any water course.

(3) A developer of a property who agrees in writing to such property being served by a regional stormwater facility must prior to the time of issue of a permit in respect of such property, contribute a reasonable pro rata amount determined by an authorised official, based on the contribution to stormwater runoff from the development site or property concerned to the regional stormwater facility in relation to the total stormwater discharge to that facility, taking into account the cost of the land purchased for, and the design and construction of such facility to, the Council.

(4) If a proposed regional stormwater facility is not in operation at the time of completion of a development on a property that is to be served by that facility, temporary stormwater quantity and quality control facilities must be constructed to the satisfaction of an authorised official. (5) Any temporary quantity and quality control facilities contemplated in subsection (4), must be subject to the terms and conditions of a written agreement on a form prescribed by the Agency, entered into between the Agency and the owners of the properties to be served by a regional stormwater facility established in terms of subsection (1).

Planning of catchment areas

46. (1) A policy, adopted by the Council concerning the management of stormwater in any catchment area, must be used by the Agency to develop requirements for a catchment area for the control at source of stormwater, stormwater treatment and erosion control at any water course and requirements relating to any wetland or other water quality sensitive area.

(2) The Agency may for the purposes of subsection (1), on the basis of a policy contemplated in that subsection, by written notice served on a developer or owner of property, require him or her to comply with any requirement stipulated in that notice, in addition to any requirement of these By-laws.

(3) Any requirement of a policy contemplated in subsection (1), may by notice in terms of subsection (2), be made applicable to the owner of a property on which a development was completed prior to date of commencement of these By-laws, if any stormwater facility or other measure to manage stormwater or to prevent pollution at the time of that development, did not comply with Part D – Urban Stormwater Management of the Guidelines for the Provision of Engineering Services in

Residential Townships issued by the national Department of Community Development in 1983, commonly referred to as the Blue Book.

2.5.2 Stormwater Management Guidelines

Definition of Predevelopment Condition

The hydrological parameters used to determine the predevelopment runoff characteristics of the site shall be those which would have existed prior to the discovery of gold on the Witwatersrand. These parameters shall apply irrespective of the existing condition of the property at the commencement of development

The SWMR shall contain target values determined by the responsible engineer, and shall include details of how these target values were determined. Examples of the determination of some target values are discussed below:

Pre-Development Target Values

In the absence of measured runoff from natural areas with topography, vegetation, soils, and geology similar to the development site target values shall be determined by computer modelling or some other acceptable calculation method. The Stormwater Management Report shall clearly set out and motivate the valued of all parameters used for these calculations. Targets shall be set for volume and frequency of runoff as described below.

Target Volume of Runoff

Summary and Recommended Target for Volume of Runoff
In the absence of measured data, the annual target runoff shall not vary above or below the values given for the relevant quaternary catchment in the Surface Water Resources of South Africa (see Table 5.1) by more than 10%.

The runoff values given in the Water Resources reports are for the total runoff including the contribution of groundwater to river flow, i.e. both direct runoff and delayed runoff in terms of the water balance calculations. The direct runoff should be regarded as 50% of the total runoff unless there are compelling reasons given to select a different value.

The relevant values from WR90 (Midgely, et al., 1994) and WR2012 (Bailey & Pitman, 2015) are given in Table 5.1. The reader is referred to WR2012 for an explanation of the differences in some of the values. The target Mean Annual Runoff (MAR) shall be taken from the most recent available literature.

If the detailed analysis of the GSI options available on the site shows that it is not reasonably possible to meet the target runoff volume, then runoff delayed by 48 hours or more following the storm may be regarded as not contributing to the volume of runoff from the site.

GSIs suitable for the reduction of runoff volume include:

i. Rainwater or stormwater harvesting for domestic or irrigation use;
ii. Retention basins that incorporate infiltration and evapotranspiration measures;
iii. Permeable paving with a permeable base;
iv. Infiltration basins and trenches;
v. Rain gardens and bioswales that incorporate infiltration measures.

Table 5.1: Mean Annual Runoff from Quaternary Catchments

Quaternary Catchment	Location	WR90			WR2012		
		MAP	MAR	% MAR	MAP	MAR	% MAR
		mm	mm	%	mm	mm	%
A21E	North west, Crocodile River	706	54.6	7.7	707	48.4	6.3
A21C	North central, includes the Jukskei, Klein Jukskei, Braamfontein Spruit, Sand Spruit and Modderfontein	682	49	7.2	682	44.7	6.6
A21B	North east, Kaal Spruit, Hennops River	672	19.1	2.8	672	14.6	2.2
C22A	South west, upper Klip River, Klip Spruit	695	31.5	4.5	695	51.2	7.4
C22B	South East, Natal Spruit and tributaries	691	31.7	4.6	691	49.6	7.2
C22D	South, middle Klip River	701	32.6	4.7	701	53.8	7.7
C22H	Far south, Riet Spruit and tributaries	639	21.9	3.4	639	20.3	3.2

Target Frequency of Runoff

In the absence of measured runoff data, it is necessary to use modelling to make an estimate of the onset of runoff from a natural catchment. The values recommended below will be updated from time to time as more detailed modelling is undertaken, or if measured values become available. Any deviation proposed in the Stormwater Management Report shall be supported by detailed modelling with clear explanations of the parameters used in the model.

Runoff commences under two possible conditions:

- Firstly, if the intensity of rainfall exceeds the infiltration capacity of the soil. This may occur if the short duration rainfall intensity exceeds the instantaneous infiltration capacity of the soil, i.e. if $i_t > f_t$, where i_t is the instantaneous rainfall intensity and f_t is the instantaneous infiltration capacity, or when the longer duration rainfall intensity exceeds the equilibrium infiltration capacity f_e. The value of f_t can be calculated from Horton's equation or the Green and Ampt equations using values suggested in Appendix A. This is referred to as "infiltration excess runoff".
- Secondly if the total rainfall exceeds the total infiltration capacity of the soil and the soil becomes saturated and unable to accept any further infiltration. This condition can be modelled using the Green and Ampt equations, which is known as "saturation excess runoff".

The commencement of runoff from natural catchments is a function of:

- Rainfall intensity and duration;
- Soil infiltration capacity, which is dependent on the soil type, with clayey or silty soils having a lower infiltration capacity than sandy soils;
- The moisture content of the soil at the onset of the rainfall event, often referred to as the **A**ntecedent **M**oisture **C**ontent (AMC).

Two possible approaches have been considered for inclusion here: firstly, the use of a range of design storms of various recurrence intervals an durations to estimate a rainfall intensity and duration that would cause runoff to commence; and, secondly, a continuous analysis using a long duration data set of short interval measured rainfall. This second approach is recommended because it eliminates the uncertainty related to antecedent moisture content of the soil and also the error introduced by the assumption of a design storm rainfall distribution.

As a guideline for use with this Manual, commencement of runoff has been calculated using a simple model with Hortonian infiltration analysed using PCSWMM:

- Catchment area 1 ha catchment with overland flow length 100m
- Overland slope 2% and 5%
- Soil types: Sandy loam f_o = 65 mm/h, f_e = 10 mm/h k= 2.988/h[1]

  Clayey loam f_o = 30 mm/h, f_e = 5 mm/h k= 2.988/h
- Triangular storm time to peak R=0.3, duration Td = 20 min to 4 h.

Sandy loam soils are typically derived from acid igneous rocks, such as the granodiorites of the Halfway House Granite, or from coarse grained sedimentary or metamorphic rocks such as the Witwatersrand Quartzites. Clayey to clayey loam soils are typically derived from basic igneous rocks such as Andesite, fine grained metamorphic or sedimentary rocks, such as the Witwatersrand Shales, as well as the Archean Greenstones of the Swazian System. Karst type systems, such as encountered in the areas underlain by Dolomite, have special characteristics not covered here.

By using Horton's infiltration equation, the analysis determined only infiltration excess runoff: the determination of saturation excess runoff would require a more sophisticated computation including the effect of shallow ground water.

a) Target Frequency of Runoff Design Storm Approach

The results of the computations show that the rainfall depth required to initiate runoff is fairly insensitive to catchment slope within the range modelled, but is sensitive to storm duration. Tables 5.2 and 5.3 give the computed values of rainfall depth required to initiate runoff from catchments with sandy loam and clayey loam soils respectively. More details of these calculations are given in Appendix E.

The recurrence intervals of the rainfall depths required to initiate runoff were also calculated using the two different equations for determining rainfall depth that are in common use in Johannesburg. These equations are: 1. the regression equations derived from the coaxial diagram of Midgley (1972) by op ten Noord and Stephenson (1982), that have different equations for coastal and inland area which use the mean annual precipitation (MAP) as the primary parameter; and 2. the equation of Hershfield, as given by Adamson (1982), which uses the 2 year recurrence interval one day rainfall depth (M2) and the average annual lightning flash density (L) at the locality as the primary parameters. The calculated recurrence intervals are given in Tables 5.2 and 5.3, which also show the discrepancy between the values calculated using the two different equations. A comparison of the rainfall depths for storm duration and recurrence interval is given in Appendix E.

[1] k = 2.988/h equivalent to k = 0.00083/s gives a decline of 95% from f_o to f_e over a period of 1 hour

The required source of storm rainfall information is the Design Rainfall Estimator of Smithers & Schulze (2012). Rainfall depths generated by this Estimator have been compared with those yielded by the equations of op ten Noord and Stephenson (1982) and Hershfield (Adamson, 1982). The Estimator reports rain depths as 10th percentile, mean, and 90th percentile. The 90th percentile values should be used for the analysis of stormwater management systems.

Ongoing research has shown that rainfall patterns vary considerably across the Johannesburg Metropolitan Area as shown on the map in Appendix A. Cognisance should be taken of these variations.

The values given in Tables 5.2 and 5.3 indicate the frequency at which infiltration excess runoff can be expected to occur from sandy loam catchments clayey loam catchments. There is a significant difference in the recurrence interval of the rain depth calculated using the different equations discussed elsewhere in the Manual. The Design Rainfall Estimator of Smithers and Schulze indicates that the recurrence interval of surface runoff from sandy loam catchments will be about 2 to 2.5 years, and from catchments with clay loam soils about 1.5 years. The rainfall depths required to initiate runoff that are given in Tables 5.2 and 5.3 were calculated on the assumption of initially dry conditions. The effect of antecedent rainfall is discussed below.

Table 5.2 Rainfall Depth required to initiate Runoff (Dry Sandy Loam Soil)

Td	Rainfall Depth	Recurrence Interval		
min	mm	Stephenson	Hershfield	Smithers & Schulze
20	20.76	1.59	1.05	3.08
30	22.03	1.07	0.83	2.45
45	25.32	1.05	0.80	2.41
60	26.89	0.96	0.73	2.22
90	29.75	0.95	0.67	2.09
120	33.36	1.13	0.69	2.19
240	45.14	2.03	0.78	2.68
480	62.22	4.21	0.94	3.54

Table 5.3 Rainfall Depth required to initiate Runoff (Dry Clayey LoamSoil)

Td	Rainfall Depth	Recurrence Interval		
min	mm	Stephenson	Hershfield	Smithers & Schulze
20	15.75	0.64	0.63	1.73
30	17.41	0.49	0.56	1.55
45	21.02	0.56	0.58	1.67
60	22.68	0.54	0.55	1.61
90	24.34	0.49	0.50	1.45
120	26.17	0.50	0.48	1.41
240	31.14	0.59	0.44	1.33
480	39.25	0.91	0.45	1.39

Table 5.4 summarises the results of the analysis of 53 years (19 449 days) of daily rainfall record from the rain-gauge in the Johannesburg Zoological Gardens (0476040_3). This analysis shows that 25 mm

or more of rain falls on an average of 7 to 8 days per year. It is probable that on most of these days, the depth of rain is spread over a period of longer than one hour, which is the reason that there is an apparent discrepancy between the frequency of total rainfall depths and the frequency of runoff.

The highlighted rows show that the rain depth exceed on average two days per year is about 44 mm and the rain depth exceeded on average one day per year is about 58 mm.

Table 5.4 Rainday Frequency Zoological Gardens

Rain Depth Exceeding	Days out of 19 449	Percent Occurrence	Average occurrence/year
mm	days	%	days
1	3434	17.7%	64.4
2	3034	15.6%	56.9
5	2196	11.3%	41.2
10	1331	6.8%	25.0
25	399	2.1%	7.5
44	**106**	**0.5%**	**2.0**
50	82	0.4%	1.5
58	**51**	**0.3%**	**1.0**
75	22	0.1%	0.4
100	7	0.0%	0.1

The antecedent moisture content of the soil also affects the probability of runoff occurring; a smaller depth of rain will be required to initiate runoff from a wet catchment than from a dry catchment. For example, the integrated form of Horton's equation (Green 1986) shows that for f_o = 65 mm/h, f_e = 10 mm/h and k =2.988/day, about 27 mm of rainfall within an hour will reduce the infiltration rate to the equilibrium value f_e = 10mm/h, and after this any rainfall at an intensity exceeding 10 mm/h will cause runoff. Table 5.5 gives the probability of occurrence of combinations of some rainfall depths over a two day period.

Table 5.5 Probability of a Rainday Following a Previous Rainday

Preceding Day Rain Depth Exceeding	Day Rain Depth Exceeding	Days out of 19 449	Percent Occurrence	Average occurrence/year
20	15	105	0.5%	1.97
15	20	101	0.5%	1.90
10	25	97	0.5%	1.82
5	30	102	0.5%	1.91

b) Target Frequency of Runoff Continuous Model

This approach applied 16.5 years of 5 minute rainfall data for the Johannesburg Botanical Gardens Weather Station to the same 1.0 ha hypothetical catchment used for the design storm approach discussed above. Details of the methodology are contained in Appendix E.

The rainfall record showed rain to have fallen on 1 456 days out of the 6 164 days of record, i.e. on about 24% of days, with a total depth of rain of 10 390 mm that corresponds to a mean annual precipitation of 630 mm/year.

The modelling showed 43 occurrences of surface runoff exceeding 0.001 m^3/s (i.e. 1.0 l/s). This corresponds to about 2 to 3 times per year on average and on about 3% of rain days, as shown in Figure 5.1.

Figure 5.1: Rainfall and computed runoff for the entire period October 1994 to December 2011

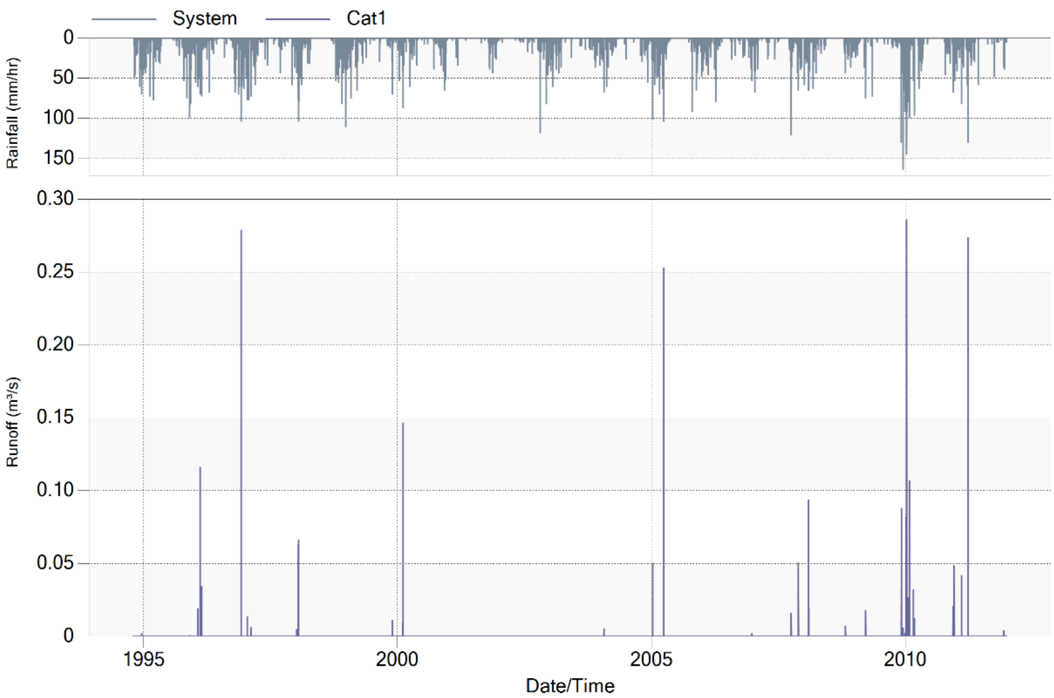
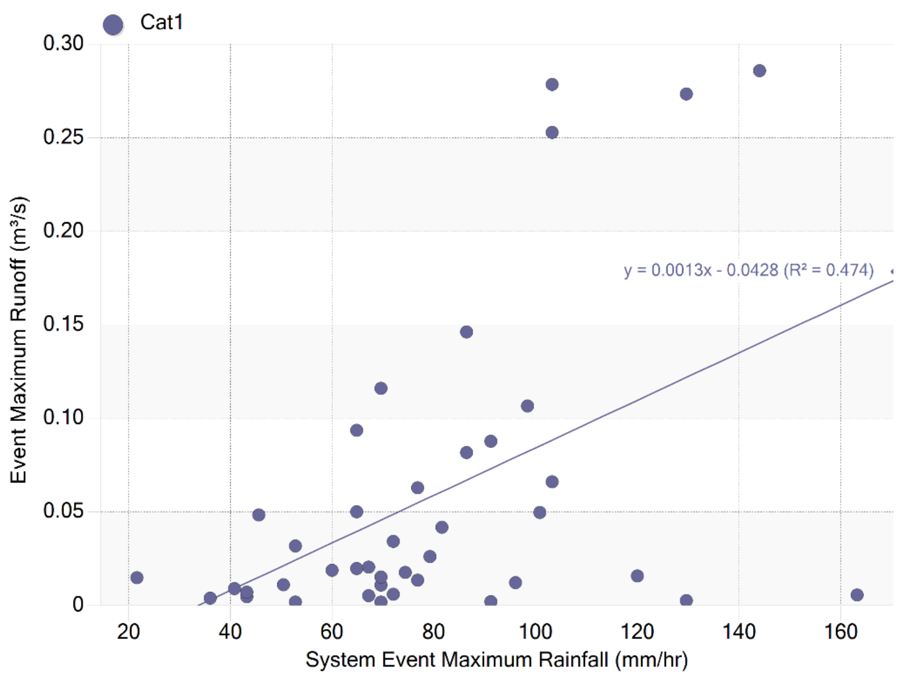


Figure 5.2: Relationship between peak discharge and event max rainfall intensity

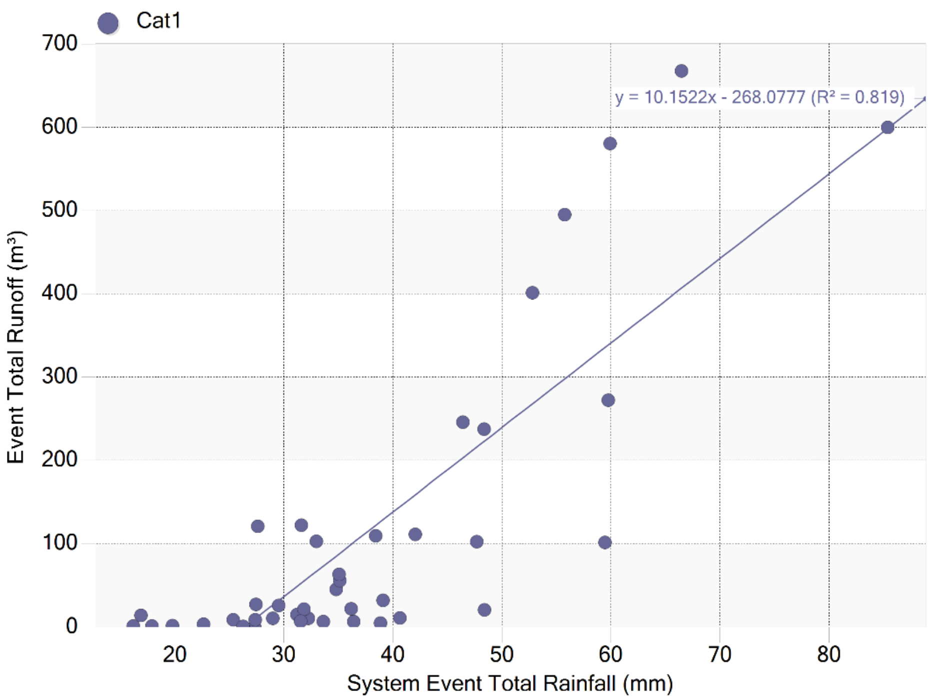


There is very poor correlation between peak discharge of any event and the maximum rainfall intensity within the storm that caused the runoff. Figure 5.2 is a plot of peak discharge against maximum event rainfall intensity. The trend line has a slope of 0.0013 (m^3/s per mm/h), which corresponds to a C value of 0.468, but with R^2 = 0.474, with better correlation for smaller events than for larger events. The form of the regression equation, with a negative constant implies that there is a minimum rainfall intensity required to initiate runoff. As would be expected, the peak discharge is more closely related to the combination of depth and duration of the preceding rain. Figures comparing the hyetographs and hydrographs of the larger runoff events are given in Appendix E.

There is a better, but still poor, correlation between the total depth of rain and the total volume of runoff as shown in Figure 5.3. The form of this regression equation, with a negative constant, implies that there is a minimum depth of rain required to initiate runoff.

Figures 5.2 and 5.3 demonstrate a major deficiency in the Rational Method.

Figure 5.3: Relationship between volume of runoff and depth of rain



Summary and recommended targets for frequency of runoff

- The target frequency of surface runoff should be twice per year unless the results of a continuous analysis prove a different target.
- Any runoff that is delayed for 48 hours or more after the end of the storm can be regarded as not being part of the storm surface runoff.
- Rainfall depths may be calculated using Hershfield's equation as given by Adamson (1982) with M2 = 62 mm and L = 6 /year.
- The Design Rainfall Estimator of Smithers and Schulze (2012) using the 90th percentile rain depths is currently the preferred approach to estimating rain depth for a design proposal.

GSIs suitable for the reduction of runoff frequency include:

1. Rainwater or stormwater harvesting for domestic or irrigation use;
2. Retention basins that incorporate infiltration and evapotranspiration measures;
3. Permeable paving with a permeable base;
4. Infiltration basins and trenches;
5. Rain gardens and bioswales that incorporate infiltration measures;
6. Kerb cuts into street tree basins.

Target Peak Discharge

In most cases the target peak discharge, or flow rate, from a development site cannot be determined by measurement because it is almost certain that the site will have undergone some sort of transformation from its natural condition. Moreover, the target peak discharge cannot be defined for a single, critical, storm duration because the impact is not confined to the point of outflow from the development area alone, but may extend for a considerable distance in the downstream drainage system, and may superimpose on stream flows with very different hydrograph shapes and critical durations.

It is also apparent from the modelling that there is a range of storm durations for any recurrence interval that will cause runoff from a natural catchment, but for durations outside of this range the design storm will not cause surface runoff. The curves in Figures 5.4, 5.5 and 5.6 (and the supporting tables in Appendix E) were generated for a one hectare catchment using triangular hyetographs with a time to peak ratio R = 0.3, but the principle would hold true for any catchment area and any design storm hyetograph.

In the absence of more detailed research, the SCS 24 hour hyetograph is regarded as unrealistic for determination of target runoff values. The long rising limb of the hyetograph will saturate the soil prior to the arrival of the storm peak, resulting in an over estimate of the runoff during the peak of the storm. Until design rain distributions derived from the continuous record are available, a more realistic evaluation is to use a range of different durations of a simplified hyetograph shape such as the triangular form used for this analysis.

Figure 5.4 Computed Natural Peak Discharge 1.01yr RI (Dry Sandy Loam)

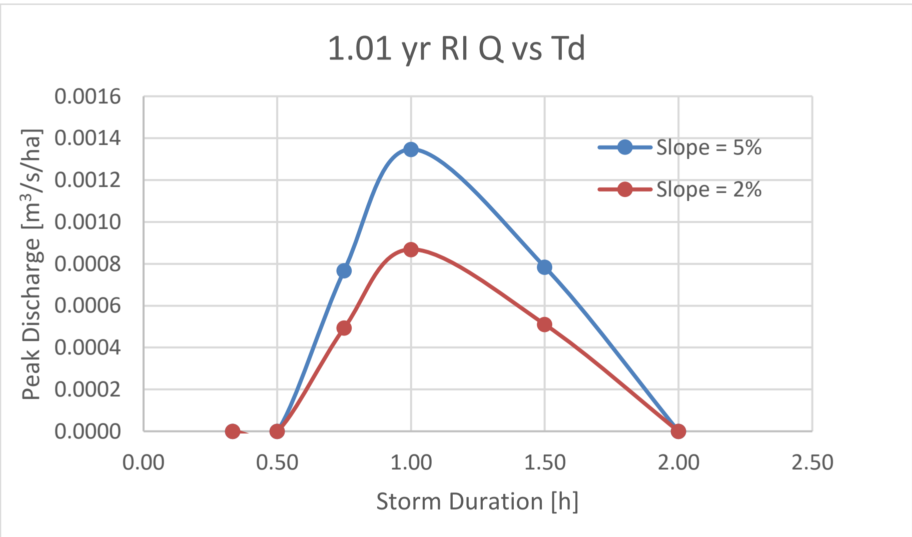


Figure 5.5 Computed Natural Peak Discharge 2yr RI (Dry Sandy Loam)

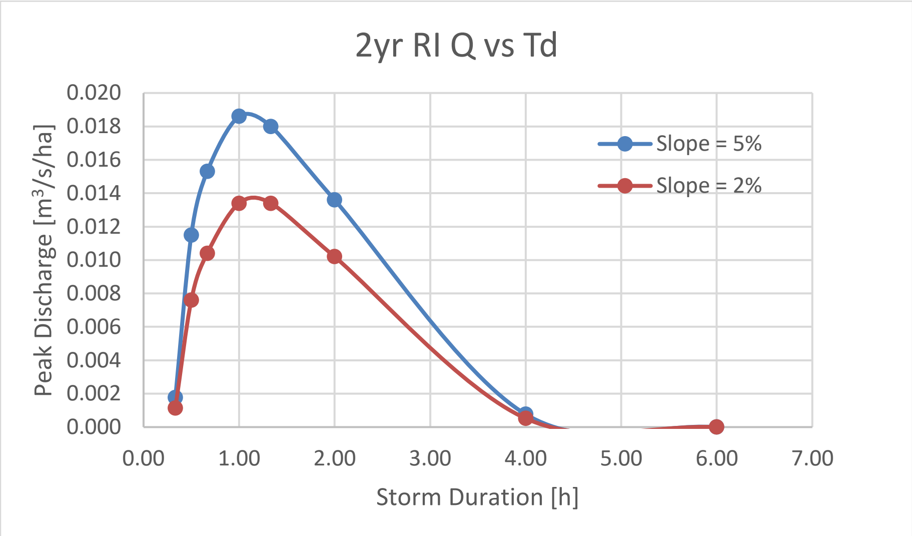
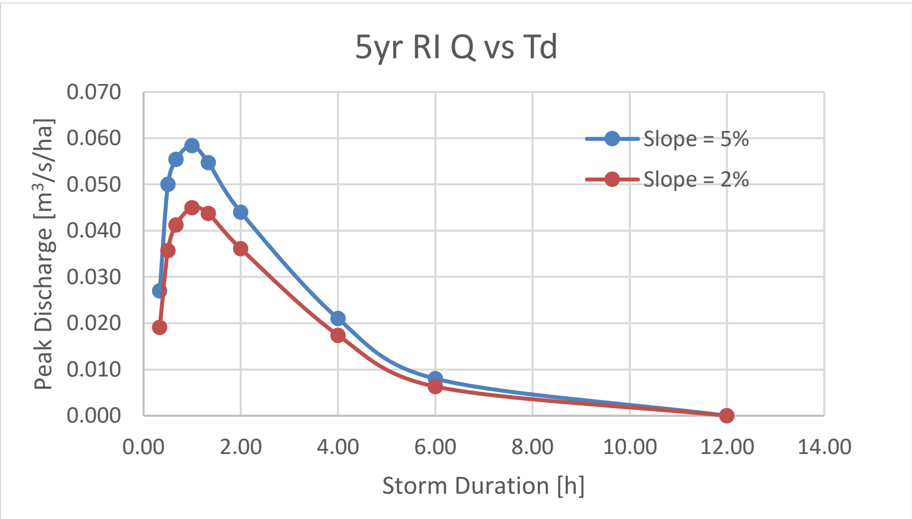


Figure 5.6 Computed Natural Peak Discharge 5yr RI (Dry Sandy Loam)



a) Peak Unit Rate of Runoff

The peak unit rate of runoff, i.e. runoff per hectare, reduces in proportion to catchment area. Modelling of catchments with areas ranging from 1.0 ha to more than 40 ha has found this relationship to be approximately linear, with the regression equations for catchments with dry sandy loam soils given in Table 5.6. Supporting data is contained in Appendix E.

The form of the equation is:

Q_p = Constant – Coefficient x Area

Q_p = Peak discharge per ha [$m^3/s/ha$]

Area = Catchment Area [ha]

Constant and coefficient from Table 2.5.6

Table 5.6: Equations of Variation in Peak Discharge with Catchment Area

Recurrence Interval years	Constant	Coefficient
1.01	0.0008	$1.0x10^{-5}$
2	0.0103	$9.0x10^{-5}$
5	0.0359	$2.0x10^{-4}$
25	0.1235	$6.0x10^{-4}$
100	0.2613	$1.2x10^{-3}$

Summary and recommended targets for peak discharge

- The Stormwater Management Report should contain a similar set of curves computed for the specific conditions encountered on the site under evaluation.
- In the absence of such curves, the Report shall demonstrate that the proposed stormwater management system yields post development discharges that lie below the curves in Figures 5.3, 5.4 and 5.5.

GSIs suitable for the reduction of peak discharge include:

1. Blue-green detention basins;
2. Rainwater or stormwater harvesting for domestic or irrigation use, provided that the storage tanks have additional volume above the full supply level that empties automatically;
3. Retention basins that incorporate storage above the normal full supply level, and this additional storage empties automatically;
4. Permeable paving with a permeable or impermeable base;
5. Infiltration basins and trenches that incorporate storage;
6. Rain gardens and bioswales that incorporate storage in addition to infiltration measures.

Target Water Quality

The discharge of sediment is discussed in detail in Section 2.3. Many researchers have found that a significant proportion of pollutants are associated with suspended solids. Wakida et al (2014) cite Morquecho and Pitt (2005) who found that the removal of suspended solids from runoff from roofs and paved areas resulted in reductions of inter alia, 47% of COD, 23% of total nitrogen, 92% of total phosphorous, 82% of lead and 72% of zinc. Management of stormwater quality should therefore concentrate on the removal of suspended material.

The regulations, contained in Government Notice 1191 of 8 October 1999, relating to the discharge of wastewater issued in terms of the National Water Act (Act 36 of 1998) permit the discharge of stormwater:

> *3.7.(2) A person may discharge stormwater runoff from any premises, not containing waste or wastewater emanating from industrial activities and premises, into a water resource.*

This regulation, which implies free discharge without concern for the quality of the stormwater, is not in keeping with the modern concerns for the quality of stormwater runoff. Table 5.7 below is a copy of Table 3.2 in the National Water Act (1998).

Recommended Target Water Quality
In the absence of better information, the quality of stormwater discharging from any development, including during construction, should comply with the General Limit contained in Table 3.2 of the regulations.

Table 5.7: Wastewater Discharge Limits (from National Water Act, 1998)

SUBSTANCE/PARAMETER	GENERAL LIMIT	SPECIAL LIMIT
Faecal Coliforms (per 100 ml)	1 000	0
Chemical Oxygen Demand (mg/l)	75	30
pH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen (mg/l)	3	2
Nitrate/Nitrite as Nitrogen (mg/l)	15	1,5
Chlorine as Free Chlorine (mg/l)	0,25	0
Suspended Solids (mg/l)	25	10
Electrical Conductivity (mS/m)	70 mS/m above intake <= 150 mS/m	50 mS/m above background <= 100 mS/m
Ortho-Phosphate as phosphorous (mg/l)	10	1 (med) & 2,5 (max)
Fluoride (mg/l)	1	1
Soap, oil or grease (mg/l)	2,5	0
Dissolved Arsenic (mg/l)	0,02	0,01
Dissolved Cadmium (mg/l)	0,005	0,001
Dissolved Chromium (VI) (mg/l)	0,05	0,02
Dissolved Copper (mg/l)	0,01	0,002
Dissolved Cyanide (mg/l)	0,02	0,01
Dissolved Iron (mg/l)	0,3	0,3
Dissolved Lead (mg/l)	0,01	0,006
Dissolved Manganese (mg/l)	0,1	0,1
Mercury and its compounds (mg/l)	0,005	0,001
Dissolved Selenium (mg/l)	0,02	0,02
Dissolved Zinc (mg/l)	0,1	0,04
Boron (mg/l)	1	0,5

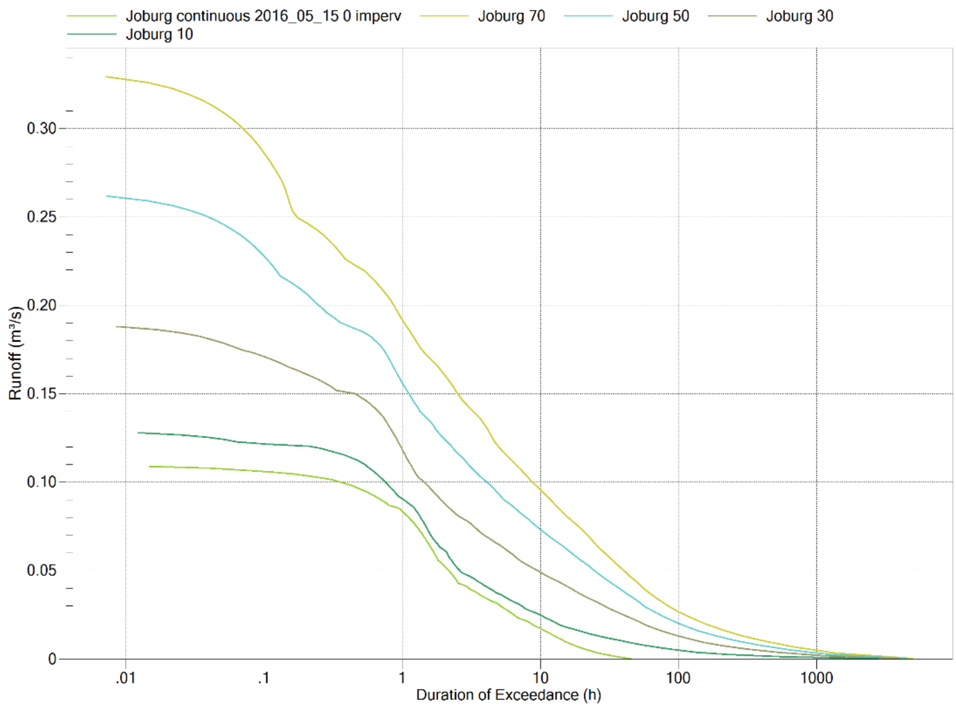
Target Duration of Runoff

Duration of runoff can be evaluated by frequency analysis, based on continuous modelling or the analysis of data from a long record of flow measurements. Figure 5.7 shows the results of a continuous analysis for the 1.0 ha hypothetical catchment using the same parameters as previously, but with percentage of impervious area increasing from 0% to 70%.

The curves show the cumulative duration of flow exceeding a particular value over the analysis period of 147 936 hours.

For the pre-development condition with 0% imperviousness, the maximum peak discharge from the catchment is about 0.11m^3/s, and the flow rate from the catchment exceeds 0.10 m^3/s for a total duration of about 0.5 h. Surface runoff will occur from the catchment for a total duration of about 60 hours, or about 0.04% of the time.

Figure 5.7 Flow duration curves calculated for a 1.0 ha catchment for imperviousness ratios from 0% to 70%



For a development with 50% imperviousness, with no runoff management, the corresponding values would be a peak discharge of about 0.26 m^3/s, and a total duration of surface runoff of about 5 000 hours, or about 3.4%. Surface runoff exceeds 0.10 m^3/s for about 5 hours. Therefore the highest peak discharge, corresponding to an event with a recurrence interval of about 16 years, would be increased by a factor of about 2.5, and the total duration of surface runoff exceeding 0.10 m3/s, i.e. that which may cause damage to the water course downstream, increased by a factor of about 10.

While increase in flow durations can have a significantly adverse impact on the morphology of receiving streams, a decrease in flow durations could similarly cause changes to the stream morphology and stress to the aquatic ecosystem. The target should therefore be that the post-development flow duration curve remains as close as possible to the pre-development curve.

Target Duration of Runoff

The recommended target is that the post-development duration of any discharge should not differ from the pre-development duration by more than 10%.

2.6 CHAPTER 6: OPERATION AND MAINTENANCE

2.6.1 Chapter 6 By-laws

Application

47. The provisions of this Chapter apply in respect of any stormwater drainage facility in existence at the date of commencement of these By-laws and any such facility constructed after that date.

Duty to maintain stormwater facilities

48. (1) Any owner of a property on which any stormwater drainage facility or other measure based on a best management practice has been constructed or provided, before or after the date of commencement of these By-laws, is responsible for the continual effective operation, maintenance and repair of such facility or measure, in accordance with the provisions of these By-laws and the manual.

> The Stormwater Management Report prepared in accordance with section 7 of the By-laws shall contain a maintenance and repair section in accordance with section 51 of the By-laws.

(2) The provisions of subsection (1) do not apply in respect of any property to the extent that the responsibility to maintain any stormwater drainage facility has been taken over by the Agency in terms of section 49 or 50.

(3) An authorised official may, if he or she considers it appropriate, provide any owner of property contemplated in subsection (1), with a maintenance manual, setting out the duty of the owner to maintain as contemplated in subsection (1), and the steps to be taken by the owner to comply with that duty.

> In order to ensure that the stormwater management facility does not deteriorate, an authorised official of the Agency, in consultation with an appropriate official of the City of Johannesburg EISD, may instruct the owner of the property on which that stormwater management facility is located to update the maintenance section of the Stormwater Management Report, or provide to owner of the property with a maintenance manual or maintenance instruction.

Acceptance by Agency of duty to maintain new stormwater facilities

49. The Agency may in writing accept the responsibility for the maintenance of the stormwater drainage facilities on any property zoned residential 1, 2 or 3 under any applicable town planning scheme, in respect of which a permit had been issued in terms of section 7, or otherwise approved by the Council or the Agency, subject to the following requirements :

(a) At least 80 percent of the construction must have been completed on the development site concerned, unless this requirement is waived in writing by an authorised official;

(b) every stormwater drainage facility must have been inspected and approved in writing by an authorised official and must have been in operation for at least one year to the satisfaction of such official;

(c) every stormwater drainage facility reconstructed during the maintenance period contemplated in the contract of construction concerned, must have been approved by an authorised official;

(d) every stormwater drainage facility, as designed and constructed, must conform to the provisions of these By-laws;

(e) written proof of registration of any servitude required in terms of section 43 must have been furnished to the Council and the Agency;

(f) in respect of any stormwater drainage facility purpose-designed for a specific situation in respect of which requirements for maintenance are not specified in the manual, an operation and maintenance manual and a maintenance schedule prepared by a professional engineer, containing a description of the operation and maintenance procedures for every stormwater drainage facility concerned, must have been submitted to, and approved by, the Agency; and

(g) a complete and accurate set of record drawings capable of being reproduced, relating to every stormwater drainage facility concerned , must have been furnished to the Agency.

Agency acceptance of duty to maintain existing stormwater drainage facilities

50. The Agency may on receipt of a written petition signed by at least fifty percent of the owners of properties in the area which is the subject of such petition, accept responsibility for the maintenance of the stormwater drainage facilities on any property in that area zoned residential 1, 2 or 3 under an applicable town planning scheme, which was in existence on the date of commencement of these By-laws, subject to the following requirements :

(a) at least 80 percent of the construction must have been completed on the development site concerned;

(b) every stormwater drainage facility must have been inspected by an authorised official and found to be functioning as designed;

(c) every stormwater drainage facility must, in the opinion of an authorised official, have had at least one year of satisfactory operation and maintenance, unless this requirement is waived by that official in writing;

(d) written proof of registration of any servitude required in terms of section 43 must have been furnished by the petitioners contemplated in this section, to the Council and the Agency; and

(e) every stormwater drainage facility under consideration, must have been inspected for defects by an authorised official and the owner concerned or in the case of a sectional title development, the body corporate, must have satisfied an authorised that any defect revealed by such inspection has been effectively remedied.

Inspections of privately maintained stormwater facilities

51. (1) The Agency must for the purpose of ensuring that stormwater facilities are being properly maintained, that stormwater quality control is not detrimentally affected and that pollution is curtailed, develop and adopt a maintenance manual applicable to all stormwater facilities which must be maintained by the owner of the property concerned.

> In the absence of a Maintenance Manual prepared by the Agency, the Stormwater Management Report prepared in accordance with section 7 of the By-laws shall contain details of how maintenance and repairs will be undertaken. The section of the Stormwater Management Report that describes the maintenance and repairs shall be kept on the

property where the stormwater management facility is located, and shall be available for inspection by an authorised official of the Agency by arrangement with the property owner.

(2) A manual contemplated in subsection (1), must contain requirements relating to –

(a) the frequency of inspections;

(b) what has to be checked in carrying out an inspection; and

(c) what action needs to be taken to properly maintain stormwater facilities.

(3) An authorised official may, if he or she is satisfied that any requirement of a manual contemplated in subsection (1), has not been complied with, by written notice served on the owner of the property concerned require such owner to take the steps specified in that notice within a period so specified.

Inspection schedule

52. (1) The Agency must for the purpose of ensuring regular and effective inspection of stormwater facilities by an authorised official, adopt an inspection schedule in respect of stormwater facilities which are not maintained by it, dealing with the frequency and extent of inspections.

(2) Any authorised official must comply with the requirements of the schedule adopted in terms of subsection(1).

2.7 CHAPTER 7: CRITICAL DRAINAGE AREAS

2.7.1 Chapter 7 By-laws

Additional requirements

53. (1) In order to mitigate or eliminate any potential stormwater-related impact on any critical drainage area, the Agency may by notice in writing served on a developer or owner of property, require any stormwater drainage facility in excess of those required in terms of these By-laws, to be provided by that developer or owner.

(2) For the purposes of subsection (1), "critical drainage area" means –

(a) any area underlain by, or shown on a 1:50 000 scale geological map to be within 500 m of any dolomitic geology;

(b) land with a slope of 3 m horizontal to 1 m vertical or greater, as determined –

(i) from a topographic survey of the site prepared by a qualified land surveyor;

(ii) from a topographic map maintained by the Council, if other topographic survey information is not available;

> High quality Lidar digital terrain data are available from the City of Johannesburg Corporate GIS Department. The most recent data set shall be used.

(iii) from a contour map generated from a 25 m grid digital elevation data obtainable from the Chief Director : Surveys and Mapping appointed in terms of section 2A of the Land Survey Act, 1997 (Act No 8 of 1997); or

(iv) by an authorised official based on a field investigation of the area concerned;

> The SWMR shall include a plan that shows any part of the site with a slope exceeding 1:3 (V:H), or the report shall contain a statement by the responsible engineer that no part of the property has a slope steeper than 1:3 (V:H).

(c) any geologic area hazardous to life or property, historically documented as an unstable slope in the records of the Council or the Agency ;

(d) land within 50 m of the high water mark of any body of water where fish spawn and which contains a rearing habitat for fish, reflected in the records of the Council or the Agency ;

(e) land designated a critical drainage area in a comprehensive stormwater drainage plan adopted by the Agency;

> A critical drainage area may be identified by the Agency at any time. It is the obligation of the owner of the property where development is contemplated to ascertain from the Agency whether the property falls into a critical drainage area.

(f) any refuse disposal site or land fill site of the Council;

(g) land which is a wetland for the purpose of any National or Provincial legislation or policy;

(h) land in respect of which requirements for the management of ground water or any aquifer as defined in the National Water Act, 1998, or sole source ground water aquifer exist under the National Environmental Management Act, 1998, or any other law;

(i) land which drains to a natural closed depression;

(j) land used for the protection of wildlife habitat and designated by the Council as a critical drainage area;

(k) land designated by or under any law as a conservation or protected area, a nature reserve or a protected environment; and

(l) land determined by the Agency to have a high potential for stormwater drainage, and stormwater quality, problems, or to be sensitive to the effects of stormwater runoff.

(3) (a) If, for the purpose of considering the applicability of subsection (2) to any land, a conflict is found to exist between a map and any other available source of information contemplated in that subsection, the decision as to whether or not land is a critical drainage area must be made by the Agency.

(b) For the purposes of paragraph (a), an authorised official may by written notice require a developer or owner of property to furnish him or her with a site inspection survey and any other topographic data specified in that notice.

2.8 CHAPTER 8: STORMWATER POLLUTION

2.8.1 Chapter 8 By-laws

Prohibition of pollution

54. (1) No person may –

(a) discharge any substance other than unpolluted stormwater runoff and other unpolluted natural surface water runoff into a stormwater system or on to a public road or other area from which such substance will be conveyed to a stormwater system;

(b) make or allow any connection to be made to a stormwater system which could result in the discharge to it of any pollutant; or

(c) make any connection to a stormwater system from the interior of any building or other structure.

Maintenance of pollution control device

55. Any owner or user of an oil/water separator, wet pond, bio-filtration facility, erosion and sediment stormwater control facility, filtration system and any other device to control pollution of stormwater, must operate and maintain such device to ensure that the performance thereof meets the level of pollutant removal intended by the manufacturer, in accordance with the maintenance schedule for such device supplied by the manufacturer.

Exemptions

56. The following discharges are exempt from the provisions of section 54:

(a) Regulated effluent from any commercial or municipal facility if the discharge of such effluent is authorised in terms of the National Water Act, 1998 or any other law;

(b) any discharge resultant upon an act of God or natural occurrence not compounded by human negligence;

(c) any discharge from a properly operating on-site domestic sewage system approved by the Department of Water Affairs and Forestry and the Council; and

(d) any discharge from land on which agricultural chemicals and materials have been applied.

Test procedures

57. If for the purposes of this Chapter the quality of stormwater is tested, the test procedures specified in the South African Water Quality Guidelines, volumes 1 to 5 inclusive, issued by the Department of Water Affairs and Forestry in 1996, as amended or substituted from time to time, must be complied with.

Stormwater quality: not addressed

58. In any circumstances or conditions relating to stormwater quality which are not specifically addressed in Chapter 5 and this Chapter, the preferred method for selection, design, and implementation of any stormwater best management practice, must be in accordance with the manual.

In the absence of detailed guidelines in this Manual, the methodology for management of stormwater quality and the prevention of pollution must be specified (as per the Stormwater Management Report discussed and elaborated in Section 2) by the Applicant. The Applicant must make it clear as to what methods are being proposed and explain how they will work.

2.8.2 Stormwater Pollution Guidelines

Filtration and Treatment

This section has been derived from *Stormwater Management Planning and Design Guidelines for New Development* (SAWE Multi-disciplinary Engineers, 2002). In addition to structural designs, stormwater management design should also provide for more subtle forms of stormwater control, which allow a reduction in quantity or improvement in quality of stormwater at source, rather than symptomatic management of stormwater produced. This approach should include ongoing education of local residents regarding water demand management principles, the effects of allowing sources of pollution to enter stormwater systems, and the value of adhering to strategic stormwater guidelines at the level of the individual property or residence. Examples include discharging water from gutters onto grassed surfaces rather than directly into road stormwater drains, or minimising areas of impervious surfaces at a development scale.

As a general principle litter, silt and other pollutants emanating from a catchment should be trapped as close to source as possible. This is of particular importance when the stormwater discharges into a sensitive environment, and where damage may result if the pollutant is not trapped and removed.

Plastic litter is a highly visible and an unsightly pollutant. Moreover, excessive plastic pollution has indirect negative ecological impacts, for example it contributes to a perception of freshwater systems as neglected, useless and unhealthy, which in turn results in a vicious cycle of neglect, where more harmful pollution of the system (e.g. dumping of organic waste, toxic runoff) is also tolerated. Micro-plastic particles, whether manufactured or arising from decomposition and abrasion of larger pieces of plastic, has severe environmental impact.

Filtration of pollutants from stormwater is a vital component of stormwater management, although its prominence in the overall stormwater management plan of a development will depend on the extent to which water quality is likely to be a problem, either within the development area, or to freshwater ecosystems and human users in the catchment downstream. Pollutants addressed by filtration include: sediment, nutrients, heavy metals, petrol- and oil-based compounds and numerous other pollutant types, depending on land use within the development area and in the upstream catchment. Filtration is best by passage of water across vegetated areas. Where plants are used to provide filtration, it should be noted that different plant species have different capacities for absorption or assimilation of different pollutants. Many pollutants and some nutrients, for example heavy metals and phosphorus, taken up by vegetation, are only temporarily sequestrated and may be released back to the water body on the death and decomposition of the plants, or washed downstream during high flow events.

Designs that rely primarily on filtration for their successful function need to take cognisance of the following factors:

- Site topography – filtration is best achieved at very gentle gradients.
- Plant species utilised – different species have different filtering capacities, as well as aesthetic qualities.
- Soil type – highly porous soils are often more suited to infiltration than filtration systems, and do not always retain sufficient moisture to maintain plant growth.
- Stormwater quality and water quality of receiving water body – the degree of filtering that can be realistically expected from a filtering device of a particular size and constitution

should be calculated. In some circumstances, water quality in surface effluent may be too poor for treatment to acceptable standards to be a realistic option. In such cases, and particularly where the natural receiving water body is a system with a high priority rank or conservation importance, consideration should be given to conveying this stormwater for treatment at a waste water treatment facility.

- Seasonal changes in water table level – groundwater should not be exposed by the swale at any time as this will promote drainage of the groundwater resource. The bottom of the swale should be at least 0.5m above than the high water-table level.

The following are typical filtrations systems and their application that can be considered:

1. Vegetated filter strips surrounding infiltration structures, adjacent to water courses and water bodies, between parking lots and stormwater management structures where drainage is primarily sheet flow;
2. Natural and artificial wetlands filter pollution through absorptive and assimilative capacities of wetland plants and their soils, promote sedimentation through filtration by plants and spreading out of flows, and retain water, reducing stormwater volumes;
3. Litter traps;
4. Sediment traps;
5. Oil separators.

2.9 CHAPTER 9: MISCELLANEOUS

2.9.1 Chapter 9 By-laws

Experimental best management practices

59. (1) If no appropriate best management practice which must be utilised for the purpose of complying with any relevant provision of these By-laws is contained in the manual, an experimental best management practice may be prepared by a developer and submitted to the Agency for approval.

> If an experimental BMP is proposed, the SWMR shall describe in detail why the responsible engineer regards the measure as suitable and shall support this with detailed calculations and examples of research into similar techniques.
>
> While Green Infrastructure interventions are gaining wider application and experience in South Africa, many of their applications are still being tested for suitability and performance in South African conditions. This is particularly the case on the Highveld where many of these methods of sustainable drainage still need to be tested under local conditions. Storm intensities, seasonal rainfall, vegetation suitability, soils and slope conditions and even atmospheric dust are among the concerns that have been raised about the suitability of these methods in Johannesburg and surrounds. Hence there may be experimental aspects to the applications of many of the BMPs identified in this Manual, and testing these in a controlled manner as part of a site development should be welcomed.

(2) An experimental best management practice approved in terms of subsection (1) may be utilised by the developer concerned.

(3) The Agency may, by notice in writing addressed to a developer contemplated in subsection (1), require the operation of an approved experimental best management practice to be monitored by that developer for a period specified in that notice, in order to ascertain the effectiveness of its operation with a view to the future use of such practice.

(4) A developer must during the period specified in a notice in terms of subsection (3) submit a written report to the Agency on the effectiveness of the operation of the experimental best management practice concerned at the intervals specified in that notice.

Deviations and exemptions from By-laws

60. (1) The Agency may, on written application by the owner or a developer of a property, permit a deviation, or grant an exemption, from any provision of these By-laws concerning the requirements for stormwater facilities.

(2) The Agency may on receipt of an application in terms of subsection (1), by written notice, require the applicant to furnish the Agency with any documentation and other information relevant to the application.

(3) The Agency must within a reasonable time grant an application received in terms of subsection (1), subject to any condition which it considers appropriate or refuse it, and the applicant must forthwith in writing be notified of the decision and be furnished with reasons for a refusal of an application.

(4) In granting an application in terms of subsection (3), the Agency must ensure that -

(a) the granting of the application will not produce a result which is contrary to the purpose of these By-laws as specified in section 2; and

(b) the granting of the application will meet the objectives of safety, function, appearance, environmental protection and maintainability based on sound engineering judgment.

Deviations and exemptions from manual

61. (1) An authorised official may on written application from an owner or developer of a property, in writing permit a deviation, or grant an exemption, from any requirement contained in the manual.

(2) The provisions of sections 60(2) and (3), read with the necessary changes, apply to an application in terms of subsection (1).

(3) In granting an application in terms of subsection (1) the authorised official concerned must ensure that -

(a) no contravention of any provision of these By-laws will result;

(b) no non-compliance with any provision of, or any condition relating to the development of the property concerned imposed in terms of, an applicable town planning scheme or any other law will result;

(c) the granting of the application will not produce a result which is contrary to the purpose of these By-laws as specified in section 2; and

(d) the granting of the application will meet objectives of safety, function, appearance, environmental protection and maintainability based on sound engineering judgment.

Progress of work

62. (1) Any work required or permitted to be done under these By-laws, must proceed in an expeditious manner and continuously to its completion : Provided that an authorised official may on written application by an owner or developer of property, in writing grant authority that such work may be interrupted for a period specified in that notice.

(2) Notwithstanding the provisions of subsection (1), work contemplated in that subsection may be interrupted due to inclement weather or an act of God or the need to co-ordinate such work with construction activities on the development site concerned.

Compliance notices

63. (1) An authorised official who becomes aware that any provision of these By-laws has been contravened or not complied with may, on a form prescribed by the Agency, issue a compliance notice to an owner, developer or other person who is in contravention of or has not complied with such provision .

(2) A compliance notice issued in terms of subsection (1) must set out –

(a) the provision which has been contravened or not complied with;

(b) details of the nature and extent of the contravention or noncompliance;

(c) any steps that are required to be taken to remedy the contravention or non-compliance and the period within which those steps must be taken; and

(d) the provisions of section 67 to the extent relevant to the contravention or non-compliance.

(3) An authorised official who is satisfied that the person to whom a compliance notice was addressed has complied with the terms of that compliance notice, must issue a compliance certificate to that effect to that person on a form prescribed by the Agency.

(4) A compliance notice issued in terms of subsection (1) remains in force until an authorised official has issued a compliance certificate in respect of that notice, in terms of subsection (2).

(5) If any person fails to comply with a compliance notice within the period contemplated in subsection (2)(c), the Agency may, if in the opinion of an authorised official, such non-compliance may result in a danger to life or property, after having served a written notice of its intention on the person to whom the compliance notice was addressed, enter the property concerned, do any work that is necessary to prevent such danger and recover the cost thereof from that person.

Stop work orders

64. (1) If an authorised official reasonably believes that there has been a contravention of or failure to comply with any provision of these Bylaws, he or she may by notice on a form prescribed by the Agency, served on an owner or developer concerned, instruct that owner or developer, immediately to cease all site development activities on the property concerned, except for erosion and sedimentation control activities authorised in writing by such an official, until further notice.

(2) A notice in terms of subsection (1) –

(a) must contain the particulars specified in section 63(2)(a) and (b); and

(b) may be issued in conjunction with a compliance order in terms of section 63(1).

Serving of notices

65. Any notice that is required to, or may, be served, delivered or given in terms of, or for the purposes of these By-laws, must be served in any of the following ways :

(a) By handing a copy of the notice at the person to whom it is addressed;

(b) by leaving a copy of the notice at the person's place of residence or business with any other person who is apparently at least 16 years old and in charge of the premises at the time;

(c) by faxing a copy of the notice to the person, if the person has in writing furnished a fax number to the Agency or an authorised official;

(d) by handing a copy of the notice to any representative authorised in writing to accept service on behalf of the person concerned;

(e) if the person concerned has chosen an address or fax number for service, by leaving a copy of the notice at that address or by faxing it to that fax number;

(f) by sending a copy of the notice by prepaid registered or certified post to the last-known address of the person concerned, and, unless the contrary is proved, it is deemed that service was effected on the seventh day following the day on which the document was posted;

(g) if the person is a company or other body corporate, by serving a copy of the notice on an employee of the company or body corporate at its registered office or its place of business or, if there is no employee willing to accept service, by affixing a copy of the document to the main door of the office or place of business;

(h) if the person is a partnership, firm or voluntary association, by serving a copy of the notice on a person who at the time of service is apparently in charge of the premises and apparently at least 16 years of age, at the place of business of such partnership, firm or association or if such partnership, firm or association has no place of business, by serving a copy of the notice on a partner, the owner of the firm or the chairman or secretary of the managing or other controlling body of such association, as the case may be.

Inspections

66. (1) In addition to any power of inspection which an authorised official may have in terms of these By-laws, he or she may for any purpose relating to the implementation and enforcement of these By-laws, between 8:00 and 17:00, enter any property and carry out an inspection for the purposes of these By-laws.

(2) An authorised official must, before the commencement of, or during an inspection in terms of subsection (1) or other provision of these Bylaws, at the request of the owner or developer concerned or any other person involved with the development on the property concerned, produce written confirmation of his or her appointment as an authorised official empowered to carry out inspections for the purposes of these By-laws.

(3) An authorised official carrying out an inspection in terms of these Bylaws, must conduct himself or herself with strict regard to decency and orderliness and with due regard to any person's rights contained in the Bill of Rights set out in Chapter 2 of the Constitution of the Republic of South Africa, 1996 (Act No 108 of 1996).

Appeals

67. (1) Any person whose rights are affected by a decision by an authorised official or any other employee of the Agency, in terms of or for the purposes of these By-laws, may appeal against that decision to the Agency by lodging written notice of appeal to the Chief Executive Officer of the Agency, within 21 days of the date on which he or she was notified of that decision.

(2) The Agency, or a committee appointed by the Agency, must within 30 days of the lodging of an appeal in terms of subsection (1), commence consideration thereof and must within a reasonable time, take any decision in respect of the appeal which it considers appropriate.

(3) The Chief Executive Officer referred to in subsection (1), must forthwith after a decision has been taken in terms of subsection (2), in writing notify the appellant thereof and furnish the applicant with reasons for the decision.

Offences and penalties

68. Any person who –

(a) contravenes or fails to comply with any provision of these Bylaws;

(b) refuses or fails to comply with any notice addressed to him or her in terms of or for the purposes of these By-laws;

(c) refuses or fails to comply with the terms or conditions of any permit issued in terms of section 7;

(d) obstructs, hinders or interferes with an authorised official in the exercise of any power or the performance of any duty under these By-laws;

(e) fails or refuses to furnish to an authorised official with any documentation or information required for the purposes of these By-laws or furnishes a false or misleading document or false or misleading information;

(f) fails or refuses to comply with any instruction given for the purposes of these By-laws ;

(g) pretends to be an authorised official , is guilty of an offence and –

(i) liable on conviction to a fine or in default of payment to imprisonment for a period not exceeding 36 months;

(ii) in the case of a continuing offence, to a further fine not exceeding R3 000, or in default of payment to imprisonment not exceeding one day for every day during the continuance of such offence after a written notice has been served on him or her by the Agency requiring the discontinuance of such offence.

Short title

69. These By-laws are referred to as the Stormwater Management Bylaws

SECTION 3: APPENDICES

APPENDIX A: GEOGRAPHICAL INFORMATION

A.1 Geology and Soils

Hydrological Characteristics of Soils

a) Infiltration

Three different methods of calculating infiltration are in common us in South Africa and are available for selection in SWMM. It should be noted that the values of the parameters given in the tables that follow are guidelines only, and should be calibrated wherever possible. Considerable guidance and detailed discussion can be found in the *Stormwater Management Model Reference Manual Volume 1 – Hydrology* (Rossman & Huber 2016)

- **Horton**

Horton's method is an empirical equation that describes the decrease of infiltration rate from water on the surface of the soil. The decrease is an exponential decay function from an initial infiltration rate to some equilibrium rate over a period of time. The integrated version of this equation developed by Green (1984; 1986) takes account of conditions where the rainfall intensity is less than the infiltration rate.

$$f = f_c + (f_0 - f_c)e^{-kt}$$

Where: f = infiltration rate

f_c = minimum or equilibrium infiltration rate

f_0 = initial or maximum infiltration rate

k = constant that reflects how rapidly the infiltration rate decays

t = time elapsed since infiltration began

Typical values of the parameters as suggested by Green are given in Tables A.1 and A.2

Table A.1: Typical Values for the Parameters in Horton's Equation

Soil Type	**f_o (dry)**	**f_c (equilibrium)**
	mm/h	**mm/h**
Sandy Soil	125	15
Loam Soil	50 - 75	5 - 10
Clay Soil	5 - 25	0 - 5

Table A.2: Rate of Decay of Infiltration for Different values of k

k			Percent of decline of infiltration capacity towards equilibrium value f_c after 1 hour
(sec^{-1})	($hour^{-1}$)	(day^{-1})	
0.00056	2.02	48.4	76
0.00083	2.99	71.7	95
0.00111	4.00	95.9	98
0.00139	5.00	120.1	99

- **Green and Ampt**

The Green-Ampt equation (Green & Ampt, 1911) explains the infiltration of water through soil using Darcy's law. Mein and Larsen (1973) adapted the equation for steady rainfall and Chu (1978) showed how the equation could be applied to unsteady rainfall.

The mechanism is simplified because infiltrated water is assumed to move downward through the soil as an abrupt wetting front that separates the wetted and unwetted soils. In reality the wetted front may not be abrupt and the soil above the front may not be fully saturated. But the approach is preferable to that of Horton because the equation represents a realistic physical process and can be adjusted as better information or explanations become available (Richards 1931), or to take account of a driving head of water standing above the soil surface that is used by SWMM in the analysis of LIDs.

The form of the Green-Ampt equation is:

$$f = K_{sat}\left(1 + \frac{(\phi - \theta)(d + \psi)}{F}\right)$$

Where f = infiltration rate

K_{sat} = Hydraulic conductivity of the saturated soil

Φ = porosity of the soil

θ = initial volumetric water content of the soil

d = depth of driving head above the soil surface (usually ignored)

ψ = capillary suction head at the wetting front

F = cumulative infiltration

The calculation is sensitive to the term ($\Phi - \theta$), i.e. the difference between the porosity of the soil, which is effectively equal to the total moisture capacity of the soil, and the initial moisture content of the soil, so care should be taken in the selection of the value of θ. The value of this parameter is related to the field capacity of the soil, i.e. the moisture content when all available water has drained out under gravity, and the wilting point, which is the point at which moisture is so tightly bound by capillary tension that it is no longer available to plants.

- **Soil Conservation Service (SCS) Equation**

The SCS equation is often incorrectly formulated as an infiltration equation because differentiation of the equation yields an infiltration rate that is proportional to rainfall (Torno, 1992). The procedure is, however, in common use in South Africa and available as a modelling methodology in SWMM. Readers wishing to use this method are referred to the literature, for example Schmidt and Schulze (1987) or Rossman and Huber (2016).

Table A.3: Suggested Green-Ampt Parameters

USDA Soil-Texture Class	Hydraulic Conductivity K_1	Wetting Front Suction Head Yf	Porosity	Water Retained at Field Capacity	Water Retained at Wilting Point
	mm/h	mm	m^3/m^3	m^3/m^3	m^3/m^3
Sand	120.40	49.02	0.437	0.062	0.024
Loamy Sand	29.97	60.96	0.437	0.150	0.047
Sandy Loam	10.92	109.22	0.453	0.190	0.085
Loamy Sand	3.30	88.90	0.463	0.232	0.116
Silt Loam	6.60	169.93	0.501	0.284	0.135
Sandy Clay Loam	1.52	219.96	0.398	0.244	0.136
Clay Loam	1.02	210.06	0.464	0.310	0.187
Silty Clay Loam	1.02	270.00	0.471	0.342	0.210
Sandy Clay	0.51	240.03	0.430	0.321	0.211
Silty Clay	0.51	290.07	0.479	0.371	0.251
Clay	0.25	320.04	0.475	0.378	0.265

After Rawls et al. (1983), Torno (1993), and Rawls & Saxton (2006)

Problem Soils

Care should be taken to ensure that stormwater management facilities are not adversely impacted by problem soils. For example, excessive erosion can occur where soils that are very erodible or dispersive are not properly protected, embankments constructed of expansive clay could be vulnerable to internal erosion of the clay dries out and cracks, or storage basins could leak excessively and fail by piping of the subsoil if constructed on collapsing soils. The reader is referred to the considerable body of literature on this topic, for example Diop, et al. (2011) and Department of Public Works (2007).

Dispersive and erodible soils are potentially a significant problem on the Halfway House granite geology of the northern part of the Johannesburg Metropolitan Area. Diop, et al. (2011) note that soils originating from all granites and granodiorites of the Swazian Complex are potentially dispersive.

Equivalence of Horton and Green and Ampt Parameters

Infiltration computed using Horton's and Green and Ampt's approaches is not directly comparable, and approximately equivalent range of parameters can, however, be determined by using a continuous model to compute and compare total infiltration (or runoff), unit peak discharge, and frequency of runoff for a representative site as shown in tables A4 and A5.

Table A4: Computed Runoff Characteristics (Horton)

Noordhang Example Catchment Area 2.8444 ha
Model duration 19/10/1994 to 31/12/2011

Parameter	Horton		Sand	Loam			Clay		
	Initial f	mm/h	125	75	60	50	25	12	5
	Final f	mm/h	15	10	10	5	5	2	1
Rain Depth	mm		10390.5	10390.5	10390.5	10390.5	10390.5	10390.5	10390.5
Total Infiltration	mm		10358	10261	10227	9990	9824	9013	8036
Total Runoff	mm		32.5	129.5	163.5	400.5	566.5	1377.5	2354.5
% Runoff	%		0.3%	1.2%	1.6%	3.9%	5.5%	13.3%	22.7%
Peak Q	m^3/s		0.16	0.27	0.29	0.34	0.4	0.46	0.49
Unit Peak Q	$m^3/s/ha$		0.06	0.09	0.10	0.12	0.14	0.16	0.17
No of events > 1 l/s	No		11	30	42	64	94	196	213

Table A5: Computed Runoff Characteristics (Green & Ampt)

Noordhang Example Catchment Area 2.8444 ha
Model duration 19/10/1994 to 31/12/2011

Parameter	Green & Ampt Parameter		Sand	Loam Sand	Sand Loam	Loam	Silt Loam	S/C/L	Clay Loam	S/C/L	Sandy Clay	Silty Clay	Clay
	Suction Head	**mm**	49.0	61.0	109.0	88.9	170.0	220.0	210.0	270.0	240.0	290.0	320.0
	Conductivity	**mm/h**	120.4	30	10.9	6.6	3.3	1.52	1.02	1.02	0.51	0.51	0.25
	Deficit(1)	**m^3/m^3**	0.413	0.390	0.368	0.347	0.360	0.262	0.277	0.261	0.219	0.228	0.210
Rain Depth	mm		10390.5	10390.5	10390.5	10390.5	10390.5	10390.5	10390.5	10390.5	10390.5	10390.5	10390.5
Total Infiltration	mm		10390.5	10389.4	10319	10192	9973	9437	8933	9008	7650	7761	7099
Total Runoff	mm		0	1.1	71.5	198.5	417.5	953.5	1457.5	1382.5	2740.5	2629.5	3291.5
% Runoff	%		0.0%	0.0%	0.7%	1.9%	4.0%	9.2%	14.0%	13.3%	26.4%	25.3%	31.7%
Peak Q	m^3/s		0	0.023	0.25	0.31	0.35	0.41	0.43	0.43	0.48	0.47	0.49
Unit Peak Q	$m^3/s/ha$		0.00	0.01	0.09	0.11	0.12	0.14	0.15	0.15	0.17	0.17	0.17
No of events > 1 l/s	No		0	0	14	38	57	112	151	141	204	200	248

(1) Initial moisture content deficit = porosity minus wilting point
S/C/L = Sandy clay loam

APPENDIX B: GI EFFECTIVENESS AND DESIGN TARGET VALUES

B.1 Defining GSI Performance

The need to define the performance in Green Stormwater Infrastructure (GSI) is no different to grey (conventional) infrastructure networks. It is necessary to demonstrate compliance with the By-laws and environmental objectives, but it is equally important for the effective planning and management of downstream systems. There are implications for hazard management and disaster relief, the long-term stability of receiving watercourses, and management of water resources. If a Site Development Plan (SDP), a Stormwater Management Plan (SWMP) or an Erosion and Sediment Control Plan (ESCP) is approved, then all the facilities identified in these plans as contributing to the overall stormwater management of a site need to be defined in terms of performance.

Performance objectives

Performance objectives will typically include the intended hydrological and hydraulic performance of the facilities, and in most cases water quality targets for at least facility will need to be defined. Other performance factors may include ecological and amenity functions.

> Priority performance objectives:
>
> Where features of the site are identified as providing important stormwater related functions, and are approved as part of the SWMP, priority shall be given to maintaining the hydrological, hydraulic and water quality performance of these facilities. All other benefits (amenity, ecology, etc.) shall be given secondary importance. The stormwater engineer will need to clearly state the performance and maintenance objectives of these features.
>
> Other areas of the site, such as landscaped areas, public amenity areas or zones of high ecological importance, may still offer stormwater co-benefits. However, the stormwater performance of these features would normally be secondary to their primary functions unless they are signed off as part of the approved SWMP. In this case the engineer would need to clarify how the features are to be maintained to meet all the objectives.

Primary performance criteria

GSI performance will need to be described for each of the six primary performance criteria in Table B1. Multidisciplinary input will be required to specify the criteria for each facility.

Table B1: List of primary performance criteria

Criterion	Outline
1. Hydrological capacity	storage, infiltration, discharge
2. Hydraulic capacity	flow rate, operating depths, surcharge conditions, size, hazard conditions, etc.
3. Water quality targets	list of target determinands, treatment flow range, inflow quality, range of anticipated discharge quality, etc.
4. Landscape requirements	hydraulic requirements, seasonal variation & stability, vegetation requirements, etc.
5. Amenity requirements	public access conditions, fencing & security, etc.
6. Ecological requirements	habitat conditions and diversity, vegetation, water level management, etc.
7. Support of other services	Water and sewer mains, electricity servitudes, road servitudes, public parks, sports facilities, car parks, etc.

GSI effectiveness criteria

The treatment performance of GSI will depend on the hydraulic loading of the system, particulate removal requirements, selection of the GSI facilities and arrangement of the treatment train. Particle size grading is useful in describing pollution characteristics, as most pollutants attach to sediment particles in stormwater. Lloyd, et al. (2002) describe typical grading for stormwater pollutants as varying from gross pollutants larger than 5mm (5000µm) to soluble pollutants smaller than 0.45µm (0.00045mm). GSI facilities are selected based on the pollutant type as outlined below (see also Figure B1).

The hydraulic loading of GSI is also different to the design of conventional grey infrastructure, which is typically sized according to a design storm event. GSI perform over a much wider range of storm flows and their effectiveness is measured by the proportion mean annual runoff that passes through each unit of the treatment train. Some units, typically the infiltration and sub-surface systems, have low hydraulic loading capacity and treat the smaller daily rain events but will surcharge under heavier storms. Other units, such as the sediment basins and attenuation ponds will have greater design storm capacity.

The range of treatments and hydraulic capacity of the different GSI components will mean that the overall performance of the treatment train will be more than the sum of the individual parts. Continuous simulation is critical to being able to evaluate the performance of the system as a whole.

B.2 Performance risk and liability

All urban drainage systems should be designed to meet performance criteria that will be specific to the site and its location in the catchment drainage network. Traditional grey infrastructure networks are typically designed to meet hydraulic performance (conveyance), with some hydrological function (e.g. attenuation). Green Infrastructure systems offer more hydrological performance and generally provide larger storage than grey systems. Therefore they tend to reach capacity in events of longer duration and performance failure usually has less impact than for grey systems.

However, Green Infrastructure systems seek to provide more than hydrological and hydraulic performance, and are vulnerable to the variable performance of natural systems. For example, vegetation cover will vary seasonally and even inter-annually affecting hydraulic performance, flood risk and erosion risk. Soil and fill media used for infiltration and retention may have variable performance under different intensities, or may vary in organic content or compaction over time, affecting both infiltration rates and saturation (rainfall storage) capacity. Stormwater engineers, developers, City of Johannesburg officials and the Johannesburg Roads Agency need to be aware of and sensitive to the performance uncertainties associated with the application of Green Stormwater Infrastructure. As a guide, the following responsibilities and liabilities are identified (Table B2).

Table B2: Responsibilities and liabilities

	Aspect	Responsibility	Liability*	Sign-off
1	Structural stability	Stormwater engineer	Developer/Landowner	CoJ / JRA Developer
2	Flood hazard	Stormwater engineer	Developer/Landowner	CoJ / JRA Developer
3	Parameter selection and testing	Stormwater engineer	None (if signed off by CoJ/JRA)	CoJ / JRA Stormwater engineer
4	Range of anticipated performance	Stormwater engineer	None (if signed off by CoJ/JRA)	CoJ / JRA Developer, Stormwater engineer
5 & 6	Maintenance of stormwater facilities	Stormwater engineer & landscape architect to define requirements	Developer/landowner (unless adopted by CoJ/JRA)	CoJ / JRA Developer
7	Preservation of the stormwater assets	Developer/landowner	Developer/landowner	CoJ / JRA Developer
8	Performance monitoring	Developer/landowner	Developer/landowner	CoJ / JRA Developer
* *In most cases the stormwater engineer will be liable to the developer.*				

Each of the items in Table B1 is explained in more detail below. However, the liabilities of the stormwater engineer are largely similar to the design and implementation of grey stormwater infrastructure. By fully disclosing the anticipated treatment parameters to the City and obtaining their sign-off, the actual performance of the facilities becomes a shared responsibility. However, this will require a higher level of effort to reach an agreement with the City officials, and a requirement on the latter to have the necessary capacity to consider and agree reasonable performance levels. An important liability will be placed on the developer and subsequent landowners to monitor and maintain stormwater facilities to ensure the desired performance. There will also be additional responsibility on the City to monitor this via a detailed asset register and database of system performance.

Structural stability

The physical integrity and structural stability of the system will remain the responsibility and liability of the developer (or subsequent landowner), and by implication the stormwater design engineer. This relates to the physical failure of the stormwater facility under all relevant design conditions that results in the erosion of the downstream stormwater network (and receiving watercourses) and associated damage (by sediment or flooding) of downstream properties. The relevant design conditions must include situations where vegetation cover may be at a minimum (assume zero cover), and extreme conditions where antecedent conditions of infiltration and storage are zero.

Flood hazard

The developer (or subsequent landowner) will be liable for any increase in flood hazard to downstream properties as a result of inadequate provision in the design for attenuation of peak flows. This liability excludes situations where poor maintenance and/or changes in upstream stormwater responses have occurred. These are addressed below.

Parameter selection and testing

The stormwater engineer is responsible for selecting and disclosing all the parameters used in determining the performance, or range of performance, of the stormwater facilities identified in the SWMP. The values chosen for the parameters will be clearly motivated by the stormwater engineer. In addition, the stormwater engineer should also identify at what point the parameters may lead to an increase in any hazard potential. Once satisfied, the City of Johannesburg and JRA representatives must sign off on the recommended parameters used in the analysis.

Statement of range of anticipated performance

The range of performance of the stormwater facilities in the SWMP must be disclosed and motivated by the stormwater engineer. Ideally this will be demonstrated by both single event performance under extreme (design) storm conditions and by continuous simulation (20 years). The stormwater engineer will also demonstrate that soil and rainfall-runoff response parameters have been verified by on-site investigations. Once satisfied that the performance range is reasonable, the City of Johannesburg and JRA shall sign off on stated range of performance.

Define maintenance requirements

The stormwater engineer, supported by a landscape architect and ecologist (as necessary) shall identify and set out the maintenance requirements of the stormwater system. This will include such aspects as frequency of inspections, methods of vegetation control, sediment removal and disposal, soil rehabilitation (e.g. bioretention filters), sweeping and jetting (permeable paving), anticipated frequency of maintenance activities and any seasonal variations.

Agree maintenance responsibilities

Maintenance responsibilities must be clearly stated and agreed between the developer, landowner and the CoJ/JRA. The landowner will at all times retain responsibility for the ongoing maintenance of all approved stormwater facilities. Maintenance will be closely associated with the performance monitoring programme (see below), which will also guide the need for any changes to the maintenance activities.

Asset register and preservation of the stormwater assets

The approved stormwater facilities must be entered onto the asset register at the City of Johannesburg. This will record the physical attributed of the assets, the anticipated performance and the actual performance. The landowner shall remain liable for the ongoing condition of the assets.

Performance monitoring

It is necessary to observe and record the long-term performance of the stormwater facilities on a site. This is important data to guide the selection and implementation of SuDS facilities in Johannesburg, as well as to monitor whether the system is providing the necessary level of stormwater treatment (quantity and quality). Monitoring is also an important part of ensuring the assets are protected. The landowner will be liable for both monitoring and maintaining the assets. Monitoring data will be relayed to the CoJ/JRA on an agreed programme.

B.3 Pre-development runoff

Pre-development runoff provides the baseline for setting performance targets for GSI and the stormwater management system. The assessment of pre-development runoff assumes the catchment to be in the condition of its natural state before human land use activities. For the greater municipal area of the City of Johannesburg the guideline pre-development state is deemed to include the conditions in Table B3. For land cover and vegetation the more recent publications through SANBI may be best, but as a representation of original land cover for the Johannesburg area the earlier works by the likes of Acocks are still seen to be relevant for the purposes of pre-development runoff estimation.

Table B3: Pre-development baseline conditions for the City of Johannesburg

Hydrological baseline	Pre-Development Condition	Reference
Land cover, vegetation	Highveld grassland cover	Mucina & Rutherford, 2006, or even Acocks (1988)
Soils	ARC Land Types	ARC-ISW, 2006
Geology	Geology as presented in WR2012	Bailey & Pitman, 2015
Mean annual precipitation (MAP)	As presented in WR2012	Bailey & Pitman, 2015
Mean annual runoff (MAR)	As presented in WR2012	Bailey & Pitman, 2015

Alternative pre-development conditions may be presented in the Stormwater Report with sufficient motivation and supporting information, but runoff responses shall be compared with the conditions in Table B3. The more conservative condition (i.e. that generating lower estimates of storm runoff) should be adopted unless agreed with the JRA and EISD.

Pre-development soils

Tables B4, B5 and B6 provide data that may be adopted for use in estimating pre-development storm runoff from a site. The data is based largely on ARC land-type surveys and are deemed to be representative of pre-development catchment conditions. The information is spatially variable and subject to interpretation. Unless a different interpretation is supported by site and location specific investigation, the CoJ will default to the most conservative estimate of pre-development runoff (i.e. lowest runoff conditions). The tables below will assist both the CoJ and stormwater designers to evaluate the more conservative pre-development conditions.

Table B4: SCS hydrological soil groups for primary soils in the City of Johannesburg area (Schmidt and Schulze, 1987).

Code	Soil form	SCS Group	Primary Series	Main Texture Class	SCS Gp Range	SCS Conductivity mm/h	SCS Final Inf. Rate mm/h
Av	Avalon	B	Av16, Av26, Av27, Av37	SaClLm	B, B/C, C	(1.8) 3.8 - 7.6	13 (6)
Cv	Clovelly	A/B	Cv16, Cv24	SaClLm	A/B	5.8 - >7.6	19
Gc	Glencoe	B	Gc24, Gc26	SaLm	B	3.8 - 7.6	13
Gs	Glenrosa	B/C	Gs14, Gs15, Gs16, Gs17, Gs18	SaClLm	B, B/C	2.8 - 5.7 (7.6)	13 (9.5)
Hu	Hutton	A	Hu14, Hu16, Hu23, Hu24, Hu26, Hu27, Hu36	SaLm	A, A/B, B	>7.6 (3.8-7.6)	25 (13 - 19)
Ms	Mispah	C	Ms10, Ms11	SaClLm	C	1.3 - 3.8	6
Sd	Shortlands	B	Sd11	SaCl	B	3.8 - 7.6	13
Wa	Wasbank	C	Wa21, Wa23	SaLm	C	1.3 - 3.8	6
Rock		D+			D+	<<1.3	<<3

Table B5: Land types and associated soil characteristics for the City of Johannesburg metropolitan area (ARC-ISCW, 2006)

Land Type	Description	N or S	Approx. area in CoJ (%)	Catchment	Geology	Primary soil (%)	Primary Series (Gaut)	Adopted Pre-dev SCS Soil Group	Typical depth (m)	Adopted Pre-dev depth (m)	% Clay	Texture
Ab7	Freely drained, red and yellow, dystrophic/ mesotrophic, apedal soils comprise >40% of the land type (yellow soils <10%)	S	10	Klip	Dolomite	Hu 89%	Hu26, Hu24, Hu23, Hu16, Hu14	A	0.75	0.75	A: 6-20; B21: 10-25	meSaLm, SaClLm
Ab11		N	<5	Modderfontein (upper)	Mafic/Ultramafic/Granite (Amphibolite, Serpentinite, schist)	deep Hu 47%, shallow Hu	Hu26, Hu27	A	0.85	0.85	A: 25-30; B21: 30-40	fiSaClLm, SaCl
Ab12		N	<5	Crocodile	Mafic/Ultramafic (Amphibolite, Serpentinite, schist)	Hu 34%, Ms 28%	Ms10, Hu26, Hu27	B	0.15; 0.85	0.85	A: 15-30; B21: 30-40	meSaLm, SaClLm, SaCl
Ba1	Red and yellow, dystrophic/ mesotrophic, apedal soils with plinthic subsoils (plinthic soils comprise >10% of land type, red soils comprise >33% of land type)	S	10	Rietspruit	Mafic/Siliciclastic (Quartzite, Shale, Sandstone)	Hu 56%, Ms 20%	Hu26, Hu36, Ms10	A/B	0.9; 0.3	0.9	A: 15-25; B21: 15-35	fi/meSaClLm, fi/meSaLm
Ba27		S	10	Klip/Klipspruit	Mafic/Ultramafic (Lava, tuff, chert, agglomerate, quartzite)	Rock 26%, Hu 23%, Av 21%	Gs16, Hu26, Hu36, Hu37, Av27, Av37	B/C	0.25; 0.4; 0.75	0.75	A: 25-40; B21: 30-50	fiSaClLm, SaCl
Ba29		S	<5	Rietspruit	Mafic/Ultramafic (quartzite, shale, slate, sandstone diabase)	Hu 52%	Hu26, Hu36, Ms10	A	0.9; 0.3	0.9	A: 15-25; B21: 15-35	fi/meSaClLm, fi/meSaLm
Ba35		N,S (ridge)	<10	Klipspruit & most northern catchment headwaters	Siliciclastic (quartzite, slate, grit)	Ms 34%, Hu 24%, Gc 21%	Ms10, Ms11, Gc24, Gc26, Cv16, Cv24, Hu26, Hu14	B/C	0.15; 0.65; 0.85	0.85	A: 6-20; B21: 6-20	LmmeSa, SaLm
Ba36		S	15	Klip/Klipspruit	Siliciclastic (quartzite, slate, grit)	Ms 35%, Hu 24%, Gc 21%	Ms10, Ms11, Gc24, Gc26, Cv16, Cv24, Hu26, Hu14	B/C	0.15; 0.65; 0.85	0.85	A: 6-20; B21: 6-20	LmmeSa, SaLm
Bb1	Red and yellow, dystrophic/ mesotrophic, apedal soils with plinthic subsoils (plinthic soils comprise >10% of land type, red soils comprise <33% of land type)	N	>25	All N streams	Granites (upper)	Hu 20%, Gs 25%, Av 26%	Gs15, Av26, Av16, Hu26, Hu16, Wa23	B	0.35; 0.5; 0.8	0.8	A: 10-30; B21: 15-35	LmcoSa, SaLm, coSaClLm
Bb2		N	20	All N streams	Granites (lower)	Gs 25%, Av 26%, Hu 20%	Gs15, Av26, Av16, Hu26, Hu16, Wa21	B	0.35; 0.5; 0.8	0.8	A: 10-30; B21: 15-35	LmcoSa, SaLm, coSaClLm
Fb5	Shallow soils (Mispah & Glenrosa forms) predominate; usually lime in some of the bottomlands in landscape	S	<10	Rietspruit/Klip	Mafic/Siliciclastic (Quartzite, shale, slate)	Ms 38%, Cv 34%, Rock 19%	Ms10, Gs16, Gs17, Hu26, Hu27	C	0.15; 0.22; 0.75	0.35	A: 15-25; B21: 18-32	fiSaLm, SaClLm, fiSaClLm
Ib41	Rock outcrops comprise >60% of land type	N,S	10	Klipspruit & most northern catchment headwaters	Mafic/Siliciclastic (Quartzite, slate, grit & conglomerate)	Rock 61%, Ms 25%	Ms10, Gs14, Gs15, Gs17, Gs18	C/D	0.18	0.18	A: 10-20; B21:	LmmeSa, SaLm
Ib43		S	<10	Klip/Klipspruit	Mafic/Ultramafic (Lava, breccia & tuff)	Rock 52%, Sd 21%	Sd11, Gs16, Hu27	C	0.45; 0.35; 0.7	0.35	A: 25-40; B21: 25-55	fiSaCl, Cl, fiSaClLm

Table B6: Soil properties for pre-development and GSI calculations (Saxton and Rawls, 2009)

Texture Class	Wilting Point (m/m)	Field Capacity (m/m)	Porosity (saturation) (m/m)	Sat. Cond. (mm/h)	Bulk. Dens. (kg/m^3)
Cl	0.300	0.419	0.489	0.83	1350
Lm	0.129	0.273	0.470	20.49	1400
Sa	0.056	0.102	0.472	115.14	1400
LmSa	0.062	0.128	0.468	93.22	1410
SaLm	0.085	0.186	0.462	52.82	1430
SiLm	0.139	0.326	0.497	14.31	1330
SaClLm	0.186	0.288	0.438	8.14	1490
ClLm	0.215	0.353	0.479	5.08	1380
SiClLm	0.211	0.381	0.520	7.04	1270
SaCl	0.262	0.372	0.442	0.84	1480
SiCl	0.278	0.415	0.537	4.38	1230

Pre-development Stormwater Runoff Calculation

The same methods used to develop the stormwater design and stormwater management plan must be used to determine the pre-development runoff in all instances. This will apply to calculations of peak flow only, to single event hydrograph estimations, and continuous simulation analysis.

B.4 Hydraulic capacity of GSI

Conveyance

Estimating hydraulic capacity of the vegetated lined systems that exist in GSI needs more careful evaluation than for hard lined grey infrastructure, especially if failure due to overtopping during storm conditions is a risk. A key factor is the height of vegetation in relation to flow depth. In many GSI systems the flow depth may be similar or even shallower than the vegetation. Under these conditions the assumptions inherent in the application of the Manning's roughness coefficient and the Manning's equation are no longer applicable.

However, the Manning's coefficient remains an industry standard. In situations where GSI or natural stream channels form part of a flood management solution in a stormwater management scheme, the approach to determining the Manning's coefficient for partially or fully emergent vegetation developed by James (2010) at the University of Witwatersrand, Dept. Civil Engineering shall be used. This will be particularly important under flood conditions where flood risk and hazard are considered significant (e.g. where human safety or severe damage to property is at risk).

In other applications where risk and hazard are low, and performance and structural stability of the GSI facility are the primary concern, Table 7 provides guidelines on the selection of Manning's coefficient. These are derived from a more detailed method for predicting the resistance of submerged grass, accounting for the effect of blade bending. Details are given by Kouwen (1992). This method has been applied parametrically to wide flows on slopes ranging from 0.0010 to 0.010, grass blade lengths (h) ranging from 0.10 m to 0.30 m and flow depths (D) up to 1.0 m. The resulting ranges of Manning's n at different relative depths are given in Table 7. The values generally increase with decreasing slope and decreasing blade height; the lower range values in the table are mostly for the steepest slope of 0.010 and the higher range values are mostly for the 0.10 m blade height.

For unsubmerged grass, effective *n* values are high but less variable than for submerged grass. Kirby et al. (2005) measured *n* values in the laboratory for three commonly used species in the United States of America with blade heights of 50-80 mm, for velocities from about 0.05 m/s to 0.10 m/s. They related *n* to the product *VR*. The values are slightly different for the different species, but a representative relationship is given in Table B7.

Table B7: Guidelines for selection of Manning's coefficient of flow resistance for estimating hydraulic capacity of GSI facilities in low flood hazard situations.

Conveyance	Conditions	Guideline values	Reference
1. Grass lined channels and swales	Submerged, flexible grass blades	*D/h* — *n* 2 — 0.068 – 0.66 4 — 0.037 – 0.13 6 — 0.029 – 0.076 8 — 0.026 – 0.065 10 — 0.024 – 0.058	Kouwen (1992)
2. Grass-lined channels	Unsubmerged, blade height less than 80 mm.	$n = 0.0053\ VR^{-0.67}$	Kirby et al. (2005)
3. Vegetation lined channel, and any overland flow (vegetation height >0.5 design flow depth)	Shrubs & stemmed plants (emergent). Cut grass, submerged. Grass & reeds, emergent.		James (2010)

It is recommended that the hydraulic capacity of all stormwater infrastructure (grey or green) are tested under conditions of both good and poor maintenance. Consequences of failure can be considered by the City before approval.

Hydraulic loading

Hydraulic loading is a measure of the volume of storm runoff treated by a GSI facility over a period of time (typically a year). It may be expressed as a percentage of the total storm runoff, or in the form of the equation below. Stormwater that bypasses (or surcharges) a GSI facility as its hydraulic loading is exceeded, will not be included in the measure of hydraulic loading. All GSI facilities are expected to surcharge at some stage; for example sediment basins and attenuation ponds will surcharge (overspill) above their design storm, while bio-filters may surcharge under more frequent rain events.

A measure of hydraulic loading is described by:

$$Hydraulic\ loading = Q_{des}/A_{facility}$$

Where: *Hydraulic loading = m/year*

Q_{des} *= treated flow per year (m³/year)*

$A_{facility}$ *= surface area of the GSI (m²)*

Further development of hydraulic loading on GSI will be provided in an update of the Manual.

B.5 Infiltration, soils & recharge

The design of GSI facilities that infiltrate stormwater runoff into the local soils on site must demonstrate the infiltration and storage capacity of the receiving soils. The design must also ensure that the foundations of nearby structures, including those on neighbouring properties, will not be negatively affected by the design.

For the likes of landscaped filter strips, rain gardens and runoff buffer areas adjacent to impervious surface areas less than $100m^2$ knowledge of the infiltration capacity of receiving soils to a depth of 1.2m below the landscaped area is recommended. For GSI facilities like infiltration trenches receiving runoff from larger surface areas, a more detailed geotechnical investigation and infiltration testing will be required to determine soil conditions and underlying geology at the location of the proposed soakaway and the surrounding area, particularly downslope of the soakaway.

The recommended method of testing for infiltration capacity of the receiving soils is the BRE Digest 365. This includes in-situ testing of test pits excavated on site and filled with water and left to drain through a sequence of tests over a period of time. This will be required for detailed design of GSI systems and determining the anticipated performance of individual GSI facilities.

B.6 Stormwater Effectiveness of GSI

GSI is best designed to function as a treatment train though on smaller sites it may be possible to achieve the desired performance with a single facility. In either case, it is the overall performance of the system that will count, but in a treatment train it will still be necessary to quantify the individual performance of each component. Many features such as buffer strips, swales and infiltration systems are designed to treat the general day to day events and these systems will be overloaded in design event conditions. However, defining their performance will still be important as the cumulative benefit of these systems will have a significant impact on the receiving environment. The performance of these systems is best analysed and designed by continuous simulation methods.

Larger facilities such, as attenuation ponds and wetlands, will be designed to perform under the larger flood event conditions. It may be possible to develop the designs using multiple single event analyses, but their full performance, and benefit, is again best assessed by continuous simulation. Hence the characteristics identified for each GSI in the sections below are those typically required for continuous simulation analysis, though the same criteria will be necessary for single event analyses.

The following will need to be considered when planning and designing the treatment train for a site:

- Determine the stormwater flow and pollutant characteristics for the site,
- Identify appropriate treatment processes,
- Assess site constraints,
- Set out the treatment sequence,
- Estimate treatment performance and compliance with catchment water quality objectives.

Site stormwater characteristics

Particle Size Gradings	Treatment Measures						Hydraulic Loading $Q_{des}/A_{facility}$
Gross solids >5mm (>5000µm)	Gross pollutant						1,000,000m/yr 100,000m/yr
Coarse to medium 5mm-0.125mm (5000µm-125µm)	traps	Sedimentation Basins (Wet & Dry)	Grass Swales				50,000m/yr 5,000m/yr
Fine 0.125mm-0.01mm (125µm-10µm)			& Filter strips	Surface flow wetlands	Infiltration		2,500m/yr 1,000m/yr
Very fine (colloidal) 0.01mm-0.00045mm (10µm-0.45µm)					Systems	Sub-surface Flow	500m/yr 50m/yr
Dissolved particles <0.00045mm (<0.45µm)						Wetlands	10m/yr

Figure B1: Best Management Practices, their target particle size range and operating hydraulic loading range (Wong, 2000, cited by Lloyd, et al, 2002)

Describe the stormwater flow and quality characteristics of the developed site. Describe the pre-development stormwater characteristics that will be used to establish the target performance criteria of the stormwater management system and associated GSI facilities.

Characteristics to be described should include:

- Present the flow-duration curves (by continuous simulation methods) for the pre-development and developed site conditions (without any stormwater mitigation measures) as outlined in Chapter 5 (Figure 5.6).
- Pre and post-development design hydrographs for the full range of return periods and durations as agreed with the JRA/CoJ (EISD). If no range has been agreed, all durations from the 15 minute to 24 hours and return periods 1 year to 100 year events should be presented. In cases where flood hazard is a concern, events greater than the 100 year event should be evaluated.
- Describe the water quality, sediment and pollution conditions in the receiving environment. Alternatively describe the water quality targets for the catchment where available (e.g. in the catchment management plan).
- Describe the anticipated pollutants and predicted loads from the developed site. These should include:
    - Total suspended solids, TSS (kg/ha, or mg/l).
    - Total phosphorus, TP
    - Total Nitrogen, TN
    - Gross pollutants,
    - eColi (counts/100ml) or Biological Oxygen Demand, BOD (mg/l or kg/ha)
    - Hydrocarbons (mg/l).

Availability of water quality data.

Currently this Manual identifies methods for estimating two of the primary pollutants in Johannesburg's streams; sediment (by site analysis) and eColi (by instream measurement). In time guidelines for other typical urban pollutants, such as Total Nitrogen, Phosphorus, and hydrocarbons will be included in the Manual to be used for the analysis of performance of GSI.

Buffer zones and filter beds

Key parameters	Description
Total area draining to buffer zone	Expressed as ratio of pervious to impervious areas.
Buffer zone area	Expressed as a percentage of upstream impervious area
Infiltration parameters	Soil water storage in buffer zone, soil texture, slope, etc.
Exfiltration rate	Rate of drainage from buffer area into underlying soils
Vegetation characteristics	Stem density, height

Swales

Key parameters	Description
Inflow characteristics	Either the upstream catchment area (expressed as a portion of the site and ratio of pervious to impervious areas, OR Discharge from an upstream GSI facility.
Size and hydraulic capacity of swale	Length, typical cross-section (base width, top width), depth, slope, flow capacity.
Vegetation characteristics	Stem density, height.
Exfiltration rate	Rate of drainage from buffer area into underlying soils

Infiltration trench

Key parameters	Description
Inflow characteristics	Either the upstream catchment area (expressed as a portion of the site and ratio of pervious to impervious areas, OR Discharge from an upstream GSI facility.
Low flow bypass (if applicable)	Expressed as a flow rate (m^3/s)
High flow bypass	Expressed as a flow rate (m^3/s) and return period.
Storage characteristics above filter zone (if applicable)	Detention depth (m), surface area (m^2), exfiltration rate (mm/h).
Filtration characteristics	Filter area (m^2) and depth (m), filter media particle size (mm), saturated hydraulic conductivity (mm/h).
Details of underdrain pipe(s)	Depth (m), and flow rate (if this is a limitation).
Exfiltration rate (if unlined)	Rate of drainage into underlying soils (mm/h)
Overflow weir capacity	Width (m), height above filter media (m), flow capacity (m^3/s)
Vegetation characteristics	This is not normally a vegetated GSI facility.

Bioretention unit and Infiltration system

Key parameters	Description
Inflow characteristics	Either the upstream catchment area (expressed as a portion of the site and ratio of pervious to impervious areas, OR Discharge from an upstream GSI facility.
Low flow bypass (if applicable)	Expressed as a flow rate (m^3/s)
High flow bypass	Expressed as a flow rate (m^3/s) and return period.
Storage characteristics above filter zone (if applicable)	Detention depth (m), surface area (m^2), exfiltration rate (mm/h).
Filter characteristics	Filter area (m^2) and depth (m), unlined filter media perimeter (m).
Filter media	Description of media as a soil type (e.g. sandy loam) or mix of components (media particle size, organic mix, etc.).
	Saturated hydraulic conductivity (mm/h)
	Total nitrogen (TN) content (mg/kg, or mg/m^3) of media.
	Orthophosphate content (mg/kg, or mg/m^3) of media.
Exfiltration rate	Rate of drainage into underlying soils (mm/h)
Details of underdrain pipe (if applicable)	Depth (m), and flow rate (if this is a limitation).
Overflow weir capacity	Width (m), height above filter media (m), flow capacity (m^3/s)
Vegetation characteristics	Describe effective nutrient removal potential of vegetation (if known and considered part of the performance of the unit), Evapotranspiration rate (mm/day, seasonal variation)

Wetland

Key parameters	Description
Inflow characteristics	Either the upstream catchment area (expressed as a portion of the site and ratio of pervious to impervious areas, OR Discharge from an upstream GSI facility.
Low flow bypass (if applicable)	Expressed as a flow rate (m^3/s)
High flow bypass	Expressed as a flow rate (m^3/s) and return period.
Inlet pond volume (if any, typically for sediment trapping).	Operational volume (m^3)
Wetland surface area	(m^2 or ha)
Permanent pool volume	Storage volume below the lowest outlet level (m^3).
	Description of media as a soil type (e.g. sandy loam) or mix of components (media particle size, organic mix, etc.).
Exfiltration rate	Rate of drainage into underlying soils (mm/h)
Evapotranspiration	Seasonal variation (% of PET)
Outlet hydraulic capacity • Overflow weir capacity • Pipe outlet controls	Width (m), height above wetland bed (m), flow capacity (m^3/s), rating curves, etc.
Vegetation characteristics	Describe type of vegetation (including diversity if applicable). Describe effective nutrient removal potential of vegetation (if known and considered part of the performance of the unit),

Pond

Key parameters	Description
Inflow characteristics	Either the upstream catchment area (expressed as a portion of the site and ratio of pervious to impervious areas, OR Discharge from an upstream GSI facility.
Low flow bypass (if applicable)	Expressed as a flow rate (m^3/s)
High flow bypass	Expressed as a flow rate (m^3/s) and return period.
Surface area	(m^2 or ha)
Extended detention depth	Depth above the permanent pool level that will still offer some detention (m).
Permanent pool volume	Volume below the lowest outlet level (m^3)
Evapotranspiration	Seasonal variation (% of PET)
Exfiltration rate	Rate of drainage into underlying soils (mm/h)
Outlet hydraulic capacity • Overflow weir capacity • Pipe outlet controls	Width (m), height above wetland bed (m), flow capacity (m^3/s), rating curves, etc.
Vegetation characteristics (if applicable).	Describe effective nutrient removal potential of vegetation (if known and considered part of the performance of the unit), Evapotranspiration rate (mm/day, seasonal variation)

Sediment Basins and Detention (Attenuation) Basins

Sediment and detention basins have similar characteristics but their application will differ.

Key parameters	Description
Inflow characteristics	Either the upstream catchment area (expressed as a portion of the site and ratio of pervious to impervious areas, OR Discharge from an upstream GSI facility.
Low flow bypass (if applicable)	Expressed as a flow rate (m^3/s)
High flow bypass	Expressed as a flow rate (m^3/s) and return period.
Surface area	(m^2 or ha)
Extended detention depth	Depth above the permanent pool level that will still offer some detention (m).
Permanent pool volume	Volume below the lowest outlet level (m^3)
Evapotranspiration	Seasonal variation (% of PET)
Exfiltration rate	Rate of drainage into underlying soils (mm/h)
Sediment characteristics (sediment basin)	Sediment loading (mg/l) Grading analysis (particle size analysis) Specific gravity
Outlet hydraulic capacity • Overflow weir capacity • Pipe outlet controls	Width (m), height above wetland bed (m), flow capacity (m^3/s), rating curves, etc.
Attenuation performance (detention basin)	Description of pre-development peak runoff (m^3/s) and attenuated development runoff (m^3/s) for a range of storm durations (15min to 24h) and return periods (3 time per year up to 100 year).
Vegetation characteristics (if applicable).	Describe effective nutrient removal potential of vegetation (if known and considered part of the performance of the unit), Evapotranspiration rate (mm/day, seasonal variation)

Rain water tank & Underground tank

The effectiveness of rainwater tanks and underground tanks are typically dependent on how they are used. They may offer simple attenuation capacity, or they may offer a retention capacity if re-use of stormwater is applied. In both cases their operation needs to be assured before the CoJ will approve their function in a Stormwater Management Plan. In many cases domestic systems in residential developments are not seen to offer reliable performance, whereas commercial and industrial applications show greater potential where the economic benefits of stormwater harvesting are demonstrated. The approval of rainwater tanks and underground tanks as part of the stormwater management plan for a site is subject to acceptance by JRA and EISD in each individual case.

Key parameters	Description
Total storage volume (m^3)	Total volume of the facility.
Attenuation volume (m^3)	Free volume that is available to stormwater attenuation before every storm event.
Time to drain attenuation volume (min or h)	The time it takes to clear the attenuation volume after each storm.
Re-use volume (m^3/week or l/day)	Assured consumption when rainwater is available.

B.7 Performance analysis

The approach to analysing the performance of SuDS facilities and will be detailed in the next update of the Manual. This will look at both hydrological performance (quantity) and treatment performance (quality). Samples of the kinds of analysis being developed are given below.

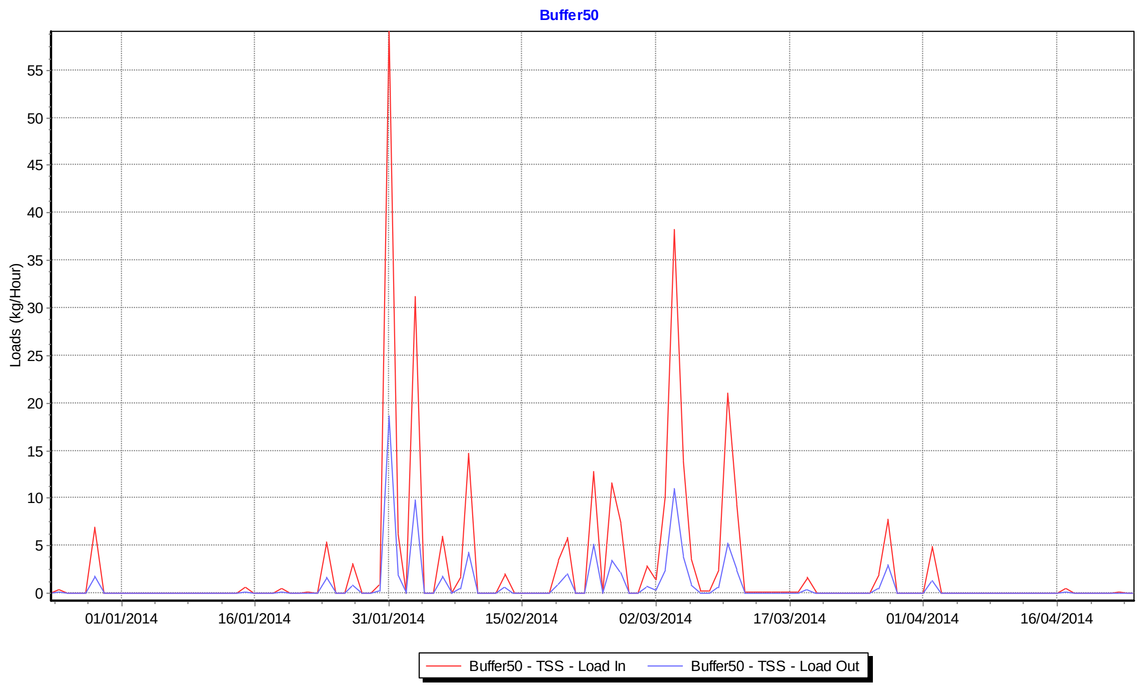
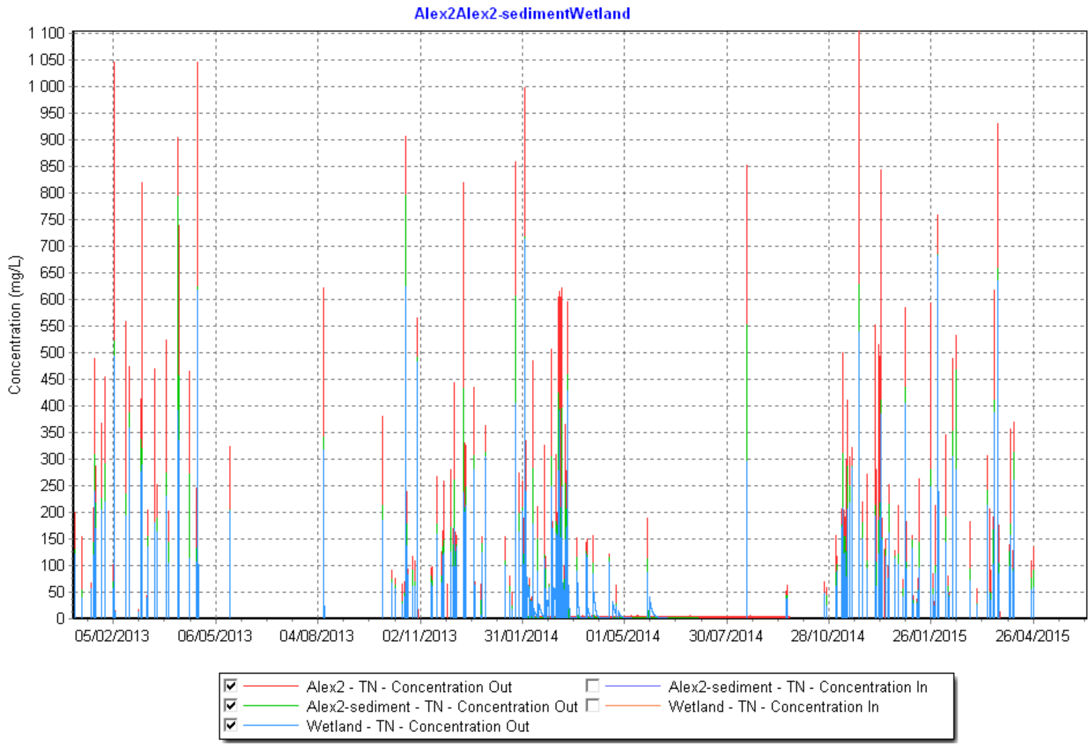


Figure B2: Treatment performance if a sediment trap



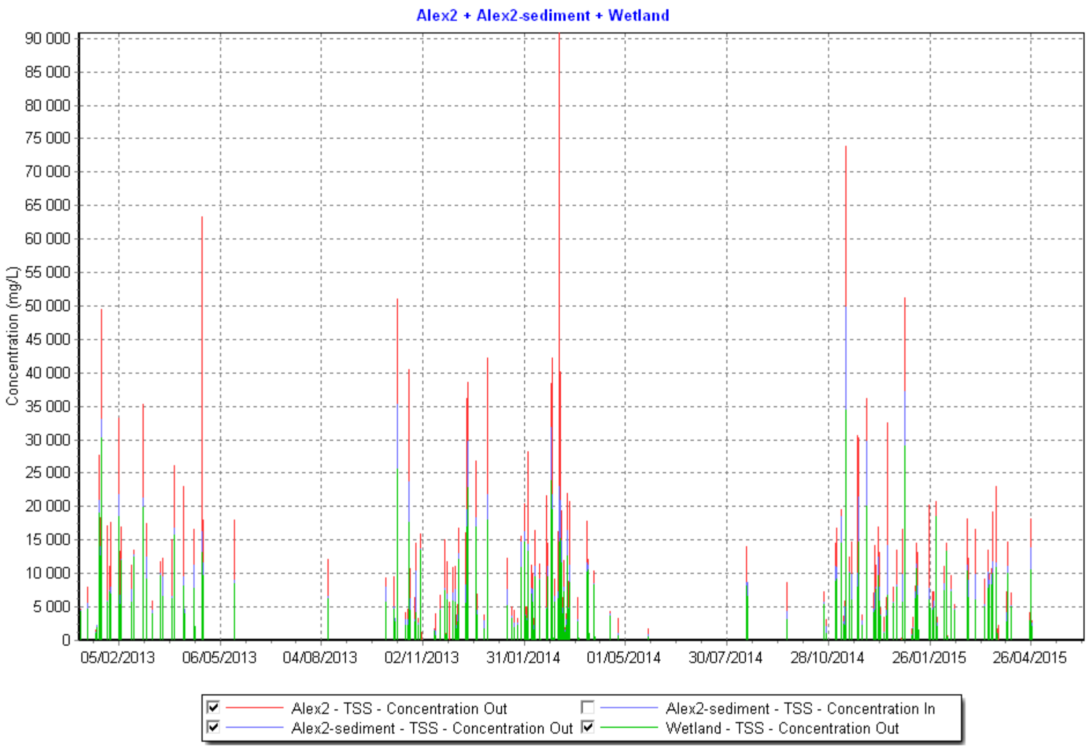


Figure B3: Treatment performance of a Wetland (Total Nitrogen and Suspended Solids)

B.8 Conveyance Estimation for Natural and Re-engineered River Channels

Estimating the relationship between discharge and flow depth for rivers under flood conditions requires gradually varied flow analysis. Steady flow analysis is generally sufficient unless the river is very wide or the gradient is very mild. Proprietary software packages, such as HEC-RAS, are available and produce results as reliable as the input information. Input requirements include the design discharge, as determined through hydrological analysis, cross-section surveys at appropriate spacings, identification of a suitable control section, and description of the physical roughness characteristics of the channel (and flood plain if applicable). The roughness characteristics are usually expressed in terms of a resistance coefficient corresponding to one of the commonly used resistance equations, i.e.

Chézy: $$V = C\sqrt{RS} \tag{1}$$

Darcy-Weisbach: $$V = \sqrt{\frac{8g}{f}}\sqrt{RS} \tag{2}$$

Manning: $$V = \frac{1}{n}R^{2/3}S^{1/2} \tag{3}$$

In these equations *V* is the cross-section average velocity (m/s), *R* is the hydraulic radius (m) (= *A*/*P* where *A* is the cross-sectional area (m^2) and *P* is the wetted perimeter (m)), and *S* is the energy gradient, which is equal to the channel gradient for steady, uniform flow. *C* ($m^{1/2}/s$), *f* and *n* ($s/m^{1/3}$) are the corresponding resistance coefficients.

The use of the different resistance equations is often a matter of choice, and may be dictated by the input requirements of particular models, or by the source of information. The Manning equation is the most popular in engineering practice, but the Darcy-Weisbach (which is more theoretically sound) is often used for developing new relationships. The equations are essentially equivalent and coefficient values can be easily converted between them using the following relationships.

$$C = \sqrt{\frac{8g}{f}} = \frac{R^{1/6}}{n} \tag{4}$$

Natural or engineered features in rivers impose resistance mainly through the shear stress at the boundary in contact with the flow and the drag of discrete objects, such as rocks, or boundary irregularities.

Rough estimates of Manning's *n* can be obtained from tables relating ranges of values to descriptions of channel characteristics, such as that presented by Chow (1959), or from photographic guides such as Hicks & Mason (1988). These should be used with caution, however, as (clearly apparent in Hicks & Mason) the value can vary considerably with changing flow conditions. The formulations given below account for such changes to some extent, but still represent approximations gathered from field and laboratory observations. The value of site-specific calibration through measurement of stage and discharge cannot be over-emphasized.

Channel bed resistance

The effect of the channel bed is the primary consideration when evaluating the resistance in a river. It is important to distinguish between immobile bed and mobile bed conditions. Beds are immobile if the prevailing flow is insufficient to move the particles. Beds of boulders or cobbles – and especially designed riprap protection – can usually be assumed to be immobile.

- **Immobile beds**

The resistance of an immobile bed depends on the size of the substrate material and also on the size relative to the flow depth. If the flow depth is more than about 10 times the bed material size the roughness is referred to as "small scale" and the value of Manning's *n* is independent of the flow depth. For flood conditions the flow will also be "hydraulically rough". For these conditions the ASCE Task Force on Friction Factors in Open Channels (1963) proposed a general formulation for the friction factor (f), which has been calibrated further by others. James (2010) presents a workable form as

$$\frac{1}{\sqrt{f}} = 2.1\log\left(\frac{12.2R}{3.5d_{84}}\right) \tag{5}$$

in which d_{84} is the size of bed particle for which 84% of particles are smaller. (The quantity $3.5d_{84}$ has become a widely accepted representation of the Nikuradse roughness, k_s.) A different equation form was used by Bray and Davar (1987), who suggested an equation that can be written (using the same k_s representation) as

$$\frac{1}{\sqrt{f}} = 2.6\left(\frac{R}{3.5d_{84}}\right)^{0.25} \tag{6}$$

Strickler (1923) proposed an equation for Manning's *n* in terms of the bed roughness:

$$n = \frac{k_s^{1/6}}{6.7\,g^{1/2}} \tag{7}$$

which, again using $k_s = 3.5d_{84}$, can also be expressed as

$$\frac{1}{\sqrt{f}} = 2.4\left(\frac{R}{3.5d_{84}}\right)^{0.167} \tag{8}$$

Equations (5) to (8) can be used to quantify Manning's *n* through the equivalence relationship given by equation (4).

If the flow depth is less than about 10 times the substrate size, the roughness is termed "intermediate scale" for the range of relative roughness down to about 1.0, and "large scale" for relative roughness less than about 1.0. Manning's *n* and *f* increase considerably as the relative roughness decreases. Intermediate and large-scale conditions are unlikely for flood flows, but are common for the low flows relevant to environmental analyses. Formulations for these conditions are presented by James (2010).

- **Mobile beds**

Channels with mobile (mainly sandy) beds present considerable difficulties for resistance estimation as the bed deforms when in motion, creating a variety of bed forms that change with flow condition. Many methods have been proposed for predicting the size and shape of bed forms and their resistance effects. James (2010) cites some of these and presents the application of the method of van Rijn (1984).

Vegetation resistance

Vegetation in rivers, along their banks, and on flood plains has a significant influence on flow resistance. The effect depends on the growth habit, the most important being submerged (wholly below the water surface) or emergent (protruding through the surface).

- **Submerged vegetation**

Most methods proposed for estimating the resistance of submerged vegetation have been developed for grasses used for lining artificial channels, but may also be used for grass-type vegetation in rivers and on flood plains. A well-established method was developed by Kouwen and co-workers and is summarized in Kouwen (1992). The method provides for calculation of the friction factor using a variant of the form of equation (5),

$$\frac{1}{\sqrt{f}} = a + b\log\left(\frac{D}{k}\right) \tag{9}$$

in which *a* and *b* are coefficients depending on the bent state of the vegetation (Table 1), *D* is the flow depth and *k* is the roughness height (m) given by

$$k = 0.14\,h\left(\frac{\left(\frac{MEI}{\tau_o}\right)^{0.25}}{h}\right)^{1.59} \tag{10}$$

in which *h* is the vegetation height (m), *M* is a non-dimensional representation of stem density, *E* is the stem material's modulus of elasticity (N/m^2), *I* is the stem's second moment of area (m^4), and τ_o is the total boundary shear (N/m^2) as given by

$$\tau_o = \rho g D S \tag{11}$$

The vegetation lining characteristics represented by *M*, *E*, and *I* are lumped together and treated as one variable *MEI* (Nm^2). The coefficients *a* and *b* depend on whether the stems are erect or prone, which is determined by the relationship of the boundary shear velocity, given by

$$u_* = \sqrt{\frac{\tau_0}{\rho}} = \sqrt{g D S} \tag{12}$$

to a critical value given by the lesser of

$$u_{*crit} = 0.028 + 6.33\,MEI^2 \tag{13}$$

and

$$u_{*crit} = 0.23\,MEI^{0.106} \tag{14}$$

The values of *a* and *b* for different conditions defined by the shear velocity are listed in Table .

Table B8: Values of coefficients *a* and *b* for submerged vegetation

Condition	Criterion	*a*	*b*
erect	$u_*/u_{*crit} \le 1.0$	0.15	1.85
prone	$1.0 < u_*/u_{*crit} \le 1.5$	0.20	2.70
prone	$1.5 < u_*/u_{*crit} \le 2.5$	0.28	3.08
prone	$2.5 < u_*/u_{*crit}$	0.29	3.50

- **Extensive emergent vegetation**

In extensive stands of emergent vegetation, such as reed beds, the resistance arises mainly from drag on the stems. In this case the velocity does not depend on the flow depth and the conventional resistance equations do not really apply, although equivalent coefficient formulations have been developed.

By combining the shear resistance on the bed and the drag on the stems an effective *f* or *n* can be determined. For use with the Darcy-Weisbach equation,

$$f = f^{/}\frac{A_{bf}}{A_b} + f^{//} \tag{15}$$

where $f^{/}$ is the usual friction factor for the substrate material and $f^{//}$ is an equivalent friction factor for the stems. A_b is the bed area between stems per unit bed area, given by

$$A_b = 1 - N\frac{\pi d^2}{4} \tag{16}$$

with *N* being the number of stems per unit area and *d* the stem diameter. .A_{bf} is the effective bed area on which shear acts, which greater than A_b because of the presence of separation zones around the stem bases. Based on work by Thompson & Roberson (1976) $A_{bf} = 2.5A_b$ is recommended.

The friction factor for the stems, $f^{//}$, is given by

$$f^{//} = 4C_D\frac{A_p}{A_b} \tag{17}$$

in which A_p is the projected stem area per unit area of bed, given by

$$A_p = N D d \tag{18}$$

and C_D is the drag coefficient for the stems. James et al. (2008) quantified the drag coefficient for phragmites stems with different degrees of foliation, bulrush stems used in experiments by Hall & Freeman (1994) and willow stems used in experiments by Armanini et al. (2005). The drag coefficient was found to depend strongly on the stem Reynolds number (Re = *Vd*/*v*, where *v* is the kinematic viscosity). The average relationship for all the data is

$$C_D = 221\mathrm{Re}^{-0.57} \tag{19}$$

For the upper limit the coefficient is 701 and the exponent is -0.66; for the lower limit the coefficient is 51 and the exponent is -0.43.

For use with the Manning equation, the combined coefficient is

$$n = \sqrt{n'^2 \frac{A_{bf}}{A_b} + n''^2} \tag{20}$$

where n' is the coefficient for the substrate and n'' is the coefficient for the stems, given by

$$n'' = \sqrt{\frac{R^{1/3}}{8g} 4 C_D \frac{A_p}{A_b}} \tag{21}$$

In most cases of emergent flow through dense vegetation the contribution of bed shear to the overall resistance is small. James et al. (2004) showed that the error in effective *f* introduced by ignoring the bed shear contribution (f') would be less than about 5% if $\lambda D > 0.10$, where λ is the stem concentration in %. For smaller values of λD the full value of *f* , including f', should be used as the error becomes very large.

As always, site-specific calibration is recommended whenever practicable. In doing this James et al. (2004) and Jordanova et al. (2006) recommend lumping the terms for vegetation and substrate and calibrating an equation of the form

$$V = \frac{1}{F}\sqrt{S} \tag{22}$$

where *F* is a site-specific resistance coefficient.

- **Emergent bank vegetation**

Emergent vegetation commonly occurs in strips along the banks of rivers. In such cases, the total channel conveyance can be estimated by subdividing the cross-section into vegetated and clear zones (Figure B4), calculating the discharge separately for the different zones and then adding the zonal discharges (James and Makoa, 2006), i.e.

$$Q_{total} = Q_{veg} + Q_{clear} \tag{23}$$

where Q_{total} is the total discharge and Q_{veg} and Q_{clear} are the discharges within the vegetated and clear zones respectively.

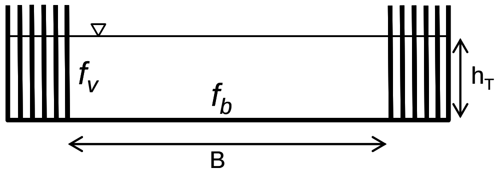


Figure B4: Sub-division of cross-section into clear and vegetated zones

The discharge within the vegetation strips can be calculated using the resistance coefficient as described for extensive unsubmerged vegetation.

The effective resistance coefficient for the clear zone is a composite of the values for the different surfaces. Hirschowitz (2007) showed that the overall friction factor can be calculated as

$$f = \frac{f_b B + 2 f_v h_T}{B + 2 h_T} \tag{24}$$

in which f_b and f_v are the friction factors for the bed and vegetation interface surfaces respectively, B is the bed width (m), and h_T is the water depth at the vegetation interface (m). Equation (24) can be easily modified for the situation of vegetation on one bank only. The friction factor for the bed can be estimated using the methods described above. For the vegetation interface Kaiser (1984) proposed that

$$f_v = f_{To} + f_I \tag{25}$$

in which f_{To} is due to the vegetation structure. Kaiser (1984) suggested $0.06 < f_{To} < 0.10$, although Hirschowitz and James (2009) suggest that this term is probably negligible for width-depth ratios greater than about 5. The term f_I is due to the flow interaction, and is given by

$$f_I = 0.18 \log\left(0.0135 \frac{V_{\inf}^{\ 2}}{h_T V_v^{\ 2}}\right) \tag{26}$$

In equation (26) V_{inf} is the depth-averaged velocity that would occur as a result of bed resistance only without the influence of vegetation, and can be estimated by the methods presented above for channel bed resistance. V_v is the unaffected velocity within the vegetation, which can be calculated by the methods presented above for extensive emergent vegetation. The height h_T is measured in metres (the number 0.0135 is also a length in metres).

The calculations using equations (24) to (26) should be carried out in terms of the Darcy-Weisbach resistance coefficients, and only converted to Manning's n for the total composite value if it is required in this form. (The bed and vegetation interface *f* values cannot be converted to Manning's *n* values without knowing or assuming the associated values of *R*.)

If the Manning equation is used, the composite resistance coefficient can be calculated using the equation of Pavlovski (1931), which is equivalent to equation (24), i.e.

$$n_e = \left(\frac{\sum_{i=1}^{N} \left(P_i \, n_i^{\,2} \right)}{P} \right)^{1/2} \qquad (27)$$

in which n_e is the equivalent Manning *n*, n_i are the zonal values, *P* is the total wetted perimeter, and P_i are the zonal wetted perimeters. No methods are currently available for estimating Manning's *n* for the vegetated interface in terms of vegetation characteristics. As an indicative value, James & Makoa (2006) found a value of approximately 0.13 for the sides of channels in the Okavango delta, which are dominated by papyrus.

- **Two-stage channels**

A compound, or two-stage, channel comprises a main channel with overbank sections or floodplains on one or both sides (Fig. 2). Compound cross-sections occur in natural rivers, and are frequently engineered to increase channel capacity for flood flows while preserving natural conditions at lower flows in the central portion to meet environmental objectives (James, 1995). The flow resistance in such a compound channel is enhanced considerably at overbank stages by the interaction between the relatively fast flow within the main channel and the relatively slow flow over the floodplains. The nature of this interaction is complex, and its influence on conveyance can only be assessed realistically through high resolution computational modelling. The transverse velocity distribution across the whole flow section, and hence by integration the conveyance, can be simulated using the Lateral Distribution Method, incorporated in the "Conveyance Estimation System" developed by HR Wallingford (2004). The software is freely available from http://www.river-conveyance.net . Approximate hand calculation methods for conveyance prediction have been developed from laboratory results for straight compound channels (Ackers, 1993) and for meandering compound channels (James and Wark, 1992); both are presented by Wark *et al*. (1994).

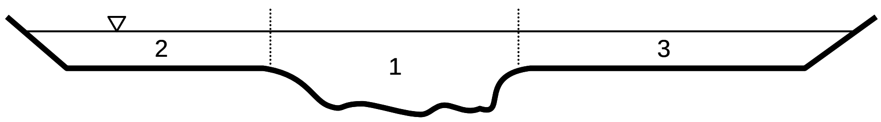


Figure B5: Compound channel section

The Ackers (1993) method for straight compound channels involves dividing the cross-section into three zones by vertical planes at the main channel edges, as shown in Figure B5. The discharge for a specified stage is calculated as the sum of the three zonal discharges (ignoring the separation planes in the definition of wetted perimeters), which is then adjusted to account for their interaction. The adjustment procedure is complicated, however, and an indication of the range of possible discharge values can be obtained by noting that the unadjusted sum of zonal discharges will invariably *over-estimate* the actual discharge, while the discharge calculated by treating the whole compound section as a unit will invariably *under-estimate* the actual discharge. These two calculations will therefore provide upper and lower possible values; if greater accuracy is required then Ackers's adjustment to the sum of the zonal discharges should be applied.

The James and Wark (1992) method for meandering compound channels is also based on a channel subdivision, but into four zones: (1) the main channel below the flood plain surface, (2) the flood plain within the width of the meander belt, and (3) and (4) the flood plains on either side beyond the extent of meandering. The zonal discharges are again calculated separately, but corrected for interaction effects before being combined. As for the straight compound channel case, the corrections to the zonal discharges are complicated. James and Myers (2002) found that reasonable estimates of conveyance for meandering main channels within meandering floodplains could be obtained with just a horizontal division plane at the bankfull level. The discharge is then the sum of the discharges of the upper and lower channels, with the division plane included in the wetted perimeter for the upper channel but not the lower one to account for interactions. This approach was shown to be adequate for laboratory channels with sinuous main channels and flood plains, but has not been confirmed for the case of straight flood plains, for which the method of James and Wark (1992) was developed.

APPENDIX C: GREEN STORMWATER INFRASTRUCTURE

C.1 Introduction to Green Infrastructure

Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services (Woods-Ballard, et al., 2015). Individual components of this environmental network are sometimes referred to as 'green infrastructure assets', and these occur across a range of landscape scales—from residential gardens to local parks and housing estates, streetscapes and highway verges, services and communications corridors, waterways and regional recreation areas (AILA, 2012).

A green infrastructure and landscape performance approach (AILA, 2012; EPA, 2017) provides a strategic decision-making framework for green infrastructure planning, design and management of our cities and should also be understood as a basis of surface water management. An integrated approach for managing landscape value within the built environment can leverage existing resources and enhance design responses to broader challenges of urban sustainability, and climate change adaptation. High quality drainage systems that are integrated into the overall design of a development will automatically provide a number of other services and become features themselves attracting tourism and investment, driving local economic growth. Where such systems are designed to make efficient use of the space available, they can often cost less to implement that underground piped systems (Woods-Ballard, et al., 2015).

Conventional engineering, also called grey infrastructure, is based on a *fail-safe* planning principle (Ahern, 2011). There has however been a growing concern that grey infrastructure is not resilient enough to handle uncertainties from climate change and unprecedented urbanization (Hossain et al., 2017). A need to move towards *safe-to-fail* approaches have therefore immersed (Ahern, 2011). The infrastructure needs to be able to handle the standard loading but also minimize failures due to adverse events (Dong 2017).

Dong (2017) argues that green infrastructure is more suited for this purpose since it has a higher adaptability and resistibility to an uncertain future. Green infrastructure (GI) is the term used to describe nature-based solutions which provide ecosystem services like water management, air quality and climate regulation to urban environments. Green roofs, vegetated swales, floating wetlands and porous pavements fall under this term (Tavakol-Davani et al*.,* 2015). Studies have shown that a combination of green and grey infrastructure is the most cost-effective and robust solution to uncertainty (Cohen et al*.* 2012 and Casal-Campos et al., 2015).

> Green infrastructure is fundamentally different from other aspects of built infrastructure, in that it has unique, inherent capacity to enhance and regenerate natural resources, rather than simply minimise the damage to environmental systems.

In stormwater management, GI approaches aim to treat run-off with soil and vegetation on site to restore hydrological and ecological functions and patterns (Dhakal and Chevalier, 2017). Although the main goal of GI in urban drainage systems, is for flood management, Askarizadeh et al. (2015) and Dhakal and Chevalier (2017), list other added benefits.

Benefits of GI Implementation:
• Reduce disturbances in flow regimes (Loperfido et al., 2014)
• Reduce pollutant loads and concentrations (Walsh et al., 2015)
• Improve urban amenity (de Graaf and der Brugge, 2010)
• Restores ecosystems and revives biodiversity (Dhakal and Chevalier, 2017)
• Carbon sequestration (Dhakal and Chevalier, 2017)
• Groundwater recharge (Dhakal and Chevalier, 2017)
• Re-establish socio-ecological connectivity (Gomez-Baggethun et al., 2013)
• Improve quality of life (Breuste et al., 2015)

When existing landscape assets are strategically connected and manged in an integrated manner within and beyond settlement boundaries, this regenerative capacity increases exponentially. Green infrastructure strategies provide a framework for more holistic planning, design and monitoring of the complex interactions between the (non-regenerative) built form and the environment within which it is situated, in order to enhance the performance of both, and to enable human settlements to function as integral components of larger landscape processes affecting energy, water, carbon and biodiversity.

C.2 Landscape Performance

The key to better management of landscape value in cities and settlements lies in understanding how *integrated green infrastructure planning strategies can enhance overall urban ecosystem functionality,* and contribute positively to broader landscape processes affecting air and water quality, energy use and biodiversity. Landscape is malleable; it can absorb a range of agendas and it fits well in a city striving to confront (and remedy) the effects of limited resources, rapid urbanization and storm water drainage issues. The landscape can process and remediate the land and the water, while simultaneously creating a highly dynamic, green public realm that extends through the city and along water courses.

C.3 Ecosystem Assets and Services

The different physical forms of green infrastructure are very diverse; however, the main categories are described below:

- Public parks and gardens, including urban parks, open space reserves, cemeteries and formal gardens;
- Greenways, including river and creek corridors, cycle-ways and routes along major transport corridors;

- Residential and other streets, comprising street verges and associated open space pockets;
- Sports and recreational facilities, including ovals, golf courses, school and other institutional playing fields, and other major parks;
- Private/semi private gardens, including shared spaces around apartment buildings, backyards, balconies, roof gardens and community gardens;
- Green roofs and walls, including roof gardens and living walls;
- Squares and plazas, including both public and private courtyards and forecourts;
- Natural green space, including national parks and nature reserves, wetlands and coastal margins;
- Utility areas, including quarries, airports, and large institutional and manufacturing sites. This category also includes unused land reserved for future use;
- Agricultural and other productive land, including vineyards, market gardens, orchards and farms. (Symons, et al., 2015)

While the list above demonstrates green infrastructure can take many forms, it also provides many different ecosystem services which can be grouped into three main areas: social, economic and environmental. These are consistent with the well-known triple bottom line approach. Green infrastructure literature covers a broad range of assets and services which indicates both its high level of complexity and its considerable potential benefits (cf. Woods-Ballard, et al., 2015; Symons, et al., 2015; Pahl-Wostel, et al. 2008).

Apart from services relating to stormwater [aquifer recharge, energy dissipation, temperature reduction, peak delay and reduction, volume reduction], green infrastructure provides additional services, including carbon sequestration, biodiversity, faunal habitat, improved urban aesthetics and air pollution reduction.

C.4 Potential Benefits of Green Infrastructure

Social benefits

The social benefits include human health and aesthetics. A diverse body of research shows that GI can enhance the quality of life in urban areas (Fitchett, 2017; Cinderby & Bagwell, 2017). This includes factors such as cultural values, aesthetics and urban amenity including the 'walkability' of streets and air quality. Research has focussed on two aspects of wellbeing: the physical and mental health of individuals; and the role of social interaction and community building. In particular, evidence suggests older people, people recovering from illness and children would especially benefit from additional green infrastructure.

Research has linked the presence of trees, plants, and green space to reduced levels of inner-city crime and violence, a stronger sense of community, improved academic performance, and even reductions in the symptoms associated with attention deficit and hyperactivity disorders (EPA, 1993; Tzoulas, et al., 2007; Coutts & Hahn, 2015).

Climate modification

A large body of research has been undertaken to examine the climatic effect of green infrastructure in urban settings. GI, including trees, green roofs, as well as Water Sensitive Urban Design practices have been found to modify urban climates through:

- Urban heat island mitigation. By providing increased amounts of urban green space and vegetation, green infrastructure can help mitigate the effects of urban heat islands and reduce energy demands. Trees, green roofs and other green infrastructure can also lower the demand for air conditioning energy, thereby decreasing emissions from power plants.
- Reduced energy use and emissions.
- Air pollution interception and mitigation (McPherson et al., 2005). Green infrastructure has the potential to ameliorate the effects of climate change in urban environments, thereby increasing resilience and liveability, and reducing energy consumption.
- Increased Carbon Sequestration. The plants and soils that are part of the green infrastructure approach serve as sources of carbon sequestration, where carbon dioxide is captured and removed from the atmosphere via photosynthesis and other natural processes.

Water management

The relationship between urban water management and the health of urban environments has only recently become a focus of researchers; however, this area has developed quickly with numerous issues being investigated (Wong, 2011). Relevant water issues include:

- access to secure and clean water supply;
- clean water environment;
- flood protection; and
- mitigating urban heat.

Green infrastructure is increasingly being recognised as an alternative to traditional engineering approaches to urban water management through integrated water cycle management and Water Sensitive Urban Design. The literature has documented the trend away from the traditional engineering approach to urban stormwater with its sole aim being the efficient and quick disposal of stormwater. The conventional approach has the negative environmental consequences in that local water resources are wasted and receiving waters are polluted, with a commensurate decline in the health of aquatic ecosystems in both local and receiving catchments (Wong, 2011, ECO Northwest, 2007). By contrast, green infrastructure in terms of urban water management includes:

- **Reduced and Delayed Stormwater Runoff Volumes**

Green infrastructure reduces stormwater runoff volumes and reduces peak flows by utilizing the natural retention and absorption capabilities of vegetation and soils. By increasing the amount of pervious ground cover, green infrastructure techniques increase stormwater infiltration rates, thereby reducing the volume of runoff entering sewer systems, and ultimately lakes, rivers, and streams.

- **Enhanced Groundwater Recharge**

The natural infiltration capabilities of green infrastructure technologies can improve the rate at which groundwater aquifers are 'recharged' or replenished. This is significant because groundwater provides a significant volume of the water needed to maintain normal base flow rates in rivers and streams. Enhanced groundwater recharge can also boost the supply of drinking water for private and public uses.

- **Stormwater Pollutant Reductions**

Green Infrastructure techniques infiltrate runoff close to its source and help prevent pollutants from being transported to nearby surface waters. Once runoff is infiltrated into soils, plants and microbes can naturally filter and break down many common pollutants found in stormwater.

- **Reduced Sewer Overflow Events**

Utilizing the natural retention and infiltration capabilities of plants and soils, green infrastructure limits the frequency of sewer overflow events by reducing runoff volumes and by delaying stormwater discharges.

Water sensitive urban design (WSUD) is a key form of green infrastructure, which has many benefits that increase the resilience and network aspect of green infrastructure.

Air Quality

Green infrastructure facilitates the incorporation of trees and vegetation in urban landscapes, which can contribute to improved air quality. Trees and vegetation absorb certain pollutants from the air through leaf uptake and contact removal. If widely planted, trees and plants can even cool the air and slow the temperature-dependent reaction that forms ground-level ozone pollution.

Food production

Urban agriculture is a form of green infrastructure that can deliver a wide range of benefits that go beyond providing a secure and healthy food supply (Marsden and Morley, 2014). Urban agriculture commonly takes place on the peri-urban boundary, providing more sustainable food sources for urban areas because of reduced transport to market (Houston, 2005). It also includes community gardens, kitchen gardens, 'edible landscapes', productive street verges, backyards and school vegetable gardens. Urban food production has many benefits including: increased sense of community, improved healthy food options, improved mental and physical wellbeing and reduction in food miles. (Redwood, 2012)

C.5 Green Infrastructure approaches

GI interventions either use infiltration practices, runoff storage, runoff conveyance or filtration systems to management urban runoff based on the characteristics of the site and the hydrological needs (Novotny et al. 2010). Below is an explanation of these approaches with application examples.

Infiltration

The aim of this group of GI interventions id to reduce runoff by capturing it and allowing it to infiltrate the soil. This reduces the amount of runoff to receiving water-bodies, replenishes groundwater resources and helps to regulate stream temperatures. Examples are: infiltration basins; rain gardens, porous paving and disconnected rainwater spouts (not feeding into the larger stormwater system). (Novotny et al., 2010)

Runoff storage

Runoff is harvested from impervious surfaces such as roofs and paving for later infiltration or storage. This approach reduces peak flows and the discharge into receiving waters. Examples are:

using void spaces for rain cisterns or tanks beneath parking lots, streets and sidewalks; increasing depressions for storage of median and landscaped islands; creating green roofs, using swales with hydraulically controlled flow structures. (Novotny et al., 2010)

Runoff conveyance

This practice reduces the flow velocity and lengthens the conveyance route to reduce and delay peak flow. Several techniques can be used as alternatives to conventional curbs and gutters, including: roughening surfaces to reduce velocity; allowing evaporation and settlement of sediment; using permeable or vegetated surfaces that promote infiltration of the groundwater, filtration and uptake of biological pollutants. Swales and grass-lined channels serve similar functions, creating roughened surfaces and low-flow paths over landscaped areas. These can be combined with smaller culvert pipes and inlets, and where slopes are steeper, can introduce terracing and check dams along the conveyance route. (Novotny et al., 2010)

Filtration

These have similar benefits to infiltration systems but filter the runoff through a medium. The process includes the physical filtration and/or cation exchange of solid particles and dissolved pollutants. Examples include: bioretention and rain gardens; vegetated swales; and vegetated filter strips or buffers. (Novotny et al., 2010)

C.6 Green Infrastructure Systems

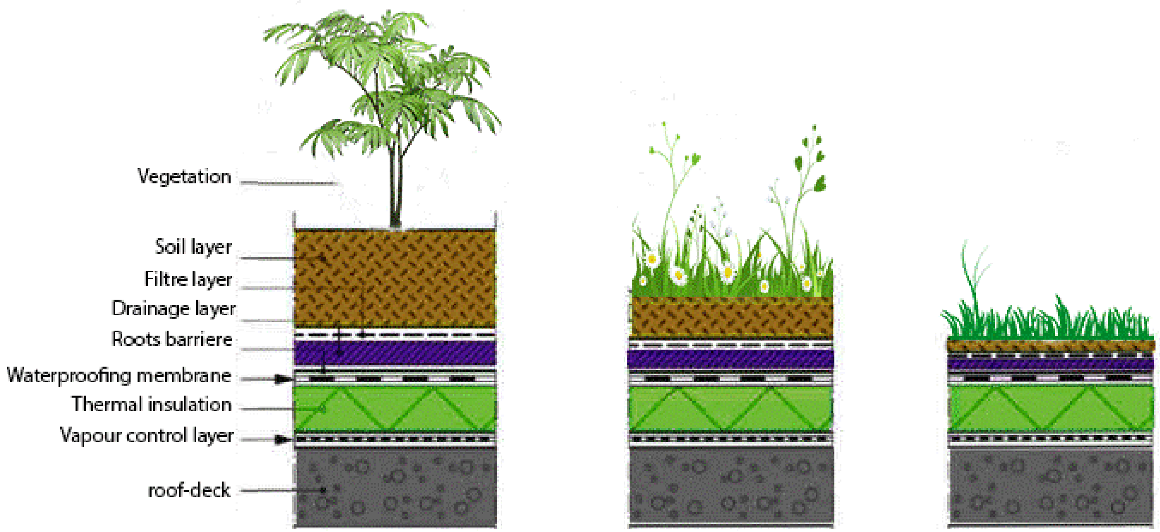
Green roofs

This is a method of increasing the pervious surfaces within a city to return a built-up area as close as possible to the pre-development state. The aim is to retain stormwater runoff for rainwater harvesting and peak flow reduction, while creating added benefits of building cooling and insulation. A typical green roof comprises a vegetated layer, growing substrate, filter medium, root barrier and waterproofing layer on top of the roof structure.

Extensive green roofs consist of a thin soil layer (150mm or less) with hardy, low-growing planting, aiming at retaining runoff and providing insulation. In the Highveld climate, indigenous vegetation is strongly recommended, to avoid the need for irrigation in the winter months, as evident in figure C1.

Intensive green roofs typically have a much thicker growing medium, allowing a much wider range of plant types and hard landscaping elements to create aesthetically pleasant spaces (Novotny et al., 2010). Table C1 sets out the differences between these two approaches.

Table C1: Comparison between intensive, semi-intensive and extensive green roofs (Adapted from Novotny et al., 2010; Kady & Yahya, 2015; SIG Design Technology, 2018)

	INTENSIVE	SEMI-INTENSIVE	EXTENSIVE
			(Green Roof Indonesia, 2018)
Maintenance	High	Medium	Low
Specification drivers	Outdoor recreational space, amenity and aesthetics important rather than performance	Ecological protection layer: - Wildlife habitat - Replicate or enhance building's predevelopment habitat - Air & water quality - Lower carbon emissions - Extended roof membrane life	Functional green roof: - Stormwater attenuation - Air & water quality - Lower carbon emissions - Extended roof membrane life
Planting	Lawn, groundcovers, perennials, shrubs, small trees Can be combined with hard landscaping materials and water features	Hardy succulents, herbs, grasses, wild flowers	Low-growing, stress-tolerant plants: Hardy succulents, herbs, grasses
Plant Diversity	High	Medium	Low

Build-up height	150-1500mm, deep soil, provide planters for trees and large shrubs	70-200mm	70-150mm, thin growing medium
Approximate weight	>200kg/m²	<90-225kg/m²	80-150kg/m²
Substrate type	Lightweight to heavy, high porosity, low organic matter	Lightweight to medium, high porosity, low organic matter	Lightweight high porosity, low organic matter
Cost	High	Medium	Low
Accessibility	Access	Semi accessible	Generally functional rather than accessible
Irrigation requirements	Regular	Little irrigation	Little or none, unless otherwise specified
Percent runoff from rainfall (depended on roof & vegetation slope)	15-35%	20-50%	20-75%

Table C2: Comparison between the three main permeable paving materials (Adapted from VDEQ, 2011; Technicrete, n.d.; Lafarge, n.d.)

DESIGN FACTOR	PERVIOUS CONCRETE	POROUS ASPHALT	PERMEABLE INTERLOCKING CONCRETE PAVERS
Scale of application	Small and large paving areas	Small and large paving areas	Micro, small and large paving areas
Paving thickness	125 – 200mm	75 – 100mm	60 – 100mm
Bedding layer	None	50mm thick, 20mm crushed stone	50mm thick, 10mm crushed stone
Reservoir layer	20mm crushed stone	35-50mm crushed stone	35-50mm crushed stone OR 50mm thick, 20mm crushed stone
Construction properties	In-situ casting, 7-day curing while covered	In-situ casting, 24-hour curing	No curing, precast and manual or mechanical placement
Design permeability	150 – 1000 l/m²/hr	50 – 100 l/m²/hr	4500 l/m²/hr
Longevity	20 – 30 years	15 – 20 years	20 – 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature reduction	Cooling in reservoir layer	Cooling in reservoir layer	Cooling at paving and in reservoir layer
Colours/ Textures	Limited range of colours and textures.	Black or dark grey	Wide range of colours and textures.
Traffic bearing capacity	All traffic loads can be handle, dependent on appropriate bedding layer.		
Surface clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable paving block jointing material
Notes:	- Typical design and sub-base layers may differ due to traffic loads and manufacturer specifications. - Longevity is based on proper maintenance. Resurfacing might be required after period indicated. - Traffic bearing conditions depend mainly on the geotechnical conditions on site.		

Table C3: Comparative stormwater functions of permeable paving designs (Adapted from VDEQ, 2011)

STORMWATER FUNCTION	LEVEL 1 DESIGN	LEVEL 2 DESIGN
Annual Runoff Volume Reduction (RR)	45%	75%
Total Phosphorus (TP) EMC reduction by BMP treatment process	25%	25%
Total Phosphorus (TP) mass load removal	59%	81%
Total Nitrogen (TN) EMC reduction	25%	25%
Total Nitrogen (TN) mass load removal	59%	81%

Table C4: Permeable paving design criteria (VDEQ, 2011)

	LEVEL 1 DESIGN	LEVEL 2 DESIGN
Volume reduction by upstream BMP	Tv = (1) (Rv) (A) / 12	Tv = (1.1) (Rv) (A) / 12
Soil infiltration rate	Less than 125mm/hr	Exceeds 125mm/hr
Underdrain requirement	Yes	Not OR A 300mm stone sump layer should be provided below the underdrain, OR The total volume (Tv) has at least 48 hours' time to drain, regulated by a control structure.
Contributing drainage area	CDA = Ppa + Upa Ratio for Ppa:Upa, should not exceed 1:2	CDA = Ppa
Abbreviations	Tv: Total volume Rv: Rainfall volume A: Area CDA: Contributing drainage area* Ppa: Permeable paving area Upa: Upgradient parking area *CDA should only include only paved surfaces to reduce sediments OR if runoff from pervious surfaces are diverted to the permeable paving area, sediment control measures should be included.	

Figure C1: Extensive green roof at University of the Witwatersrand

Permeable paving

Permeable paving is an environmentally responsible alternative to conventional paved or asphalt surfaces. The aim is to allow stormwater runoff to infiltrate into a porous medium directly below the paved surface for temporary storage or to encourage infiltration into the natural soil medium (Novotny et al., 2010)). This practice reduces runoff volume, replenishes groundwater, enhances infiltration capacity and improves runoff quality if it is discharged elsewhere (Novotny et al., 2010; VDEQ, 2011).

There are various types of permeable paving materials, including: pervious concrete, porous asphalt, interlocking concrete pavers; and modular concrete blocks that can take vegetation. (VEDQ, 2011). The choice of material can be guided by the comparison provided in Table C2. The typical layering of pervious paving is shown in Figure C2.

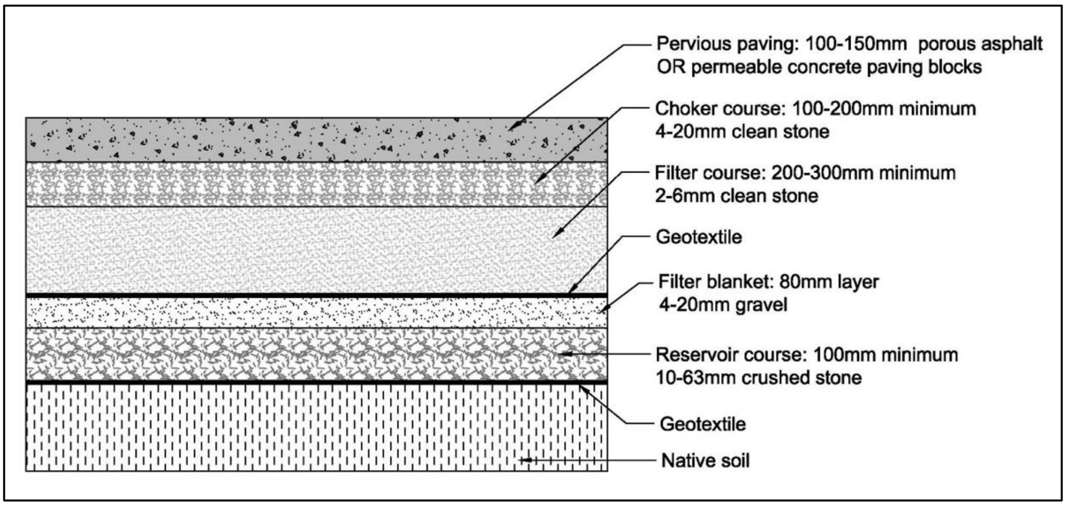


Figure C2: Cross section through typical permeable paving layers (after Novotny et al., 2010; Technicrete, n.d.)

Permeable paving can be installed on any type of soil medium and does not require additional space as with some of the other green infrastructure systems. There are added benefits to stormwater management through the method of permeable paving, as indicated in Table C3. The runoff infiltrate rate determines whether the runoff is just stored, or whether it is allowed to infiltrate (VEDQ, 2011). Table C4 sets out the design criteria for a Level 1 and Level 2 design, based on the soil's infiltration rate.

Biofilters

Biofiltration is a term that describes all green infrastructure which relies on biofiltration to remove pollutants from effluent. It includes grassed swales, rain gardens, filter strips, environmental buffer zones, bioswales and bioretention basins (Novotny et al., 2010). Biofiltration has proved to be very effective at removing total suspended solids, phosphorus, nitrogen, lead and zinc (Read et al., 2008; Hatt et al., 2009). Table C5 provides a summary of the results from Milandri et al. (2012) who tested the pollutant removal of various indigenous and exotic plant species. However, the final choice of plant species should consider the site-specific environmental conditions to ensure the highest survival rate.

Table C5: Pollutant removal of various plant species (adapted from Milandri et al., 2012)

Orthophosphate	Ammonia	Nitrate
80-90% reduction	66-99% reduction	49-75% reduction
Dryland species: *Agapanthus praecox* *Pennisetum clandestinum* *Stenotaphrum secundatum*	**Dryland species:** *Agapanthus praecox* *Pennisetum clandestinum* *Stenotaphrum secundatum*	**Dryland species:** *Agapanthus praecox* *Carpobrotis edulis* *Pennisetum clandestinum* *Stenotaphrum secundatum*
Wetland species: *Phragmites australis* *Typha capensis* *Zantedeschia aethiopica*	**Wetland species:** *Ficinia nodose* *Phragmites australis* *Typha capensis* *Zantedeschia aethiopica*	**Wetland species:** *Ficinia nodose* *Typha capensis* *Zantedeschia aethiopica*

Water by Design (2014) sets out the different contexts in which bioretention systems can be incorporated in the urban landscape. These systems can take many forms and sizes, and can be implemented in the following situations:

- Allotments on private land;
- Streetscapes;
- Civic spaces such as plazas and squares;
- Parkland areas
- Other public open spaces (Water by Design, 2014)

Bioretention systems can take many configurations, based on the available space (Water by Design, 2014). Jurries (2003) argues that inadequate space is not a reason to exclude biofilters, since they are always valuable in pollutant removal, even if they are small, such as biopods and bioretention street trees. Figure C3 illustrates a bioswales with a sub-surface gravel drainage trench, an active soil layer with a swale soil profile, and vegetation.

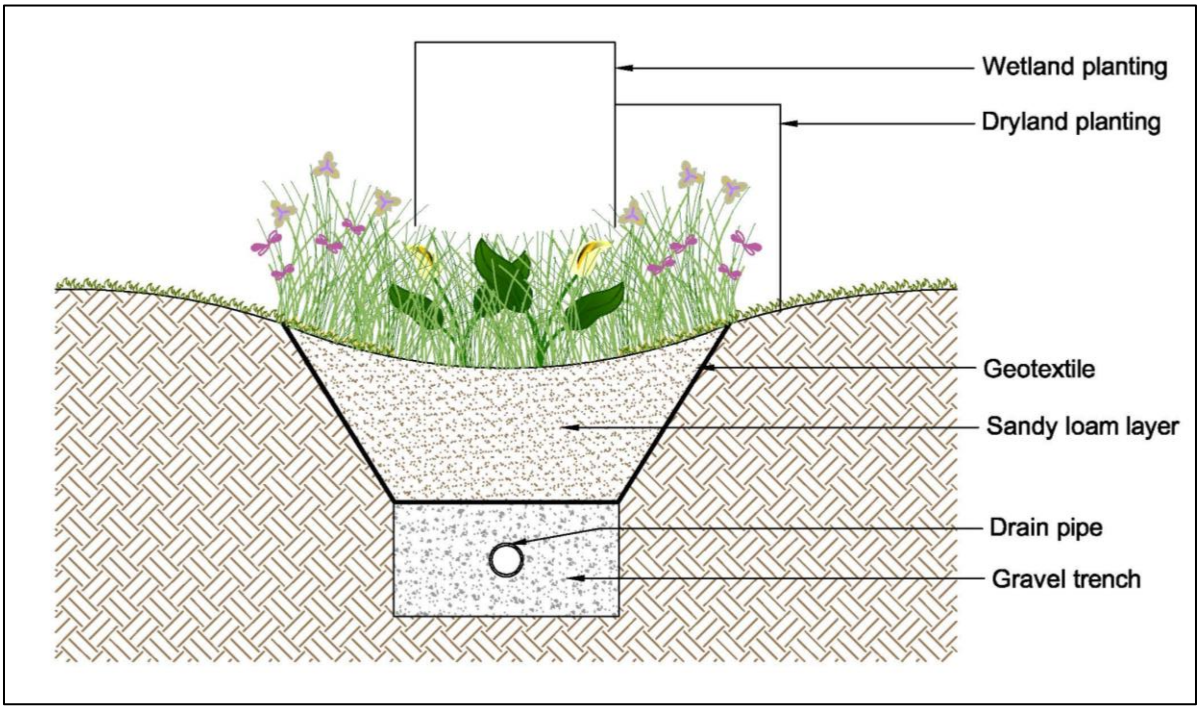


Figure C3: Cross section through a typical biofilter

APPENDIX D: CALCULATION METHODS AND MODELLING

D.1 Model Selection and Use

SWMM and Derivatives

It is recommended that analysis of stormwater management systems in the City of Johannesburg be done using the US EPA Stormwater Management Model (SWMM) or any of its derivatives that use, or can generate, native SWMM input and report files that can be read using the free version of SWMM. The primary reasons for this are:

1. The nature of the program and its support:
    a. SWMM is available for free download from the US EPA website so does not impose any additional cost burden on the practitioner;
    b. SWMM is probably the most widely used and therefore best tested stormwater management software in the world;
    c. SWMM is strongly supported by a voluntary community of experts, including the authors of the reference manuals;
    d. SWMM has exceptionally good reference material at no cost to the practitioner;
    e. Training in SWMM and some of its derivatives is widely available in South Africa.
2. Until the reviewing engineers have been trained or become experienced in the use of many different programs, it is sensible to standardise on one program.
3. Most of the input variables are physically measurable or derived from measurable properties of soils, or characteristics of the catchment land use and topography.
4. The mathematics underlying the computational processes of the program are physically defensible.

Rational Method and Derivatives

At this time, the use of the Rational Method and its derivatives is not recommended for calculation of the effectiveness of stormwater management intervention in the City of Johannesburg. Some reasons for this are:

1. The By-laws call for the use of the "…latest and best technology…" and the Rational Method does not meet this requirement.
2. Effective management of stormwater requires that the system be capable of controlling runoff from storms with the same recurrence interval, but different durations. We are not aware of any objective method of determining the variation of the runoff coefficient "C" with variation in storm duration.
3. The value of the runoff coefficient varies with antecedent moisture conditions and we do not know of any objective method of determining this variation.
4. There is little to support the fundamental assumptions of the Rational Method:
    a. The recurrence interval of the runoff is the same as the recurrence interval of the storm;
    b. The rainfall is of uniform intensity and duration exactly equal to the time of the concentration of the drainage system.

D.2 Rainfall

Further research is being conducted on rainfall patterns in Johannesburg. Until this research is finalised and the results verified, it is recommended that the design depth/duration/frequency characteristics of rainfall be derived from the Design Rainfall Estimator of Smithers and Schulze (2012).

The 90th percentile rain depths should be used to apply a partial factor of safety to the loading of the system. Application of partial factors of safety to the various uncertain input parameters such as load, materials, construction and operation is best practice in most fields of engineering. The factors can be reduced or increased, depending on the degree of confidence that the practitioner has in the value of the input parameter.

D.3 Model Parameters

Standard values for input parameters can be obtained from the literature. The practitioner should understand the sensitivity of the design to variations in the values of the input parameters and should describe and defend the values used in the Stormwater Management report.

Further research is being conducted into the appropriate range of design values for use in Johannesburg, and the results of this research will be published from time to time in updates to this Manual.

D.4 Design Guidelines for GSI

The minimum depth of rain required to initiate runoff from a dry catchment will depend on the time over which that rainfall occurs. These depths have been estimated for different storm durations. Detailed guidelines are being developed as part of ongoing research and will be included in future versions of this Manual.

D.5 Rainfall and Runoff

Peak Discharges for Storm Duration

SWMM was used to compute peak discharges from catchments 1 ha in area with an overland flow length of 100 m for two different soil types to demonstrate the effect of storm duration of peak discharge rate.

Computation parameters:

In all cases the catchment area was 1.0 ha with an overland flow length of 100 m

Triangular storm R=0.3 hyetograph, varying duration and varying average intensity determined using Hershfield's equation. One day 2 year rain depth M_2 = 62mm, Lightning strike density L = 6/km^2/yr.

Soil infiltration using Horton's equation with:

Initially dry sandy loam soil f_o = 65mm/h, f_e = 10 mm/h, k =2.988/h

Initially dry clayey loam soil f_o = 30mm/h, f_e = 5 mm/h, k =2.988/h

Triangular storm R=0.3

The results of these calculations show that, for the recurrence intervals calculated, there is a threshold storm duration shorter than which no runoff will occur and a similar threshold for maximum storm duration. Any stormwater management intervention should match this runoff profile and ensure that short and long duration storms do not result in any runoff.

The results for initially dry, sandy loam soil are shown in Tables D1, D2 and D3 and graphically in Figures D1, D2 and D3.

Table D1: Computed Natural Peak Discharge 1.01yr RI Initially Dry Sandy Loam Soil

Td	Total Precip.	Ave Intensity	Slope = 5% Q	Slope = 2% Q
	mm	mm/h	m^3/s	m^3/s
20 min	17.23	51.69	0.0000	0.0000
30 min	21.17	42.34	0.0000	0.0000
45 min	24.73	32.97	0.0008	0.0005
60 min	27.13	27.13	0.0013	0.0009
90 min	30.21	20.14	0.0008	0.0005
2 hr	32.27	16.14	0.0000	0.0000
4 hr	36.59	9.15	0.0000	0.0000

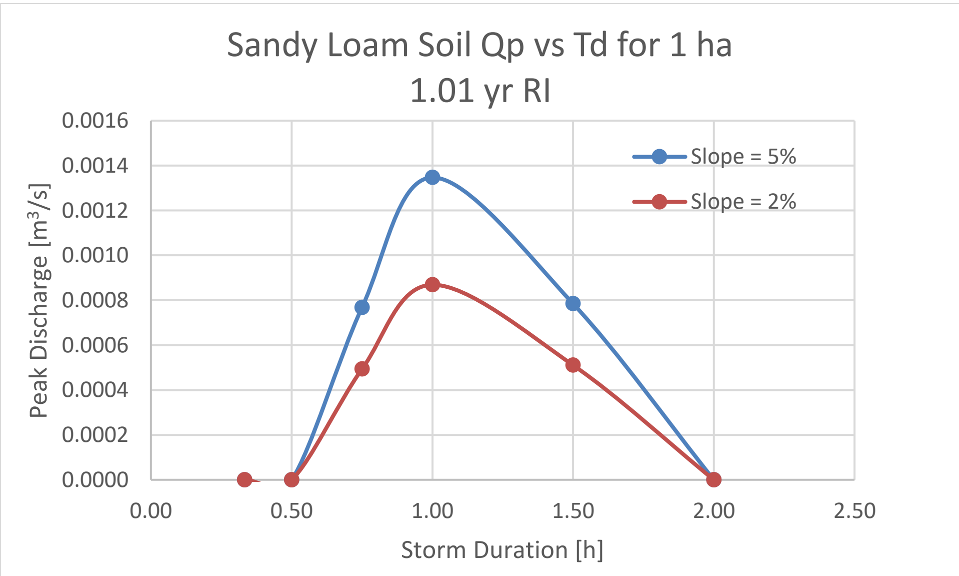


Figure D1: Peak Runoff vs Storm Duration 1.01 yr RI (Initially Dry Sandy Loam)

Table D2: Computed Natural Peak Discharge 2yr RI Initially Dry Sandy Loam Soil

Td	Total Precip	Ave Intensity	Slope = 5% Q	Slope = 2% Q
	mm	mm/h	m^3/s	m^3/s
20 min	21.15	63.45	0.002	0.001
30 min	25.99	51.98	0.012	0.008
40 min	29.03	43.55	0.015	0.010
60 min	33.28	33.28	0.019	0.013
80 min	35.97	26.98	0.018	0.013
2 hr	39.61	19.81	0.014	0.010
4 hr	44.91	11.23	0.001	0.001
6 hr	47.78	7.96	0.000	0.000

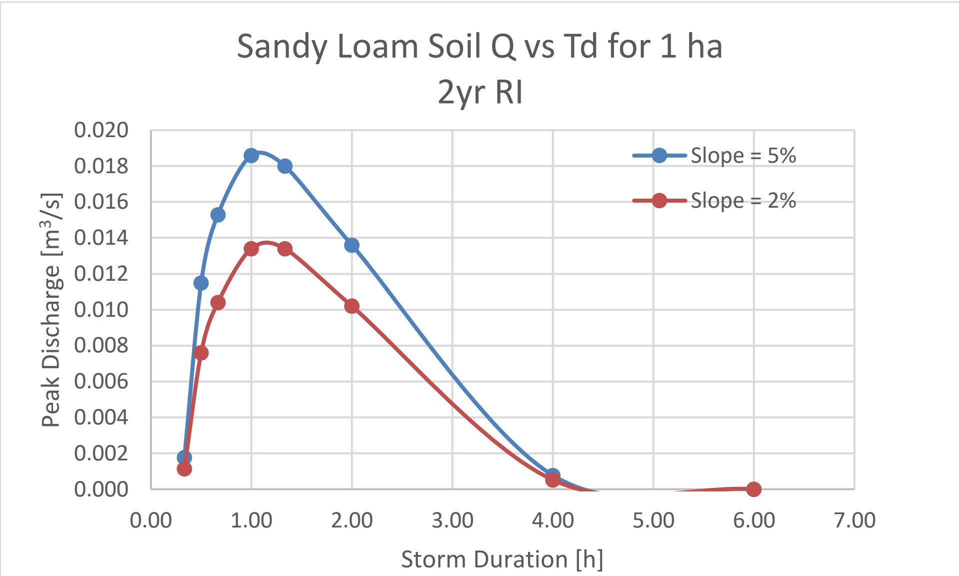


Figure D2: Peak Runoff vs Storm Duration 2 yr RI (Initially Dry Sandy Loam)

Table D3: Computed Natural Peak Discharge 5yr RI Dry Sandy Loam Soil

Td	Total Precip	Ave Intensity	Slope = 5% Q	Slope = 2% Q
	mm	mm/h	m^3/s	m^3/s
20 min	27.86	83.58	0.027	0.019
30 min	34.22	68.44	0.050	0.036
40 min	38.22	57.33	0.055	0.041
60 min	43.81	43.81	0.058	0.045
80 min	47.47	35.60	0.055	0.044
2 hr	52.11	26.06	0.044	0.036
4 hr	59.1	14.78	0.021	0.017
6 hr	62.88	10.48	0.008	0.006
12 hr	69.06	5.76	0	0

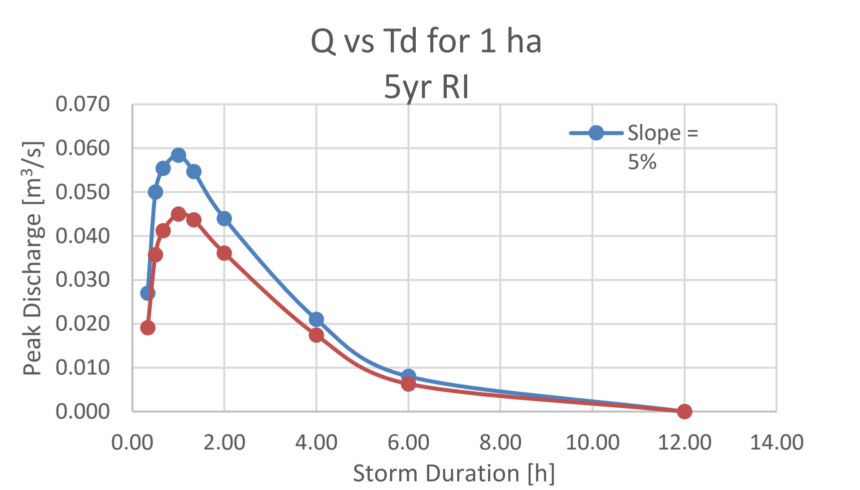


Figure D3: Peak Runoff vs Storm Duration 5 yr RI (Initially Dry Sandy Loam)

The results for initially dry, clayey loam soil are shown in Tables D4, D5 and D6 and graphically in Figures D4, D5 and 6.

Table D4: Computed Natural Peak Discharge 1.01yr RI Initially Dry Clayey Loam Soil

Td	Total Precip	Ave Intensity	Slope = 5% Q	Slope = 2% Q
	mm	mm/h	m^3/s	m^3/s
20 min	17.23	51.69	0.0040	0.0026
30 min	21.17	42.34	0.0116	0.0077
45 min	24.73	32.97	0.0163	0.0116
60 min	27.13	27.13	0.0181	0.0131
90 min	30.21	20.14	0.0177	0.0133
2 hr	32.27	16.14	0.0159	0.0123
4 hr	36.59	9.15	0.0078	0.0061
8 hr	40.52	5.07	0.000	0.000

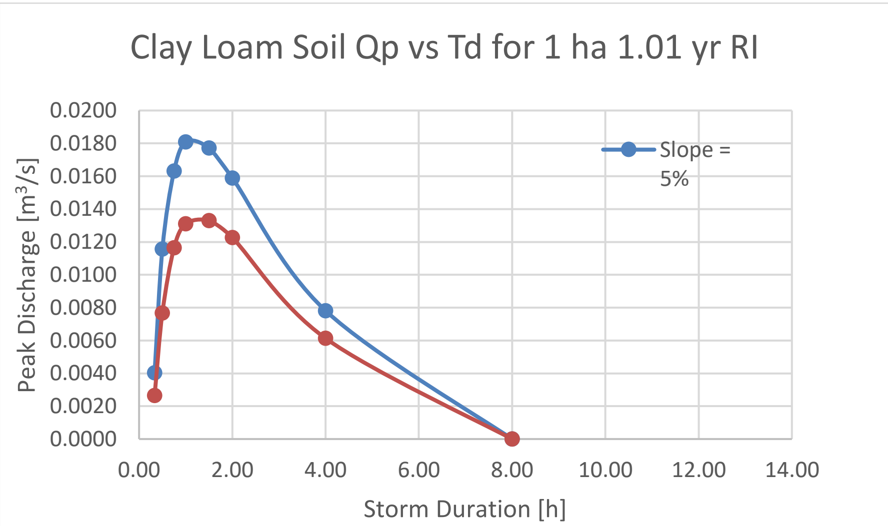


Figure D4: Peak Runoff vs Storm Duration 1.01 yr RI (Initially Dry Clayey Loam)

Table D5: Computed Natural Peak Discharge 2yr RI Dry Clayey Loam Soil

Td	Total Precip	Ave Intensity	Slope = 5%	Slope = 2%
			Q	Q
	mm	mm/h	m^3/s	m^3/s
20 min	21.15	63.45	0.019	0.013
30 min	25.99	51.98	0.033	0.023
40 min	29.03	43.55	0.037	0.027
45 min	30.36	40.48	0.039	0.028
60 min	33.28	33.28	0.040	0.030
90 min	37.1	24.73	0.037	0.030
2 hr	39.61	19.81	0.031	0.027
4 hr	44.91	11.23	0.020	0.017
6 hr	47.78	7.96	0.012	0.010
8 hr	49.73	6.22	0.0065	0.0053
12 hr	52.46	4.37	0	0

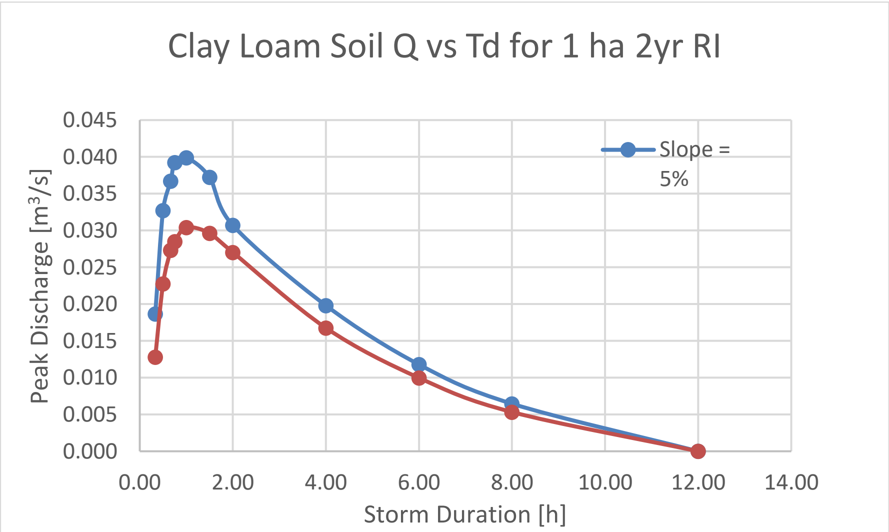


Figure D5: Peak Runoff vs Storm Duration 2 yr RI (Initially Dry Clayey Loam)

Table D6: Computed Natural Peak Discharge 5yr RI Dry Clayey Loam Soil

Td	Total Precip	Ave Intensity	Slope = 5%	Slope = 2%
			Q	Q
	mm	mm/h	m^3/s	m^3/s
20 min	27.86	83.58	0.056	0.039
30 min	34.22	68.44	0.077	0.057
40 min	38.22	57.04	0.082	0.061
45 min	39.98	53.31	0.083	0.065
60 min	43.81	43.81	0.080	0.065
90 min	48.83	32.55	0.072	0.060
2 hr	52.11	26.06	0.063	0.054
4 hr	59.1	14.78	0.040	0.035
6 hr	62.88	10.48	0.027	0.024
8 hr	65.49	8.19	0.019	0.017
12 hr	69.06	5.76	0.010	0.0085
18 hr	72.64	4.04	0.001	0.00093
24 hr	75.99	3.17	0	0

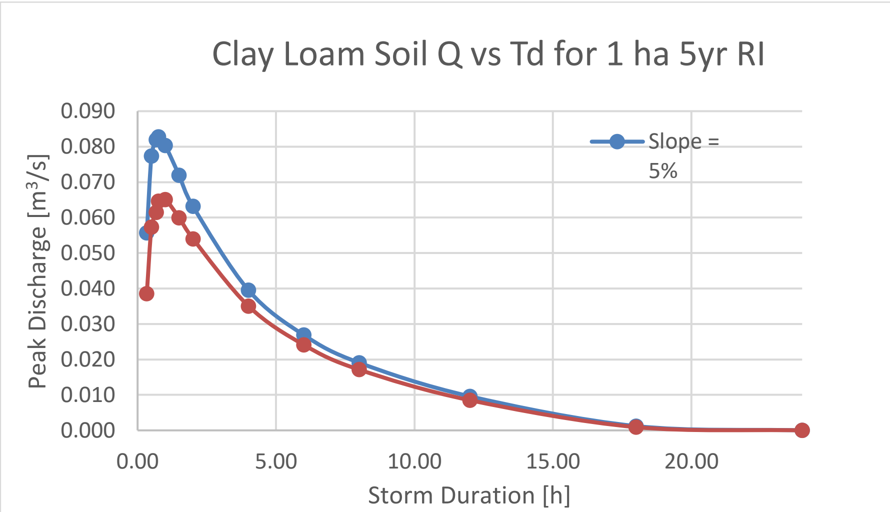


Figure D6: Peak Runoff vs Storm Duration 5 yr RI (Initially Dry Clayey Loam)

Rainfall Depth Required to Initiate Runoff

The results of these calculations given in Tables D.1 to D.6 can be extrapolated to give an estimate of the depth of rain for any duration required to initiate runoff. Tables D.7 and D.8 and the accompanying graphs Figures D.7 an D.8 show the results of this extrapolation for initially dry sandy loam and initially dry clayey loam respectively. The linear regression equations for the rain depths from storms of durations ranging from 20 minutes to 480 minutes required to initiate runoff are shown on the graphs.

Table D7: Rainfall and Discharge at Initiation of Runoff (Initially Dry Sandy Loam)

Td	RI	1.01	2	5
20 min	P	17.2	21.15	27.86
	Q	0	0.001773	0.02736
30 min	P	21.17	25.99	34.29
	Q	0	0.01149	0.05026
40 min	P		29.03	38.22
	Q		0.01513	0.05541
45 min	P	24.73	30.36	39.98
	Q	0.000768	0.01645	0.05823
60 min	P	27.13	33.28	43.81
	Q	0.001347	0.01864	0.05843
90 min	P	30.21	37.1	48.83
	Q	0.000785	0.01723	0.05163
120 min	P	32.27	39.61	52.11
	Q	0	0.01357	0.04397
240 min	P	36.59	44.91	59.11
	Q	0	0.000774	0.021
480 min	P	49.73	65.49	103.13
	Q	0	1.54E-06	0.03221

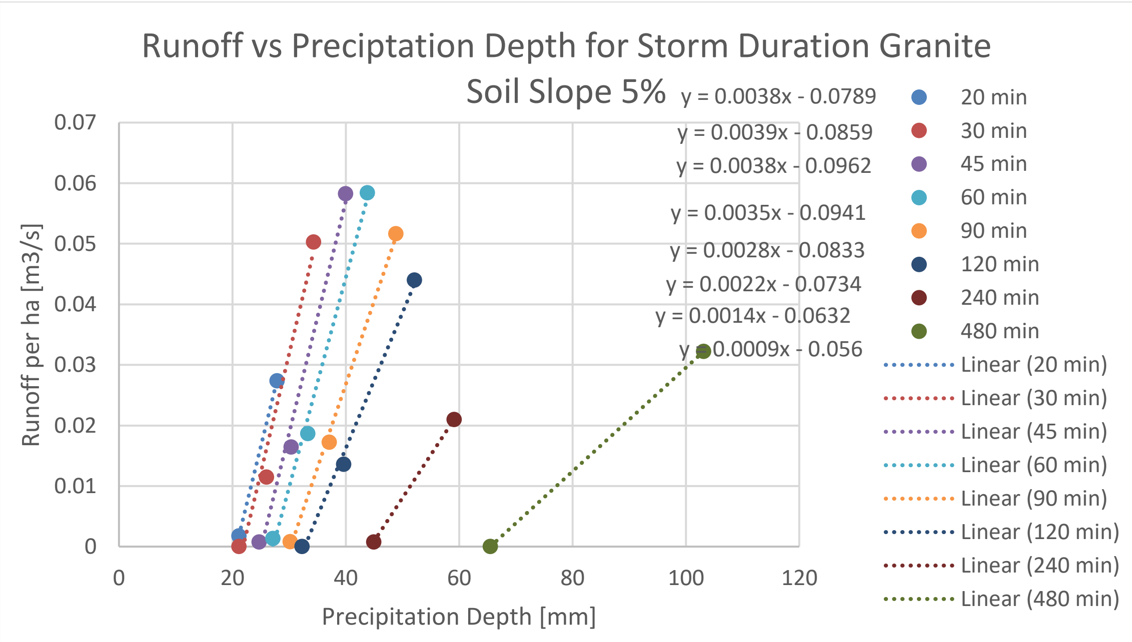


Figure D.7: Runoff vs Precipitation Depth for Storm Duration (Initially Dry Sandy Loam)

Table D8: Peak Runoff vs Precipitation Depth for Storm Duration (Initially Dry Clayey Loam)

Td		1.01	2	5
20 min	P	17.2	21.15	27.86
	Q	0.004039	0.019	0.039
30 min	P	21.17	25.99	34.29
	Q	0.01157	0.033	0.057
45 min	P	24.73	30.36	39.98
	Q	0.0163	0.039	0.083
60 min	P	27.13	33.28	43.81
	Q	0.0181	0.040	0.080
90 min	P	30.21	37.1	48.83
	Q	0.0177	0.037	0.072
120 min	P	32.27	39.61	52.11
	Q	0.0159	0.031	0.063
240 min	P	36.59	44.91	59.11
	Q	0.0078	0.020	0.040
480 min	P	40.52	49.73	65.49
	Q	0.000	6.46E-03	0.019

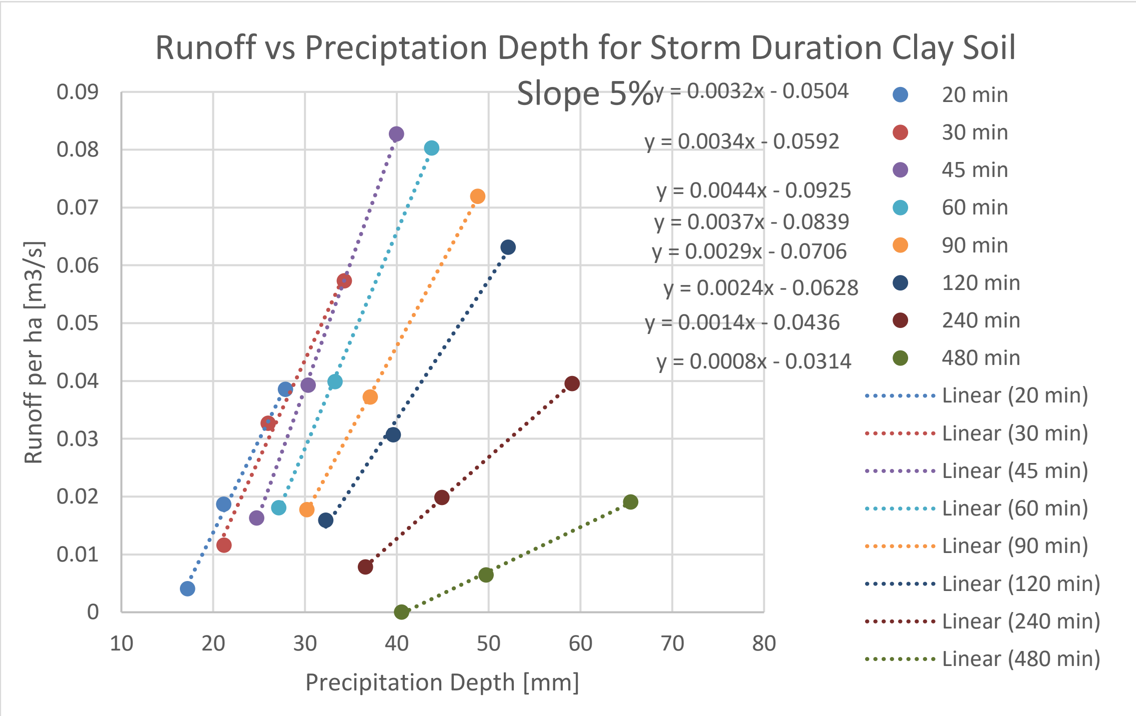


Figure D8: Peak Runoff vs Precipitation Depth for Storm Duration (Initially Dry Clayey Loam)

Comparison of Rainfall IDF Curves

Table D9 and Figure D9 show a comparison between the values of rainfall depth for duration and recurrence interval calculated using the equations of op ten Noord and Stephenson (1982) and of Hershfield (Adamson 1982).

A perfect correlation between values calculated using these two methods would plot as straight lines with a slope of 1.0. The regression equations of Stephenson and Op ten Noord were derived from the coaxial diagrams prepared by Midgley (1969) (1972). The equation of Hershfield (1972) is cited by Adamson (1981)

Parameters: MAP = 750 mm/year

Two year RI one day rainfall depth M_2 = 62 mm

Annual Lightning flash density L = 6 strikes/year

Table D9: Comparison of Rainfall Depths Calculated Using Equations of Stephenson & Op ten Noord and Hershfield

Equation	RI	Rain Depth for Td							
		20	30	40	60	90	120	240	480
Steph	1.01	18.10	21.64	24.08	27.33	30.33	32.29	36.60	40.53
Hersch		19.14	22.77	25.58	29.90	34.68	38.38	48.46	60.45
Steph	2	22.22	26.56	29.55	33.55	37.22	39.64	44.93	49.74
Hersch		25.41	30.24	33.97	39.70	46.05	50.96	64.35	80.26
Steph	5	29.25	34.96	38.90	44.16	49.00	52.18	59.14	65.48
Hersch		33.83	40.25	45.21	52.85	61.30	67.83	85.65	106.84
Steph	10	36.01	43.04	47.90	54.37	60.33	64.24	72.81	80.62
Hersch		40.19	47.82	53.72	62.79	72.83	80.60	101.77	126.95
Steph	25	47.40	56.66	63.05	71.57	79.41	84.57	95.85	106.12
Hersch		48.61	57.83	64.97	75.94	88.08	97.47	123.07	153.52
Steph	50	58.36	69.75	77.62	88.12	97.77	104.12	118.01	130.65
Hersch		54.97	65.41	73.48	85.88	99.61	110.23	139.19	173.63
Steph	100	71.85	85.88	95.56	108.48	120.37	128.18	145.28	160.85
Hersch		61.34	72.98	81.98	95.83	111.15	123.00	155.31	193.74

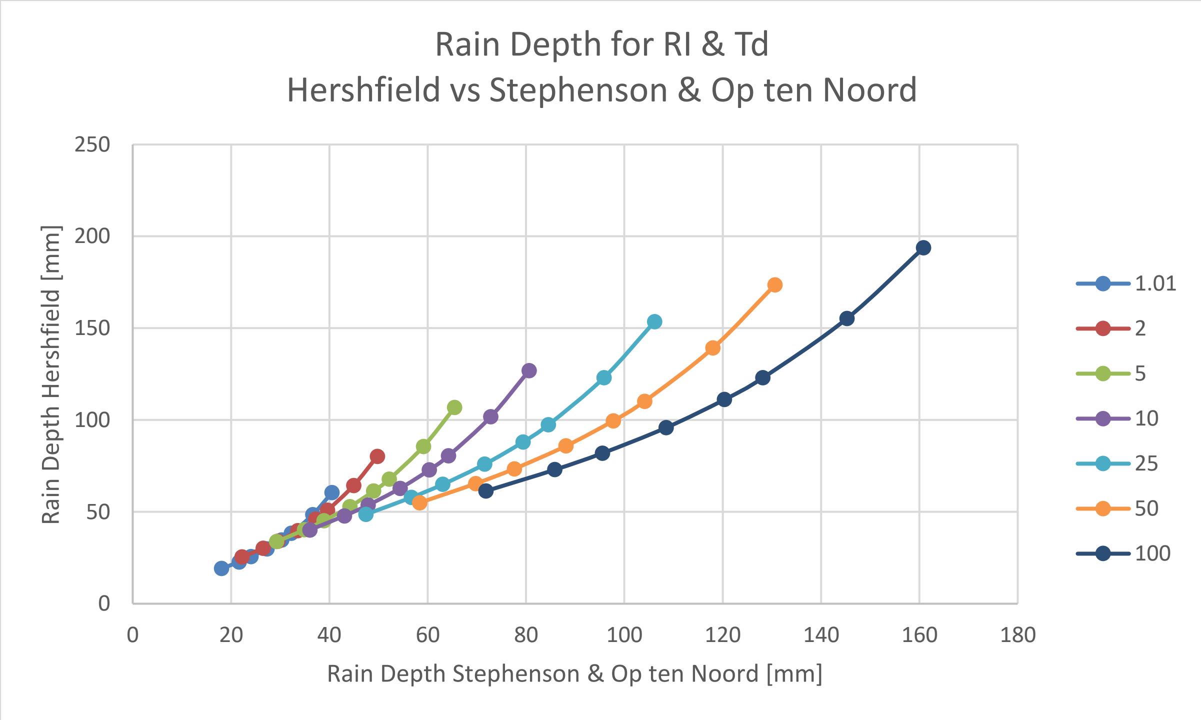


Figure D9: Comparison of Rain Depth for RI & Td between Stephenson & Op ten Noord and Hershfield

A regression surface can be fitted to the rain depths for different durations and recurrence intervals generated by the Design Rainfall Estimator of Smithers and Schulze. These results are compared with compared with the rainfall depths yielded by the equation of Hershfield as shown in Table D10 and Figure D10. This preliminary analysis shows a very strong linear relationship between the rain depths generated by these two methods.

Table D10: Comparison of Rainfall Depths calculated using Equations of Hershfield and Smithers & Schulze

Equation	RI	Rain Depth for Td							
		20	30	40	60	90	120	240	480
S&S	1.01	11.11	13.04	14.49	16.66	19.01	20.81	25.67	31.47
Hersch		19.14	22.77	25.58	29.90	34.68	38.38	48.46	60.45
S&S	2	17.02	19.97	22.19	25.52	29.12	31.87	39.32	48.20
Hersch		25.41	30.24	33.97	39.70	46.05	50.96	64.35	80.26
S&S	5	24.94	29.27	32.53	37.40	42.68	46.71	57.63	70.65
Hersch		33.83	40.25	45.21	52.85	61.30	67.83	85.65	106.84
S&S	10	30.94	36.31	40.34	46.39	52.93	57.94	71.48	87.62
Hersch		40.19	47.82	53.72	62.79	72.83	80.60	101.77	126.95
S&S	25	38.86	45.61	50.68	58.27	66.49	72.77	89.79	110.07
Hersch		48.61	57.83	64.97	75.94	88.08	97.47	123.07	153.52
S&S	50	44.85	52.64	58.49	67.26	76.75	84.00	103.63	127.05
Hersch		54.97	65.41	73.48	85.88	99.61	110.23	139.19	173.63
S&S	100	50.85	59.68	66.31	76.25	87.00	95.23	117.48	144.02
Hersch		61.34	72.98	81.98	95.83	111.15	123.00	155.31	193.74

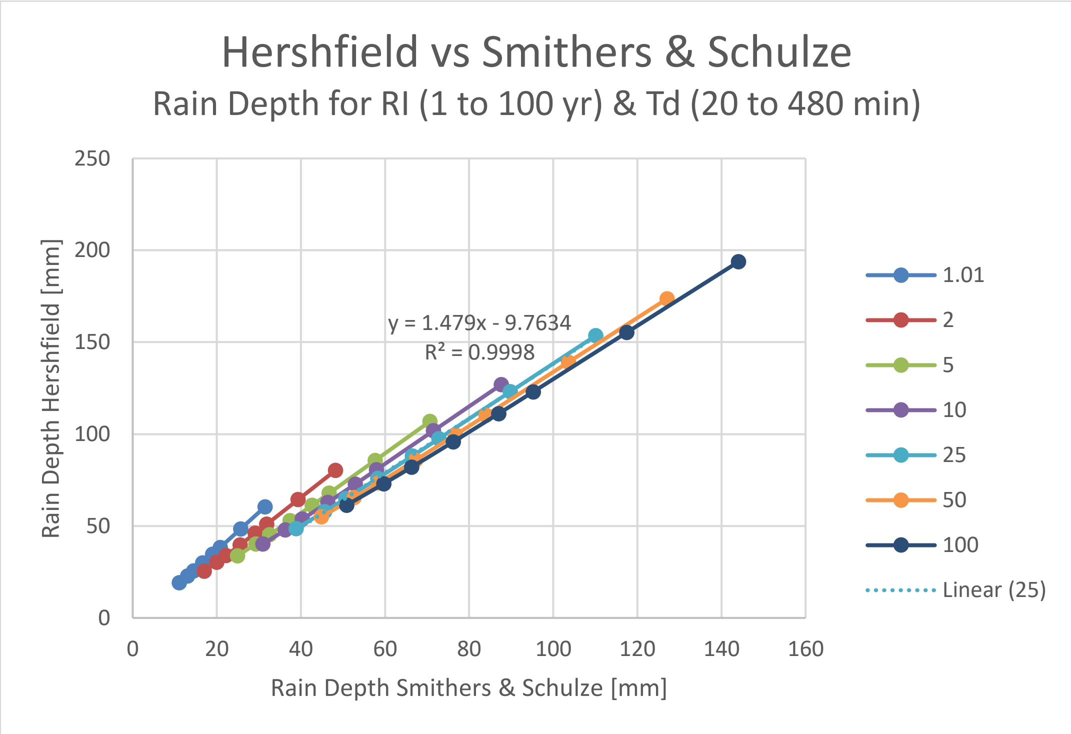


Figure D10: Comparison of Rain Depth for RI & Td between Hershfield and Smithers & Schulze

Variation of Unit Runoff with Catchment Area

Modelling has shown that peak runoff per unit area decreases with increasing catchment area. The results of some of that modelling for sandy loam soils are shown in Table D11 and Figure D11.

Table D11: Variation in Peak Discharge with Catchment Area

Location	Area	1.01 yr.	2 yr.	5 yr.	25 yr.	100 yr.
	ha	$m^3/s/ha$	$m^3/s/ha$	$m^3/s/ha$	$m^3/s/ha$	$m^3/s/ha$
Outfall3	1.2236	0.0013	0.0112	0.0363	0.1217	0.2596
Outfall6	15.4049	0.0001	0.0080	0.0314	0.1137	0.2492
Outfall4	31.1070	0.0001	0.0061	0.0279	0.1014	0.2086
Outfall1	46.3234	0.0002	0.0068	0.0282	0.1056	0.2349
Outfall2	59.3740	0.0001	0.0047	0.0194	0.0731	0.1668
Outfall7	72.5404	0.0000	0.0035	0.0200	0.0801	0.1864

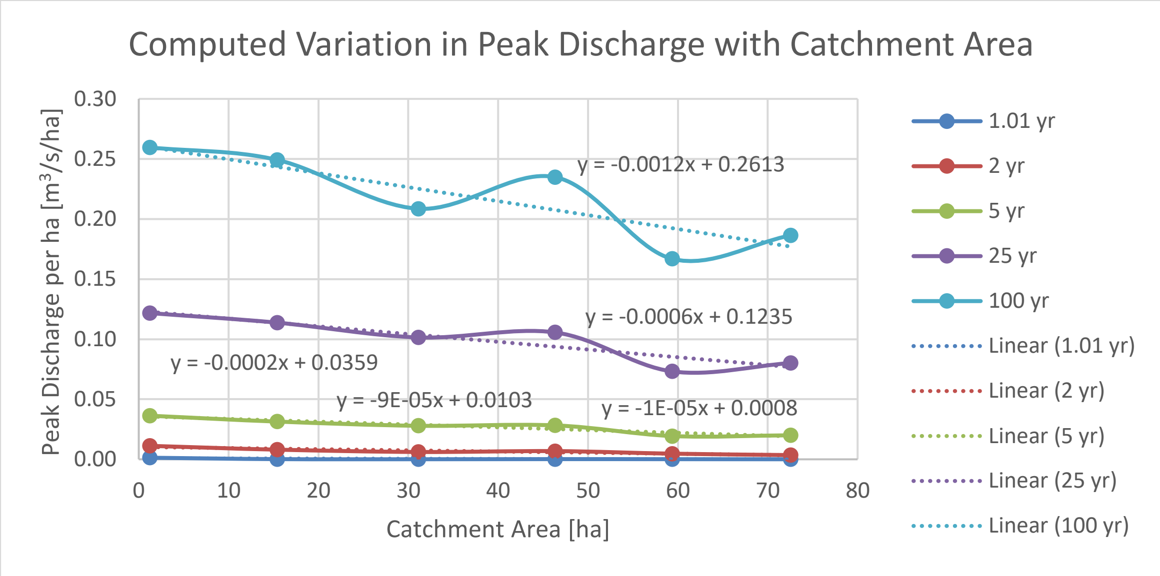


Figure D11: Variation in Unit Peak Discharge with Catchment Area

Continuous Modelling

Preliminary results of continuous model using PCSWMM for a hypothetical 1.0 hectare grassed hillslope catchment with roughness and Hortonian infiltration characteristics commonly used for granite soils are given below.

The results are uncalibrated because we have no suitable data set for calibration.

- **Model**

PCSWMM Version 6.2.2071 with SWMM 5.0.022

Catchment area 1 ha with 2% slope, overland flow length 100m.

Imperviousness	0%	
Infiltration	initial 65 mm/h,	final 10 mm/h
	Decay 5.4 /hour i.e. >99% decay in 1 hour	
	Drying time 7 days	

Infiltration rates are within the range given by Green (1984) for loam soil

Roughness	Imperv. n = 0.02	Perv. n = 0.20

The pervious area roughness corresponds to that give by Green for "Short veld grass"

- **Rainfall data**

Botanical Gardens 17 years of the 5 minute rain data set for the period 19 October 1994 to 21 December 2011 supplied by Weather SA.

Total number of days modelled	6164		
Total raindays (P>0.0mm)	1456	% raindays	24%
Total rain depth	10 390 mm		

No of rain seasons		16.5	
MAP		630 mm/year	

The total rain depth and number of rain days were extracted from the 5 minute data using a Python program, so may not agree exactly with the daily record from the site. Missing data were patched with zero values. A total of 3.1% of zero records were added with no discernible seasonal or time pattern.

- **Runoff**

Total Runoff

Total runoff	198 mm	Percent runoff	1.91%

This runoff can be compared with the percentage MAR given in WR2012 for the quaternary catchment A21C that includes Jukskei River, and Klein Jukskei, Braamfontein and Sand Spruits that drain most of the granite areas of Johannesburg

WR2012 MAP	682 mm		
WR2012 MAR	44.7 mm	Percent runoff	6.6%

The MAR is made up of both the surface water and ground water contributions to river flow. The ground water contribution in quaternary catchment A21C is not known, so the computed percentage of runoff cannot be determined, except to note that it is within the expected range. More research in this field would be useful.

Runoff Events

The model calculated 43 events that caused runoff with a peak discharge exceeding 0.001 m^3/s (i.e. 1.0 l/s). Figure D12 compares the distribution of the runoff events with the rainfall record. The modelling showed runoff to occur on 43 out of 1 456 rain days in 16.5 years, i.e. on average 2 to 3 times per year and on about 3% of rain days.

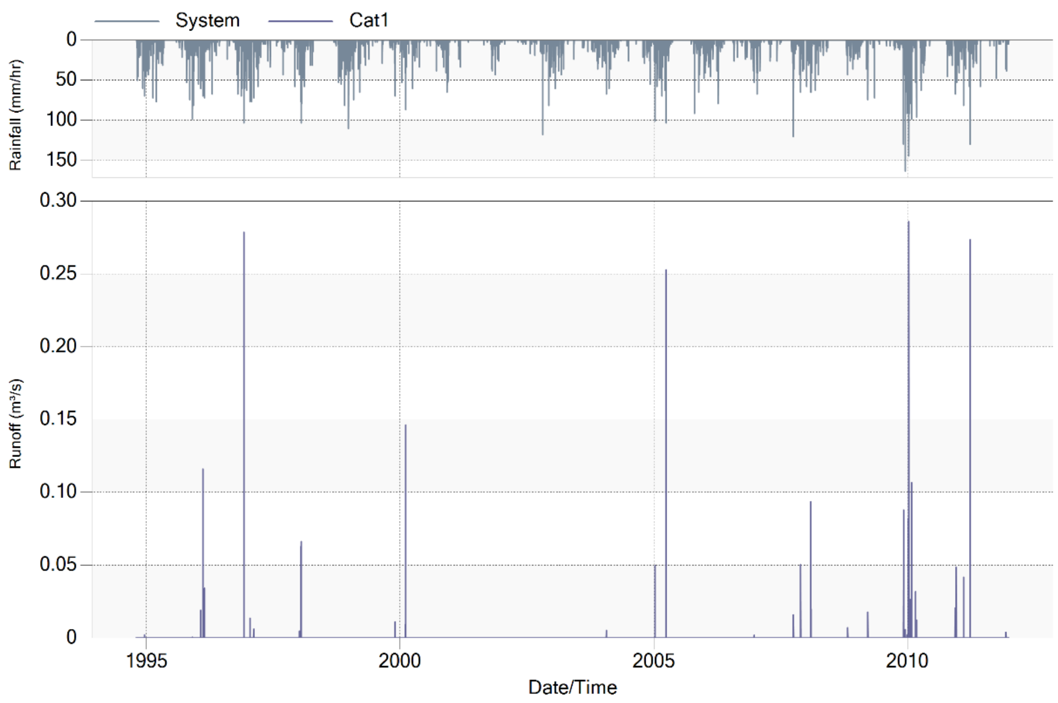


Figure D12: Rainfall and computed runoff for the entire period October 1994 to December 2011

Rainfall Intensity vs Peak Discharge

Events were defined as 1 hour preceding and 1 hour following any occurrence of runoff exceeding 0.001 m^3/s

There is very poor association between peak discharge of any event and the maximum rainfall intensity within the storm that caused the runoff. Figure D13 is a plot of peak discharge against maximum event rainfall intensity. The trend line, if forced through the graph origin, has a slope of 0.000317 (m^3/s per mm/h), which corresponds to a C value of 0.114, but with $R^2 = 0.207$. There is, however, a minimum depth of rain that must fall before runoff can commence, so the equation reflected in Figure D13, namely y = 0.0013x – 0.0428, that corresponds to C = 0.468 is conceptually more correct, but the value of R2 = 0.474 indicates a very poor correlation between the peak rainfall intensity and the peak discharge from the catchment.

Event Rainfall Depth vs Event Runoff Volume

There is a better, but still poor, correlation between the total depth of rain and the total volume of runoff as shown in Figure D14. The form of this regression equation, with a negative constant, implies that there is a minimum depth of rain required to initiate runoff which is in agreement with the results shown earlier in Figures D7 and D8.

Figures D13 and D14 demonstrate a major deficiency in the Rational Method. They show clearly that there is no unique relationship between rainfall intensity and rate of runoff from a catchment, and hence there is no unique value for the runoff coefficient defined as “C” in the Rational Formula

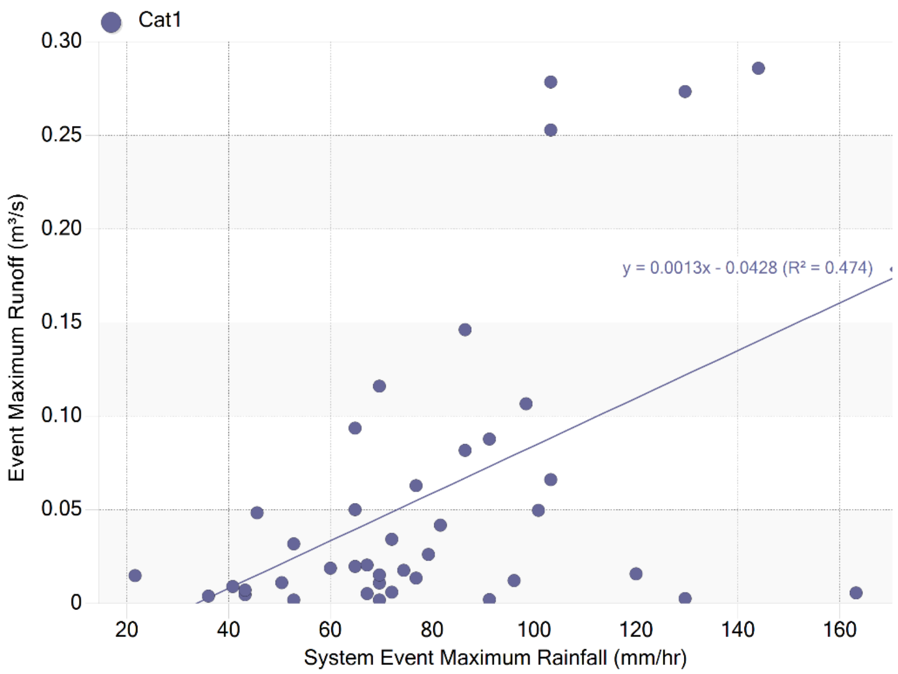


Figure D13: Relationship between peak discharge and event max rainfall intensity

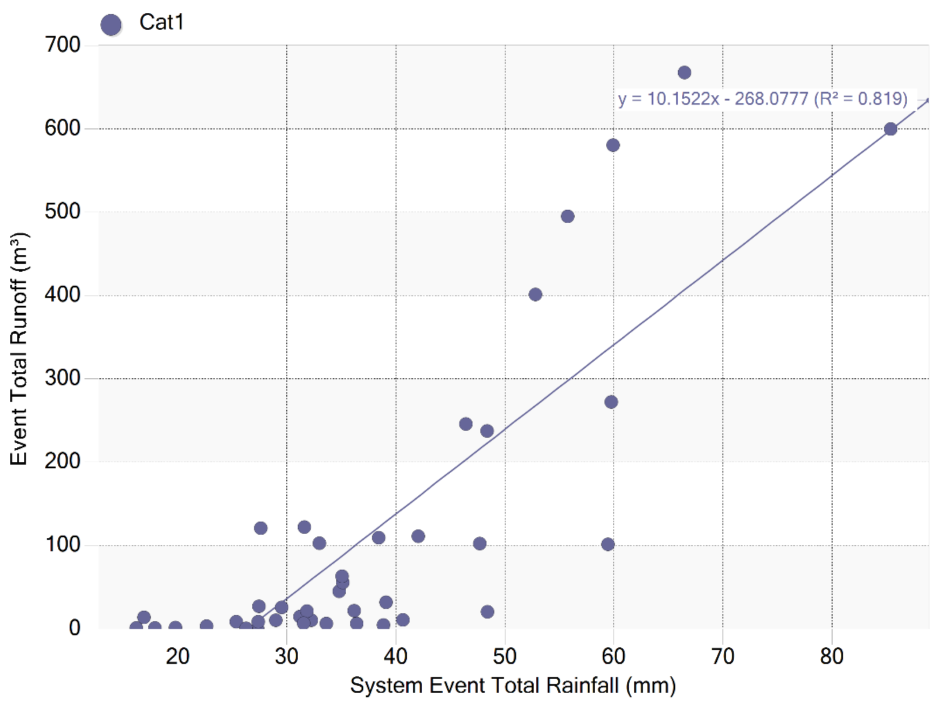


Figure D14: Relationship between event volume of runoff and event total rain depth

As would be expected the peak discharge is more closely related to the combination of depth and duration of the preceding rain. Figures D15 to D19 show the hydrographs and hyetographs of the four events with the greatest peak discharge. Figure D19 shows the hydrograph resulting from the storm with the highest intensity rainfall which occurred during a storm of very short duration. The hydrograph plot is quite coarse; the time step was set at 5 minutes to limit the size of the SWMM output file.

The recurrence intervals (RIs) of the peak rainfall intensity and the peak discharge were calculated using the Weibull plotting position. The plot of the RI of peak discharge against the RI of peak rainfall intensity in the appendix to this note, and the table in the same appendix show poor correlation between the RIs.

It is interesting to note that the four greatest discharges range from 0.1055 m^3/s to 0.1101 m^3/s and differ by less than 5% while the peak rainfall intensity of the causative storms ranges from 103.2 mm/h to 144.0 mm/h, which is a difference of 40%. The total depth of rain of these storms ranged from 52.2 mm to 64.8 mm, a difference of 24%.

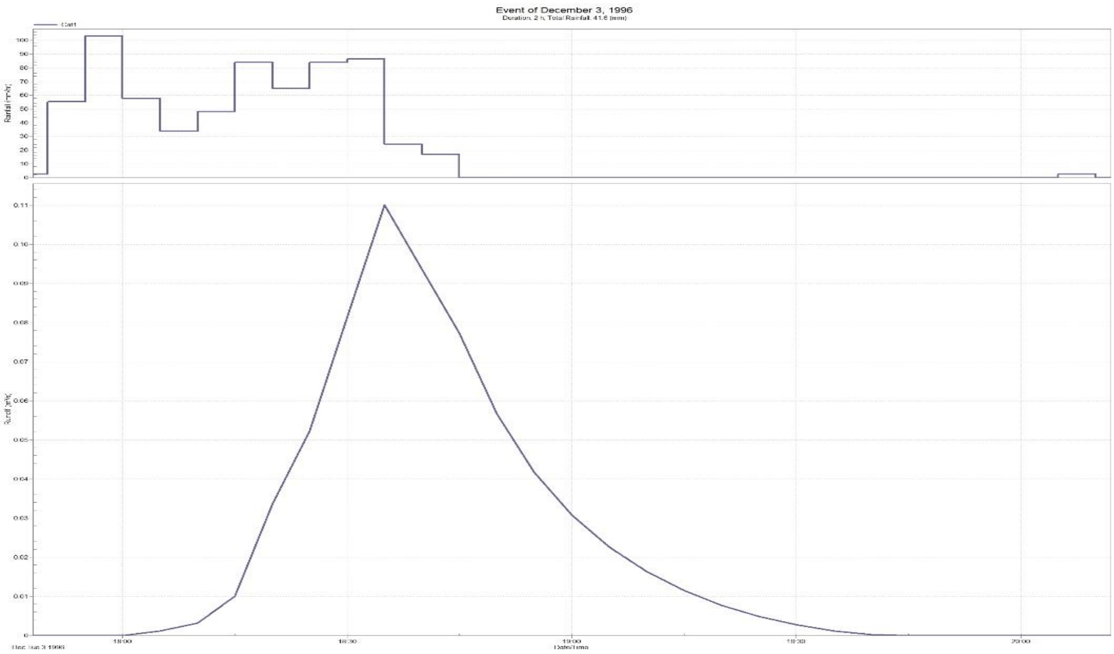


Figure D15: Hydrograph and Hyetograph for Event 7 on 3 December 1996, Total Rain 55.6 mm

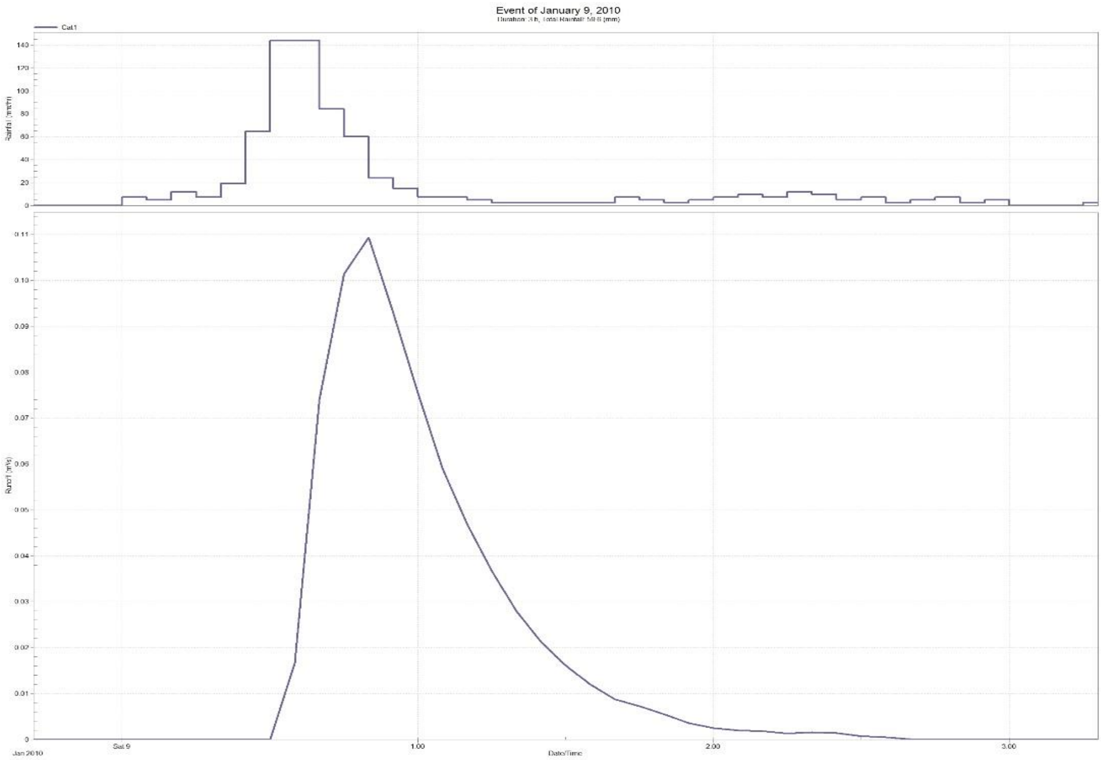


Figure D16: Hydrograph and Hyetograph for Event 32 on 9 January 2010, Total Rain 59.6 mm

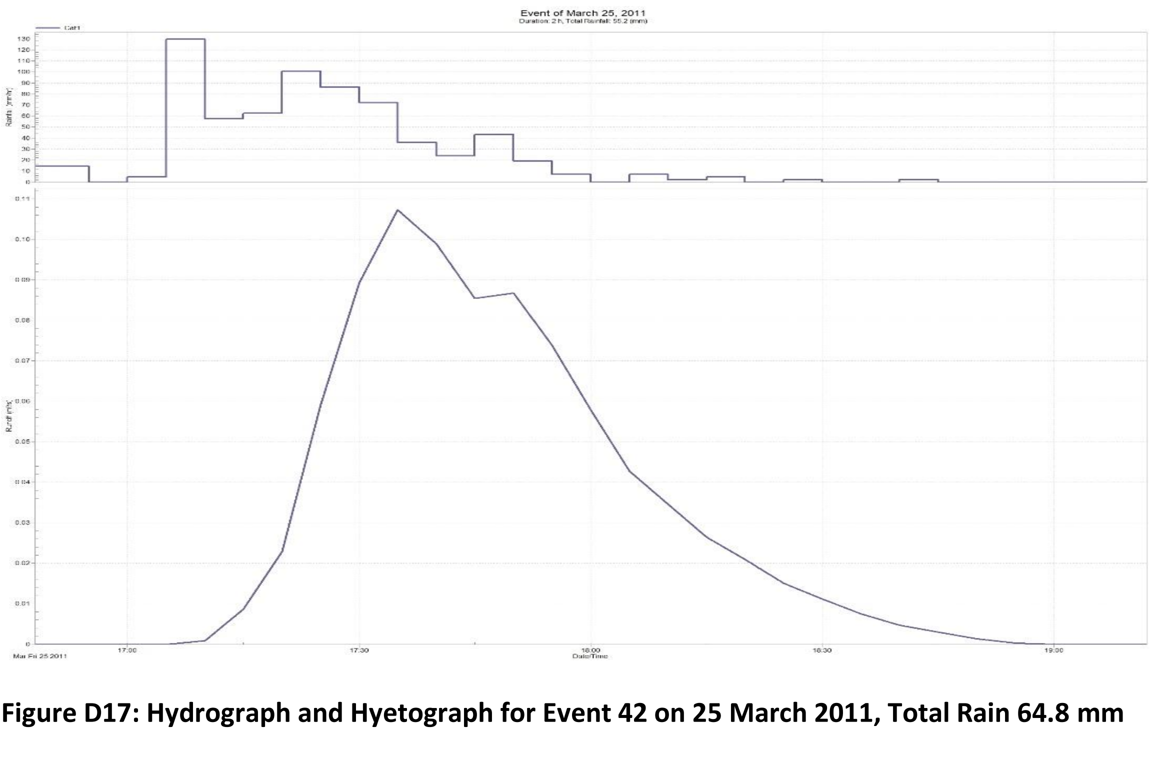


Figure D17: Hydrograph and Hyetograph for Event 42 on 25 March 2011, Total Rain 64.8 mm

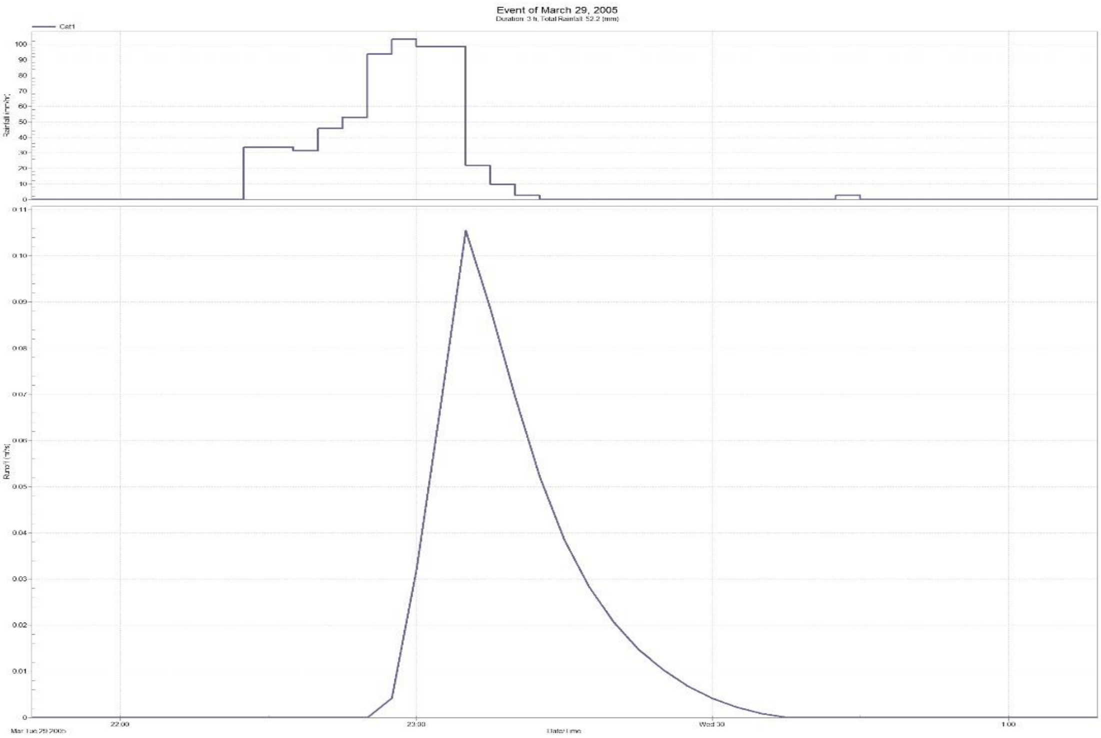


Figure D18: Hydrograph and Hyetograph for Event 19 on 29 March 2005, Total Rain 52.2 mm

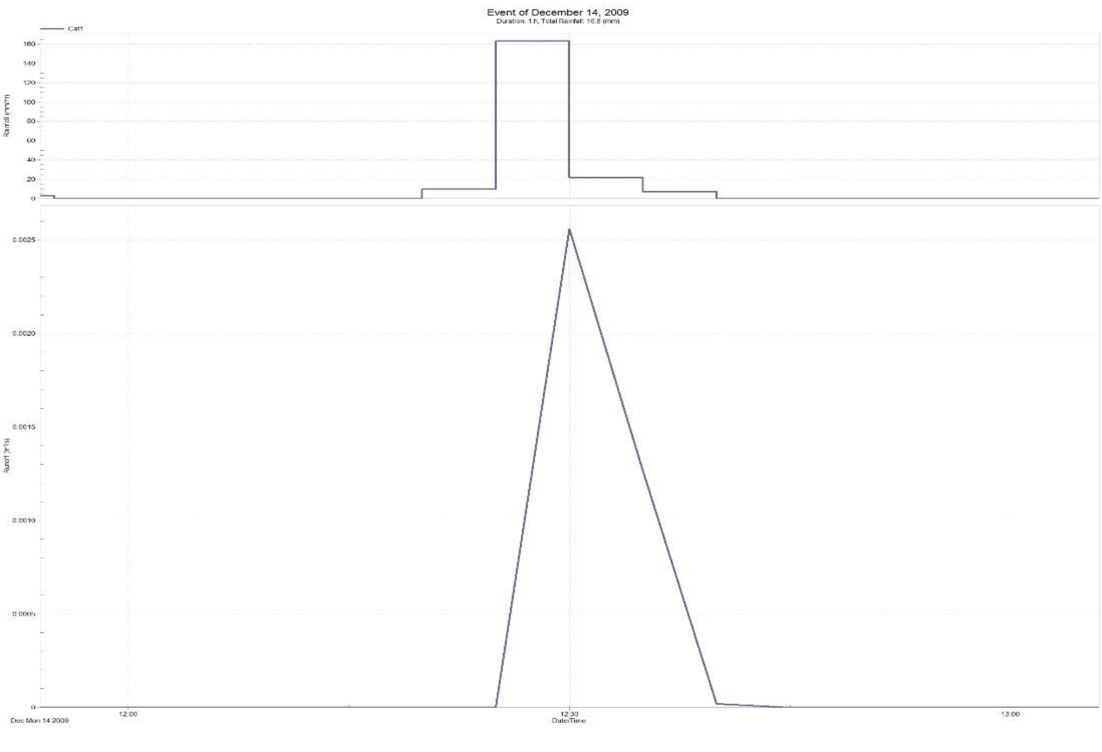


Figure D19: Hydrograph and Hyetograph for Event 29 on 14 December 2009. Total rain 17.4 mm

APPENDIX E: REVIEW OF DESIGN RAINFALL FOR JOHANNESBURG

E.1 Introduction

Storm rainfall is central to all deterministic methods for the estimation of urban runoff, and it has the largest influence on the outcome. Different sources of design rainfall are available to the stormwater engineer, and along with it the potential for different design runoff (peak flow, volume) using the same deterministic method. Hence a review of literature relevant to the City of Johannesburg area has been done in an attempt to identify an appropriate standard approach to selecting design rainfall for the metropolitan area. In the process, the review has also looked at weather systems, climate and orographic conditions specific to the City of Johannesburg that should be considered in identifying critical storm conditions for design runoff estimation.

E.2 Assumption of Stationarity

This assumption underpins much of stormwater design and flood risk practice, where predictions of current or future flood risk are derived on the basis of historical record. While recognised for its flaws, it has generally been seen to be a practical assumption for most design applications. However, in urban drainage design, the assumption of stationarity is more vulnerable to failure. In metropolitan areas, and particularly those experiencing rapid expansion, flood risk determination requires more foresight and catchment management to ensure that flood risk estimations provide reasonable cover for the design life of developments.

In recent years, the concern has extended from consideration of changing runoff responses due to increased paved areas to include consideration of changing rainfall conditions. There has been an increasing appreciation of natural variability at temporal scales beyond that of rainfall stations, and there is also greater acknowledgement of changes in rainfall patterns due to anthropogenic climate change (Westra & Sharma, 2010).

This document explores some of the recent climate and rainfall studies relevant to the Johannesburg area with the intention of alerting engineers and planners to this part of the debate on stationarity, and it is left to the individual professional to consider the risks in each design situation. The results of the analysis of recent downscaled rainfall projections from climate modelling is presented, but such is the nature of rainfall predictions in climate modelling that this information should be updated every few years. This review has not investigated any cyclical variations in rainfall, and storm rainfall in particular, as it has been assumed that the length of records at weather stations around Johannesburg will cover for any effect on estimating design rainfall. However, this assumption has not been tested for Johannesburg, and has been shown to be flawed in other locations, such as in Australia (Thyer et al., 2006). Hence the assumption of stationarity warrants further analysis for application in the Johannesburg context.

Therefore, the guideline for design rainfall that is derived in this Manual does not depart too far from the assumption of stationarity, but this first edition should alert practitioners to the issue and provide reasonable scenarios for testing catchment responses under climate change.

E.3 Design Event Analysis vs Continuous Simulation

Due to the size and increasing complexity of stormwater management systems, the incorporation of sustainable drainage techniques, and the need to understand the performance of the systems under natural conditions, designs based on continuous simulation modelling are now seen as best practice for modern design. This involves the simulation of the system over a period of a season, a year or a number of years with input of a rainfall series. The benefits of this approach are numerous, though some of the main ones include:

- Assumptions on antecedent conditions are avoided, and a more realistic performance of stormwater infrastructure can be analysed;
- If the period of simulation is long enough, the need to determine critical storm durations is also avoided;
- If the period of simulation is long enough the need to determine design rainfall is also avoided as the frequency of flood responses can be analysed directly.

E.4 General Climate of Johannesburg

The City of Johannesburg is located in the summer rainfall region of the country. The rain season is October to March, though occasional rain due to frontal events can occur in winter. MAP is of the order of 700mm and there are typically about 100 days of rain per year (Dyson, 2009). Splitting the rain season into early summer (October to December) and late summer (January to March), Dyson (2009) analysed seasonal summer rainfall over Gauteng (Table E1). Median values are fairly similar between early and late summer, but the late summer rainfall shows more variability and with more extremes. It is interesting that Dyson (2009) noted a trending decrease in early summer rainfall and an increase in late summer rain.

Table E1: Statistics of summer rainfall (mm) over Gauteng, 1977/78 to 2008/09 (after Dyson, 2009).

Season	Early Summer (Oct-Dec)	Late Summer (Jan-Mar)	Total
Average	278	309	587
Median	266	279	567
Maximum	452	568	968
Minimum	159	110	341

E.5 Topography of the City of Johannesburg

The metropolitan municipality straddles the Witwatersrand, a ridge that forms the watershed between the Crocodile/Limpopo and Vaal/Orange catchments. Rain falling in the municipal area may drain either to the Indian or Atlantic oceans. Altitude ranges from 1350m aMSL where the Jukskei River crosses the municipal boundary in the north, to 1800m aMSL in Hillbrow on the ridge of the Witwatersrand. A profile across the Witwatersrand, following the Braamfontein Spruit draining north and the Klipspruit draining south is given in Figure E1. The ridge is aligned east-west across the municipality (Figure E1) and provides for orographic uplift that is shown to have a significant influence on the distribution of storm rainfall and intensity across the metropolitan area.

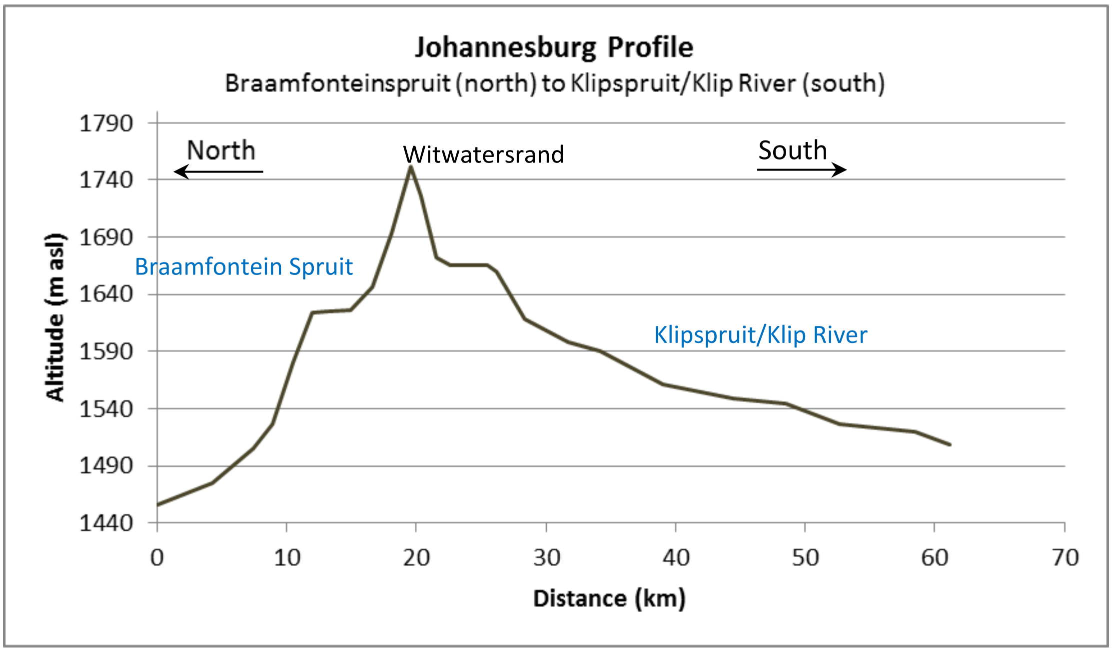


Figure E1: The Witwatersrand ridge and the profiles of the Braamfontein Spruit and Klipspruit draining north and south of the ridge respectively.

E.6 Weather Systems Affecting Johannesburg

There are three main weather systems that produce heavy rainfall in Gauteng, and Johannesburg in particular, as described below.

Frontal cyclones (or mid-latitude cyclones)

These are typically associated with what are known as the cold fronts that move up from the Western Cape, mainly in the cooler months, but which occur throughout the year (Goliger, et al, 2007). They are often accompanied by low intensity, consistent rain over a number of days. They are also often preceded by thunderstorms, typically in a line (squall line) along the face of the front, that can result in heavy rainfall.

Tropical Cyclones and Ridging Indian Ocean Highs

Tropical cyclones over the Indian Ocean occur annually and are mainly active east of Madagascar, though they can move into the Mozambican channel, usually resulting in widespread rainfall along the east coast of Southern Africa. On occasion, they push further inland and have been the cause of some of the most severe flooding over eastern and northern South Africa, including Gauteng, in recent past. Cyclone Eline is an example of such an event that saw widespread flooding over Gauteng and the Limpopo Provinces in February 2000 (Dyson, 2009). These events produce the 3-7 day rainfall extremes and can be associated with wet antecedent conditions, as occurred in February 2000 (Smithers, et al, 2001). These weather systems are of particular importance for analysing and designing attenuation and retention systems.

Other tropical influences include the ridging of Indian Ocean Highs over the eastern and north-eastern parts of the country, often in conjunction with a deep trough in the west (Kruger, et al, 2010). These systems can affect large areas over the central parts of the country, bringing widespread rain and even thunderstorms. An example of this occurred in March 2014, where

Gauteng, Limpopo, and Mpumalanga provinces experienced two weeks of heavy rains and flood damage, and a loss of 32 lives (Hill, 2014). A similar condition in February 1996 saw a persistent supply of moist tropical air over the north-eastern parts of South Africa that produced heavy rain over an 8-day period over parts of KwaZulu-Natal, Mpumalanga, Limpopo and Gauteng, including a particularly high 3-day rainfall of 266mm recorded in Pretoria (de Coning, et al, 1998).

Thunderstorm systems and tornados

Thunderstorms are closely associated with urban design rainfall over most of South Africa, particularly on the Highveld. They occur over most of the country in summer, particularly in central, northern and eastern areas of the country. The heating of the earth's surface initiates thunderstorm development, but other factors play a role; orographic uplift, frontal uplift, and large-scale convergence ahead of a trough or east of a low-pressure cell. The latter forms a moisture boundary typically aligned north-west to south-east and occurs as the moist Indian Ocean air moves over the drier Atlantic Ocean air coming in from the south-west. A line of thunderstorms, or "line squalls", can form parallel to, and ahead of, trough lines (Kruger, et al, 2010).

Thunderstorms can develop into one of two arrangements:

- Squall lines of cells, usually in advance of a frontal cyclone, where the cells are organised over hundreds of kilometres and can influence each other;
- Multi-cell clusters of storm cells which can evolve into large mesoscale systems.

Thunderstorms are the dominant weather system for urban stormwater management. The lifecycle of a thunderstorm cell is typically less than an hour in the Johannesburg area (Mader, et al, 1986), though the experience on the ground may be less than this if the storm cell is moving. Wind gusts are often an indication of rainfall intensity and precede the release of the rain by the storm cell. In the period 1993 to 2008 between 86% and 92% of the highest annual wind speeds in Johannesburg were generated during thunderstorms.

Table E2: Summary of Tornado Activity Recorded in Gauteng (from Goliger, et al, 1997)

FPP Scale	Gauteng Count	Damage Indicator	Max. wind speed (m/s)		Path length (km)		Path width (m)	
			From	To	From	To	From	To
F0	7	Light: chimney damage, sign boards & branches broken.	20	30	0.5	1.5	5	15
F1	18	Moderate: roof surfaces peeled off, cars pushed.	30	50	1.5	5	15	30
F2	12	Considerable: roofs torn off, large trees snapped.	50	70	5	16	30	160
F3	5	Severe: roofs and walls torn off, heavy cars lifted.	70	90	16	50	60	510

The Gauteng Province has the highest density of recorded tornados in the country, which are a severe form of thunderstorm. Records show that 42 were recorded in the province between 1905 and 1996 (Goliger, et al, 1997). Goliger and Retief (2007) show Gauteng to lie within the zone of intense thunderstorms/tornados/downbursts, assigning a point probability of 1:10,000 chance of a tornado strike. Most tornados (64%) occur between October and February, but the months of November to January show the most activity with almost 45% of recorded occurrences. Applying the Fujita and Pearson classification system, a summary of tornados recorded in Gauteng (1905-1996) is given in Table E2.

E.7 Storm Rainfall Frequency

Dyson (2009) analysed the statistics of rainfall over the area of Gauteng for the summer seasons 1977/78 to 2008/09, the results of which are summarised in Table E3. Note that significant heavy and very heavy rainfall thresholds refer to an average daily rainfall depth over the province (16,500km2), and not to point rainfall. The data are indicative of the likelihood of wet weather and heavy rain over the months of the wet season. They do not determine design rainfall at a site scale, but have relevance for planning at a catchment scale.

Table E3 also suggests there is a stronger likelihood that heavy rainfall events will occur in the late summer period, and particularly in January and February. However, Dyson's (2009) analysis of station data shows that extreme events may occur in any of the summer months. A summary of the maximum recorded 24-h events in each month in Gauteng is given in Table E4.

Table E3: Statistics of monthly and daily rainfall over Gauteng (after Dyson, 2009)

	Early Summer			Late Summer			Season
	Oct	Nov	Dec	Jan	Feb	Mar	
Average monthly total (mm)	72	96	109	126	97	86	587
Max. monthly rain (mm)	190	183	179	324	277	296	968
Ave. days with rain (no.)	15	20	24	23	19	17	118
Max. days with rain (no.)	25	28	29	28	26	26	142
Ave. days with significant rain (>10mm)	2.1	2.6	2.9	3.8	2.8	2.6	16.8
Max. days with significant rain (>10mm)	5	7	5	11	10	10	31
Ave. days heavy rain (>15mm)	1.1	1.1	1	1.6	1.7	1.3	7.8
Max. days heavy rain (>15mm)	4	5	4	8	6	5	18
Ave. days very heavy rain (>25mm)	0.3	0.3	0.2	0.5	0.4	0.4	2.2
Max. days very heavy rain (>25mm)	2	2	2	4	4	3	10

The data in Table E5 are derived from an analysis by Dyson (2009) of point rainfall records and therefore more helpful for stormwater design. The statistics in Table E5 are collective across all stations in Gauteng and do not refer to one station only. They show that the occurrence of 24-h, 50mm rainfall events is common across all stations within Gauteng. On average, one can expect close to five such days across all stations in December and February, and seven such days in January. Over an average season one would expect a collective 28 days across the province with rainfall greater than 50mm. In rare cases, there may be as many as ten days in December, going up to 17 days each in January and February. The maximum in a season has been a collective 56 days of rainfall above 50mm measured at stations across Gauteng. This occurred in the 1999/2000 summer season (Dyson 2009).

Table E4: Maximum recorded 24-h rainfall at a single station in Gauteng, 1977/78 to 2008/09 (Dyson, 2009).

Month	Max. 240h rainfall (mm)	Average intensity (mm/h)
Oct	220	9.2
Nov	200	8.3
Dec	300	12.5
Jan	280	11.7
Feb	142	5.9
Mar	260	10.8

The pattern continues for higher threshold events. The average number of days expected to record events greater than 115mm in January is 0.59 across all stations in Gauteng. This would equate to approximately once every second year in the month of January, but the records show these events occur in only 38% of January months (meaning that in some years, more than one event above this threshold is experienced in January, although not necessarily at the same station). The maximum number of days on which more than 115mm was recorded in the month of January anywhere in Gauteng is three days, which occurred in 1996 (Dyson, 2009). Similarly, February shows an average of 0.28 days per month with rainfall above the 115mm threshold, recorded in only 13% of the years on record. Again, some years record more than one event in February above the 115mm threshold and Dyson (2009) shows that as many as five days have been measured in February of a year across the province. Dyson also notes that the record sample is probably skewed by the 1995/96 season and the 1996 event itself. Table 4 also shows a clear distinction between the frequency of large point-rainfall events in early summer and late summer, with the latter proving to be the more likely period for high, and most likely more intense, rainfall events at a site.

Table E5: Summary of monthly and daily average statistics for point rainfall measurements within Gauteng (Dyson, 2009).

	Early Summer			Late Summer			Season
	Oct	Nov	Dec	Jan	Feb	Mar	
Ave. days with significant rain (>50mm)	2.3	3.5	5.1	7.0	5.1	4.6	27.6
% occurrence in all months	78%	88%	97%	100%	97%	94%	100%
Max. days with significant rain (>50mm)	10	10	10	17	17	15	56
Max. consecutive days with significant rain (>50mm)	5	5	5	8	9	7	
Ave. days heavy rain (>75mm)	0.9	1.1	1.3	2.6	1.9	1.7	9.5
% occurrence in all months	47%	66%	53%	88%	69%	63%	97%
Max. days heavy rain (>75mm)	6	4	4	7	10	10	24
Max. consecutive days with significant rain (>75mm)	3	2	3	5	6	5	
Ave. days very heavy rain (>115mm)	0.25	0.09	0.25	0.59	0.28	0.38	1.84
% occurrence in all months	19%	6%	22%	38%	13%	22%	66%
Max. days very heavy rain (>115mm)	3	2	2	3	5	4	9
Max. consecutive days with significant rain (>115mm)	1	1	1	2	3	2	

E.8 Distribution of Storm Frequency across the Metropolitan Area

Dyson (2009) identifies the Witwatersrand watershed that divides the Vaal catchment to the south from the Limpopo/Crocodile catchment to the north as also being a divide in the occurrence of heavy rainfall events. She notes that stations to the south of the watershed record about half the number of heavy and very heavy rainfall events that are recorded to the north. Point rainfall events greater than 75mm are estimated to occur 1.7 times more often north of the watershed than to the south, while events greater than 115mm are likely to occur 2.6 times more.

E.9 Likelihood of Antecedent Rainfall

Table E4 indicates the chance of consecutive days of rainfall above the 50mm threshold. These vary between five and nine consecutive days of rainfall above 50mm as being the maximum number in each month observed at least at one site in the 32-year record. This is particularly significant for stormwater design and catchment planning, especially where volume control is the default stormwater management requirements. There is also a record of two consecutive days measuring above 115mm in January at a station in the Gauteng area and as many as three consecutive days above 115mm in February.

A specific analysis of the likelihood of antecedent rain in association with design rainfall conditions was not found in the literature, but this could easily be done with the quality of data from rainfall stations in the metropolitan area. However, the work by Dyson reported above suggests that it would be reasonable to assume that a design storm may be preceded by one or more wet days, including some with significant (>50mm) rainfall, and that this should be included in the tests done on design alternatives for a site.

E.10 Storm Speed and Trajectory

Storm movement can have an impact on the runoff response of a catchment. The effect can be small to negligible where the catchment size is smaller than the area of the storm cell, but where catchments are larger than the storm cell, the effect on runoff can be significant. Stephenson (1984) reports that storm clouds can travel at wind speeds between 2km/h and 60km/h in South Africa, while Tyson and Preston-Whyte (1998) demonstrate storm movement and trajectory over Johannesburg covering 190km in 4 hours (47.5km/h). An analysis of radar records for the Highveld area by Mader et al. (1986) showed the range of storm speeds to be 5km/h to 90km/h, and that the median storm cell speed is 25km/h.

There is a view that storms travelling down the catchment will usually result in higher peak runoff (SANRAL, 2007). Experience in the Witwatersrand area is that thunderstorm cell movement is typically north to north-east. This is particularly the case with the squall line storm systems and convection systems that are the main sources of thunderstorms over Johannesburg (Tyson & Preston-Whyte, 1988). Mader et al. (1986) noted that storm cells can travel in any direction, but that they tend to move from south-west to north-east over the region.

Many of the Johannesburg catchments flow either in a northerly or southerly direction, this storm trajectory may have the following influence on catchment responses:

- A northerly to north-easterly trajectory will tend to reduce the time of concentration and therefore the critical storm duration in north draining catchments, thereby increasing the peak discharge; and

- The same storm will have a flattening effect on the flood peak on south draining catchments as the time of concentration and critical storm duration increases.

Stephenson (1984) showed that constant rainfall storm cells larger in area than the catchment, and moving down the catchment, will have no influence on the peak runoff. However, storm cells smaller than the catchment area, with associated higher intensities, moving down the catchment will result in higher peak flows. Hence, moving storms will affect the critical storm duration, and therefore storm intensity. SANRAL (2007) proposes that the time of concentration (t_c) be reduced by the travel time of the storm along the catchment to determine the critical storm duration.

There is sufficient information for stormwater engineers to determine critical storm duration, testing catchment sensitivity to storm movements, particularly in the north draining catchments where the critical storm duration may be shorter than that indicated by calculations of time of concentration. A test may be performed where the storm is assumed to be travelling in the downstream direction of the catchment with a storm speed of the order of 25km/h. The standard t_c is then reduced by this time and the appropriate storm duration and intensity can be applied.

E.11 Storm Rainfall Intensity

An indication of the potential intensity of thunderstorms in the Highveld area has already been given through the association between thunderstorms and tornados and the record of the latter over Gauteng. A measure of storm intensity was presented as a set of synthetic rainfall distributions for South Africa developed by Weddepohl (1988), which were refined and published by Schmidt and Schulze (1987). They have been widely applied to storm rainfall and stormwater calculations. The SA Type 3 synthetic rainfall distribution is applicable to the Johannesburg area, and is second only to the Type 4 distribution in storm intensity, which is limited to the eastern Drakensberg escarpment. The synthetic distribution is a curve of accumulated one-day design rainfall (Figure E3), and could be easily applied to the one-day records that are the most readily available in South Africa. Rainfall depths for shorter durations suitable for urban catchments are then obtained by the applying the ratio for the Type 3 distribution in the following formula to the one-day rainfall depth (Schmidt & Schulze, 1987):

$$\mathrm{R} = \frac{0.73402 \text{ x D}}{(0.23 + D)^{0.9}}$$

Where R = ratio of D-hour to one-day storm depth

D = storm duration for which R is to be calculated (in hours)

In 2012, the 5-minute rainfall data at OR Tambo International Airport was tested against the Type 3 distribution. The results presented in Figure 3 suggest the SA Type 3 profile is still relevant for the Johannesburg area (Piketh, et al, 2013).

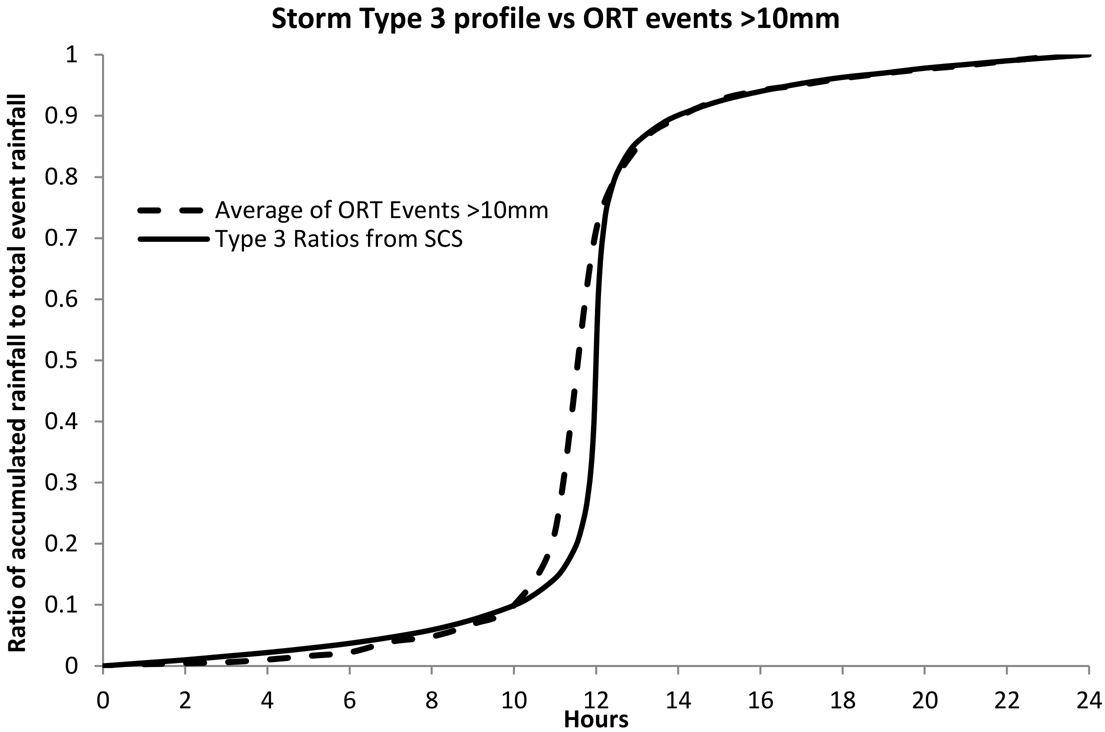


Figure E2: Comparison of storm profiles of rainfall events > 10mm at OR Tambo (1994-2010) and the Storm Type 3 profile for the greater Johannesburg area (Piketh et al., 2013).

E.12 Design Storm Event Data for Johannesburg

The Drainage Manual (SANRAL, 2007) provides a useful summary of design rainfall sources for the more standard deterministic design hydrology methods currently in use. The implication is that different rainfall sources are best suited to different hydrology methods (Table E6). Two of the commonly adopted design rainfall data sources date from the 1970s (HRU1/72) and 1980s (TR102) (Adamson, 1982), while the SCS method presents design rainfall developed in the late 1980s (Schmidt and Schulze, 1987). A comparison of the 20-year, 1-hour storm depths from each source for Waterkloof, Pretoria, is given in Table E6. There is almost a 25% variation between the estimates.

A more recent review of design rainfall across the country has been undertaken by Smithers and Schulze (2012). Referred to as the RLMA-SI approach, their analysis of over 1700 daily rainfall stations and over 170 digitised rainfall stations included regional analysis to develop regional growth curves across the country for storm durations <24 h to 7 days. The regression analysis accounts for MAP, latitude and altitude, and design rainfall is presented on a minute-by-minute of arc grid across the country. The 20-year, 1-hour storm depth for Waterkloof provided by this method is notably lower than the values promoted by the other methods (Table E5).

Gericke and du Plessis (2011) analysed the application of the different design rainfall sources across 44 catchments in South Africa and concluded that the RLMA-SI approach should be used as the standard source to develop Depth-Duration-Frequency (DDF) relationships for all critical storm durations. Furthermore, they propose that the HRU1/72 and Hershfield applications are conservatively high.

For the purposes of a consistent application of design rainfall across the City of Johannesburg, it is recommended that the RLMA-SI data source provided by Smithers and Schulze (2012) be used.

Furthermore, the resulting distribution of rainfall appears to agree with the findings of Dyson (2009) that the northern areas of the City will have higher storm rainfall than the southern areas.

Table E6: Comparison of 20-year, 1-hour point rainfall depths at Waterkloof (Pretoria), as obtained from the different methods in the Drainage Manual (SANRAL, 2007).

Method	Peak flow or hydrograph	Rainfall source	Point rainfall $P_{20y,1h}$ (mm)
Rational Method	Peak	HRU 1/72 (DDF nomograph).	60
"Alternative Rational Method"	Peak	TR102 & modified Hershfield eqn.	88
Unit hydrograph	Hydrograph	HRU 1/72 (DDF nomograph).	60
SDF Method	Peak	TR102 & modified Hershfield eqn.	88
SCS Method	Peak & volume	Schmidt & Schulze, 1987.	76
Smithers & Schulze	Point rainfall	Smithers & Schulze, 2012.	50 (40.3-59.4)

E.13 Rainfall Data for Continuous Simulation

Data for continuous simulation should be the recorded rainfall at the nearest rainfall recording station. The main points to consider include:

i) The frequency and magnitude of storm rainfall varies significantly across the area of the City of Johannesburg. A rainfall station representative of the site location should be used.

ii) The length of record required will depend on the design and analysis requirements. However, if flood frequency is to be analysed then the longer the rainfall record the better (the issue of non-stationarity is relevant here). In this Manual, it is recommended that at least 20 years of rainfall records should be used to analyse frequencies up to the 5-year event. For larger events, the maximum record length available should be used.

iii) Most rain stations record daily totals, which is not suitable for urban stormwater analysis. However, the daily totals may be transformed using a cumulative storm profile. An alternative would be to consider using the 5-minute data records available at a few stations in and around the City of Johannesburg (e.g. Johannesburg Botanical Gardens, OR Tambo International Airport, Grand Central Airport). This should be supported by an assessment of the suitability of the data to the site.

iv) The calibration of the continuous simulation is critical. However, storm event rainfall is highly localised within the City of Johannesburg area and if the station is more than 2km from the site, then model calibration may need to be supported with more local records (even if only daily totals are recorded), or by using radar imagery from the SA Weather Service.

E.14 Climate Change – Key Issues

The assumption of stationarity is central to most approaches to flood risk assessment and stormwater design but that in large urban environments the flaws of this assumption can have significant bearing on the reliability of the design. Key issues affecting design rainfall determination include:

- Natural rainfall variability in cycles that are longer than rainfall records. The effect of this has been assumed to be relatively small due to the length of record of stations around Johannesburg. However, research is showing this to be a flawed assumption, and in fact there can be significant associations between flood risk and climatic cycles such as those influenced by the El Niño effect (Jain and Lall, 2001). Therefore, this assumption needs to be tested for Johannesburg.
- The impacts of climate change that research and climate modelling shows could influence:
    - Storm frequency and magnitude, and
    - Antecedent conditions.

This review has not considered the influence of natural climate cycles on design rainfall for the Johannesburg area, but there is more information relating to climate change now available and this is summarised here. Trends of changes in rainfall on a global and regional scale from global climate models provide limited information to assist the stormwater manager and designer at a municipal scale. Hence consideration is given to investigations of changing storm rainfall at a local scale. While these are few, they at least offer a starting point for testing non-stationarity due to climate change on stormwater systems. They are based on both the analysis of recent trends (of recorded data) and long-range trends suggested by downscaled climate model output.

Climate Change – Recent Trends

A review of different sources shows a range of differing views on current trends in rainfall over the Johannesburg area. The Climate Change Adaptation Plan (CoJ, 2009) proposes that there may have been a slight general decrease in rainfall since the 1960, particularly in the late summer/autumn period, though any such trend is small and not statistically significant. The study utilised data from a weather station in Krugersdorp and analysed 30-day totals, daily rainfall, number of rain days, and even number of rain days greater than 10mm. Fatti and Vogel (2011) analysed data at OR Tambo International Airport for the same period and also pointed to no significant statistical trend, although a plot of the seasonal totals suggest a general increase in summer rainfall. Dyson (2009) analysed trends at stations across the Gauteng area and noted a trending decrease in early summer rainfall and an increase in late summer rain. Hence the data relevant to the CoJ municipal boundary need to be analysed with care.

More recently, in their CDP submission, the CoJ (2014) lists among the climate change related risks to include:

- More frequent (storm) rainfall (a serious risk of immediate concern)
- More hot days (a serious risk of immediate concern)
- More intense rainfall (a serious risk of immediate concern)
- Flooding (a serious risk of long-term concern)

Analysing rainfall records at OR Tambo International Airport (1960-2008) in conjunction with observed storm cloud formations, Fatti & Vogel (2011) showed a marked trend of decreasing number of thunderstorms per year. The reduction is significant, with the number of thunderstorms in 2000-2008 being 25% to 50% of the number of events in 1960-1970. In contrast, the average rainfall per thunderstorm event shows an increasing trend, with the average storm rainfall in 2008 being almost 70% greater than that in 1960. However, their study showed that the number of "heavy storm" events (comprising the top 10% of the recorded storms) has been consistent over the period 1960 to 2008. So, there are fewer storms with more rainfall per event, but no meaningful change in the number or magnitude of large events. This implies a significant shift in the magnitude of the lower order events (e.g. possibly including the 2 and 5 year events) but not the larger events.

APPENDIX F: REVIEW OF SEDIMENT CONTROL BMPS

F.1 Background

Setting Limits for Acceptable Sediment Discharge

Sediment levels are measured as Total Suspended Solids (TSS), typically measured in mg/l, but is often also measured by water turbidity, measured in nephelometric turbidity units (NTU). Turbidity is more easily monitored in real time with in-stream sensors and therefore more suitable for detection of pollution or flood incidents, whereas TSS usually requires grab sampling. However, turbidity is not a precise measurement of sediment loads as it can be affected by inorganic and organic loads, algae, and coloured organic compounds that will absorb light.

Targets for discharge limits should be determined by the sensitivity of the receiving stream and any strategic objectives for the stream. These will vary with location, even within a municipality. In the absence of any such requirements, upper limits for general conditions may be assumed. A summary of these limits is presented in Table F1.

In the State of the Rivers report for the City of Johannesburg (Iliso, 2010), the range of median turbidity measurements in streams across the metropolitan area varied between 1.2 NTU to 9 NTU, while the 95-percentile non-exceedance values varied between 9 NTU and 30 NTU. These were spot measurements, typically on a monthly rotation and are unlikely to have been taken during flood events. However, they indicate very low levels of suspended sediment and suggest that normal streamflow across Johannesburg is well within the guidelines in Table F1. The SA Water Quality guidelines state that sediment loads should not vary by more than 10% in ideal conditions.

Table F.1: Summary of water quality guidelines for South African rivers and streams.

Source	Determinand	Unit	Limit	Comment
SA Water Quality Guidelines (DWA, 1996a)	TSS	mg/l	100 50	All aquatic ecosystems. Aquaculture, clear water fish species.
SA Water Quality Guidelines (DWA, 1996a)	Turbidity	NTU	25	Aquaculture, clear water fish species.

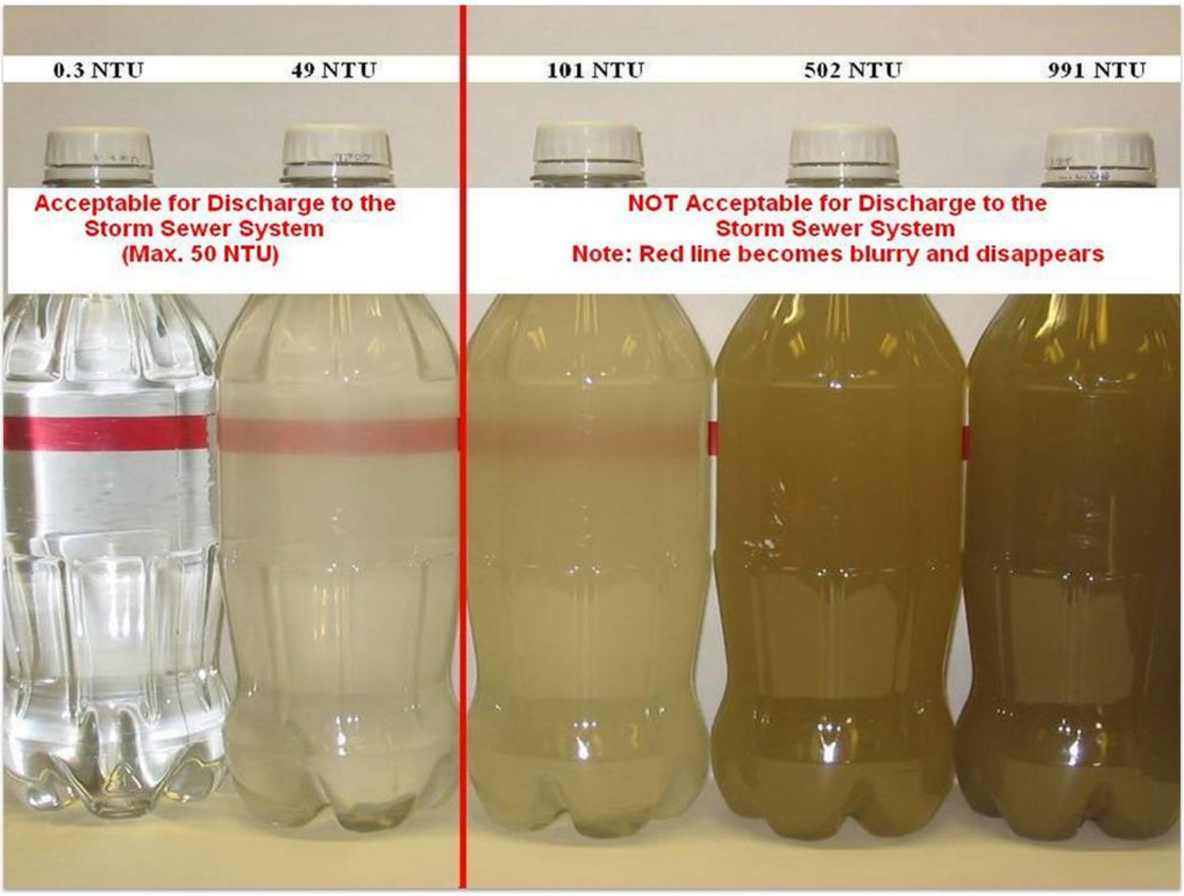


Figure F1: Examples of turbidity (City of Calgary, Canada, 2007)

Flood conditions present a different picture. The reality for many South African watercourses is that sediment loads do vary by considerably more than 10% under flood conditions. Observations at the same location on the Braamfontein Spruit in Johannesburg early in 2015 are shown in Figures F2(a) and F2(b). Under normal flow (Figure F2(a)) the turbidity appears to be in line with the measured 1 to 9 NTU reported in the State of Rivers Report (Iliso, 2010). After a storm event the turbidity levels are well above 500 NTU, and most likely above 1000 NTU (Figure F2(b)). It is not clear what sediment loads would be under natural catchment conditions, and while sediment loads may vary by more than 10%, the conditions in Figure F2(b) are excessive and unacceptable.

The problem is not one for Johannesburg alone and setting limits for allowable sediment discharges have proved contentious internationally. For example, in 2008 the US Environmental Protection Agency (US-EPA) set a limit of 13 NTU for discharge from a construction site greater than 12 ha (30 acres). In 2009 this was adjusted to 280 NTU for sites greater than 4 ha (10 acres) after objections from developers and even sediment control practitioners on the 13 NTU limit. The US-EPA then withdrew the limit entirely in 2010 with the view that further research was required (Forester, 2015).

At present, it is not possible to set sediment discharge limits for sites in Johannesburg based on baseline natural catchment conditions, as these are unknown, and regional research may be required to obtain guideline values. Instead the following interim guideline is proposed in Table F3.2, based on trapping different grades of sediment by a combination of settlement and filtration.

Figure F2(a): Braamfontein Spruit during normal flow with low turbidity (February 2015)

Figure F2(b): Braamfontein Spruit after a storm event showing high turbidity (January 2015)

Many of the soils in the City of Johannesburg area have relatively significant clay content (>15%). Clay particles are difficult to settle in sediment traps and instead require filtration. The latter will be possible for average storm events, but may be difficult for design events (≥2 years). Therefore, treatment of clay particles is (0.002mm dia.) is provisionally limited to daily storm events for construction sites. Higher clay particle trap efficiencies are possible with vegetated drainage systems.

At the other end of the scale, all sand particles ≥0.2mm should be trapped up to and including the 10-year design event, while substantial trap efficiency up to the 20 year event is also identified. Sediment settlement is expected to be the primary treatment method to achieve these targets.

Table F.2: Interim trap efficiency of on-site sediment treatment facilities.

Particle size	Category	Treatment	Trap Efficiency (per design storm event)			
		Primary(1) Secondary(2)	1.01 yr.	5 yr.	10 yr.	20 yr.
≥0.2mm	Gravel, coarse to fine sand	Settlement(1)	100%	100%	100%	90%
≥0.075mm	fine sand	Settlement(1), filtration(2)	100%	100%	90%	65%
≥0.04mm	coarse silt	Settlement(1), filtration(2)	100%	55%	35%	25%
≤0.04mm	medium to fine silt & clay	Filtration(1), settlement(2)	50%	10%	~	~

Trap efficiency is for the design event. This requires testing the system for the same range of design hydrographs required for testing retention and attenuation facilities. If the system design is based on peak flow only, the same targets will need to be achieved even though this will be more conservative. The design of the sediment management system will also require grading analysis of erodible material on site, including soils, excavated areas, stock piles and spoil heaps. Performance of the system will need testing by sampling during storm events.

APPENDIX G: GUIDELINES FOR DATA CAPTURE

G.1 The need for data

In hydrological and hydraulic studies among the first of the enquiries would focus on the availability of measured data for the site (or catchment) and the rainfall events. The availability of data significantly improves the certainty of stormwater designs. Where data is limited, and hydrological analysis reverts to, for example, empirical methods and published guidelines for parameters, the resulting design becomes increasingly uncertain, impacting on risk and cost.

In earlier decades when data availability and computing capability were more limited, stormwater engineers were assisted by researchers and some municipalities who provided guideline data for hydrological and hydraulic parameters (e.g. soil data, Manning's resistance coefficient) and design rainfall (e.g. depth-duration-frequency curves). Over time many of these have never been updated, or adapted for local applications, yet they have become entrenched in stormwater design practice. Of greater concern is that many practitioners in stormwater design are ignorant of the implications of always reverting to their adopted references instead of first investigating the availability of relevant local data that will decrease the uncertainty in the design.

G.2 Objectives for stormwater design in the City of Johannesburg

This Manual seeks to set a minimum standard for the capture and use of data in stormwater designs, as well as provide guidelines for the long-term development of key hydrological information the city will need to manage and improve stormwater resources.

The minimum standards will be a work-in-progress. Initially they will recognise publicly available data as well as set out minimum requirements for site investigations. Over time, through research and feedback from stormwater management plans, guideline parameters for specific application in the municipal area may be introduced.

The long-term development of key hydrological information will relate more to stream flow, rainfall and other climate records. These are not only critical to sustainable stormwater management, but are also critical to the City's requirements for climate change and water security adaptation measures. The guidelines in this chapter will assist the City to develop a programme of weather and runoff monitoring which will include working with public and private institutions where possible.

> Responsibilities:
>
> It is important that all stormwater planning and design are based on a common set of data. The City of Johannesburg undertakes to review and update the recommended sources of data presented in this section, and will publish updated from time to time.
>
> However, it is the responsibility of the design engineer to ensure that the best available data is used. The designer is entitled to recommend more appropriate alternative data, suitably motivated, in the Stormwater Report.

G.3 Variable stormwater conditions across the City

Understanding the variable nature of the weather and physical conditions across the metropolitan area of the City of Johannesburg is important for stormwater planning and design (Figure G.1). The location of the site should acknowledge the following:

A. Primary catchment, terrain, slope, aspect.
B. Geology.
C. Original soil conditions (type, depth, land type).
D. Rainfall.

Stormwater design should acknowledge the conditions at the site location and how these are likely to influence storm runoff responses. This will also help guide the scope of field investigations for data capture. For example, infiltration solutions (and potential risks) are likely to be different on granite and dolomitic geologies. Hill slope seep (and therefore potential SuDS solutions) will vary between steeper and flatter terrains.

Sources for general baseline data for the City will be published by the City of Johannesburg and updated from time to time. The use of these is outlined in the sections below.

G.4 Rainfall data

Single event design rainfall data

The design rainfall extraction utility developed by Smithers and Schulze (2002) is to be used for stormwater design in the City of Johannesburg. This utility enables the user to extract design rainfall depths for a range of durations (5 minute to 7 days) and return periods (2 to 200 years) for a given location determined by coordinates. The report and software are freely available from the Water Research Commission.

Rainfall records

There are sufficient rainfall records available for the City area for both independent statistical analysis and for the purposes continuous simulation hydrological modelling of stormwater systems. The location of suitable weather stations is presented in Figure G.2. The stations maintained by the South African Weather Service (SAWS) include a mixture of daily, hourly and 5 minute recording stations. The hourly and 5 minute records are best for stormwater design, while the daily records are suitable for water balance analyses. A summary of the SAWS stations is given in Table G.1.

The TAHMO stations are independently operated and will supply data to the City under license. The stations will provide a range of weather data, including rainfall, all recorded at 5 min intervals. The first of these stations were established in 2017, so it will take a few years before the record lengths will be suitable for most stormwater design operations. However, the TAHMO stations will be particularly useful for analysis of specific storm events (see below) and model calibration.

It is intended that all weather data for stormwater design will be sourced via the City of Johannesburg. Data costs may apply depending on license agreements with both SAWS and TAHMO. Until these are finalised, the SAWS data should be used and procured directly from SAWS.

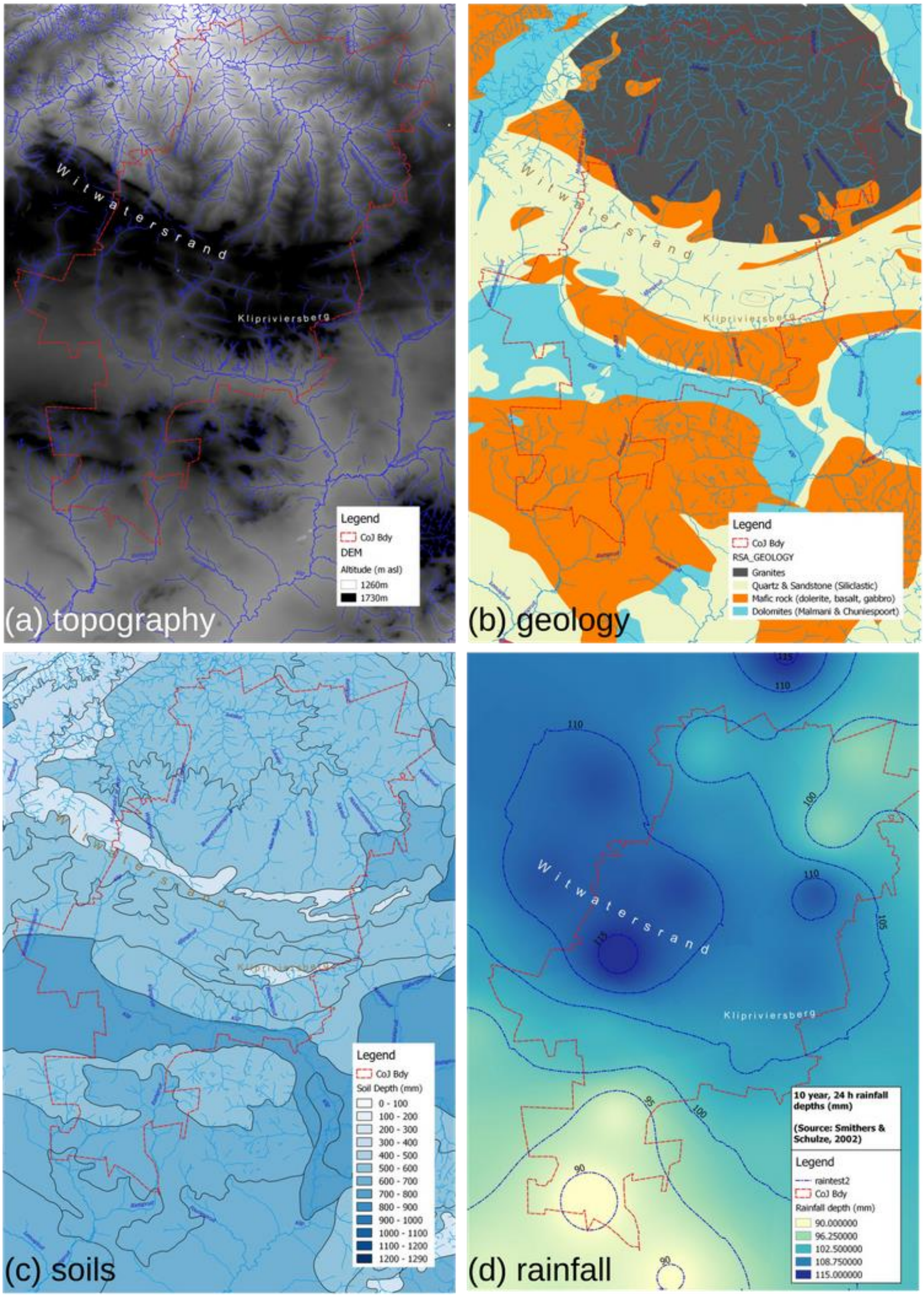


Figure G.1 Examples of variability of conditions across the CoJ area.

Guidelines for the selection and use of weather station data specific to the City's conditions will be developed in time, though it is expected that stormwater designers will have the necessary design hydrology experience suitable for the level of design being undertaken. Initial guidelines are given below.

- The recommended record length for statistical analysis is the full record at a station. Nearby stations with longer records should also be considered.
- The recommended minimum record length for continuous simulation is 20 years of record. The most recent period should be obtained for design purposes.
- Where the nearest station provides only daily records, it is recommended that records are also used from the nearest 5 minute or hourly recording station to test the hydraulic performance of the stormwater network under more realistic storm intensity conditions.
- Selection of station(s) should consider factors such as distance from site, whether north or south of the Witwatersrand, and location in the catchment (e.g. in the upper or lower reaches of the primary catchment). Locations similar to the project site should be given priority.
- It is also recommended that SuDS systems and complex stormwater networks are tested under a 5 minute data set from one of the stations with reasonable record length. For this reason, the station at OR Tambo International Airport and Grand Central Airport (now closed) are included in the list of recommended stations.

Table G.1: SAWS Weather Stations

SAWS STATION NAME	Lat	Long	Start	End	Years	Recording
JOHANNESBURG_LEEUKOP	-26.0032	28.0461	1951	current	66	Daily
JOHANNESBURG-ZOOLOGICAL_GARDNS	-26.1685	28.0376	1915	current	102	Daily
JOHANNESBURG–TURFFONTEIN	-26.2347	28.0421	1909	current	108	Daily
JOHANNESBURG_SANDTON_ARS	-26.1026	28.0690	1971	current	46	Hourly
ALEXANDRA_DEPOT–ARS	-26.1088	28.1130	2011	current	6	Hourly
JOHANNESBURG_INT_WO	-26.1430	28.2346	1953	current	64	5 min
ZUURBEKOM_AWS**	-26.3008	27.8136	1960	current	57	Hourly/5min
WALTER_SISULU_NAT.BOT_GARDNS	-26.0800	27.8500	2000	current	17	Hourly
DOBSONVILLE_ARS	-26.2232	27.8626	2011	current	6	Hourly
ROODEPOORT–KLOOFENDAL	-26.1308	27.8799	2017	current	0	Daily
GOUDKOPPIES_ARS	-26.2715	27.9265	1990	current	27	Hourly
JHB_BOT_TUINE	-26.1566	27.9991	1985	current	32	5 min
GRAND CENTRAL			2003	2015	12	5 min

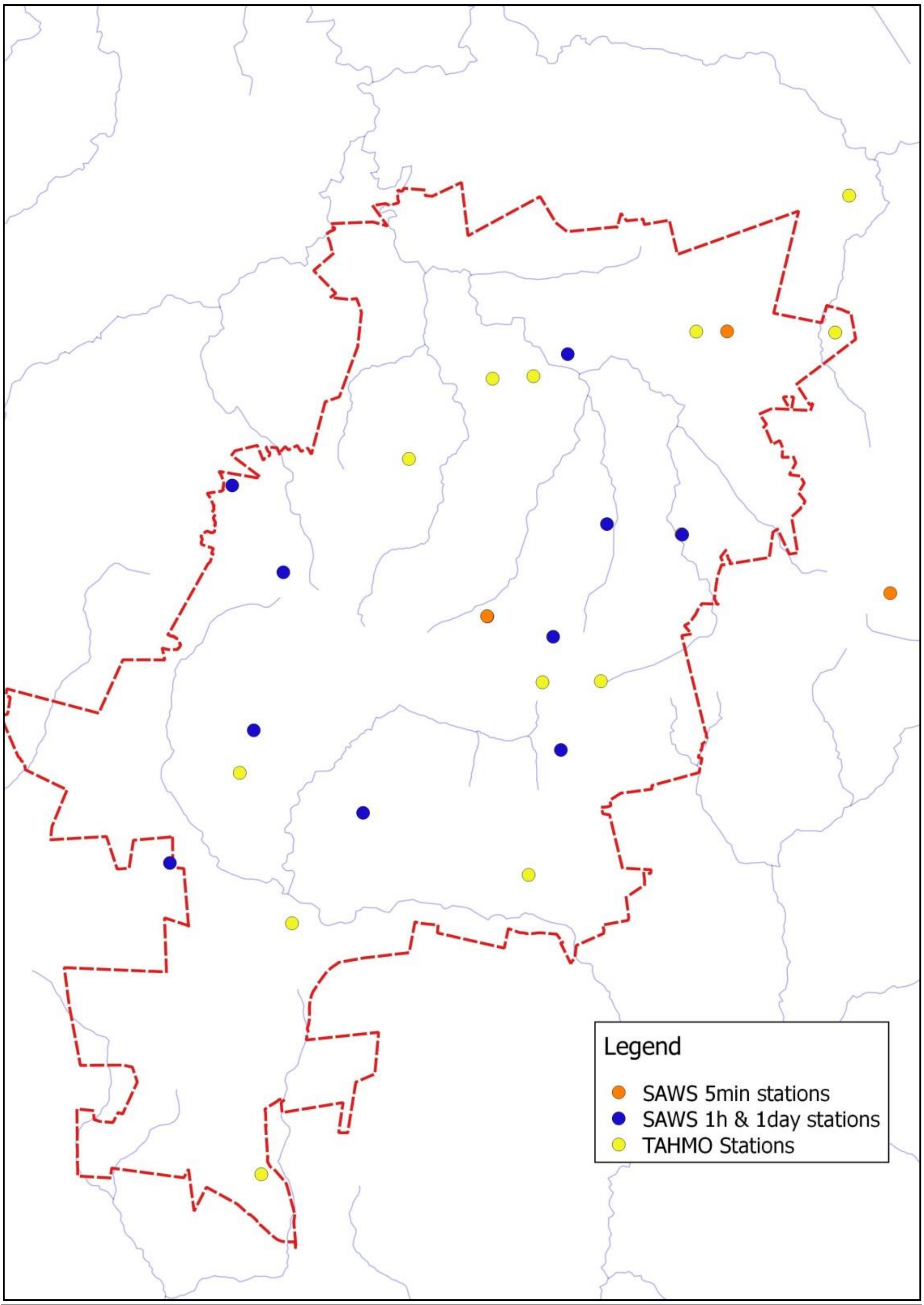


Figure G.2: Weather stations suitable for stormwater design.

Site rainfall records

It is recommended that developers establish rain gauges at site as soon as possible. This is a requirement for the construction phase, but it should be implemented earlier in the planning and design, and should ideally continue after construction is completed and the development is operational. This will improve design confidence (if implemented early), but importantly will assist in the long-term monitoring of the performance of the stormwater network.

At this stage, this is not a requirement for the approval of the site development plan and Stormwater Report.

G.5 Flow data

Pre-development runoff estimation

Runoff coefficients for single storm event analysis will depend on undisturbed soils conditions which should be estimated from the Land Type reports published by the Agricultural Research Council: Institute for Soil, Climate and Water (ARC-ISCW, see below). Land cover will be Highveld Grassland (see below). Other factors such as slope will be determined from site measurements (topographical surveys, etc.). The designer is advised to present the pre-development site runoff coefficient(s) as a range, and to then recommend a value for the site. If in doubt, the City may adopt a more conservative value in the range.

Site runoff under continuous simulation will be measured against the MAR/MAP ratio presented in WR2012 (Bailey and Pitmen, 2015) for the quaternary catchment in which the site is located. These vary between 3% (0.03) and 7% (0.07) for the City area. Any deviation from the given quaternary natural flows will require motivation by the design engineer.

Streamflow data

The City of Johannesburg will be establishing a network of flow measurement stations in the primary streams and rivers in the main catchments. The provisional location of the gauging stations will be at existing weir of bridge structures in the lower reaches of the primary catchments as shown in Figure 3. In the short-term, records from these stations will be useful for storm event calibration for design at a site. As the length of flow records increases the data will also benefit flood analysis and water resource assessments.

On-site flow measurement

It is currently optional, but recommended that flow measurement be considered and established in the receiving stream early in the site planning and design stages of a development. This would especially apply to sites larger than $8000m^2$ discharging to natural streams and watercourses.

The purpose would be to establish a measure of the low level and post-storm flow conditions in the receiving environment which will help the design of any proposed slow release of retained stormwater from the development. It would also assist the stormwater engineer to defend solutions that do not comply with standard regulations but where a better environmental solution is being proposed.

Flow measurement requirements will depend on local conditions but may take the form of continuous (water level) data logging, a temporary 'V' notch weir, or regular flow measurements with hand-held flow measurement units. Flow measurements could be coupled with water quality sampling in the receiving stream.

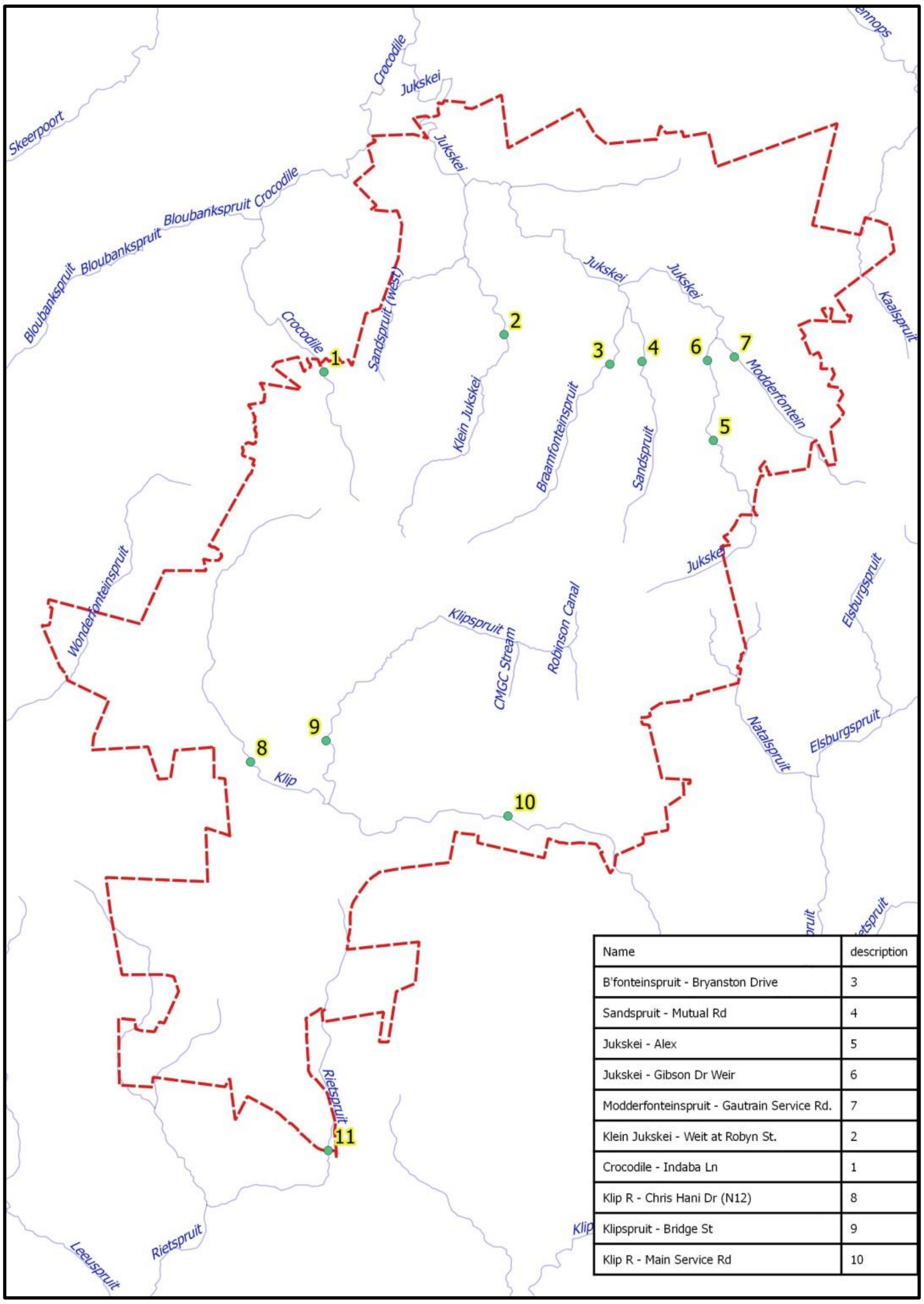


Figure G.3: Provisional location of flow gauging stations.

G.6 Soils and geological data

Design of infiltration and stormwater treatment systems for SuDS, and for erosion control and sediment management facilities require an understanding of the local soils and geology. Preliminary planning and concept design may utilise published references, but detailed design requires site investigation. Ideally the latter is an extension of the geotechnical site investigation for the development, but participation of the stormwater designer in the field investigations are important. In addition to determining the design requirements for stormwater facilities, the designer needs to ensure the structural integrity of other structures and services, as well as neighbouring properties, are addressed in the stormwater design.

Precautionary approach:

Without sufficient tests to confirm on-site soils and geology, the worst case conditions shall be adopted for design.

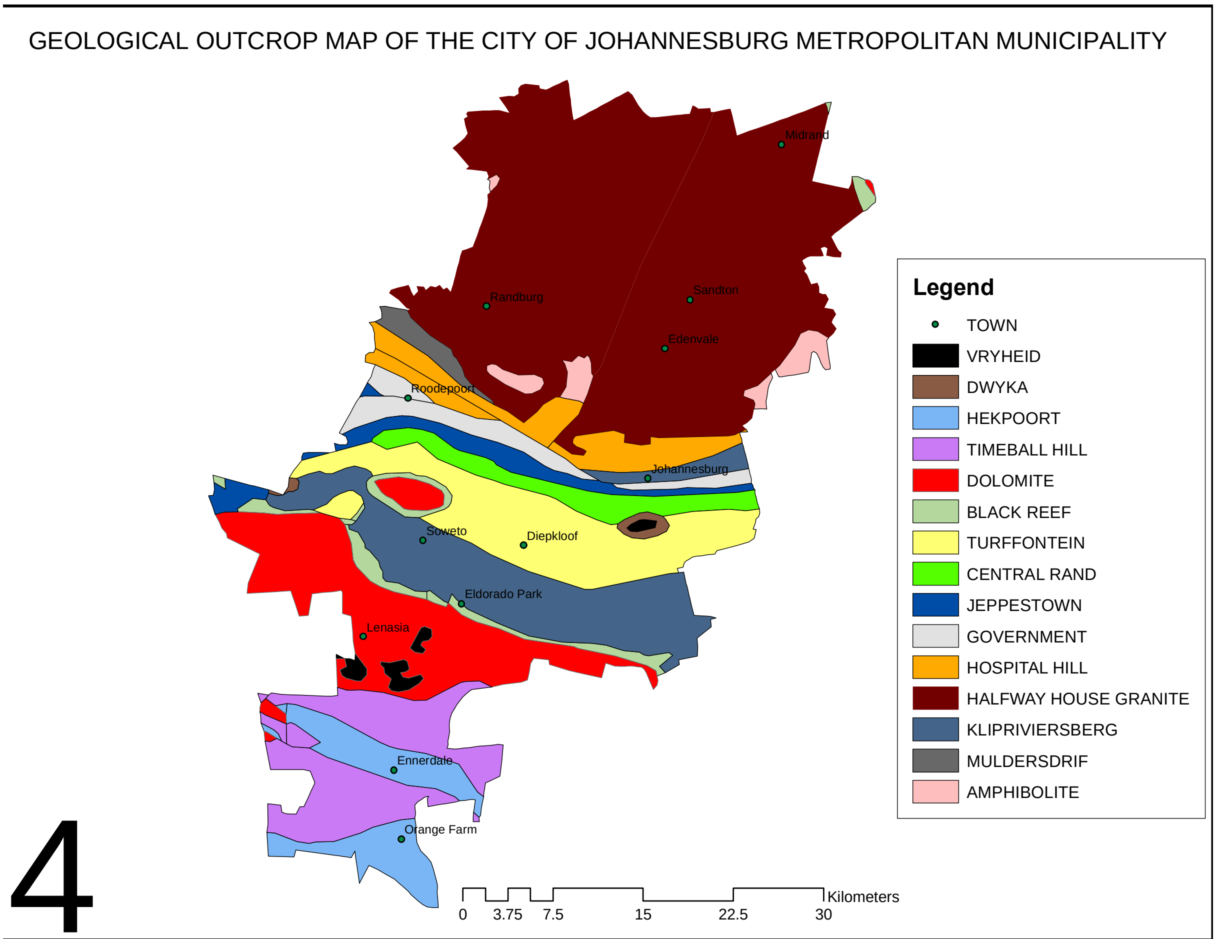


Figure G.4 Geological outcrop map

G.7 Planning data

For initial planning and concept design, the designer may use published data and data sets. Those listed below will be accepted by the City, but the designer may recommend other data sets if more detailed or up-to-date information is available. The following data is available in GIS (shapefile) formats from the organisations concerned.

Soils: Use the inventories published by the Agricultural Research Council: Institute for Soil, Climate and Water (ARC-ISCW, 2006).

Geology: Use either of the simplified or detailed geology data sets for the country as published with WR2012 (Bailey and Pitman, 2015).

Design data: soils

The soils conditions specific to the site need to be determined for design purposes. In most cases they are likely to be disturbed from the pre-development condition. The standard geotechnical site investigations and tests will provide much of the information needed for assessment of infiltration potential, risk of groundwater contamination, subsurface stormwater flows and risk to structures, and erosion control and sediment management. The typical tests that need to be considered are summarised in Table 2. It is strongly advised that the stormwater engineer inspects samples and trial pits while the geotechnical engineer is on site and directs the latter on the tests required.

Design data: Geology

Local geology may influence the selection of stormwater management facilities. Depth to bedrock or impervious layers (e.g. hardpan and perched water table conditions) are important in designing infiltration and/or recharge systems, ensuring groundwater protection and ensuring against damage to the foundations of adjacent structures and services. Designers should work with a geotechnical engineer to determine the necessary tests specific to a site.

Planning and designing unlined stormwater systems on sites over dolomites should be done in consultation with a specialist engineering geologist.

Table G.2: Typical soil tests for stormwater design.

Test	Purpose
Soil profiling	SUDS planning & design.
Soil grading analysis	Sediment & erosion analysis
Bulk density	Porosity (soil water storage potential)
Specific gravity	Sediment trap efficiency
Plasticity Index	Erosion risk,
Permeability test (undisturbed sample)	Infiltration design, pollution risk.
Water table (level and quality sample)	Resource risk, structural protection, recharge potential.
On-site soak-away tests (Full soak-away tests (e.g. BRE, 2016) are recommended above other methods such as double or single ring infiltrometer tests.)	More accurate testing of local infiltration capacity. Testing multiple events.

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