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ENGINEERING IN CIVIL ENGINEERING

# Quantifying stormwater pollutants and the efficacy of Sustainable Drainage Systems on the R300 highway, Cape Town



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## Declaration

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Signed: Abby Robertson Date: 28-Feb-17

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## Abstract

Stormwater provides a direct link between urban infrastructure and the urbanised natural environment. In particular, highway drainage presents a high risk of pollution when compared to other urban land use areas (Ellis *et al.*, 2012); introducing heavy metals, suspended solids and hydrocarbons to urban waterways.

This research investigated runoff from the R300 highway, located in the greater Cape Town area. The City of Cape Town Management of Urban Stormwater Impacts Policy requires the treatment and attenuation of stormwater from developments within the city, and proposes Sustainable Drainage Systems (SuDS) as a means to achieve this (CSRSM, 2009b). SuDS are structural and process controls that attenuate surface drainage, improve runoff water quality, provide amenity and deliver ecosystem services. This study characterized the R300 runoff through a sampling program and modelling exercise in order to provide an indication of the ability of SuDS to manage highway runoff in South Africa.

Sediment and runoff samples were collected from the road surface and an undeveloped parcel of land adjacent to the highway. The sampling results showed that heavy metals, suspended solids and phosphorus are present in significantly greater concentrations in road runoff compared to rainwater from the same area. The concentration of aluminium, copper, lead, zinc and phosphorus exceed the Department of Water and Sanitation's water quality guidelines for aquatic ecosystems in excess of 1000%. The concentration of heavy metals, phosphorus and fats, oils and greases was significantly greater in road sediment compared to sediment from the surrounding area. Barring copper, all contaminant concentrations in the road surface sediment are less than the maximum concentration required to protect ecosystem health.

The R300 rainfall-runoff response was modelled in PCSWMM to evaluate the performance of SuDS such as infiltration trenches, bioretention areas and swales for managing highway runoff in terms of quantity and quality. The modelling exercise showed SuDS to be a viable means to attain the City of Cape Town's stormwater objectives, provided that SuDS are implemented in treatment trains along the entire road length.

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## Acronyms and abbreviations

AADT	Annual average daily traffic
AEV	Acute Effect Value
CoCT	City of Cape Town
COD	Chemical oxygen demand
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation
EMC	Event mean concentration
GIS	Geographic Information System
HC	Hydrocarbons
LOD	Limit of detection
MAP	Mean annual precipitation
NEMWA	National Environmental Management Waste Act
O&G	Oils and greases
PAH	Polycyclic aromatic hydrocarbon
PET	Polyethylene terephthalate
PGM	Platinum group metals
RI	Recurrence interval
SANRAL	South African National Roads Agency Limited
SD	Standard deviation
SRTC	Sensitivity-based radio tuning calibration
SuDS	Sustainable Drainage Systems
SWMM	Storm Water Management Model
TP	Total phosphorus
TSS	Total suspended solids
TWQR	Target Water Quality Range
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compound
WSD	Water Sensitive Design

# 1. Introduction

## 1.1 Background

The approach to urban water management in South Africa is changing due to an increase in environmental awareness and in response to the additional burden placed on water services by rapid urbanisation (Carden *et al.*, 2009). Water Sensitive Design (WSD) is an approach that integrates the urban water cycle into urban design to develop adaptive systems that prioritise water management alongside traditional infrastructure (Ward *et al.*, 2012). Stormwater is an important link in the urban water cycle that forms a connection between urban infrastructure and the urbanised natural environment. Preserving waterways is a key mechanism to create liveable space and to provide ecosystem services in the urban environment.

Highway drainage is a significant source of pollution such as suspended solids, heavy metals and hydrocarbons to urban waterways. It presents the highest risk of pollution to receiving waters when compared to other urban land use areas (Ellis *et al.*, 2012). Urban highway runoff conveys chronic and shock pollution loads to receiving waters in concentrations that cause toxic effects in aquatic species (Sartor *et al.*, 1974). Pollution threatens over 60% of South Africa's river ecosystems (Hedden & Cilliers, 2014). Surface water pollution affects the human population too, and the Department of Water and Sanitation (DWS) has identified pollution as one of the major threats to water provision in South Africa (DWS, 2013).

Highway drainage systems are traditionally designed to ensure road user safety and pavement integrity by removing stormwater runoff from the road surface rapidly, with little (if any) focus on ecosystem preservation (Marsalek & Chocat, 2002). The resulting surface water drainage systems concentrate runoff flows, accumulate pollutants from the road surface and deposit the contaminated runoff into receiving waters causing erosion, siltation and pollution.

The Drainage Manual (SANRAL, 2013a), which provides South African road drainage guidelines, only requires stormwater flow (quantity) management. There are, however, documents and policies such as the City of Cape Town Management of Urban Stormwater Impacts Policy (CSRM, 2009b) and the South African Guidelines for Sustainable Drainage Systems (Armitage *et al.*, 2013b), which assist and enable engineers to implement holistic stormwater drainage solutions. Both documents propose Sustainable Drainage Systems (SuDS) as a solution for stormwater management. This umbrella term describes drainage systems that attenuate surface drainage and improve water quality through structural and process controls. SuDS aim to protect water courses in and downstream of the urban environment, and to manage stormwater locally, as opposed to directing it in concentrated flows to established water channels (Scholes *et al.*, 2008).

## 1.2 Research needs

There is a large international body of work describing the impacts and water quality characteristics of highway runoff (Sartor *et al.*, 1974; Deletic, 1998; Legret & Pagotto, 1999; Khan *et al.*, 2006; Opher & Friedler, 2010; Barbosa *et al.*, 2012). Highways are identified as a significant source of non-point pollution. Pollutant composition, concentrations and total pollutant loads are site specific, with a wide range of reported values.

Several papers suggest SuDS, including swales, bioretention areas and permeable pavements, as treatment devices for the management of highway runoff (Yousef *et al.*, 1987; Ellis *et al.*, 1994; Shutes *et al.*, 1999; Terzakis *et al.*, 2008). The treatment capacity of SuDS solutions depends on environmental factors such as local climate, topography, underlying geology and system maintenance, as well as design specific factors such as system sizing, configuration, soil type and plant species characteristics *inter alia*. Consequently, it is evident that stormwater contamination and treatment is region and site specific. This indicates a need for data detailing stormwater characteristics and the performance of SuDS under local conditions.

The City of Cape Town (CoCT) Management of Urban Stormwater Impacts Policy requires the treatment and attenuation of stormwater from developments within the city and proposes SuDS as a means to achieve this (CSRM, 2009b). The extent of pollution emanating from local highways, and the ability for SuDS to treat this runoff to acceptable levels under local conditions is unknown.

This investigation responded to the research need by implementing a sampling program and modelling exercise to characterise local highway runoff. The sampling program consisted of a series of grab samples to provide primary data on road runoff contamination by analysing stormwater and surface sediment for heavy metals, nutrients and hydrocarbons. The modelling exercise addressed alternative SuDS designs appropriate for brownfield road developments to determine whether it is likely that SuDS can provide the required treatment within the limited space afforded in the road reserve of an urban highway.

## 1.3 Research question

The scope of this study is limited to a case study on the R300, a regional six-lane dual carriageway highway in the greater Cape Town area. The research hypothesis is that:

*Surface runoff from the R300 is problematic in terms of water quantity and water quality. The drainage has been designed according to standard procedure, which does not attempt to ameliorate peak flows or runoff quality. The system conveys storm peaks off the road maintaining user safety, but there are areas along the R300 where drainage capacity and surface flow is problematic. The surface runoff water contains metals and hydrocarbons in concentrations exceeding the target standards for aquatic ecosystems set down by the Department of Water and Sanitation.*

*Furthermore, the existing drainage infrastructure does not achieve the suspended solids and nutrient removal targets set down in the City of Cape Town in the Management of Urban Stormwater Impacts Policy. SuDS provide a reasonable means to manage the stormwater runoff from the R300 to ensure sufficient water quantity management and ameliorate water quality to the required standards.*

Key research questions for this study are thus:

- What are the primary contaminants in the R300 surface runoff water?
- What is the range of concentrations in the R300 runoff water and how does this compare to the water quality requirements set down by local and national government?
- What SuDS alternatives are suitable for road drainage on the R300?
- What is an estimate of the peak flow reduction and pollutant removal capacity for various SuDS scenarios?

## 1.4 Report layout

This dissertation consists of seven chapters, a reference list and appendices. An overview of the content of each chapter is provided below.

**Chapter 1** introduces the research, grounding highway drainage in the context of urban water management. The research aims, hypothesis and key questions are provided.

**Chapter 2** presents a review of the literature relating to road drainage design, surface water contamination, Sustainable Drainage Systems and stormwater modelling.

**Chapter 3** begins with a description of the research site. The traffic characteristics, current drainage issues, and operations and maintenance on the R300 are then discussed.

**Chapter 4** details the sampling exercise undertaken for this research. The sampling procedure is described, and the results are provided with a discussion of the method's limitations.

**Chapter 5** details the modelling exercise conducted for this research. The data collection, simplifying assumptions and the alternative modelling scenarios are provided. This is followed by a discussion of the results and limitations.

**Chapter 6** presents a summary of the research findings.

**Chapter 7** provides recommendations for further research.

The **Appendices** provide supporting documentation including calculations, analysis reports and additional resources.

## 2. Literature review

### 2.1 Introduction

This chapter provides an overview of the literature relating to road drainage. It commences with an introduction to the current drainage design practices and the legislative context in South Africa. There is a detailed discussion on surface water contamination, followed by an overview of modern drainage systems that provide holistic stormwater management. Lastly, stormwater modelling is discussed as a means to evaluate the performance of surface drainage systems.

### 2.2 Road drainage design

The provision of water services is fragmented across South African governance structures and stormwater management often falls under the ‘roads and stormwater’ branch; separate from potable water, sanitation and solid waste management (Armitage, 2011). Road drainage design traditionally addresses water quantity requirements with the objective of rapidly removing water from the road environment.

The Drainage Manual (SANRAL, 2013a), the primary reference for road drainage design in South Africa, describes road drainage systems as structures to limit the risk to road users, road structures and the environment. The accumulation of runoff on the roadway is the primary risk addressed by the recommended design solutions. The environmental concerns referred to in the Manual are limited to erosion control and flood mitigation. The recommended design solutions include combinations of kerbs, berms, conveyance channels and inlet and outlet structures. While successful in maintaining road user safety and pavement integrity, this design approach does not lead to Water Sensitive Design, nor facilitate the implementation of Sustainable Drainage Systems (see Section 2.5).

Internationally, the SuDS approach is increasingly recognized as best practice to realise holistic stormwater management (Marsalek & Chocat, 2002). Several WSD and SuDS manuals and guidelines have been published to assist engineers in designing sustainable stormwater infrastructure. Salient documents informing best practice in road drainage design include:

- The South African Guidelines for Sustainable Drainage Systems (Armitage *et al.*, 2013b)
- Water Sensitive Urban Design (WSUD) for South Africa: Framework and Guidelines (Armitage *et al.*, 2014)
- Alternative Technology for Stormwater Management: Report and South African Case Studies (Armitage *et al.*, 2013a)
- The SuDS Manual (Woods-Ballard *et al.*, 2007b)
- SUDS for Roads (Pittner & Allerton, 2009)

## 2.3 Legislation

South Africa is governed on three principal levels: national, provincial and local administration. Legislation is issued by the respective bodies in line with this hierarchical structure. The Department of Water and Sanitation's Water Quality Guidelines recognise that aquatic ecosystems provide services to people by providing aesthetically pleasing environments, recreational space, livelihood where people depend on water body for food and (potable) water, and maintain biodiversity (DWS, 1996). The DWS requires effluent to be treated before it is returned to natural water courses as a precautionary approach so that active measures are taken to minimise potential risks of negative impacts on the environment. There are, however, currently no national or provincial policies for pollutant removal from stormwater, and stormwater management is regulated at a local level. The following national legislation has an indirect bearing on stormwater management across South Africa:

- *National Water Act, No. 36 of 1998*
- *National Building Regulations and Building Standards Act, No. 103 of 1977*
- *National Environmental Management Act, No. 107 of 1998*
- *National Environmental Management: Biodiversity Act, No. 10 of 2004*
- *National Environmental Management: Protected Areas Act, No. 57 of 2003*

The City of Cape Town has a number produced local bylaws and policies governing the management and disposal of stormwater in the city, namely: the CoCT Stormwater Management Bylaw (CoCT, 2005), the Management of Urban Stormwater Impacts Policy (CSRSM, 2009b) and the Floodplain and River Management Policy (CSRSM, 2009a). Collectively, these policies aim to *ensure sustainable development and associated activities within or adjacent to natural and built stormwater systems, and that there is a balanced consideration of potential flood risk, environmental impacts and socio-economic needs*. Additionally, the City aims to *reduce the impact of flooding on community livelihoods and regional economies and safeguard human health, protect natural aquatic environments, and improve and maintain recreational water quality* (CSRSM, 2009a).

The Stormwater Management Bylaw (CoCT, 2005) defines the stormwater system *as both the constructed and natural facilities, including pipes, culverts, watercourses and their associated floodplains, whether over or under public or privately owned land, used or required for the management, collection, conveyance, temporary storage, control, monitoring, treatment, use and disposal of stormwater*. Furthermore, it prohibits activities that may have a detrimental effect on stormwater management such as the disposal of household waste into the stormwater system, illegal dumping near watercourses, infilling floodplains or disposing of wastewater via the stormwater system.

The Management of Urban Stormwater Impacts Policy (CSRM, 2009b) recognises urban water bodies as a valuable resource that should be optimised by introducing Water Sensitive Design principles to stormwater management within the City. The policy states the following objectives: to improve quality of stormwater runoff, to control quantity and rate of stormwater runoff and to encourage natural groundwater recharge. The policy typically requires an 80% reduction in total suspended solids (TSS) and a 45% reduction in total phosphorus (TP) of the annual stormwater pollutant load for existing and new developments. All developments are required to trap litter, oil and grease at source. Furthermore, the policy requires the protection of downstream channel stability, the prevention of frequent downstream flooding and the protection of floodplains from adverse impacts of extreme floods through stormwater detention and the reduction of peak flows. To this effect, the policy requires 24-hour extended detention of a 1 year return interval (RI), 24-hour storm event and the reduction of the 10 year RI peak flow to the pre-development level. The full criteria are provided in Appendix A.

## **2.4 Surface water contamination**

### **2.4.1 Pollutants in highway runoff**

Stormwater runoff from highways contains a variety of contaminants including: TSS), heavy metals, oils and greases (O&G), biodegradable organic matter, organic micro pollutants (including hydrocarbons), pathogenic organisms and nutrients (Legret & Pagotto, 1999). A large percentage of roadway pollutants are inorganic compounds such as sand and silt (Sartor *et al.*, 1974). Biodegradable organic matter, pathogenic microorganisms and nutrients are not generated in significant quantities in the road reserve (Barbosa *et al.*, 2012). The pH of highway runoff ranges between 6.3 – 7.9 and is typically near neutral (Legret & Pagotto, 1999).

Suspended solids are the most common constituent in highway runoff (Kayhanian *et al.*, 2007). Fine suspended particles (<200µm) transport pollutants such as heavy metals and hydrocarbons, and account for a large portion of the overall pollution potential (Sartor *et al.*, 1974; Vaze & Chiew, 2002). Several studies report a strong correlation between total suspended solids and heavy metal concentrations (Shinya *et al.*, 2000; Han *et al.*, 2006; Desta *et al.*, 2007).

Copper, iron, lead and zinc are the most commonly reported heavy metals found in highway runoff waters (Opher & Friedler, 2010). The concentration of lead has decreased worldwide with the introduction of unleaded fuel (Khan *et al.*, 2006), and current reported values are approximately 10% of those reported prior to the 1970s (Opher & Friedler, 2010). Other widely reported metals include cadmium, chromium, magnesium and nickel (Göbel *et al.*, 2007). Platinum group metals; platinum, palladium and rhodium, are found in road sediment in decreasing concentrations with distance from the road surface (Schäfer & Puchelt, 1998).

Organic matter such as oils and greases, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) are a common constituent in highway runoff waters. Organic substances originate from vehicle fluids such as oils, fuel, brake fluid, wear and tear of

rubber elements and engine emissions (Legret & Pagotto, 1999). PAHs are created by incomplete engine combustion; with the highest emission rate generated by accelerating vehicles (Göbel *et al.*, 2007). PAHs consisting of more than three benzene rings are considered carcinogenic or mutagenic, and are recognised as chemicals of emerging concern (Nieuwoudt *et al.*, 2011).

Biodegradable organic compounds stimulate bacterial growth in receiving waters, and the oxygen consumed during the breakdown of these substances depletes the dissolved oxygen in the water body threatening the aquatic environment (Khan *et al.*, 2006).

Pollutant concentration is often reported as an event mean concentration (EMC) value, which is a flow-weighted average concentration. Göbel, Dierkes & Coldewey (2007) compiled data from over 300 field surveys to provide a summary of pollutant EMCs in urban runoff. Table 2-1 provides the EMCs for selected contaminants in highway runoff.

**Table 2-1: Reported EMCs of selected highway runoff contaminants**  
(adapted from Göbel, Dierkes & Coldewey, 2007)

Parameter	Unit	EMC <sub>MIN</sub>	EMC <sub>MAX</sub>	EMC <sub>MEAN</sub>
pH	-	6.4	7.9	7.4
TSS	mg/l	66	937	153
COD	mg/l	63	146	107
TP	mg/l	0.23	0.34	0.20
NH <sub>4</sub>	mg/l	0.5	2.3	0.5
NO <sub>3</sub>	mg/l	0	16	2.5
Cd	µg/l	0.3	13	3.7
Zn	µg/l	120	2000	345
Cu	µg/l	97	104	65
Pb	µg/l	11	525	224
Ni	µg/l	4	70	27
Cr	µg/l	6	50	13
Na	mg/l	5	474	194
Mg	mg/l	1	1.4	5
Ca	mg/l	14	57	37
Σ <sub>16</sub> PAH	µg/l	0.2	17.1	2.6

Where COD = chemical oxygen demand

## 2.4.2 Pollutant sources

Pollutant sources include pavement degradation, corrosion of roadside barriers and signage, construction and maintenance activities, atmospheric deposition, fuel and vehicle lubricants, vehicle wear and tear and other anthropogenic wastes (Legret & Pagotto, 1999). Table 2-2 summarises the mechanisms through which vehicles contribute major pollutants to runoff pollution.

**Table 2-2: The primary mechanisms by which vehicles produce major pollutants**  
(after Legret & Pagotto, 1999; Opher & Friedler, 2010)

Mechanism	Major pollutants
Leakage of fuel, hydraulic fluids, lubricants and coolant	O&G, HC, Cd, Cr, Cu, Ni, Pb, Zn
Wear and tear of tyres, clutch and brake linings	Pb, Cu, Cd, Zn
Exhaust emissions	HC, CO, NO <sub>x</sub> , SO <sub>2</sub> , PAHs, PGMs
Dirt, rust and substances dropped from the undercarriage	Miscellaneous

Where: HC = hydrocarbons, PGMs = platinum group metals

Pollutants contributed through atmospheric deposition are largely dependent on surrounding land use. The pollutant settling rates depend on the atmospheric constituent concentration, ambient conditions such as wind speed and the physical properties of each substance (Murphy *et al.*, 2014). Atmospheric deposition is cited as a main source of cadmium, mercury and VOCs in highway runoff waters (Opher & Friedler, 2010).

Roadside structures such as lamp posts, signage, safety barriers and guardrails contribute metals to runoff waters through corrosion. In a laboratory study, rain water removed 950g/km/year of zinc from a galvanised steel safety barrier (Legret & Pagotto, 1999).

## 2.4.3 Factors influencing concentration

Pollutant concentration is influenced by various factors relating to the site, climate and traffic characteristics. Research aimed at identifying explanatory variables has revealed that there are no simple relationships between runoff pollutant concentration and physical characteristics.

Rainfall intensity and duration are the primary parameters pertaining to runoff pollutant concentration. Rainfall intensity is positively correlated with an increase in runoff pollutant concentration as higher intensity storm events have greater energy for removing particles from the road surface (Egodawatta & Goonetilleke, 2008). Total pollutant load increases with increasing storm duration; although no fixed relationship between duration and runoff concentration has been identified (Crabtree *et al.*, 2006). Climatic conditions such as temperature, humidity, wind and exposure to sunlight may accelerate or decelerate processes such as oxidation and volatilization of various pollutants (Opher & Friedler, 2010).

There are conflicting findings as to whether there is a correlation between antecedent dry days and the concentration of pollutants in highway runoff (Opher & Friedler, 2010). The antecedent dry days preceding a storm event allow for pollutant buildup and decomposition. Deletic & Maksimovic (1998) found antecedent dry days to have no significant effect on pollutant concentrations, yet correlate with an increase in runoff conductivity. This is due to the physical and chemical breakdown of pollutants on the road surface by tyre action and sunlight *inter alia*. Vaze & Chiew (2002), however, found that antecedent storms loosen more pollutants from the road surface than is removed by the runoff, leaving additional material available for washoff in the subsequent rainfall event. This shows that antecedent storms in close succession affect the runoff quality of subsequent rainfall events. The effect of antecedent dry days is therefore closely linked to storm characteristics and other climatic variables.

A first flush effect, or higher concentration of various pollutants in the first runoff of a rainfall event, varies between storm events and locations. Empirical qualitative evidence is often cited, but the usefulness thereof remains limited as the data are site specific. Deletic (1998) identified a first flush effect for suspended solids and conductivity on urban asphalt catchments, which is supported by observations by Han *et al.* (2006) on highways throughout California.

Vehicles are a major source of pollutants and loosen solids from the road surface by creating turbulence through tyre action and wind generation. Kayhanian *et al.* (2007) found annual average daily traffic (AADT) to have a significant impact on highway runoff pollutant concentrations on American highways. In contrast, Crabtree *et al.* (2006) found no relationship between traffic flow and runoff concentrations on rural highways in England. Gan *et al.* (2008) found that urban land use significantly correlated with decreased highway runoff quality when comparing urban and rural highways where the rural highway had a greater AADT. This indicates that land use is an important factor to account for when assessing the impact of AADT. The traffic load, however, is closely related to the land use adjacent to the road, making it difficult to distinguish between the effect the two parameters on the concentration of pollutants in the runoff.

In summary, there are a multitude of factors influencing the composition and concentration of pollutants in highway runoff. The intricate, reciprocal effects between variables make determining cause and effect relationships challenging, and often inconclusive.

#### **2.4.4 Sampling procedures**

Sampling programs to determine the water quality of urban runoff include sediment and runoff sampling. The pollutant levels in sediments provide an indication of the pollutants available for washoff. Runoff concentrations include the effects of wet atmospheric deposition and the mobilisation of pollutants from the road surface by vehicles.

Urban runoff is typically sampled using auto-samplers which create composite samples based on flow volume (Ma *et al.*, 2009). Auto-samplers are not used for O&G and PAH sampling as these constituents are known to adsorb to the sampler tubing and containers (Khan *et al.*, 2006). Furthermore, there is a risk of contaminating the sample with the sampler materials.

An alternative to auto-sampling is to collect a series of grab samples. Ma *et al.* (2009) found auto-sampling to be a far superior method of determining the EMC of chemical oxygen demand (COD) in highway runoff, even when compared to 100 grab samples. It was determined that 30+ grab samples are required to estimate the storm EMC within 20% error. Alternatively, it was shown that an extended grab sample, which consists of a creating a composite grab sample taken over a short period of time (e.g. collecting a small volume every minute for five minutes), reduces the error in EMC estimation.

Constituent concentrations vary throughout storm events depending on a multitude of factors (Section 2.2.3). Therefore, grab sample timing with respect to the storm duration is an important variable. Khan *et al.* (2006) and Lee *et al.* (2007) concur that grab samples should be taken after the first hour of a storm event in order to estimate the EMC. The best time to sample runoff for calculating the EMC of hydrocarbons is 1 – 6 hours after the start of runoff, which will lead to a slight underestimation of the EMC (Khan *et al.*, 2006). For multi-constituent analysis, grab samples are most representative of the EMC when collected 2 – 3 hours after the first runoff (Han *et al.*, 2006; Lee *et al.*, 2007).

## **2.5 Sustainable Drainage Systems**

### **2.5.1 Design philosophy**

Standard stormwater management practices focus on water quantity; channelling stormwater flows through drainage networks to receiving waters without regard for environmental consequences (Ahiablame *et al.*, 2012). The result is erosion, siltation, pollution and a reduction in infiltration and groundwater recharge (Armitage *et al.*, 2013b).

In response, Sustainable Drainage Systems provide a means to achieve holistic, multi-purpose stormwater drainage management. SuDS is an umbrella term to describe drainage systems that attenuate surface drainage and improve water quality through structural and process controls (Scholes *et al.*, 2008). They aim to protect water courses in and downstream of the urban environment, and to manage stormwater locally, as opposed to directing concentrated flows to receiving waters. SuDS recognise surface drainage as a significant water resource and an integral part of the urban water cycle. They provide water quantity control, water quality improvements, enhance amenity and maintain biodiversity (Armitage *et al.*, 2013b).

SuDS mitigate the adverse effects of stormwater runoff on the environment by:

- reducing the volume and intensity of stormwater flows into receiving waters,
- reducing the frequency of stormwater flows entering receiving waters,
- maintaining groundwater recharge,
- increasing water quality before the stormwater reaches receiving waters, and
- providing enhanced amenity through the provision of aesthetic green spaces and wildlife habitats (Fletcher *et al.*, 2015).

### 2.5.2 SuDS elements

SuDS include a wide range of structural and non-structural systems that can improve runoff water quality and attenuate peak flows. The following are examples of SuDS options that may be appropriate for managing highway road runoff (Scholes *et al.*, 2008; Armitage *et al.*, 2013b):

**Soakaways** are underground excavated pits that are filled with rocks or other coarse aggregate. Water is detained in the pit and subsequently infiltrates into the in-situ ground through the base and the sides.

**Permeable pavements** are load bearing pervious surfaces. Permeable pavements are typically constructed with porous asphalt or paving blocks that sits atop a stone sublayer. The stone sublayer provides a temporary storage reservoir.

**Filter strips** are vegetated drains that allow shallow overland flow to filter into the ground surface.

**Swales** are vegetated broad shallow channels that are typically lined with grass. Swales are primarily used as conveyance structures.

**Infiltration trenches** are similar to a long soakaway. The trenches are often lined with a geotextile and like a soakaway, filled with rocks or other coarse aggregate. The trench is unplanted but hosts algal growth.

**Bioretention** areas are vegetated depressions that facilitate infiltration into the in-situ soil. The retention area is typically underdrained and contains engineered soils and selected vegetation to enhance pollutant removal.

**Sand filters** typically consist of an interconnected sedimentation chamber and sand filtration chamber, through which stormwater is temporarily stored and filtered.

**Detention ponds** are large depressions with a low level outlet. Detention ponds are structural controls that are typically dry, but store stormwater during wet periods and attenuate flood peaks.

**Constructed wetlands** are vegetated areas that attempt to mimic natural wetlands. The wetland may contain a soil or gravel substrate and are planted with hydrophilic species.

SuDS may be used in isolation or in series in a so-called treatment train. Treatment trains improve performance by providing a greater level of assurance, improved water quantity management and facilitating diverse pollutant removal (Armitage *et al.*, 2013b). Pretreatment elements such as sediment forebays can be placed upstream to assist with solid waste management by collecting macro pollutants and keeping them above ground where they are visible and easy to remove from site. According to the South African Guidelines for Sustainable Drainage Systems (Armitage *et al.*, 2013b), road runoff should be treated by three to four components in a treatment train.

SuDS make use of a number of mechanisms to manage stormwater runoff. These include but are not limited to: infiltration, filtration, onsite storage and detention, evapotranspiration, absorption, adsorption, precipitation, biodegradation and percolation (Ahiablame *et al.*, 2012).

## 2.6 Stormwater modelling

Simulation modelling provides a valuable tool to evaluate the performance of different stormwater management techniques across temporal and spatial bounds. The quality and accuracy of the model depends on accurate data inputs and decision making by the user, which makes it a subjective process (Scholes *et al.*, 2008; Ahiablame *et al.*, 2012). The United States Environmental Protection Agency's (US EPA) Storm Water Management Model (SWMM) is one of the best known and most widely used models (Cambez *et al.*, 2008). There are a number of SWMM-based packages including SWMM5, PCSWMM and InfoSWMM. PCSWMM was selected to perform this research as it provides the necessary functionality, is commonly used in South Africa and comes with excellent support services.

### 2.6.1 SWMM/PCSWMM

SWMM is a comprehensive stormwater model that provides combined hydrologic and hydraulic modelling such that the rainfall-runoff response becomes input to the hydraulic system (Gironás *et al.*, 2012). It includes water quality modelling with the capability to explicitly model SuDS units. The model is capable of running single event or long term continuous simulations (Ahiablame *et al.*, 2012). PCSWMM, owned by Computational Hydraulics International (CHI), is an advanced modelling software that is built on the SWMM hydraulic engine. PCSWMM incorporates GIS and statistical processing abilities with the hydraulic and hydrological capabilities of SWMM.

The SWMM model consists of four modules, which simulate the movement of water through the system, namely: the atmosphere, land surface, groundwater and transport module (Cambez *et al.*, 2008). The land surface receives precipitation and atmospheric deposition from the atmosphere module. It then supplies water to the groundwater module via infiltration, or to the transport module which accounts for surface runoff, conveyance, storage and water treatment.

The land surface is represented by homogeneous subcatchment areas. Each subcatchment has impervious and pervious fractions that allow for infiltration and surface storage. Infiltration through pervious areas is modelled by Horton, Green & Ampt or SCS Curve Number methods. Surface runoff is calculated using Manning's equation for overland flow (James *et al.*, 2010). Evaporation is calculated based on user-input of maximum potential evapotranspiration or using the Hargreaves' method based on climate data (CHI, 2016a).

Flow routing through the conveyance system is modelled by conservation of mass and momentum equations. The user is able to select steady flow routing, kinematic wave routing or dynamic wave routing for gradually varied and unsteady flow equations. Flow rate, flow depth and water quality are simulated at each time step during the simulation period.

Water quality is modelled based on land uses, which are assigned to each subcatchment. Each pollutant of interest is modelled using either event mean concentrations or buildup and washoff equations. Pollutants are added to the system via atmospheric deposition or surface buildup and are routed through the transport module. Pollutant removal is modelled through the application of SuDS units.

## 2.6.2 Continuous modelling

Urban drainage systems are typically modelled using an event-based design storm approach. It has been shown that small storms (RI <1 year) produce roughly 75% of the nonpoint source pollutant load by mass in urban areas. Larger rains account for only 5% of yearly events and account for a small portion of the total pollution load (Huber *et al.*, 2006; Rivard, 2010). Typical design storm events fall into the latter category. Therefore, it is necessary to model small storm events in order to determine pollutant loading in urban drainage systems.

Where SuDS are used as part of the urban drainage system, the various elements of the system such as conveyance, storage, treatment and control structures are sensitive to different aspects of rainfall events. For instance, storage devices are sensitive to the total event volume while conveyance structures are more sensitive to the variation in rainfall intensity. Therefore, the full range of meteorological events must be considered to determine the temporal variability in system performance (Adams & Papa, 2000).

In order to suitably model small storm events, it is necessary to use continuous models (Adams & Papa, 2000; Huber *et al.*, 2006; Rivard, 2010). When modelling small scale storm volumes, hydrological abstractions such as infiltration, depression storage and evapotranspiration must be accounted for (Rivard, 2010). The most common approach to continuous modelling is to use observed long-term climate data as a direct input to the model (Adams & Papa, 2000). The rainfall resolution should be smaller than the time of concentration of the subcatchments to generate accurate flow rate calculations (Rees & Schoen, 2009).

### 2.6.3 Pollutant buildup and washoff

There is a large body of research relating to the buildup and washoff of pollutants with stormwater (Manning *et al.*, 1977; Alley, 1981; James & Boregowda, 1986). Pollutant buildup refers to the dry and wet deposition of pollutants on the subcatchment surface, while washoff refers to the removal of pollutants by erosion or solution during surface runoff events. Buildup and washoff data models in the literature are primarily empirical and site-specific (James *et al.*, 2010). Most data imply a linear or exponential buildup of pollutants, although sometimes with poor correlation coefficients (Rees & Schoen, 2009). Pollutant washoff is influenced by surface characteristics, accumulated pollutant load, rainfall frequency, intensity, and duration (Butler, 2015). While there are theoretical approaches for modelling the mechanics of sediment pickup and transport on impervious surfaces, there is typically insufficient field data to correctly inform the various parameters required by these formulations (Rees & Schoen, 2009). Urban pollutant buildup and washoff modelling is crude and requires calibration based on local site conditions.

An alternative approach is to represent the complex pollutant buildup and washoff processes as an average pollutant concentration in the runoff that accounts for the variability in pollutant loading. The EMC is a statistical parameter that represents the flow-proportional average concentration of a contaminant. When combined with flow measurements, the EMC can be used to estimate the total pollutant load for a storm event. In practice, the EMC is measured by creating a flow weighted composite sample and the concentration is calculated as the total constituent mass divided by the total volume (Equation 2.1).

The EMC is widely used and viewed as the most useful means to quantify land-use specific storm loads (Huber *et al.*, 2006). Pollutant modelling using an EMC approximation is most suitable for long term modelling, where event-to-event errors are not problematic (Rees & Schoen, 2009). The EMC value should preferably be informed by local conditions, as it may otherwise misstate the total pollutant loading (Sutherland *et al.*, 2006).

$$EMC = \frac{\sum_{j=1}^n V_j C_j}{\sum_{j=1}^n V_j} \quad (2.1)$$

Where:  $V_j$  = volume of flow during the period  $j$ ;  $C_j$  = average concentration associated with the period and volume  $V_j$ ; and  $n$  = total number of measurements taken during event.

### 2.6.4 SuDS modelling in PCSWMM

There are two typical approaches to SuDS modelling. The first is to successively model each unit process occurring in the drainage system (Ahiablame *et al.*, 2012). An example of this would be to model filtration, infiltration, evapotranspiration, adsorption, biological uptake and sedimentation for a bioretention area (Debo & Reese, 2003). This approach requires suitable data inputs regarding the relative importance and efficacy of each unit process and extensive

computational power. When performed with accurate data, the results are sufficiently detailed to be used for design and optimisation of the drainage system. The second approach is to provide a single measure that represents an aggregation of all processes occurring in the drainage system (Ahiablame *et al.*, 2012). This method simplifies multiple procedures into an approximate measure, which may or may not accurately represent the performance of the entire system. The second approach has the advantage of being quick and easy to implement and is suitable for high level decision making.

SWMM uses the first approach, where the hydraulic behaviour and the associated water treatment performance are modelled as a train of unit processes (Ahiablame *et al.*, 2012). The input parameters may vary with design specifications, hydrological and climatic conditions and system age (Scholes *et al.*, 2008). In the absence of field data, the user must provide an estimation. It is evident that suitable field data regarding the incoming stormwater characteristics and the SuDS treatment capacity within a local context are required for a competent model.

SWMM is capable of modelling SuDS as specific entities within the model. They may either be placed within a standard subcatchment or may be placed to occupy an entire subcatchment, which allows the SuDS to be linked in a treatment train. The hydrological performance of each SuDS unit is calculated based on time dependent water balance models.

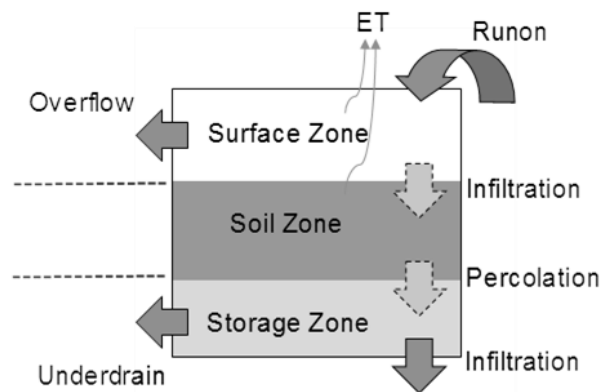
A SuDS unit is represented in SWMM as a number of vertical layers, as illustrated in Figure 2-1. The surface zone receives precipitation from the associated rain gage and run-on from linked subcatchments. Surface water is lost through evapotranspiration, depression storage, surface runoff and infiltration. The soil zone is assigned properties of the engineered soil mix designed to support vegetative growth, through which water percolates to the storage zone. The storage zone typically consists of coarse gravel and detains water in a storage volume, which infiltrates to the underlying in-situ soil or exits through a perforated underdrain system.

The hydraulic performance of the SuDS unit is computed using mass balance equations across each layer, which calculates the change in water volume as the difference between the inflow water flux rate and the outflow water flux rate (Rossman, 2010). The complex underdrain flow rate hydraulics are simplified to an empirical power equation. This set of equations is solved at each time step to determine the surface runoff, infiltration, sub-surface storage and sub-surface drainage of the SuDS unit.

SWMM is capable of modelling bioretention cells, rain gardens, green roofs, infiltration trenches, permeable pavements, rain barrels and vegetative swales as combinations of the surface, pavement, soil, storage and underdrain layers. The layer representation of each SuDS element is provided in Table 2-3, where ‘x’ indicates a necessary system component and ‘o’ indicates an optional layer.

The pollutant removal capacity of SuDS is often modelled on an EMC basis rather than through representing unit processes. This is due to the number and complex nature of the pollutant removal processes that take place in SuDS units and the difficulty of quantifying on-site variability. The EMC method coupled with long-term data has been observed to produce the

best results for identifying acute and chronic pollution (Huber *et al.*, 2006). The pollutant removal capacity of various SuDS elements is typically provided as a percentage removal value (Woods-Ballard *et al.*, 2007b; Armitage *et al.*, 2013b). It is important to be aware that the EMC method for pollutant removal capacity may not indicate the performance of the SuDS unit with time and ignores the effects of maintenance. Furthermore it may overestimate the removal efficiency in treatment trains and where influent concentrations are low (Huber *et al.*, 2006).



**Figure 2-1: SWMM representation of a generic SuDS element (CHI, 2016b)**

**Table 2-3: SWMM layer representation of SuDS elements (CHI, 2016b)**

LID type	Surface	Pavement	Soil	Storage	Drain
Bioretention cell	x		x	x	o
Rain garden	x		x		
Green roof	x		x		
Infiltration trench	x			x	o
Permeable pavement	x	x	o	x	o
Rain barrel				x	x
Vegetative swale	x				

Where 'x' indicates a necessary system component and 'o' indicates an optional layer

## 2.7 Summary

Highway runoff, traditionally viewed as a waste by-product, is becoming recognised as a water resource through a paradigm shift in the approach to urban water management. Water Sensitive Design is a design philosophy that requires practitioners to integrate water management with their design, addressing environmental, social and technical needs. In the case of highway runoff, SuDS provide a means to mitigate the effects of stormwater on the environment while addressing

the technical requirements of road drainage. SuDS provide structural and process controls that attenuate runoff volumes and provide water quality treatment through a variety of processes.

The Drainage Manual (SANRAL, 2013a) requires flow (quantity) management and disregards the effects of road runoff on the environment. This is effective in maintaining road user safety and pavement integrity, but has negative effects on receiving water bodies through erosion, siltation and pollution. The CoCT Management of Urban Stormwater Impacts Policy provides guidelines for the holistic management of stormwater in the city. The policy requires an 80% reduction in TSS and a 45% reduction in TP of the annual stormwater pollutant load and that litter, oil and grease are trapped at source. Additionally, the 1 year RI, 24-hour storm event must be detained over 24 hours, and the 10 year RI peak runoff flow must be reduced to the pre-development level.

Highway runoff contains TSS, heavy metals, oils and greases, biodegradable organic matter, hydrocarbons, pathogenic organisms and nutrients in varying concentrations. Pollutant sources include pavement degradation, corrosion of roadside barriers and signage, maintenance activities, atmospheric deposition, fuel and vehicle lubricants, vehicle wear and tear and other anthropogenic wastes. Pollutant concentrations are influenced by traffic characteristics, climate, rainfall characteristics (volume, intensity, duration) and surrounding land use.

There is a large body of international literature on runoff contamination, yet there is, to the author's best knowledge, no published data detailing highway runoff contamination in South Africa. Sampling procedures to determine average levels of contamination typically make use of automated sampling devices as this is the most accurate method of sampling. Grab sampling, however has significant cost and time advantages. When looking to determine average contaminant concentrations, grab sampling results can be improved by taking a composite grab sample 2-3 hours into a storm event.

Stormwater modelling provides a valuable tool to evaluate the performance of different stormwater management techniques across temporal and spatial bounds. PCSWMM was chosen as a suitable software package with the ability to model the dynamic rainfall-runoff response in urban catchments, pollutant transport and SuDS elements. Continuous modelling is recommended over the design storm approach in order to correctly account for pollutant generation by small storms, which produce the majority of the total pollutant load.

In this chapter, the aspects and treatment of highway surface runoff are discussed in the context of a South African urban road. The local legislation and standard drainage practices are described, along with reference to policies and guidelines that enable practitioners to implement sustainable drainage solutions. The anticipated contaminants and factors influencing their concentration in highway runoff are described as well as suitable methods for sampling. Drainage modelling is presented as a means to evaluate alternative drainage management in a time and cost effective manner. Based on the literature, the combined approach of stormwater sampling and analysis by stormwater modelling provides a comprehensive means to assess the highway runoff from the R300.

## 3. Site description

### 3.1 Introduction

This chapter provides a description of the research site, providing detail on aspects of the site that are pertinent to surface drainage. The site selection, surrounding land use and local climate are described. Thereafter, the highway traffic characteristics, existing drainage infrastructure and routine maintenance are discussed. A map of the site is provided (Figure 3-1), showing the site location and nearby points of interest.

### 3.2 Site selection

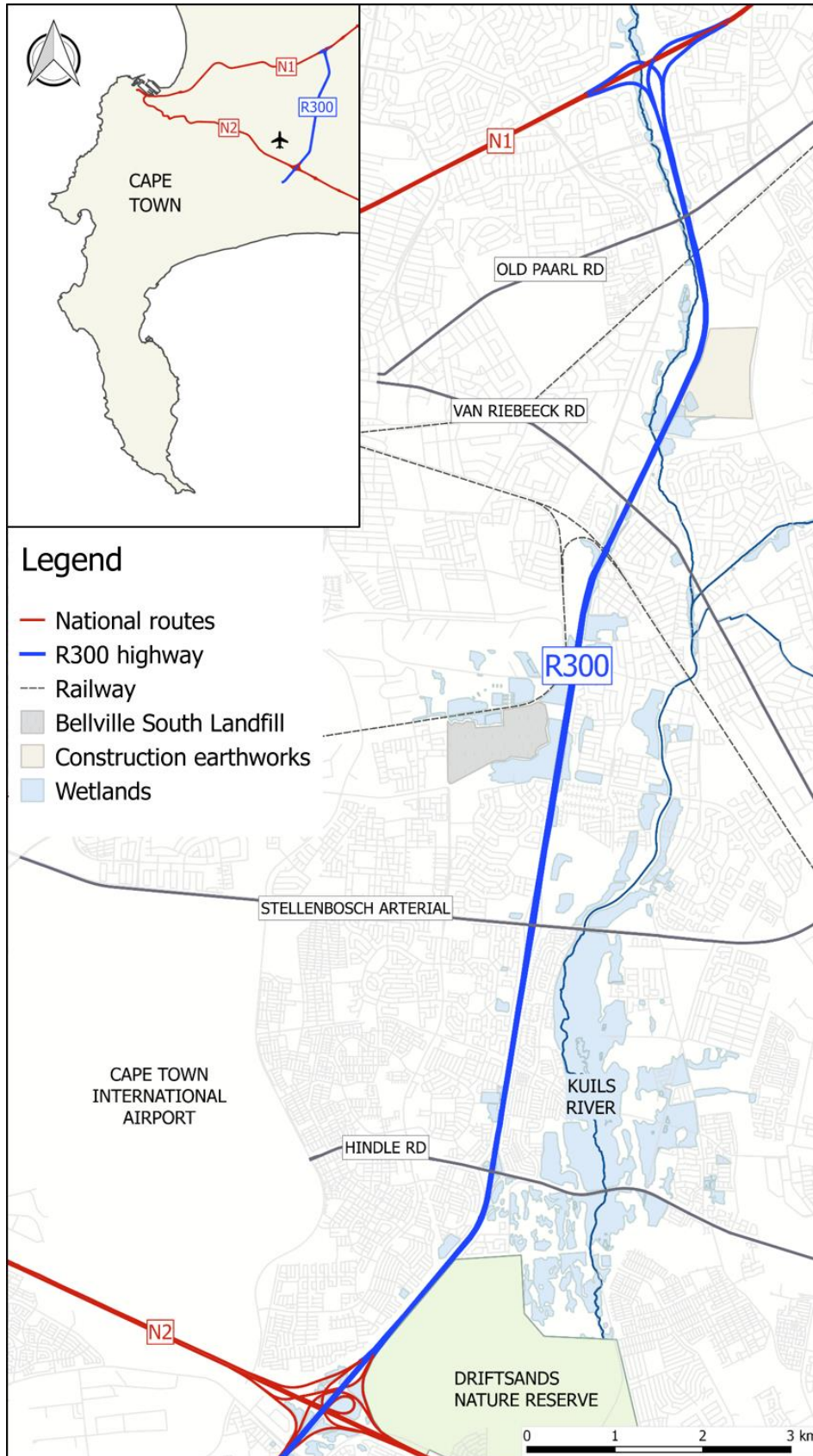
The research site was selected based on proximity to the University of Cape Town, the highway traffic characteristics and drainage infrastructure, and on the availability of surface and weather data. The R300, a highly trafficked regional route in the greater Cape Town area, was selected. The pavement is good quality asphalt and the surface drainage is varied, making use of concrete surface drains, catchpits, culverts, down chutes and earth drains. The road is located close to the Cape Town International Airport and the South African Weather Service Kuilsriver weather station, which enabled access to high resolution weather data. Furthermore, detailed as-built drawings of the site were made available to the author for the purposes of this research.

### 3.3 Description

The R300 regional route, shown in Figure 3-1, is located in the greater Cape Town area. It is an asphalt highway consisting of three lanes in each direction with a speed limit of 120km/h. The R300 runs roughly north to south between the national routes, N2 and N1. It is managed and maintained by the South African National Roads Agency Limited (SANRAL). Between 2008 and 2010, major road improvements were designed and constructed on the R300. These included:

- upgrading from a 4 to 6 lane dual carriageway,
- providing a concrete median barrier,
- widening structures such as bridges and interchanges, and
- rehabilitating the existing pavement (SNA-SSI Joint Venture, 2008a).

There are mixed land use areas surrounding the R300. South of the Van Riebeeck interchange is primarily low income formal and informal housing, while north of the interchange includes commercial, industrial and higher income residential areas. The topography of the area surrounding the R300 is relatively flat with only a  $\pm 35\text{m}$  drop in elevation from north to south along the  $\pm 15\text{km}$  section of roadway.



**Figure 3-1: Location map of the R300**

The R300 road grade ranges between 0 and 0.8%, with an average 0.2% longitudinal slope. Occasionally, the road is raised for clearance over crossroads and the railway line, where the maximum grade is 3.3% (SNA-SSI Joint Venture, 2008a).

A large portion of the land surrounding the R300 north of Stellenbosch Arterial contains critically endangered fauna and flora (SANBI, 2015). Maps generated by the South African National Biodiversity Institute's online mapping tool are provided in Appendix B. At the intersection of the R300 and the N2 is the Driftsands Nature Reserve, which is managed by Cape Nature, a provincial government conservation body. The reserve consists of wetland area and Strandveld vegetation, which is endemic to the Cape Flats region. Only a quarter of the original extent of the Strandveld remains undeveloped (Johnson, 2012).

There are several national wetlands in the vicinity of the roadway, which are largely situated within the Kuils River floodplain. The Kuils River runs parallel to the northern section of the R300, crossing near the Van Riebeeck Road interchange via a river bridge. The bridge will be upgraded with the next road improvement to address the movement of the river bed (Roux, personal communication 2016, June 14). The proximity of the highway to nationally recognised significant and threatened ecosystems makes managing stormwater in a holistic manner particularly important.

### **3.4 Climate**

The R300 is in a moderate climatic region characterised by a Mediterranean climate. The summers (December to February) are warm and dry, and winters (June to August) are wet and moderate. The average daily temperature is 18°C in winter and 27°C in summer (SNA-SSI Joint Venture, 2008a). The maximum and minimum temperatures recorded on site are 41°C and -1°C respectively. Annual rainfall ranges between 362 – 751mm, with a MAP (mean annual precipitation) of 515mm. Table 3-1 summarises rainfall characteristics for 25 years on the R300. The greatest average monthly precipitation is 94mm, which occurs in June. Figure 3-2 shows the average monthly rainfall from January to December on the R300.

### **3.5 Traffic**

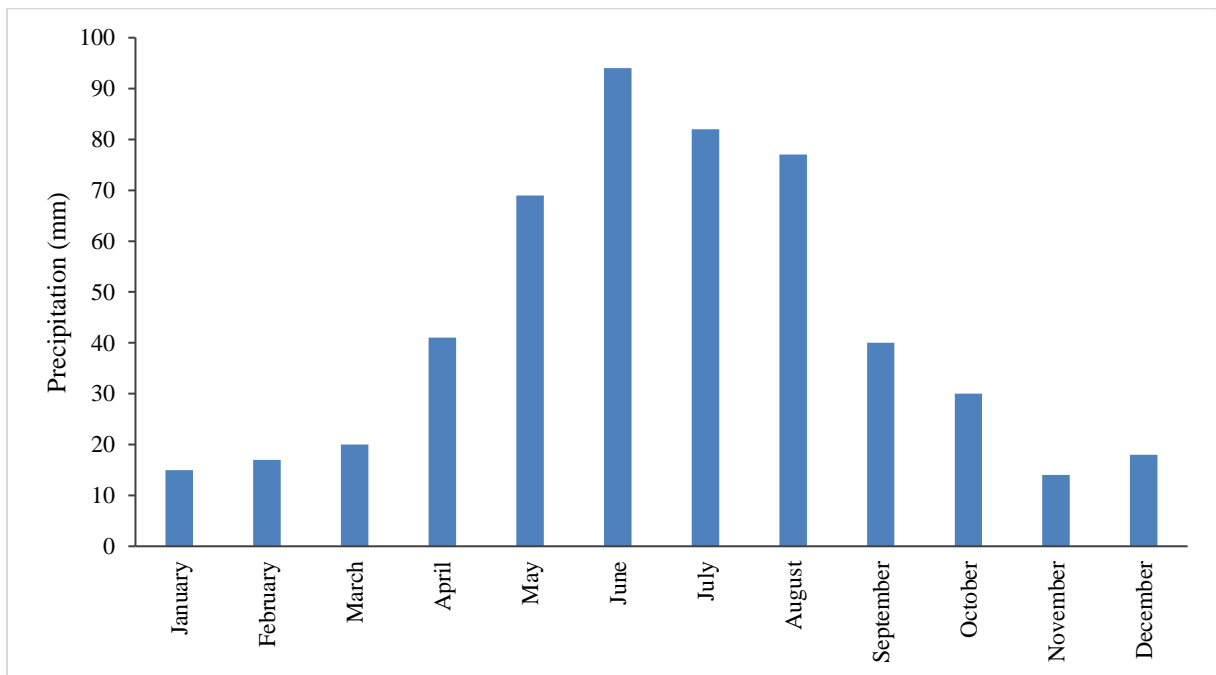
The AADT (annual average daily traffic) for 2013 was 37,100 vehicles/direction/day (SANRAL, 2013b). Assuming a 10% annual increase in AADT (SNA-SSI Joint Venture, 2008a), the 2016 AADT is approximately 49,400 vehicles/direction/day.

According to the SANRAL Yearbook Report (2013b), traffic is bimodal on weekdays with peak volumes between 07:00 and 08:00, and 16:00 and 17:00. Daily traffic volume is approximately halved on weekend days with a single peak in the afternoon. The average speed for light vehicles is 93km/h, with 15<sup>th</sup> and 85<sup>th</sup> percentile speeds of 75km/h and 113km/h respectively. Heavy vehicles account for approximately 6% of total traffic. Traffic is distributed

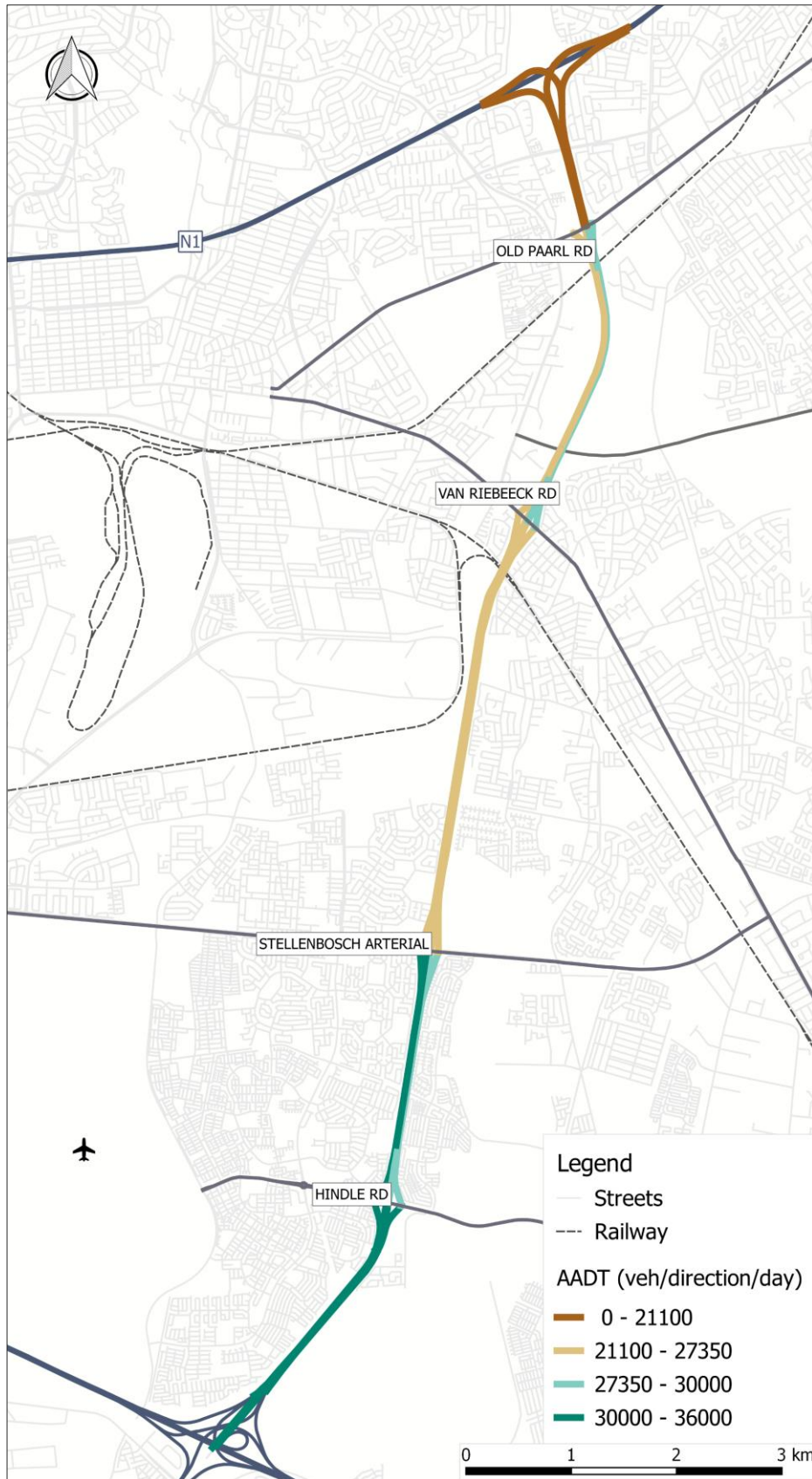
from South to North, with 12% more traffic than the mean between the N2 and Hindle Road, and 24% less traffic than the mean between Old Paarl and the N1 (SNA-SSI Joint Venture, 2008a). Figure 3-3 shows traffic distribution for five contiguous sections along the R300.

**Table 3-1: Rainfall characteristics along the R300 (SNA-SSI Joint Venture, 2008a)**

	Average monthly precipitation (mm)	Max 24-hour precipitation (mm)
January	15	41
February	17	27
March	20	42
April	41	39
May	69	<b>65</b>
June	<b>94</b>	58
July	82	61
August	77	56
September	40	29
October	30	53
November	14	30
December	18	21



**Figure 3-2: Average monthly rainfall on the R300**



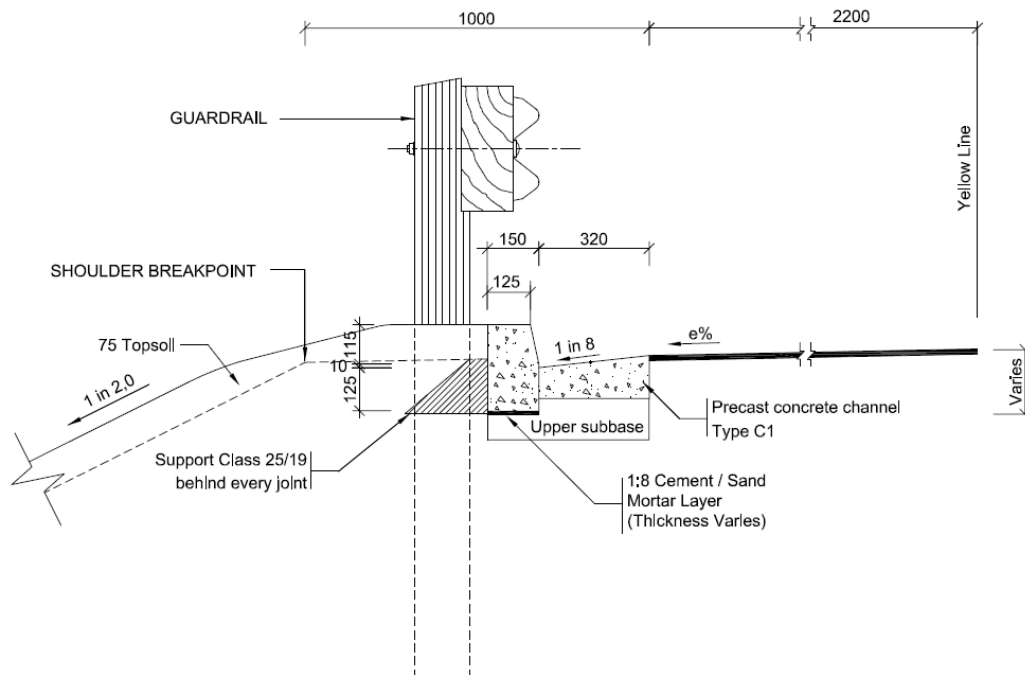
**Figure 3-3: Traffic distribution on the R300 for north and southbound lanes**

### 3.6 Drainage

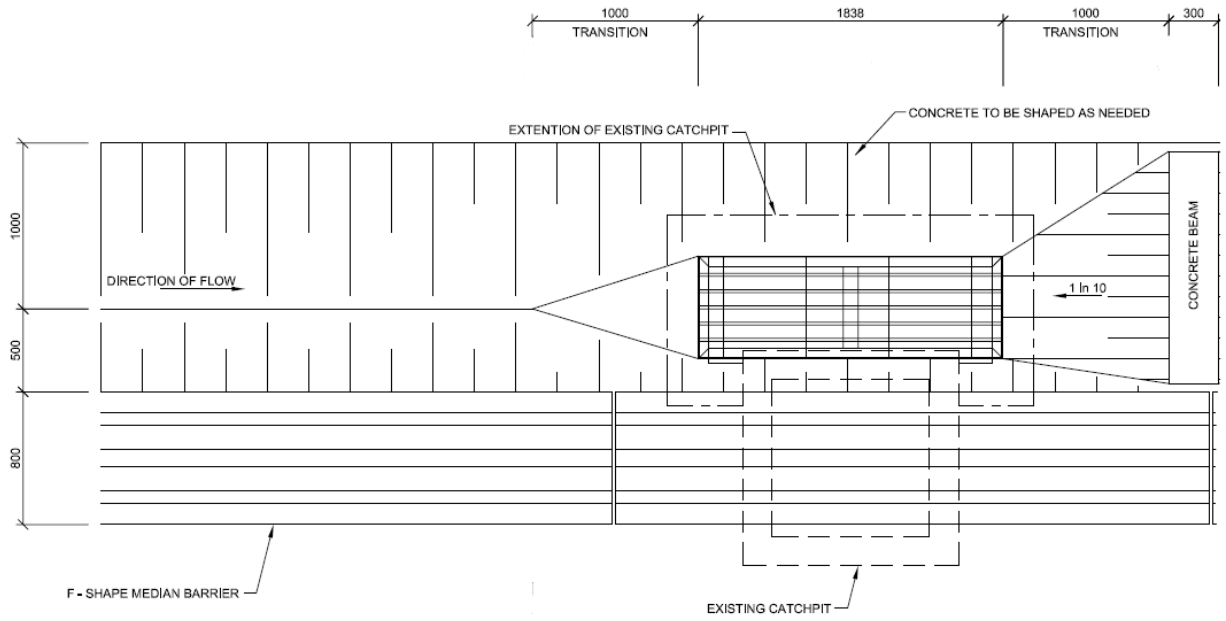
Road drainage along the highway is towards the median drains, side drains, or directly onto the verge. The median drains are connected to catchpits, which drain to the verge. Side drains lead towards down chutes, which drain to the verge. Figures 3-4 to 3-6 show design drawings for standard drainage elements. Detailed as-built design drawings for the surface water drainage on the R300 are provided in Appendix C. The verge consists of sandy soils with sparse grass cover. In wetter areas there are expanses of *typha capensis*.

Figure 3-4 shows a section view of the typical side drain element. The side drains are constructed using precast concrete channels that are 320mm wide and 115mm deep. They exit to stilling basins or the outfall is protected by an earth berm. At low points, there are catchpits and down chutes to channel surface runoff. Where necessary, catchwater banks are constructed in the road reserve to direct runoff.

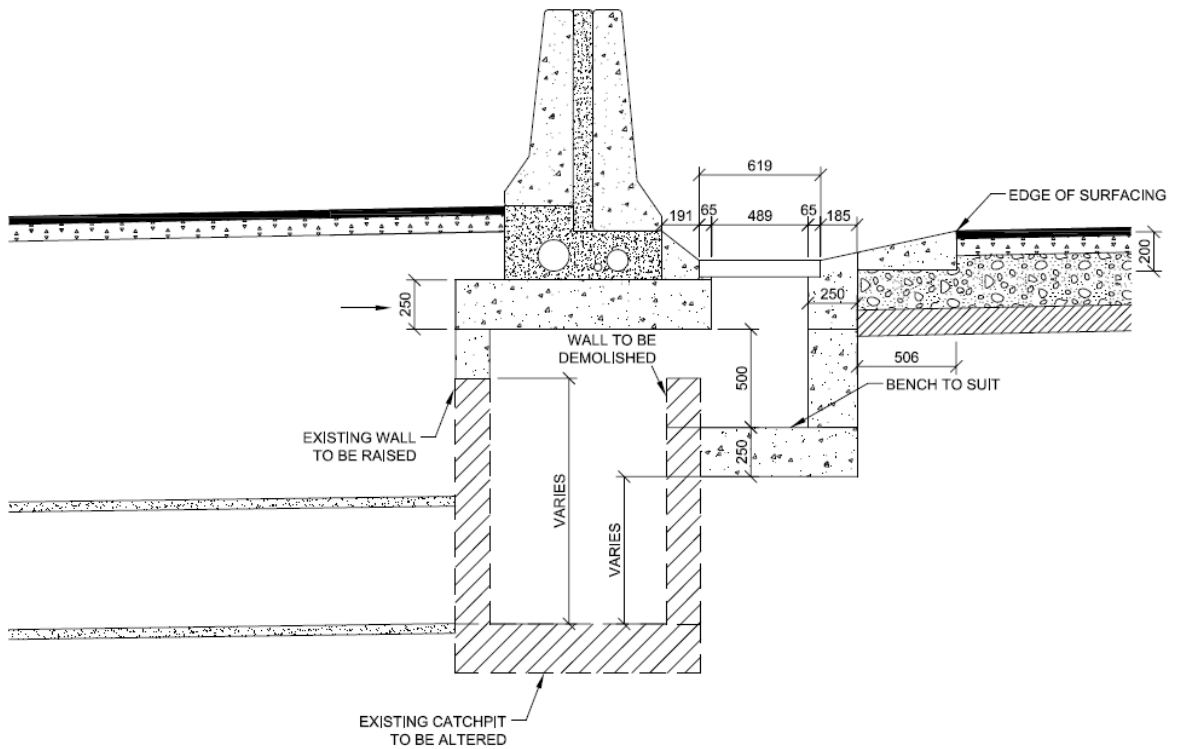
Figure 3-5 shows a plan view of a standard median catchpit. Catchpits collect runoff from the median drains, which is channelled to a 600mm diameter drainage pipe that drains to the verge. Figure 3-6 shows a cross section of the median catchpits. The catchpits have an F-shaped profile as a result of the road upgrading process, where existing median catchpits were retrofitted to the new road geometry.



**Figure 3-4: Typical cross section of an R300 side drain (SNA-SSI Joint Venture, 2008b)**



**Figure 3-5: R300 median drain plan view (SNA-SSI Joint Venture, 2008b)**



**Figure 3-6: R300 median drain cross section (SNA-SSI Joint Venture, 2008a)**

Figure 3-7 and Figure 3-8 are photographs taken on site depicting the as built surface drainage infrastructure. Figure 3-7 shows: (a) a median surface drain leading towards a catchpit, (b) a plan view of the catchpit and underground drain connection, and (c) the outfall to the verge. Figure 3-8 (a) shows a down chute leading from a side drain to the verge. Figure 3-8 (b) shows a sandy roadside drainage ditch. These ditches are present in flat areas where there is a sufficient longitudinal slope to convey water to a nearby water body or stormwater pond. The drains are typically 1000mm deep and 4000mm wide (SNA-SSI Joint Venture, 2008b).



**Figure 3-7: R300 road drainage structures where the road drains to the median: (a) a median surface drain, (b) catchpit plan view, and (c) outfall to the verge**



**Figure 3-8: R300 road drainage structures located in the verge: (a) concrete down chute, and (b) sandy drainage ditch**

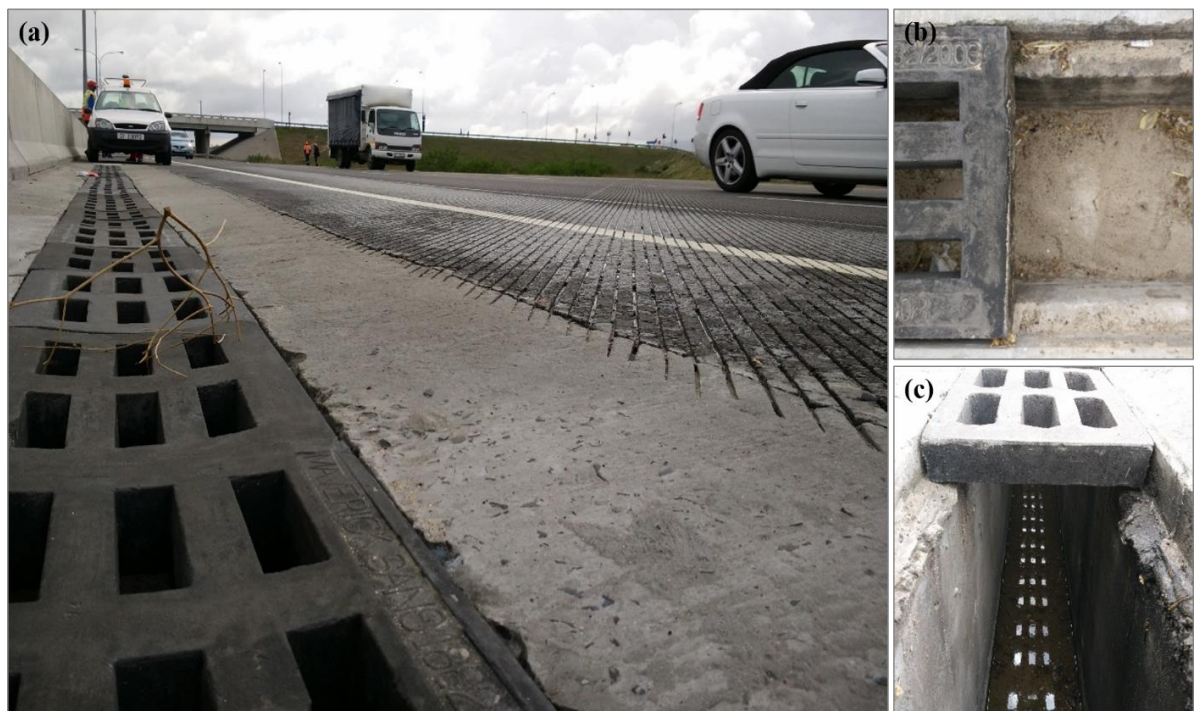
### 3.6.1 Runoff quantity management

Road maintenance staff report the following drainage related problems on the R300 (Roux, White, personal communication 2016, April):

- i) Erosion / scour surrounding down chutes
- ii) Erosion at the bottom of down chutes
- iii) Standing water on the road surface near the Hindle Road interchange

Erosion problems have been addressed by increasing the size of the down chutes, stabilising the soil around the down chutes with gabions and/or concrete and providing stilling basins using either gabions or grouted stone pitching.

Standing water at the Hindle Road interchange was identified as a risk to road users and additional drainage measures were installed to ameliorate the problem. This section of road is on a horizontal curve and includes an on-ramp from Hindle road. As a result of these elements, the road geometry created a flat area that did not drain sufficiently. A longitudinal trench drain was installed along the road median, varying in depth from 100mm to 1000mm where the drain enters an existing catchpit. Additionally, grooves were cut into the road surface, which provide a flow pathway and temporary storage for runoff. These elements are shown in Figure 3-9.



**Figure 3-9: Drainage solution near Hindle Road: (a) asphalt catchment, (b) plan view, and (c) view inside the longitudinal drain**

The runoff quantity management at the Hindle Road interchange highlights the importance of road drainage for maintaining road user safety. An analysis was conducted on vehicle crash data from 2010 – 2015, mapping the location of incidents that occurred on a wet surface and those that occurred in dry conditions. This revealed high concentrations of crashes at the Hindle Road and Old Paarl Road interchanges during wet weather. The analysis is provided in Appendix D.

### 3.6.2 Solid waste

While conducting field work, it was observed that the median catchpits collect a large amount of sediment, organic matter and solid waste. Based on visual inspection at each sampling event, the volume of solids collecting in each catchpit between storm events ranged between 0 – 0.5m<sup>3</sup>. Following rainfall events, the catchpits were typically scoured clean (Figure 3-10b).

The concrete median barrier provides an obstacle for windswept objects, causing sediment and solid waste to accumulate in the median drains and catchpits. The sediment collected in the catchpits resembles the sand in the road reserve, while the organic matter typically consists of grass cuttings, leaves and reeds. The solid waste collected in the catchpits, shown in Figure 3-11 (a) and (b), includes: cigarette butts; food packaging such as soda cans, chip packets, sweet wrappers and fast food packaging; and miscellaneous items such as polystyrene, plastic, cardboard and paper. There were incidents after smaller storms where standing water was observed in catchpits, which appeared to be due to silted up (c) and/or blocked drains (d).



**Figure 3-10: Median catchpit scoured clean by a rainfall event: (a) prior (b) subsequent to a rainfall event**



**Figure 3-11: Accumulated solid waste in median catchpits: (a) food wrappers, cigarette butts and sediment, (b) packaging waste, (c) silted up drain, and (d) blocked drain**

### 3.7 Operations and maintenance

The SANRAL Standard Specifications for Routine Road Maintenance (2001) provide requirements for the maintenance of drainage structures along SANRAL-owned roads. Several salient maintenance requirements are provided below to provide an indication of the scope and capacity of the highway drainage maintenance activities that are currently conducted.

#### 3.7.1 Waterway structures

These are structures with an inlet area greater than 5m<sup>2</sup>. They are to be cleared of all obstructions restricting flow, debris, vegetation and silt. All material removed from these structures is to be disposed of at designated spoil sites.

#### 3.7.2 Prefabricated culverts

Culverts are to be cleared of all vegetation, silt and debris at the inlet and outlet areas, where no more than 20% of the vertical height is to be filled at any point. Material removed from culverts may be spread neatly in the road reserve where it cannot wash back into the structure.

### **3.7.3 Concrete drains and channels**

Drains and channels are to be cleaned once a week during the rainy season and twice a month thereafter. Silt and debris removed from roadside channels, kerbs and side drains may be disposed of in the road reserve where it cannot wash back onto the road. Where vegetation borders concrete channels, no more than 5% of the channel area may be covered with encroaching vegetation. Earth side drains and channels must be cleaned of silt, debris and vegetation.

### **3.7.4 Vegetation**

Hedges, shrubs, trees and grassed areas should be maintained by trimming, fertilising, watering, eradicating undesired vegetation, and removing noxious weeds and invader plants. The height of grass in the road reserve should be between 50mm and 450mm at all times.

### **3.7.5 Litter**

Litter should be removed on a weekly basis for an urban road. The road pavement, down chutes, side drains, drainage grids and bridge drainage elements must be inspected for foreign articles, debris and rubbish weekly.

## **3.8 Summary**

This chapter describes aspects of the research site relevant to the contamination and treatment of surface runoff. The R300 is an asphalt highway in the Cape Town region with a high traffic load. The AADT is approximately 49,400 vehicles/direction/day. The surface drainage on the R300 is constructed according to traditional design methods, making use of open concrete channels, catchpits and culverts. The land use adjacent to the highway includes formal and informal housing, commercial and industrial areas. The site receives most rainfall during winter, with the greatest average monthly precipitation in June. The R300 is maintained according to the SANRAL Standard Specifications for Routine Road Maintenance (2001), which require weekly cleaning of drainage structures and removal of litter during the rainy season. It was observed that the catchpits accumulate up to 0.5m<sup>3</sup> of sediment, organic matter and solid waste in between rainfall events.

## 4. Highway sediment and runoff sampling

### 4.1 Introduction

This chapter outlines the research methodology for collecting sediment and stormwater runoff samples from the R300 highway. A map (Figure 4-2) and description of the sampling sites are provided, showing the spatial distribution and sample site characteristics. The sampling method, chemical analysis results, and limitations are discussed for the sediment and runoff analytes.

Grab samples were collected at nine different sampling events over a four-month period in 2016 as shown in Figure 4-1. The aim of the sampling exercise was to identify contaminants in the road runoff and to quantify the extent of the pollution potential in broad terms. Samples were collected at three locations on the highway and one location of undeveloped land adjacent to the road. The samples were analysed for heavy metals, hydrocarbons and nutrients at Jones Environmental, an independent laboratory.

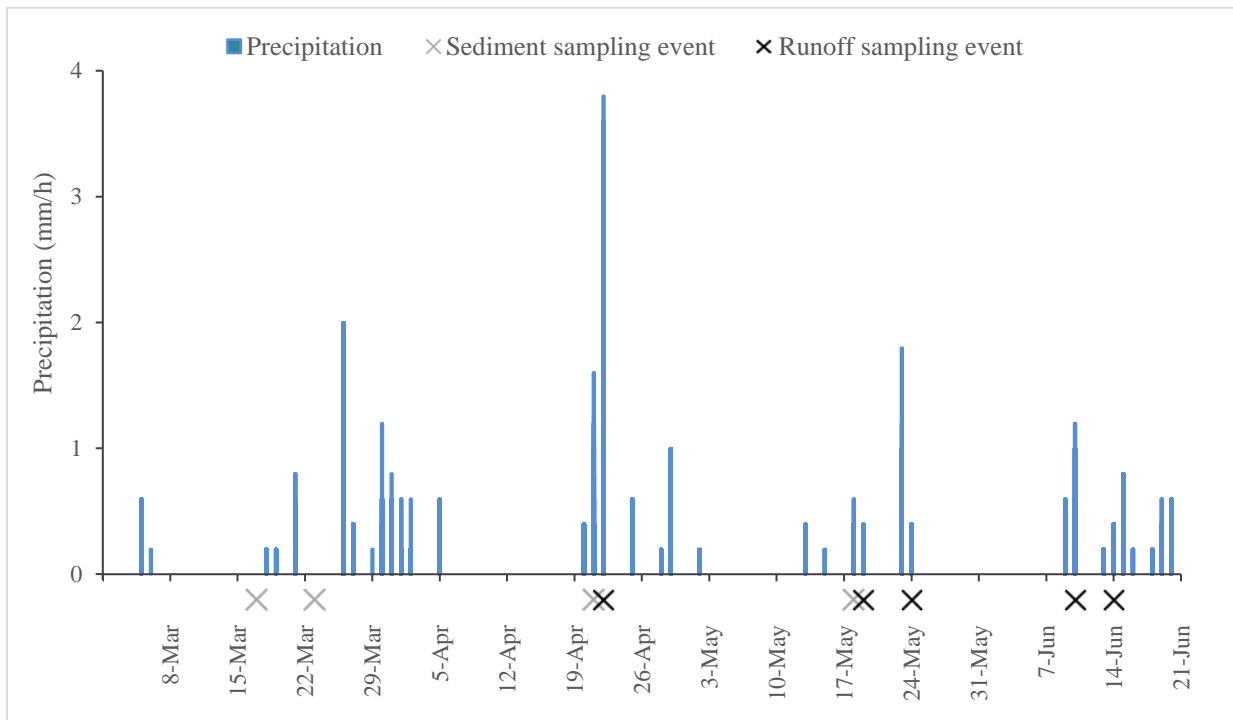


Figure 4-1: Time series of sampling events and precipitation from March to June 2016

### 4.2 Sampling sites

The sampling sites were distributed along the entire length of the road in order to mitigate local effects. Additional restraints included choosing locations where it was possible to stop and exit a vehicle safely, safety concerns due to a prevalence of violent crimes on the R300, avoiding

local sources of pollution such as the Bellville South Landfill and financial constraints limiting the analysis. Figure 4-2 locates the research sites and areas of interest on a map. Three sampling locations were identified on the highway and one location on a vacant plot adjacent to the roadway. The latter sample location provided an environmental sample to distinguish between the ambient levels of contamination and the contaminants present due to road use activities.

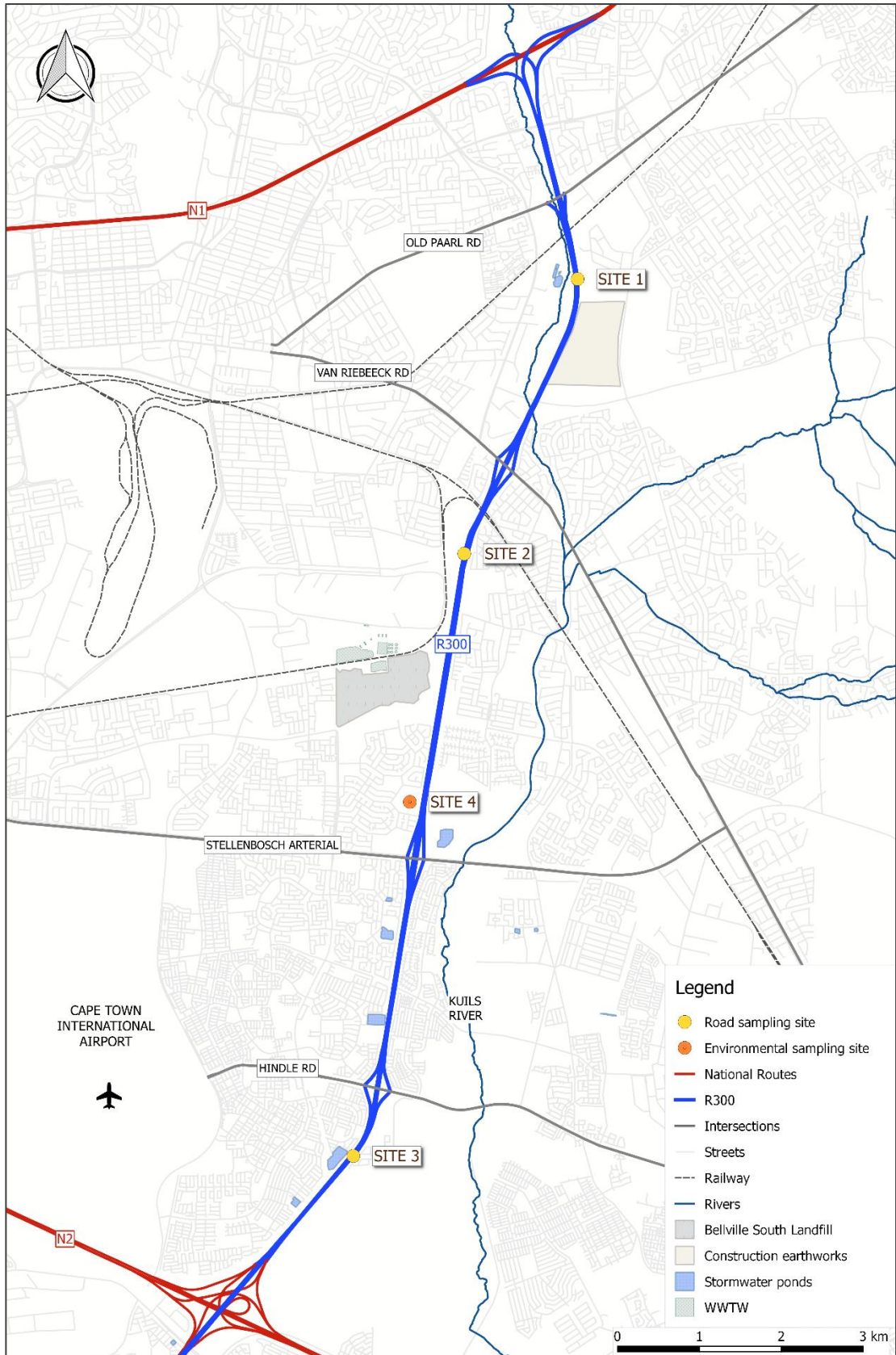
**Site 1**, shown in Figure 4-3, is at a catchpit alongside the road median on the southbound carriageway near the Old Paarl Road interchange. The site is on a horizontal curve  $2/3^{\text{rds}}$  of the distance down a hill, at a grade of 1%. The road is three lanes wide and all three lanes drain toward the median. A standard median drain leads to the catchpit which is 2m deep. The median drain continues downstream of the catchpit.

**Site 2**, shown in Figure 4-4, is at a catchpit alongside the road median on the northbound carriageway near the Van Riebeeck Road interchange. The site is on a vertical curve at the bottom of rises to the north and south. The road is three lanes wide and all three lanes drain toward the median. A standard median drain leads to the catchpit which is 1.5m deep. The catchpit collects water from 100m of median drain at a 3% slope to the north and 10m of median drain at a 1.5% slope to the south.

**Site 3**, shown in Figure 4-5, is at a longitudinal drain alongside the road median on the southbound carriageway near the Hindle Road interchange. The road is three lanes wide and all three lanes drain toward the median. The site is located on a horizontal curve. Sand samples were taken from the longitudinal drain alongside the road median while runoff samples were collected from a downstream catchpit that collected runoff from a standard median drain. The longitudinal drain is 250mm wide and increases in depth from 100mm to 1000mm in order to maintain a sufficient slope for adequate drainage. The drain is covered by plastic grates, and the catchpit is 500mm deep and corresponds to the standard catchpit design.

**Site 4**, shown in Figure 4-6, is on an undeveloped parcel of land adjacent to the northbound carriageway near the Stellenbosch Arterial interchange. The site has the surface and soil conditions of the area and is mostly undisturbed. There are footpaths crossing the area and it is not possible to enter the area with a vehicle. Sand samples were collected 80m away from the roadside, which is sufficient distance for pollutants originating on the road to have negligible effect (Smith *et al.*, 2010; Zafra *et al.*, 2011). Rainwater samples were collected to form the environmental baseline for the runoff samples. Rainwater collectors were installed 20m away from the roadside, approximately 1.2m above ground level.

Site visits were conducted with the assistance of road maintenance personnel. A marked road maintenance vehicle with an amber warning light was used since it was necessary to stop alongside the road median to access the catchpits. Once the vehicle was stationary, a flagger positioned himself to warn oncoming vehicles of our presence. Standard personal protection equipment (PPE) was worn for all site visits to increase visibility. An armed response vehicle accompanied the research vehicle to mitigate the risks of mugging or other violent crime. On two occasions samples were not collected from sample Site 4 due to safety concerns.



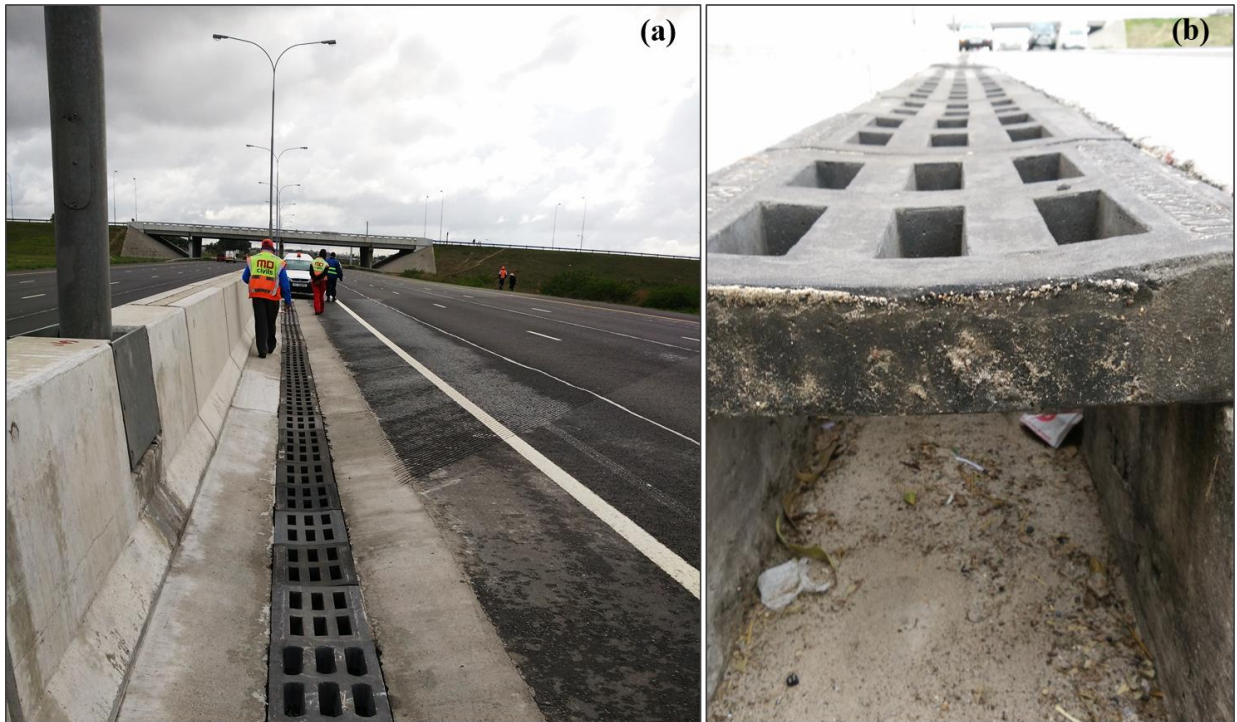
**Figure 4-2: Map locating sampling sites along the R300**



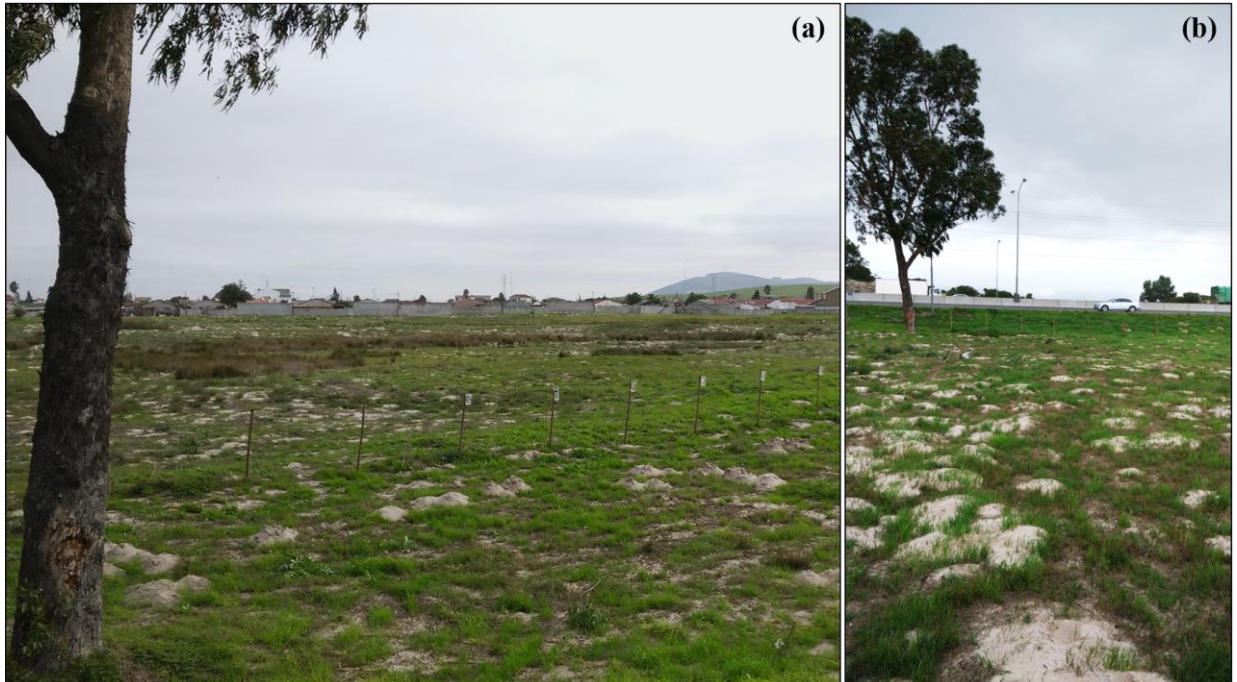
**Figure 4-3: Sample Site 1 (a) the asphalt catchment area and concrete median drain, (b) concrete drain and catchpit inlet, and (c) plan view of the catchpit**



**Figure 4-4: Sample Site 2 (a) the catchpit inlet grid, (b) the asphalt catchment and concrete median drain, and (c) view inside the catchpit**



**Figure 4-5: Sample Site 3 (a) the asphalt catchment area and longitudinal drain, and (b) view inside the longitudinal drain**



**Figure 4-6: Sample Site 4 (a) view from the road towards the sample site, and (b) view from the sample site towards the road**

Literature regarding contaminants in highway sediment and stormwater indicate that heavy metals and hydrocarbons are the most significant pollutants originating from road use (Shinya *et al.*, 2000). Analysis was conducted for constituents that are both likely to occur and expected to have consequences in significant quantities. The primary heavy metals of concern are zinc, lead, cadmium, chromium, copper and manganese. Furthermore, platinum group metals are emitted by catalytic converters and have been observed to accumulate on the road surface. Both heavy metals and platinum group elements bio-accumulate and do not degrade in the environment, potentially causing toxic effects in fauna and humans. Oils and greases and other hydrocarbons originate from vehicle wear and tear and degradation of the road surface, potentially hindering growth and reproduction of certain organisms (Erickson *et al.*, 2013).

As there is little local data regarding road runoff contaminants in South Africa, the sampling analysis was adjusted in accordance with results as they were received. Initially, sand samples were tested for cadmium, chromium, copper, lead, zinc, platinum, palladium, rhodium, PAHs and oils and greases. After receiving results with negligible concentrations of PAHs and platinum group metals, these constituents were abandoned and a more complete set of metals was tested for. Runoff samples and subsequent sand samples were tested for aluminium, arsenic, cadmium, chromium, copper, lead, manganese, nickel, zinc, total phosphorus and total nitrogen. Furthermore, runoff samples were analysed for chemical oxygen demand, oils and greases and total suspended solids.

### 4.3 Sediment sampling method

Sediment samples were collected on 17 March, 23 March, 21 April and 18 May 2016. At each sampling event, samples were collected from all sample sites.

Prewashed sample containers were provided by Jones Environmental Laboratory in line with the analysis requirements. 60g Amber glass jars were used to store the samples, which prevented sample contamination and the decay of constituents. Sample containers were labelled prior to the sampling event and received a unique identification (ID) identifying the location and date of collection. After collection, the samples were refrigerated and couriered to the laboratory in polystyrene chests with ice packs to maintain a 10°C temperature in order to preserve the sample.

Sand samples were swept with a horsehair brush into a polypropylene dustpan and transferred to the sample jars on site. Care was taken to include the fines fraction in the sample volume as this fraction is inclined to adhere to the surface of the sampling equipment and has been shown to contain the highest concentration of contaminants (Zafra *et al.*, 2011). Large particles including glass, grass, stones and insects were removed from the samples. Between sampling locations, the brush and dustpan were wiped clean with a cotton cloth. Between sampling events the sampling equipment was washed with detergent and rinsed to prevent cross contamination.

At Sample Locations 1 and 3, samples were collected from the concrete median drains approaching the catchpits. Care was taken to sweep from different locations along the drain at each sampling event. At Site 2, samples were collected from within the longitudinal drain where the drain had a depth of approximately 250mm. Samples were collected from locations containing sand that was free from insects, organic matter and motor fluids. At Site 4, samples were collected from approximately 20mm below the surface in order to obtain environmental baseline contamination levels. Samples were taken from locations where the sand was loose and free from noticeable localised contamination. Table 4-1 presents a summary of the sampling events. Additional details are provided in Appendix E.

**Table 4-1: Summary of sediment sampling events**

	Sample Event 1	Sample Event 2	Sample Event 3	Sample Event 4
Date	17-03-2016	23-03-2016	21-04-2016	18-05-2016
Time	10:50 - 11:25	10:05 - 10:55	10:35 - 11:40	13:15 - 14:00
Conditions	Hot and dry	Hot and dry	Overcast and humid	Windy, light drizzle
Temperature	27°C	25°C	17°C	17°C
Wind	2m/s WSW	4m/s S	4m/s NW	6m/s NNW
Precipitation	0mm	0mm	1.5mm	0mm
Sample contents	Sediment	Sediment	Sediment	Sediment
Sample type	Single	Single	Single	Single
Deviations/ comments	Included sand caught in catchpit grid and from expansion joints in the concrete drain.	Included sand caught in catchpit grid and from expansion joints in the concrete drain.	Wet samples due to rain. Sampled from within the catchpit at Site 2 as drain was washed clean.	Swept from drain leading towards and away from catchpit. Large number of ants/insects that were difficult to exclude

#### 4.4 Sediment sampling results

Analysis results of the sediment sampling are presented in Table 4-2 and Table 4-3. ‘R300 sediment’ refers to samples taken from the road surface including surface drains and catchpits, while ‘environment’ refers to samples taken from the undisturbed area approximately 80m from the roadway. Analysis for platinum group metals and PAHs were discontinued following two sampling events, as results were consistently below or close to the detection limits.

A particle size distribution test was performed on composite samples collected from the road surface at each sample event in accordance with *British Standard 1377-2:1990, Determination of particle size distribution, Dry sieving method* (British Standards Institution, 1990). Particle size ranged between 0.02mm and 5mm, with an 85<sup>th</sup> percentile size of 0.83mm, which compares to other highway sediment studies (Vaze & Chiew, 2002).

**Table 4-2: Contaminant concentrations in road and environmental sediment for all sampling events**

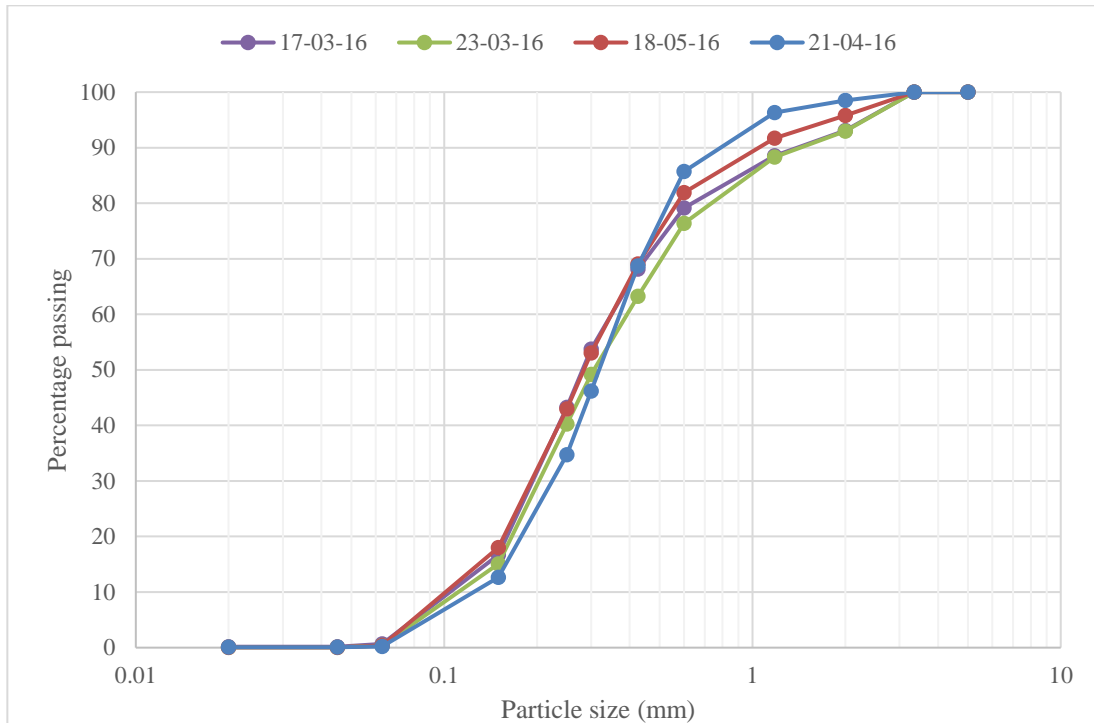
Sample ID	LOD*	Unit	R300 sediment											Environmental				
			27.6S-0317-1	17.9S-0317-1	24.4N-0317-1	27.7S-0323-1	17.7S-0323-1	24.4N-0323-1	27.7S-0421	17.7S-0421	24.4N-0421	27.7S-0518-1	17.7S-0518-1	24.4N-0518-1	21.4N-0317-1	21.4N-0323-1	21.4N-0421	21.4N-0518-1
Aluminium	<50	mg/kg							5348.0	2614.0	2213.0	4913.0	3213.0	2337.0			416.0	413.0
Arsenic	<0.5	mg/kg							4.6	2.2	1.3	5.1	2.5	2.3			<0.5	0.5
Cadmium	<0.1	mg/kg	<0.1	0.1	0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.3	<0.1	<0.1	<0.1	<0.1
Chromium	<0.5	mg/kg	104.5	56.2	68.6	168.8	116.6	124.0	46.7	30.9	28.6	65.8	29.2	24.1	17.1	34.4	3.3	3.3
Copper	<1	mg/kg	83.0	42.0	37.0	68.0	54.0	25.0	63.0	29.0	28.0	54.0	37.0	24.0	2.0	1.0	<1	2.0
Lead	<5	mg/kg	17.0	43.0	31.0	95.0	34.0	191.0	35.0	45.0	26.0	31.0	53.0	23.0	<5	<5	<5	<5
Manganese	<1	mg/kg							139.0	83.0	68.0	322.0	95.0	155.0			8.0	7.0
Nickel	<0.7	mg/kg							8.6	4.4	3.9	11.6	6.3	4.8			<0.7	<0.7
Zinc	<5	mg/kg	76.0	171.0	116.0	114.0	141.0	147.0	231.0	266.0	169.0	161.0	144.0	70.0	<5	<5	<5	<5
Phosphorus	<10	mg/kg	344.0	484.0	281.0	373.0	406.0	319.0	345.0	322.0	377.0	472.0	450.0	330.0	196.0	231.0	200.0	188.0
Total nitrogen	<0.01	%							0.1	0.1	<0.01	0.1	0.1	<0.01			0.1	<0.01
Palladium	<5	mg/kg	<5	<5	<5	<5	<5	<5							<5	<5		
Platinum	<5	mg/kg	<5	<5	<5	<5	<5	<5							<5	<5		
Rhodium	<1	mg/kg	<1	<1	<1	<1	<1	<1							<1	<1		
Fats, O&G	<30	mg/kg	119.0	265.0	141.0	156.0	247.0	209.0	175.0	216.0	221.0	255.0	203.0	219.0	<30	<30	<30	<30
Moisture Content	<0.1	%	0.5	0.5	<0.1	<0.1	<0.1	<0.1	18.9	42.1	18.9	0.5	0.8	0.1	0.0	0.5	0.5	0.2

\*LOD = Limit of Detection

Table 4-3: PAH concentrations in road and environmental sediment and runoff samples

	LOD	Unit	R300 sediment						Environmental		LOD	Unit	Runoff			Rain water
			27.6S-0317-2	17.9S-0317-2	24.4N-0317-2	27.7S-0323-2	17.7S-0323-2	24.4N-0323-2	21.4N-0317-2	21.4N-0323-2			27.7S-0614	17.05S-0614	24.4N-0614	21.4N-0614
Naphthalene	<0.04	mg/kg	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1	µg/l	<0.04	<0.04	<0.04	<0.04
Acenaphthylene	<0.03	mg/kg	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.013	µg/l	<0.013	0.03	<0.013	<0.013
Acenaphthene	<0.05	mg/kg	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.013	µg/l	<0.013	<0.013	<0.013	<0.013
Fluorene	<0.04	mg/kg	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.014	µg/l	0.03	0.04	0.02	0.02
Phenanthrene	<0.03	mg/kg	0.06	0.16	0.08	0.19	0.16	0.03	<0.03	<0.03	<0.011	µg/l	0.19	0.18	0.04	0.04
Anthracene	<0.04	mg/kg	<0.04	<0.04	<0.04	0.05	<0.04	<0.04	<0.04	<0.04	<0.013	µg/l	0.02	0.03	<0.013	<0.013
Fluoranthene	<0.03	mg/kg	0.12	0.20	0.08	0.62	0.19	0.04	<0.03	<0.03	<0.012	µg/l	0.28	0.35	0.07	0.02
Pyrene	<0.03	mg/kg	0.09	0.17	0.07	0.44	0.17	0.04	<0.03	<0.03	<0.013	µg/l	0.22	0.43	0.07	<0.013
Benzo(a)anthracene	<0.06	mg/kg	<0.06	<0.06	<0.06	0.26	0.09	<0.06	<0.06	<0.06	<0.015	µg/l	0.03	0.07	<0.015	<0.015
Chrysene	<0.02	mg/kg	0.06	0.08	0.03	0.28	0.09	0.03	<0.02	<0.02	<0.011	µg/l	0.08	0.11	<0.011	<0.011
Benzo(bk)fluoranthene	<0.07	mg/kg	<0.07	0.10	<0.07	0.25	0.14	<0.07	<0.07	<0.07	<0.018	µg/l	0.04	0.14	<0.018	<0.018
Benzo(a)pyrene	<0.04	mg/kg	<0.04	0.05	<0.04	0.10	0.08	<0.04	<0.04	<0.04	<0.016	µg/l	<0.016	0.10	<0.016	<0.016
Indeno(123cd)pyrene	<0.04	mg/kg	<0.04	<0.04	<0.04	0.05	0.07	<0.04	<0.04	<0.04	<0.011	µg/l	<0.011	0.12	<0.011	<0.011
Dibenzo(ah)anthracene	<0.04	mg/kg	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.01	µg/l	<0.04	<0.04	<0.04	<0.04
Benzo(ghi)perylene	<0.04	mg/kg	<0.04	0.07	<0.04	0.05	0.09	0.04	<0.04	<0.04	<0.011	µg/l	<0.011	0.30	<0.011	<0.011
Benzo(b)fluoranthene	<0.05	mg/kg	<0.05	0.07	<0.05	0.18	0.10	<0.05	<0.05	<0.05	<0.195	µg/l	0.03	0.10	<0.195	<0.195
Benzo(k)fluoranthene	<0.02	mg/kg	<0.02	0.03	<0.02	0.07	0.04	<0.02	<0.02	<0.02	<0.01	µg/l	0.01	0.04	<0.02	<0.01
PAH 16 Total	<0.6	mg/kg	<0.6	0.80	<0.6	2.30	1.10	<0.6	<0.6	<0.6	<0.01	µg/l	0.89	1.90	0.20	<0.01
PAH % Recovery	<0	%	102	109	105	119	117	118	103	122	<0	%	72	71	73	71

The particle size distribution for the four sampling events is shown in Figure 4-7. The particle size envelope is relatively small, indicating a homogenous and consistent particle size distribution in the surface sediment.



**Figure 4-7: Particle size distribution of sediment samples on the R300**

The environmental samples contain lower levels of all contaminants for every sampling event when compared to the road samples. Higher concentrations of PAHs were found when the sample was taken from within the catchpit as opposed to the median surface drain, which indicates that the catchpits may concentrate hydrocarbons. Fluoranthene and Pyrene were found in the highest concentrations, with maximum concentrations of 0.62mg/kg and 0.44mg/kg respectively. The road sediment contained aluminium, total phosphorus, zinc and manganese in the highest concentrations, while cadmium, arsenic and nickel were found in low concentrations. The concentration of aluminium is an order of magnitude greater than the other metal contaminants. The high concentrations of zinc and manganese, and low concentrations of nickel and cadmium closely compare with results obtained from a highway in Spain (Zafra *et al.*, 2011).

A two-sample t-test assuming unequal variances was performed to assess whether there is a statistically significant difference between road and environmental sediment contamination. The total heavy metals concentration in road sediment (mean = 2116mg/kg, standard deviation (SD) = 2093mg/kg) is significantly greater than the total metals concentration in environmental sediment (mean = 227mg/kg, SD = 231mg/kg);  $t(12) = 3.1$ ,  $p = 0.005$ . Similarly, the total phosphorus concentration in road sediment (mean = 375mg/kg, SD = 65mg/kg) is significantly

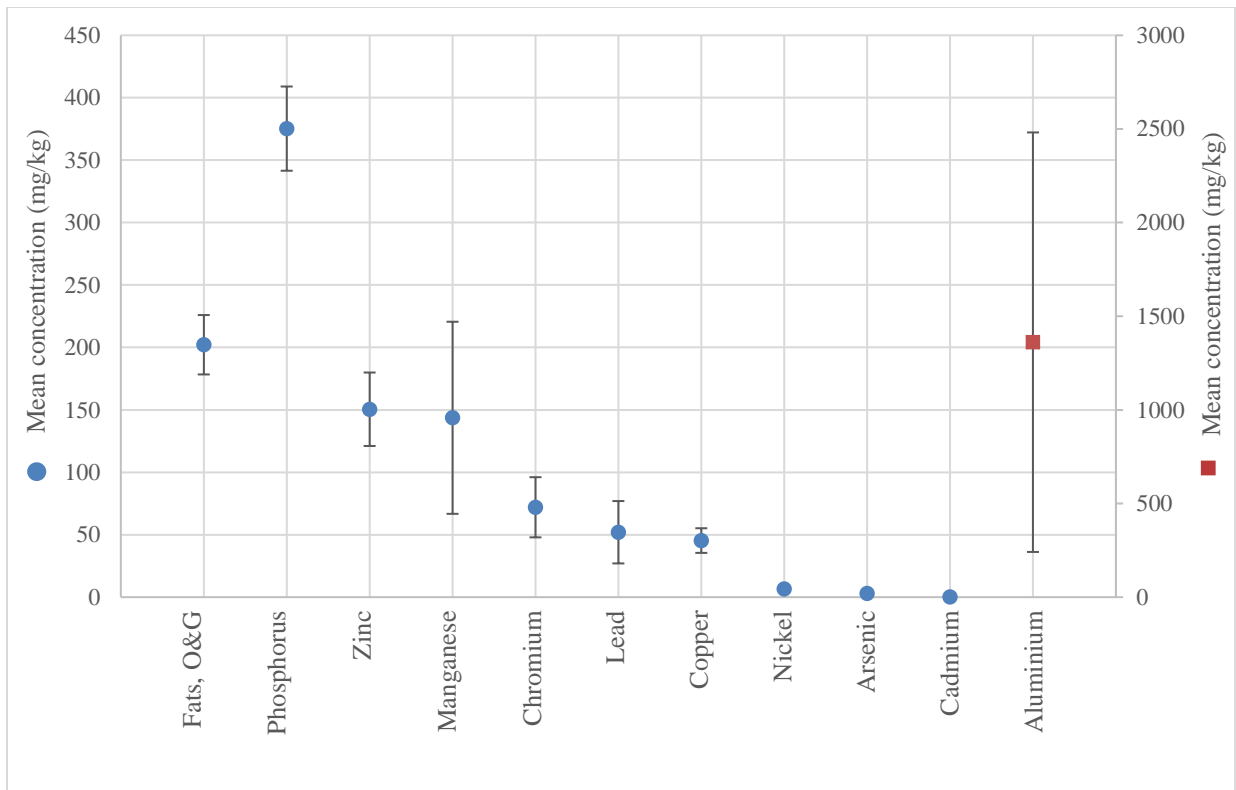
greater than the environmental concentration (mean = 204mg/kg, SD = 19mg/kg);  $t(14) = 8.2$ ,  $p = 5.4E-07$ . Lastly, the concentration of fats, oils and grease in road sediment (mean = 202mg/kg, SD = 46mg/kg) is significantly greater than the concentration in environmental sediment (mean = 0mg/kg, SD = 0mg/kg);  $t(11) = 15.2$ ,  $p = 4.7E-09$ . Calculations are provided in Appendix F. These results show that sediment collected on the R300 highway is significantly more contaminated than the surrounding sediment for heavy metals, phosphorus and fats, oils and greases.

Descriptive statistics were generated for the road sediment results using the t-distribution to calculate confidence intervals. The t-distribution assumes a normally distributed population and is suitable for small samples where  $n < 30$ . The mean concentration is provided with a confidence interval (90% confidence level) for each contaminant in Table 4-4. Figure 4-8 presents this information graphically; note that aluminium is plotted on a secondary axis.

The *Draft National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (NEMWA, No. 59 of 2008)* provides minimum standards for assessing environmental protection measures. Table 4-5 compares the R300 road surface sample mean contamination with the maximum permissible concentration set down in the norms and standards. Target concentrations for all land uses (including the protection of human and ecosystem health, considering contaminant migration to water resources) and for the protection of ecosystem health, excluding human health, are provided. The mean concentration of chromium, copper and lead exceed the target concentrations for the protection of human health. Barring copper concentrations, all contaminant concentrations in the road surface sediment are within the range required to protect ecosystem health.

**Table 4-4: Descriptive statistics for the sediment contaminant concentrations**

Contaminant	Unit	Count	Min	Max	Range	Mean $\pm$ confidence interval (90% confidence level)
Aluminium	mg/kg	6	2213	5348	3135	3440 $\pm$ 1120
Arsenic	mg/kg	6	1	5	4	3 $\pm$ 1
Cadmium	mg/kg	12	0	0	0	0 $\pm$ 0
Chromium	mg/kg	12	24	169	145	72 $\pm$ 24
Copper	mg/kg	12	24	83	59	45 $\pm$ 10
Lead	mg/kg	12	17	191	174	52 $\pm$ 25
Manganese	mg/kg	6	68	322	254	144 $\pm$ 77
Nickel	mg/kg	6	4	12	8	7 $\pm$ 2
Zinc	mg/kg	12	70	266	196	151 $\pm$ 29
Phosphorus	mg/kg	12	281	484	203	375 $\pm$ 34
Total Nitrogen	%	6	0	0	0	0 $\pm$ 0
Fats, oils and grease	mg/kg	12	119	265	146	202 $\pm$ 24



**Figure 4-8: Mean concentrations of contaminants in R300 sediment**

**Table 4-5: Sediment contaminant concentrations in comparison to norms and standards for polluted land and soil quality (NEMWA, No. 59 of 2008)**

		Sample mean	Target concentration	
		R300	All land uses protective of water resources	Protection of ecosystem health
Arsenic	mg/kg	3.0	5.8	580
Cadmium	mg/kg	0.1	7.5	37
Chromium	mg/kg	72.0	6.5	260
Copper	mg/kg	45.3	16	16
Lead	mg/kg	52.0	20	100
Manganese	mg/kg	143.7	740	36000
Nickel	mg/kg	6.6	91	1400
Zinc	mg/kg	150.5	240	240

## 4.5 Runoff sampling method

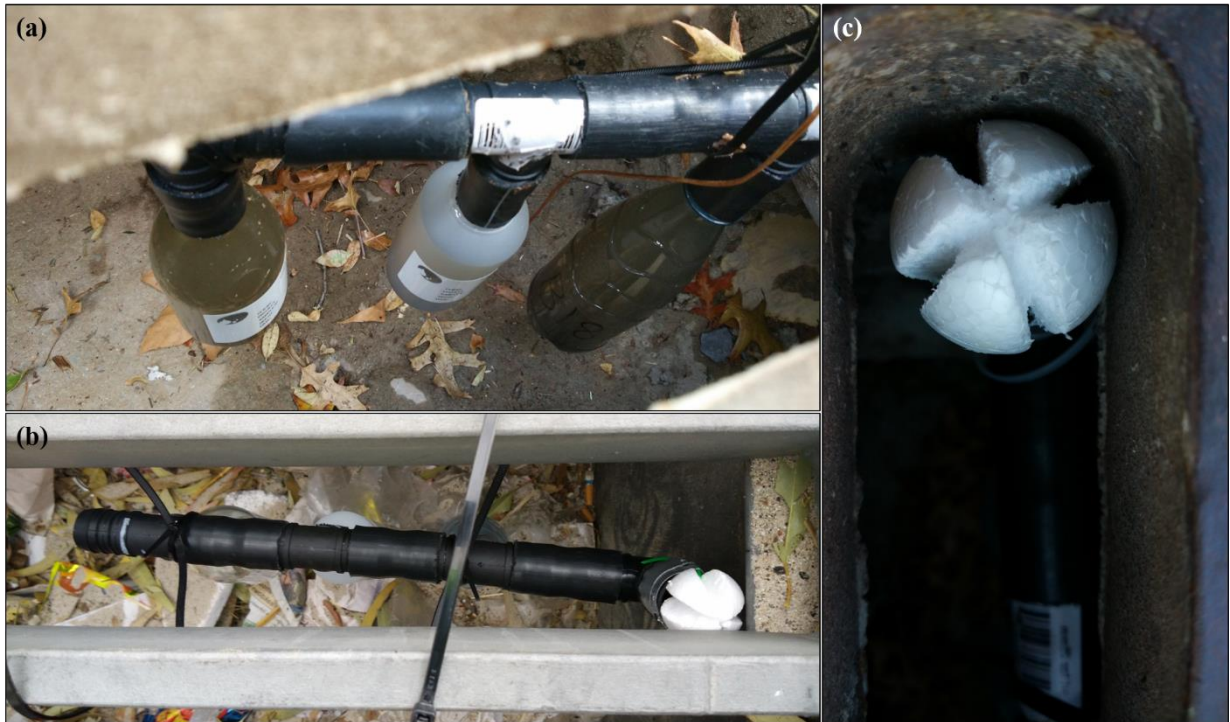
Highway runoff and rainwater samples were collected on 22 April, 18 May, 24 May, 6 June and 14 June. These dates correspond with the first rains of the 2016 winter season in Cape Town, barring one event, as it occurred over a weekend which precluded sampling.

Prewashed sample containers were provided by Jones Environmental Laboratory in line with the analysis requirements. 250ml Clear glass bottles (for O&G and PAH analysis) and 250ml clear plastic bottles (for metals, nutrients, COD and TSS analysis) were used to store the samples. Sample containers were labelled prior to the sampling event and received a unique ID identifying the location and date of collection. After collection, the samples were refrigerated and couriered to the laboratory in polystyrene chests with ice packs to maintain a 10°C temperature in order to preserve the sample.

Due to financial constraints, sampling was limited to 20 grab samples for analysis. Furthermore, due to safety and organisational constraints it was not possible to take samples during the rainfall event. Therefore, runoff capture devices were installed in the catchpits and collected either on the day of the rainfall event or one day subsequent. At Sample Sites 1, 2 and 3, custom-made devices modelled on a design by René Schieritz, a previous master's degree student at the University of Cape Town, were installed in the catchpit to sample the stormwater runoff. The runoff sampling device is shown in Figure 4-9 and shown installed on site in Figure 4-10. At Sample Site 4, rainwater was collected in modified polyethylene terephthalate (PET) bottles.



**Figure 4-9: Custom-made runoff sampling device**



**Figure 4-10: Runoff sampling device on site: (a) sample containers, (b) placement in catchpit with incoming flow from the right hand side, and (c) flow restricting inlet**

The runoff sampling device was designed to remain in the catchpit and take a composite sample of the runoff entering the drain. Stormwater flows around the polystyrene ball into the black, polyethylene pipe, from which it sequentially fills the sample bottles. The modified polystyrene ball located at the entrance to the device ensures that the pipes are not blocked by debris and limits inflow. Each sample bottle contains a polystyrene ball which floats until it reaches the neck of the bottle where it blocks additional inflow. Compressed paper washers were glued to each bottle lip in order to create a better seal with the polystyrene ball.

It is recommended in the literature that grab samples are obtained 2 – 3 hours after the first runoff, and that a composite grab sample is collected in order to obtain a good estimation of the average contaminant concentrations (Ma *et al.*, 2009; Lee *et al.*, 2011). Research by Deletic (1998) indicates that road surfaces may have a minor first flush effect. Therefore, the device included a 500ml storage volume, shown on the right hand side of Figure 4-9, to capture the initial stormwater runoff, which can contain a higher concentration of contaminants. As the intention was to obtain an estimate of the mean concentration for comparative and modelling purposes, the contents of this first bottle were discarded, and the labelled sample bottles were sent to the laboratory for analysis.

The device was tested under controlled conditions to ensure that it functioned as expected on site. In preliminary tests, the device was installed in a similar catchpit to those on site and a known volume of water was poured into the drain leading to the catchpit. The device collected

approximately 1% of the incoming flow. This fraction varies according to how the bottle is installed relative to the incoming flow, the flow rate and temporary blockages caused by leaves and other debris. Once the bottles were full, dye was poured into the device in order to ensure that the bottles were sealing. If dye was observed in the sample bottles, it would indicate that the bottles were allowing inflow past the polystyrene ball plug.

Rainwater was collected using modified PET bottles. The bottles were washed with detergent and rinsed with a dilute sulphuric acid solution prior to field use. They were then suspended on wooden fence poles approximately 1.2m above the ground surface. Care was taken to ensure the bottle lip was above the wire fence strands to minimise contamination.

Table 4-6 summarises the runoff sampling events. Photographs of the runoff samples from each sampling event are provided in Appendix G. There were several variations to the sampling procedure as follows:

- On 22 April 2016, grab samples were taken during the rainfall event by holding the sample bottle in the runoff stream flowing into the catchpit. Samples were only taken at Site 1, Site 2 and Site 4 for safety reasons. The rainwater sample was attached to a metal lamppost.
- On 18 May 2016, samples were not collected from Site 3 due to safety concerns.
- On 14 June 2016, samples were analysed for PAHs, COD and TSS rather than the standard analysis.

**Table 4-6: Summary of runoff sampling events**

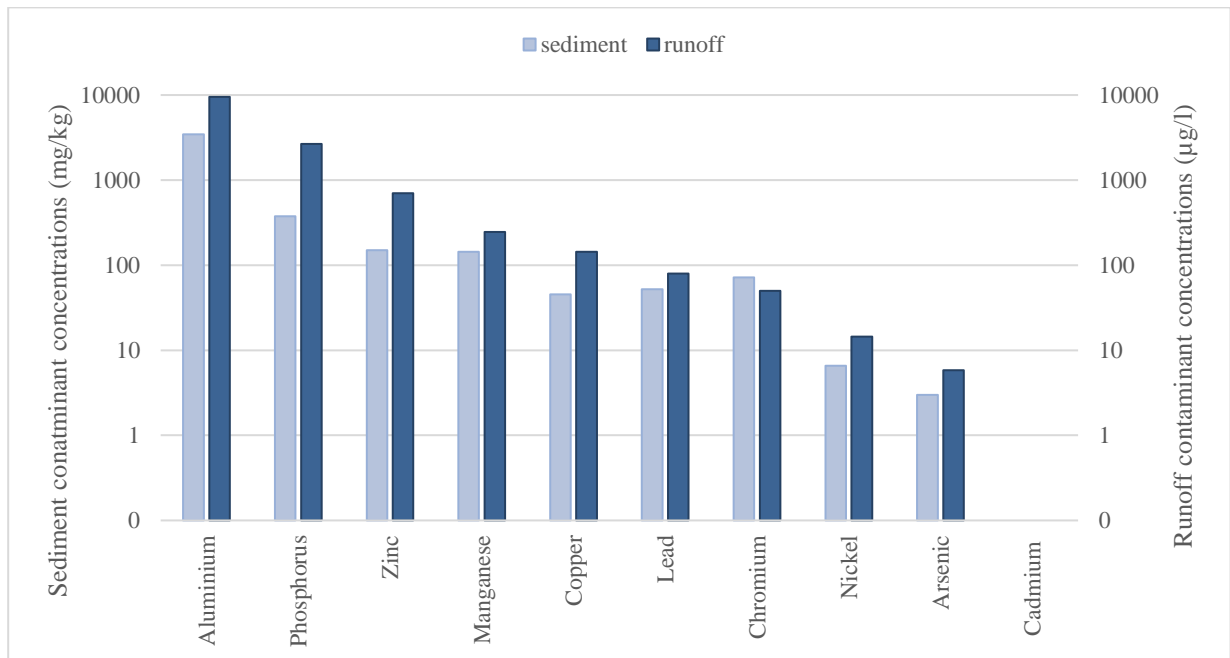
	<b>Sample Event 5</b>	<b>Sample Event 6</b>	<b>Sample Event 7</b>	<b>Sample Event 8</b>	<b>Sample Event 9</b>
Date	22-04-2016	19-05-2016	24-05-2016	10-06-16	14-06-2016
Time	15:30 - 16:05	13:30 - 13:45	10:55 - 11:20	10:00 - 10:40	10:15 - 10:45
General conditions	Intense rain, first storm of the rainy season	Large storm system over cape region	Afternoon/evening rainfall	Overnight rainfall. Cold and overcast	Partly sunny, cold
Temperature	18°C	18°C	15°C	14°C	13°C
Wind	6m/s NNW	6m/s SSE	5m/s N	5m/s NE	4m/s NNW
Precipitation	29mm	4mm	12mm	17mm	8mm
Contents	Runoff	Runoff	Runoff	Runoff	Runoff
Sample type	Single grab sample	Extended grab sample	Extended grab sample	Extended grab sample	Extended grab sample
Deviations/comments	Accident near Site 1, but this did not contaminate runoff	Large amount of sediment trapped in sampling device	All sediment and debris cleared from catchpits by rainfall event	Lots of organic matter including grass cuttings and leaves in catchpits	Sample containers deployed in catchpits on Friday 10-06-16

## 4.6 Runoff sampling results

Analysis results of the runoff sampling are presented in Table 4-7 and Table 4-8. Samples were collected from runoff as it entered the catchpit and the environmental sample was obtained by collecting rainwater during sampling events at the environmental site. Analysis was conducted for metals, TSS, nutrients, COD and oil and grease. One sample was analysed for PAHs, which yielded similar results to the sand sampling as shown in Table 4-3. Fluoranthene and pyrene were found in the highest concentrations, with maximum concentrations of 0.35 $\mu\text{g/l}$  and 0.43 $\mu\text{g/l}$ .

The rainwater samples contain lower levels of all contaminants for every sampling event when compared to the runoff samples, except for two instances where the rainwater sample contained higher concentrations of zinc. For these two events, the sample container was attached to a metal lamp post rather than a wooden fence pole, which is the most likely source of the zinc (Legret & Pagotto, 1999). This result indicates that metal roadside structures such as signage, barriers and posts are an important source of metals in stormwater runoff.

The results for the surface runoff show a higher level of variability than the sediment samples. The surface runoff contained aluminium, total phosphorus, zinc and manganese in the highest concentrations, while cadmium, arsenic and nickel were found in low concentrations. Figure 4-11 shows the distribution of metal concentrations in the sediment and runoff samples, indicating the relative concentration of each contaminant. Note that the samples are measured in different units and presented on a logarithmic scale. This graph illustrates that the pollutant concentration profile is similar in road sediment and runoff on the R300. This supports the notion that sediment analysis provides useful information regarding runoff water quality.



**Figure 4-11: Relative contaminant concentrations in sediment and runoff on the R300**

**Table 4-7: Contaminant concentrations in R300 surface runoff**

Sample ID	LOD	Units	27.7S-0422	27.7N-0422	24.4N-0422	27.7S-0518	24.4N-0518	27.7S-0524	24.4N-0524	17.4S-0524	27.7S-0610	24.4N-0610	17.0S-0610	27.7S-0614	17.0S-0614	24.4N-0614
Total Aluminium	<20	µg/l	3341	3479	3088	5682	9620	6333	9517	10390	5615	41770	5426			
Total Arsenic	<2.5	µg/l	<2.5	<2.5	<2.5	3.3	5.5	5.9	5.3	8.8	<2.5	28.9	6.2			
Total Cadmium	<0.5	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5			
Total Chromium	<1.5	µg/l	13.9	13.9	14.7	29.8	39.1	32.8	53.4	34.3	26.1	250.3	41			
Total Copper	<7	µg/l	67	74	71	120	150	126	191	138	93	389	155			
Total Lead	<5	µg/l	32	32	32	50	59	61	122	66	50	316	57			
Total Manganese	<2	µg/l	93	95	84	219	260	174	259	195	171	909	243			
Total Nickel	<2	µg/l	6	5	5	13	17	13	16	13	9	50	12			
Total Zinc	<3	µg/l	232	242	287	471	568	582	843	667	371	2826	593			
Total Phosphorus	<5	µg/l	333	361	383	1485	1681	965	2401	1445	1383	14930	3895			
Total Nitrogen	<0.5	mg/l	3.6	2.8	3.3	97.2	51.7	6.8	5.7	5.4	7.8	11.9	15.3			
COD	<9	mg/l	12	27	86	300	180	320	140	200	67	170	300	72	133	60
Oil and Grease	<50	mg/l	<50	70	<50	89	<50	6779	<50	108	746	410	161	<50	53	50
Total Suspended Solids	<10	mg/l	<10	33	116	154	298	550	8588	3372	108	176	208	126	354	30

**Table 4-8: Contaminant concentrations in rainwater collected adjacent to the R300**

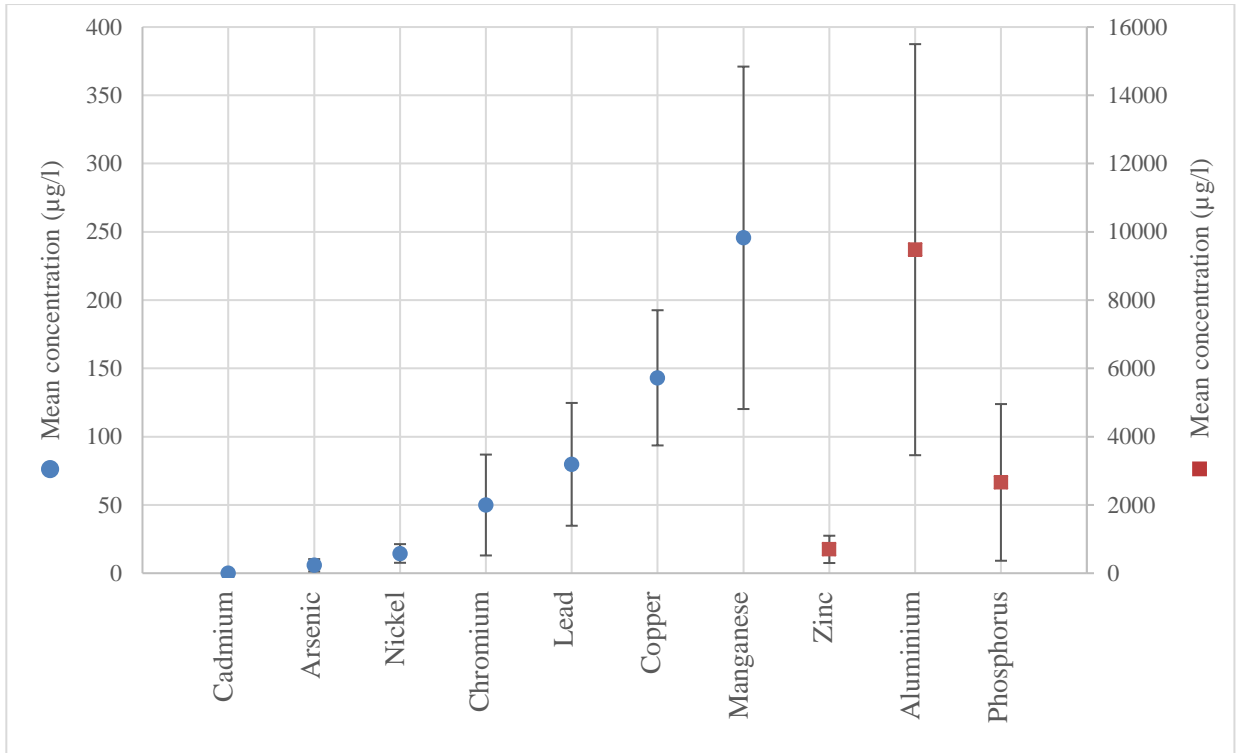
Sample ID	LOD	Units	21.4N-0422	21.4N-0518	21.4N-0524	21.4N-0610	21.4N-0614
Total Aluminium	<20	µg/l	<20	96.0	42.0	83.0	
Total Arsenic	<2.5	µg/l	<2.5	<2.5	<2.5	<2.5	
Total Cadmium	<0.5	µg/l	<0.5	<0.5	<0.5	<0.5	
Total Chromium	<1.5	µg/l	<1.5	4.3	<1.5	<1.5	
Total Copper	<7	µg/l	<7	<7	<7	<7	
Total Lead	<5	µg/l	<5	<5	<5	<5	
Total Manganese	<2	µg/l	<2	6.0	<2	<2	
Total Nickel	<2	µg/l	<2	<2	<2	<2	
Total Zinc	<3	µg/l	969.0	773.0	154.0	30.0	
Total Phosphorus	<5	µg/l	43.0	43.0	49.0	47.0	
Total Nitrogen	<0.5	mg/l	2.4		1.3	1.1	
COD	<9	mg/l	<9		9.0	<9	<9
Oil and Grease	<50	mg/l	<50		<50	321.0	<50
Total Suspended Solids	<10	mg/l	<10		<10	<10	<10

A two-sample t-test assuming unequal variances was performed to assess whether there is a statistically significant difference between road runoff and rainwater quality characteristics. Results for the oil and grease and TSS concentrations from 24 May have been excluded from this analysis as Jones Environmental reported that the sample temperature on receipt was inappropriate. The statistical analysis is available in Appendix F. The total metals concentration in road runoff (mean = 10,715 µg/l, SD = 12,223 µg/l) is significantly greater than the metals concentration in rainwater (mean = 539 µg/l, SD = 447 µg/l) in the same location;  $t(10) = 2.8$ ,  $p = 0.01$ . Similarly, the TSS concentration is greater in road runoff (mean = 146 µg/l, SD = 110 µg/l) compared to rainwater (mean = 0 µg/l, SD = 0 µg/l);  $t(10) = 4.4$ ,  $p\text{-value} = 0.0007$ . Based on the sample results, it is not possible to say whether the oil and grease concentration is different in road runoff and rainwater.

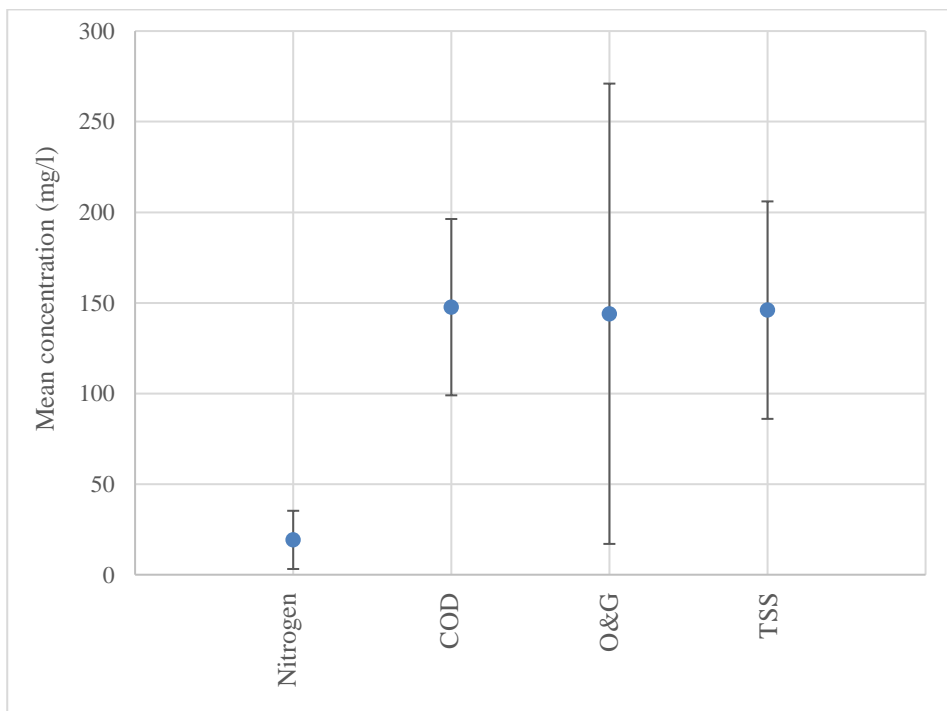
Descriptive statistics were generated for the results using the t-distribution to calculate confidence intervals. The mean concentration for each contaminant is provided with a confidence interval (90% confidence level) for each contaminant in Table 4-9. This information is shown graphically in Figure 4-12 for metals and Figure 4-13 for non-metals. Note that zinc, aluminium and phosphorus are plotted on a secondary axis in Figure 4-12 to account for the variation in pollutant concentrations.

**Table 4-9: Descriptive statistics for the runoff contaminant concentrations**

Contaminant	Unit	Count	Min	Max	Range	Mean ± confidence interval (90% confidence level)
Total Aluminium	µg/l	11	3088	41770	38682	9478 ± 6021
Total Arsenic	µg/l	11	0	29	29	6 ± 5
Total Cadmium	µg/l	11	0	0	0	0 ± 0
Total Chromium	µg/l	11	14	250	236	50 ± 37
Total Copper	µg/l	11	67	389	322	143 ± 50
Total Lead	µg/l	11	32	316	284	80 ± 45
Total Manganese	µg/l	11	84	909	825	246 ± 125
Total Nickel	µg/l	11	5	50	45	14 ± 7
Total Zinc	µg/l	11	232	2826	2594	698 ± 399
Total Phosphorus	µg/l	11	333	14930	14597	2660 ± 2295
Total Nitrogen	mg/l	11	3	97	94	19 ± 16
COD	mg/l	14	12	320	308	148 ± 49
Oil and Grease	mg/l	11	0	746	746	144 ± 127
Total Suspended Solids	mg/l	11	0	354	354	146 ± 60



**Figure 4-12: Mean concentration of metal contaminants in R300 runoff waters**



**Figure 4-13: Mean concentration of non-metal contaminants in R300 runoff waters**

In the absence of water quality guidelines that specify constituent concentrations for stormwater, the runoff sample results are compared to the guidelines provided by the DWS for aquatic environments. The water quality guidelines are to ensure the sustainable use of aquatic ecosystems (including their use as a disposal pathway for stormwater drainage) in a manner that enables ecosystems to maintain their integrity (DWS, 1996). The DWS does not provide a guideline for oil and grease concentration in aquatic environments. The Department of Environmental Affairs (DEA), however, provides regulations for the oil and grease concentration in effluent draining to a river catchment. In this instance, the mean concentration of oil and grease in the highway runoff waters is 144mg/l, which greatly exceeds the effluent standards of 2.5mg/l (DEA, 1984).

Table 4-10 compares the runoff quality to two aspects of the water quality guidelines from the DWS; the upper limit of the Target Water Quality Range (TWQR) and the Acute Effect Value (AEV). The TWQR represents a range of concentrations for which there are no adverse effects on ecosystem health, and the AEV indicates a concentration above which up to 5% of the species in the aquatic community will experience toxic effects. If acute effects persist or occur at too high a frequency, sensitive species of the aquatic ecosystem will perish.

Mean concentrations of arsenic and cadmium are below the TWQR, while mean concentrations of manganese and chromium fall below the AEV but exceed the TWQR. The mean concentrations of aluminium, copper, lead, phosphorus and zinc all exceed the AEV in excess of 1000%.

**Table 4-10: Runoff contaminant concentrations compared to the DWS water quality guidelines**

	Units	Runoff	Aquatic ecosystem water quality guidelines	
		Mean	Target Water Quality Range	Acute Effect Value
Total Aluminium	µg/l	9478.3	5	100
Total Arsenic	µg/l	5.8	10	130
Total Cadmium	µg/l	0.0	0.25	6
Total Chromium	µg/l	49.9	12	340
Total Copper	µg/l	143.1	0.8	4.6
Total Lead	µg/l	79.7	0.5	7
Total Manganese	µg/l	245.6	180	1300
Total Nitrogen	mg/l	19.2	0.5	10
Total Phosphorus	µg/l	2660.2	0.5	250
Total Zinc	µg/l	698.4	2	36
Total Suspended Solids	mg/l	145.7	100	-

Two important points must be made with regard to this data. Firstly, the runoff water entering the catchpits is significantly cleaner than the water exiting the culverts to the verge when assessed on odour and visual indicators such as clarity and oil sheen. The catchpits concentrate pollutants (Figure 3-11) that then remain in the culvert due to sedimentation and low flow rates. Stagnant pools form between rainfall events, contaminating the subsequent incoming runoff which washes the pollutants to the verge. Secondly, in the case of the R300, runoff waters from the road surface will be diluted by runoff from the verge before entering nearby aquatic ecosystems. The R300 verge runoff is unlikely to contribute significant quantities of metals, hydrocarbons or nutrients, as the surface is primarily sparsely vegetated sandy soil.

## 4.7 Errors and limitations

The following section details the limitations of the sampling exercise. The runoff was sampled by collecting a small fraction of the incoming flow with a device that created a composite sample. This technique provides more robust measurements than collecting a sample at a single point in time (Ma *et al.*, 2009), but is inferior to the standard technique of creating a flow weighted sample volume. Moreover, it was not possible to ascertain the time it took to fill the sample during each sampling event, or the time at which the initial storage volume was filled and the sample bottles began to collect runoff. As such, the sample volumes for different sampling events consist of different fractions of the total rainfall volume.

The extended grab samples provide data that is specific to a singular time period and place. This ‘snapshot’ gives a loose estimate of the mean concentration and the range of pollutant concentrations in the R300 runoff waters. The sediment samples were collected as isolated grab samples, making these measurements more susceptible to random variation and localised effects. The sampling was conducted over three months from April to June, therefore the data is unable to account for seasonal or temporal variation.

The concentration results were collected without corresponding traffic data such as the number of vehicles during the storm, the average axel load or the average vehicle speed. Rainfall data specific to the R300 such as the storm intensity, volume and duration were not obtained for the sampling events. This limited the interpretation of the results as these parameters are often cited as explanatory variables for pollutant concentrations in runoff waters.

The limited number of samples, with an average count of 11 samples per constituent, restricted the statistical analysis of the results. As noted in Section 4.5, the oil and grease and TSS concentrations from 24 May, 2016 were omitted from the data analysis as the laboratory reported an inappropriate sample temperature on receipt.

Thus, the rainfall and sediment pollutant concentrations should be regarded as point data that indicate the potential range of pollutant concentrations in the road environment

## 4.8 Summary

This chapter provides an overview of the sampling exercise conducted for this research. Sediment and runoff samples were collected from four locations on R300 highway during 2016. The samples were analysed at Jones Environmental Laboratory for metals, hydrocarbons and nutrients. The results indicate that the stormwater runoff from the highway contains hydrocarbons, aluminium, copper, lead, phosphorus and zinc in quantities that are detrimental to aquatic ecosystems. The concentration of contaminants in the surface sediment, however, is within the range required to protect ecosystem health.

## 5. Drainage modelling

### 5.1 Introduction

This section describes the modelling of the R300 drainage in PCSWMM, a computational decision support system based on the US EPA's SWMM engine. The data collection, model inputs and model construction are described. Thereafter, four alternative designs are assessed; comparing the current drainage design to various SuDS stormwater management scenarios. The model outputs are compared to the CoCT's Management of Urban Stormwater Impacts Policy requirements, hereafter referred to as the CoCT Stormwater Policy, to assess their respective performance.

### 5.2 Methodology

The road surface and hydraulic system were modelled from the intersection of the R300 with the N2 to the intersection with the N1 for varying drainage design scenarios. An as-built model was created and compared to deterministic flood calculation methods. Thereafter, alternative SuDS scenarios were developed in order to assess the potential for SuDS to manage highway runoff. PCSWMM requires user input regarding surface data, hydraulic connectivity, climate data and pollutant characteristics. A discussion of the data acquisition for these elements follows.

Climate data was sourced from the Cape Town International Airport, which lies between 4km to 12km from the near and far end of the R300 respectively. 5-Minute data was obtained from two recording stations at the Airport; CT-WO and CT-AWS. The data was verified by comparing the statistical parameters for each data set and using the PCSWMM audit function, which checks datasets for inconsistencies, redundancy and missing data. 5-Minute rainfall and temperature data from 2010 through 2016 from CT-WO were input into the model. The largest storm in the record is a 13 year RI storm with a total rainfall of 77mm. 98% of the rainfall events in the dataset have a recurrence interval less than 2 years. The total precipitation for each year is provided in Table 5-1.

**Table 5-1: Annual precipitation at the Cape Town International Airport**

Year	Total precipitation (mm)
2010	384
2011	350
2012	467
2013	655
2014	518
2015	348
2016 (Jan-Mar)	48

The average annual precipitation for the modelling period is lower than the MAP used for the current R300 drainage design (SNA-SSI Joint Venture, 2008a). The design MAP of 515mm is greater than the precipitation for all years in the modelling period except 2013, where the rainfall was in excess of 650mm. Temperature data from 2010-2016 was processed to obtain daily maximum and minimum temperatures. Evaporation was calculated in the model as a function of the temperature using the Hargreaves' method. The model was executed using both design storm and continuous rainfall data. 24-Hour SCS-SA Region II design storms for ½, 1, 2, 5, 10, 20, 50 and 100 year return intervals were modelled (SANRAL, 2013a). The design storms were sized with the design point rainfall for the South African Weather Service Kuilsrivier weather station, which lies approximately 5km from the R300.

Pollutant modelling in PCSWMM can be implemented by specifying buildup and washoff functions related to the subcatchment land use, or applying an event mean concentration. Pollutant buildup and washoff functions are highly variable and have been shown to be site specific (Egodawatta & Goonetilleke, 2008). In the absence of such data, it was decided that pollutant loading would be modelled using EMCs. The EMCs were determined based on literature and the field sampling results. The upper and lower EMC limits in the literature were compared to the median, maximum and minimum sample concentration results. The median was used as opposed to the mean as the mean was found to be skewed by an outlying sampling event. It was found that the upper EMC limits corresponded well with the median sampling result. As such, the site-specific median sampling concentration was used as the EMC for TSS (146mg/l), TP (3mg/l) and oil and grease (144mg/l) concentrations in the model.

Surface data was obtained from as-built drawings provided by SANRAL. Longitudinal section elevation data consisted of three survey points at 20m intervals on the inner, middle and outer lane for each carriageway. This was processed to determine the subcatchment elevation, area, cross fall and vertical slope. The location of hydraulic elements including surface drains, catchpits, down chutes, underground pipes and culverts were obtained from plan drawings. The drainage schedule provided road surface and invert levels for each drainage element at road left, road right and road centre. This informed the drainage element depths, slopes and the hydraulic connectivity input to the R300 model.

A number of simplifying assumptions were made in creating the model. Surface subcatchments were delineated based on a change in vertical slope, change in horizontal slope, the location of catchpits, drains and down chutes, and the type of surface (e.g. road, verge and SuDS elements). Subcatchment surface properties are provided in Table 5-2. Subcatchment flow length and slope were calculated as a function of the road cross fall, vertical slope and road width. The flow length and surface slope were subsequently assessed using the PCSWMM sensitivity calibration tool and adjusted accordingly.

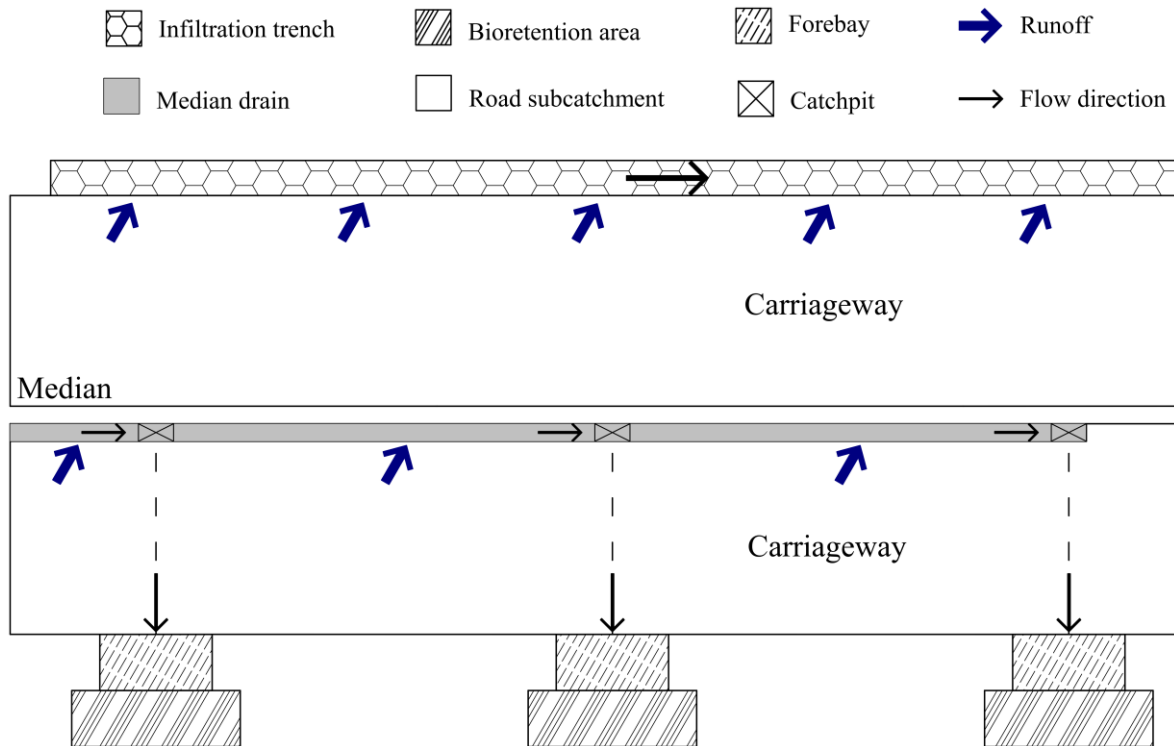
**Table 5-2: Subcatchment properties**

Parameter	Road surface	Infiltration trench	Bioretention area	Bioretention area forebay	Swale
% imperviousness	100	0	0	80	0
Manning's <i>n</i>	0.016	0.1	0.1	0.08	0.027
Storage depth (mm)	0.5	1500	550	20	250
% area not contributing to runoff	25	0	0	25	25
% subcatchment routed to hydraulic system	100	100	100	100	100

Surface drainage conduits were modelled in line with design drawings for typical drainage elements on the R300. Three types of conduits were modelled: median drains, side drains and culverts beneath the road that connect median catchpits to outfalls. Culverts flowing beneath the road with the sole function of linking the two verge areas were omitted from the model. Catchpits were modelled as storage elements with a constant depth-area relationship. Surface drainage nodes were given a ponded area of 2m<sup>2</sup> in order to prevent flooding, but retain the excess stormwater volume in the model without creating a significant head at the node.

SuDS design alternatives were selected in response to the need for surface water treatment while considering the limitations imposed by the site. The site offers a relatively small space for stormwater treatment in the verge, with a need to direct water away from the road subsurface layers. Furthermore, there is a high water table during the wet season and a large amount of sediment transport due to the wind and soil characteristics.

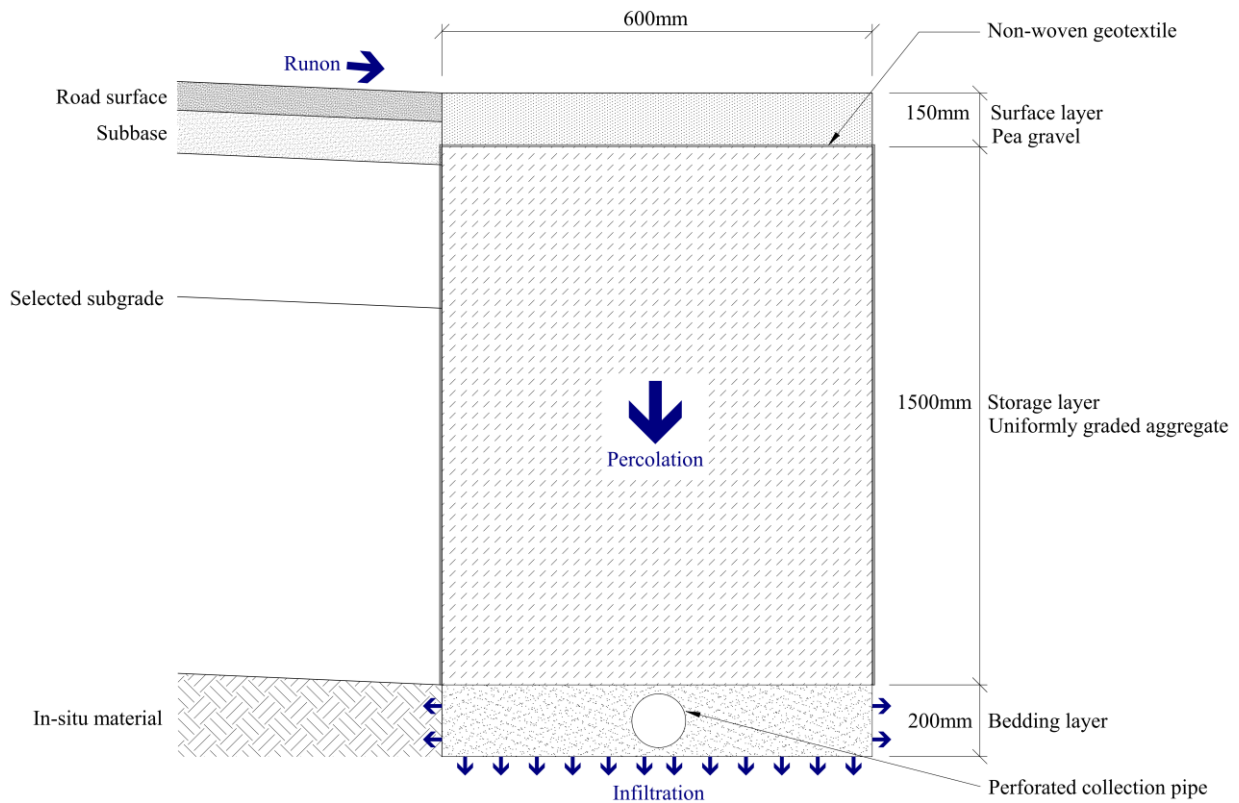
The current drainage design has large areas where the road runoff exits the road as sheet flow that infiltrates into the verge, without being concentrated in stormwater channels. Additionally, there are two locations where the existing R300 drainage infrastructure makes use of vegetated surface drains. Four design scenarios were investigated in PCSWMM; an as-built model, and Alternatives I – III, which investigate various SuDS scenarios. The SuDS Alternatives were modelled as retrofits to the current road drainage infrastructure, replacing surface drains with SuDS infrastructure. Technical details of the SuDS modelling parameters are provided in Appendix I. Figure 5-1 shows a plan view of the SuDS elements placed along a section of the R300.



**Figure 5-1: Plan showing SuDS placement along a section of the R300 (not to scale)**

### 5.2.1 Alternative I: Infiltration trenches

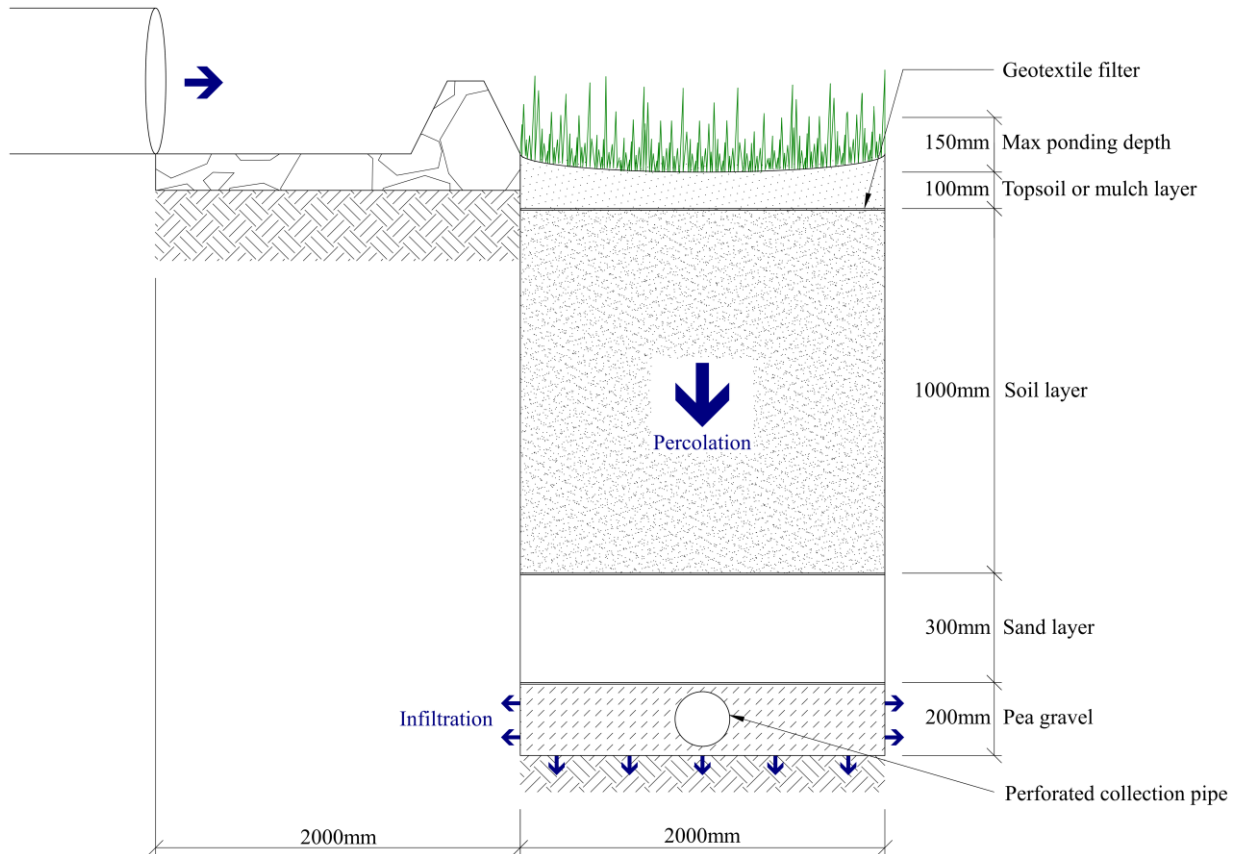
Alternative I involves replacing side channels adjacent to the verge in the existing drainage design with infiltration trenches, which are identified in SuDS drainage manuals as suitable devices for road drainage (Woods-Ballard *et al.*, 2007b; Pittner & Allerton, 2009; Armitage *et al.*, 2013b). Figure 5-2 shows a cross-sectional view of the infiltration trenches modelled in PCSWMM. Each infiltration trench has a width of 600mm and a depth of 1500mm, in keeping with the SuDS Manual recommendations (Woods-Ballard *et al.*, 2007a). The void ratio of the storage area is 0.5 voids/solids, typical for coarse aggregate and the seepage rate into the surrounding in-situ sand is 50mm/h (CHI, 2016c). Each trench has an underdrain, since the infiltration capacity in winter will be reduced due to the high water table. The infiltration trenches are expected to address the problem of erosion surrounding existing down chutes by reducing the runoff peak and allowing for distributed infiltration rather than concentrating the surface flow through drainage outlets. The pollutant removal capacity was modelled according to the South African Guidelines for Sustainable Drainage Systems (Armitage *et al.*, 2013b), using the lower limit of 60% removal capacity for TP, 70% removal capacity for TSS and 0% removal capacity for O&G.



**Figure 5-2: Cross section of an infiltration trench**

### 5.2.2 Alternative II: Bioretention areas

Alternative II is to place a bioretention area and pretreatment forebay at the outfall of every culvert draining the road surface. These areas are located where the road surface drains to the road median and runoff is concentrated in catchpits that drain to the verge. Bioretention areas were selected as they provide good treatment capacity with limited space requirements, which make them easy to integrate with existing drainage infrastructure. The bioretention areas modelled in PCSWMM are shown in Figure 5-3. They were modelled with a pretreatment forebay to capture litter and sediment, and slow the volumetric flow rate as water enters the bioretention area. The forebays are 4m x 2m, with a 2% surface slope and 80% impervious area. Each forebay has a 20mm depression storage capacity. The bioretention areas are 5m x 2m, with a 200mm berm height, which provides a fairly large storage capacity. The soil thickness is 1000mm with a 300mm sand layer, and 200mm storage layer beneath. The soil properties were assigned based on typical bioretention soil properties (CHI, 2016c). The bioretention areas were modelled with a constant pollutant removal capacity according to the South African Guidelines for Sustainable Drainage Systems, using the lower limit of 50% removal capacity for TP, 50% removal capacity for TSS and 50% removal for O&G (Armitage *et al.*, 2013b).



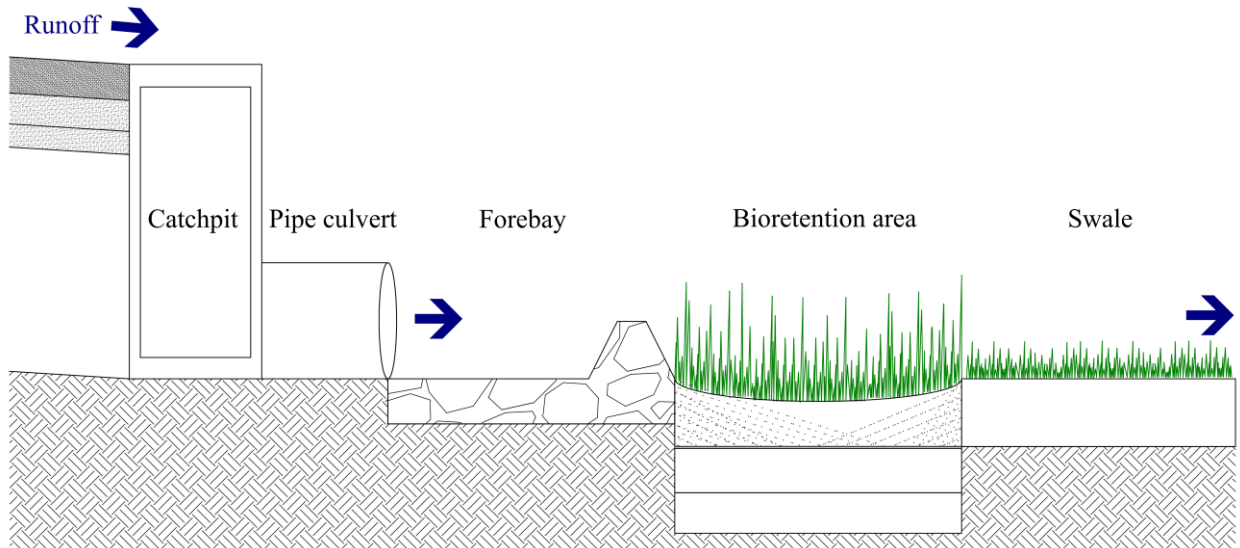
**Figure 5-3: Cross section of a bioretention area**

### 5.2.3 Alternative III: Integrated design

Alternative III is to implement infiltration trenches, swales and bioretention areas at suitable locations in the verge across the total road length. Swales were modelled as pervious subcatchments with a storage depth of 250mm and an infiltration capacity related to the existing sandy verge. The surface is modelled as grass cover, with a Manning's  $n$  value of 0.027. The pollutant removal capacity for each swale is 25% for TP, 60% for TSS and 70% for O&G (Armitage *et al.*, 2013b). Where suitable, SuDS were modelled in treatment trains, where the outfall from one SuDS element enters the subsequent downstream SuDS device. Figure 5-4 shows one of the treatment trains implemented in Alternative III.

## 5.3 Results

A PCSWMM model was developed to assess different scenarios for road drainage design on the R300. The results were used to assess the proposed SuDS alternatives against the CoCT Stormwater Policy. Additionally, the runoff volume, peak runoff rates and pollutant loads generated by the alternative scenarios are compared to the as built scenario.



**Figure 5-4: SuDS treatment train schematic**

The model remains uncalibrated with real world data, since the scope of this project did not justify the large cost of the monitoring equipment required to obtain volumetric runoff calibration data. The PCSWMM Sensitivity-based Radio Tuning Calibration (SRTC) tool was used to perform a sensitivity analysis on user input parameters including the subcatchment width, surface slope, Manning's  $n$  for impervious and pervious areas and depression storage. The SRTC tool runs a series of modelling events varying the chosen parameters within a user specified range, and the results are compared to a base scenario. The R300 model is most sensitive to the subcatchment width parameter, which yielded a 5% increase in maximum outflow for a 25% increase in subcatchment width.

The model peak flow results were compared to the Rational Method in order to determine whether the results were suitable. The Rational Method was calculated for the entire road subcatchment, with a runoff coefficient of 0.85. Calculations are available in Appendix H. The model was run applying the 24-hour SCS-SA Type II storm distribution with design point rainfall obtained from the Kuilsrivier weather station, made available in the Drainage Manual (SANRAL, 2013a). Table 5-3 provides the peak flow for recurrence intervals of 2 – 100 years generated by the Rational Method and the R300 model. The R300 model results for each return interval are approximately 60% of the Rational Method results. Without additional information to verify the model, this was accepted as an adequate result.

**Table 5-3: Peak runoff for the R300 calculated using PCSWMM and the Rational Method**

Recurrence interval (years)	2	5	10	20	50	100
R300 model peak runoff (m <sup>3</sup> /s)	2.0	2.9	3.5	4.2	5.2	6.0
Rational method peak runoff (m <sup>3</sup> /s)	2.8	4.8	6.2	7.7	9.7	11.1

The pollutant load and peak flow reduction capacity of SuDS Alternatives I, II and III were evaluated using design storm and continuous modelling approaches, which are discussed below.

For the ½ year RI, 24-hour water quality design storm event, the CoCT Stormwater Policy requires 80% removal of the annual TSS pollutant load and 45% removal of the annual TP pollutant load. Table 5-4 shows the outcome of the proposed SuDS interventions. These results show that while the individual performance of the SuDS elements is good, SuDS must be implemented across the entire road length as in Alternative III in order to achieve meaningful pollution mitigation for road runoff.

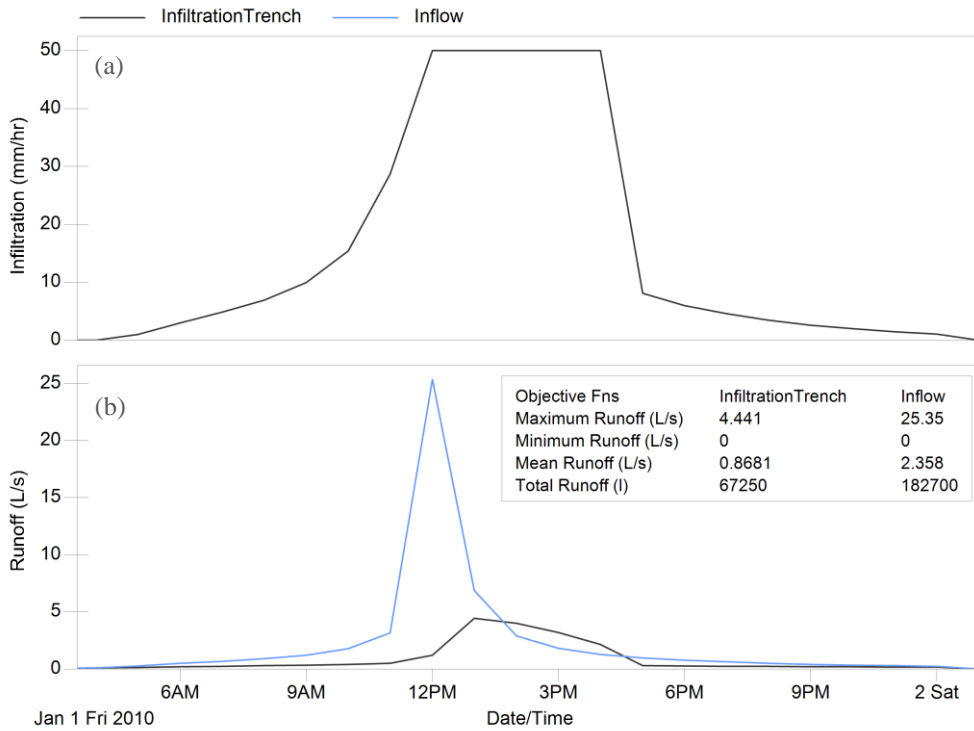
**Table 5-4: Pollutant removal for the ½ year RI water quality design storm event**

	TP removal %	TSS removal %	O&G removal %
CoCT Stormwater Policy criteria	45	80	
Alternative I (Infiltration trenches)	21	22	17
Alternative II (Bioretention areas)	6	6	6
Alternative III (Integrated design)	69	80	42

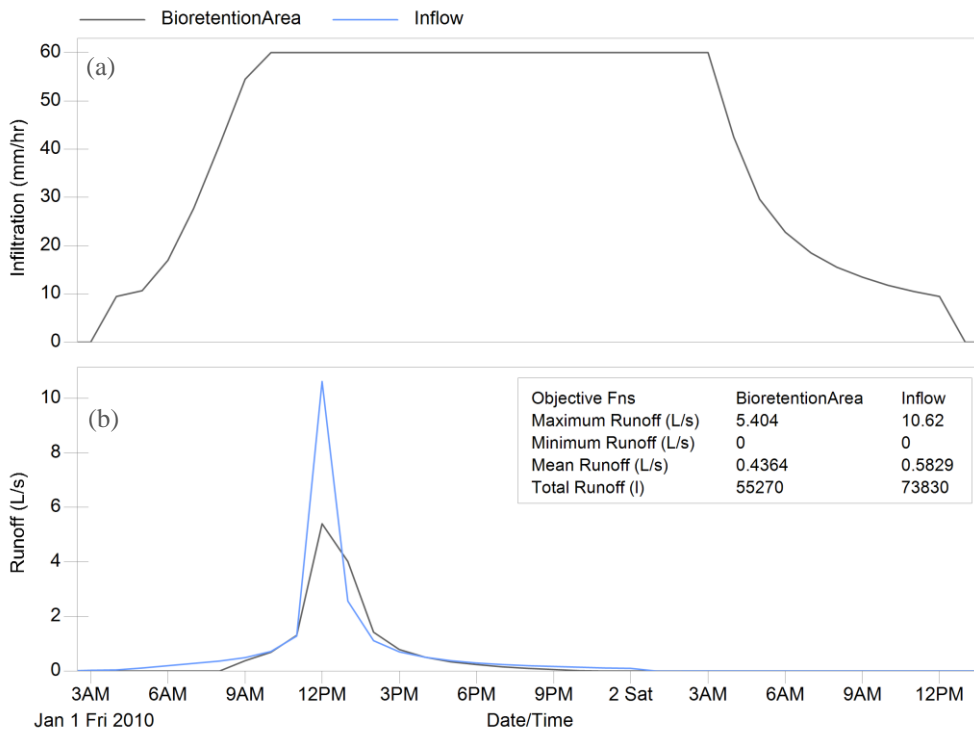
For the 1 year RI 24-hour storm, the CoCT Stormwater Policy requires 24-hour extended detention of the surface runoff. Table 5-5 summarises the peak and total flow reduction for the Alternative SuDS scenarios. Figure 5-5 shows the extended stormwater detention in a typical infiltration trench for the 1 year RI event; where (a) shows infiltration for 15 hours following the inflow runoff peak and (b) shows the incoming and outgoing surface runoff. This indicates that stormwater is detained in the infiltration trench for 15 hours and that the device fails to capture the full storm volume as there is some surface runoff. Figure 5-6 shows the extended detention of a bioretention unit for the 1 year RI event; where (a) shows infiltration for 25 hours following the incoming runoff peak and (b) shows the incoming and outgoing surface runoff. This indicates the bioretention areas detain stormwater for a 24-hour period but fail to capture the full storm volume.

**Table 5-5: Flow reduction for the 1 year RI design storm event**

	Peak flow reduction %	Flow volume reduction %
Alternative I (Infiltration trenches)	18	13
Alternative II (Bioretention areas)	3	3
Alternative III (Integrated design)	60	47



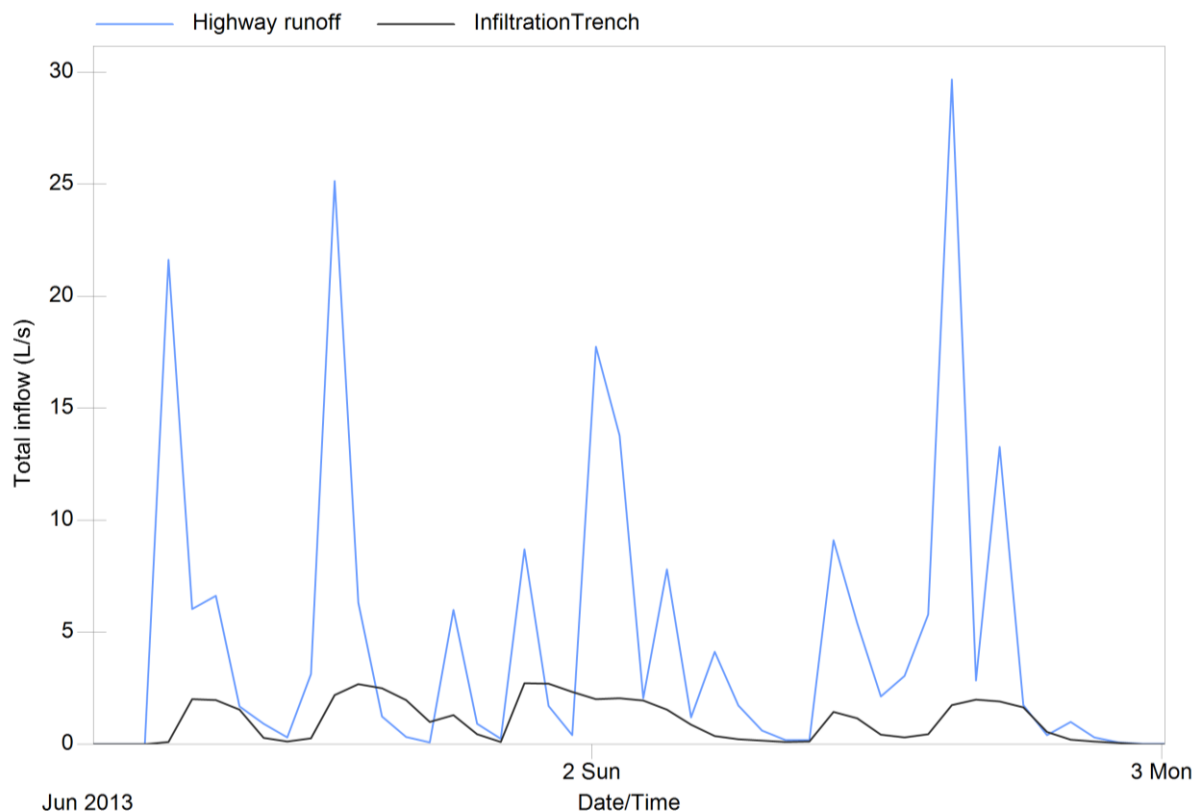
**Figure 5-5: Extended detention through an infiltration trench for the 1 year RI storm:  
(a) infiltration and (b) runoff**



**Figure 5-6: Extended detention through a bioretention area for the 1 year RI storm:  
(a) infiltration and (b) runoff**

For the 10 year RI, 24-hour storm, the CoCT Stormwater Policy requires that the peak flow is reduced to the predevelopment level. In this instance, the predevelopment condition was assumed to be a flat, permeable, sparsely vegetated area with an estimated runoff coefficient of 0.3. When compared to the post development runoff coefficient, this corresponds to a 60% required reduction in the peak flow. Alternatives I and II obtained peak flow reductions below 20% for the entire road runoff, indicating the necessity for more extensive and/or effective measures such as treatment trains. Alternative III achieved a peak flow reduction of 61% with the integrated design. Peak flow reduction can be improved by applying more SuDS units in the treatment train, or by increasing the size of SuDS units where space allows. The results indicate that it may be necessary to apply regional SuDS controls outside of the road reserve to achieve the necessary peak flow reduction for differing road configurations.

The R300 model was run with five years of continuous rainfall and climate data for the period from January 2010 – March 2016. Similar results were obtained when compared to the design storm scenarios for peak flow and pollutant load reduction. Performance of individual elements during extended storm events is good. For instance, Figure 5-7 shows the peak flow reduction by a standard infiltration trench for a two day, 43mm rainfall event. For this event, the infiltration trench reduced the runoff volume by 79% and peak flow by 93%.



**Figure 5-7: Outflow from an infiltration trench for the continuous simulation compared to the outflow at the same location for standard drainage design**

Table 5-6 summarises the peak flow, flow volume and pollutant load reduction for the SuDS Alternative design scenarios for the five-year continuous modelling period. Alternative III, which implements an integrated SuDS design throughout the entire road length, meets the CoCT Stormwater Policy requirements for pollutant removal and reduces the total outflow from the road surface by over 40%.

The results of Alternatives I, II and III indicate that SuDS must be implemented throughout the full extent of the catchment in order to achieve the stormwater management requirements of the CoCT Management of Urban Stormwater Impacts Policy.

**Table 5-6: Performance of the Alternative SuDS scenarios for the continuous simulation**

	<b>Peak flow reduction %</b>	<b>Flow volume reduction %</b>	<b>TP removal %</b>	<b>TSS removal %</b>
Alternative I (Infiltration trenches)	21	17	22	23
Alternative II (Bioretention areas)	7	3	7	7
Alternative III (Integrated design)	37	41	76	81

## 5.4 Errors and limitations

The following section details the limitations of the modelling exercise.

The model of the R300 drainage is not calibrated with real world data. The subcatchment surface properties are, however, fairly homogeneous and well defined (e.g. the surface roughness of the asphalt). The comparison to deterministic calculations verifies the model as a reasonable approximation of the hydraulic processes. Without a formal verification and calibration exercise, the model is only indicative of the hydraulic system performance.

There are many possible alternative SuDS devices and configurations that were not tested in this modelling exercise. Additionally, the modelling was limited to SuDS that fit within the existing road reserve area. The results, therefore, do not provide an overview of all possible outcomes of implementing SuDS on the R300.

The interaction between SuDS elements and groundwater flow was omitted from the model. Groundwater may influence SuDS performance on the R300 due to the high winter water table. Additionally, erosion and slope stability was not directly accounted for in the modelling process.

The pollutant modelling is executed in a simplistic manner in PCSWMM. The pollutant removal is approximated by a user-defined percentage removal and the pollutants removed due to the reduction in runoff. This approach, however, provided more robust results than detailed mechanistic modelling of the pollutant removal processes given the available data on local material characteristics and pollutant behaviour. The long term effects of maintenance and

clogging on the SuDS performance were not accounted for. As such, the results provide an indication of relative performance rather than a quantitative assessment of potential pollutant removal.

## **5.5 Summary**

This chapter details the modelling of the R300 surface drainage. The existing drainage system and three alternative SuDS scenarios were modelled in PCSWMM. The alternative SuDS designs make use of infiltration trenches, bioretention areas and swales to manage the highway runoff. Both continuous and design storm modelling was undertaken to assess the scenarios. The model results show that SuDS must be implemented along the entire road length to achieve the CoCT Stormwater Policy's peak flow reduction and pollutant removal requirements. The R300 model provides indicative results that should not be used to inform detailed drainage design. The results form the basis for more detailed research into SuDS performance on South African highways.

## 6. Conclusions

Highways are ubiquitous in the urban environment, threading through environmentally sensitive and resilient areas. Roadways account for a large percentage of urban impermeable surfaces, concentrating runoff flows and increasing flow peaks. They produce non-point source pollution in varying degrees according to road use, climatic conditions and surrounding land use. Sustainable Drainage Systems (SuDS) provide an alternative to standard surface drainage infrastructure for managing surface runoff in a manner that reduces peak runoff flows, ameliorates water quality, provides amenity and supports biodiversity.

Surface runoff from the R300 is problematic in terms of flow (quantity) management at selected locations. Concentrated runoff flows cause erosion surrounding several down chutes, and surface water drainage near the Old Paarl Road interchange appears problematic for road user safety. Most incidents on the R300 occur during the rainy season and alongside major national holidays. Large volumes of solid waste including organic matter, sediment and litter accumulate in the median catchpits. The waste causes sedimentation and blockages in the surface drainage infrastructure, in spite of weekly litter removal and cleaning of surface drains during the rainy season. The sediment and solid waste transport has implications for SuDS implementation along the R300. If designed with appropriate pre-treatment elements, SuDS can mitigate the effects of the solid waste by processing organic matter and keeping macro pollutants above ground.

Surface runoff water quality from the R300 is highly variable. When compared to environmental samples, sediment and runoff samples from the road surface contain higher levels of all contaminants. The primary contaminants in the R300 surface water are aluminium, copper, lead, phosphorus, zinc, TSS, and oil and grease when comparing mean concentrations to water quality requirements for aquatic ecosystems. In light of these findings, it is recommended that runoff water quality is addressed by road drainage design where runoff may influence a sensitive or valuable aquatic ecosystem.

Several SuDS elements including bioretention areas, infiltration areas and swales, are suitable for managing highway runoff. The available land in the road reserve is the primary limitation for SuDS implementation on an urban highway. Additionally, the capacity of the surrounding soils for infiltration, the anticipated water quality characteristics, and effluent requirements and other site specific conditions play a large role in determining a suitable drainage solution. A PCSWMM modelling exercise confirmed the ability of SuDS to provide water quality management in accordance with the CoCT Management of Urban Stormwater Impacts Policy, provided SuDS elements are implemented along the entire length of the roadway.

## 7. Recommendations for further research

This research investigated the surface drainage and the effects thereof on the R300 highway. The results indicate a need for more in depth studies on highway runoff quality and the suitability of SuDS as alternative surface drainage infrastructure. Detailed research that addresses the temporal and spatial variation of highway runoff quality in South Africa is required. To this end, several measures are proposed:

- a comprehensive, site-specific sampling regime such that continuous, flow weighted samples are collected for all rainfall events during the monitoring period. Additionally, information such as rainfall intensity, storm volume and duration should be collected in conjunction with the pollutant concentration data,
- a long-term sampling regime conducted over a minimum time period of one calendar year to account for seasonal variation,
- a sampling regime conducted across multiple highway sites within the City of Cape Town to account for the effect of adjacent land use and localised climatic effects, and
- a sampling regime conducted across multiple cities to account for the variation in climate and road use throughout South Africa (e.g. Cape Town, Johannesburg, Durban).

There is a need for a greater understanding of SuDS performance under local conditions. Several research opportunities specifically relating to road drainage include:

- the assessment of SuDS elements suited to highway runoff control in a laboratory setting. These include but are not limited to bioretention areas, infiltration trenches, filter strips and soakaways. The SuDS units should be constructed with locally available material and at a minimum, the input and output contaminant concentrations should be monitored,
- the monitoring of an on-site SuDS system. The system should be installed with sufficient monitoring equipment to assess the incoming and outgoing flow rate and contaminant concentrations, and
- the assessment of on-site SuDS systems in multiple locations throughout South Africa.

Stormwater modelling provides a time and cost effective means to assess the performance of several drainage design alternatives. Results from flow and pollutant measurements proposed above should be used to calibrate and verify site specific models. These models can be used to generate detailed SuDS designs with an acceptable level of assurance.

The Freeway Management System implemented on the R300 provides valuable data for assessing road design performance. This data should be analysed on a regular basis using statistical and mapping tools to identify locations that present a higher risk to the road user and/or the environment. The efficacy of design interventions should be assessed based on the temporal variation of the data.

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# Appendix A : City of Cape Town’s criteria for stormwater drainage management

**Table A-1: Interim criteria for achieving Sustainable urban Drainage System objectives (CSRM, 2009)**

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

**Table A-2: Interim criteria for achieving Sustainable urban Drainage System objectives continued (CSRM, 2009)**

<b><u>SUDS OBJECTIVES</u></b>		<b>Greenfield Developments  and  Brownfield and Existing Sites located in catchments of sensitive receiving water systems</b>	<b>Brownfield and Existing Development Sites  &gt; 50 000 m<sup>2</sup></b>	<b>Brownfield and Existing Development Sites  4000 m<sup>2</sup> – 50 000 m<sup>2</sup>  and  Total impervious area (exist &amp; new) &gt; 15% of site</b>	<b>Brownfield and Existing Development Sites  &lt; 4000 m<sup>2</sup>  and  Total impervious area (exist and new) &gt; 600m<sup>2</sup></b>
<b><u>CONTROL QUANTITY AND RATE OF RUNOFF</u></b>	<i>Protect the stability of downstream channels</i>	24 hour extended detention of the 1-year RI, 24h storm event	24 hour extended detention of the 1-year RI, 24h storm event	Combination of on-site and regional off-site measures to achieve requirements as for development sites >50 000m <sup>2</sup>	On-site runoff control measures not required but encouraged where practicable  Regional off-site runoff control measures to be provided to achieve requirements as for development sites > 50 000m <sup>2</sup>
	<i>Protect downstream properties from fairly frequent nuisance floods</i>	Up to 10-year RI peak flow reduced to pre-development level	Up to 10-year RI peak flow reduced to pre-development level		
	<i>Protect floodplain developments and floodplains from adverse impacts of extreme floods</i>	Up to 50-year RI peak flow reduced to existing development levels. Evaluate the effects of the 100-year RI storm event on the stormwater management system, adjacent property, and downstream facilities and property.	Up to 50-year RI peak flow reduced to existing development levels. Evaluate the effects of the 100-year RI storm event on the stormwater management system, adjacent property, and downstream facilities and property.		
		Manage the impacts through detention controls and / or floodplain management	Manage the impacts through detention controls and / or floodplain management		
		Developments adjacent to floodplains must adhere to the requirements of the Floodplain and River Corridor Management Policy			
<b><u>ENCOURAGE NATURAL GROUNDWATER RECHARGE</u></b>		Where appropriate, site specific requirements to be considered in consultation with Council			

# Appendix B: South African National Biodiversity Institute maps

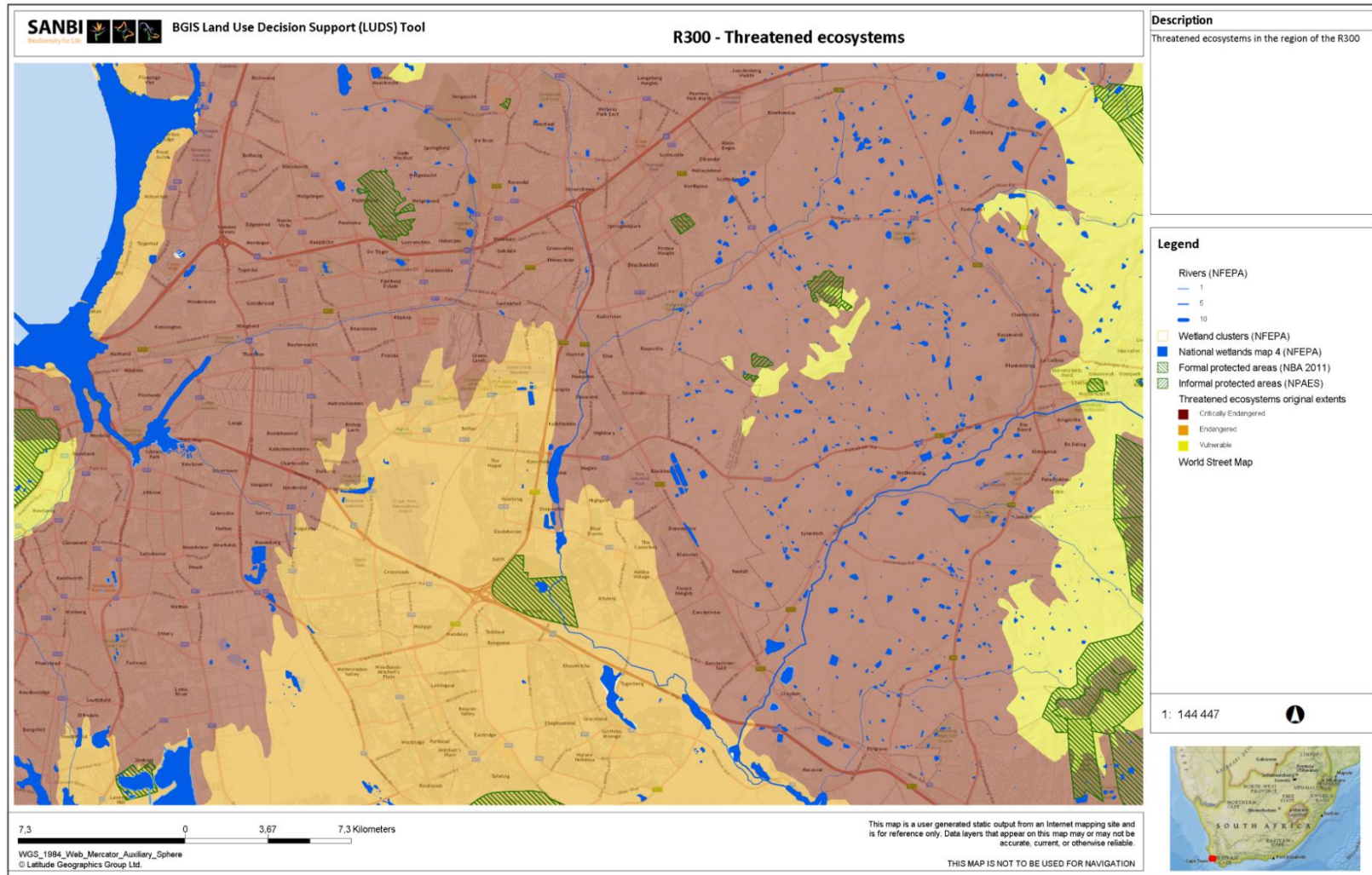
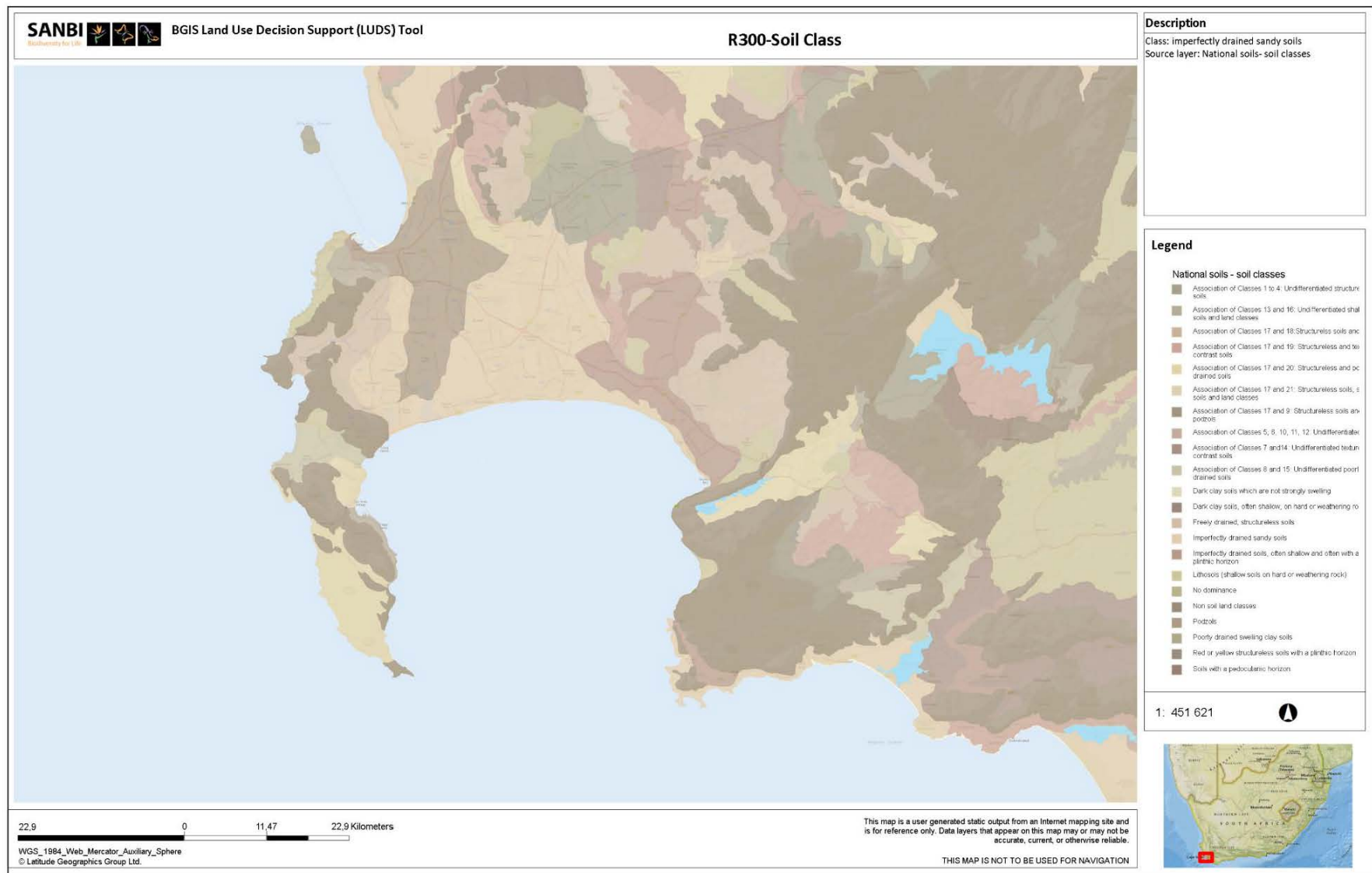
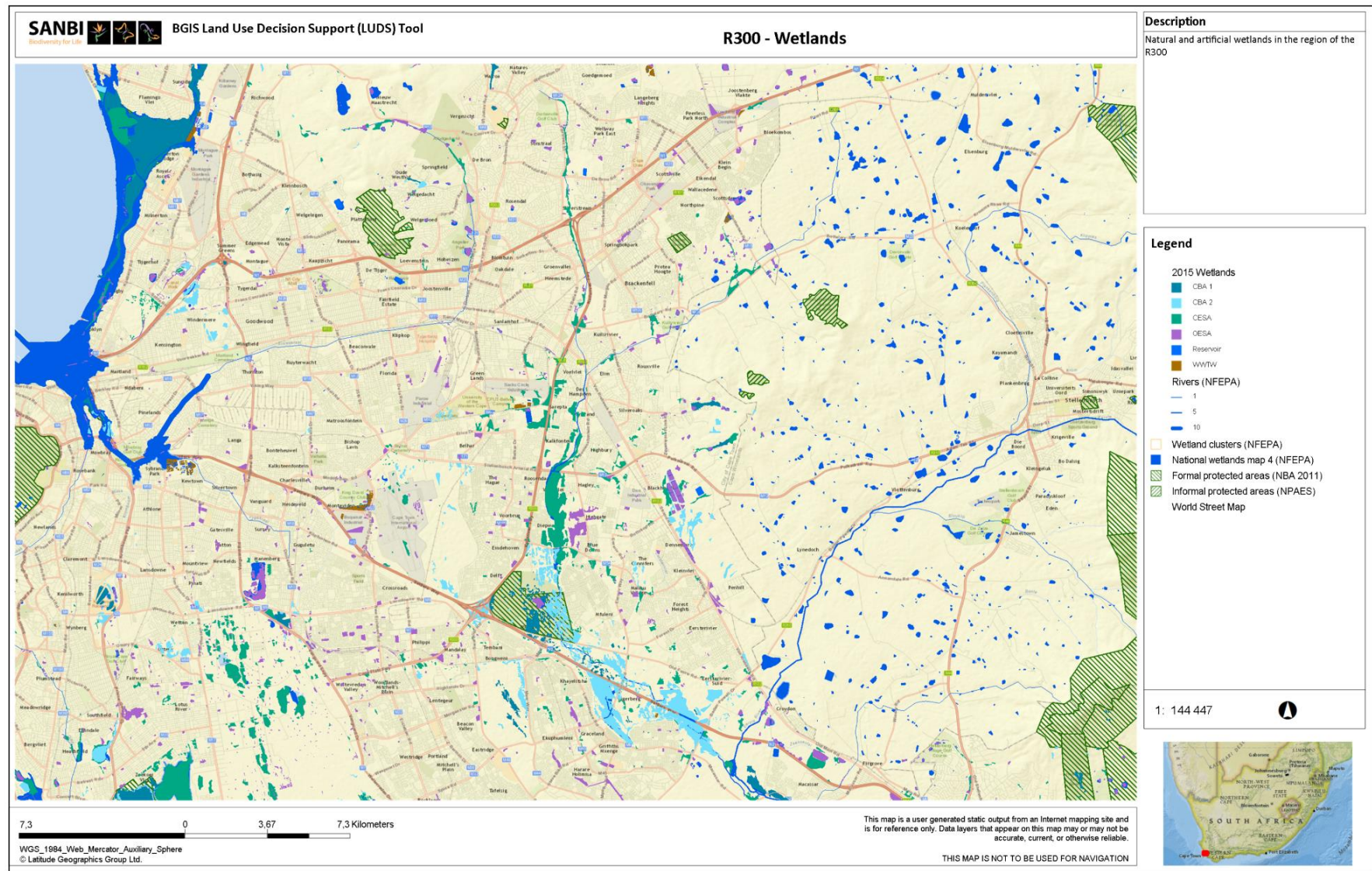


Figure B-1: Extent of threatened ecosystems in the region of the R300 (SANBI, 2015)



**Figure B-2: Soil classes in the region of the R300 (SANBI, 2015)**



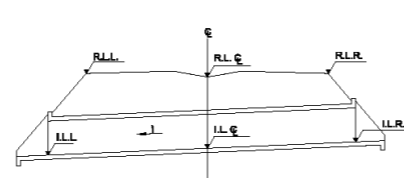
**Figure B-3: Wetlands in the region of the R300 (SANBI, 2015)**

## **Appendix C : Selected as-built drawings of the R300**

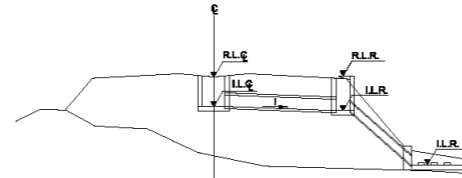
STAKE VALUE (km)	SIZE	TYPE	ANGLE (Deg.)	STRUCTURE NUMBER	EDGE OF TAR TO H/WALL		HEADWALL TO BE RAISED	EXTENTION OF CULVERTS	GRADE OF FLOOR -LEFT/+RHS	ROAD LEVEL			CULVERT LEVEL			OTHER COMMENTS
					LHS	RHS				RLC	RLR	ILL LEFT	ILC MEDIAN	ILR RIGHT		
14,085	1 x 600 Ø	PC	0°	01	-	1.94 m			+1.35%	38.93	40.21	38.93		37.90	37.84	
15,180	1 x 600 Ø	PC	45°	04	-	-			+1.59%	42.28	43.80	42.97		41.71	41.37	
15,530	1 x 600 Ø	PC	0°	04a	-	-			-	-	-	-		-	-	
15,880	1 x 600 Ø	PC	3°	06a	-	-			+1.35%	39.40	39.79	39.40		38.18	37.92	
16,237	1 x 600 Ø	PC	10°	07	3.13 m	2.64 m	0.3m		-0.22%	39.28	39.66	39.28	37.30	37.35	37.40	
16,485	1 x 600 Ø	PC	0°	08	-	-			-0.79%	39.18	39.58	39.19	37.50	37.65		
16,800	1 x 600 Ø	PC	2°	09	-	2.30 m			+1.52%	39.06	39.47	39.06		37.80	37.30	
16,930	1 x 600 Ø	PC	2°	10	-	2.92 m			+0.89%	39.03	39.42	39.03		37.55	37.37	
17,180	1 x 600 Ø	PC	-	10a	-	3.82 m			-	39.95	39.34	39.95		-	-	
17,495	1 x 600 Ø	PC	0°	11	-	8.79 m			+4.88%	39.97	40.06	41.16		38.87	37.39	
18,005	1 x 600 Ø	PC	0°	13	2.85 m	4.80 m			+2.10%	40.60	41.00	40.83	39.03	38.56	38.16	
18,205	1 x 600 Ø	PC	0°	14	1.82 m	3.41 m			+2.08%	40.39	40.78	40.39	39.23	38.89	38.42	
18,605	1 x 600 Ø	PC	2°	19	1.92 m	-			-5.07%	40.24	40.63	40.24	38.72	38.90		
19,000	1 x 600 Ø	PC	1°	20	3.16 m	-			-5.74%	42.02	42.41	42.02	40.27	41.70		
19,220	1 x 600 Ø	PC	1°	21	2.48 m	3.44 m			+1.29%	43.03	43.42	43.03	41.77	41.47	41.25	
19,423	1 x 600 Ø	PC	0°	22	1.88 m	-			-1.31%	43.97	44.36	43.97	42.50	42.75		
19,715	1 x 600 Ø	PC	2°	23	-	4.47 m			+1.18%	45.14	45.53	45.14	43.47	43.21		
19,918	1 x 600 Ø	PC	4°	24	-	3.28 m			+1.98%	45.94	46.33	45.93	44.50	44.09		
20,124	1 x 600 Ø	PC	0°	24a	0.51 m	-			-	46.76	47.15	46.75	44.06	-	-	
20,255	1 x 600 Ø	PC	2°	25	-	-			-3.39%	47.27	47.66	47.26	44.80	45.64		
20,383	1 x 400 Ø	PC	59°	27	-	-			+1.37%	48.70	49.29	48.43	48.00	-	47.09	
20,500	1 x 600 Ø	PC	1°	28	-	-			-1.10%	50.47	50.87	50.49	47.52	47.75		
20,695	1 x 600 Ø	PC	0°	30	-	4.53 m			+1.33%	55.45	55.84	55.44	54.00	53.70		
21,025	1 x 600 Ø	PC	2°	33	-	3.21 m			+1.22%	56.12	56.51	56.11	54.55	54.30		
21,165	1 x 600 Ø	PC	2°	38	-	6.76 m			-8.69%	53.81	54.01	53.63	52.10	50.00		
21,260	1 x 600 Ø	PC	4°	39	-	-			-3.48%	53.01	53.40	53.01	50.88	51.47		
21,409	1 x 600 Ø	PC	2°	40	2.11 m	1.53 m	0.3m	2.88m SB	-0.16%	53.14	53.69	53.02	51.41	51.45	51.49	
21,650	1 x 600 Ø	PC	0°	41	4.13 m	-			-2.40%	53.70	54.09	53.70	51.49	52.01		
21,915	1 x 600 Ø	PC	0°	42	3.05 m	-			-2.41%	54.17	54.56	54.17	52.13	52.62		
22,110	1 x 600 Ø	PC	1°	43	1.89 m	3.07 m			+2.47%	54.52	54.909	54.52	52.87	52.87	51.99	
22,300	1 x 600 Ø	PC	1°	44	3.16 m	4.80 m			+2.15%	54.73	55.12	54.73	53.00	52.40	52.10	
22,540	1 x 600 Ø	PC	0°	45	1.83 m	-		1.22 m NB	-1.82%	54.609	55.201	54.609	52.48	52.83		CLOSED UP MEDIAN INLET
22,720	1 x 600 Ø	PC	0°	46	2.00 m	3.80 m	230 mm NB		+0.36%	54.505	55.931	54.505	52.46	52.46	52.31	
22,924	1 x 600 Ø	PC	1°	47	1.90 m	0.77 m		1.22 m SB	-0.91%	54.405	55.828	54.405	52.61	52.56	52.97	
23,140	1 x 600 Ø	PC	1°	48	0.98 m	2.90 m			+1.13%	53.985	55.410	53.987	52.67	52.41	52.23	
23,340	1 x 600 Ø	PC	2°	49	0.55 m	2.70 m		1.22 m NB	+1.05%	53.348	54.772	53.350	51.87	-	51.46	
23,545	1 x 600 Ø	PC	1°	50	0.88 m	2.50 m		1.22 m NB	+0.44%	52.682	54.118	52.682	51.13	51.03	50.96	
23,651	1 x 600 Ø	PC	4°	51	1.10 m	2.17 m	170 mm NB		+0.65%	52.351	53.780	52.358	51.02	50.83	50.77	
23,825	1 x 600 Ø	PC	1°	52	1.10 m	2.30 m			+2.04%	51.479	52.908	51.408	50.35	49.82	49.56	
24,079	1 x 600 Ø	PC	1°	53	1.00 m	2.90 m			+1.78%	51.001	52.414	51.023	49.76	49.50	49.07	
24,185	1 x 600 Ø	PC	3°	54	0.87 m	2.30 m	230 mm NB		+1.52%	50.797	52.072	50.654	49.47	49.14	48.88	
24,377	1 x 600 Ø	PC	0°	55	-	3.40 m			+1.18%	51.407	51.994	49.810	48.50	48.26		
24,435	1 x 600 Ø	PC	1°	56	-	3.10 m			-0.41%	51.901	52.106	50.323	49.28	-	49.45	
24,495	1 x 600 Ø	PC	2°	57	-	3.10 m			+3.87%	53.037	53.233	53.441	49.79	48.98		
24,899	1 x 600 Ø	PC	3°	58	-	4.20 m			+1.88%	58.436	58.958	57.471	55.91	55.50		
25,047	1 x 600 Ø	PC	0°	59	-	4.40 m			+1.26%	59.075	60.740	58.175	57.91	57.55		
25,386	2 x 400 Ø	PC	1°	61	14.40 m	14.50 m			-0.18%	57.294	58.705	57.290	49.67	-	49.79	
25,425	1 x 600 Ø	PC	3°	63	-	2.60 m			+1.77%	56.902	58.321	56.918	55.40	55.05		
25,607	1 x 600 Ø	PC	5°	65	-	2.30 m			+1.61%	54.238	55.863	54.306	52.76	52.40		
26,020	1 x 600 Ø	PC	2°	68	4.00 m	2.50 m			+0.54%	51.790	53.202	51.791	49.56	49.44	49.30	
26,059	1 x 600 Ø	PC	0°	69	2.90 m	4.60 m			+0.41%	51.746	53.159	51.746	49.88	-	49.70	
26,219	1 x 600 Ø	PC	1°	70	-	2.80 m			+1.37%	51.890	53.103	51.891	50.21	49.94		
26,340	1 x 600 Ø	PC	0°	71	2.20 m	-			-2.00%	52.387	53.800	52.387	50.51	50.91		
26,519	1 x 600 Ø	PC	1°	72	4.10 m	-			-7.37%	55.087	56.475	55.088	52.00	53.86		
26,541	1 x 3000 x 2200	BC	0°	73	0.27 m	1.20 m			-0.81%	55.357	56.789	55.357	52.71	-	53.00	
26,752	1 x 3000 x 2200	BC	0°	74	3.30 m	2.90 m		1.0 m NB	+0.41%	56.552	57.984	56.552	52.55	-	53.11	
26,784	1 x 600 Ø	PC	0°	75	-	3.20 m			+1.37%	56.466	57.891	56.466	54.52	54.40		
26,920	1 x 400 Ø	PC	1°	76	1.10 m	-			-2.00%	56.114	57.526	56.114	54.93	55.44		
27,019	1 x 400 Ø	PC	0°	77	2.00 m	1.90 m			-7.38%	58.297	57.711	58.722	55.15	55.51	55.73	
27,193	1 x 600 Ø	PC	1°	78	1.00 m	-			-0.81%	56.894	58.875	58.772	55.77	55.99		
27,314	2 x 600 Ø	PC	0°	79	0.92 m	1.90 m			-1.57%	57.922	59.808	59.705	56.47	-	58.25	
27,574	2 x 800 Ø	PC	1°	80	1.40 m	2.40 m			+0.56%	59.922	61.804	61.701	58.27	58.68	59.43	
27,719	2 x 800 Ø	PC	1°	81	2.10 m	3.50 m			-2.82%	61.070	62.909	62.707	59.54	58.84	60.37	
27,934	1 x 600 Ø	PC	1°	82	8.20 m	4.50 m		1.22 m SB	-5.87%	63.893	65.572	65.464	58.93	58.54	61.84	
28,102	1 x 600 Ø	PC	2°	83	2.90 m	7.80 m		1.22 m NB	+4.91%	67.492	68.778	67.898	65.40	65.61	63.02	
28,410	7 x 1100 Ø	PC	27°	84	22.1 m	21.00 m			-	66.397	70.006	66.545	-	-	-	
28,515	1 x 600 Ø	PC	7°	85	-	14.00 m			+0.83%	67.861	69.214	67.913	66.27	66.00		
28,655	1 x 600 Ø	PC	0°	86	8.00 m	5.80 m			-0.95%	65.448	66.788	65.448	60.70	61.18		
28,815	1 x 600 Ø	PC	2°	87	-	1.40 m			+0.26%	63.343	63.940	63.343	62.00	61.85		

NOTE:

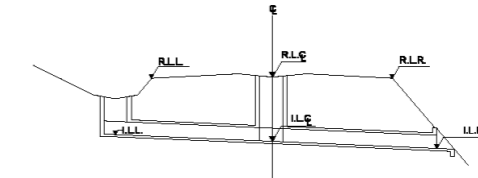
- FOR DETAILS OF RAISING H/WALLS & W/WALLS REFER TO PLAN SP-D-4-1E/2
- FOR DIMENSIONS AND BENDING SCHEDULE OF NEW INLET & OUTLET STRUCTURE REFER TO PLAN SP-P-4-1-22.
- STRUCTURE NUMBERS SHALL BE AS PER PLAN SP-B-1-9 TYPE II. CULVERTS RECEIVING STRUCTURE NUMBERS SHALL ALSO RECEIVE STRUCTURE NUMBER BOARDS, REFER TO PLAN SP-B-1-8.
- THE CONDITION OF EXISTING INLET / OUTLET STRUCTURES ARE TO BE INSPECTED ON SITE. EXTENT OF SILTATION IS TO BE NOTED AND INSTRUCTIONS IN THESE WORKS WILL BE ISSUED AT THAT STAGE.



TYPICAL LONGSECTION OF CULVERT UNDER FREEWAY



TYPICAL SECTION OF CULVERT WITH SIDE AND MEDIAN INLETS



TYPICAL SECTION OF CULVERT WITH SIDE AND MEDIAN INLETS

<b>SNA / SSI JOINT VENTURE</b> CIVIL AND STRUCTURAL ENGINEERS (PTY) LTD 116 FLOOR RATTLEDOP OFFICE PARK 1601 RIVERVIEW DRIVE, SANDHURST, 7682 TEL: (021) 940 8071 FAX: (021) 940 7598 EMAIL: info@sna-ssi.co.za		<b>SSI</b> A DHV COMPANY P.O. BOX 9196 TYDERSVALLEY 7539 TEL: (021) 946 4114 FAX: (021) 946 0203 EMAIL: info@ssi.co.za		DESIGNED BY: JW Gillmer NAME: JW Gillmer Prof. Reg. No.: 64086 Date: 17/01/2008 CHECKED BY: CM Smith NAME: CM Smith Prof. Reg. No.: 87049		HEAD OFFICE: 1204 Park Street, Hatfield, Pretoria, 0083 THE SOUTH AFRICAN NATIONAL ROADS AGENCY LTD Private Bag 218, Bellville, 7535 Tel: (012) 426 8000		WESTERN REGION: Puro du Cap Building 6, Chr. Willem Steyn, Welle, Scherers, Bellville, 7535 Private Bag 218, Bellville, 7535 Tel: (021) 947 4908		ACCEPTANCE: THIS ACCEPTANCE IS FOR PROCEDURAL AND ADMINISTRATIVE REVIEW PURPOSES ONLY AND DOES NOT ATTRACT LEGAL LIABILITY OR LIABILITY OF ANY KIND FROM WHATEVER CAUSE OR HOWSOEVER ARISING. BY: [Signature] DATE:		PROJECT DESCRIPTION: IMPROVEMENT OF NATIONAL ROUTE R300 FROM SWARTKOP INTERCHANGE (km 14,0) TO STELLENBERG INTERCHANGE (km 31,0) DRAWING DESCRIPTION: DRAINAGE SCHEDULE		PROJECT NUMBER: R300-010-2007/1 DRAWING LOCATION DATA: START R300, END R300 SECTION: ROAD - DRAINAGE DRAWING TYPE: ROAD - DRAINAGE BRIDGE/STRUCTURE No.: CONSULTANT DRAWING No.: R300/121/108 SANRAL DOC # 173088	
No. DATE REVISION V2: 27/09/2010 FINAL CONSTRUCTION RECORD V1: 17/03/2008 ORIGINAL VERSION		JW GILLMER CONSULTANT ENGINEER		JW GILLMER CONSULTANT ENGINEER		JW GILLMER CONSULTANT ENGINEER		JW GILLMER CONSULTANT ENGINEER		SCALE: N.T.S. SHEET 1 OF 2		V2			

Figure C-1: Drainage schedule (SNA-SSI Joint Venture, 2008)

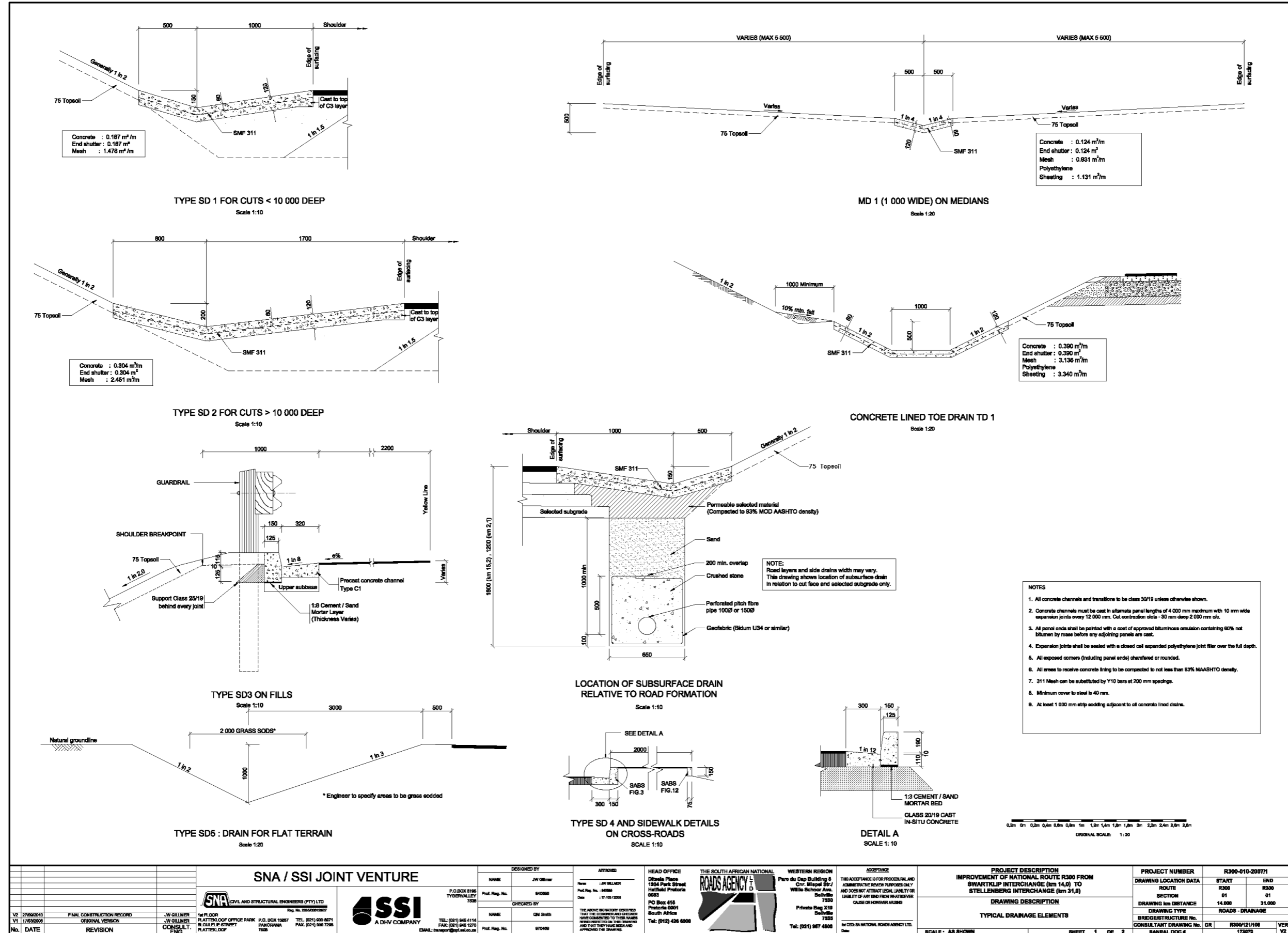


Figure C-2: Typical drainage elements (1) (SNA-SSI Joint Venture, 2008)

<b>SNA / SSI JOINT VENTURE</b> SNA CIVIL AND STRUCTURAL ENGINEERS (PTY) LTD P.O. BOX 9186 TYGERVALLEY 7028 SSI A DIV COMPANY P.O. BOX 9186 TYGERVALLEY 7028 TEL: (021) 845 4114 FAX: (021) 848 1270 EMAIL: info@ssi.co.za		DESIGNED BY NAME: J.W. GILLMER Prof. Reg. No.: 64086 DATE: 17/03/2008 CHECKED BY NAME: C.M. SMITH Prof. Reg. No.: 67048	HEAD OFFICE Disdale Plaza 1304 Park Street Hatfield Pretoria 0028 PO Box 416 Pretoria 0001 South Africa Tel: (012) 436 6000	WESTERN REGION Private Bag Building 8 Cnr. Mispel St & Willie Schoor Ave. Bellville 7530 Private Bag 5718 Bellville 7535 Tel: (021) 967 4800	PROJECT DESCRIPTION IMPROVEMENT OF NATIONAL ROUTE R300 FROM SWARTKOP INTERCHANGE (km 14,0) TO STELLENBERG INTERCHANGE (km 31,0) DRAWING DESCRIPTION TYPICAL DRAINAGE ELEMENTS	PROJECT NUMBER R300-010-2007/1 DRAWING LOCATION DATA ROUTE: R300 SECTION: 01 DRAWING km DISTANCE: 14,000 ROADS - DRAINAGE BRIDGE/STRUCTURE No.: CONSULTANT DRAWING No.: CR R300/12/1/06 SANRAL DOG #: 172675	SCALE: AS SHOWN SHEET 1 OF 2 VER V2
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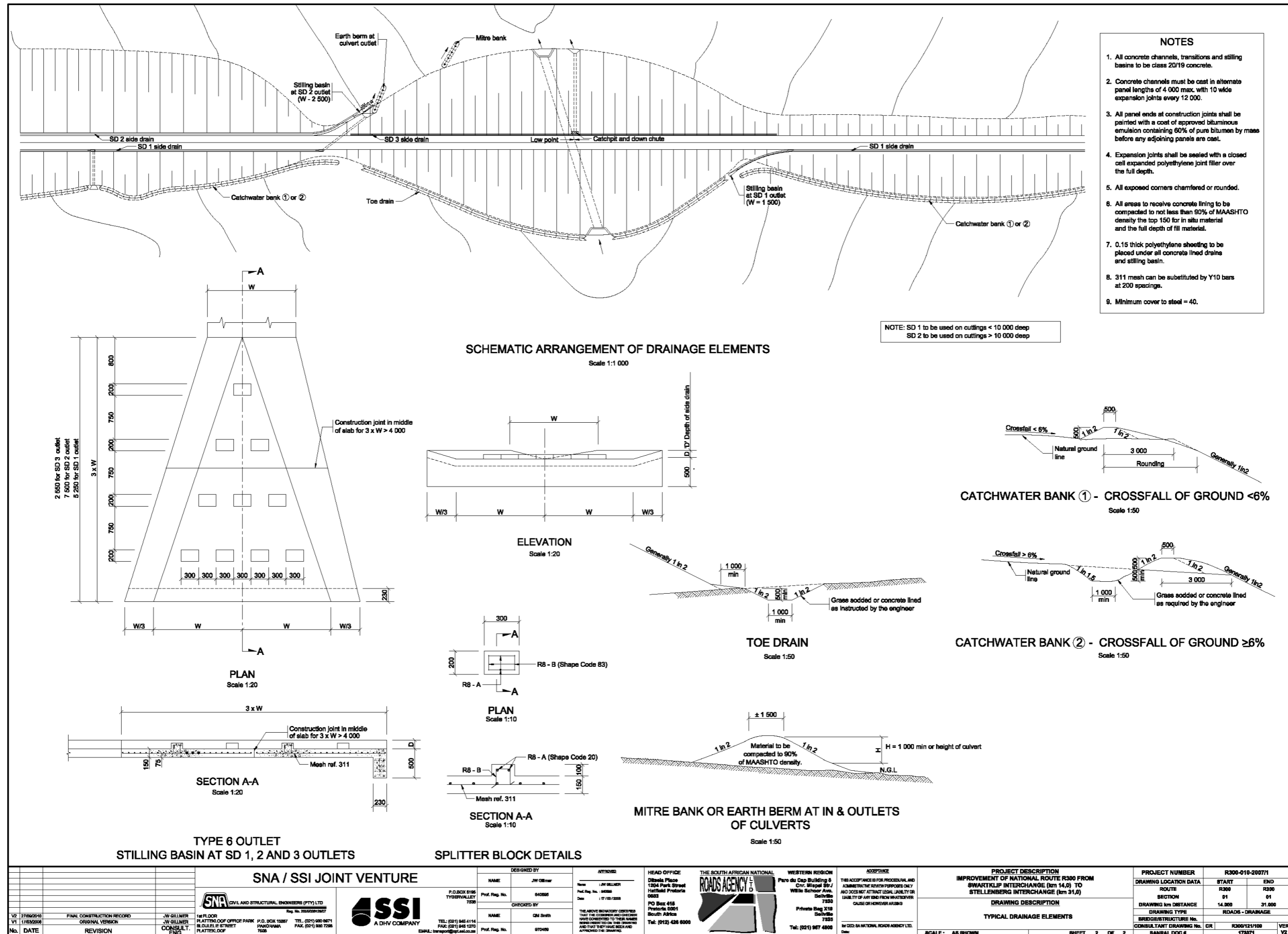


Figure C-3: Typical drainage elements (2) (SNA-SSI Joint Venture, 2008)

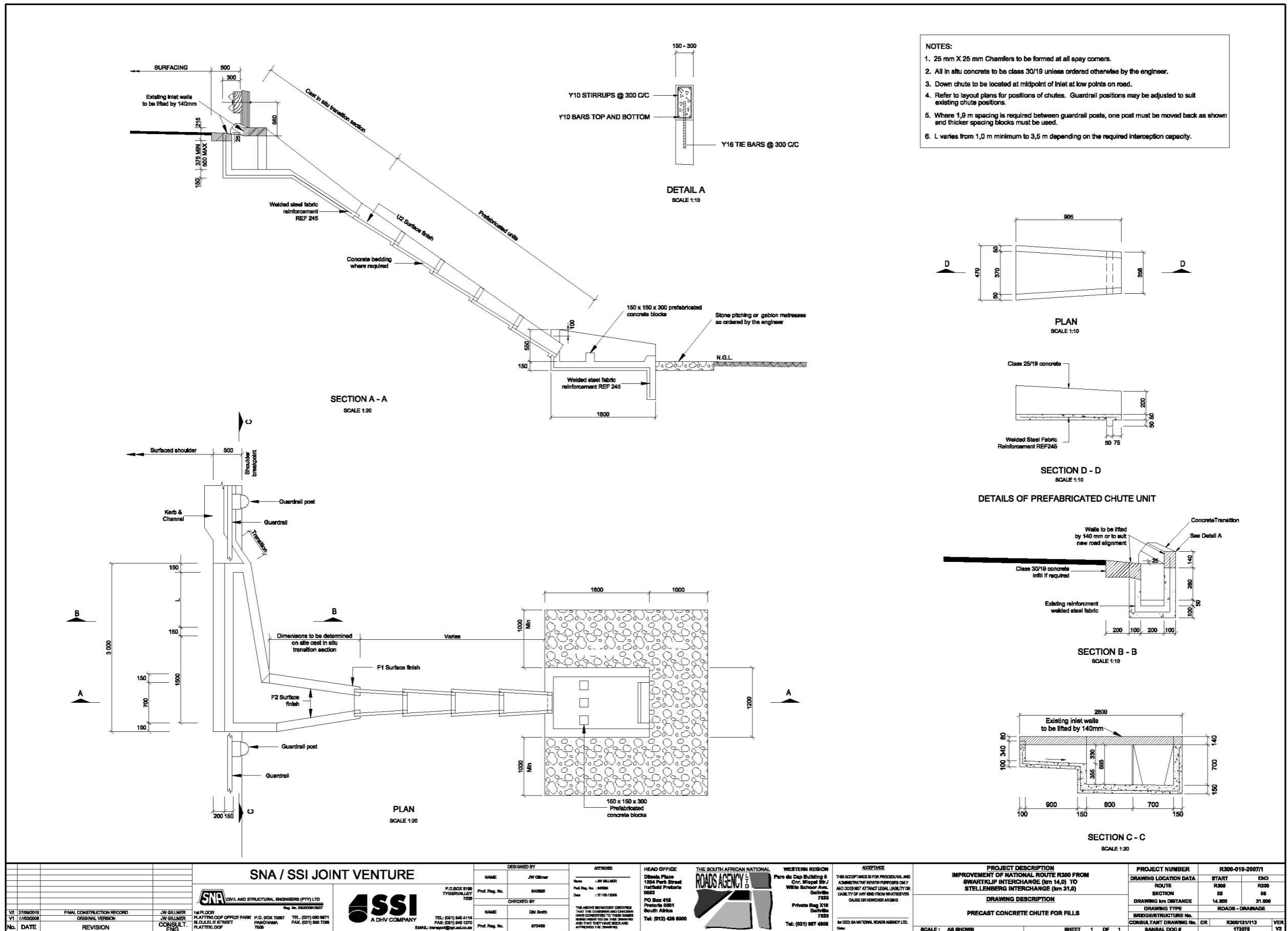
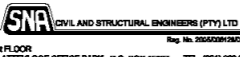



Figure C-4: Pre-cast concrete chutes (SNA-SSI Joint Venture, 2008)

<b>SNA / SSI JOINT VENTURE</b>  		<b>DESIGNED BY</b> NAME: JW Gillmer Prof. Reg. No. 64086 Date: 17/03/2008		<b>APPROVED</b> Name: JW Gillmer Prof. Reg. No. 64086 Date: 17/03/2008		<b>HEAD OFFICE</b> Dikela Place 1204 Park Street Hatfield Pretoria 0003 P.O. Box 416 Pretoria 0001 South Africa Tel: (012) 436 8000		<b>WESTERN REGION</b> Puro du Cap Building & City: Bloubaai Str. Wille Schuur Ave. Stellenbosch 7130 Private Bag X18 Stellenbosch 7130 Tel: (021) 947 4800		<b>ACCEPTANCE</b> THIS ACCEPTANCE IS FOR PROCEDURAL AND ADMINISTRATIVE REVIEW PURPOSES ONLY AND DOES NOT ATTRACT LEGAL LIABILITY OR LIABILITY OF ANY KIND FROM WATERREVER CHUTE OR HOWEVER ARISING by CEO: SA NATIONAL ROADS AGENCY LTD.		<b>PROJECT DESCRIPTION</b> IMPROVEMENT OF NATIONAL ROUTE R300 FROM SWARTKOP INTERCHANGE (km 14,0) TO STELLENBERG INTERCHANGE (km 31,8) <b>DRAWING DESCRIPTION</b> PRECAST CONCRETE CHUTE FOR FILLS		<b>PROJECT NUMBER</b> R300-010-2007/1 <b>DRAWING LOCATION DATA</b> ROUTE: R300 SECTION: 08 DRAWING NO. DISTANCE: 14,300 DRAWING TYPE: ROADS - DRAINAGE SUB-DIVISION/STRUCTURE No.: DR CONSULTANT DRAWING No.: R300/12/113 BANRAL DOC # 473076		SCALE: AS SHOWN SHEET 1 OF 1 VER V2
<b>REVISION</b> No. DATE REVISION V2 27/09/2010 FINAL CONSTRUCTION RECORD V1 17/03/2008 ORIGINAL VERSION		<b>DESIGNED BY</b> NAME: JW Gillmer Prof. Reg. No. 64086 Date: 17/03/2008		<b>APPROVED</b> Name: JW Gillmer Prof. Reg. No. 64086 Date: 17/03/2008		<b>HEAD OFFICE</b> Dikela Place 1204 Park Street Hatfield Pretoria 0003 P.O. Box 416 Pretoria 0001 South Africa Tel: (012) 436 8000		<b>WESTERN REGION</b> Puro du Cap Building & City: Bloubaai Str. Wille Schuur Ave. Stellenbosch 7130 Private Bag X18 Stellenbosch 7130 Tel: (021) 947 4800		<b>ACCEPTANCE</b> THIS ACCEPTANCE IS FOR PROCEDURAL AND ADMINISTRATIVE REVIEW PURPOSES ONLY AND DOES NOT ATTRACT LEGAL LIABILITY OR LIABILITY OF ANY KIND FROM WATERREVER CHUTE OR HOWEVER ARISING by CEO: SA NATIONAL ROADS AGENCY LTD.		<b>PROJECT DESCRIPTION</b> IMPROVEMENT OF NATIONAL ROUTE R300 FROM SWARTKOP INTERCHANGE (km 14,0) TO STELLENBERG INTERCHANGE (km 31,8) <b>DRAWING DESCRIPTION</b> PRECAST CONCRETE CHUTE FOR FILLS		<b>PROJECT NUMBER</b> R300-010-2007/1 <b>DRAWING LOCATION DATA</b> ROUTE: R300 SECTION: 08 DRAWING NO. DISTANCE: 14,300 DRAWING TYPE: ROADS - DRAINAGE SUB-DIVISION/STRUCTURE No.: DR CONSULTANT DRAWING No.: R300/12/113 BANRAL DOC # 473076		SCALE: AS SHOWN SHEET 1 OF 1 VER V2

## Appendix D: Incident analysis

The R300 is monitored by 21 cameras located at intersections, bridges and key points along the road. Figure D-1 shows the R300 (blue) with the location and orientation of the permanent CCTV cameras installed along the route. Incidents such as crashes, adverse weather, hijacking and stationary vehicles are recorded as part of the Freeway Management System (FMS) implemented on the route.

An analysis of FMS data from mid-2010 to 2015 revealed the following trends in accident data. There is an increase in crashes per year, shown in Figure D-2, which agrees with a yearly increase in traffic volume. Most incidents occur during the rainy season (June through August) and alongside major national holidays (Easter and Christmas/school holidays), as shown in Figure D-3. When compared to the mean, there are 32% more crashes in June, 50% more crashes in August, and 20% more crashes in December.

The primary function of road drainage systems is to maintain road user safety by conveying water away from the road surface and minimising the runoff depth. The efficacy of the road drainage system can be assessed by looking at the difference between crash data associated with rainfall and crash data during dry periods. If there is a significant increase in crashes at a particular location during wet weather, this implies that the road drainage system is not functioning optimally and that the drainage design should be reassessed.

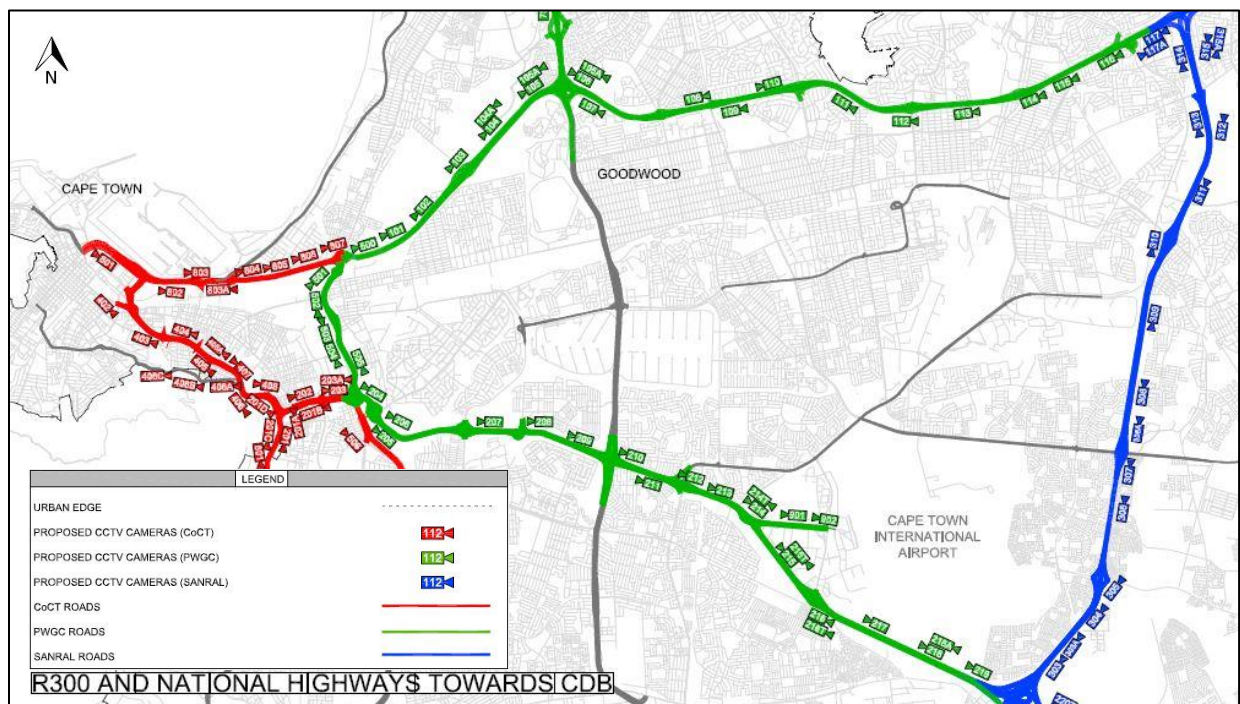
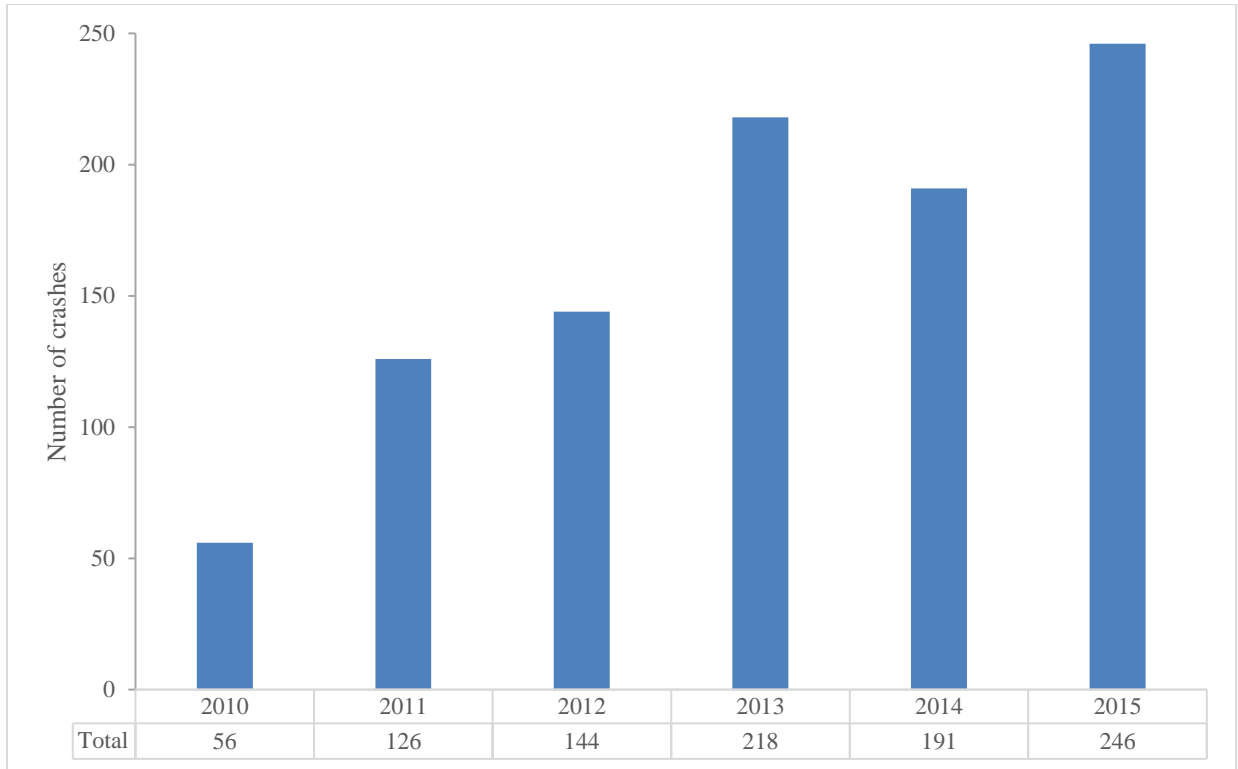
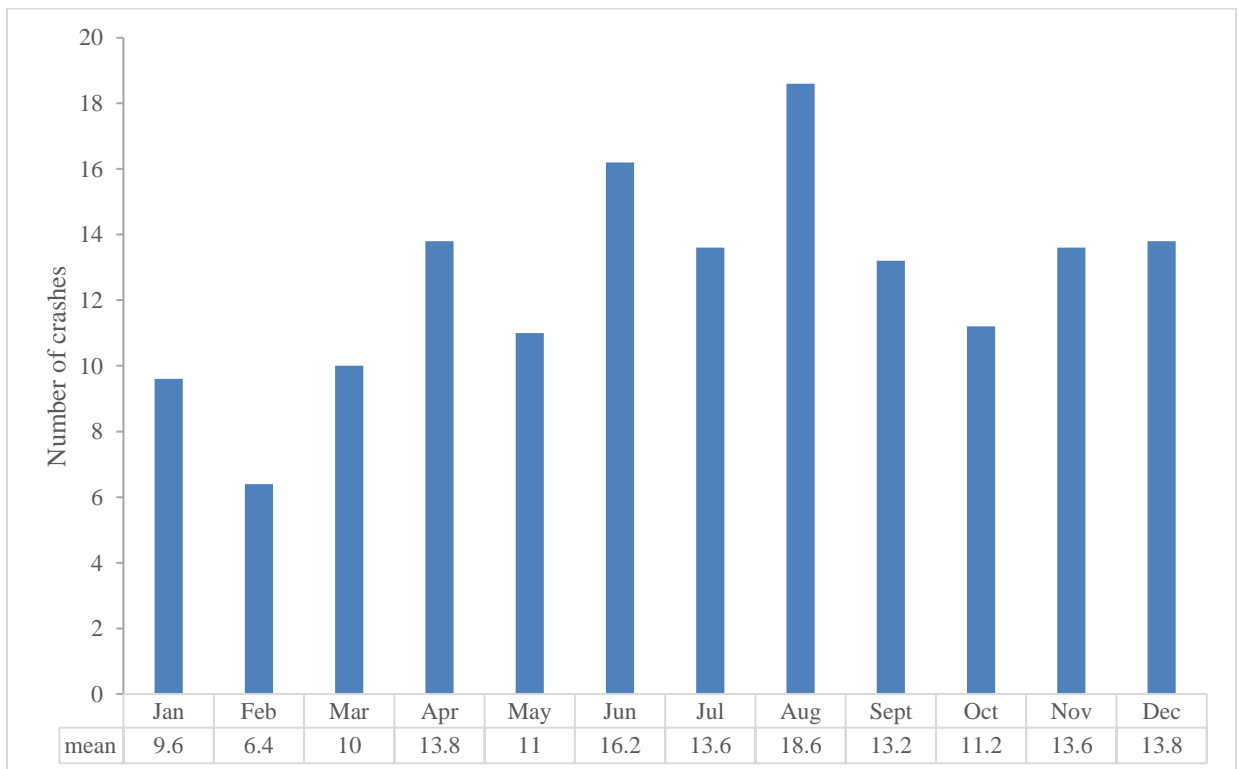


Figure D-1: Map of the R300 (blue) showing camera locations (SANRAL, 2015)



**Figure D-2: Total number of crashes per year on the R300 for 2011-2015**



**Figure D-3: Average number of crashes per month on the R300 for 2011-2015**

The FMS data was sorted and vehicle crash data were retained; incidents relating to pedestrians, hijacking, stationary vehicles etc. were discarded for the purposes of this analysis. Thereafter, crash data was coupled with rainfall data from the Cape Town International Airport, which is approximately 5km from the R300. The total rainfall 15 minutes either side of a crash was determined, and accidents were deemed to have a significant quantity of rain where the cumulative 30-minute rainfall was greater than 0.3mm. The location of crashes that occur during dry conditions was mapped to identify areas where accidents are most frequent. Likewise, the location of crashes associated with rain were mapped and the two figures were compared to identify areas that have disproportionately more crashes during wet weather.

Figure D-4 shows a heat map of incidents during dry weather along the R300. Accidents are concentrated in the region of the Stellenbosch Arterial interchange, Hindle Road interchange and the Swartklip (N2) interchange. Figure D-5 shows a heat map of the crashes that are associated with rainfall. The crashes that occur in wet conditions are more localised and less dispersed than the crashes in dry weather. Areas with the highest concentration of crashes during wet weather include the horizontal curve near Old Paarl Road and the Hindle Road interchange area.

The concentration of incidents at Hindle Road confirms the issue of standing water at the interchange, which was only recently remedied. During the research period, on 23 April 2016, there was an accident at the Old Paarl location during a rainfall event. On reviewing video footage, the vehicle, travelling faster than other road users at the time, rapidly lost control and spun out, careering from the inside lane to the verge. It is most likely that this vehicle hydroplaned due to a combination of speed, tyre and surface runoff conditions. This incident, coupled with the high concentration of crashes associated with rain, and low concentration of crashes without rain at this location suggest that the road drainage may be insufficient at this location.

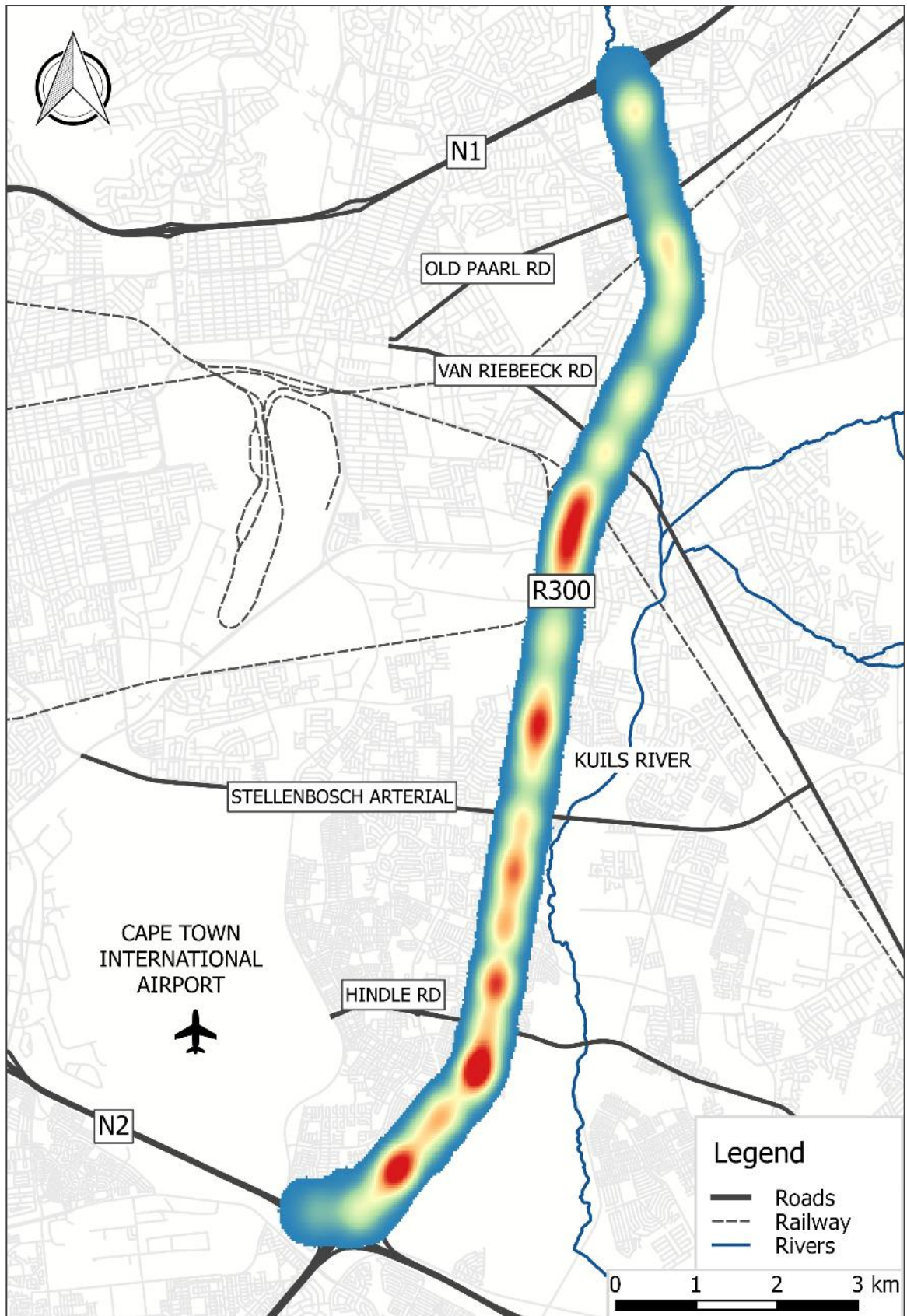


Figure D-4: Heat map of crashes during dry weather on the R300 for 2010 – 2015

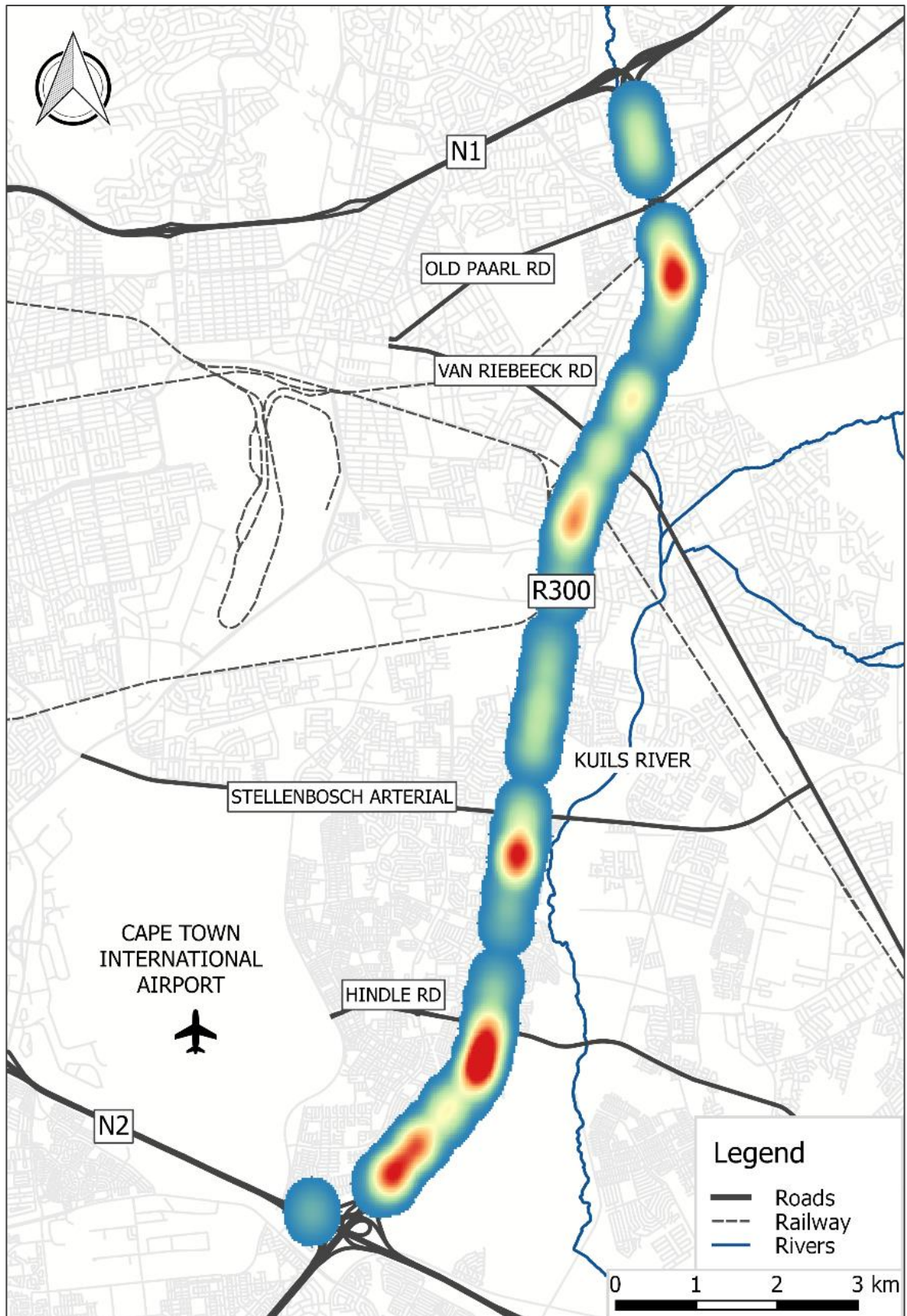


Figure D-5: Heat map of crashes associated with rain on the R300 for 2010–2015

## Appendix E: Sample event details

**Table E-1: Summary of Sample Event 1**

<b>Date</b>	17-03-2016	<b>General conditions</b>	Hot and dry	
<b>Time</b>	10:50 - 11:25	<b>Temperature</b>	27°C	
<b>Sample contents</b>	sediment	<b>Wind</b>	2m/s WSW	
<b>Sample type</b>	single	<b>Precipitation</b>	0mm	
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.6S-0317-1/2	24.4N-0317-1/2	17.9S-0317-1/2	21.4N-0317-1/2
<b>Method of collection</b>	Swept from concrete drain leading to catchpit	Swept from concrete drain leading to catchpit	Swept from inside longitudinal catchpit, approx. 300mm deep	Swept from grassy area alongside road, approx. 35m from road edge
<b>Deviations/comments</b>	Included sand caught in the catchpit grid	Included sand brushed out of expansion joints in the concrete	None	Large fraction of fine particles

**Table E-2: Summary of Sample Event 2**

<b>Date</b>	23-03-2016	<b>General conditions</b>	Hot and dry	
<b>Time</b>	10:05 - 10:55	<b>Temperature</b>	25°C	
<b>Sample contents</b>	sediment	<b>Wind</b>	4m/s S	
<b>Sample type</b>	single	<b>Precipitation</b>	0mm	
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.7S-0323-1/2	24.4N-0323-1/2	17.7S-0323-1/2	21.4N-0323-1/2
<b>Method of collection</b>	Swept from concrete drain leading to catchpit	Swept from concrete drain leading to catchpit	Swept from inside long catchpit, approx. 250mm deep	Swept from grassy area alongside road, approx. 80m from road edge
<b>Deviations/comments</b>	Included sand brushed out of expansion joints in concrete drain	Included sand caught in catchpit grid and expansion joints	None	None

**Table E-3: Summary of Sample Event 3**

<b>Date</b>	21-04-2016	<b>General conditions</b>	Overcast and humid	
<b>Time</b>	10:35 - 11:40	<b>Temperature</b>	17°C	
<b>Sample contents</b>	sediment	<b>Wind</b>	4m/s NW	
<b>Sample type</b>	single	<b>Precipitation</b>	1.5mm	
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.7S-0421-1/2	24.4N-0421-1/2	17.7S-0421-1/2	21.4N-0421-1/2
<b>Method of collection</b>	Swept from concrete drain leading to and away from catchpit	Sand swept from within the catchpit as the median drain was clean.	Swept from inside long catchpit, approx. 250mm deep	Swept from grassy area alongside road, approx. 80m away. Obtained dry sand a few cm below surface
<b>Deviations/comments</b>	Sand quite wet, sticking together. Included sand trapped in the catchpit grid.	Sampled from within catchpit. Sand moderately wet, sticking together and clumping	Very wet sample. Drain cleaner than usual due to preceding rain	None

**Table E-4: Summary of Sample Event 4**

<b>Date</b>	18-05-2016	<b>General conditions</b>	Windy, light drizzle	
<b>Time</b>	13:15 - 14:00	<b>Temperature</b>	17°C	
<b>Sample contents</b>	sediment	<b>Wind</b>	6m/s NNW	
<b>Sample type</b>	single	<b>Precipitation</b>	0mm	
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.7S-0518-1/2	24.4N-0518-1/2	17.7S-0518-1/2	21.4N-0518-1/2
<b>Method of collection</b>	Swept from concrete drain leading towards and away from catchpit.	Swept from concrete drain leading towards catchpit on both sides.	Swept from within longitudinal drain, approx. 200mm deep.	Swept from grassy area alongside road, approx. 80m from road edge
<b>Deviations/comments</b>	A fair amount of glass and large stones	Included sand brushed out of expansion joints in the concrete drain	Lots of ants, tried to exclude them	None

**Table E-5: Summary of Sample Event 5**

<b>Date and time of rainfall event</b>	22-04-2016, 13:25		<b>General conditions</b>	Intense rain, first storm of the rainy season
<b>Date collected</b>	22-04-2016		<b>Temperature</b>	18°C
<b>Time collected</b>	15:30 - 16:05		<b>Wind</b>	6m/s NNW
			<b>Precipitation</b>	29mm
<b>Sample location</b>	Site 1	Site 1.1	Site 2	Site 4
<b>Sample ID</b>	27.7S-0422-1/2	27.7N-0422-1/2	21.4N-0422-1/2	24.4N-0422-1/2
<b>Sample contents</b>	runoff	runoff	runoff	rainwater
<b>Sample type</b>	single	single	single	single
<b>Method of collection</b>	Grab sample from runoff at north catchpit entrance. High flow rate	Grab sample from outfall (flowing water) to verge	Grab sample from runoff at north catchpit entrance. High flow rate	Sample container attached to metal lamp post
<b>Deviations/ comments</b>	Accident on road nearby, did not contaminate runoff	Sample collected from outfall to road reserve	Large amount of debris caught on south side of the catchpit	Sample container collected insufficient volume of rainwater and was removed from site on Monday, 25th at 13h15
	*Unable to sample at Site 3 for safety reasons			

**Table E-6: Summary of Sample Event 6**

<b>Date and time of rainfall event</b>	18-05-2016, 12:15		<b>General conditions</b>	Large storm system over cape region
<b>Date collected</b>	19-05-2016		<b>Temperature</b>	18°C
<b>Time collected</b>	13:30 - 13:45		<b>Wind</b>	6m/s SSE
			<b>Precipitation</b>	4mm
<b>Sample location</b>	Site 1	Site 2	Site 4	
<b>Sample ID</b>	27.7S-0518-1/2	24.4N-0518-1/2	21.1N-0518-1	
<b>Sample contents</b>	runoff	runoff	rainwater	
<b>Sample type</b>	composite	composite	composite	
<b>Method of collection</b>	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	1 sample container mounted on metal lamppost, 2 mounted on wooden fence poles	
<b>Deviations/ comments</b>		Most of the litter in catchpit washed away, sand remained		
	*Unable to sample at Site 3 for safety reasons. Large amounts of sand trapped at entrance to sample bottles			

**Table E-7: Summary of Sample Event 7**

<b>Date and time of rainfall event</b>	23-05-2016, 15:30		<b>General conditions</b>	Afternoon/evening rainfall
<b>Date collected</b>	24-05-2016		<b>Temperature</b>	15°C
<b>Time collected</b>	10:55 - 11:20		<b>Wind</b>	5m/s N
			<b>Precipitation</b>	12mm
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.7S-0524-1/2	24.4N-0524-1/2	17.4S-0524-1/2	21.4N-0524-1/2
<b>Sample contents</b>	surface runoff	surface runoff	surface runoff	rainwater
<b>Sample type</b>	composite	composite	composite	composite
<b>Method of collection</b>	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	8 x sample containers mounted on wooden fence poles
<b>Deviations/ comments</b>	Sample bottle 2 not completely full, struggled to remove polystyrene ball.	Collected from north side of catchpit. Catchpit washed clean by rainfall event	Catchpit much more shallow than others with fair amount of debris. Sample appeared especially grey/opaque	Tied bottles to fence with lip above top wire. Samples appeared to have more organic matter than previously
	Large amounts of sand trapped at entrance to sample bottles			

**Table E-8: Summary of Sample Event 8**

<b>Date and time of rainfall event</b>	09-06-2016, 20h00		<b>General conditions</b>	Overcast, windy and cold
<b>Date collected</b>	10-06-16		<b>Temperature</b>	14°C
<b>Time collected</b>	10:00 - 10:40		<b>Wind</b>	5m/s NE
			<b>Precipitation</b>	17mm
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.7S-0610-1/2	24.4N-0610-1/2	17.4S-0610-1/2	21.4N-0610-1/2
<b>Sample contents</b>	surface runoff	surface runoff	surface runoff	rainwater
<b>Sample type</b>	composite	composite	composite	composite
<b>Method of collection</b>	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	8 x sample containers mounted on wooden fence poles
<b>Deviations/ comments</b>	Glass sample bottles not entirely full	Both sample bottles not completely full	Fair amount of debris in catchpit	Tied bottles to fence with lip above top wire to try and prevent contamination.
	Lots of organic matter; grass cuttings, leaves in catchpits			

**Table E-9: Summary of Sample Event 9**

<b>Date and time of rainfall event</b>	23-06-2016, 16:00		<b>General conditions</b>	Partly sunny, cold
<b>Date collected</b>	14-06-2016		<b>Temperature</b>	13°C
<b>Time collected</b>	10:15 - 10:45		<b>Wind</b>	4m/s NNW
			<b>Precipitation</b>	8mm
<b>Sample location</b>	Site 1	Site 2	Site 3	Site 4
<b>Sample ID</b>	27.7S-0614	24.4N-0614	17.4S-0614	21.4N-0614
<b>Sample contents</b>	surface runoff	surface runoff	surface runoff	rainwater
<b>Sample type</b>	composite	composite	composite	composite
<b>Method of collection</b>	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	Sample containers suspended in catchpit using pipe device	8 x sample containers mounted on wooden fence poles
<b>Deviations/ comments</b>	One sample bottle deployed	One sample bottle deployed	One sample bottle deployed	Tied bottles to fence with lip above top wire to try and prevent contamination.
	Sample containers deployed in catchpits on Friday 10-06-2016. Samples much cleaner than previously based on visual assessment			

	Colour	Odour					Clarity				Floating solids	Settled solids	Suspended solids	Oil sheen
		none	sewage	sulfur	petrol	solvents	clear	slightly	cloudy	opaque				
<b>Sample Event 5</b>														
27.7S-0422-1/2	clear, grey				x			x				black/grey, fibrous material, clumped together	yes	
27.7N-0422-1/2	clear, grey				x			x				black/grey, fibrous material, clumped together	yes	
21.4N-0422-1/2	clear						x							
24.4N-0422-1/2	clear, grey				x			x				black/grey, fibrous material, clumped together	yes	yes
<b>Sample Event 6</b>														
27.7S-0518-1/2	brown/yellow				x	x			x			white sand, black substance clumped together	very fine	
24.4N-0518-1/2	none	x					x							
21.1N-0518-1	grey/yellow				x	x				x		white sand, black substance clumped together	very fine	
<b>Sample Event 7</b>														
27.7S-0524-1/2	grey/brown				x	x				x		white sand, larger black particles	yes	
24.4N-0524-1/2	dark grey				x	x				x		white sand, black particles, fine plant matter	yes	
21.4N-0524-1/2	clear	x					x					few plant particles	yes, fine	
17.4S-0524-1/2	grey/brown				x	x				x		white sand, larger black particles	yes	
<b>Sample Event 8</b>														
27.7S-0610-1/2	brown				x	x				x	bugs, plant matter	white sand, larger black particles	yes	
24.4N-0610-1/2	brown	grass			x					x	bugs, plant matter	sand, stones, plant matter, black particles	yes	
21.4N-0610-1/2	clear	x					x					few unidentified particles		
17.4S-0610-1/2	yellow brown				x	x				x	bugs	white sand, larger black particles, plant matter	yes	
<b>Sample Event 9</b>														
27.7S-0614	light brown				x				x		bugs, plant matter	white sand	yes	
17.0S-0614	light brown				x				x		bugs	white sand	yes	
21.4N-0614	clear	x					x							
24.4N-0614	almost clear	x						x				white sand (small amount)		

Table E-10: Visual assessment of runoff samples

## Appendix F: Statistical analysis

**Table F-1: Contaminant concentrations in sediment used for statistical analysis**

		R300 sediment										
Sample ID	27.6S-0317-1	17.9S-0317-1	24.4N-0317-1	27.7S-0323-1	17.7S-0323-1	24.4N-0323-1	27.7S-0421	17.7S-0421	24.4N-0421	27.7S-0518-1	17.7S-0518-1	24.4N-0518-1
Total metals	280.5	312.3	252.7	445.8	345.7	487.0	5875.9	3074.5	2537.8	5563.5	3580.1	2640.5
Phosphorus	344.0	484.0	281.0	373.0	406.0	319.0	345.0	322.0	377.0	472.0	450.0	330.0
Total Nitrogen							0.1	0.1	0.0	0.1	0.1	0.0
Fats Oils & Grease	119.0	265.0	141.0	156.0	247.0	209.0	175.0	216.0	221.0	255.0	203.0	219.0
		Environmental sediment										
Sample ID	21.4N-0317-1	21.4N-0323-1	21.4N-0421	21.4N-0518-1								
Total metals	19.1	35.4	427.3	425.8								
Phosphorus	196.0	231.0	200.0	188.0								
Total Nitrogen			0.1	0.0								
Fats Oils & Grease	0.0	0.0	0.0	0.0								

**Table F-2: F-Test; Two-Sample for Variances**

H<sub>0</sub>: variances are the same

	metals		phosphorus		fats, oils & grease	
	Road	Environ.	Road	Environ.	Road	Environ.
Mean	2116.4	226.9	375.3	203.8	202.2	0
Variance	4.4E+06	53191.5	4231.8	354.9	2104.9	0
Observations	12	4	12	4	12	4
df	11	3	11	3	11	3
F	82.4		11.9		65535.0	
P(F<=f) one-tail	0.0		0.0		#DIV/0!	
F Critical one-tail	8.8		8.8		8.8	

**Table F-3: t-Test; Two-Sample Assuming Unequal Variances**

H<sub>0</sub>: mean concentrations are the same

	metals		phosphorus		fats, oils & grease	
	Road	Environ.	Road	Environ.	Road	Environ.
Mean	2116.4	226.9	375.3	203.8	202.2	0
Variance	4.4E+06	5.3E+04	4231.8	354.9	2104.9	0
Observations	12	4	12	4	12	4
Hypothesized Mean Difference	0		0		0	
df	12		14		11	
t Stat	3.07		8.16		15.26	
P(T<=t) one-tail	4.8E-03		5.4E-07		4.7E-09	
t Critical one-tail	1.78		1.76		1.80	
P(T<=t) two-tail	0.01		0.00		0.00	
t Critical two-tail	2.18		2.14		2.20	



**Table F-4: Contaminant concentrations in runoff results used for statistical analysis**

	R300 runoff waters													
Sample ID	27.7S -0422	27.7N -0422	24.4N -0422	27.7S -0518	24.4N -0518	27.7S -0524	24.4N -0524	17.4S -0524	27.7S -0610	24.4N -0610	17.0S -0610	27.7S -0614	17.0S -0614	24.4N -0614
Total metals	3784.9	3940.9	3581.7	6588.1	10719	7327.7	11007	11512	6335.1	46539	6533.2			
Total Phosphorus	333.0	361.0	383.0	1485.0	1681.0	965.0	2401.0	1445.0	1383.0	14930	3895.0			
Oil and Grease	0.0	70.0	0.0	89.0	0.0				746.0	410.0	161.0	0.0	53.0	50.0
Total Suspended Solids	0.0	33.0	116.0	154.0	298.0				108.0	176.0	208.0	126.0	354.0	30.0
<b>Day / Landuse</b>	<b>Rainwater</b>													
Sample ID	21.4N -0422	21.4N -0518	21.4N -0524	21.4N -0610	21.4N -0614									
Total metals	969.0	879.3	196.0	113.0										
Total Phosphorus	43.0	43.0	49.0	47.0										
Oil and Grease	0.0		0.0	321.0	0.0									
Total Suspended Solids	0.0		0.0	0.0	0.0									

**Table F-5: F-Test; Two-Sample for Variances**

H<sub>0</sub>: variances are the same

	metals		phosphorus		oil&grease		TSS	
	Road	Rain	Road	Rain	Road	Rain	Road	Rain
Mean	10715.3	539.3	2660.2	45.5	143.5	80.3	145.7	0
Variance	1.5E+08	2.0E+05	1.8E+07	9.0E+00	5.4E+04	2.6E+04	1.2E+04	0
Observations	11	4	11	4	11	4	11	4
df	10	3	10	3	10	3	10	3
F	747.2		1.9E+06		2.1		65535.0	
P(F<=f) one-tail	0.0		0.0		0.3		#DIV/0!	
F Critical one-tail	8.8		8.8		8.8		8.8	

**Table F-6: t-Test; Two-Sample Assuming Unequal Variances**

H<sub>0</sub>: mean concentrations are the same

	metals		phosphorus		oil&grease		TSS	
	Road	Rain	Road	Rain	Road	Rain	Road	Rain
Mean	10715.3	539.3	2660.2	45.5	143.5	80.3	145.7	0
Variance	1.5E+08	2.0E+05	1.8E+07	9	54200.9	25760.3	12146.0	0
Observations	11	4	11	4	11	4	11	4
Hypothesized Mean Difference	0		0		0		0	
df	10		10		13		10	
t Stat	2.8		2.1		0.5		4.4	
P(T<=t) one-tail	0.0		0.0		0.3		0.0	
t Critical one-tail	1.8		1.8		1.8		1.8	
P(T<=t) two-tail	0.0		0.1		0.6		0.0	
t Critical two-tail	2.2		2.2		2.2		2.2	

$H_0$ : road runoff concentration is the same as rainwater concentration

$H_1$ : road runoff concentration > rainwater conc.

**metals**

F > F critical                      reject  $H_0$ , variances are different

t stat                                      2.76

t crit (one tail)                      1.81

Reject  $H_0$  based on t stat

**Total metals concentration in road runoff > rainwater conc.**

**phosphorus**

F > F critical                      reject  $H_0$ , variances are different

t stat                                      2.07

t crit (one tail)                      1.81

Reject  $H_0$  based on t stat

**Total phosphorus concentration in road runoff > rainwater conc.**

**oil and grease**

F < F critical                      accept  $H_0$ , variances are the same

t stat                                      0.50

t crit (one tail)                      1.77

Cannot reject  $H_0$  based on t stat

**Oils and grease concentration in road runoff not greater than rainwater conc.**

**TSS**

F > F critical                      reject  $H_0$ , variances are different

t stat                                      4.39

t crit (one tail)                      1.81

Reject  $H_0$  based on t stat

**TSS concentration in road runoff > rainwater conc.**

## Appendix G: Photographs of runoff samples



Figure G-1: Sample bottles from Sample Event 5, 22-04-2016



Figure G-2: Sample bottles from Sample Event 6, 18-05-2016



Figure G-3: Sample bottles from Sample Event 7, 24-05-2016



Figure G-4: Sample bottles from Sample Event 8, 10-06-2016



Figure G-5: Sample bottles from Sample Event 9, 14-06-16

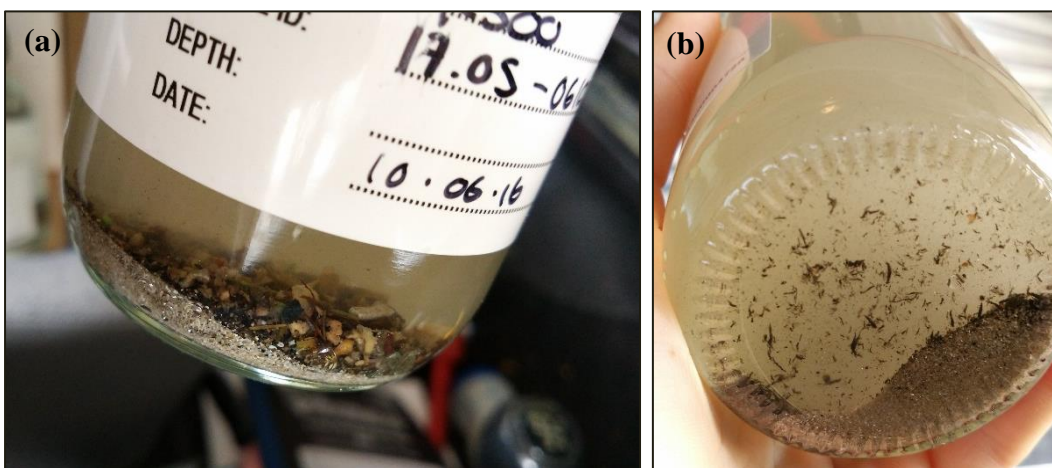


Figure G-6: Close up view of sediment in sample bottles (a) front (b) bottom

# Appendix H: Rational Method calculations

RATIONAL METHOD: ALTERNATIVE 2								
Description of the catchment				Section of R300 highway from km15.56 - km28.8				
River details				None				
Calculated by		Abby Robertson		Date		12-Jun-16		
Physical characteristics								
Size of the catchment (A)		0.436934	km <sup>2</sup>	Days of thunder per year (R)		1	days / year	
Longest watercourse (L)		1	km	Weather Services		Area distribution factors		
Average slope (S <sub>av</sub> )		0.025	m/m	Station		Rural ( α )	1	
Dolomite area (D <sub>%</sub> )		0	%	Number		Urban ( β )	0	
Mean annual rainfall (MAP)		515	mm	1 day T(2) rainfall		Lakes ( γ )	0	
Rural				Urban				
Surface slope		%	Factor	C <sub>s</sub>		Description		
Vleis and pans				0.000		Lawns		
Flat areas				0.000		Sandy, flat (<2%)		
Hilly				0.000		Sandy, steep (>7%)		
Steep areas				0.000		Heavy soil, flat (<2%)		
Total		0		0.000		Heavy soil,steep (>7%)		
Permeability		%	Factor	C <sub>p</sub>		Residential area		
Very permeable						Houses		
Permeable						Flats		
Semi-permeable				0.000		Industry		
Impermeable				0.000		Light industry		
Total		0		0.000		Heavy industry		
Vegetation		%	Factor	C <sub>v</sub>		Business		
Thick bush & plantation						City centre		
Light bush and farmlands				0.000		Suburban		
Grasslands				0.000		Streets		
No vegetation				0.000		Maximum flood		
Total		0		0.000		Total		
						0.85		
Time of concentration (T <sub>c</sub> )				Notes				
Overland flow		Defined watercourse						
$T_c = 0.604 \left( \frac{rL}{\sqrt{S_{av}}} \right)^{0.467}$		$T_c = \left( \frac{0.87L^2}{1000S_{av}} \right)^{0.365}$						
Tc =	0.23	hours	Tc =		hours			
Run-off coefficient								
Return period (years), T		2	5	10	20	50	100	Max
Combined run-off coefficient C <sub>1</sub> (= αC <sub>1T</sub> + βC <sub>2</sub> + γC <sub>3</sub> )		0.850	0.850	0.850	0.850	0.850	0.850	0.850
Rainfall								
Return period (years), T		2	5	10	20	50	100	Max
Point rainfall (mm), P <sub>T</sub>		6.31	10.64	13.92	17.20	21.53	24.81	200.00
Point intensity (mm/hour), P <sub>IT</sub> (= P <sub>T</sub> / T <sub>C</sub> )		27.43	46.27	60.52	74.77	93.61	107.87	869.62
Area reduction factor (%), ARF <sub>T</sub>		100	100	100	100	100	100	100
Average intensity (mm/hour), I <sub>T</sub> (= P <sub>IT</sub> xARF <sub>T</sub> )		27.43	46.27	60.52	74.77	93.61	107.87	869.62
Peak flow								
Return period (years), T		2	5	10	20	50	100	Max
Peak flow (m3/s) $Q_T = \frac{C_T I_T A}{3.6}$		3	5	6	8	10	11	90
Runoff volume x10 <sup>6</sup>		0.028	0.046	0.061	0.075	0.094	0.108	0.874

## Appendix I: PCSWMM modelling parameters

**Table I-1: Subcatchment properties**

Parameter	10 <sup>th</sup> Percentile	Average	90 <sup>th</sup> Percentile
Area (ha)	0.0008	0.3226	0.8704
Width (m)	0.6	178.8	496.0
Flow Length (m)	2.0	67.0	158.0
Slope (%)	0.003	0.025	0.044
Imperv. (%)	0	63	100
N Imperv	0.000	0.015	0.016
N Perv	0.100	0.099	0.100
Dstore Imperv (mm)	0.0	0.4	0.5
Dstore Perv (mm)	0.0	4.9	0.1
Zero Imperv (%)	0	14	25
Percent Routed (%)	100	100	100

**Table I-2: SuDS properties**

	Name	Bioretention Area	Infiltration Trench
Surface	Berm height (mm)	250	0
	Vegetative Cover (fraction)	0	0
	Surface roughness (Manning's n)	0.1	0
	Surface slope (percent)	0	0
Soil	Soil Thickness (mm)	1000	
	Porosity (volume fraction)	0.437	
	Field capacity (volume fraction)	0.062	
	Wilting point (volume fraction)	0.024	
	Soil Conductivity (mm/hr)	60	
	Conductivity slope	5	
	Suction Head (mm)	49.02	
Storage	Storage Height (mm)	300	1500
	Storage Void Ratio (voids / solids)	0.75	0.5
	Storage Conductivity (mm/hr)	100	50
	Storage Clogging Factor	0	0
	Drain coefficient (mm/hr)	0	2
	Drain exponent	0	0.5
	Drain offset height (mm)	0	0

**Table I-3: Rainfall characteristics**

	2010	2011	2012	2013	2014	2015	2016*
Maximum Rainfall(mm/hr):	48.00	28.80	60.00	57.60	50.40	33.60	21.60
Minimum Rainfall(mm/hr):	0	0	0	0	0	0	0
Mean Rainfall(mm/hr):	0.04	0.04	0.05	0.07	0.06	0.04	0.02
Total Rainfall(mm):	384	350	467	655	518	348	48

\*January - March

# Appendix J: Ethics approval documentation

Application for Approval of Ethics in Research (EiR) Projects  
Faculty of Engineering and the Built Environment, University of Cape Town

## APPLICATION FORM


### Please Note:





Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form before collecting or analysing data. The objective of submitting this application prior to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form. <http://www.ebe.uct.ac.za/ebere/research/ethics.pdf>

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant	Abby Jane Robertson	
Department	Civil Engineering	
Preferred email address of applicant:	rorabb002@myuct.ac.za	
If a Student:	Your Degree: e.g., MSc, PhD, etc.,	MSc.Eng
	Name of Supervisor (if supervised)	Prof. Neil Armitage, A.Prof Mark Zuidgeest
If this is a research contract, indicate the source of funding/sponsorship	N/A	
Project Title:	The potential for the implementation of Sustainable Drainage Systems (SuDS) on SANRAL-owned roads	

### I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings will be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Abby Jane Robertson		28 May 2015

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Neil Phillip Armitage		29/5/15
	Mark Zuidgeest		02/06/15
HDD (or delegated nominee) <small>Final authority for all applicants who have answered NO to all questions in Section 1, and for all Undergraduate research (including Honours).</small>	Neil Phillip Armitage		
Chair : Faculty EIR Committee <small>For applicants other than undergraduate students who have answered YES to any of the above questions.</small>	George Sifhole		2 June 2015

## **Documentation submitted to the ethics in research committee (6/9/2015)**

**Project Title:**The potential for the implementation of Sustainable Drainage Systems (SuDS) on SANRAL-owned roads

### **Cover Letter:**

This research looks at the potential for implementing sustainable urban drainage systems (SuDS) on the R300, an urban freeway in the greater Cape Town area. To this end the research will look at road drainage quantity and quality issues.

The research will be approached from a number of angles. Firstly, the road drainage system will be modelled using PC SWMM, a hydrological modelling software. The model will be informed by as-built drawings of the R300 obtained from SANRAL. There are no foreseen ethical issues with this aspect of the research.

CCTV footage of the R300 will be monitored to identify problematic drainage areas. This research will focus on standing water on and near the road surface. The CCTV cameras are installed and maintained by SANRAL. People captured on the CCTV footage do not necessarily know they are being filmed, and it is not possible to gain their consent. This is seen as a potential ethical issue. It is not in the interest of the research to collect identifiable records of individuals. The monitoring will be conducted at the SANRAL traffic monitoring centre in accordance with their operating procedures and under supervision of the TMC staff.

Sweepings of particulate matter on the road surface will be collected. I will accompany the SANRAL maintenance staff when they perform their regular maintenance. Quality analysis will be conducted on the samples obtained. Road runoff samples will be collected using spot sample bottles that will be deployed in catch pits along the R300. The samples will be analysed for water quality indicators. There are no foreseen ethical issues with this aspect of the research.

Throughout the course of the research, I will interact with various SANRAL staff and other built environment professionals. The content of these informal interviews will differ according to the person's expertise and role in the management of the R300. Prior to obtaining any information, I will clearly inform the person of my research objectives. In the case that it is not possible to keep the identities of individuals anonymous, written consent will be obtained from all persons cited. The person will have the opportunity to view the work prior to submission and/or publishing. In the event that a person is uncomfortable with being identified, or with the content of the work, then this information will be amended or excluded accordingly.

Any external requests for information will be evaluated on a case by case basis by myself with the guidance of my supervisors, Neil Armitage and Mark Zuidgeest.

**Researcher(s):** Abby Robertson  
**Department:** Civil Engineering  
**E-mail:** rbrabb002@myuct.ac.za  
**Status of Applicant:** Student  
**Degree Being Studied:** MSc.Eng  
**Name of Supervisor:** Neil Armitage, Mark Zuidgeest  
**Review Track:** Normal  
**Motivation for an Expedited Review:** n/a

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**SECTION 1: Overview of ethics issues in your research project:**

**Question 1: Harm to Third Parties:** No

**Question 2: Human Subjects as Sources of Data:** Yes

**Question 3: Participation or Provision of Services to Communities:** No

**Question 4: Conflict of Interest:** No

If you have answered **YES** to any of the above questions, please ensure that you append a copy of your Research Proposal (**Addendum 1**), as well as any interview schedules or questionnaires and consent documentation (**Addendum 2**) and complete further addenda as appropriate.

**I hereby undertake to carry out my research in such a way that:**

1. there is no apparent legal objection to the nature or the method of research; and
  2. the research will not compromise staff or students or the other responsibilities of the University;
  3. the stated objective will be achieved, and the findings will have a high degree of validity;
  4. limitations and alternative interpretations will be considered;
  5. the findings could be subject to peer review and publicly available; and
  6. I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism
- 

**ADDENDUM 1 Supporting documents:** n/a

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**ADDENDUM 2 To be completed if you answered YES to question 2 in section 1:**

It is required that you read the UCT Code for Research involving Human Subjects in order to be able to answer the questions in this addendum.

Ethical research should safeguard the interests of society and the welfare of all who participate in the research, be they individuals or groups. In this section the researcher is asked to consider the implications of their research on participants in the research. The researcher should outline risks that participants will face by being involved in the research.

When a research involves vulnerable people, a researcher is expected to obtain **informed consent from participants**. This informed consent should be signed by the participants. Informed

consent is intended to protect the interest of both participants and the researcher should something go wrong or should conflict arise between the researcher and the participant.

**Question 2.1:** No

**Question 2.2:** No

**Question 2.3:** No

**Question 2.4:** No

**Question 2.5:** No

**Question 2.6:** Yes

**Question 2.7:** No

**Additional Comments:**

The research will involve monitoring CCTV footage of the R300. The CCTV cameras are installed and maintained by SANRAL for traffic monitoring purposes. People captured on the system do not necessarily know that they are being filmed and it is not possible to obtain their consent.

CCTV monitoring will be conducted at the traffic monitoring centre (TMC) at SANRAL under supervision of the TMC staff and in accordance with their usage procedures. The research will focus on standing water on and near the road surface. It is not in the interest of the research to keep identifiable records of individuals.

All information obtained at the TMC that relates to human behaviour will be treated as confidential. It is a possibility that the researcher may view violence / road accidents / traffic incidents on the CCTV footage. The researcher will make use of the counselling facilities provided by the Student Wellness Services at UCT if necessary.

Throughout the course of the research, I will interact with various SANRAL staff and other built environment professionals. The content of these informal interviews will differ according to the person's expertise and role in the management of the R300. Prior to obtaining any information, I will clearly inform the person of my research objectives. In the case that it is not possible to keep the identities of individuals anonymous, written consent will be obtained from all persons cited. The person will have the opportunity to view the work prior to submission and/or publishing. In the event that a person is uncomfortable with being identified, or with the content of the work, then this information will be amended or excluded accordingly.