UNIVERSITY *of the*
WESTERN CAPE

EFFECTS OF LAND-COVER - LAND-USE ON WATER QUALITY WITHIN THE KUILS - EERSTE RIVER CATCHMENT

By

Wisemen Chingombe

A thesis submitted in fulfilment of the requirements for the degree of Philosophae Doctor (PhD) in the Faculty of Science, Earth Sciences Department, University of the Western Cape
South Africa

Supervisor: Dr Abraham Thomas

Co-supervisor: Prof Dominic Mazvimavi

February 2012

DEDICATION

I dedicate this thesis to my wife Shailot Mwakaemureyi and my children, Tinotenda Wisemen Jr, Tafadzwa Kevin, Cassandra and Kudzai.

DECLARATION

I declare that the thesis, entitled *'**Effects of land-cover – land-use on water quality within the Kuils - Eerste river catchment**'* which I hereby submit for the degree of Philosophae Doctor (PhD) at the University of the Western Cape, is a result of my own work, and has not been submitted previously by me for a degree at another university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

February 2012

W. CHINGOMBE

ABSTRACT

The most significant human impacts on the hydrological system are due to land-use change. The conversion of land to agricultural, mining, industrial, or residential uses significantly alters the hydrological characteristics of the land surface and modifies pathways and rates of water flow. If this occurs over large or critical areas of a catchment, it can have significant short and long-term impacts, on the quality of water. While there are methods available to quantify the pollutants in surface water, methods of linking non-point source pollution to water quality at catchment scale are lacking. Therefore, the research presented in this thesis investigated modelling techniques to estimate the effect of land-cover type on water quality. The main goal of the study was to contribute towards improving the understanding of how different land-covers in an urbanizing catchment affect surface water quality. The aim of the research presented in this thesis was to explain how the quality of surface runoff varies on different land-cover types and to provide guidelines for minimizing water pollution that may be occurring in the Kuils-Eerste River catchment. The research objectives were; (1) to establish types and spatial distribution of land-cover types within the Kuils-Eerste River catchment, (2) to establish water quality characteristics of surface runoff from specific land-cover types at the experimental plot level, (3) to establish the contribution of each land-cover type to pollutant loads at the catchment scale.

Land-cover characteristics and water quality were investigated using GIS and Remote Sensing tools. The application of these tools resulted in the development of a land-cover map with 36 land classifications covering the whole catchment. Land-cover in the catchment is predominantly agricultural with vineyards and grassland covering the northern section of the catchment. Vineyards occupy over 35% of the total area followed by fynbos (indigenous vegetation) (12.5 %), open hard rock area (5.8 %), riparian forest (5.2 %), mountain forest (5 %), dense scrub (4.4 %), and improved grassland (3.6 %). The residential area covers about 14 %. Roads cover 3.4 % of the total area.

Surface runoff is responsible for the transportation of large quantities of pollutants that affect the quality of water in the Kuils-Eerste River catchment. The different land-cover types and the distribution and concentration levels of the pollutants are not

uniform. Experimental work was conducted at plot scale to understand whether land-cover types differed in their contributions to the concentration of water quality attributes emerging from them. Four plots each with a length of 10 m to 12 m and 5 m width were set up. Plot I was set up on open grassland, Plot II represented the vineyards, Plot III covered the mountain forests, and Plot IV represented the fynbos land-cover. Soil samples analyzed from the experimental plots fell in the category of sandy soil (Sa) with the top layer of Plot IV (fynbos) having loamy sand (LmSa). The soil particle sizes range between fine sand (59.1 % and 78.9 %) to coarse sand (between 7 % and 22 %). The content of clay and silt was between 0.2 % and 2.4 %. Medium sand was between 10.7 % and 17.6 %. In terms of vertical distribution of the particle sizes, a general decrease with respect to the size of particles was noted from the top layer (15 cm) to the bottom layer (30 cm) for all categories of the particle sizes. There was variation in particle size with depth and location within the experimental plots.

Two primary methods of collecting water samples were used; grab sampling and composite sampling. The quality of water as represented by the samples collected during storm events during the rainfall season of 2006 and 2007 was used to establish water quality characteristics for the different land-cover types. The concentration of total average suspended solids was highest in the following land-cover types, cemeteries (5.06 mg L^{-1}), arterial roads/main roads (3.94 mg L^{-1}), low density residential informal squatter camps (3.21 mg L^{-1}) and medium density residential informal townships (3.21 mg L^{-1}). Chloride concentrations were high on the following land-cover types, recreation grass/ golf course (2.61 mg L^{-1}), open area/barren land (1.59 mg L^{-1}), and improved grassland/vegetation crop (1.57 mg L^{-1}). The event mean concentration (EMC) values for NO_3-N were high on commercial mercantile (6 mg L^{-1}) and water channel (5 mg L^{-1}). The total phosphorus concentration mean values recorded high values on improved grassland/vegetation crop (3.78 mg L^{-1}), medium density residential informal townships (3mgL^{-1}) and low density residential informal squatter camps (3 mg L^{-1}). Surface runoff may also contribute soil particles into rivers during rainfall events, particularly from areas of disturbed soil, for example areas where market gardening is taking place. The study found that different land cover types contributed differently to nonpoint source pollution.

A GIS model was used to estimate the diffuse pollution of five pollutants (chloride, phosphorus, TSS, nitrogen and NO_3-N) in response to land cover variation using water quality data. The GIS model linked land cover information to diffuse nutrient signatures in response to surface runoff using the Curve Number method and EMC data were developed. Two models (RINSPE and N-SPECT) were used to estimate nonpoint source pollution using various GIS databases. The outputs from the GIS-based model were compared with recommended water quality standards. It was found that the RINSPE model gave accurate results in cases where NPS pollution dominate the total pollutant inputs over a given land cover type. However, the N-SPECT model simulations were too uncertain in cases where there were large numbers of land cover types with diverse NPS pollution load. All land-cover types with concentration values above the recommended national water quality standard were considered as areas that needed measures to mitigate the adverse effects of nonpoint pollution.

The expansion of urban areas and agricultural land has a direct effect on land cover types within the catchment. The land cover changes have adverse effect which has a potential to contribute to pollution.

KEY WORDS: Surface runoff, Nonpoint source pollution, Pollutant loading, GIS, Runoff modelling.

DISSEMINATION/PUBLICATIONS

1. **Wisemen Chingombe**, James Ayuk, Abraham Thomas and Dominic Mazvimavi (2009). Runoff, infiltration and nonpoint source pollution assessment of the Kuils-Eerste River catchment, Western Cape Province, South Africa. Map Africa 2009, 4th Annual African conference and Exhibition on Geospatial information, technology and applications, 16th - 18th September 2009, Birchwood Hotel & OR Tambo Conference Center, Johannesburg, South Africa.

2. **Chingombe, W.** and Thomas. A., (2009). Influence of land-cover on overland flow pollution: Case study of Kuils-Eerste River catchment, Africa GIS 2009 International conference 'Geospatial information and sustainable development in Africa; Facing challenges of global change', October 26th – 30th 2009, Kampala, Uganda.

ACKNOWLEDGEMENTS

I have received tremendous assistance and encouragement from several people during my PhD studies in both South Africa and Zimbabwe. Firstly, I would like to thank Dr. Abraham Thomas for accepting the challenge of supervising and guiding me through this Thesis, several discussions and comments made on drafts of this thesis have been very illuminating. At all stages of preparing this thesis, Dr. Thomas went out of his way to provide me with the necessary support. Special thanks go to Prof. Dominic Mazvimavi who agreed to be my co-supervisor when Dr. Thomas left the Institute and made valuable contributions that revealed the dimension and scope of the tasks I had to accomplish. The contribution of Prof. Mazvimavi is highly appreciated, given the circumstances that characterised the research path followed. I am greatly indebted to his guidance and scientific advice at different stages of the final draft. I would like, also to thank Dr. J. Mukwada for spending time to read my maiden concept paper that gave birth to the whole PhD product and the subsequent enrolment at UWC and his hospitality on arrival at the university. The input of Dr. N.Z. Jovanovic from the CSIR Stellenbosch is highly appreciated. Dr. Jovanovic gave me the understanding and insight into the soil analysis conducted in the study and his input is greatly appreciated. Special mention also goes to Professor Innocent Nhapi of the Civil Engineering Department of the University of Zimbabwe for giving advice on matters relating to water quality.

I would also like to thank the Water Research Commission of South Africa (WRC), and the VLIR Prestigious Scholarship for their efforts in allocating funds to support me through the graduate school. The support provided by professors and lecturers in the Earth Science Department and my colleagues is greatly appreciated especially James Ayuk and Thokozani Kanyerere.

I am most grateful for the support and encouragement throughout my education from my mother, and late grandmother. I am thankful for the continuous encouragement from my brother and sisters. Emily, your lifetime wish has been granted, be proud of your brother; William, thank you for standing in for me during my sojourn, you are a true brother. My PhD studies kept me away from my family and they had to stand on

their own during my absence. I wish to express my gratitude for their sacrifice, support and encouragement. Tafadzwa ‘Tata’ Kevin your cell-phone text messages were a source of encouragement and Tinotenda ‘Tino’ Wisemen Jr; your special reminders still ring in my ears, Kudzai keep on smiling and Cassandra your dream has been fulfilled too. To my wife Shailot Mwakaemureyi, your patience is beyond any words to describe. I will always treasure your words of encouragement when the chips were down and the quality of perseverance you demonstrated, you fortified the castle I was building, thank you. I know no amount of verbal thanks - giving can fully say what I hold for your personality but all the same thank you my dear.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
BMPs	Best Management Practices
CMC	Cape Metropolitan Council
CN	Curve Number
DWAF	Department of Water Affairs and Forestry (now known as DWA; Department of Water Affairs)
EMC	Event Mean Concentrations
GIS	Geographic Information System
HSG	Hydrologic Soil Group
ICM	Integrated Catchment Management
IDW	Inverse Distance Weighted
IWRM	Integrated Water Resource Management
K_h	Hydrological conductivity
KNPRRP	Kruger National Park Rivers Research Programme
K_s	Saturated hydrological conductivity
LCDB2	Land-cover Database Version 2
LDR	Low Density Residential
MDR	Medium Density Residential
MLC	Metropolitan Local Councils
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
N-SPECT	Nonpoint Source Pollution and Erosion Comparison Tool
PSD	Particle Size Distribution
RINSPE	Runoff Infiltration and Nonpoint Source Pollution Estimation
SCS	Soil Conservation Service
UIDs	Unsatisfactory Intermittent Discharges
USEPA	United States Environmental Protection Agency
WWTW	Waste Water Treatment Works

CHAPTER 1

INTRODUCTION

1.1 Background

The most significant human impacts on the hydrological system are due to land-use change (Bhaduri *et al.,* 2000). The conversion of land to agricultural, mining, industrial, or residential uses significantly alters the hydrological characteristics of the land surface and modifies pathways and rates of water flow. If this occurs over large or critical areas of a catchment or region, it can have significant short and long-term impacts, including increased downstream flooding and decreased long-term deep and shallow groundwater recharge. Lowering of the water table can in turn dry up wetlands and produce intermittent or dry streams during low flow periods (Mitsch and Gosselink, 1993). In urbanizing areas, fast runoff from impervious surfaces and engineered drainage systems, increases flood peaks, and degrades water quality. Land-use change, dominated by an increase in urban/impervious areas, has a significant impact on water resources (Bhaduri *et al.,* 2000). This includes impacts on nonpoint source (NPS) pollution, which is a major cause of water quality degradation in catchments located in areas experiencing urbanization. Storm water from urban areas contains a wide range of pollutants, including nutrients, pesticides, pathogens, oil, grease, sediment, and heavy metals, and is a leading cause of water quality impairment (USEPA, 1986).

In general terms, land-use change, and urbanization in particular, has significant impacts on drainage basin processes that affect water quality and quantity over a range of temporal and spatial scales. However, the nature and scale of these impacts are dependent on the form and scale of the land-use change and climatic characteristics of the region within which the change is taking place (Bhaduri, *et al.* 2000). Hydrological impacts in turn affect human health and welfare. Other effects such as river channel erosion and widening, loss of riparian and wetland habitats, declining aquatic populations, reduced ecological diversity, pollution of water, have significant negative impacts (Gosselink and Turner, 1978; Burke, 2006; Mitsch and Gosselink, 1993).

Normally, an assessment of the hydrological impacts of land-use change is performed on an event-specific basis (Bhaduri *et al.,* 2000). Studies in the United States indicate that the initial assessment of hydrological impacts of land-use change requires a simple model that runs with readily available input data to provide preliminary estimates of impacts of catchment development and identify the need for complex modelling such as physically-based models (Bhaduri, *et al.,* 2000). Land-use changes occur at different rates on different parts of the catchment. Consequently, surface runoff and nonpoint source (NPS) pollution production vary according to the extent of land-use change in different parts of the catchment (Gosselink and Turner, 1978; Burke, 2006; Mitsch and Gosselink, 1993).

Urbanization is not a single condition; instead, it is a collection of actions that lead to recognizable landscape forms and, in turn, to changes in stream conditions (Konrad and Booth, 2005). No single change defines urbanization but the cumulative effects of human activities influence streams and their biota. In a study conducted in the United States of America, Konrad and Booth (2005) observed that the hydrological effects of urban development were evident from a comparison of runoff from two headwater catchments in western Washington DC. The results indicated that land-cover is one of the most important factors determining NPS pollutants in urban storm water. Activities, such as construction, contribute significantly to pollution of storm water (Tsihrintzis and Hamid, 1997; Konrad and Booth, 2005).

Population projection figures indicate that more than 60 % of the world's population will be living in urban areas by 2030 and much of this growth will occur in developing nations (UN Population Division, 1997). South Africa is an urbanizing nation with approximately 28 million people (59 % of the overall population) living in more than 3,000 urban communities, including informal settlements (AFDEC, 2006). The nine largest cities have the combined population of 16 million inhabitants (37 % of the national population) and provide 50 % of the nation's work force. While these cities cover only 2 % of the overall surface area of the country, their ecological footprint is significant at the national level. The rapid growth of informal urban settlements presents a major challenge in South Africa. Approximately five million

people (28 % of the urban population) live in such settlements without proper water supply and sanitation (AFDEC, 2006). Some informal settlements like Khayelitsha in Cape Town are located along rivers, and have a high potential to contaminate these rivers. The catchment management areas of Cape Town have also experienced a marked increase in the number of people living in them (City of Cape Town, 2004).

The type of land-cover in an area can be used to predict effects on water quality (Hatt *et al.*, 2004). However, assigning a pattern of pollutant output to a particular land-cover provides significant insight into the processes affecting aquatic systems, and or how to manage that land-cover in order to reduce pollutants.

Effective management of the impacts of urbanization on water quality requires identification of activities that contribute most to pollutant loads. Although the major activities and land-cover are recognized as important driving forces for water quality conditions of rivers (Gergel *et al.*, 2002), the mechanisms to explain the presence of pollutants in the water are not fully explained.

Most of the studies of water quality done in South Africa, (Lord and Mackay, 1993; Wright *et al.*, 1993; Hoffman 1994; van Ginkel *et al.*, 1996; Pearce and Schumann, 1997; Simpson, 1998; Grobicki, 2001; Herold and van Eeden, 2001; Quibell *et al.*, 2003) emphasize point source pollution. Nonpoint sources of pollution in urban areas (Lord and Mackay, 1993; Wright *et al.*, 1993; van Ginkel *et al.*, 1996; Grobicki, 2001) and agricultural areas (Kienzle *et al.*, 1997; Simpson, 1998) have been studied separately and no study has focused on an area that is experiencing rapid urbanisation like the Kuils-Eerste River catchment in Cape Town. The main land-use change in the Cape Town Metropolitan area is the conversion of agricultural land to built up areas. Urbanisation has also resulted in the destruction of many of the wetlands and vleis that naturally absorb or detain floodwaters (Brown and Magoba, 2009).

There are few water pollution studies focusing on sections of the river carried out on the Kuils-Eerste River catchment. These studies (Taylor, 2000; Petersen, 2002; Hendricks, 2003; Joseph, 2003) did not consider the whole catchment. The coverage

of the real extent of nonpoint source pollution in these studies (Taylor, 2000; Petersen, 2002; Hendricks, 2003; Joseph, 2003) is inadequate for an understanding of the phenomenon. A detailed investigation of the land-cover practices and their contribution to nonpoint source pollution will offer a better understanding of the origins of surface water pollution and its management. It is hypothesized that a model reflecting the way in which surface runoff contributes to pollutant loading could be applied to estimate pollution loads and with the results being used in determining approaches for best practice management that minimise pollutant loads from different land-cover types. In order to understand the phenomenon related to nonpoint source pollution and their relationship to land-cover changes this study strives to estimate pollution loads from different land-cover types in an urbanizing catchment.

1.2 Problem statement

Urbanization is a rapidly growing form of land-cover change. The phenomenon is common in both the developed and developing countries though much of this growth is occurring in developing countries (Brown and Magoba, 2009). Whereas the overall land area covered by urban growth remains small, its ecological consequence is large. Urbanization is second only to agriculture as the major cause of impairment of water quality even though the total area covered by urban land is small in comparison to agricultural land (Brown and Magoba, 2009).

There are a range of pollutants present in urban storm water (Brown and Magoba, 2009). These include plant nutrients, oxygen demanding organic compounds, heavy metals, hydrocarbons, sediments, pesticides, litter, and microbiological pollutants. Although the levels of pollutants in urban runoff are often within the prescribed effluent quality standards (Brown and Magoba, 2009), their significance needs to be evaluated in terms of the ability of the receiving water to assimilate pollutants in the long term. These criteria are based on a variety of considerations, including human health, and toxicity to aquatic life. From these considerations and the ability of the receiving waters to assimilate pollutants, appropriate water quality criteria can be set for runoff from a particular catchment.

Despite the threat that urbanization poses to stream ecosystems, several analyses of the ecological effects of urbanization on rivers exist in South Africa. Simpson, (1986); Simpson *et al., (*1998); Wimberley, (1992) Wimberley *et al.,(*1993); Wright *et al., (*1993); Pegram and Görgens, (2001); Herold and Eeden, (2001); Grobicki, (2001); Quibell *et al*., (2003); Brown and Magoba, (2009) have discussed the impacts of aspects of urbanization associated with urban storm water drainage, and urban stream management.

NPS pollution is a difficult issue to deal with because by definition, it comes from diverse, hard to identify sources. NPS pollution takes place within different environmental settings (Pegram *et al.,* 1990). However, the use of Geographical Information Systems (GIS) tools provides an extensive approach to describe land-cover types and the spatial distribution of nonpoint source contamination.

1.3 Goal

The main goal of this study is to contribute towards improving understanding of how different land-covers in an urbanizing catchment affect surface water quality.

1.3.1 Aim

This study seeks to explain how the quality of surface runoff varies on different land-cover types and to provide guidelines for minimizing water pollution that may be occurring in the Kuils-Eerste River catchment.

1.3.2 Research Objectives

The research objectives are:

- To establish types and spatial distribution of land-cover types within the Kuils-Eerste River catchment.
- To establish water quality characteristics of surface runoff from specific land-cover types at the experimental plot level.
- To establish the contribution of each land-cover type to the pollutant loads at the catchment scale.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

During the past two decades, urban storm water in many cities in the world has become a large contributor to water quality deterioration as this transports a wide spectrum of pollutants to receiving waters with an extensive cumulative effect (Hansen *et al.,* 2000). The pollutants include visible matter, suspended solids, and oxygen demanding materials, nutrients, pathogenic microorganisms and toxicants such as heavy metals, pesticides, and hydrocarbons. These pollutants affect aquatic life and human health, and impair uses of water resources. Typical urban storm water-related water quality problems include the degradation of aquatic habitats (Brown and Magoba, 2009), accelerated rates of eutrophication in lakes and estuaries (Thornton, 1980; Magadza, 1994 and 1997), and thermal pollution (Goel, 2006; Laws, 2000). These problems have been prevalent in many water systems near urban areas.

2.2 Rural-urban land-cover analysis

2.2.1 Patterns of Land-cover

Land-cover patterns can be highly dynamic (Niehoff *et al.,* 2002). The most noticeable variation of land-cover change occurs predominantly for arable land. The spatial variations of land-cover need to be considered in water quality studies (Hansen *et al.,* 2000).

The terms land-cover and land-uses are not synonymous. Land-cover is anything covering the surface of the earth, while land-use implies a human component (Anderson *et al.,* 1976). For example, the land-cover in a particular area can be urban or built-up, while the land-use could be residential (Anderson *et al.,* 1976).

The type of land-cover has a major influence on the quality of water originating from a specific area. Hunsaker and Levine (1995) found in their studies of river basins in Texas and Illinois, that the percentage of land with forest and other uses were the best predictors of overall water quality. Similar results obtained in the southern Appala-

chians indicated the percentage of land with non-forest cover and the density of paved roads were among the most important variables influencing water quality. There is a well-defined link between land-cover and water quality changes (Swank and Bolstad, 1994) and this suggests that even small changes in non-forest land-cover have important implications for water quality.

Having accurate and timely information describing the nature and extent of land-cover and changes over time is important, especially in rapidly growing metropolitan areas. Such relevant information is in different formats. Work by Yuan *et al.* (2005) has shown that satellite remote sensing as one such format of information, has potential to provide accurate and timely geospatial data, which can be used in describing the distribution and changes in land-cover of metropolitan regions.

In South Africa, the change in the urbanisation pattern has seen the development of large low cost, high-density urban areas to cater for the rapid urbanisation. Gross overcrowding and the development of several informal settlements around the existing Cape Town Metropolitan area are common sights (Wright *et al.* 1993). Patterns of land-cover have been studied in South Africa focusing on different development strategies. For example, studies done by Herold and van Eeden (2001) in the Rietspruit catchment, where the areas have relatively uniform land-use development. The strength of Herod and van Eeden's (2001) methodology was demonstrated by means of an example of the impact on water pollution of an assumed new high density urban development. The use of their methodology in conjunction with GIS based land-use data was also considered. Some of the settlements have virtually no sanitation or basic hygiene infrastructure presenting considerable problems for the people and for the environment.

Wright *et al*. (1993) established that another major source of NPS pollution is the manner in which land is used. Different agricultural activities generate sediment outputs depending on the type of agricultural activity resulting in sediment export, which is related to agricultural NPS pollution. Wright *et al.* (1993) observed that the land

hardly could hold water, which leads to increased overland flow, soil erosion and the siltation of downstream waterways, impoundments and natural ecosystems.

Hoffman (1994), in a study conducted in the Hennops River Valley in South Africa, further argues that the catchment with agricultural (Olifantsfontein, Irene Estate), residential (Olifantsfontein, Tembisa, Ivory Park, Rabie Ridge), and commercial and industrial land uses were the major source of pollution in the Hennops River Valley included pollution from solid waste and faecal contaminants which were as a result of pipe blockages in Tembisa a high population density area and ineffective onsite sanitation facilities in Ivory Park.

There are several areas in South Africa where water quality variables have been studied covering the main groups of water quality criteria, namely physico-chemical parameters; organic content; content of solids; nutrient content; toxins; and microbiological indicators. These include the Johannesburg, (Green *et al*., 1986); Pinetown Study, (Simpson, 1986);Three Anchor Bay, (Wright *et al*., 1987); Three Anchor Bay, (Kloppers, 1989); Atlantis, (Wright, 1991).

The contribution that agriculture makes to non-point source pollution in the Breede, Middle Vaal and Mgeni catchments as representatives of different agricultural practices led to the conclusion that, in its broadest sense agriculture appeared to have a major impact on salinity loads (Cullis *et al*., 2005). Although the contribution to nutrient loads was less significant due to the natural removal of nutrient loads from point sources with the Breede and Middle Vaal recording a first flush impact at the start of the wet season.

2.2.2 Applications of Remote Sensing and GIS techniques

South Africa is not richly endowed with natural water resources (Zietsman *et al.* 1996). Furthermore, this scarce natural resource is unevenly distributed in space. Information on current land-use patterns and trends underlies effective management of natural water resources in catchments. Conventional methods of data collection used in making an inventory of land-use are expensive and require more time to obtain ac-

ceptable results. Therefore, alternative methods of data collection need to be considered. Modern technology, such as Remote Sensing and Geographical Information Systems, is in theory able to provide a cost effective and regular means of collecting information on land-use and constitutes an option for this study (Zietsman *et al.* 1996).

Various techniques and approaches can be used to determine the distribution and change of land-cover type classes (Moolman *et al*., 2003; Treitz and Rogan, 2004). The methods for change detection and classification fall into two; pre-classification techniques, and post classification techniques. The pre-classification techniques apply various algorithms, including the identification of differences between images and image rationing, based on the use of single or multiple spectral bands. Vegetation indices and principal components can be used directly to multiple dates of satellite imagery to generate 'change' versus 'no-change' maps. These techniques locate changes but do not provide information on the nature of change. Mengistu and Salami (2005) in their study in Nigeria on the application of Remote Sensing and GIS in land-cover mapping and change detection used the classification scheme consisting of seven land-cover classes and then applied a post interpretation phase that included preparation of land-use land-cover maps and detection of changes.

A similar method for identification of land-cover classes was used in a study in South Africa to measure the spatial extent, and a comparison of the findings to current water quality data (Showalter *et al.*, 2000; Treitz and Rogan, 2004). Results indicated that deterioration of water quality conditions was largely a by-product of growth in informal settlements. Based on the results, the identification of the position, size and nature of informal settlements in relation to hydrologically significant factors using remotely sensed data was achieved (Showalter *et al.*, 2000). Consequently, the preparation of maps became critically important to show areas with differential risk of non-point source pollution. The differences are attributed to land management techniques that modify or change present land-cover activities.

2.2.3 General NPS pollution Models

A wide range of models have been developed to aid understanding of the NPS problems. These models include simple screening and planning models, (Section 2.3). These hydrological and water quality models serve different purposes but a good NPS pollution model should represent the spatial variability of the area and simulate the distributed physical process of water pollution (Kang and Bartholic, 1994; León et al., 2000). However, this type of distributed model not only requires large volumes of input data, but also creates equal (or more) amounts of output results. The difficulty in modelling NPS is the problem of identifying sources of pollution and quantifying the loads (León, *et al*., 2000). In contrast to a point source, diffuse pollution is an aggregate of small contaminant inputs distributed throughout a basin. Since the early 1970s, a large number of NPS models have been developed. There are two approaches to model diffuse pollution. The more widely used are lumped-parameter models, while models that are more complex are based on the distributed-parameter concept. Reviews of the available runoff-water quality models applicable to diffuse pollution modelling of urban and agricultural catchments cover a wide range of models (León *et al*., 2000). Some of the most relevant NPS models are ARMHSPF, AGNPS (Young *et al.*, 1987) and N-SPECT (NOAA Coastal Services Center, 2004). Most of these models simulate processes of interception, infiltration, surface storage, and surface flow for the hydrological component. Some of them use the Soil Conservation Service (SCS) runoff curve number approach. For example, AGNPS calculates surface runoff for each grid-cell using the SCS Curve Number (CN) method (Grunwald, and Norton, 1999). The key parameter in this method is the curve number, which is dependent on land-use, soil type, and hydrologic condition. Surface runoff calculated in each grid cell is routed through the watershed based on flow directions from one grid cell to the next until it reaches the drainage outlet.

2.2.4 Geographical Information Systems and NPS pollution

GIS has gained popularity (Dabrowski *et al.*, 2002a; 2002b; Huai-en *et al*., 2003) as a useful tool to evaluate land-cover and the distribution of NPS pollution. This is because sources of pollution vary with land-cover characteristics and NPS pollution relates well with the hydrological properties of the catchment (Dabrowski *et al.*,

2002; Huai-en *et al.*, 2003). Integrating GIS and NPS pollution modelling assists in the identification of areas sensitive to NPS pollution.

The Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT), developed by the NOAA Coastal Services Centre (2004) is an extension to ESRI's ArcGIS software package which allows users to examine relationships between land-cover, nonpoint source pollution, and erosion. N-SPECT has been used to understand and predict the impacts of management decisions on water quality in Wai'anae region of Oahu, Hawaii NOAA Coastal Services Centre (2004).

Pollutant concentrations were estimated in Hawaii using coefficients that represent the contribution of each land-cover class to the overall pollutant load (NOAA Coastal Services Centre, 2004). These coefficients were derived from local water quality sampling data where an overall water quality rating was assigned to the stream network within each watershed or sub-watershed by comparing estimated total pollutant and sediment concentrations to local water quality standards. This water quality rating helped water resource managers to make informed decisions about water quality and identified areas to target for improvement.

Nonpoint Source (NPS) pollution of water has been identified as one of the primary concerns in South Africa (Kang and Bartholic, 1994; Brown and Magoba, 2009). The water quality of rivers in the urban areas of Cape Town and Stellenbosch is poor, with effluent discharges into the rivers being one of the many factors contributing to the situation (Brown and Magoba, 2009). Urban litter that enters rivers via storm water discharges or is dumped by members of the public also blocks river channels and impedes the flow of floodwaters. The combination of increased runoff, an increased desire for channel obstructions, development within the natural floodplain of rivers and the rainfall in the Cape winter, has necessitated the development of an intense, expensive, and often ecologically- destructive river maintenance programme aimed at the prevention of flooding in urban areas (Brown and Magoba, 2009). Pollutants generated from agricultural activities are diffuse, stochastic, and dynamic in nature (Bailey and Swank, 1983). Therefore, NPS management usually requires a three-step

procedure: (i) identification of critical areas, (ii) determination of Best Management Practices (BMPs), and (iii) construction of a comprehensive area-wide pollution control plan.

Due to scarcity of data, studies done have tried to combine different spatial data sets with distributed hydrological NPS pollution models to reduce the time and effort required for data input (Vieux and Needham, 1993). The integration of GIS and spatial (digital elevation, soil, and land-cover) databases in the data input process is one of the popular approaches. Kang and Bartholic (1994), Tsihrintzis *et al. (*1997), León *et al., (*2000), Weng (2001) and NOOA Coastal Services (2004), have used the distributed model for critical area identification, through integration of distributed models (database and GIS), to facilitate decision-making. This study builds on this research path of NPS pollution.

2.3 NSP Pollution Modelling

A number of models to estimate pollutant loads and movement have been developed in the past decades. In South Africa several water quality models have been used for water quality assessment and used to develop land-use management practices (BMPs) (Pegram and Görgens, 2001). The models have been used to simulate the impacts of current and future development and to predict the hydrological impacts of land-use and climate change and the effects on water resources availability (Huber and Dickenson, 1988, Schmitz and Villiers, 1997, Hughes and van Ginkel, 1994).

For example a simplified river water quality model was formulated based on a conceptual hydraulic sub-model and simplification of an existing river water quality model. The simplified water quality was derived from the River Water Quality Model No. 1, one of the most comprehensive basic river water quality models available in literature (Reichert *et al*., 2000; Deksissa *et al*., 2004). The applicability of the simplified model in data limited situations was investigated using a case study of inorganic nitrogen (nitrate and ammonia) in the Crocodile River (South Africa). The model was calibrated and validated on the basis of independent data collected for four years

(1987–1990) with the results showing that the model adequately described the seasonal dynamics of inorganic nitrogen in the Crocodile River.

However, the models applied in South Africa are considered too comprehensive and complex to be applied directly in many situations where there are limited available data, which is the case in this study.

2.3.1 NPS pollution modelling in South Africa

Detailed descriptions of the various modelling approaches are not provided. The first is the Storm Water Management Model (SWMM), which is an urban runoff simulation model used by the US EPA (Huber and Dickenson, 1988), and provides high resolution continuous or event-based simulation of complex storm water systems. SWMM is a useful urban storm water model that may be used to evaluate the quality of runoff from urban areas, as well as to support the selection of storm water management measures (Pegram and Görgens, 2001). The Cape Town Metropolitan Council adopted the SWMM in 1999 as the model of choice for urban river management initiatives.

The ACRU-NPS model, (Schmitz and Villiers, 1997) simulates storm events, using the SCS Curve Number approach (1972). The urban component is based on the accumulation and washoff from pervious surfaces and impervious surfaces, using the equations from SWMM. The model has been applied to the Palmiet catchment in Durban using parameters derived from the Pinetown catchment monitored by Simpson (1986), to which the model was applied for eleven storm events. The key results of the model were such that total catchment pollution export values were presented in kg/ha/day for ten selected storm events. A reasonable correlation was obtained between simulated and observed values, except for nitrogen and chromium.

The model had a number of limitations among which are that it did not provide a breakdown of the contributions from different land-use types, although it was possible to apply the model separately to smaller more homogeneous areas, as with the general ACRU model (Schmitz and de Villiers, 1997).

The Hydrological Simulation Program-Fortran (HSPF) is a comprehensive package for hydrological and water quality simulation in urban and or rural catchments (Matji and Görgens, 1999). The HSPF provides tools for evaluating the impacts of non-point source washoff in predominantly urban catchments, particularly where in stream transport must be considered. It is also viable in rural catchment though the potency factor approach makes it more appropriate for adsorbed contaminants (Matji and Görgens, 1999). The model was applied in the Berg catchment by Matji and Görgens, (1999) to compare the reliability of its pollutant load predictions against those of other simpler models. The HSPF requires rainfall and water quality data for calibration (Matji and Görgens, 1999).

The other model is the PEXPM specifically designed for application to informal urban areas in South Africa (Hughes and van Ginkel, 1994). The model was applied in three predominantly urban township settlements (Ilitha, Mdantsane and Zwelitsha), a rural village (Mlakalaka), and an informal settlement (Needs Camp). The phosphorus budgets were calculated based on detailed socio-economic surveys of activities contributing to phosphorus accumulation on pervious and impervious surfaces in these settlements, including waste disposal, water supply and sanitation, livestock, crop production and informal economic activities.

Although the accuracy of the phosphorus loading estimates for this model may be questioned, the approach provides valuable information about the relative phosphorus inputs and export from different settlements. This enables the identification and prioritization of activities contributing to phosphorus production within settlements (Pegram and Görgens, 2001).

The Phosphorus Export Model (PEM) (Weddepohl and Meyer, 1992) was developed to simulate monthly soluble and particulate phosphorus export from non-point sources in predominantly rural catchments. The model uses estimates of surface runoff from the Pitman model (WRSM90; 2000) (Hughes and Metzler 1998 and Bailey 2008) and sediment yield from the Universal Soil Loss Equation (USLE). For one of

the catchments, Mgeni, a good correspondence between observed and simulated P loads was achieved, but in the case of the other catchment the goodness of fit of the simulated values were relatively poor (Pegram and Görgens, 2001). The model has to be calibrated against nutrient and stream flow data, and can only be applied to monitored catchments or those with similar characteristics to a catchment where the model has been calibrated. As part of the limitations of the model no distinction is made between land-use types, or production and delivery processes, which restrain its use to scoping or coarse evaluation assessments.

The last model to be considered applied in South Africa represents the relationships between rainfall, runoff and nutrient wash-off from developing urban areas of the Orange Free State near Bloemfontein and of the Eastern Cape Province near east London (Hughes and van Ginkel, 1994). The model was used in conjunction with a previously developed socio-economic survey approach designed to determine annual amount of phosphorus that was being discharged onto the catchment surface (Hughes and van Ginkel, 1994). The nutrient export model was linked to an SCS (Soil Conservation Service of the United States) type runoff generation algorithm with a storage depletion nutrient mass balance function (Hughes and van Ginkel, 1994). The model forms part of a larger model application system (HYMAS- Hydrological Modelling Application System) developed by the Institute for Water Research at Rhodes University. In the model, conceptualising the relationship between runoff and nutrient wash-off was found to be difficult due to the lack of either a reasonably thorough understanding of the processes or observed time series data to illustrate the effects of the processes. However, some sensitivity analyses of the major parameters derived indicated the impact on the model results of changing parameter values within certain ranges.

Considering the levels of accuracy, reproducibility and practicality, no technique is clearly preferable though statistical methods are the most accurate and reproducible, followed by rainfall-runoff methods. The computerised methods are very useful for their ability to simulate responses to changes in the catchment, the value which should offset the effort to establish the model. Given these conclusions drawn from

the reviews of the different models in general it is evident that the rainfall-runoff methods offer the best opportunities for application to urban runoff modelling.

2.3.2 Selected model to be used in the study

Considering the utility of geographic information systems (GIS) and satellite imagery to identify and describe the regional causes of water pollution, Langley (2004) argues that the studies that have placed water pollution data in a geographic context achieve generalizations relating to the impact of regional land-cover practices on water quality. Such findings have been useful in the remediation of impaired catchments, and in identifying unexamined catchments with a high risk of impairment. These methods are particularly useful in evaluating the causes of non-point source (NPS) pollution.

The SCS TR-55 Peak Discharge and Runoff model has been widely used to estimate storm runoff depth based on curve numbers (CN) (Grunwald, and Norton, 1999). Curve numbers are estimated on the basis of permeability and infiltration characteristics. Integrating GIS and land-cover types in runoff modelling, two processes are involved: (i) hydrological parameter determination using GIS, and (ii) hydrological modelling within GIS. Hydrological parameter determination using GIS entails preparing land-cover, soil, and precipitation data that go into the SCS model, while hydrological modelling within GIS automates the SCS modelling process using generic GIS functions.

The N-SPECT model which estimates NPS pollution and soil erosion uses the SCS CN method as the basis for its runoff estimates. The *CN* values are estimated using field survey data with reference to USDA's SCS tables. *CN* values approaching 100 are associated with high runoff arising from relatively impermeable areas while low to moderate *CN* values indicate the reduced runoff from heavily vegetated areas (Weng, 2001). If the initial abstraction at a given cell is greater than the rainfall at that cell, N-SPECT sets runoff depth to zero. This prevents the reintroduction of artificial sinks to the runoff analysis.

N-SPECT model incorporates the SCS method for runoff estimation which takes into account the variation in land-cover type. Since this study intends to examine how land-cover type affects NPS pollution, N-SPECT is likely to be appropriate for this study. In addition N-SPECT can be applied in a GIS environment.

The Nonpoint Source Pollution and Erosion Comparison Tool, which was developed by the NOAA Coastal Services Center (2004) allows users to examine relationships between land-cover, nonpoint source pollution, and erosion. The N-SPECT model is useful for understanding and predicting the impacts of management decisions on water quality and addresses several issues of concern to water quality specialists (NOAA Coastal Services Center, 2004). The model has the following capabilities:

- Estimating runoff depth and volume.
- Estimating pollutant loads and concentrations.
- Identifying areas highly susceptible to erosion by water.
- Estimating sediment loads and concentrations.
- Assessing the relative impacts of land-use changes with scenario analysis.

The estimation of pollutant concentrations is achieved using coefficients that represent the contribution of each land-cover class to the overall pollutant load. These coefficients are derived based on local water quality sampling. Erosion rates and sediment loads are calculated using the Revised Universal Soil Loss Equation (RUSLE)

$$A = R * K * L * S * C * P \qquad (2.1)$$

where:

A = average annual soil loss: S = slope steepness factor

R = rainfall/runoff erosivity factor: C = cover management factor

K = soil erodibility factor: P = supporting practices factor

L = slope length factor

The Modified Universal Soil Loss Equation (MUSLE)

$$S = 18.943 * (Q * qp)^{0.877} * K * C * P * LS \qquad (2.2)$$

where:

S = sediment yield from an individual storm (Kg)

Q = storm runoff volume

qp = peak runoff rate (cubic metres per second)

K = soil erodibility factor

C = cover management factor

P = supporting practices factor

L = slope length factor

S = slope steepness factor

Lastly, an overall water quality rating is assigned to the stream network within each catchment or sub-catchment by comparing estimated total pollutant and sediment concentrations to local water quality standards. This water quality rating is used by resource managers to make informed decisions about water quality and identify areas to target for improvement (NOAA Coastal Services Center, 2004).

The significance of storm water pollution and its control demands that water management systems should be planned within a systematic framework to achieve high levels of storm water quality control (City of Cape Town 2004). Urbanized watersheds have impervious surface areas and drainage systems designed for efficient removal of surface water. The alterations to the land surface generally result in increased runoff volumes, higher peak flow rates and reduced rainwater infiltration and pollutant filtering by subsurface flow. Surface runoff carries dissolved, and sediment with adsorbed materials into receiving water bodies. Water resources professionals and government authorities involved in surface water management in South Africa face the issues of stringent water quality regulatory requirements and a watchful public (City of Cape Town 2004). At the same time, they are constrained by inadequate budgets, limited resources, and incomplete information, which compel them to rely on models to evaluate the implications of their decisions.

The works of Huai-en, *et al. (*2003), Chow and Yusop (2008), and Brown and Mago-ba (2009), provide good background information to consider for proposing analogous

pollutant loading applications for the Kuils-Eerste River catchment. The challenges associated with adopting some of the GIS-based approaches (e.g., Source Loading and Management Model, Novotny, 1992) are that the models do not incorporate the changes taking place in the urbanized environment within the catchment over space and time. In addition, the result of the model calibration procedure, which entails comparison between the measured load and model estimates, does not suggest a particularly great degree of correspondence between the measured and simulated loads on the studied catchments.

The review of NPS pollution modelling applications indicates that the use of a GIS cell-based approach is appropriate because of the focus on the value of the cell which indicates the concentration of pollutants and their spatial distribution. This approach is ideal for the study area as it focuses on the data in a cell (pixel) and also considering the catchment's transformation from an agricultural area into an urbanising area. The nature of the water pollution problems facing the Kuils-Eerste River catchment suggests that the GIS-based NPS pollution model employed by NOAA Coastal Services Center using *N-SPECT* could be applied since the model analyses the issue from a cell-based approach. The application would enable the replication of the model in a different land-cover set up. At the same time, the model is cost-effective as observed in Hawaii and easy-to-implement for the purposes of identifying the critical and severe NPS pollution areas within a catchment (NOAA Coastal Services Center, 2004).

2.4 Surface water quality parameter selection

The major contributions to non-point source pollution from agricultural lands are increased salinity; increased erosion, sediment yield, pesticides and nutrient yield from crop lands associated with disturbed soil and applied fertilizers (Cullis *et al*., 2005). Non-point source related nutrient enrichment is generally associated with surface runoff and sediment from agricultural fields where fertilizer is applied. Phosphorus and nitrogen are the two key nutrients associated with urban and agricultural activities. Cullis *et al*. (2005), in their study of first order estimate of the contribution of agriculture to NPS pollution, considered a number of water quality constituents on the

basis of their representativeness as key impacts of agriculture on surface water resources.

Water quality is generally linked to land-use/land-cover (LULC) in a catchment (Ahearn *et al.,* 2005), and studies have been focusing on their relationships with water quality variables such as dissolved salts, suspended solid, and nutrients (Hill, 1981, Allan *et al.,* 1997, Johnson *et al.,* 1997, Osborne and Wiley, 1988, Smart *et al*., 1998). In view of the conditions discussed in this section the selection of water quality parameters is based on the factors inherent in the study design, and locality. The catchment is agriculturally based with elements of urbanization encroaching to take up the greater part of the western side of the catchment. Five components were chosen as indicators of water quality for the study area's surface waters, nitrogen, chloride, TSS, phosphorus, and NO_3N and of these phosphorus and nitrogen were considered as good indicators of the level of domestic pollution in surface waters.

2.5 Event Mean Concentration

Event Mean Concentration (EMC) is useful for estimating runoff loads for rain events. They are determined by measuring the flow rate and the concentration at regular intervals during and after a rain event. The EMCs are then calculated by forming a weighted average of the concentrations using the flow rates for the weights. Loads for future rain events can then be estimated based upon the EMCs observed for past rain events. The literature review of the EMC rates offers sufficient justification for employing the model in determining the load rates. Research involving this approach developed EMC values from water quality analysis performed from USGS Stream Gauges, Quenzer (1998).

Pollutant loading estimates provide an indication of the potential impact of a storm water discharge on a receiving water body. The calculation of pollutant loads provides a direct quantitative measurement of the pollutants in storm water discharge to the receiving water. Pollutant loadings can be calculated using either an estimate of flow in an average year (annual load), or flow measured during a specific storm event

(instantaneous load). A dynamic model also can calculate the expected frequency of exceedances. In addition, a dynamic model can account for the variability inherent in storm water discharge data including variations in concentration, flow rate, and runoff volume. Thus, it can be used to calculate the entire frequency distribution for the concentration of a pollutant and the theoretical frequency distribution (i.e., the probability distribution) for loadings from the outfall or sub basin. This enables the modeller to describe the effects of observed discharges on receiving water quality in terms of the frequency at which water quality standards are likely to be exceeded.

Whatever method is used to estimate annual pollutant loadings, an estimate of the event mean concentration (EMC) should be used as input. The EMC is defined as the constituent mass discharge divided by the flow volume and is essentially the pollutant mass per unit of discharge volume. In storm water monitoring programs, the EMC is estimated from the concentration of a constituent in a flow weighted composite sample.

Lenz *et al.,* (2000), contend that, the water quality expected in runoff can be modelled by two basic theories: build-up/wash off and event mean concentration (EMC). The build-up/wash off method is based on the theory that solids and other pollutants are accumulated during dry periods and washed off during storm events. Pollutants accumulate based on time, independently or in conjunction with land use, curb length, or area. Wash off can be a function of time or a function of runoff. An EMC is a constant concentration assigned to runoff at all times. Loads differ between storm events based on variable flows. An EMC is independent of time and is strictly a function of land use. While literature values are available for both SCS hydrology and EMCs, in the case of the American situation, calibration remains the key step in applying SCS hydrology and EMCs to the urban environment.

2.6 Overview of Water Quality Standards

Guidelines compiled by The Department of Water Affairs (DWA, 1996) entitled the South African Water Quality Guidelines provide water quality criteria for all possible uses of water from industrial to recreational, with the intention of maintaining and

managing sustainable water resources in South Africa at acceptable water quality levels for their intended use. Of interest is the observation made that there are no guidelines specifically for storm water runoff. The general practice in South Africa has been to use the General and Special Standards for Discharge, in terms of the South African Water Act (Section 21 of the Amendment Act, 1980). The standards were established in 1956 for treatment works and industrial discharges. The National Water Act (NWA) (1998) introduced updated general and special limits. Although storm water is not specifically categorised, the definition of "wastewater" and the "wastewater limit value" are broad to include runoff. Wastewater is defined as water that contains waste, or has been in contact with waste material (NWA, 1998). The wastewater limit value provides the concentration limit for a specific contaminant that may not be exceeded at any time. The limit applies to the last point of collection where the discharge enters the receiving water body (NWA, 1998).

The quality of water is defined in terms of its physical, chemical and biological parameters, and ascertaining its quality is crucial before use for various intended purposes such as potable water, agricultural, recreational and industrial water uses, *etc.* (Sargaonkar and Deshpande, 2003). A major objective of water quality assessment is to determine whether or not the water quality meets previously defined objectives for designated uses.

Traditional approaches to assessing water quality are based on a comparison of experimentally measured parameter values against existing guidelines. In many cases, the use of this methodology allows proper identification of sources of pollution and may be essential for checking legal compliance. However, assessments of water quality are subject to defined objectives and designated uses (ANZECC, 1992, Debels *et al*., 2005).

Ever since the first water quality index (WQI) was proposed, a great deal of consideration has been given to the development of 'water quality index' methods with the intention of providing a tool for simplifying the reporting of water quality data (Liou *et al*., 2004). WQI improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status

and evaluates water quality trends. These indices assess the appropriateness of the quality of the water for a variety of uses (CCREM, 1987, Cude, 2001). They are considered more appropriate for disseminating information to general audiences. The WQI concept is based on the comparison of the water quality parameter with respective regulatory standards (Khan *et al*., 2003).

The need to address both the spatial variability of impacts of land-use change on hydrology as well as NPS pollution, provided motivation for development of usable models to assess the long term impacts of urbanization on hydrology and water quality. The task of NSP pollution assessment is viewed by Pegram *et al,* (2001) as consisting of three components, namely the management goal, the water quality concern and the source area (or catchment) character. A combination of the three, they argue, outline the information needs of assessment and are therefore referred to as nonpoint source assessment task.

2.7 Summary

Storm water runoff from urban areas has been found in many studies to be a major source of pollution of their receiving water bodies. The magnitude of nonpoint source (NPS) pollution in urbanising catchments is of concern to many urbanizing catchments.

The models discussed do not represent all of the modelling options available for runoff water quality simulation, but they are certainly the most widely used and most operational in South Africa and other countries as indicated in this review. Any consideration to use any of these models is often made on the basis of personal preference and familiarity, in addition to needed model capabilities.

The studies reported above discuss water quality differences attributable to surface water pollution and urbanisation. The changing nature of urban development in South Africa has posed problems with regard to the pollution threat to the environment. Urban development creates sources of pollution.

The main idea is to use the simplest approach that will address the project objectives at the time. This usually means to start simple with a screening tool such as constant concentration, regression, statistical or loading function approach. If these methods indicate that more detailed study is necessary or if they are unable to address all the aspects of the problem, e.g., the effectiveness of control options or management alternatives, then one of the more complex models must be used. No method currently available as discussed above can predict absolute (accurate) values of concentrations and loads without local calibration data, including complex build-up and washoff models for urban areas, and soil process models for agricultural croplands.

Thus, if a study objective is to provide input loads to a receiving water quality model, local site-specific data will be required. On the other hand, several methods and models might be able to compare the relative contributions from different source areas, or to determine the relative effectiveness of control and/or management options.

In the absence of studies in which a combination of the land-cover types are considered, as shown by the literature discussed for South Africa, it is imperative that detailed land-cover types be considered as surrogate indicators of the magnitude of the hydrological implications of land-cover contribution to surface runoff pollution. The apparent gap in the literature reviewed places the need to consider the role played by the different land-cover types in terms of diffuse pollution. In South Africa, no studies have focused on both an urbanising and agricultural catchment. A focus on an urbanising catchment and application of South African water quality standards would yield interesting results in the study of NPS pollution. This phenomenon is characterising a number of third world countries in terms of urban sprawl and growth. The rate at which urban development is taking place in cities is a challenge that pollution management strategies must deal with. Understanding the threat of NPS pollution and their management using a GIS based modelling approach would offer an alternative to the current strategies of environmental management.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the study area, the monitoring conducted and the methods used in analysing the water quality data collected. Methods used for data collection and analysis are discussed.

3.2 Description of study area

Kuils-Eerste River catchment is located in the south Western Cape coastal area of the Republic of South Africa, between the Cape Fold Mountains (Cape Peninsula) and the Hottentot-Hollande mountain belts, near the Cape of Good Hope (Figure 3.1). The geographical extent of the study area lies between latitudes 33º 50' and 34º 07' S and between longitudes 18º 30’ and 19º 05' E.

The main consideration in selecting Kuils-Eerste River catchment for this study is the extension of human settlement into agricultural land and the transformation of the several land-cover types which have the potential to affect water quality. The total catchment area is 660 km^2 with 45 % being drained by the Kuils River while the remaining 55 % (360 km^2) is the catchment area of the Eerste River.

Previous studies (Petersen, 2002; Hendricks, 2003; Fisher, 2003) have focused on the upper reaches of the river while other rivers in the metropolitan area have had studies conducted focusing on the effects of stream canalisation. The criterion used to select the catchment is based on the understanding of the dual characteristics of the catchment, mainly urban and rural, and it is assumed that these are likely to have different effects on NPS pollution.

The topography of the area varies greatly from steep mountains to very flat regions near the coast. For example, the Jonkershoek area comprises steep mountain ridges, cliffs, ravines and spurs including the almost level ground of the main Jonkershoek Valley. Altitude varies from 120 m to 1220 m above sea level.

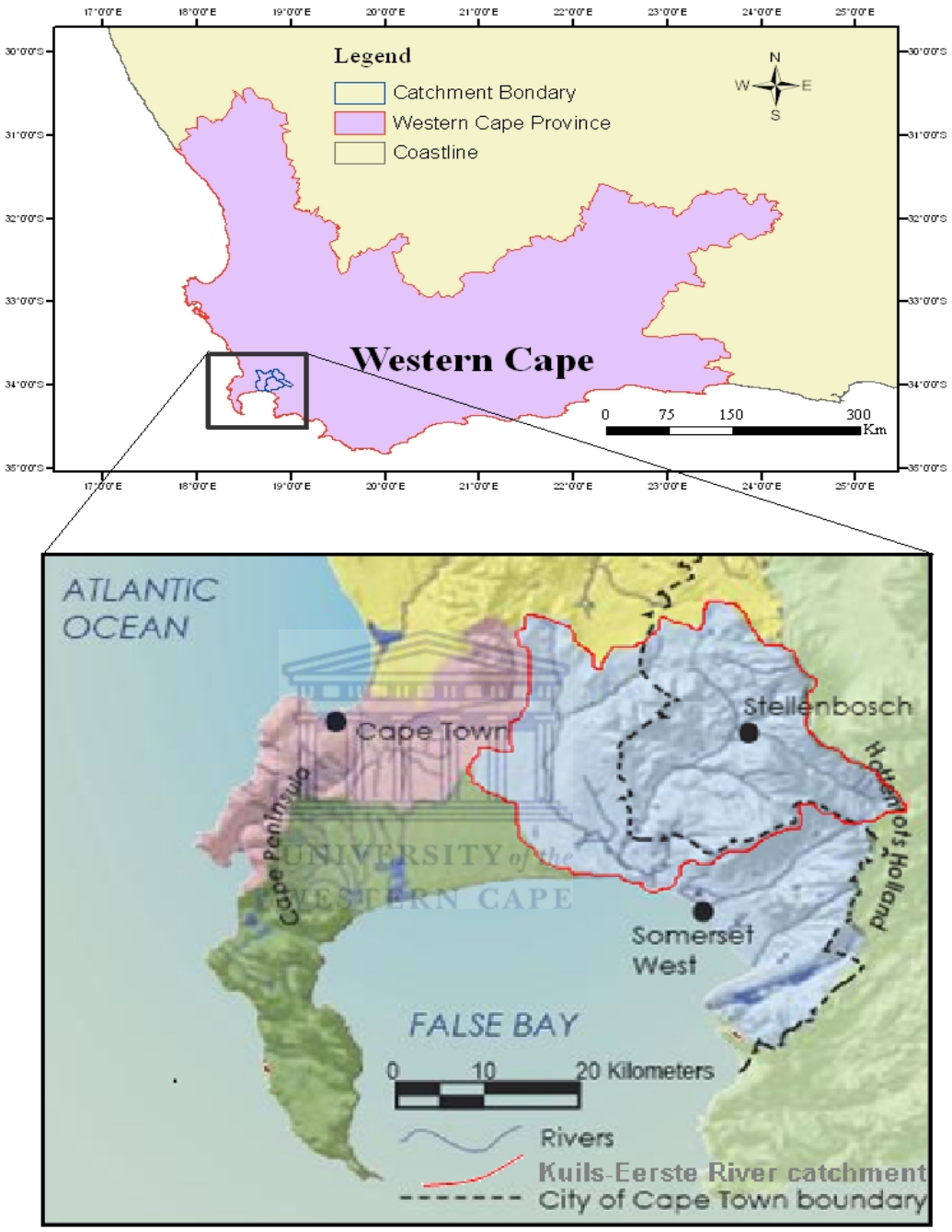


Figure 3. 1: The location of the Kuils-Eerste River catchment in the south Western Cape region. A municipal boundary line divides the catchment into two municipal jurisdictions of Cape Town and Stellenbosch (Modified from River Health Programme, 2005).

The Kuils-Eerste River drains part of the Cape Metropolitan Authority (CMA) and Stellenbosch Municipal areas. The Eerste River drains a comparatively larger area that extends into the Stellenbosch municipality before joining Kuils River, close to Macassar and about 4 km from the river mouth on the False Bay (Figure 3.2).

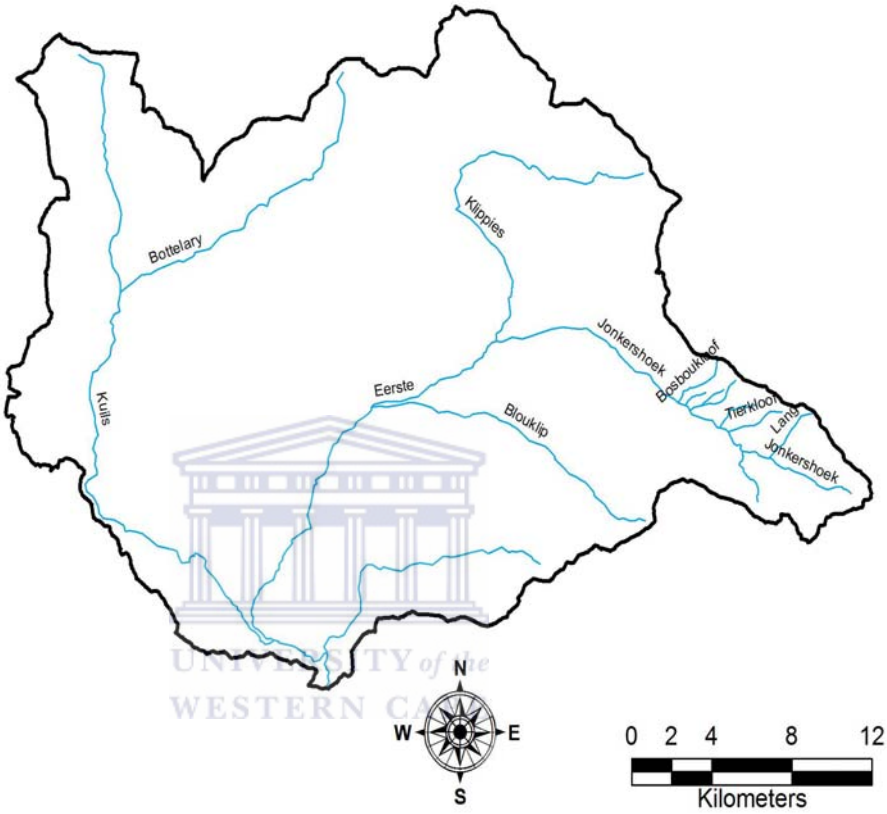


Figure 3. 2: Location and distribution of the stream network in the Kuils - Eerste River urban catchment area.

The Kuils River starts from the highlands of Durbanville, near Kanonkop in the Tygerberg Hills, and flows towards the south through the industrial and residential areas of Bellville and Kuils River. It flows largely through sandy plains of the Cape Flats, and crosses the N2 Freeway below the Driftsands Nature Reserve and flows towards the east of Khayelitsha to Macassar. This river flows along its lower course through wetlands which are of significance to the ecosystems diversity (Petersen, 2002).

The Eerste River originates in the Jonkershoek Forest Reserve, and it flows through mainly agricultural land and the town of Stellenbosch towards the confluence with the Kuils River. After the confluence with the Kuils River in the Cape Flats region, the catchment has mainly undeveloped open land after the Moddergat Spruit tributary. There are four wastewater treatment works located within the Kuils-Eerste River catchment and disposing effluent into these two rivers (Table 3.1 and Figure 3.3).

Table 3. 1: Design capacity of wastewater treatment works within the Kuils-Eerste River catchment

Name	**Design Capacity (m^3/day)**	**River into which effluent is disposed**
Bellville	5,500	Kuils River
Scottsdene	1,200	Bottelary-Kuils River
Stellenbosch	1,350	Eerste
Macassar	1,400	Eerste
Total	**9,450**	

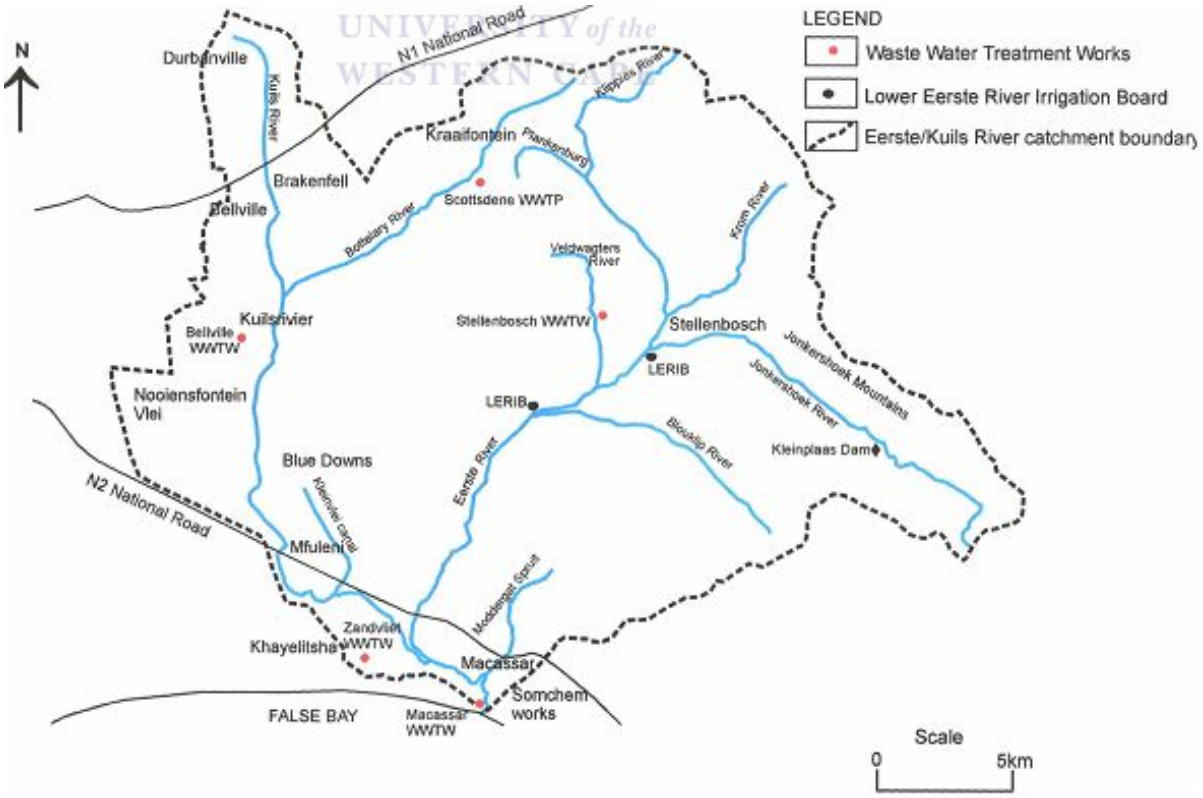


Figure 3. 3: Location of the wastewater treatment works (WWTW) in the study area.

3.2.1 Climate

The Kuils-Eerste River catchment has a Mediterranean climate with most rainfall occurring in winter, from April to September. The south Atlantic anti-cyclones generally influence climate as the catchment falls in the south easterly wind regime (Schulze *et al.,* 1996; Petersen, 2002). Summers are dry, warm to very hot with strong south-easterly winds prevailing with average daily temperatures between 14^{o} C to 20^{o} C. Winters are wet and cold, often with gale-force north-westerly winds that decrease temperatures, often leaving the high peak valleys inundated with snow (Hendricks, 2003). About 85% of the rainfall is received within six months of the winter period, which is from April to September (van Wyk, 1989).

The influence of topography results in the highest rainfall being experienced in the east where the frontal systems are funnelled through False Bay and are forced to rise up the Hottentots Holland, Jonkershoek and Groot Drakenstein mountains before releasing their moisture. Rainfall decreases from the east (1700 mm/y) across the Cape Flats to the west coast, where the mean annual precipitation is around 400 mm/y (Brown and Magoba, 2008).

3.2.2 Land-cover

The Kuils-Eerste River is highly urbanized and has residential, industrial, and commercial areas and some agricultural areas (Figure 3.4). Vineyards are the major land-use outside the urban area. The remaining portion of the cultivated land is used for growing fruits and lucerne. The other land-covers are mainly fynbos vegetation, wetland vegetation, wetlands, vleis, ponds, reservoirs or dams.

Agricultural areas

Agricultural land occupies significant sections of the catchment and all activities related to agriculture have a bearing on the levels of pollution likely to be generated. The greater part of the catchment immediately after the Cape Town metropolitan boundary towards Stellenbosch consists of agricultural land. In a study of the Lourens River, Schulze *et al*. (1996) detected water contamination due to wastes from inten-

sively cultivated orchards. The Lourens River is adjacent to the Kuils River. Site-specific details of the land-cover practices in the agriculture domain for the Eerste River catchment would necessitate intensive field evaluations and in situ data acquisition from the farmers concerned, as a way of increasing information available on the subject so far.

Residential Settlements

Some riverside settlements, which are mostly rural farm settlements, have been studied by Hendricks (2003). Examples are the Zandvlei and Malabos informal settlements. These have been described as characteristically low population density settlements with limited facilities. The sources of pollution therefore have been predominantly from domestic areas resulting from ablution facilities, sanitation, and laundry and dumping on open spaces (Hendricks 2003; Brown and Magoba, 2009). Despite the presence of informal settlements, there are formal settlements with well-planned drainage systems. The towns of Stellenbosch and parts of Khayelitsha have an impact on the urban development programmes that contribute significantly to pollution in the catchment. The Kuils River, in its original state flowed through a flat sandy valley (Brown and Magoba, 2009). Due to an increased demand for housing in the 1980s, the Kuils River valley was identified for low cost house development giving rise to the establishment of the following low-income urban residential areas Mfuleni, Kleinvlei, Blue Downs and Delft. These settlements were located on relatively high ground but inevitably some informal development took place in the floodplain (Brown and Magoba, 2009).

Industry

Industrial development in the study area has been well developed in areas around Bellville, Brackenfield and Kuils River Blackheath and Sarepta (Figure 3.4) (Brown and Magoba, 2009).

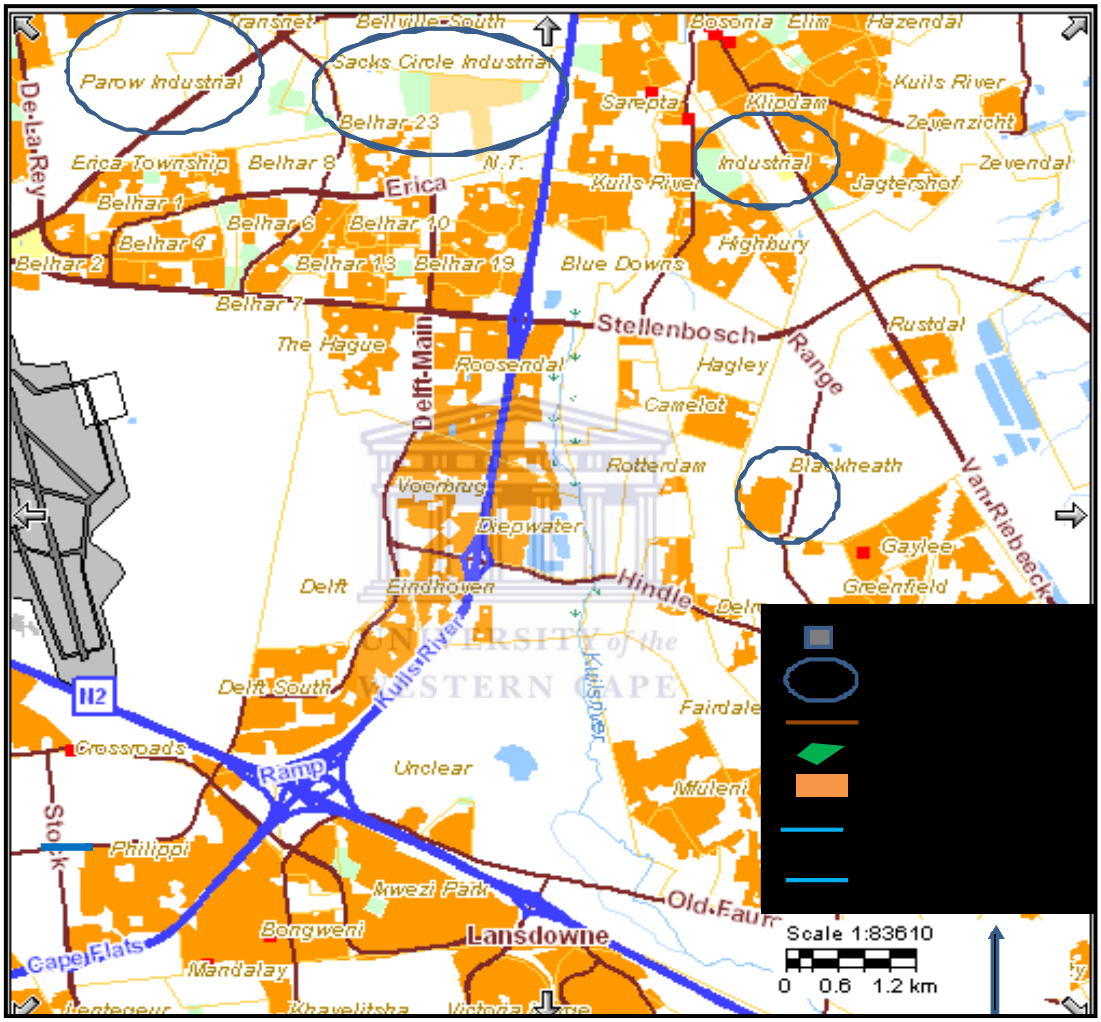


Figure 3. 4: Distribution of different land cover/land use types including residential, industrial, commercial, roads, and rivers in the Kuils-Eerste River catchment, which occupy the north-eastern section of the catchment with low cost house development which gave rise to the establishment of townships of Mfuleni, Kleinvlei, Blue Downs and Delft (Source: Southafrica.info).

3.2.3 River channel modifications

The Kuils River has been modified between Van Riebeeck road and the Stellenbosch Arterial road and between the highway R300 and Van Riebeeck Road to reduce

flooding. This was done by lining sections of the river with concrete. Not all sections of the river channel were lined but the sections lined have suffered environmental challenges not anticipated. The main reason for the deteriorating environment (Hendricks, 2003) and loss in aesthetic value and recreational value of this river has been the impact of uncontrolled human encroachment in the catchment area that led to significant alterations in the river system.

3.3 Approach to the study

3.3.1 Determination of land-cover types

The need for spatially explicit data to describe the catchment's land-cover, and management practices was driven by the recognition of the heterogeneity of the land, water and vegetation resources in the catchment. The need to characterise the land-cover classes was necessary if the understanding of water quality issues were to be achieved. The procedure used to extract land-cover information from satellite imagery was based on an integrated land-cover mapping approach developed by Thomas (2001). This approach uses a multilevel, hierarchical land-use classification based on a priori knowledge of the study area. A specially formulated land-cover classification scheme, in which thematic map layers that build up to the final map were obtained through digital image classification, visual interpretation, and manual on-screen digitisation. The procedure was dependent upon an understanding of local knowledge of the area. The method also involved multiple image processing algorithms discussed later in this chapter and provided by different software packages. The choice of the method was based on the number of classes it generates for the classification of land-cover. The a-priori classification method uses standardized classes (De Bie *et al.,* 1996; AFRICOVER, 1998). The hierarchical system of classification included different levels of land-cover information for further subdivisions of levels to account for more land-cover detail (Thomas, 2001; Thomas *et al.,* 2009).

The preparation of the Kuils-Eerste River land-cover map involved the use of Remote Sensing and GIS techniques. The supervised classification approach for classifying the imagery required the prior generation of suitable training sites through the digitization of known features that represented the classes required. The process

involved acquiring the Landsat ETM imageries of 2002 and SPOT5 of 2005 followed by rectification and enhancement of the images. Thereafter, the use of aerial photographs helped to identify most of the required land-cover classes. Topographic sheets of the region were consulted where visual interpretation of features not clear on aerial photographs were encountered. Local knowledge of the area was relied on for visual interpretations. Once representative classes were identified, training sites were created through manual digitisation. The supervised approach for image classification, and training sites were selected following the land-cover classification scheme that was generated as a guide to identify the class level. Classification using the supervised approach (classifier algorithms) was performed on both Landsat and SPOT scenes using ENVI 4.4 and ILWIS 3.2 software. To solve the challenges of insufficient spectral differentiation of the image, an integrated approach of image classification was used. The alternative approach involved the use of both supervised and unsupervised methods to select individual thematic layers or single land-cover features and adding to other correct existing land-cover classes detected by the previous classification attempts.

Accuracy estimation was performed using 200 randomly sampled points generated in Microsoft Excel spreadsheet using the Analysis ToolPak extension. Minimum and maximum values of *x* and *y* coordinates were identified using ArcMap. Random data points for 200 locations were generated (because there were 36 land-cover classes each, class was expected to have at least one accuracy check point) and displayed in ArcMap as an event layer (by adding the table as *XY* data). Only 98 samples fell within the catchment boundary and 24-land-cover types were represented from the 98 locations identified. An error matrix was created using the ground truth information and map data information obtained from this table and the overall map accuracy was calculated for the whole map. The overall map accuracy was calculated by dividing the total number of correctly classified sample points by the total number of sample points chosen for accuracy estimation.

3.3.2 Determination of water quality of each land-cover type

Establishing the quality of urban storm water is an important prerequisite to the effective management of urban runoff, which is recognized as the major nonpoint source of pollution (Francey *et al.*, 2010). Unfortunately, surface water contamination is not the only threat in an urbanising catchment. Increased pollutant loading from point sources into waterways can also cause significant environmental degradation. Nutrient loadings caused by changes in land-cover or management practices can cause nutrient enrichment of water resources, resulting in eutrophication, as well as triggering and sustaining algae blooms.

Water quality criteria

A review of urban storm water quality studies was carried out that informed the decision upon which the main study was premised. Annex 3.2 provides a summary of water quality variables used in the reviewed studies. The water quality variables selected for this study cover the main groups of water quality criteria, namely, physico- chemical parameters; inorganic content; and nutrients content. The water quality variables include: a) chloride, b) phosphorous, c) nitrogen, d) total suspended solids and e) NO_3-N. These were chosen because of the type of land-cover that characterises the catchment, a well-developed urban area and one in transition from an agricultural to an urbanising catchment. The area is characterised by agricultural, industrial, residential and domestic activities. The selection of sampling sites for the study was governed by a number of factors including, i) distribution of different land-cover types as depicted by the land-cover map developed for the study area, ii) local known contaminant sources, iii) accessibility to the different sites where runoff water samples were collected from overland flow.

Sampling

Sampling was undertaken during the rainfall period of 2007 to 2008. Grab sampling at selected sites was done during the rainfall events only. The sampling interval was targeted at the first flush floods the moment when the first runoff is observed on the surface. This was done in order to ensure maximum concentration of pollutants being washed off. Sampling during the early stages of runoff was meant to monitor any

'first flush' effect that may be present. The sampling activities were also dependent upon the number and occurrence of rainfall events within the catchment. This meant that in the case that no rainfall events were registered within the catchment no sampling would be done and as long as the occurrences of the events increased the sampling activities would also be increased. Studies in other parts of the world have indicated that the routine sampling procedures and protocols indeed vary with location and objective of sampling framework (Feio *et al.,* 2008).

Quality control measures were applied during sample collection. All samples were collected in 250 ml plastic bottles. In the field, each bottle was rinsed twice with the water to be sampled. No special sampling procedure such as filtering in the field was required for total phosphorus, total nitrogen, chloride, totals suspended solids and NO_3-N, the five water quality parameters. Once collected these samples were immediately stored in a 'cool box' and transported to the laboratory within 24 hours of sample collection. This was meant to reduce the effects of biochemical processes and reactions that may cause changes in water quality parameters. During sampling in-situ dissolved oxygen, electrical conductivity, and temperature of the water were also measured using a potable WTW OXI 92 type meter.

One hundred and four grab samples were collected at 53 sites throughout the catchment during the 2006 and 2007 rain seasons. The number of samples collected was dependent on the intensity and number of the rainfall events. A large number of samples improve accuracy of the mean concentration values. For example, in a long-term urban runoff study, Marsalek and Ng (1987) found that the mean concentration of the first 13 in a series of 117 events monitored, was not statistically different from the mean of the entire data set for six out of eight constituents.

Marsalek and Ng (1987) further argued that the minimum number of samples required at each site depends on the sample variation. The number of samples must be sufficient such that the uncertainty in estimating the mean concentration is sufficiently low enough to permit relative comparisons of pollutant sources. It was not possible to determine sample variability until after the samples had been

collected. Unless the data were actively reviewed, this meant that the number of samples collected initially would be high. For each site a minimum of three samples per event were collected to ensure that the number of samples was representative.

Two types of field quality control (QC) samples were collected in this study, field blanks, which were used to estimate bias, and field duplicates used to estimate variability. In addition to ensuring that samples were free from contamination the data were reviewed, validated, verified, and checked for usability prior to post analysis.

The following procedure was used for field blank collection:

1. All equipment was rinsed with the reagent grade water following the procedures normally used for field rinsing.
2. A field-blank sample was obtained by pouring the blank water into the bottle used for sample collection.
3. The sample was processed according to normal procedures for each constituent.
4. The last site and date at which the sampling equipment was used were recorded to make it possible to identify the source of contamination.

Two primary methods of collecting water samples were used: (i) Grab; and (ii) Composite methods.

The simplest, grab sampling method was used. The quantity of water taken (250 ml bottle) was sufficient for all the physical and chemical analyses that were to be done on the sample. This followed recommendations from the laboratory which conducted the laboratory analysis. The grab sampling technique is concerned with the practice of taking a relatively small sample over a very short period. A grab sample reflects water quality characteristics at the time the sample was collected.

Grab sampling allowed for the analysis of specific types of parameters that change quickly such as pH, dissolved oxygen, chlorine residual, nitrites and temperature. However, the most widely used indicators of surface water quality, including TSS

(total suspended solids) and TN (total nitrogen) required the use of composite sampling techniques. Grab samples were generally collected as a number of discrete samples of at least 250 ml, taken within a short period (less than 15 minutes) during the first 30 minutes after the onset of a flush flood. The time was monitored using stopwatches in the field.

3.3.3 Determination of the Curve Number

The curve number method is an empirical description of infiltration. It combines infiltration with initial losses (interception and detention storage) to estimate the rainfall excess, which would appear as runoff. In this method, runoff producing capability is expressed by a numerical value varying between 0 - 100. This model requires few input parameters, and has been widely applied in the fields of soil physics and hydrology (Chow, et al., 1988; Hawkins, 1998; Hawkins et al., 2002; Mishra and Singh, 2004; Mishra et al., 2004, 2005, 2006). The method is applicable to the situation in which amounts of rainfall, runoff, and infiltration are of interest (USEPA, 1986). The curve method predicts direct surface runoff using the following equation:

$$Q = (P - I_a)^2 / [(P - I_a) + S] \quad (3.1)$$

$$I_a = 0.2 * S \quad (3.2)$$

$$S = (1000 / CN) - 10 \quad (3.3)$$

Where:

Q = runoff (mm)

P = rainfall (mm)

S = potential maximum retention after runoff begins (mm)

I_a = initial abstraction (mm)

CN = runoff curve number

Note: If $(P - I_a) = 0$, then $Q = 0$

If the initial abstraction at a given cell is greater than the rainfall at that cell, the model sets runoff depth to zero (Baltas 2007). This prevents the reintroduction of artificial sinks to the runoff analysis.

S, also called the retention parameter, is a statistically derived parameter related to the initial soil moisture content or soil moisture deficit. The value of *S* is determined based on the type of soil and the amount and kind of plants covering the ground. The numerical description of the impermeability of the land in the catchment varied from 0 (100 % rainfall infiltration) to 100 (0 % infiltration – e.g., road/concrete).

The CN is a hydrologic parameter that relies implicitly on the assumptions of extreme runoff events; however, during non-extreme runoff events for example in humid regions, the underlying assumptions are almost never valid. The CN was initially developed as a design tool to estimate the transformation of return period rainfall into return period runoff for traditional agricultural lands in the United States. However, the CN method is now being used worldwide (Fennessey and Hawkins, 2001).

The techniques required basic data similar to that used in the Rational Method. However, the CN approach is more sophisticated in that it considers the following:

- time distribution of rainfall
- initial rainfall losses to interception and depression storage
- an infiltration rate that decreases during the course of a storm.

CN method produced the direct runoff for a storm, by subtracting infiltration and other losses from the total rainfall using a method sometimes termed the Runoff Curve Number Method.

The primary input variables for the CN method are as follows:

- drainage area size (*A*) in square kilometres
- time of concentration (T_c) in hours
- weighted runoff curve number (RCN)
- rainfall distribution (Type II or III for catchment)

- total design rainfall (*P*) in millimetres.

There are three distinctly different modes of application for CN. 1) Determination of runoff volume of a given return period, given total event rainfall for that return period. This is perhaps its most common routine application; 2) determine the direct runoff for individual events. This acknowledges the variation between events and is the basis for the development and the Antecedent Runoff Conditions (ARC) bands; 3) in process models, an inferred application as an infiltration model, a soil moisture-CN relationship, or as a basis for source area distribution. The CN method of estimating runoff volumes from rainfall has a number of advantages as it is simple and easy to use.

3.3.4 Estimation of event mean concentration (EMC)

The measure of pollutant level during a runoff event is the expected mean concentration, or EMC, measured in mgL^{-1} defined as the ratio of the mass of pollutant in the event divided by the volume of runoff. The expected mean concentration has a statistical distribution, and varies in value from event to event. It is assumed that the expected mean concentration is directly related to the land-use in the drainage area. For the Kuils-Eerste river catchment, the land-cover is defined by the land-cover map developed for the catchment study, developed using an a-priori land-cover classification. Using GIS, the land-use in each $100m^2$ cell was determined. By using land-use and expected pollutant concentrations, the corresponding expected mean concentration for various pollutants was determined for each land-cover on the basis of the cell size.

3.3.5 Estimating contaminant loads

The contribution of the contaminant load (*L*) that each cell (10 m x 10 m) makes to downstream can be found by taking the product of the cell area, *A* (m^2), the runoff per cell area, *Q* (m^3/yr^{-1}), and the expected concentration, *C* (kg/m^3), using the equation:

$$\boldsymbol{L = Q\ (m^3/yr^{-1})\ C\ (kg/m^3)\ A\ (m^2)} \qquad (3.11)$$

A value of *L* is computed for each cell in the landscape to represent its local contribution to contaminant loading. The accumulated loading going downstream is determined by summing the loadings arising from all upstream cells.

Conceptually, the annual mean concentration (*AMC)* is determined by analyzing the event mean concentrations (*EMCs*) obtained through laboratory analysis of water samples collected during storm events. As a consequence three types of mean concentrations were considered for estimating contaminant loads with some consideration being made with respect to which one to use of the three options; i) single-event means, ii) multi-event means, and iii) multi-site means. Rainfall event means were estimated using rainfall event or composite samples. Rainfall means were calculated using rainfall mean data from the rainfall measuring stations in the catchment. The data were useful in comparing contaminant concentration and loading between sites. The option for this study was to use the multi-site rainfall means as they represented different sites within each land-cover type.

Event Mean Concentrations (*EMC*) are average values of water quality for a particular pollutant in runoff for a given land-cover (Naranjo, 1998). Pollution is due to the effects of the build up and washoff processes (Butcher, 2003). *EMC* values are calculated based on the total constituent mass discharged during a rainfall event divided by the total volume of discharge during the event. The *EMCs* vary from storm to storm and from site to site (Chow and Yusop, 2008). The *EMC* is determined using the following equation:

$$EMC = \frac{\sum_{i=1}^{n}(C_i Q_i)}{\sum(Q_i)} \qquad (3.12)$$

where C_i = concentration of runoff at interval *i* (mm per event)

Q_i = flow rate at time when sample was taken (m^3s^{-1})

n = number of events during the study period

i = rainfall event interval

EMC is usually estimated from flow weighted composite samples in the field or calculated from discrete measurements (Naranjo, 1998; Butcher, 2003). The runoff vol-

ume (Q) can be determined by way of field measurements as well as through estimation techniques such as the curve number (CN) method.

The other possible approach to get an estimate of *EMC* value was to calculate the arithmetic average concentrations from a site during a rainfall event or different rainfall events. This approach was applied for the catchment wide assessment.
The arithmetic average EMC was defined as:

$$\text{EMC} = \frac{\sum_{j=1}^{m} EMC_j}{m} \qquad (3.13)$$

where, m = number of events (samples) measured from a site and

$j = EMC$ site values.

Using this method the arithmetic average *EMC* for selected pollutants over the catchment were obtained, whose values were a requirement of the model.

3.3.6 Experimental plots

Research on pollutant transport occurs at a variety of scales - from laboratory models (Kleinman *et al.,* 2005) to runoff plots used to investigate processes occurring at field level (Srinivasan *et al.,* 2002). Each scale of investigation is associated with a specific set of processes when applied to water quality assessment. For instance, laboratory models enable determination of differences in runoff resulting from individual management objectives (Kleinman et al., 2005), but their design and homogenous nature restricts their extension to heterogeneous landscapes. At the same time, catchment monitoring quantifies cumulative impacts of farm or field-level management practices on water quality, but provides limited insight into the role of individual management factors as observed by Heathwaite (2003). Given the diverse and numerous land-cover types identified for the catchment, it was considered necessary to use runoff plots to identify types of pollutants emanating from specific land types. The experimental field plots represented a spatial scale intermediate between soil runoff boxes and catchments. These have been used to investigate effect of soil

and management factors on water quality Pote *et al., (*1996); Gascho *et al., (*1998); Sharpley *et al., (*2001); Sharpley and Kleinman, (2003).

The selection of the location of the plots in the study area was influenced by a number of factors, among the important ones being the security of the equipment to be installed, accessibility of the sites and the type of cover. Four land-cover types were then selected after a secure location had been identified. The plots were designed so as to exclude the changes in water quality that occur when overland flow travels from one land-cover type to the other. Four experimental plots each representative of the major non-urban land-cover types were set up. These land-cover types are i) open grassland; ii) fynbos; iii) vineyards; and iv) mountain forest. As a way of understanding the relationships of environmental processes in the different land-cover scenarios, the experimental plots offered an option where results could be generated under controlled conditions.

The experimental plots were constructed on Skoonheid Farm (Figure 3.5). The farm is located 33^{o} 57’ 26, 59’’ S and 18^{o} 43’ 35, 24’’ E on the slopes of Kanonkop Hills to the east of the Kuils River sub-catchment. The farm is accessible through M12 Freeway from Cape Town. Permission was sought from the owner of the farm to set up experimental plots on his property that would represent different land-cover types.

The locations of the plots within the farm were selected to ensure that the plots had soils that had comparable properties. The locations of the sites are shown on the map (Figure 3.5). Each plot represents a specific land-cover type (grassland, vineyard, Mt forest and fynbos), and represents on a broader scale what is obtained in the catchment.

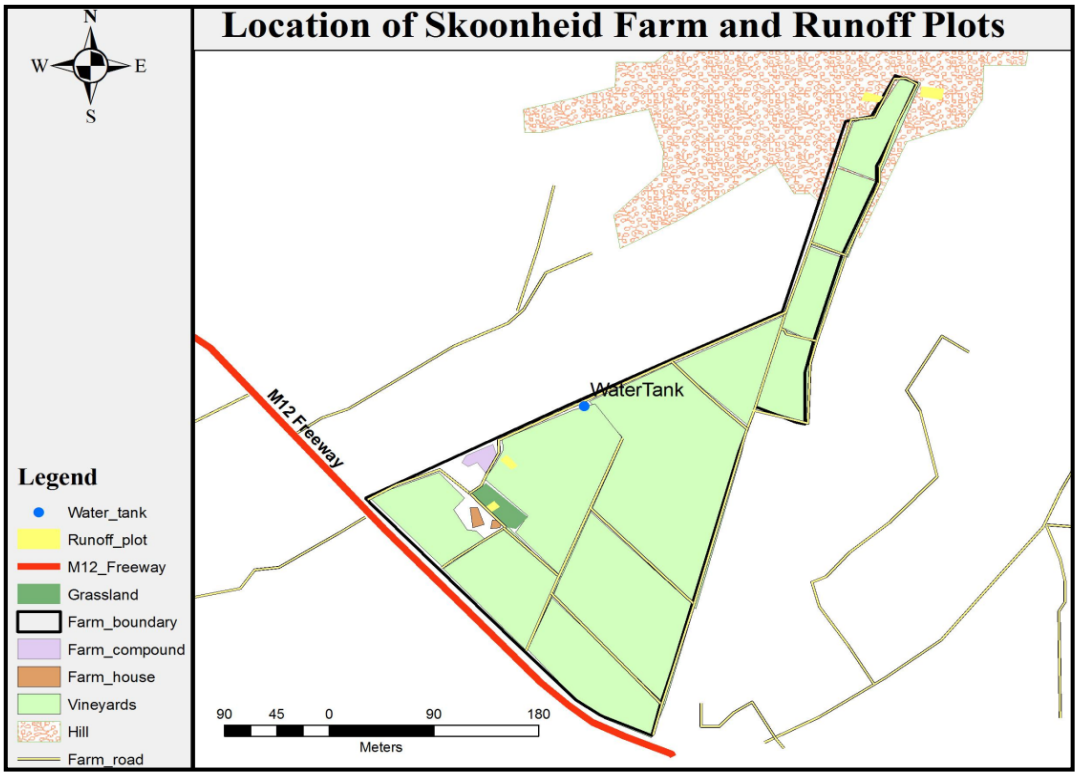


Figure 3. 5: Experimental plots set up on Skoonheid Farm, located on the slopes of Kanonkop Hills east of the Kuils River sub-catchment.

The experimental plots were constructed based on the layout illustrated in Figure 3.6. The rectangular experimental plots were constructed with galvanized sheets inserted 15 cm into the soil and extending 15 cm above the soil. Rectangular experimental plots have been used for more than 50 years (Návar and Synnott, 2000; Liu *et al.*, 2007). A trough for collection of water and sediments was located at the lower end of each sample plot. The trough had a lateral pipe inserted into the soil to avoid leakage of water and sediments. The top part of the trough was covered with a galvanised iron sheet to avoid soil particles splashing. Runoff was collected using a 20 *L* plastic container. Rainfall intensity was measured with a recording rain gauge located close to each plot. The volume of surface runoff was calculated by measuring the depth of the water in the collecting tank. A composite sample was taken at the end of a rainfall event. The samples were collected in a common container as the rainfall event progressed. At the end of the event a sample of 250 ml was taken from the tank after a thorough mixing to bring up all pollutants in suspension where runoff was channelled from the runoff experimental plots. The sample was taken to the laboratory and the procedure was repeated for each rainfall event monitored. Hartanto *et al.* (2003) have used the same methodology for two catchments in Indonesia. The analysis of the

water samples collected represented the average content of pollutants of surface runoff over the experimental plot during the rainfall event.

Table 3.2 shows the characteristics of the plots showing the land-cover type, dimensions of the plot, soil type, and the location of the plot in the study area.

Table 3. 2: Characteristics of the plots

	Plot I	**Plot II**	**Plot III**	**Plot IV**
Land cover	Grassland	Vineyard	Mountain forest	Fynbos
Dimension	10 m x 5 m	10 m x 5 m	10 m x 5 m	12 m x 6 m
Soil type	Sandy	Sandy	Sandy	Sandy
Location	Situated on the lower slope of a vine farm Figure 3.6.	Situated on an agri-cultural field Figure 3.7	Situated on Pine forest Figure 3.8	Situated in the fynbos Figure 3.9

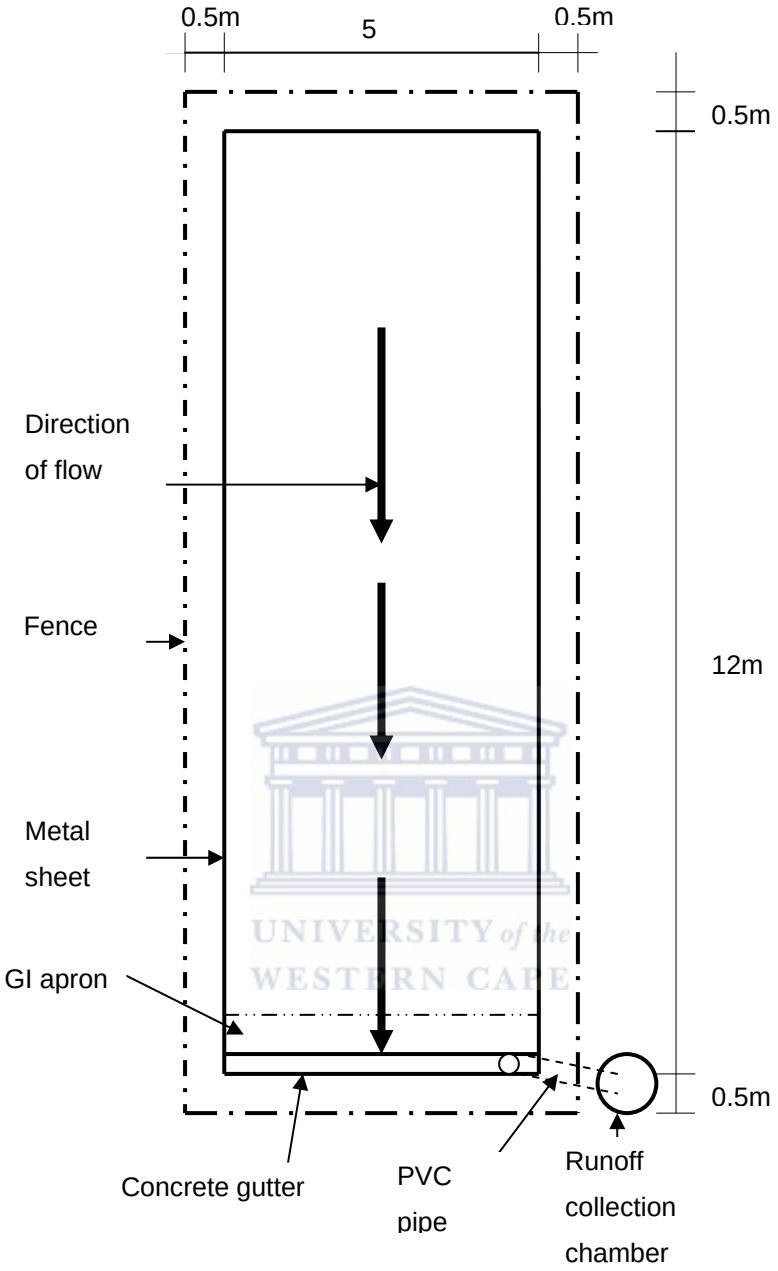


Figure 3. 6: Sketch diagram of the Runoff Experimental Plots (Not drawn to scale).

Figure 3. 7: Plot 1 with open grassland during the set up of the experimental plots in the catchment.

Figure 3. 8: Plot 2 with a vineyard as the land-cover type.

Figure 3. 9: Plot 3 with a pine forest as the land-cover type.

Figure 3.10: Plot 4 with fynbos as the land-cover type.

Further studies relating to soil characteristics were conducted. Soil particle size distribution (PSD) is one of the most fundamental physical attributes due to its great influence on other soil properties related to water movement, productivity, and soil erosion (Gui *et al.,* 2010). Accordingly, characterizing variations in the PSDs of soils is an important issue in environmental research. For example, Wang *et al.* (2008) investigated the soil PSD characteristics under different land-cover types in the Loess Plateau using the fractal theory. Similarly, Hu *et al*., (2005) examined the soil PSD characteristics under different land-cover types in Inner Mongolia. The results of these studies revealed that soil PSD differed among land-cover types and demonstrated that the land-cover types and changes in land-cover were the primary factors responsible for variations in the soil PSD. However, there are no studies conducted to examine soil PSD characteristics and their variations under different land-cover types in the Kuils-Eerste River catchment. The soil PSD was characterized to determine the primary factors that influenced the movement of surface runoff.

The soil samples (0–30cm) were collected at selected points within the experimental plots. The distance between adjacent sampling sites was selected to represent the up-

per part of the plot and the lower part. Two replicates of each soil sample were collected using a hand held soil auger which resulted in a total of 12 soil samples being obtained. The soil samples were transported to the laboratory, for PSD analysis. The measured distribution data and particle size volumes of all soil samples evaluated to identify the primary factors that influence soil PSD.

3.3.7 Water quality analysis

Water quality analysis was done by a private company, BemLab Laboratory. The methods of analysis used by BemLab are based on cadmium reduction methods and auto-analytical techniques. The accuracy levels which BemLab provided are shown in Table 3.3.

Table 3. 3: Cadmium reduction methods and auto-analytical techniques for water analysis used by BemLab.

Detection limits	
Lower limit	0.08 mg/L^{-1}
Lowest quantifiable concentration	0.27 mg/L^{-1}
Uncertainty of measurement	3.2 %
Calibration range for which the data were valid	0 mg/L^{-1} - 10.0 mg/L^{-1}

The results of monitoring surface water quality were compared to those used by regulatory agencies' (DWA 1993;1996 and 2001) standards to determine whether detailed assessment was required. Factors which were taken into consideration included, i) type of contaminants detected, ii) the contaminant levels detected, iii) the number of samples in which the contaminant was detected, iv) known sources of the contaminant within the collection system, v) annual discharge volumes, and vi) the sensitivity of the receiving environment.

3.3.8 The NPS pollution assessment model

In this study, a simplified model of non-point source pollution assessment developed using the ArcView geographic information system is presented. The result of the application of this method is an estimate of the mean annual runoff, pollutant

concentration and pollutant loading for each cell in a grid laid over the landscape of the catchment. The steps involved in the method proposed are outlined in Figure 3.11.

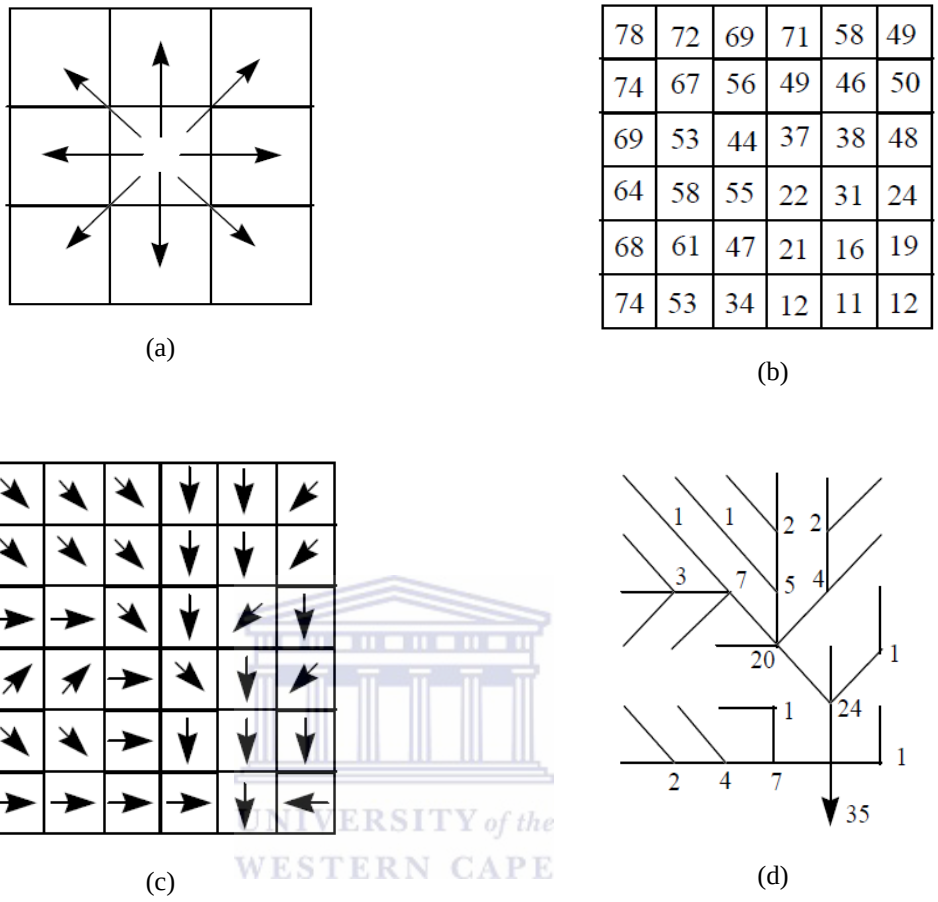


Figure 3. 11: Processing of Digital Elevation Data. (a) The 8-direction pour point model; (b) a grid of elevation values; (c) flow direction grid; (d) flow accumulation grid. (Saunders and Maidment, 1995).

The catchment digital elevation model (DEM) data were procured from the Chief Directorate of Surveys and Mapping in Cape Town. The DEM is based on a 30 meter by 30 meter data spacing with the Universal Transverse Mercator (UTM) projection. Each 7.5 minute by 7.5 minute block provides the same coverage as the standard 1:50 000 scale map series. The DEM was re-sampled to a 10 meter by 10 meter grid to improve on the accuracy of modelling.

Runoff passes from each cell to only one of its eight neighbouring cells (four on the principal axes and four on the diagonals) in the direction of steepest descent, as defined by the digital elevation data, thus generating a flow direction for each grid

cell (Figure 3.11a). By tracing these cell-to-cell drainage connections downstream, the drainage path from every cell to the catchment outlet is determined, thus generating a flow connectivity network through the whole basin (Figure 3.11d). From any cell, the number of cells upstream can be counted which is called the flow accumulation grid. Streams are identified as lines of cells whose upstream drainage area exceeds a threshold value. Catchments are identified as the set of cells whose drainage passes through a particular outlet cell on a stream.

In the low-lying areas, the observed drainage network contains many straight constructed channels. To ensure that the mapped streams are correctly reproduced in the drainage paths derived from the digital elevation data, the mapped streams were "burned in" to the landscape by artificially raising the elevation of all the off-stream cells by an arbitrary amount. This ensured that the grid streams and the mapped streams were completely consistent at the expense of some distortions in the catchment boundaries where the mapped streams and the digital elevation data were not matching.

The flow diagram below (Figure 3.12) illustrates the way grid maps were combined and the expected outcomes from each combination.

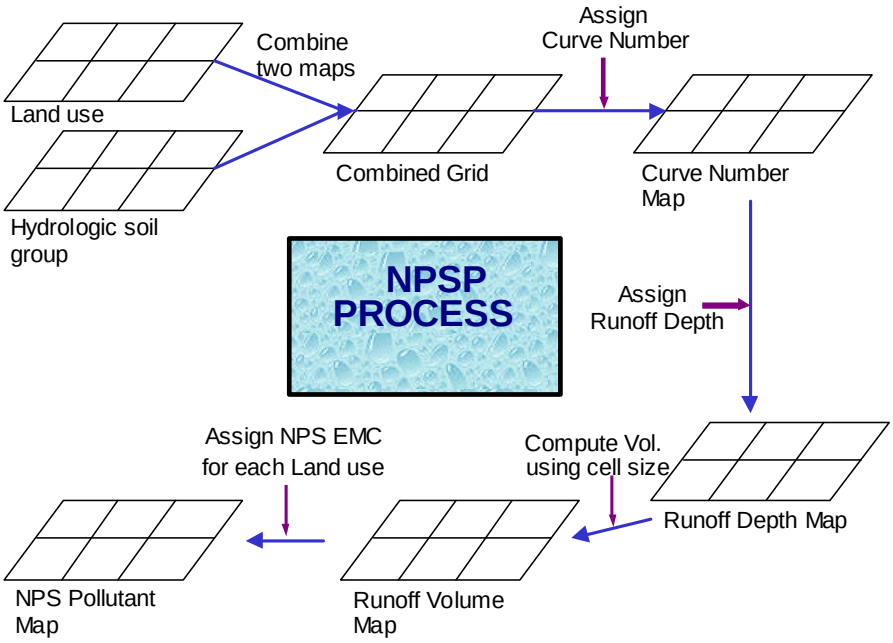


Figure 3. 12: GIS Model Overview adapted from Naranjo (1998).

3.3.9 Soil data

The soils data were obtained from the Council for Scientific and Industrial Research (CSIR). The data set contains soil type distribution for the whole of South Africa. A few modifications were done in order to make this data adaptable and suitable for the models.

The soil data were classified into Hydrological Soil Group classes (HSG). The HSG defines the soil infiltration capacity (infiltration rates). These HSG's are grouped into four categories, *A* through *D*, based on decreasing infiltration rates (*A* = high infiltration, *D* = very slow infiltration). The codes represent the descriptions. Areas where the actual soil type could not be determined were coded as Hydrological Soil Group *D.* In areas where soil cover was well defined, the HSG definition was based on the soil texture characteristics as indicated in the soil data provided by the CSIR. In instances where the soil units have been represented as compound hydrological groups, the latter symbol (the rightmost soil group) was assigned for the polygon. Lastly, the individual HSG's were converted to specific numeric codes used in the model.

3.3.10 Precipitation data

Table 3.4. Shows rainfall stations in the study area whose data was used in this study.

Table 3. 4: The rainfall stations used in the study

Station Name	Longitude	Latitude	Rainfall 2OO6 (mm)	Rainfall 2OO7(mm)
Wellington	19.0158	-33.6500	662.1	729.0
Vogel Vallij	19.0408	-33.3417	569.5	659.6
Zachariashoek	19.0825	-33.8333	715.3	768.9
Assegaaibos	19.0658	-33.9417	1669.0	1483.6
Withoogte	18.6678	-33.0672	464.3	522.3
Brakke Fontein Sewage	18.4825	-33.6083	400.9	515.2
Higgovale Cape Town	18.4117	-33.9375	772.2	968.5
Tafleberg	18.4033	-33.9792	1440.0	1761.0
Tafelberg	18.4492	-33.9667	1266.0	1756.0
Malan DF Airport	18.5992	-33.9667	436.1	680.6
Stellenbosch	18.8700	-33.9417	486.2	630.6
Jonkershoek	18.9492	-33.9833	1360.7	1796.3
Jonkershoek	18.9286	-33.9639	1093.0	1330.0
Kogel Baai	18.8514	-34.1797	996.5	959.0
Altydgedacht	18.6330	-33.8330	488.0	651.4
Maitland	18.5860	-33.9200	484.1	614.1
Skoonheid	18.7333	-33.95	463.0	679.0

Rainfall for each of the stations was plotted as point data using the locational attributes of the stations. Using an algorithm in the ArcView software the data was extrapolated basing on the Thiessen Model of rainfall estimation to give spatial distribution in the form of a grid. The analysis of the rainfall distribution was conducted for annual values as the input data for the model required spatial distribution of rainfall in the form of a grid. Inverse distance weighted (IDW) algorithms were used to show the annual spatial rainfall distribution. The IDW is an inverse distance to power gridding method and is a weighted average interpolator. The IDW estimated cell values by averaging the values of sample data points in the neighbourhood of each processing cell. The closer a point was to the centre of the cell being estimated, the more influence or weight it had in the averaging process. The technique was chosen for its potential to estimate surface values for each cell using the value and distance of nearby rain gauges. The method of interpolation used ESRI's Spatial Analyst Interpolation to Raster tools to assign values to locations based on the surrounding measured rainfall based on specific mathematical formulae.

CHAPTER 4

LAND-COVER CHARACTERISTICS OF THE CATCHMENT

4.1 Land-cover characteristics

A SPOT5 summer scene image (March 2005) procured from the Western Cape Provincial Government office for Environmental Affairs and Planning with high resolution and in a multi-spectral mode of 10 m for all three spectral bands in the visible and near infrared ranges of the electromagnetic spectrum was used. The SPOT5 data set was preferred for further processing to the Landsat7 ETM+ (2002) for higher resolution quality (10 m) because the data suited the purposes of preparing a detailed land-use map at regional scale basis (small catchment – approximately 660 km^2). A land-cover map (4.2) was produced based on the SPOT 5 image (Figure 4.1). The map was divided into thirty-six classes. Figure 4.2 shows the catchment and the different land-cover/ land-use classes.

Figure 4. 1: The False Colour Composite combination from a summer image from SPOT5 (March 2005). Image supplied by SAC, CSIR.

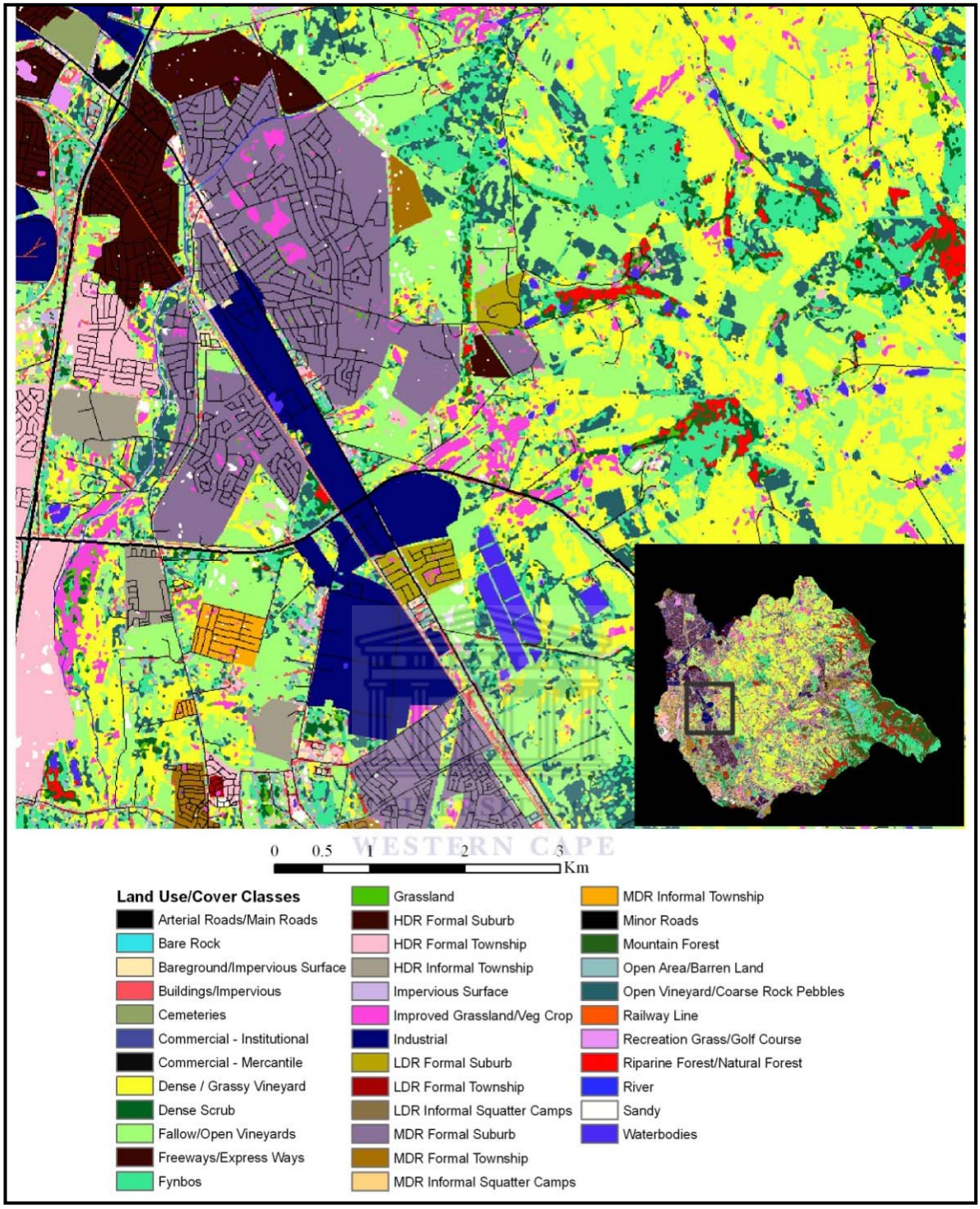


Figure 4. 2: Part of the land-cover map of the Kuils-Eerste River catchment map.

Results show that the land-cover/use types are urban and suburban settlements including industrial and commercial activities in the western part of the catchment with extensive open agricultural fields, mainly vineyards in the central part of the catchment, including forest tree plantation and naturally vegetated areas in the eastern section. The relief is generally flat in the western part of the catchment changing to gently undulating hills around the central part of the catchment and rugged relief with mountain ranges in the eastern part (1.220m).

Agricultural coverage dominates with only the western segment of the catchment indicating evidence of residential and industrial activities. Figure 4.3 is the final result of the classification of land-cover developed for the catchment. This map was used as the input data for the models in the study of NPS pollution in the catchment.

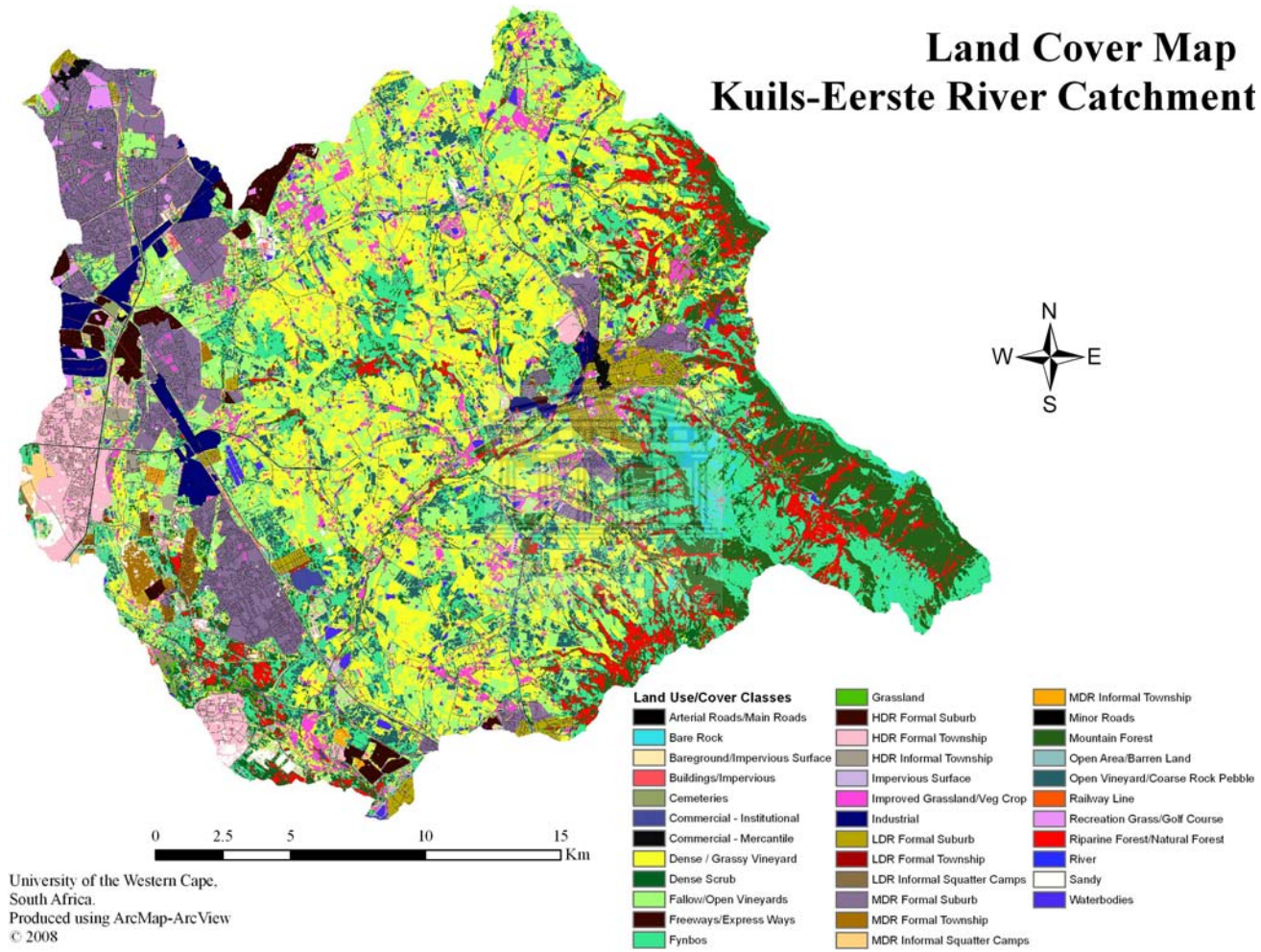


Figure 4. 3: Land-cover map of the Kuils-Eerste River catchment showing the 36 land-cover classes.

4.2 Land-cover type description

Dense/Grassy Vineyard occur on 20.4 % of the catchment followed by Fallow/Open Vineyard 14.4 % (Table 4.1), making agricultural activity the predominant land-cover. Formal and informal settlements occupy 14.3 % of the catchment, making it an equally significant land-cover type of the catchment. Table 4.1 shows that at least 12.5 % is made up of fynbos. One fifth of the catchment area (19.4 %) has road networks, residential and industrial coverage areas.

Agricultural land (which combines vineyards and all cultivated land for different agricultural produce) occupies 40.6 % of the catchment while Fynbos has 12.5% and the forests both riparian, mountain and scrub makes for the 14.6 %. Grasslands occupy only 10.8 % of the catchment. The communication road network within the catchment occupies 3.4%, representing the level of impervious surfaces in the catchment. residential areas is another land-cover type with considerable coverage. Combined altogether, the different categories of residential areas take up 12.8% of the catchment with commercial areas taking up 0.4 %.

An assessment of the accuracy of the land-cover map was performed using randomly selected sampling points generated (Figure 4.4). The ground truth information for the sample points were later displayed as an event layer in ArcMap. An error matrix was created using the ground truth information collected and land-cover types shown on the classified map. The overall map accuracy had a Kappa value (coefficient of agreement) of 0.9 giving a 91% accuracy for the whole map.

Table 4. 1: Total percentage areas of land-cover / land-cover units in the catchment.

Class No.	Land-cover type	Hectares	% Area
1	Mountain Forest	3241.3	5.0
2	Riparian Forest/Natural Forest	33905.6	5.2
3	Dense Scrub	28489.7	4.4
4	Fynbos	81284.3	12.5
5	Grassland	1157.9	1.8
6	Impervious Surface	413.4	0.6
7	Railway Line	86.5	0.1
8	Bare ground/Impervious Surface	357.7	0.6
9	Bare Rock	361.3	0.6
10	Open Vineyard/Coarse Rock Pebbles	3798.7	5.8
11	Open Area/Barren Land	1166.8	1.8
12	Improved Grassland/Vegetable	2348.2	3.6
13	Buildings/Impervious	493.0	0.8
14	Dense/Grassy Vineyard	13292.0	20.4
15	Fallow/Open Vineyard	9376.3	14.4
16	Recreation Grass/Golf Course	237.8	0.4
17	Freeways/Express Ways	52.1	0.1
18	Arterial Road/Main Road	235.4	0.4
19	Minor Roads	1899.7	2.9
20	Sandy	592.1	0.9
21	Water bodies	738.2	1.1
22	HDR* Formal Suburb	941.8	1.5
23	MDR* Formal Suburb	4556.1	7,0
24	LDR* Formal Suburb	937.0	1.4
25	HDR Formal Township	2174.0	3.3
26	MDR Formal Township	347.4	0.5
27	LDR Formal Township	2.4	0.0
28	HDR Informal Township	98.6	0.2
29	MDR Informal Township	67.0	0.1
30	MDR Informal Squatter Camps	149.9	0.2
31	LDR Informal Squatter Camps	42.8	0.1
32	Commercial- Mercantile	124.3	0.2
33	Commercial- Institutional	143.7	0.2
34	Industrial	1150.5	1.8
35	Cemeteries	20.9	0.0
36	Rivers	135.7	0.2
	Total	**194420.1**	**100**

* HDR=High Density Residential; MDR=Medium Density Residential; LDR=Low Density Residential

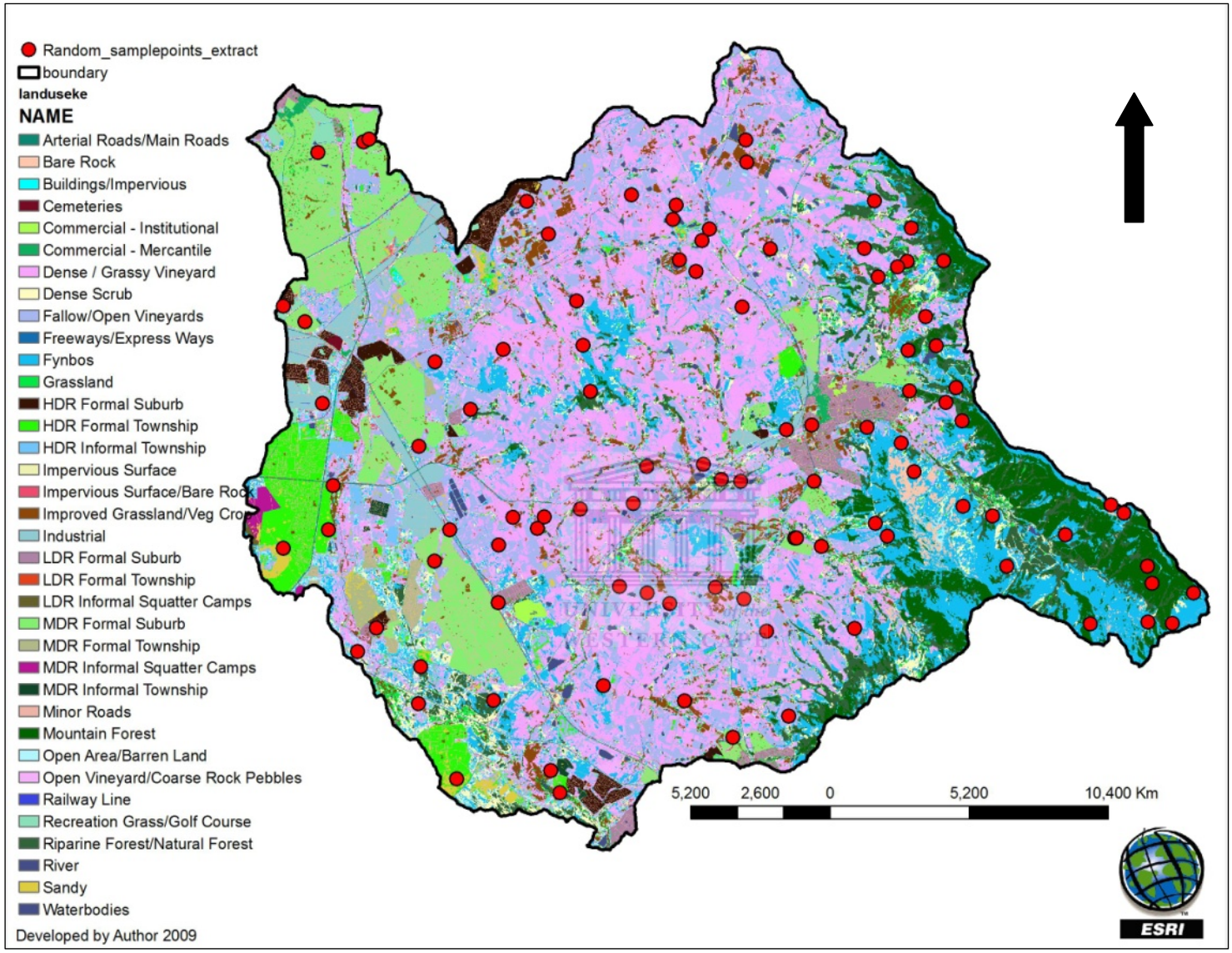


Figure 4. 4: Randomly selected sampling points generated by a computer and used for accuracy check.

CHAPTER 5

EXPERIMENTAL RUNOFF PLOTS

5.1 Introduction

In this chapter, the outcomes of the experimental work conducted at plot scale are presented. The main focus was to understand whether land-cover types differed in their contributions to the concentration of water quality attributes emerging from them. The plots were designated with a code to distinguish one from the other. Plot I was set up on open grassland, Plot II represented the vineyards, Plot III covered the mountain forests and finally Plot IV represented the fynbos land-cover.

5.2 Physical soil characteristics

Soil samples of varying depth (15 cm and 30 cm) were collected from the four experimental plots. Three replicates of each soil sample were collected, which resulted in 36 soil samples being obtained. Three factors were considered in determining the appropriate sampling depth, 1) the influence on the movement of pollutants with changes in soil morphology and depth (i.e., horizonation), 2) the influence on the movement of pollutants through surface soil management (e.g., tillage), and 3) the necessity to maintain sample collection depth uniform across all the plots.

Soil particle size distribution (PSD) is one of the most fundamental physical attributes due to its great influence on other soil properties related to water movement, productivity, and soil erosion (Gimtnez 1997; Montero 2005; Huang and Zhang 2005). Accordingly, characterizing variations in the PSDs of soils is an important issue in the study of water quality in the Kuils-Eerste River catchment.

The particle size distribution (PSD) classification schemes are used, with 3 (sand, silt, clay) or 7 (very coarse sand, coarse sand, medium sand, fine sand, very fine sand, silt, clay) texture classes subdivision. This study considered the point pedotransfer procedures which estimate some specific points of interest of the water retention characteristic and/or saturated hydraulic conductivity as implemented in SOILPAR based on procedures elaborated by Jabro, (1992). The Jabro point pedotransfer method availa-

ble in SOILPAR uses the PSD, BD variables and estimates hydraulic saturated conductivity (*Ks*). There are 13 methods that can be used in SOILPAR and only four can be used to determine *Ks*. The most recent was used in the study.

Soil samples analyzed from the experimental plots fell in the category of sandy soil (Sa) with the top layer of Plot IV (fynbos) being characterized as loamy sand (LmSa). The soil particle sizes range between fine sand (59.1 % and 78.9 %) to coarse sand (between 7 % and 22 %). The content of clay and silt is between 0.2 % and 2.4 %. Medium sand is between 10.7 % and 17.6 %. In terms of vertical distribution of the particle sizes, a general decrease with respect to the size of particles is noted from the top layer (15 cm) to the bottom layer (30 cm) for all categories of the particle sizes. There was variation in particle size with depth and location within the experimental plots when the upper part of the plot was compared to the bottom part where runoff exits the plots.

5.2.1 Soil differences between experimental plots

The results obtained from the analysis indicate that the dominant sediment class between the four plots was sand with some traces of loam sandy soils found in the fynbos plot.

A comparison of coarse sand content shows that grassland (Plot I) and vineyards (Plot II) contain 7 % to 8 % of coarse sand. These values were the lowest amongst the four plots. Mountain forest (Plot III) and fynbos (Plot IV) have 16 % to 22 % coarse sand content. Clay and silt content does not vary with the percentage content ranging between 0.2 % and 2 % for Silt, and 2 % to 2.4 % for Clay as indicated in Figures 5.1a and 5.1b. Fine sand varies significantly amongst the plots with the grassland plot having the highest value of 78.9 % content and the least value being recorded for the Fynbos plot with 59.2% content.

Figure 5.1a shows the particulate size distribution of the soil at 15 cm and 30 cm depth (Figure 5.1b). Fine sand distribution reflected high percentage content on the grassland and gradually diminished with the fynbos having the least value of 59.2 %.

The distribution of clay and silt in the 15 cm layer of the soil (Figure 5.1b) showed no percentage difference throughout the plots though there was content variation between 2% and 2.5% of clay. Vineyards and fynbos in comparison to the grassland and mountain forest plots had higher percentage values.

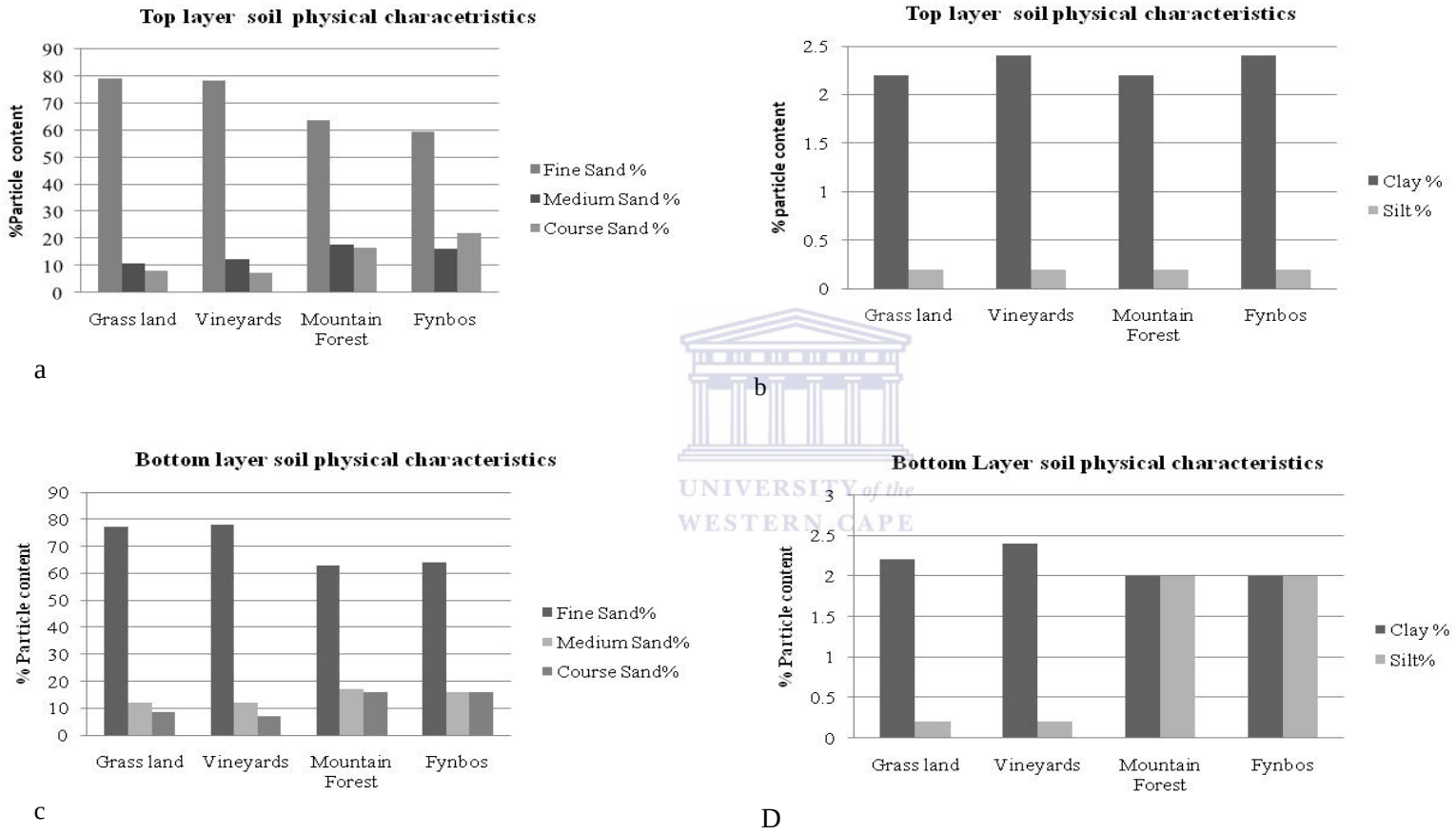


Figure 5.1: The sediment, clay and silt distribution for the top and bottom layers of the soil profiles from the experimental runoff plots.

5.2.2 Estimation of hydraulic conductivity

Hydraulic conductivity is one of the most important soil physical properties for determining infiltration rate and drainage characteristics. Hydraulic conductivity, symbolically represented as K_s, describes how water can move through a porous material such as soil. It depends on the intrinsic permeability of the material and on the degree of saturation. The soil samples were collected using the methods explained in Section 3.3.6.

Hydraulic conductivity is not an exclusive property of the soil alone, since it depends on the properties of the soil and the fluid. It may change as water permeates and flows in a soil due to various chemical, physical and biological processes.

The estimation of hydraulic conductivity of the soil was done using the method proposed by Acutis and Donatelli (2003). This method is an empirical approach by which the hydraulic conductivity is correlated to soil properties like pore size and particle size (grain size) distributions, and soil texture.

The method is contained within the SOILPAR 2.0 Software available on http://www.sipeaa.it.ASP/ASP2/SOILPAR.asp. Saturated hydraulic conductivity was estimated from particulate size distribution and bulk density using the relationship developed by Jabro (1992).

The observed and predicted values of saturated conductivity (K_s), based on SOILPAR computations, are given in Table 5.1. Given the physical characteristics of the soil and their distribution within the plots, there is no significant difference between the top layer (15 cm) and the lower layer (30 cm) as indicated by the results for Grassland-cover and Vineyard cover. A slight change is recorded for the Mt Forest cover and Fynbos cover.

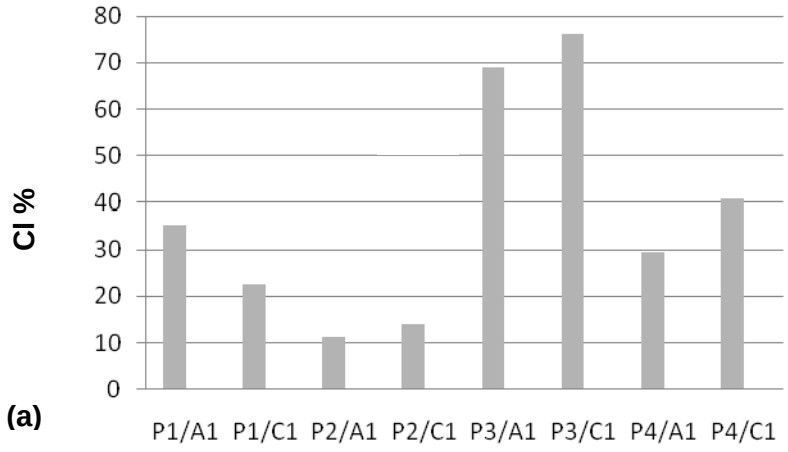
Table 5. 1: Predicted values of saturated conductivity (K_s), based on computations using the *Soilpar* software.

Soil Depth (cm)	Grassland K_s(cm/day^{-1})	Vineyard K_s(cm/day^{-1})	Mt Forest K_s(cm/day^{-1})	Fynbos K_s(cm/day
15	42.4	41.5	42.4	41.5
30	42.4	41.5	44.1	44.1

Estimates of K_s obtained at a depth of 15cm for grassland and Mt forest were K_s = 42.4 cm/day^{-1} resulting in high permeability of the soil. Fynbos and Fynbos had K_s = 41.5 cm/day^{-1} both classed as high permeability. Variations in K_s where noted at the 30cm depth where Mt forest and fynbos registered equal values of 44.1 cm/day^{-1}. The other two plots, grassland and vineyard, registered the following values 42.4 cm/day^{-1} and 41.5 cm/day^{-1} respectively.

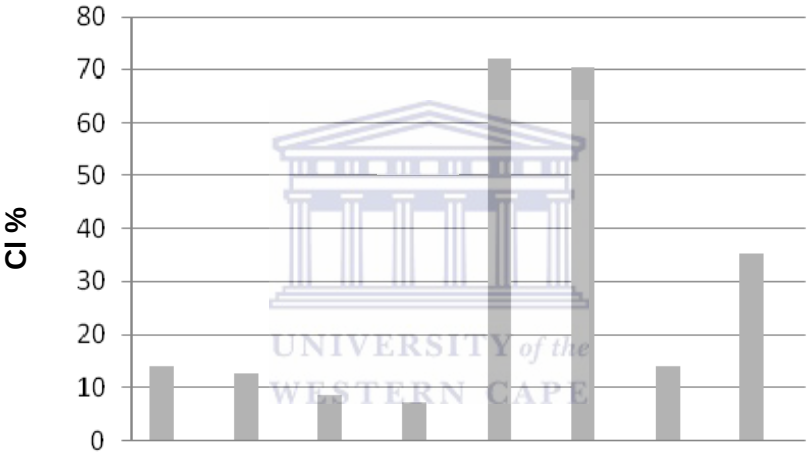
5.2.3 Soil chemical characteristics

For all the plots, consideration was given to the differences that exist within the plot and between the plots in terms of the concentration of the pollutants. For each plot four soil samples were taken at two different depths. The soil samples were collected from the upper part of the plot and the bottom part of the plot considering the slope of the terrain. The samples were collected in one day considering the weather conditions. Figure 5.2a and Figure 5.2b show differences both within plots and amongst the plots in terms of chloride quantities. While chloride is conservative, its presence in the grassland and vineyard plots is less as compared to mountain forest and fynbos plots. Cl recorded highest values for the mountain forest followed by fynbos with the upper part of the plot registering high values amongst the four land-covers. The concentration for the two soil layers indicates a decline with depth as shown in Figure 5.2a and Figure 5.2b.



(a)

Plot distribution, A1= Upslope of plot, C1 = Downslope of plot at a depth of 15cm

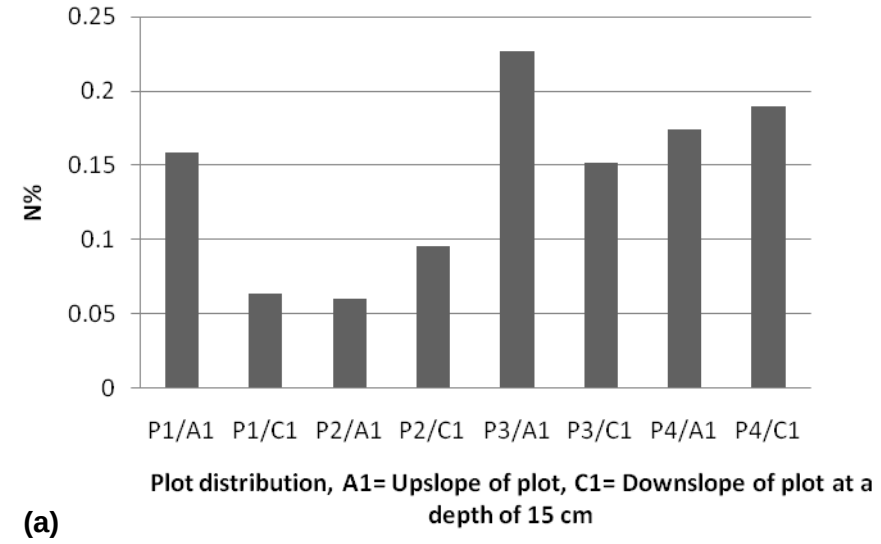


(b)

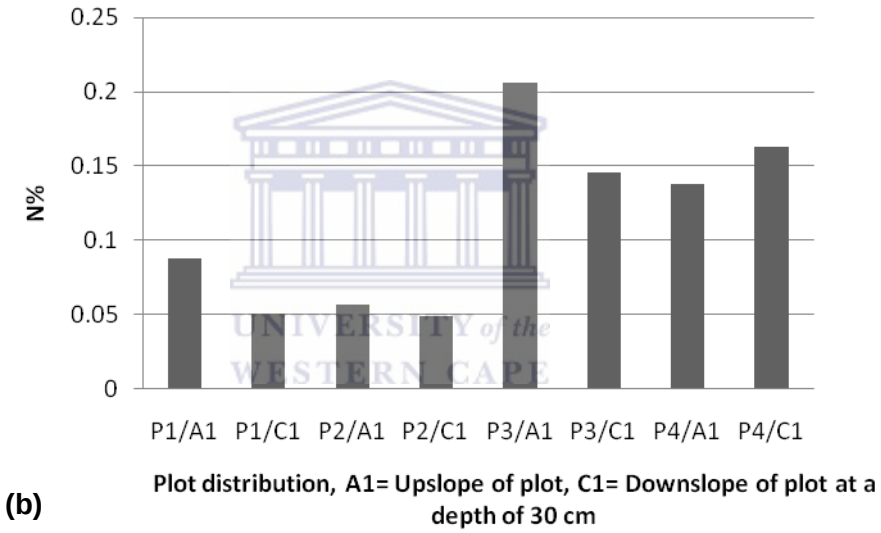
Plot distribution, A1= Upslope of plot, C1 = Downslope of plot at a depth of 30cm

Figure 5. 2: Chloride percentage concentration in the soil on the plots showing variations along an upslope and down slope profile. Figure a: shows the top layer (15cm) and Figure b: shows the distribution in the bottom layer (30 cm)

The concentration of nitrogen (N) was characterised by differences within the plots and between the plots (Figure 5.3a and Figure 5.3b). The decline in quantity was well defined from the upslope zone to the down slope zone of the plot in the grasslands and vineyards. A decline in concentration of N was defined with depth for each plot. Mountain forest registered the highest value followed by the fynbos and grassland fin the 15cm zone.



(a)



(b)

Figure 5. 3: Nitrogen percentage concentration in the soil on the plots showing variations along an upslope and down slope profile. Figure a: shows the top layer (15cm) and Figure b: shows the distribution in the bottom layer (30 cm)

The presence of phosphorus (*P)* and potassium (*K)* content were analysed at the same time and the concentration varied between plots and within plots (Figure 5.4 and Figure 5.5). High values of *P* were noted in grassland and vineyards respectively while the mountain forest and fynbos recorded lower values. Differences within plots were noted for the grassland and vineyards with an increase from the upslope zone to the down slope zone. Mountain forest and fynbos registered very insignificant variations and the quantity phosphorus and potassium was low. The differences between plots

were well marked. *P* increased from the upslope to down slope and *K* concentration was highest in the fynbos.

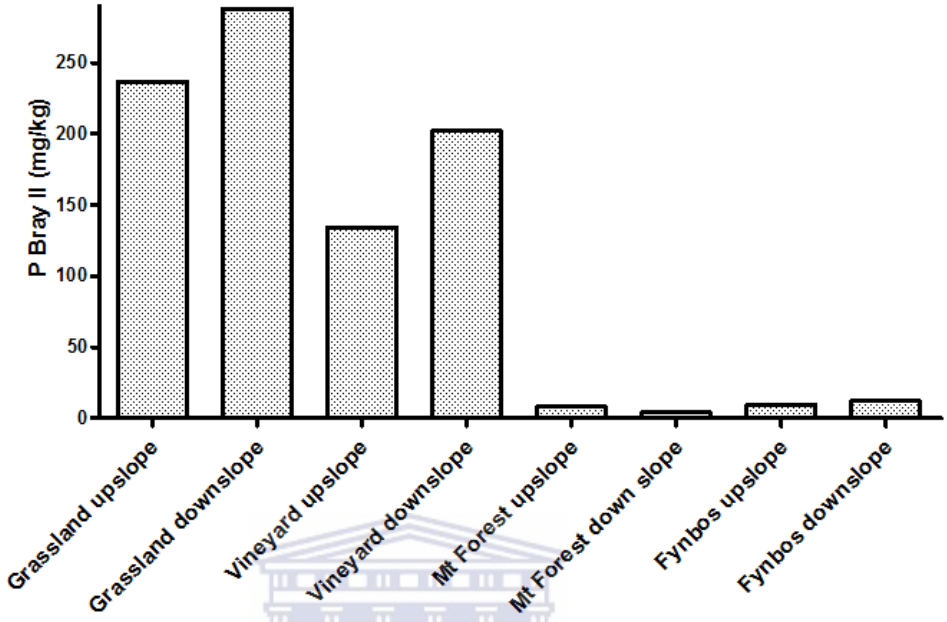


Figure 5. 4 Concentration of phosphorus between plots for the top layer (15cm) and showing the plot variations along an upslope and down slope profile.

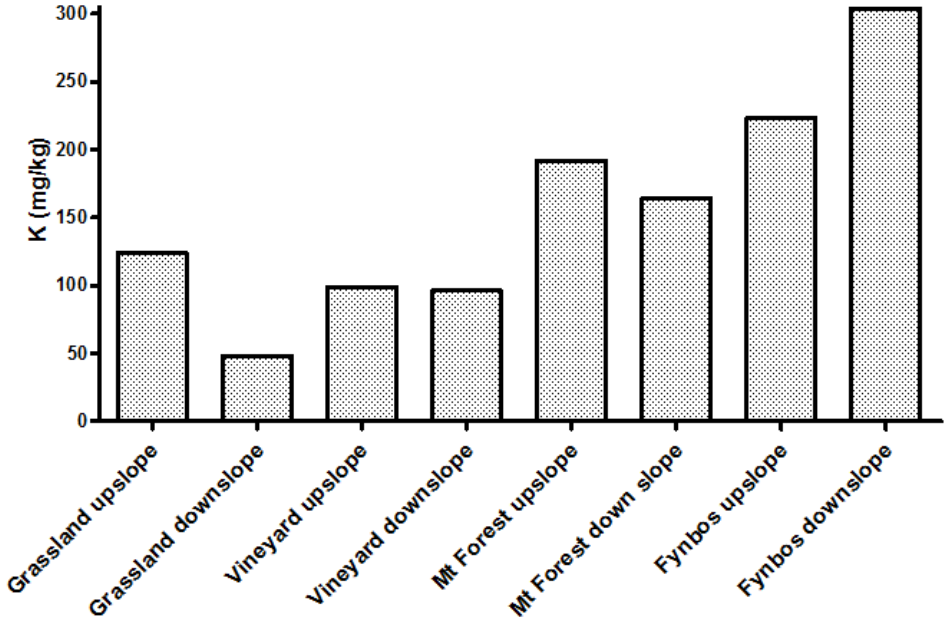


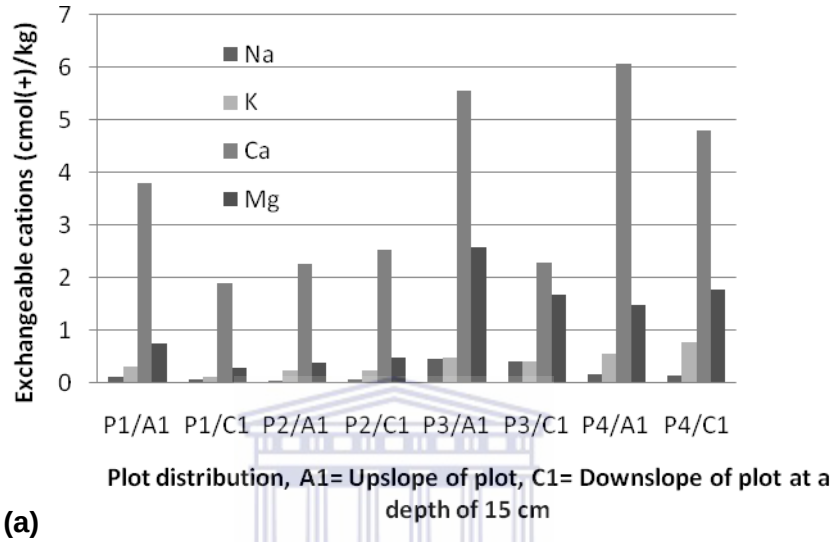
Figure 5. 5: Concentration of potassium between plots for the top layer (15cm) and showing the plot variations along an upslope and down slope profile.

Analyses of the exchangeable cations between plots as well as within the plots showed marked differences. Ca^{2+}, Mg, K and Na indicated the potential that the soil has to provide nutrients to plants. The distribution of these elements varied, for example, Mg was highest in mountain forest while the least was recorded in the fynbos (Figure 5.6). This distribution varied in depth as well. Values for Ca^{2+} declined in the grassland from the upslope zone to the down slope zone of the plot in the 15 cm and 30 cm zones. In the vineyards, an increase from upslope towards the downslope zone was noted for the 15cm depth though for the 30 cm depth there was a decline in concentration. In the mountain forest the concentration of Ca^{2+} declined in both depths. The fynbos registered the highest concentration values though the same pattern shown in the other land-covers was noted. Generally, K values were low in all the plots. In the grassland, the values declined from upslope to downslope. A gradual increase was noted from the grassland to the fynbos. Na was low in the grassland and vineyards and declined with depth in the mountain forest and fynbos.

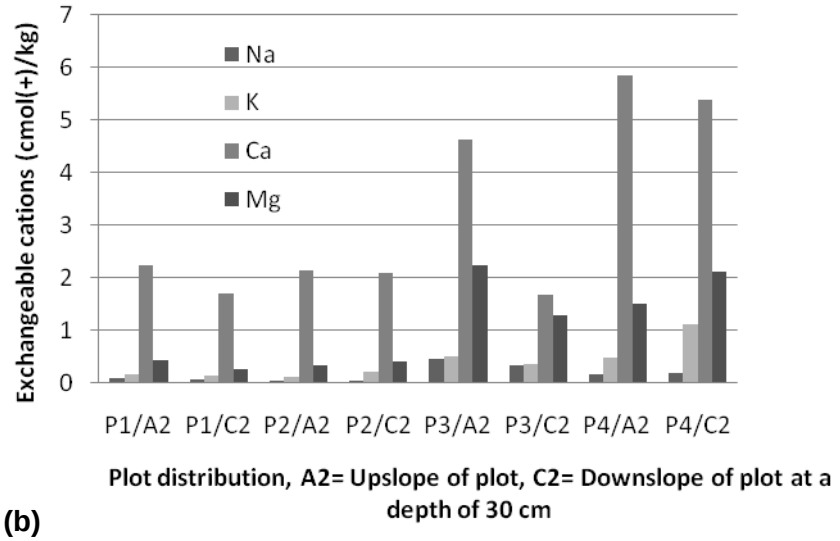
Figure 5.6a and Figure 5.6b show that the distribution of sodium (*Na*) within and between the land-cover types varied significantly. Mountain forest had the highest values and the decrease in concentration varied from upslope to down slope. Grassland registered an increase from downslope towards upslope. In the fynbos, variation was noted within the plot from upslope towards down slope. Calcium *(*Ca^{2+}*)* values were high for the grassland and vineyards (above 60 %) and there was a gradual decline from upslope to downslope zone. The fynbos plot showed a decline of the quantity below 60 % and the distribution was the same as for the other land-covers. There was a general decrease indicated by magnesium (*Mg)* in the grassland and fynbos and an increase in the vineyards and mountain forest. The highest values were found in the mountain forest.

Base saturation values and the exchangeable cations do not vary greatly suggesting that the mineralogy on which the soils have developed could be the same. Studies to evaluate how afforestation affects mineral soil quality; including pH, sodium, exchangeable cations, organic carbon and nitrogen have indicated that the magnitude of changes where vegetation occupies a greater part of the area the values are high. Acutis and Donatelli (2003) examined soils on diverse land-cover types to a depth of

30 cm of mineral soil, and observed significant decreases in nutrient cations (Ca^{2+}, *K*, *Mg*), increases in sodium (*Na*), or both with afforestation. Across the data set, afforestation reduced soil concentrations of the macronutrient Ca^{2+} by 29 % on average ($P < 0.05$). Afforestation alone decreased soil *K* by 23 % ($P < 0.05$). Overall, plantations also led to a mean 71% increase of soil *Na* ($P < 0.05$).



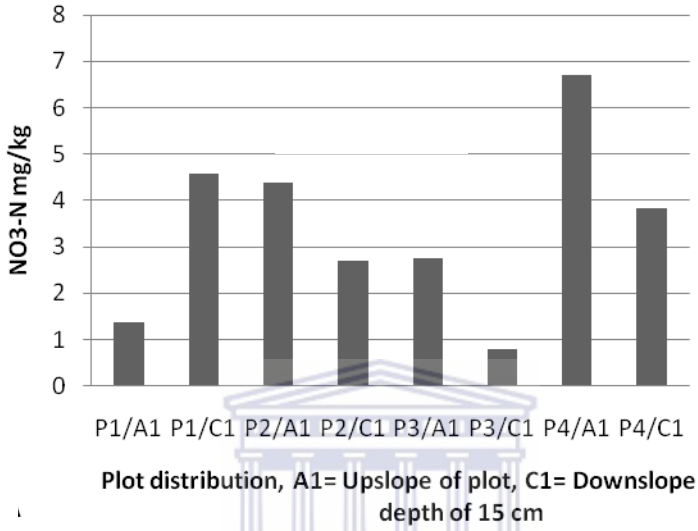
(a)



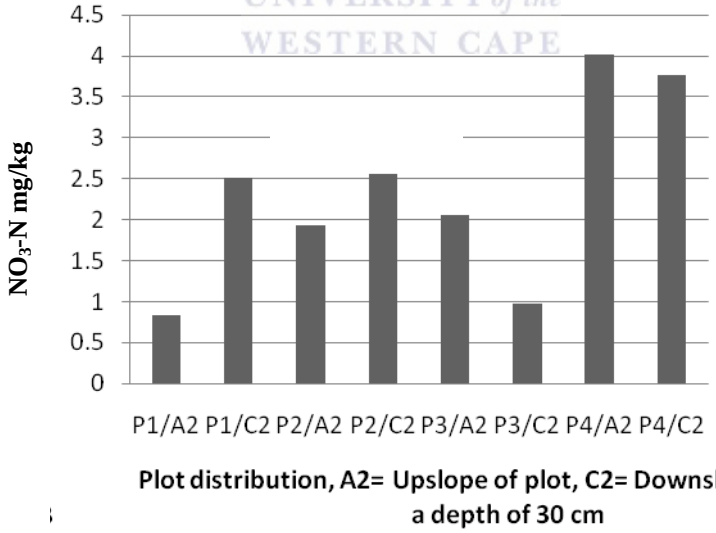
(b)

Figure 5. 6: Concentration of exchangeable cations. Figure (a): shows the distribution for the top layer (15cm) and Figure (b): shows the bottom layer (30cm).

NO_3-*N* in its mobile form leaches easily in semi-arid conditions and *N* transforms to ammonia in the soil. In more oxidizing conditions, it is found as nitrate. In general, from the soil depths analysed, (Figure 5.7a and Figure 5.7b) the presence of nitrogen/nitrates showed that there was more NO_3-*N* in the top soil (15 cm) in the vineyards and fynbos land-covers. In the 30 cm layer the concentration was generally lower for all land-covers. The highest concentration was recorded for the fynbos.



(a)



(b)

Figure 5. 7: NO_3-N concentration in the soils recorded by plot distribution and by depth. Figure a: shows values of NO_3-N at a depth of 15cm and Figure b: at a depth of 30cm.

5.3 Experimental plots water quality variations

The pollutant concentrations from the plots were analysed using the graphical analysis approach instead of other statistical analyses because the samples were too few to merit any meaningful statistical treatment. Box Whisker plots were used to compare seasonal trends between runoff water quality and land-cover.

5.3.1 Grassland (Plot I)

The main findings in relation to the water quality parameters in the grassland are indicated in Figure 5.8. Levels of nitrogen recorded (Figure 5.8a) were higher during the rainfall event of 28th August 2007 with more than 500 mg L^{-1} being found in the surface water of the grassland. The second parameter monitored NO_3-*N* shows increased concentration in August 2008 with above 0.6 mgL^{-1} being recorded (Figure 5.8b).

Total suspended solids (*TSS)* (Figure 5.8c) were high for the first event (158 mg L^{-1}) and maintained constant values for three events with 30mgl-1 and subsequently two months with equal values also of 41 mg L^{-1}. The high values of TSS coincide with the onset of the sampling and rainfall period for the catchment. Phosphorus (*P*) recorded low values in the first four events with the least value of less than 0.2 mg L^{-1} being registered on June 2007. A gradually increase towards the end of 2008 recorded values of 1.8 mg L^{-1}. A similar concentration pattern was shown by chloride, (Figure 5.8e) where the first four months showed similar variations as *P*. The month of August 2007 recorded the highest value of phosphorus for the grassland.

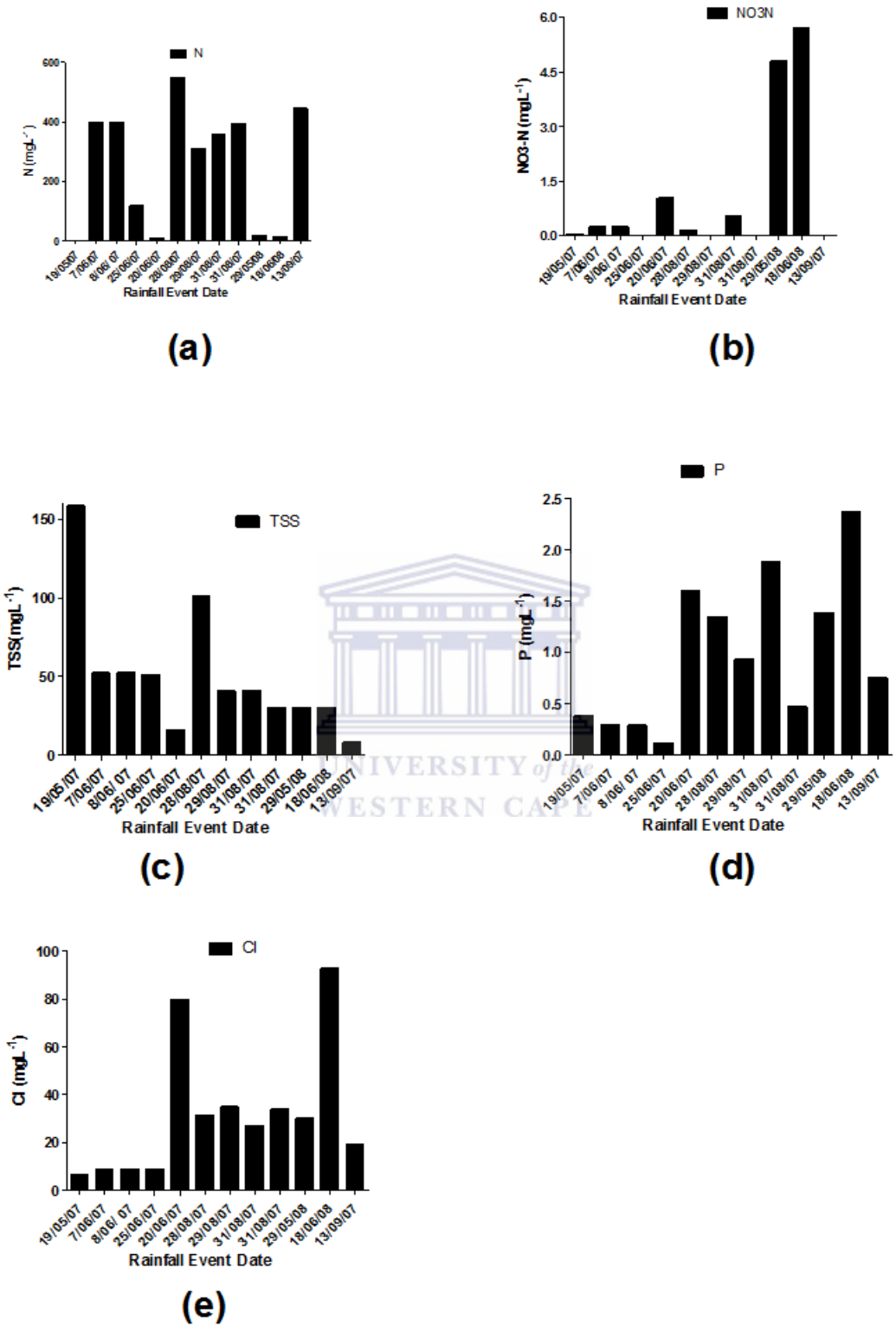


Figure 5. 8 Water quality characteristics for grassland (Plot I)

5.3.2 Vineyard (Plot II)

Water quality parameters analysed from the vineyards plot showed high values of Nitrogen (Figure 5.9a) for the event of 3rd September 2007 (802 mg L^{-1}). NO_3-*N* variation was so pronounced in the events recorded. Figure 5.9c shows the two events with 2.03 mg L^{-1} representing the highest level of concentration. Four rainfall events were associated with high values of chloride. The highest value was 84.27 mg L^{-1} (Figure 5.9d). Finally, *TSS* (Figure 5.9e) had very high values (590 mg L^{-1}) and the following events did not register high values.

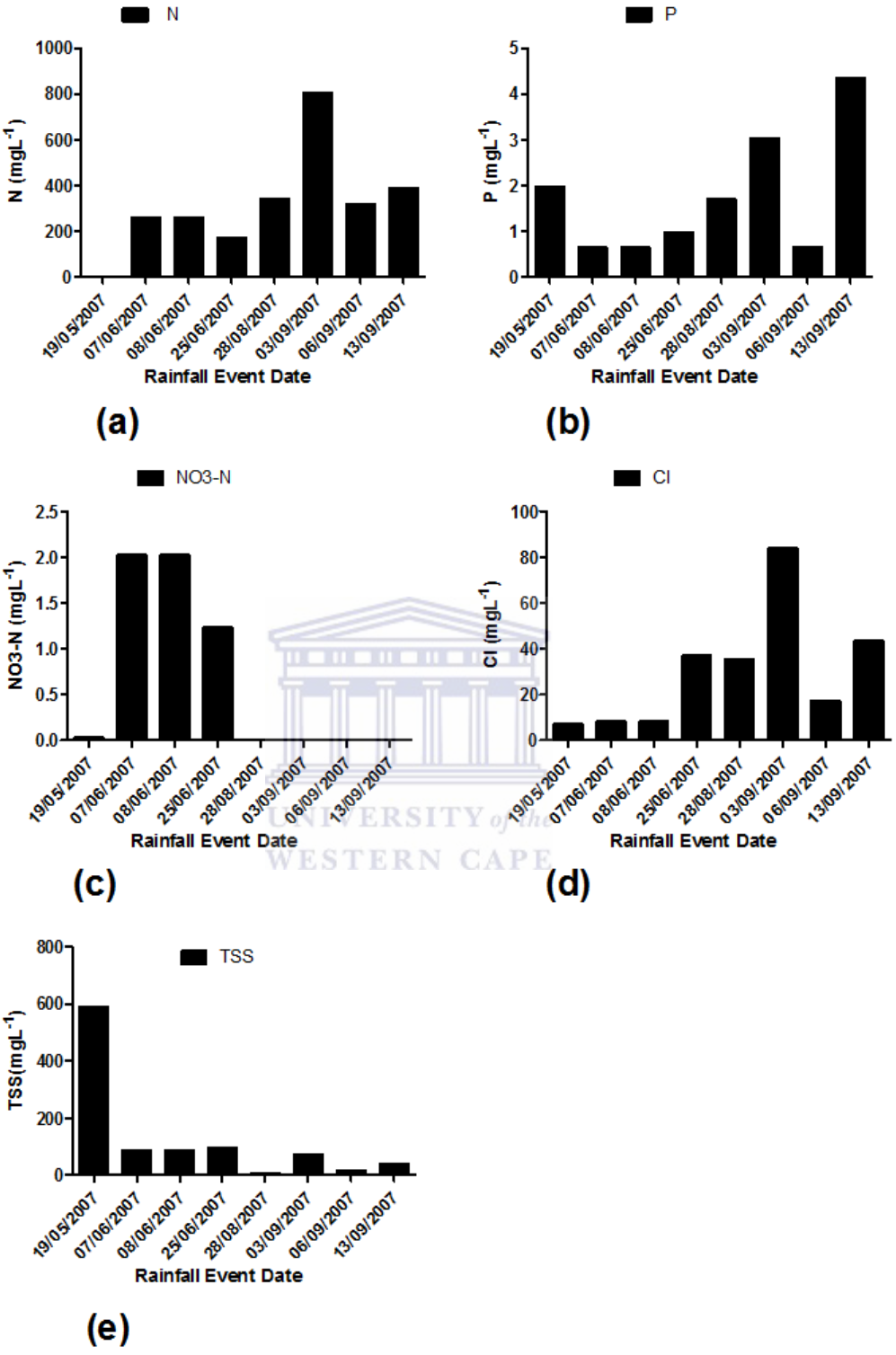


Figure 5. 9: Pollutant concentration for Vineyard land-cover (Plot II).

5.3.3 Mountain Forest (Plot III)

Figure 5.10 shows the water quality variables measured during the study period. Nitrogen had increasing values in the first three events with the highest values (11 mg L^{-1}) being registered on the 20th of June 2008. The highest values of NO_3-N (2.96 mg L^{-1}) for the mountain forest were recorded on the 29th of May 2008 (Figure 5.10b). This parameter was variable throughout the rainfall events recorded. The remainder of the events showed a steady increase in the quantities and a sharp fall on the amount recorded for the 19th of June 2008 (Figure 5.10a). Phosphorus recorded high values (0.4 mg L^{-1}) on the 29th of May 2008 and 0.39 mg L^{-1} on the 20th of June 2008 (Figure 5.10c). Chloride varied greatly with the highest value of 32.6 mg L^{-1} being recorded during the rainfall event of 29th of May 2008 (Figure 5.10d). Total suspended solids registered its highest values during the last rainfall event recorded with a value of 870 mg L^{-1} (Figure 5.10e).

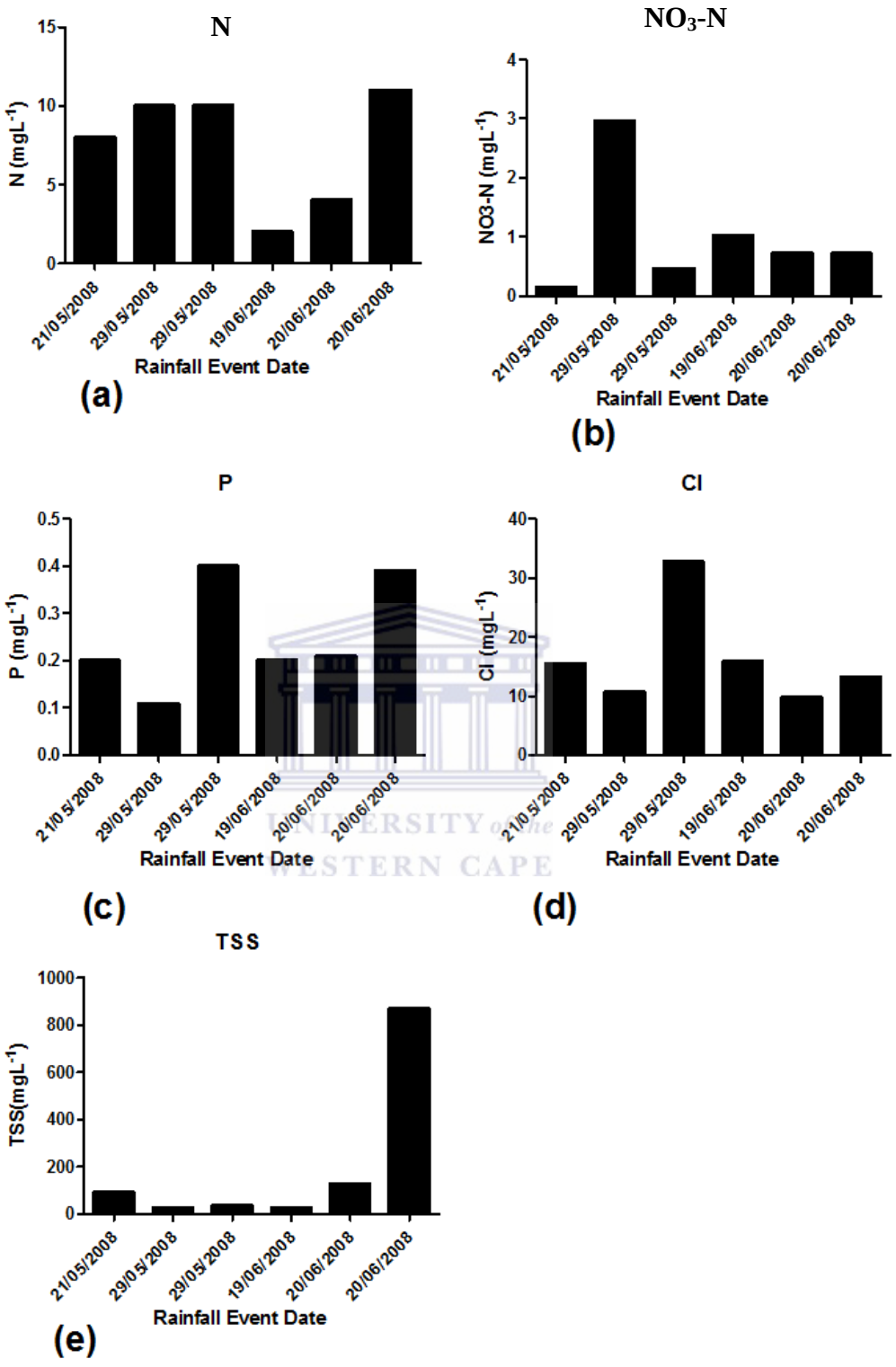


Figure 5. 10: Pollutant concentration for the Mt Forest land-cover (Plot III)

5.3.4 Fynbos (Plot IV)

Nitrogen concentration was the same during the first two events (2 mg L^{-1}) and experienced a sharp rise of 16 mg L^{-1} during the third event during the month of May 2008 (Figure 5.11a). A gradual decline for the first three events was recorded for NO_3-*N* with the first rainfall event registering 1.15 mg L^{-1} (Figure 5.11b). There is a gradual decline for Phosphorus recorded from the first rainfall event through to the third event (Figure 5.11c), an increase in the values was registered after the third event (0.3 mg L^{-1}). Chloride value was high during the first rainfall event and declined during the second event registering a steady rise in the subsequent events eventually declining in the last event. The highest value (22.96 mg L^{-1}) was recorded on the 9th of June 2008 (Figure 5.11d). Lastly *TSS* values were high during two rainfall events the first on the 25th and the second on the 29th of June 2008 respectively. The recorded values were 80mgL^{-1} and 83mgL^{-1} respectively (Figure 5.11e).

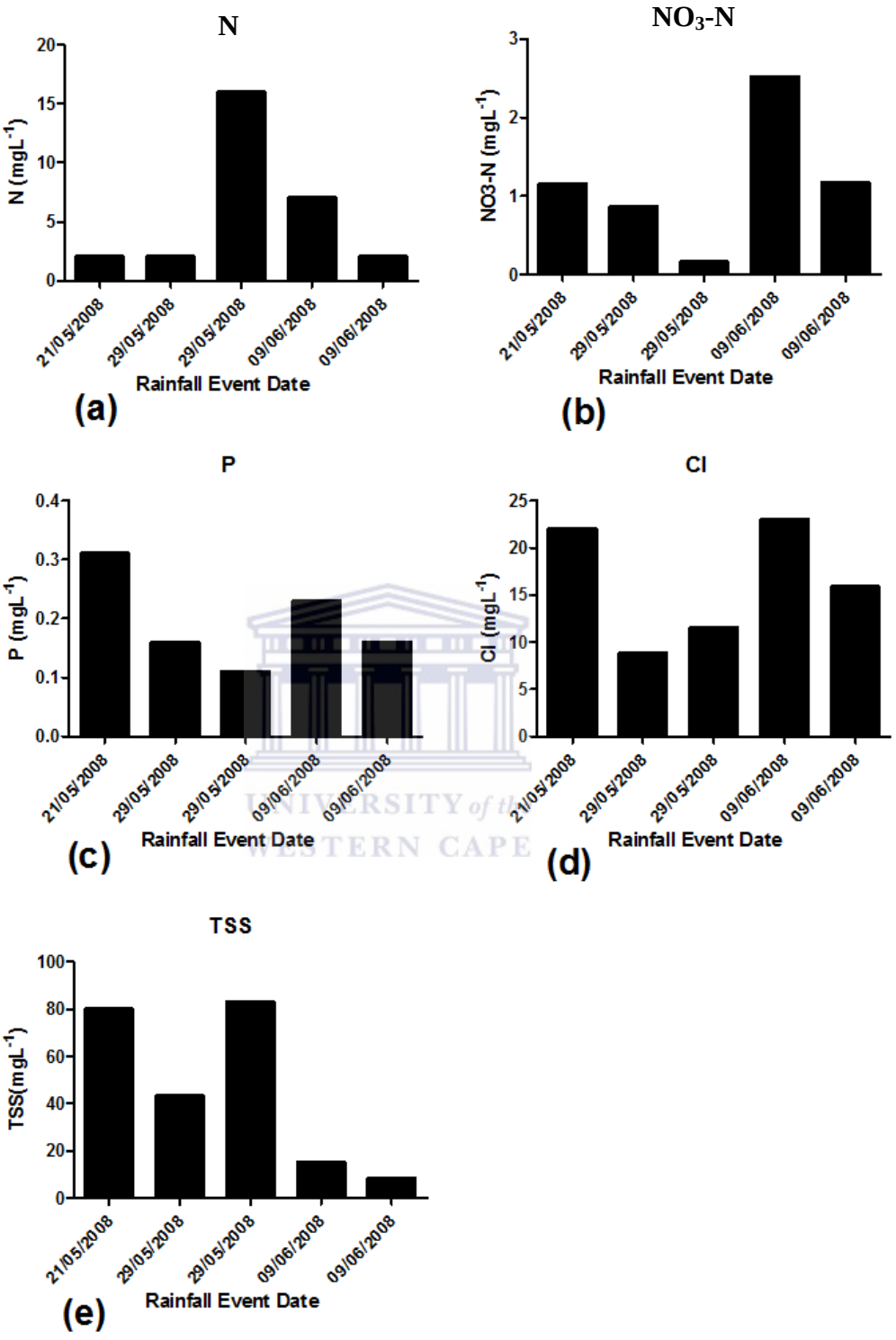


Figure 5. 11: Pollutant concentration for the Fynbos land-cover (Plot IV)

5.3.5 Variation of water quality between plots

Graphical analysis of the distribution of concentration values indicated that mountain forest (Plot III) recorded the highest concentration values of TSS followed by vine-yards (Plot II). The mean values are within the same range for all the plots at 0.95 co-efficient of interval for all the graphs. The concentration values did not show marked difference for TSS (Figure 5.12).

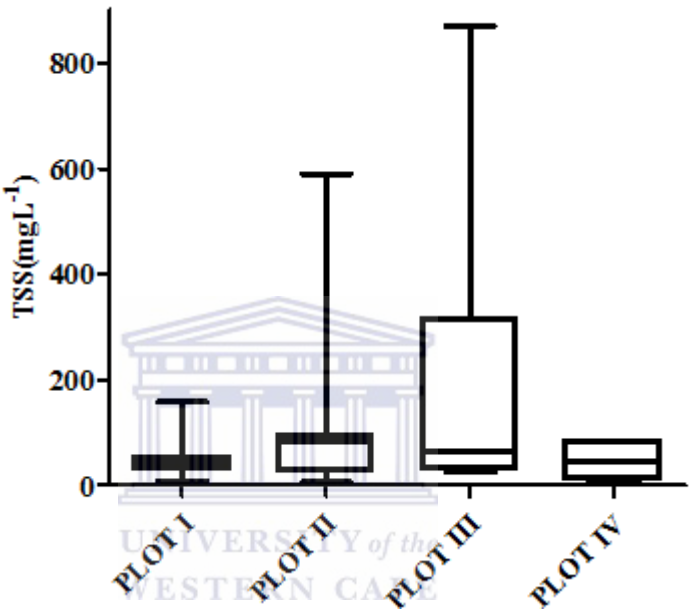


Figure 5. 12: Box and whisker plots showing variations of values and average concentrations of TSS (Plot I- Open grassland; Plot II- Vineyard; Plot III- Mt Forest and Plot IV- Fynbos)

The average concentration values for chloride are shown for Plot I and Plot II indicating large variability within the plots while Plot III and Plot IV show small variation. The mean concentration values fall within the same range implying no significant difference of chloride amongst the plots. Figure 5.13 shows the range of values for chloride.

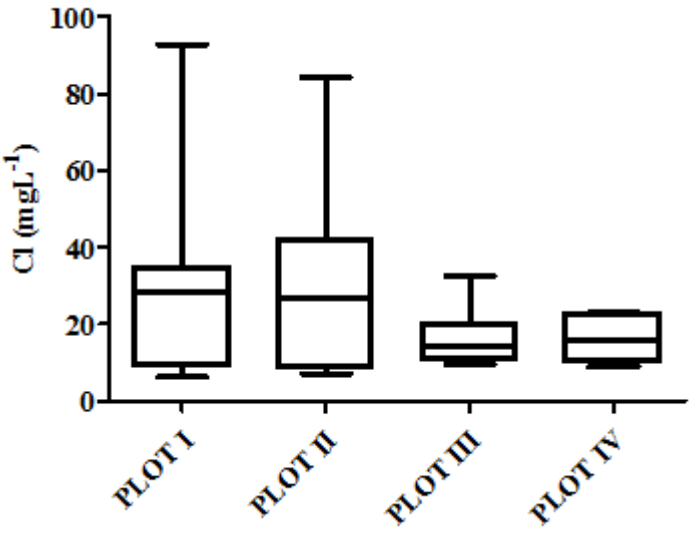


Figure 5. 13: Box and whisker plots showing variations of values and average concentrations of chloride (Plot I- Open grassland; Plot II- Vineyard; Plot III- Mt Forest and Plot IV- Fynbos)

Large variability in terms of concentration characteristics were noted for phosphorus (Figure 5.14). Grassland and vineyards did not show marked differences compared to the other two plots, mountain forest and fynbos. Mt. forest and fynbos were different from the grassland and vineyard plots. The grassland and vineyard were closely associated with the farming activity on the farm.

Phosphorus is a nutrient that occurs naturally at low concentrations even in pristine catchments. Relatively high phosphorus levels in Plot II are caused by human activities i.e. the vineyard. Most of the phosphorus in soils is bound to soil particles or is part of soil organic matter.

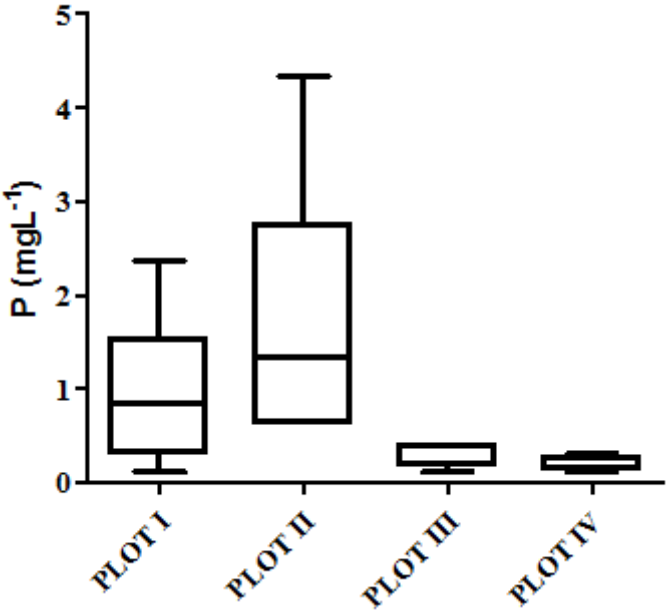


Figure 5. 14: Box and whisker plots showing variations of values and average concentrations of Phosphorus (Plot I- Open grassland; Plot II- Vineyard; Plot III- Mt Forest and Plot IV- Fynbos)

There was large variability within the plots for nitrates (Figure 5.15) mean values indicated little change between the plots. Land-cover type did not play an important role as the concentrations did not show significant difference amongst the plots.

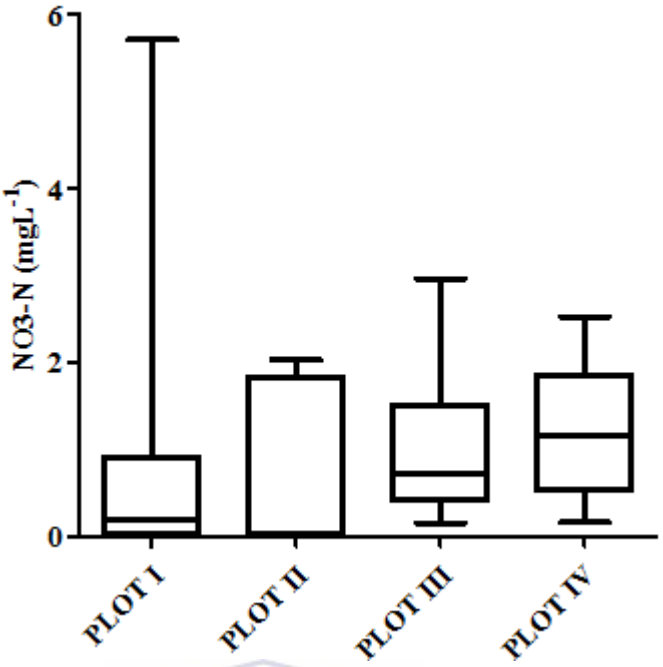


Figure 5. 15: Box and whisker plots showing variations of values and average concentrations of *NO_3-N* (Plot I- Open grassland; Plot II- Vineyard; Plot III- Mt Forest and Plot IV- Fynbos).

The last water quality parameter to be analysed is nitrogen. Nitrogen occurs naturally in surface waters even in pristine native areas albeit at low concentrations. Under these circumstances, nitrogen is washed from the soil and from the decay of organic material such as leaves. The average concentration amongst the four plots indicated high variability within Plot I (grassland) and Plot II (vineyards) (Figure 5.16). Plot I and Plot II significantly differed from Plot III. There were marked agricultural activities influencing Plot I and Plot II. Plot III and Plot IV had very low concentrations. The differences amongst the land-cover types were so pronounced and the activities carried out on them contribute to the variation of concentration of the water quality parameters. Plot I and II were cultivated or had some form of agricultural activity having been carried out on them and fertilizers applied as opposed to the remainder of the plots.

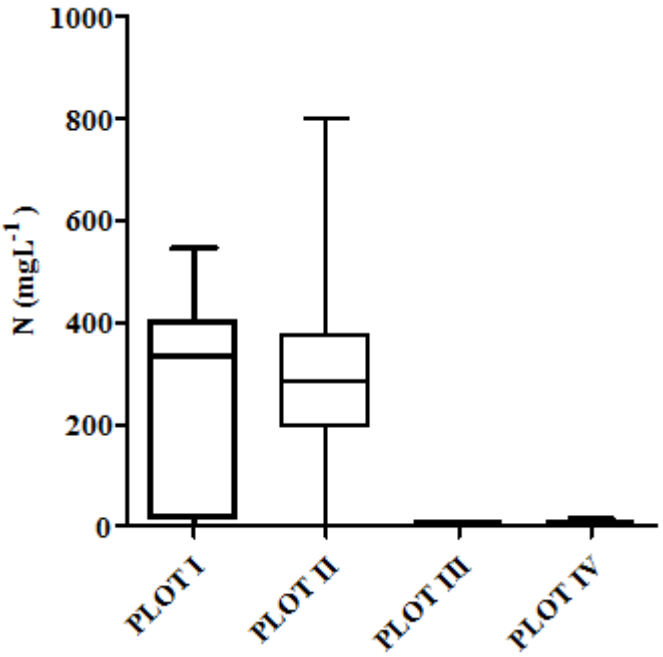


Figure 5. 16: Box and whisker plots showing variations of values and average concentrations of Nitrogen (Plot I- Open grassland; Plot II- Vineyard; Plot III- Mt Forest and Plot IV- Fynbos)

From the observations of the concentrations of pollutants in the plots, the differences amongst the land-cover types and the concentrations of the pollutants are so clearly marked for phosphorus and not the same for nitrogen and TSS. Table 5.4 indicates the pollutants whose concentration levels were notably dominant on each land-cover as represented by the experimental plots. High concentrations of nitrogen in water were usually the result of human activities. Decaying organic matter, including vegetation such as vineyard clippings, can produce nitrogen rich leachate, particularly after pruning takes place in the fields. Regardless of the land-cover type nitrogen levels showed a pattern with elevated levels of organic matter in winter months, when leaching from the soil was greatest, and lower levels in summer months.

Table 5. 2: Pollutant concentration values that dominate on each land-cover.

Plot number	**Land-cover**	**Dominant pollutant**
Plot I	Grassland	*NO_3-N*, and *Cl*
Plot II	Vineyard	*N*, and *P*
Plot III	Mountain Forest	*TSS*
Plot IV	Fynbos	*NO_3-N*

In the case of Kuils-Eerste River catchment, the knowledge gained from the experimental plots informs our understanding of how land-cover controls the concentrations of pollutants and this is important. The significance of these results lies in the fact that they indicate the variability of pollutant concentration and the contribution from each land-cover type. The plot results contribute towards the achievement of the objectives of the study specifically to establish the contribution of each land-cover type to the pollutant loads at the catchment scale.

CHAPTER 6

WATER QUALITY FOR VARIOUS LAND-COVER TYPES AT SAMPLED SITES

6.1 Introduction

The present chapter focuses on the water quality parameters as determined from the laboratory analysis of the samples of surface water collected from the different land-covers occurring within the Kuils-Eerste River catchment over the study period, 2007 and 2008. Results of experimental plots presented in Chapter 5, show that the generation and distribution of the pollutants dependent upon the land-cover type. This chapter examines how water quality varies with land-cover type at the catchment scale. This chapter further examines the quality of water as represented by the samples collected during storm events and develops a water quality profile for the different land-cover types. Information on how water quality varies with land-cover type is necessary for the modelling of how pollutants are distributed and loaded into the river system.

The main question being addressed in this chapter is: is it possible to predict the water quality of runoff from an area with a specific/uniform land-cover type? Other studies (Naranjo, 1998; Butcher, 2003; Chow and Yusop, 2008) have investigated surface water pollution and water quality related problems using GIS models to make predictions of the magnitude of the problem. This chapter includes data sets generated in Chapter 4 which looked at the land-cover characteristics of the catchment and Chapter 5 which focused on the experimental plots. The experimental plots focused on four land-cover types. Essentially, it is intended that the knowledge generated through this study will contribute to the development of a plan for pollution management for the Kuils-Eerste River catchment.

6.2 Water quality standards (WQS)

In this study, the quality of water is described in terms of the concentration of five organic and inorganic parameters present in the water, together with certain physical

characteristics of the water. These parameters were determined by in situ measurements and laboratory analyses of water samples. The main elements of water quality monitoring exercise conducted are on-site measurements, the collection and analysis of water samples, the study and evaluation of the analytical results, and the reporting of the findings. The approach compares well to other studies as indicated in Table 6.1. Water quality is determined by assessing three classes of attributes: biological, chemical, and physical. There are standards of water quality set for each of these three classes of attributes.

Table 6. 1: Water quality parameters considered in similar studies

Water quality parameters	Studies in which used
Total Suspended Solids, Phosphorus, Chloride, Nitrogen and NO_3-N	Kloppers (1989) *Urban Storm water runoff: A water quality study.* Simpson (1991) *Quantification of the land-use effects of runoff water quality in selected catchments in Natal.* Simpson (1992) *Urban runoff pollution research in Natal.* MacKay and Lord (1993) *The impact of Urban Runoff on the Water quality of the Swartkops Estuary: Implications for Water quality Management.* Hoffmann (1995) *Non-point source pollution in the Hennops River valley.* Pearce and Schumann (1997) *The effects of land cover on Gamtoos estuary water quality.* Simpson (1998) *Collection and evaluation of runoff water quality from a disused feedlot in KwaZulu- Natal.* London *et al* (2000) *The quality of surface and groundwater in the rural Western Cape with regard to pesticides.* Grobicki (2001) *Integrated catchment management in an urban context the Great and little Lotus rivers, Cape Town.* Pegram and Gorgens (2001) *A guide to non-point source assessment.* Quibell *et al (*2003) *Development of a non-point source assessment guide: test cases studies.* Dallas and Day (2004) *The effects of water quality variables on aquatic ecosystems.*

A range of representative WQ variables relating to those studied in the catchment are shown in Table 6.2 based on the acceptable concentration limits for the water to be considered as polluted and unfit for specific use by the different international organisations. The South African standards (SANS241) for acceptable water quality are also given for comparison purposes and the DWA standards used in the study.

Table 6. 2: Water quality variables and standards used for the assessment of the quality of water in the catchment.

Parameter	**Units**	**DWAF standard**
NO_3-N	mgL^{-1}	<0.5
Phosphorus	mgL^{-1}	<5
Chloride	mgL^{-1}	0.2
Nitrogen	mgL^{-1}	<6
Total suspended solids	mgL^{-1}	<100

6.2.1 Water quality sampling form the land-cover types

Based on the 36 - land-cover classification types determined the sites for sampling purposes were identified. These were identified based on the distribution of the rain-fall events, their occurrence and distribution. Figure 6.1 shows the sampling points used in the collection of data. The points were considered based on their accessibility and being representative of the land-cover types. The eastern part of the catchment could not be sampled as this is mountainous with very steep slopes and therefore in-accessible.

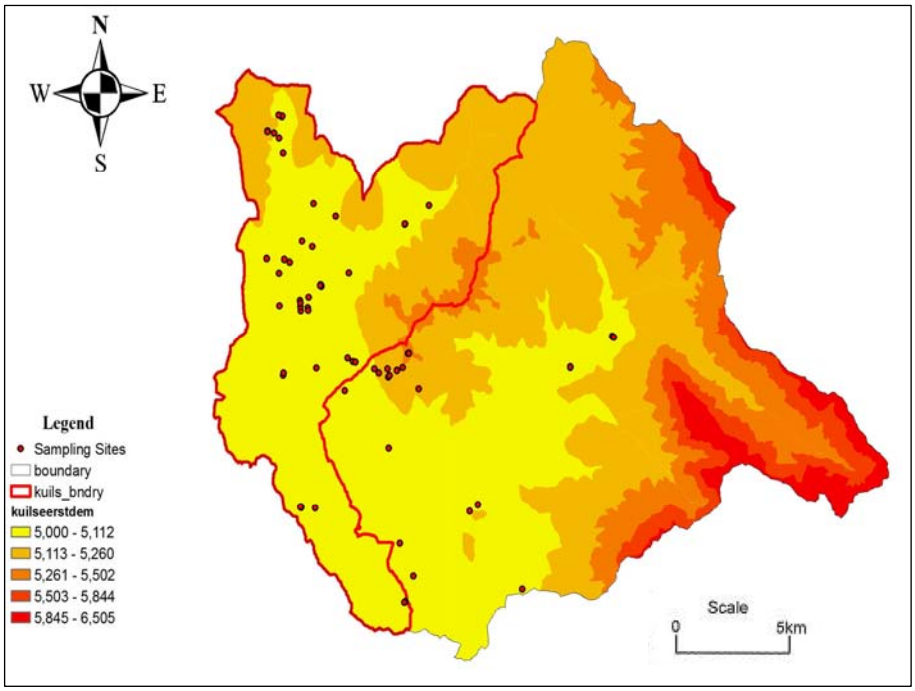


Figure 6. 1: Sampling points within the catchment.

Table 6.3 presents the land-cover types covered during water sampling and the number of samples for each of the land-cover types. A total of 125 sites were used for the sampling with the land-cover types representing 60.4 % of the total catchment area.

Table 6. 3: Some of the selected sampling sites with percentage coverage of land-cover used in the study

Land-cover	**Number of sites**	**Land-cover as a % the catchment**
Mt Forest	6	5
Fynbos	5	12.5
Grassland	28	1.8
Impervious Surfaces Land-cover	9	0.6
Open Vineyard/Coarse Rock Pebbles	9	5.8
Dense/Grassy/Vineyard	12	20.4
Arterial Roads/Main Roads	6	0.4
Minor Roads	5	2.9
HDR Formal Suburb	3	1.5
MDR Formal Suburb	8	7
HDR Informal Township	4	0.2
Commercial Mercantile	11	0.2
Cemeteries	1	0.1
Commercial Institutional	2	0.2
Industrial	16	1.8
Total	**125**	**60.4**

6.2.2 Event mean concentration values (EMC)

Table 6.5 shows the event mean concentration values of the chemical parameters under study. The values were obtained as averages for several samples collected within a specific land-cover during the study period. This information is used in the modelling part and the method used to obtain these is stated in section 3.3.4 of Chapter 3. The values are not for point samples but are a representative spatial value of the quantity of the pollutant considered for the land cover type. The value through the GIS tool is then represented as a spatial value on the basis of the land cover type.

The standard error of the mean for all the samples is shown in the following Figure 6.2. The bars are standard error mean bars (SEM) for the five pollutants. The differences are not significant as shown on the error bars with the same number of land-cover types though the maximum, values of the pollutant concentration vary with the least being Total phosphorus and the highest being Total nitrogen. The SEM quantifies how accurately the true mean of the pollutants is as a representative value. Additional information is given in Table 6.4 showing the statistics relating to the mean values used in the study. It should be noted also that the number of cases being dealt with here correspond the number of land cover types and therefore values of EMC assigned appear to be for one land cover. The values that relate to the land cover are therefore average values for the specific land cover and any similarity is not an indication that they are derived from same values based on the number of samples used to compute the mean value.

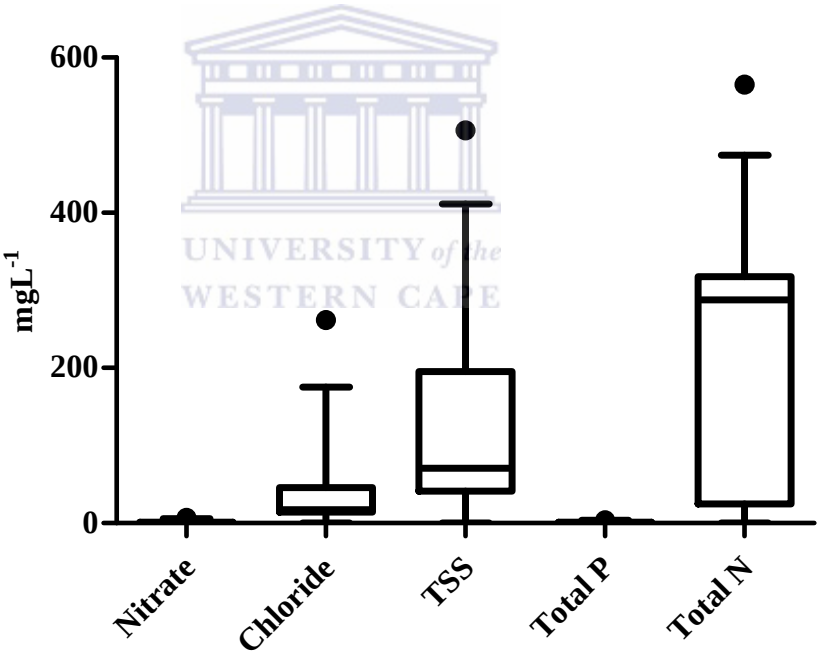


Figure 6. 2 Box and whisker plots showing variations of values and average concentrations of sstandard error of the mean for all EMC values of the pollutants

Table 6. 4: Statistics for the water quality parameters

	Nitrate	Chloride	TSS	Total P	Total N
Number of values	36	36	36	36	36
Minimum	0	0	0	0	0
25% Percentile	0.1	10	40	0.2	20
Median	0.7	20	70	0.3	300
75% Percentile	1	50	200	1	300
Maximum	7	300	500	4	600
Std. Deviation	1	60	100	1	200
Std. Error	0.2	10	20	0.2	30
Lower 95% CI	0.5	30	80	0.4	200
Upper 95% CI	1	70	200	1	300

Table 6. 5: Composite Table of EMC Values for the Land-cover Types in the Catchment.

Land use/Land Cover	Nitrate	Chloride	TSS	P	T N
Mountain Forest*	1.01	16.27	196.17	0.25	7.50
Riparian Forest/Natural Forest*	1.01	16.27	196.17	0.25	7.50
Dense Scrub*	1.01	16.27	196.17	0.25	7.50
Fynbos	1.17	16.24	45.80	0.19	5.80
Grassland	1.01	36.08	66.90	3.32	319.86
Impervious Surface	1.21	16.87	70.56	0.24	317.59
Railway Line*	0.00	0.00	0.00	0.00	0.00
Impervious Surface/Bare Ground*	1.21	16.87	70.56	0.24	317.59
Bare Rock*	1.21	16.87	70.56	0.24	317.59
Open Vineyard/Hard Rock	0.51	58.11	61.44	0.08	367.22
Open Area/Barren Land	0.69	159.80	68.00	0.03	50.00
Improved Grassland/Veg Crop	0.69	157.29	234.50	3.78	295.50
Buildings/Impervious	1.21	16.87	70.56	0.24	317.59
Dense / Grassy Vineyard	1.79	48.21	96.25	2.12	249.09
Fallow/Open Vineyards	1.79	48.21	96.25	2.12	249.09
Recreation Grass/Golf Course	0.03	261.60	9.00	0.12	565.00
Freeways/Express Ways	0.08	12.19	236.50	0.15	458.00
Arterial Roads/Main Roads	0.12	34.94	394.29	0.57	147.69
Minor Roads	0.13	29.40	75.00	0.58	329.34
Sandy	0.00	0.00	0.00	0.00	0.00
Water bodies	0.00	0.00	0.00	0.00	0.00
HDR Formal Suburb	0.23	33.43	99.67	1.27	420.33
MDR Formal Suburb	0.17	21.03	40.63	0.29	287.65
LDR Formal Suburb	0.17	21.03	40.63	0.29	287.65
HDR Formal Township*	0.22	12.27	41.80	0.31	294.34
MDR Formal Township*	0.22	12.27	41.80	0.31	294.34
LDR Formal Township*	0.22	12.27	41.80	0.31	294.34
HDR Informal Township	0.10	13.62	35.07	0.39	177.00
MDR Informal Township	1.85	134.42	321.00	3.53	24.50
MDR Informal Squatter Camps	0.18	18.11	41.02	0.30	289.88
LDR Informal Squatter Camps	1.85	134.42	321.00	3.53	24.50
Commercial - Mercantile	6.65	26.25	112.18	0.31	258.14
Commercial - Institutional	0.12	11.04	108.00	0.16	337.27
Industrial	0.71	38.63	192.63	2.13	285.18
Cemeteries	0.69	16.78	506.00	0.14	3.00
River	5.59	150.45	24.84	1.80	383.17
Std Error	0.20	10.00	20.00	0.20	30.00

Note:* Denotes values obtained from literature review (Butcher, 2003; Naranjo, 2003; Chow and Yusop, 2008). HDR = High Density Residential, MDR = Medium Density Residential and LDR = Low Density Residential.

6.2.3 Variations of Water Quality with land-cover

The results (Table 6.5) show that for nitrogen the land-cover types that have high concentration values are the recreation grass/golf course, freeway/ expressways, HDR formal settlements, commercial institutional and open vineyards.

Human activities are the major contributing source of the high concentrations of nitrogen. In urban areas overuse of fertilizer on lawns, gardens and playing fields results in high nitrate levels in surface water. This surface water then drains into streams taking the nitrate with it. The following observations explain the contributions of the levels of concentrations of the pollutants in the study area.

- Broken or overflowing sewage systems, which are a potential source of high nitrogen in HDR formal settlements.
- Decaying organic matter, including vegetation such as grass clippings on recreation grass/golf course and open vineyards, which can produce nitrogen rich leachate, particularly when stockpiled in large quantities.
- Some industrial/commercial wastes and/or contaminated storm water runoff, such as food production residues/wastes, can contain high nitrogen concentrations.
- Vehicle exhaust emissions are high in nitrous oxide. Therefore, main vehicle thoroughfares and freeway/ expressways have storm water with elevated nitrogen (4.58 mg L^{-1}) due to particles settling out from the air.

The concentration of total suspended solids was relatively high in the following land-cover types, cemeteries (5.06 mg L^{-1}), arterial roads/ main roads (3.94 mg L^{-1}), LDR informal squatter camps (3.21 mg L^{-1}) and MDR informal townships (3.21 mg L^{-1}).

Chloride concentrations were relatively high on the following land-cover types, recreation grass/ golf course (2.61 mg L^{-1}), open area/barren land (1.59 mg L^{-1}), and improved grassland/vegetation crop (1.57 mg L^{-1}). NO_3-N event mean concentration levels were high on the following land-cover types, commercial mercantile (6.7 mg L^{-1}) and river (5.6 mg L^{-1}). The phosphorus concentration mean values recorded high values on improved grassland/ vegetation crop (3.9 mg L^{-1}), MDR informal township

(3.5 mg L^{-1}) and LDR informal squatter camps (3.5 mg L^{-1}). Surface runoff may also contribute soil particles into waterways during rainfall events, particularly from areas of disturbed soil and those where market gardening is taking place. The major contributing activities are listed below:

- Discharges of sewage from overloaded or failed sewerage infrastructure in LDR informal township and LDR informal squatter camps.
- Detergent discharges from domestic or commercial sources associated with cleaning of vehicles, equipment or products.
- Urban storm water runoff containing fertilisers, animal wastes (e.g. dog poo) and plant material.

The following Figures 6.3, 6.4 and 6.5 show the distribution of the pollutants across the catchment depending on the land-cover type. The maps show the various water quality parameters and how they vary with land-cover type. Each water quality parameter was considered 'desirable', moderately desirable' or 'not desirable' based on the values obtained compared to the guideline limit values. The use of these terms simply explains whether a value is within a given range or exceeds that range. Where the value is below the guideline then the conclusion was to consider it desirable in terms of management strategies that might be taken into consideration.

In the Kuils-Eerste River catchment 19 land-cover types have nitrate concentrations above the water quality guideline limit (Figure 6.3). The mostly affected land-cover types are commercial mercantile (6.65 mg L^{-1}), medium density residential (MDR), informal townships, low density residential (LDR), informal squatter camps (1.85 mg L^{-1}), dense/grassy vineyards, and fallow open vineyards (1.79 mg L^{-1}). The remainder have concentrations that range from 0.69 mg L^{-1} to 1.69 mg L^{-1}. Nitrate in water is derived from three primary sources: rainfall, decomposition of soil organic matter, and nitrogen amendments (fertilizers, manures, etc.). Ideally, most of the nitrate in the soil is removed by the harvested crop. Problems occur when the crop does not remove sufficient nitrate, and the excess is flushed into streams after harvest, or when no growing roots are present to intercept it as it moves toward the tile.

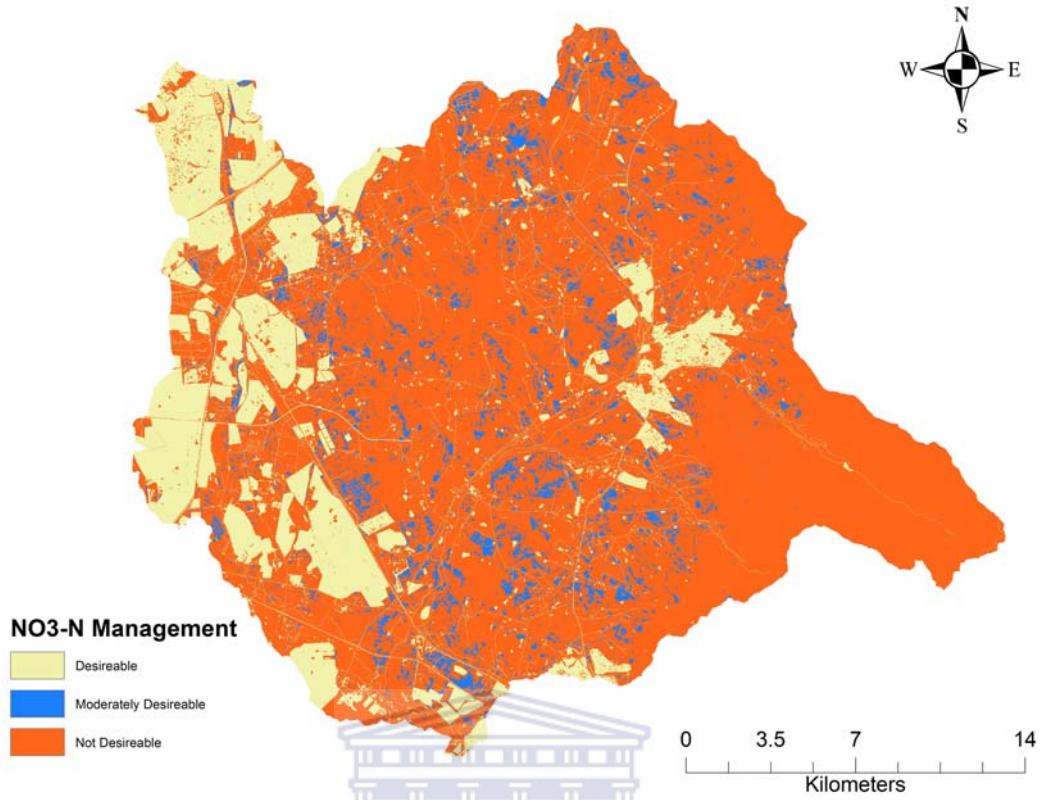


Figure 6. 3: Model output results showing variation of NO_3-N concentration throughout the catchment based on land-cover type

The total suspended solids (TSS) concentration is a measure of the amount of material suspended in water. The results from the study of the Kuils-Eerste River catchment indicate that 12 out of 36 land-cover types have TSS concentration values above the water quality guideline limit (Figure 6.4). The land-cover types with values above the limit are mountain forest, riparian forest/natural forest, and dense scrub with 1.96 mgL^{-1} all, improved grassland/vegetation cover with 2.34 mg L^{-1}, freeway/express ways with 2.36 mg L^{-1}, arterial roads/main roads with 3.94 mg L^{-1}, MDR informal townships and LDR informal squatter camps with 3.21 mg L^{-1}, commercial mercantile and commercial institutional with 112.18mgL^{-1} and 1.08 mg L^{-1} respectively and finally cemeteries that indicate 5.06 mg L^{-1}.

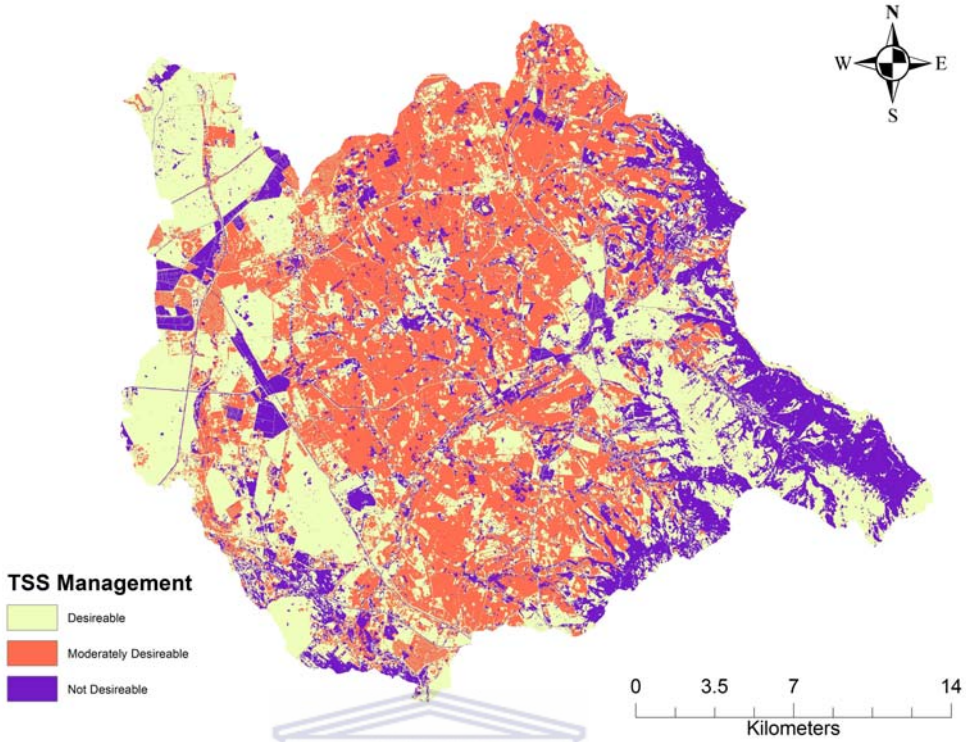


Figure 6. 4: Model output results showing variation of TSS concentration throughout the catchment based on land-cover type

Chloride concentrations were higher in informal residential areas (1.34 mg L^{-1}) than in formal residential areas (3.34 mg L^{-1}). Agricultural related land-cover types recorded concentration levels which also surpassed the water quality guideline limit. Recreation grass/golf course carried the highest concentration of 2.16 mg L^{-1}. Only three land-cover types had chloride concentration below the water quality guideline limit and 33 land-cover types showed levels of concentration above the limit (Figure 6.5).

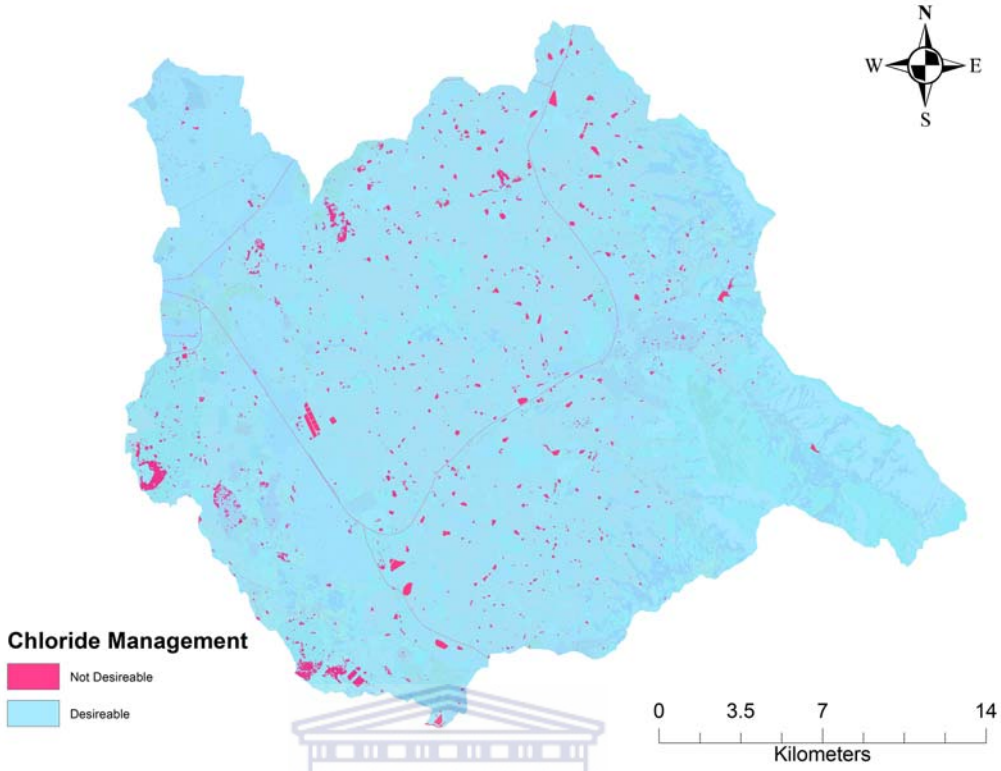


Figure 6. 5: Model output results showing variation of chloride concentration throughout the catchment based on land-cover type

Ten land-cover types had nitrogen concentration values below water quality guideline limits of nitrogen and 26 land-cover types registered values higher than the water quality guideline limits (DWA, 1996) (see Table 6.2). The highest mean values were recorded for recreation grass/ golf course with 5.65 mg L^{-1} with a standard error mean of 30. The land-cover types with values less than the guide-line limits were also below the SEM determined for the pollutant. Figure 6.6 shows the distribution of nitrogen throughout the catchment depending on the land-cover type.

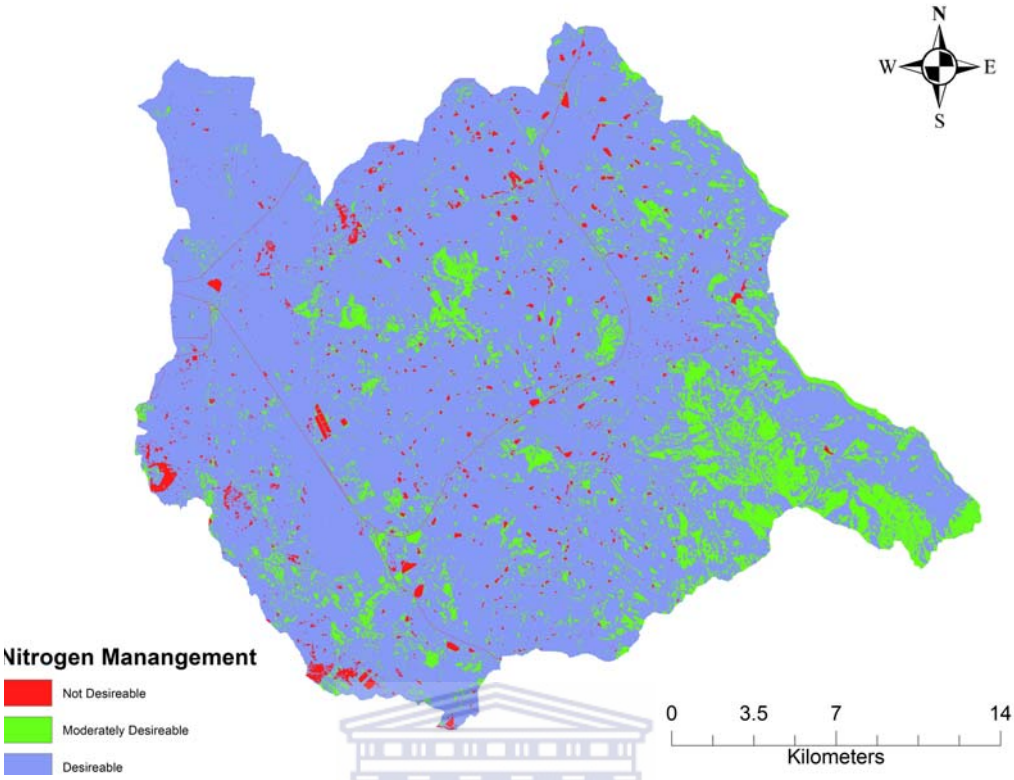


Figure 6. 6: Model output results showing variation of nitrogen concentration throughout the catchment based on land-cover type

6.3 Summary remarks

This work has focused on the determination of water quality profile for the catchment based on the land-cover type distribution described in this study. It is conceded that variations do exist relating to the spatial distribution of the pollutants. The variations compare well with results obtained in other studies where the acceptable standard limit was based on the one proposed by DWA (1996).

The water quality standards formed the comparative criteria and the results obtained compared well with those found in other research conducted in the country by Kloppers, 1989; Simpson 1998; Lord and MacKay, 1993; Hoffman, 1994; Pearce and Schumann, 1997; Grobicki, 2001; Pegram and Görgens, 2001, Quibell *et al*., 2003 and Dallas and Day, 2004. Table 6.6 shows a summary of surface water quality in different areas as compared to Kuils-Eerste River catchment. Unfortunately no standard set of water quality variables has been used in South African studies. In the Kuils-Eerste River catchment , however, the lack of overland flow means that many pollutants are filtered out in the sandy soils giving a poor quality runoff throughout the

year irrespective of whether its base-flow or storm-flow conditions. Kuils-Eerste River catchment thus has more pollution within the catchment though not all of it finds its way into surface runoff. The nutrient concentrations in Alexandria vary significantly with very high concentrations at times (NO_3-N = 5.25 mg L^{-1}). This level of contamination is not even comparable to that of the HDR Informal Squatter Camps in the Kuils-Eerste River catchment (0.18 mg L^{-1}).

Table 6. 6: A comparison between Kuils-Eerste River catchment surface water quality and other South African studies

Determined (mgL^{-1})	**Khayelitsha**			**Johannesburg**			**Pinetown**	**Shembe**	**Mitchells Plain**	**Atlantis**		**Motherwell**
	Shacks	**Serviced sites**	**Formal housing**	**Montgomery Park**	**Hillbrow**	**Alexandria**				**Residential**	**Industrial**	
Cl	291	164	191	31	120	87	9			158	236	
NO_3-N	22.8	13.6	4.05	9.93	<0.1	2.88	2.79	4.84	8.98	5.12	<0.1	5.2
P	<0.05	0.10	<0.05			3.68	0.57	2.39	0.02	0.05	0.10	0.28

CHAPTER 7

MODELLING OF POLLUTANT LOADING IN SURFACE RUNOFF

7.1 Introduction

In order to establish the contribution of each land-cover type to the pollutant loads at the catchment scale and to determine how each of the different land-cover types affects the quality of surface runoff, an understanding of the quality of water was necessary. This chapter focuses on contaminant loading estimation, which has one of the highest priorities in environmental protection policy in many countries including South Africa (Allen and Herold, 1988, Boyacioglu, 2006, Pegram *et al.*, 1990; Simeonov *et al.*, 2002). The estimation of pollution loads and runoff volumes using land-cover information is investigated.

The results of the application of the GIS tool for estimating runoff and pollution loading are divided into two sections, a) estimation of runoff and b) contamination loading estimation.

An approach which links the NSP models with GIS capabilities was used with the *RINSPE* model by Thomas and Chingombe (2010). This model offers useful visualization capabilities. The data layers are processed using the analytical capabilities of a cell-based GIS. The results presented below are in two sets, the first obtained using the *RINSPE* and the later using *N-SPECT* models. The model assumes that land-cover and land-cover-related properties do not vary within the period being considered during the analysis.

7.2 *RINSPE* Model results

7.2.1 Estimation of surface runoff

The major outputs from the *RINSPE* model are annual estimates of surface runoff volume and infiltration, pollutant loads in surface runoff, and pollutant concentration of each chosen pollutant.

The first result to be discussed is the Curve Number (CN) that were mapped as estimates using land cover/use types by the model (Figure 7.1). The central region has CN values between 62 and 68 while the lowest values were in the Jonkershoek area ranging from 30 to 37. Each value was determined based on several factors, most important being the hydrologic soil group, ground cover type, antecedent runoff condition and whether impervious areas were connected directly to drainage system. These values indicate the potential that each land-cover has for the transformation of rainfall into runoff. A high curve number means that the land-cover types within that category have the potential to generate high runoff volumes whereas a low curve number for the specific land-cover means low runoff and high infiltration. Some of the areas have high CN because they are urban areas or they have low CN due to the dry soils found on these parts of the catchment. The CN is a function of the hydrologic soil group.

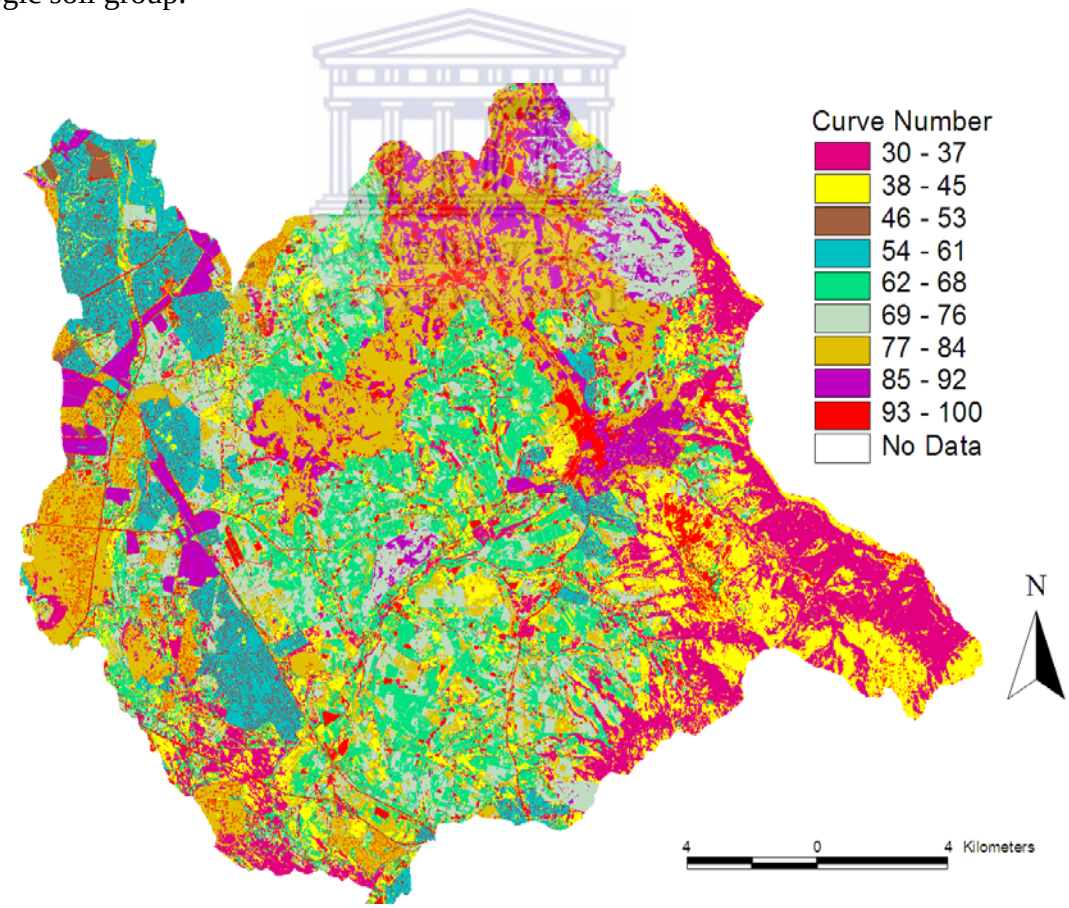


Figure 7. 1: Model output results showing Curve number grid of the catchment

Figure 7.2 presents the annual runoff for 2006 estimated using the curve number, and rainfall. The estimated runoff volume for the year 2006 shows that several land-cover types had values between 0.09 m^3 yr to 13.30bm^3 yr per pixel (10m x10m). The greater part of the western area in the catchment had runoff volume estimated between 21.00 m^3 yr to 27.83 m^3 yr.

Figure 7.2 shows a general decrease of runoff from the eastern part of the catchment towards the western part with the lowest rainfall values being registered within the range of 250 m^3 yr to 500 m^3 yr. The areas with the highest values of precipitation also account for the highest concentration values of the runoff.

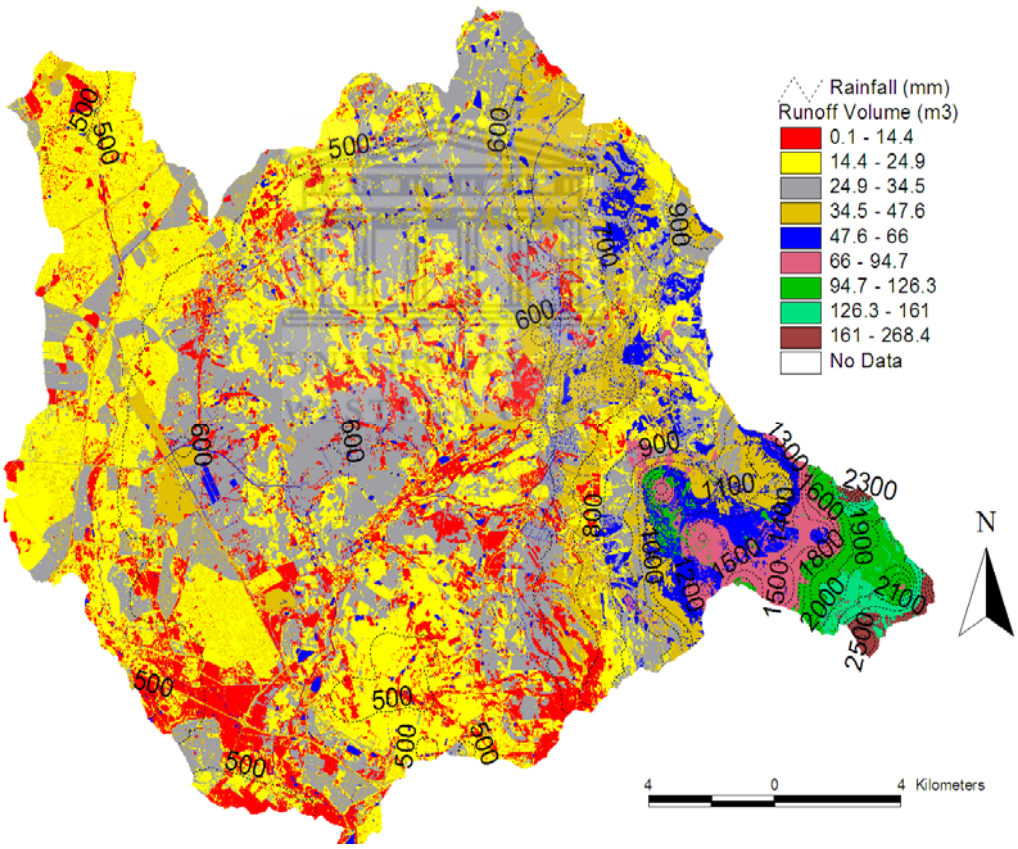


Figure 7. 2: Model output results showing estimated annual runoff volume (m^3 /yr) per pixel for the hydrological year 2006- 2007. The values show volume of runoff produced per pixel

The map (Figure 7.3) shows the estimated runoff volume as it accumulates in the river channels. The result is based on the runoff accumulation grid developed using the digital elevation model of the catchment. The values of accumulated runoff volume

for every pixel are shown in Figure 7.3. The map shows high volume in the river between Stellenbosch and the confluence of Kuils River and Eerste River. There is a gradual increase in volume of runoff as one move downstream.

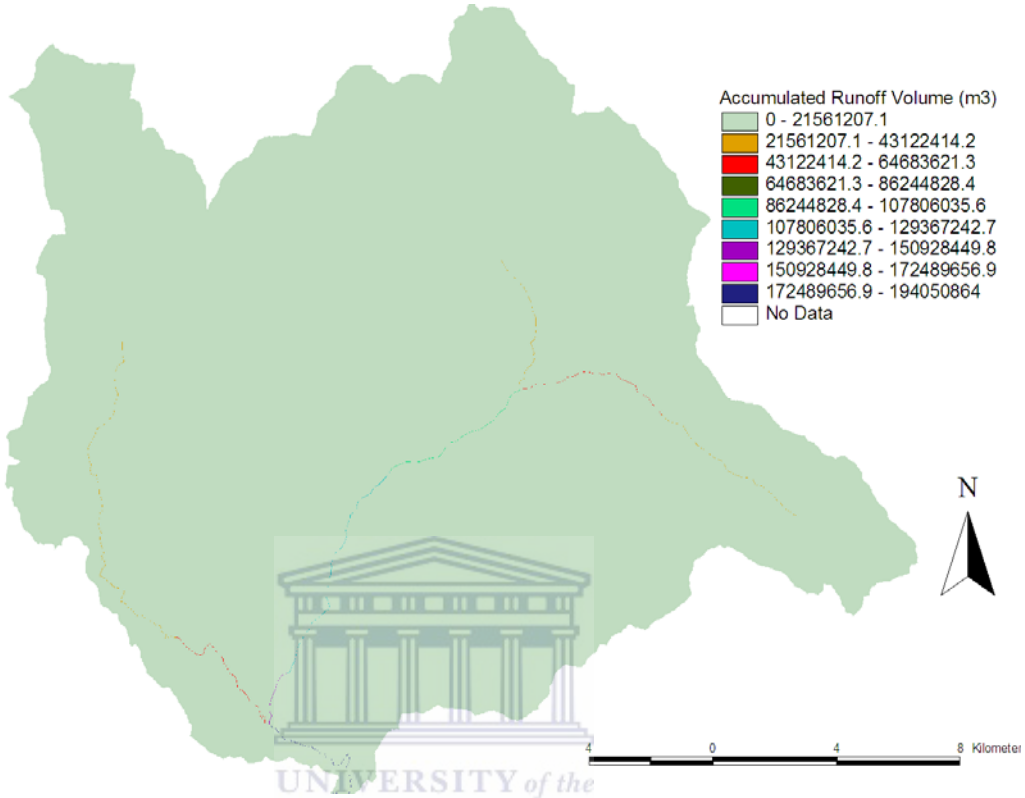


Figure 7. 3: Model output results showing accumulated runoff volume (m^3 /yr) along the river for the catchment

7.2.2 Spatial distribution and accumulation of pollutants

The spatial variation of nitrate distribution estimated using the method detailed in Section 3.3.4 and Section 3.3.5 are presented in Figure 7.4. The distribution map shows high values of nitrate concentration ranging between 1.06 kg yr to 1.17 kg yr per pixel. The least affected zone within the catchment falls within the western part and the values of concentration range between 0kg yr^{-1} and 1.06kg yr^{-1}per pixel.

The values that are shown by the spatial distribution of nitrate (Figure 7.4) were used to model the amount of the pollutants that would end up in the river system. This gives the loading rates of the same pollutant (Figure 7.5). The value of nitrate in-

creases with the contribution from each land-cover type being added to the load attaining highest values (1.16 kg yr per pixel) as the river enter the estuarine zone.

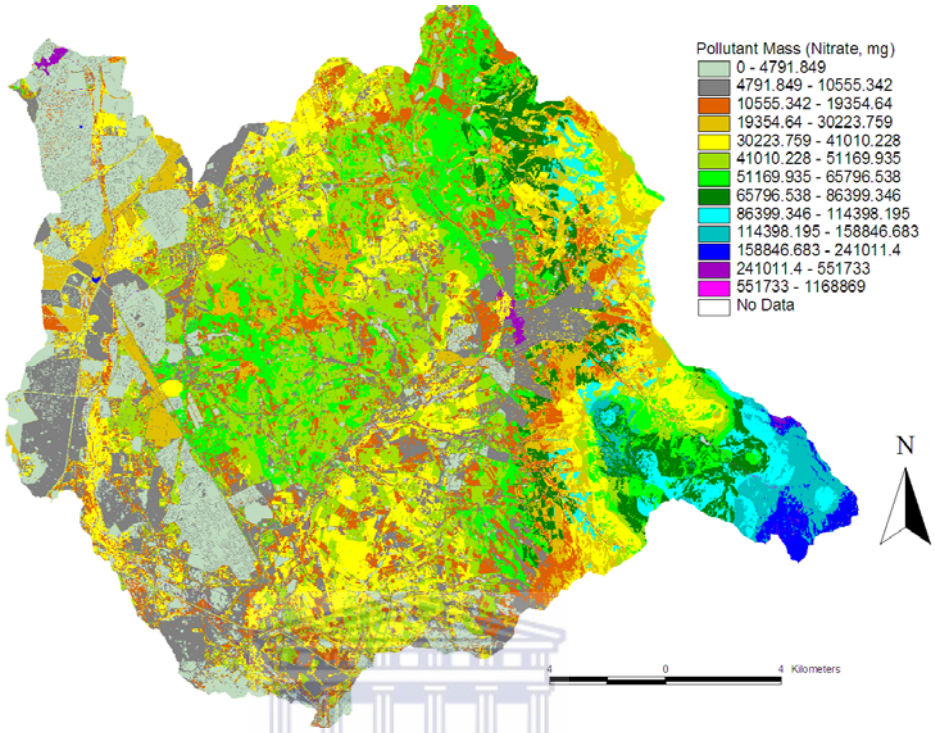


Figure 7. 4: Model output results showing Nitrate (mg/ yr) distribution per pixel across the land-covers types in the catchment

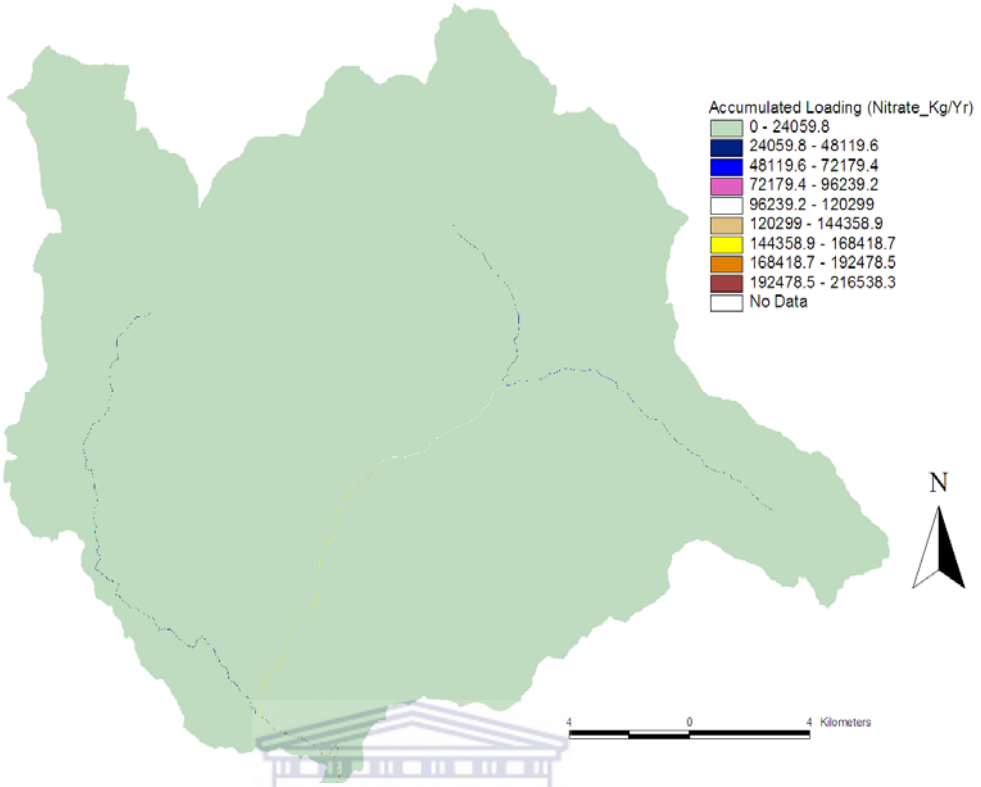


Figure 7. 5: Model output results showing loading rate for Nitrate in kg /yr per pixel along the river network in the catchment

Following the results generated for nitrates, the next pollutant to be modelled was nitrogen. The spatial distribution of nitrogen across the catchment was based on the land-cover type and is shown in Figure 7.6. The pattern of distribution is divided into three zones for easier understanding of the magnitude of the spatial coverage. The highest concentrations are associated with agricultural activities while low concentrations occur on mountains around Jonkershoek. The dominant zone is the central part of the catchment with values ranging between 6.65 kg/yr to 8.50 kg/yr per pixel. The south-eastern zone has values that range between 3.90 kg/yr to 5.63 kg/yr pr pixel and the dominant land-cover type is the vineyard. The results are determined based on the pixel values which relate to land-cover type.

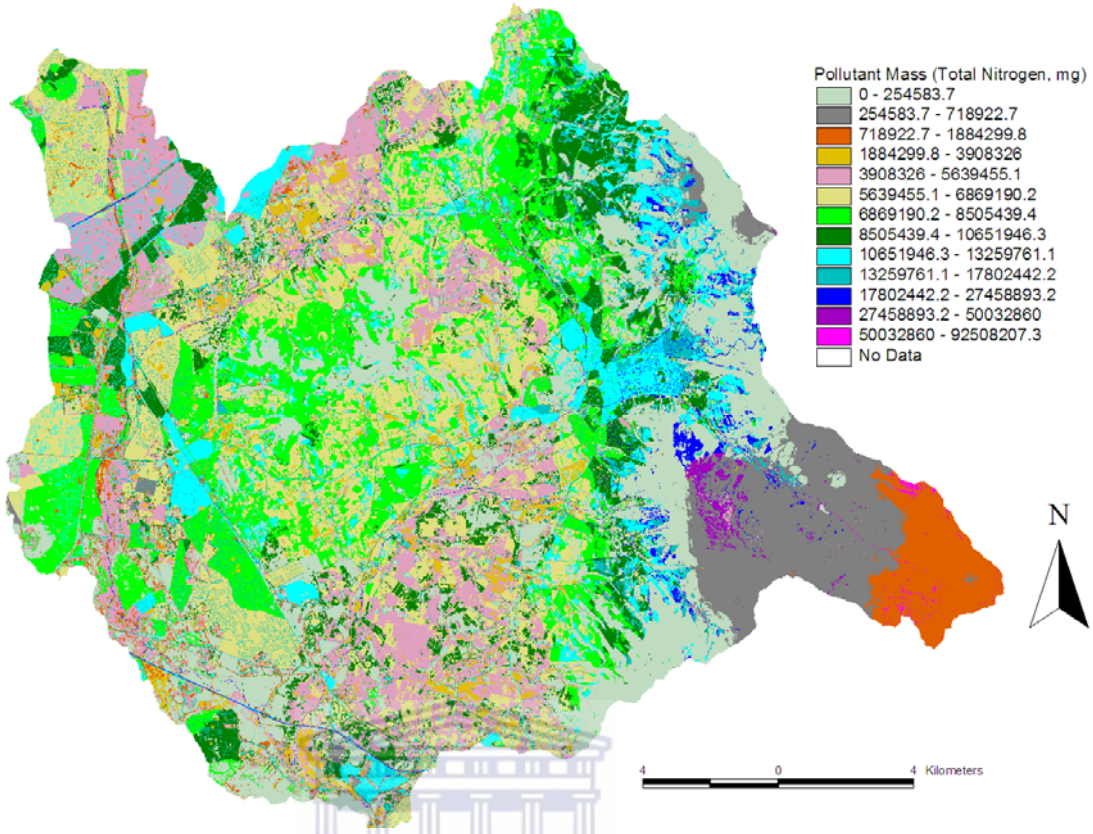


Figure 7. 6: Model output results showing Nitrogen (mg /yr^{-1} per pixel) distribution for the land-cover types in the catchment

The accumulation values of nitrogen along the river channel are presented in Figure 7.7. High values are generated to the west of Stellenbosch, these gradually increase downstream, and at the confluence with the Kuils River, the values increase because of the combined input from the two tributaries (Kuils and Eerste Rivers).

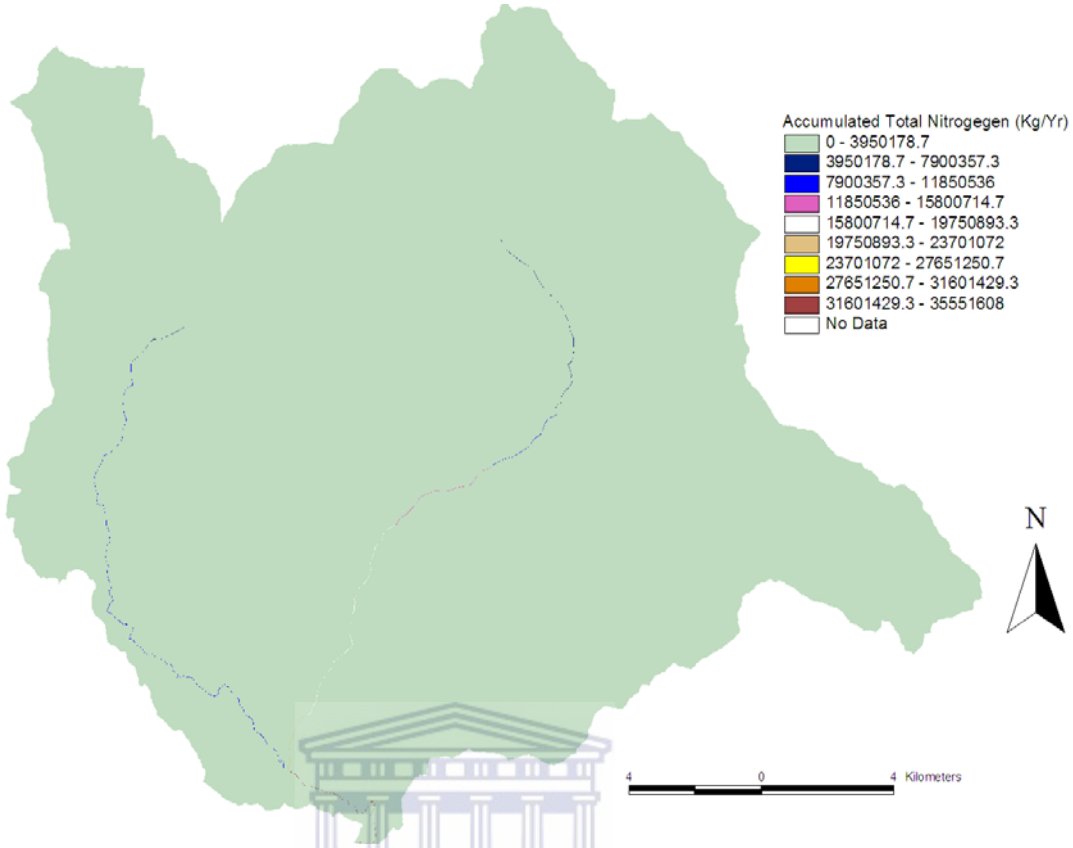


Figure 7. 7: Model output results showing Nitrogen (kg/ yr) loading in the river network

Figure 7.8 shows the results of the spatial distribution of phosphorous in the catchment. Several zones are indicated by the variations of concentration of phosphorus. The zone that lies along the mountainous areas east of Stellenbosch recorded the least values of the pollutant. This area is mountainous and no agricultural activities are carried out due to the ruggedness of the terrain. The greater part of the central zone has load values ranging between 3.90 kg/yr to 1.78 kg/yr per pixel. These values are confined to the areas of vineyard production and decrease as the urban areas encroach into these agricultural areas. These spatial variations are explained by the presence of various land-cover types and their responds to variations in runoff.

Phosphorus accumulation shows an increase of the pollutant along the river course especially along Eerste River before the confluence with Kuils River (Figure 7.9). The accumulation is related to the land-cover which is predominantly agricultural, where the use of fertilizers is well spread. Where the Kuils River passes through is predominantly a residential area and the levels recorded are not high.

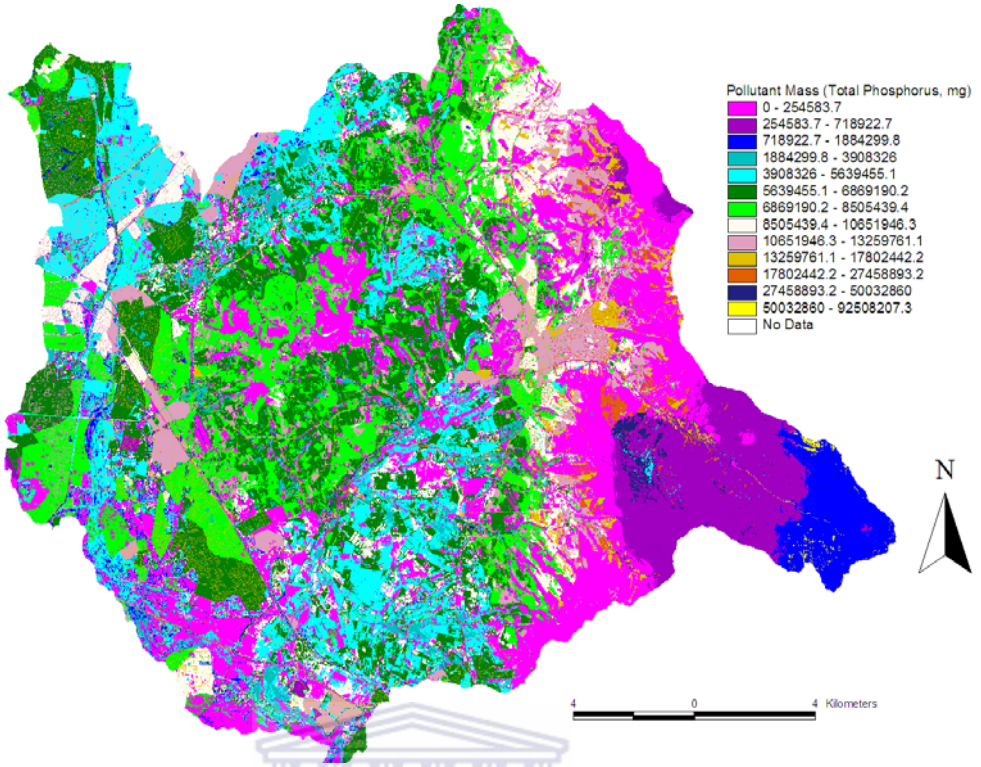


Figure 7. 8: Model output results showing the spatial distribution of phosphorous (mg/ yr per pixel) across the catchment with values indicated per pixel

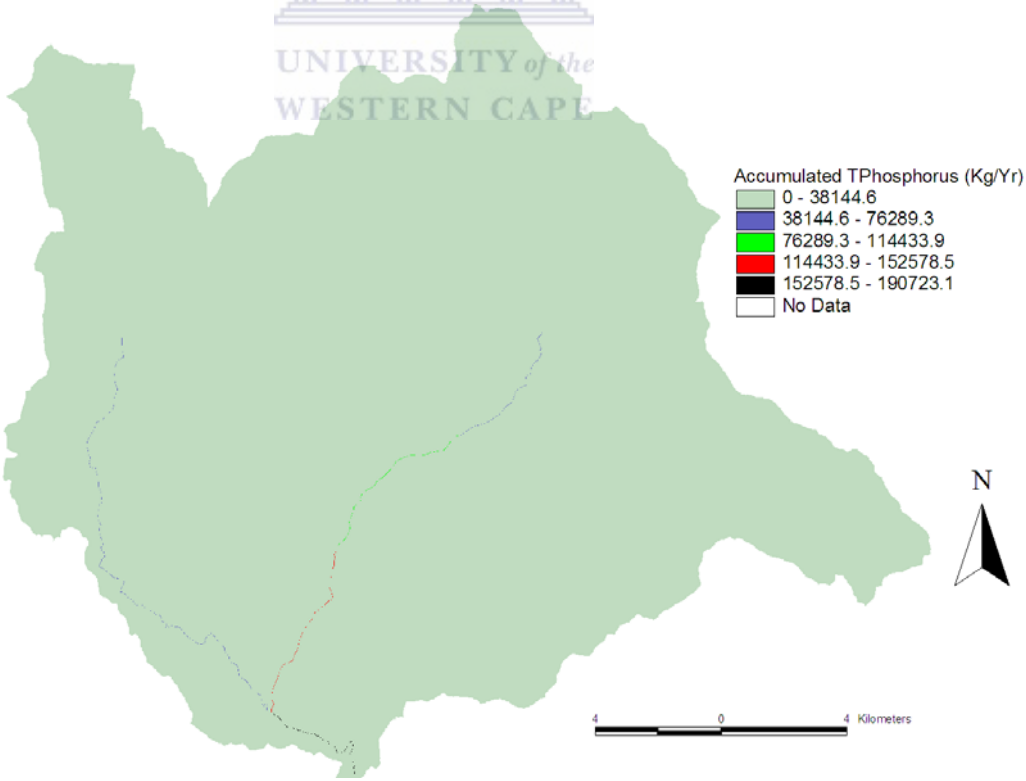


Figure 7. 9: Model output results showing Phosphorus (kg/ yr per pixel) loading along the river network of the catchment

Chloride distribution across the catchment is displayed in Figure 7.10 with the spatial characteristics indicating that the eastern part has low loads while the central part has moderate loads. High values are found within the extreme flanks to the east and west of the catchment.

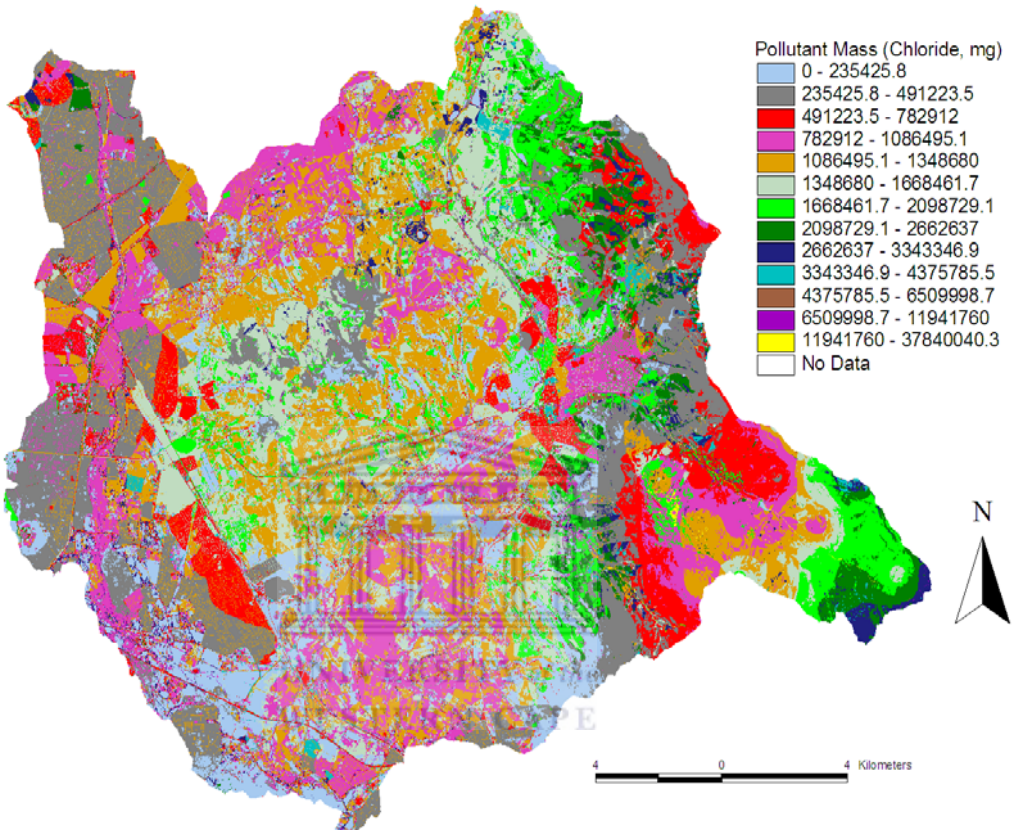


Figure 7. 10: Model output results showing Chloride (mg/yr per pixel) spatial distribution across the catchment with values indicated per pixel

The accumulation of chloride in the river is shown by the chloride accumulation map (Fig 7.11). High values occur on the Eerste River after Stellenbosch town and towards the confluence with the Kuils River. There are industrial activities around Stellenbosch as indicated by the land-cover type map developed for the study and these industries probably generate considerable quantities of the pollutant and during rainfall events these are washed off by runoff.

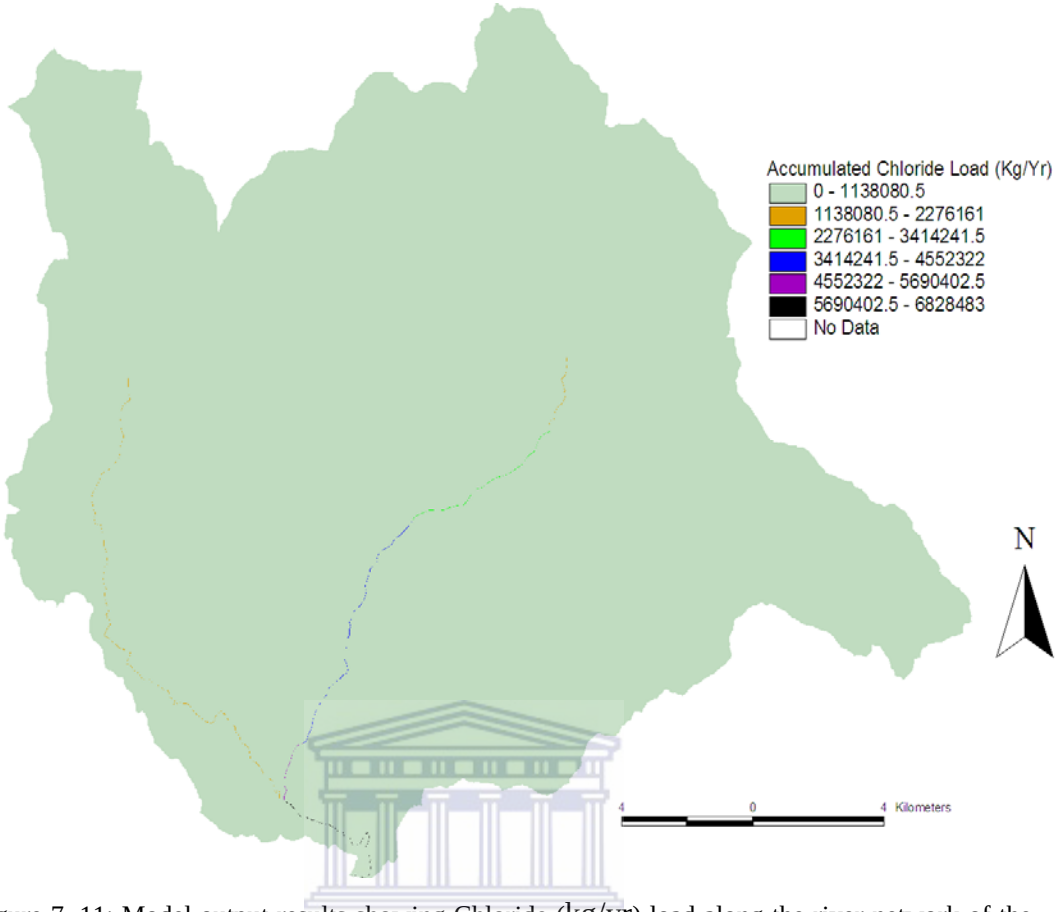


Figure 7. 11: Model output results showing Chloride (kg/yr) load along the river network of the catchment

The last pollutant to be considered is total suspended solids. The spatial distribution of the pollutant is presented in Figure 7.12. High values of the pollutant are noted in the Jonkershoek area and the central region of the catchment. The western fringe of the catchment has low values and this is a predominantly residential zone of the catchment.

The accumulation of TSS (Figure 7.13) along the river network was also considered and the generated map shows that the loading of TSS in the river network has high concentration towards land-cover types closer to the mouth of the river and the confluence between Kuils River and Eerste River with values ranging from 14.1x 10^6 kg/yr to 16.5x10^6 kg/yr.

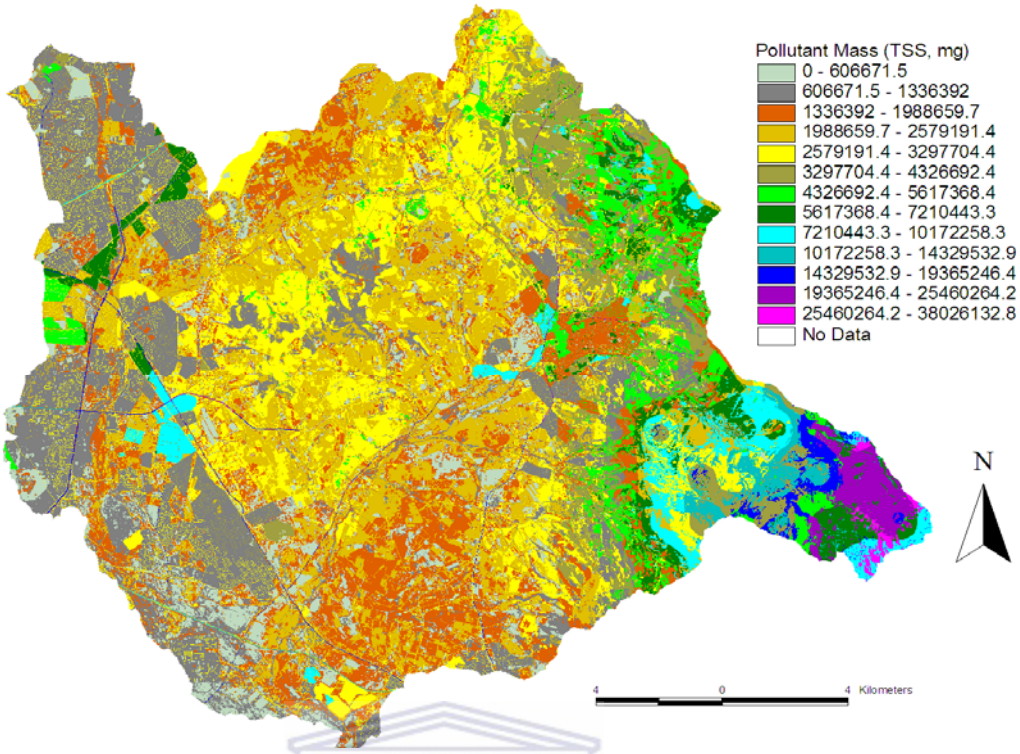


Figure 7. 12: Model output results showing Total Suspended Solids (mg/yr per pixel) distribution across the catchment with values indicated per pixel

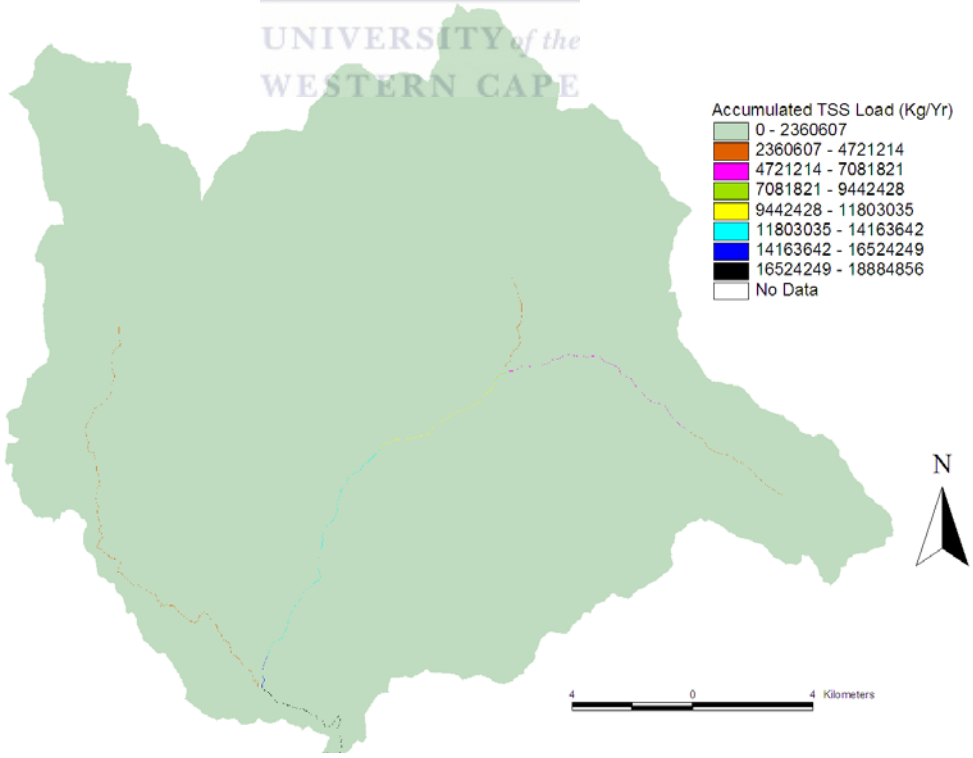


Figure 7. 13: Model output results showing TSS load (kg/yr) accumulated along the river network for the catchment

7.3 Limitations of the RINPSE model

The *RINPSE* model takes into account the following hydrological processes, runoff and infiltration. Since the model is incorporated in a GIS environment, it allows for the effects of spatial heterogeneity to be investigated.

All units of the same land-cover type are assumed to have the same *EMC* value regardless of their spatial location within the catchment. However, in reality the concentration of pollutants in surface runoff water will vary depending on factors such as topography, land-cover types, soils and rainfall.

A water quality model was applied to the Kuils-Eerste River to demonstrate the impact of urban storm runoff on water quality. Not only is the water quality affected by increasing pollutant loads from urban areas but also the water quality affected by the dynamic change of the land-cover types. To estimate the effects of both factors, the *RINSPE* model was coupled to a GIS platform. Pollutant concentrations for Kuils River were generated by this model for annual scenarios for 2006 and 2007.

Changes in water quality can indicate a change in some aspect of terrestrial, or in-channel ecosystem. From a pollution perspective, among the many water quality elements related to water quality, NPS pollution is one of the most problematic areas to consider.

7.4 Estimation of pollutants using *N-SPECT* model

N-SPECT estimates pollutant concentrations by using land-cover as a proxy (Burke, 2006) and the procedure does not explicitly take duration or intensity of rainfall into account. The use of pollutant contribution coefficients (similar to event mean concentrations) and land-cover classes in the model results in a map output of a runoff volume grid. Export coefficients represent the average total amount of pollutant loaded annually into a system from a known area, and are reported as mass of pollutant per pixel.

N-SPECT was used to estimate concentrations values for five pollutants (nitrogen, phosphorus, chloride, total suspended solids and NO_3-*N*), though the model is not limited to the estimation of these pollutants as it is capable of estimating additional user-specified pollutants. In its running mode, the model creates the accumulated runoff grid from the flow direction grid and the runoff volume grid. Each cell in the accumulated runoff grid represents the total amount of water that passes through that cell, including contributions from upstream cells. A pollutant concentration grid is then created from pollutant coefficients similar to EMC values derived from local sampling data where each cell is assigned a value based on its land-cover classification. The coefficient derivation process centers on a *FORTRAN* programme that generates pollutant coefficient values for all land-cover classes in the catchment. These coefficients represent the contribution of a particular land-cover to the overall pollutant load. For each of the water quality parameters, the programme solves multiple regression equations simultaneously to yield a single pollutant coefficient value for each land-cover class present within the catchment. The equation takes the following form:

$$L_o = (C_o * LC_o) + (C_1 * LC_1) + (C_2 * LC_2) + \ldots\ldots + (C_N * LC_N) \quad (7.1)$$

where L_o = pollutant load representing individual pollutant measurement.

LC = the percentage of the total upstream contributing area identified by a given land-cover class.

C = the pollutant coefficient associated with land-cover class for the particular pollutant.

For each of these equations based on measured or estimate loads as estimated in Chapter 6, L_o and *LC* variables are known and the C_o, C_1, C_2, C_3,…C_n variables are unknown. The mean and standard deviation for each coefficient for each land-cover type were calculated and were part of the model output.

The output data sets that are produced after a pollutant concentration estimation process has been done by the model which includes, total accumulated pollutant (Kg), pollutant concentration (mg L^{-1}), are then compared to pollutant standards (which

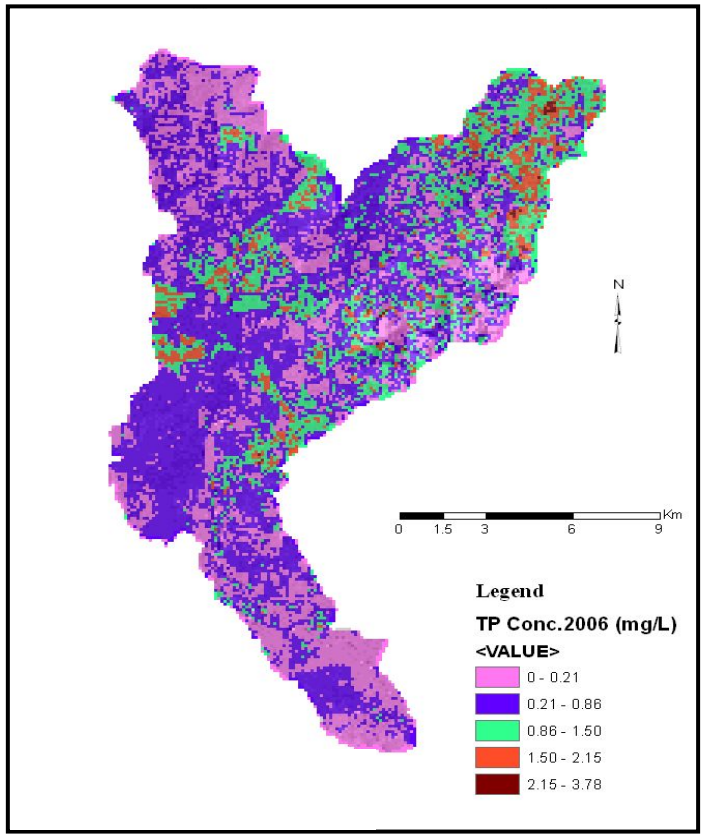
could exceed set standard or be below the set standard) grid for each pollutant specified. The resulting grid represents the expected pollutant concentration value if a sample were taken at a given cell location. A local effect analysis could be performed and the resultant grids would represent the ratio of pollutant to runoff produced at each individual cell with no input from upstream cells. The pollutant concentration grids are used as inputs to the water quality assessment and reporting component of *N-SPECT*.

7.5 *N-SPECT* Model results

The *N-SPECT* model was configured and run on the Kuils River catchment. The results are estimates of surface runoff, and pollution caused by surface runoff for the hydrological years 2006 – 2007 and 2007- 2008.

7.5.1 Spatial distribution of pollutants

The distribution of phosphorus across the catchment is presented in Figure 7.14 shows the spatial distribution of pollutants in the catchment and compares the contributions of each land-cover to the observed pollution generated. Each land-cover contributes different amounts of phosphorus, though high values (1.50 – 2.15 mg L^{-1} for 2006 and 1.55 – 2.21 mg $L^{-1}$for 2007) are associated with the agricultural zones of the catchment. The residential and other land-cover types do not have high values. Scattered parts in the agricultural areas show the highest values ranging between 2.15 – 3.75 mg L^{-1} for 2006 and 2.21 – 3.78 mg $L^{-1}$for 2007. The spatial distribution of pollutants shows a variation in the amounts over each land-cover. In the HDR Formal Townships the variation in concentration is shown by the magnitude of range between 0.03 and 0.04 mg L^{-1}. These results compare well with those in the literature on studies done in South Africa (Simpson and Kemp 1982, 1992; Hoffman, 1994). For example, Pegram and Görgens (2001), indicate that over several land-cover types total phosphorous distribution especially from informal settlements range between 1.0 – 3.0 kg ha/yr, for suburban 0.4 - 1.3 kg ha/ yr, townships 0.5 - 4.0 kg/ha/ yr, commerce 0.1 - 0.9 kg/ha/yr, industrial 0.9 - 4.1 kg/ha/ yr, highways 0.7 - 2.5 kg/ha/yr, forestry 0.02 - 0.8 kg/ha/ yr and croplands 0.2 - 0.8 kg/ha/ yr. The acceptable phosphorous concentration limit indicated by DWA (1996) is <5 mg L^{-1}. Concentrations were mostly below this acceptable limit.



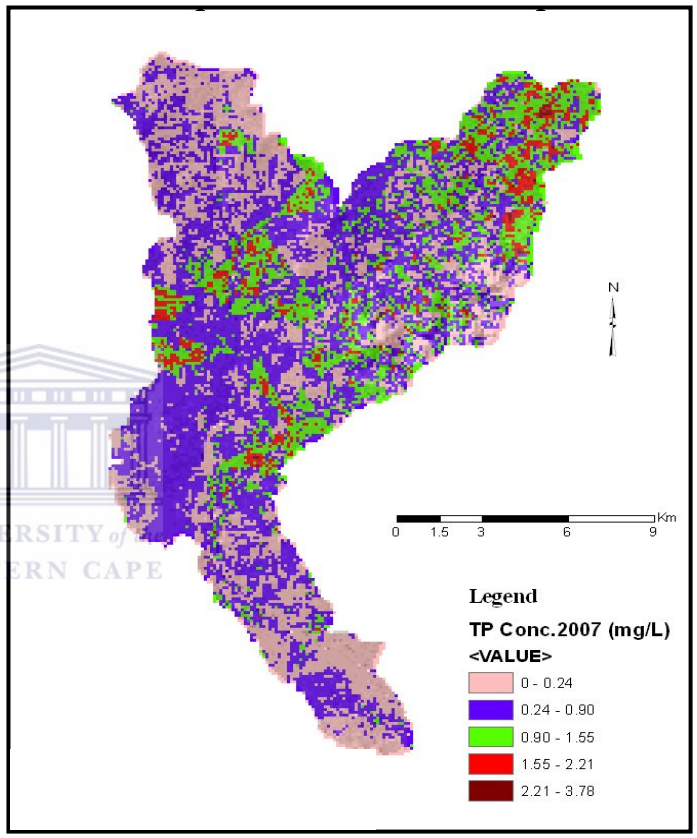


Figure 7. 14: Model output results showing Total phosphorus concentration distribution per pixel over the Kuils River catchment for the years 2006 and 2007

Nitrate distribution across the catchment shows no differences in distribution pattern between the 2006 and 2007 (Figure 7.15). The concentration levels range between 0mgL^{-1} and 6.65 mg L^{-1} per pixel. The 2007 distribution map shows an increase per land-cover concentration though the spatial distribution pattern is the same. The increase is a response to an increase in the amount of rainfall (Table 3.4) received during the period under review. Variations are also noted for fallow open vineyards (0.72 - 1.29 mg L^{-1} for 2006 and 0.76 - 1.33 mg L^{-1} for 2007), HDR Formal Township (0.15 - 0.72 and 0.18 - 0.76 mg L^{-1}), Mt. forests and dense grassy vineyards show variation in terms of concentration for the years 2006 and 2007.

From the results it is clear that the main land-cover types with high concentration of nitrate are those areas found in the agricultural zone of the catchment where values as high as 6.60 mg L^{-1} have been recorded. Such values are above the DWA water quality guideline limit of <0.5 mg L^{-1}.

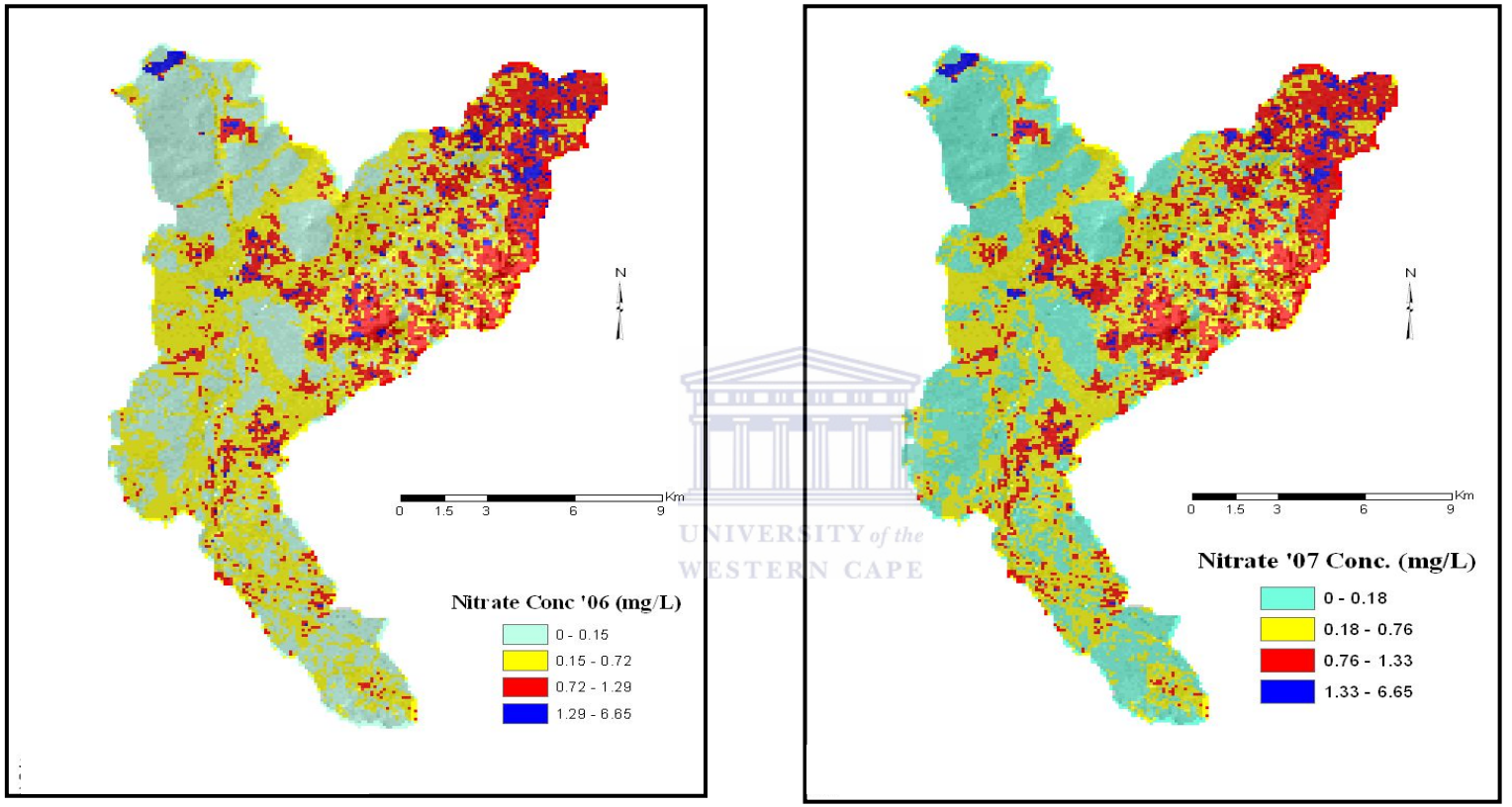


Figure 7. 15: Model output results showing nitrate distribution per pixel over the Kuils River catchment for the years 2006 and 2007

The distribution of total suspended solids over the catchment shows an increase from 2006 to 2007 of 1.97 mg L^{-1} across the catchment (Figure7.16) probably due to the increased amount of runoff which was able to transport larger quantities of pollutants. Land-cover types with notable values of concentration are as follows: HDR formal settlement which had high concentrations with values as high as 1.73 – 3.94 mg L^{-1} for 2006 and 1.23 – 3.94 mg L^{-1} for 2007, respectively. These results fall within the range of concentration limits found in other studies in South Africa for the following land-cover types, suburban (6.20 – 23.00 kg/ha/yr), townships (7.00 – 30.00 kg/ha/yr), commerce (50 – 83.0 kg/ha/yr), industrial (45.0 -170.0 kg/ha/yr) and high-ways (45.0 – 200.0 kg/ha/yr), (Pegram and Görgens, 2001). Dense grassy vineyards, recreation grass, improved grass land and dense scrub also have high variations be-tween the years.

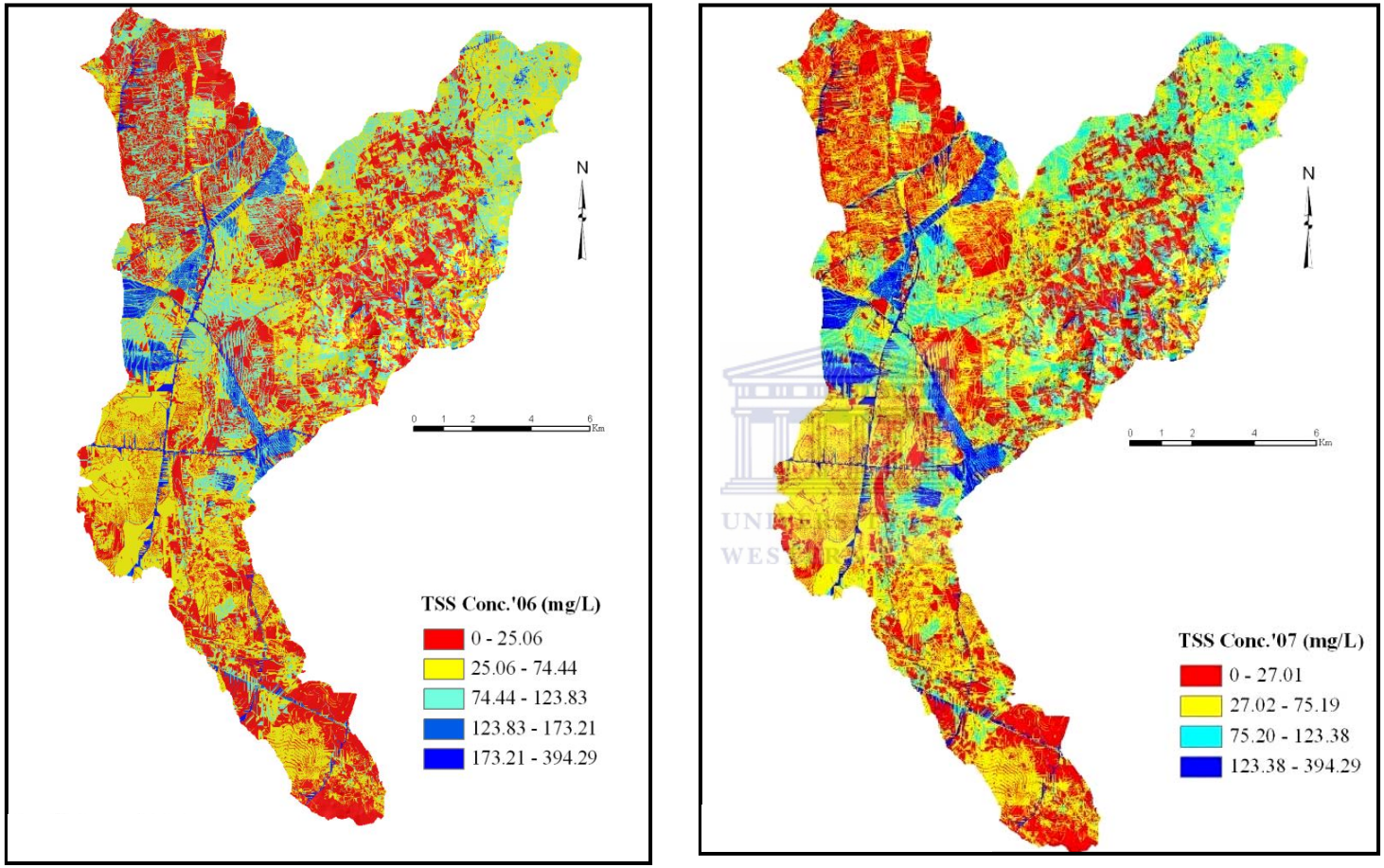


Figure 7. 16: Model output results showing Total suspended solids distribution per pixel over the Kuils River catchment for the years 2006 and 2007

There is a general increase over time (from 2006 to 2007) in the concentration of chloride across the catchment with different land-cover types showing differences (Figure 7.17). The year 2007 experienced a general increase in the spatial concentration values for the land-cover types within the lowest range. The difference in the second category is almost 3.7 mg L^{-1}.

Major land-cover types with high concentrations are HDR Informal townships and HDR formal townships (28.6 – 47.1 mg L^{-1} for 2006) and 34.3 - 58.2 mg L^{-1} for 2007), fallow open vineyards, dense grassy vineyards, improved grass and fynbos (47.1 - 65.5 mg L^{-1} for 2006 and 58.2 - 261.6 mg L^{-1} for 2007), MDR Formal suburbs, industrial and LDR formal suburbs (65.6 - 261.6 mg L^{-1} for 2006 and 58.2 - 261.6 mg L^{-1} for 2007). These results indicate land-covers with concentrations above the acceptable limit of 0.2 mg L^{-1} as indicated by DWA values.

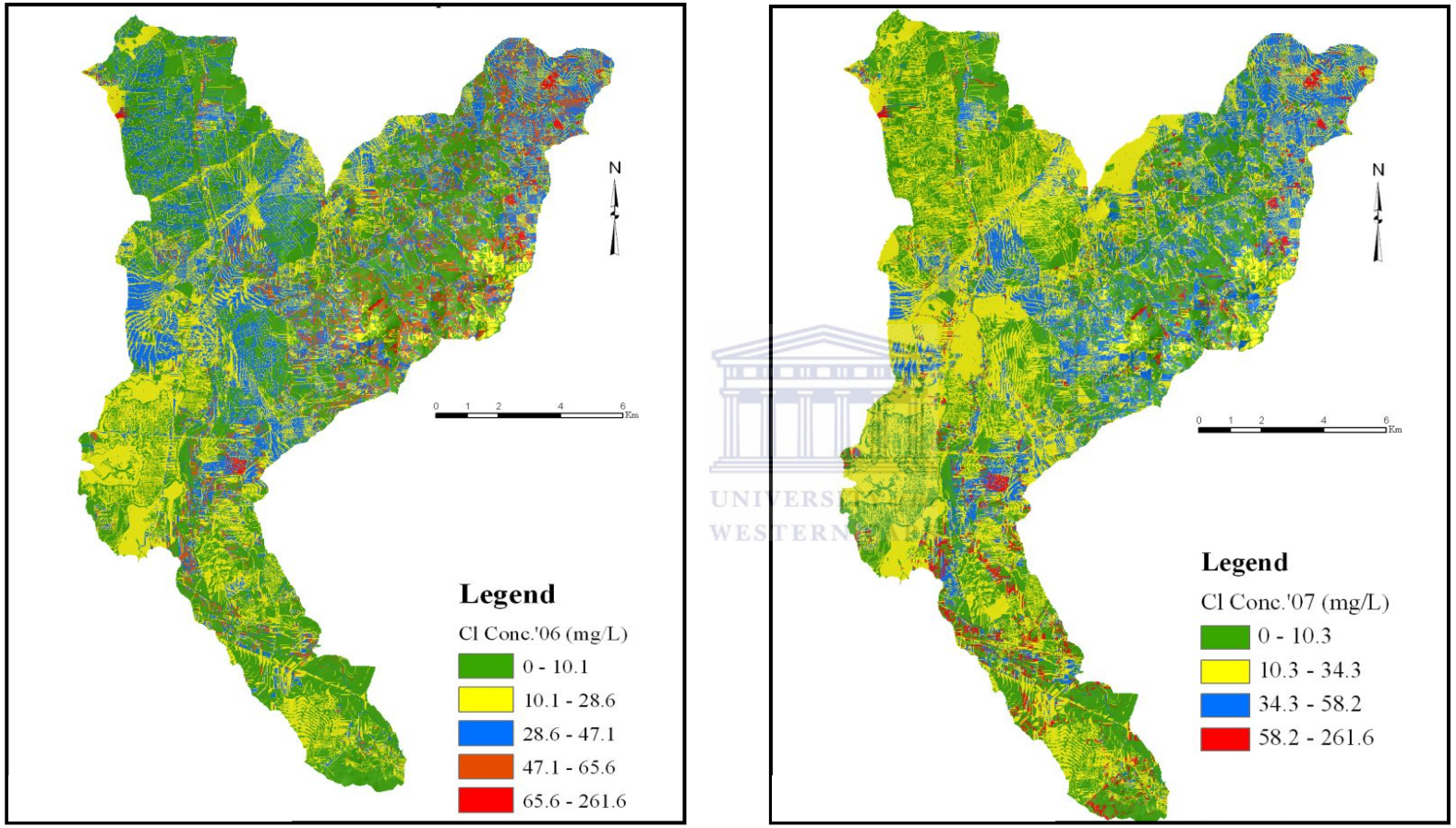


Figure 7. 17: Model output results showing chloride concentration distribution per pixel over the Kuils River catchment for the years 2006 and 2007

7.5.2 Pollutant accumulation along the river network of the catchment.

Another set of results generated was the amount of pollutants in the river. A map was generated for each pollutant, showing the quantity of accumulated pollutant. Higher values were recorded for 2007 as compared to 2006, for similar reasons as explained above where the amount of rainfall received resulted in the significant variations.

The map analysis shows that the accumulated loads of pollutants from the Kuils River catchment increased substantially for all the pollutants from the year 2006 to the year 2007. Figure 7.18 show that nitrogen loads increased from 3, 5 x 10^6 kg in 2006 to 6, 8 x10^6 kg in 2007 towards the confluence with Eerste River. These results differed from those given in Figures 7.6, 7.8, 7.10, 7.12 and 7.14 as they represent the values within the channel and not values over land-cover.

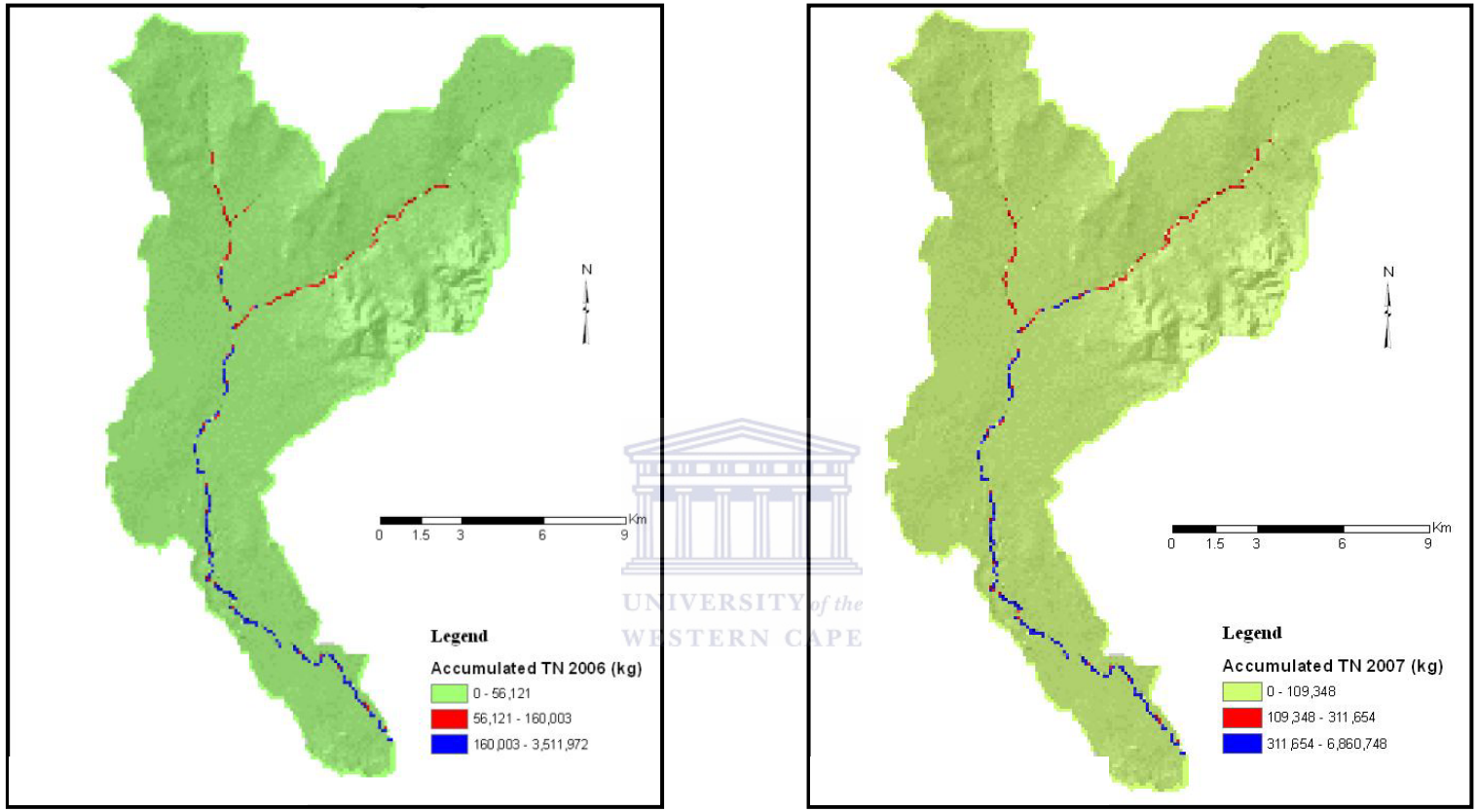


Figure 7. 18: Model output results showing nitrogen accumulations in the Kuils River for year 2006 and 2007

Annual nitrate accumulation in the river increased from 7,473 kg in 2006 to 17,931 kg in 2007 (Figure 7.19). A general increase throughout the catchment is noted, as the values of concentration of the pollutant are higher for the year 2007 compared to 2006. The first category shows a difference of 96 kg and the accumulation of nitrate per land-cover increases substantially.

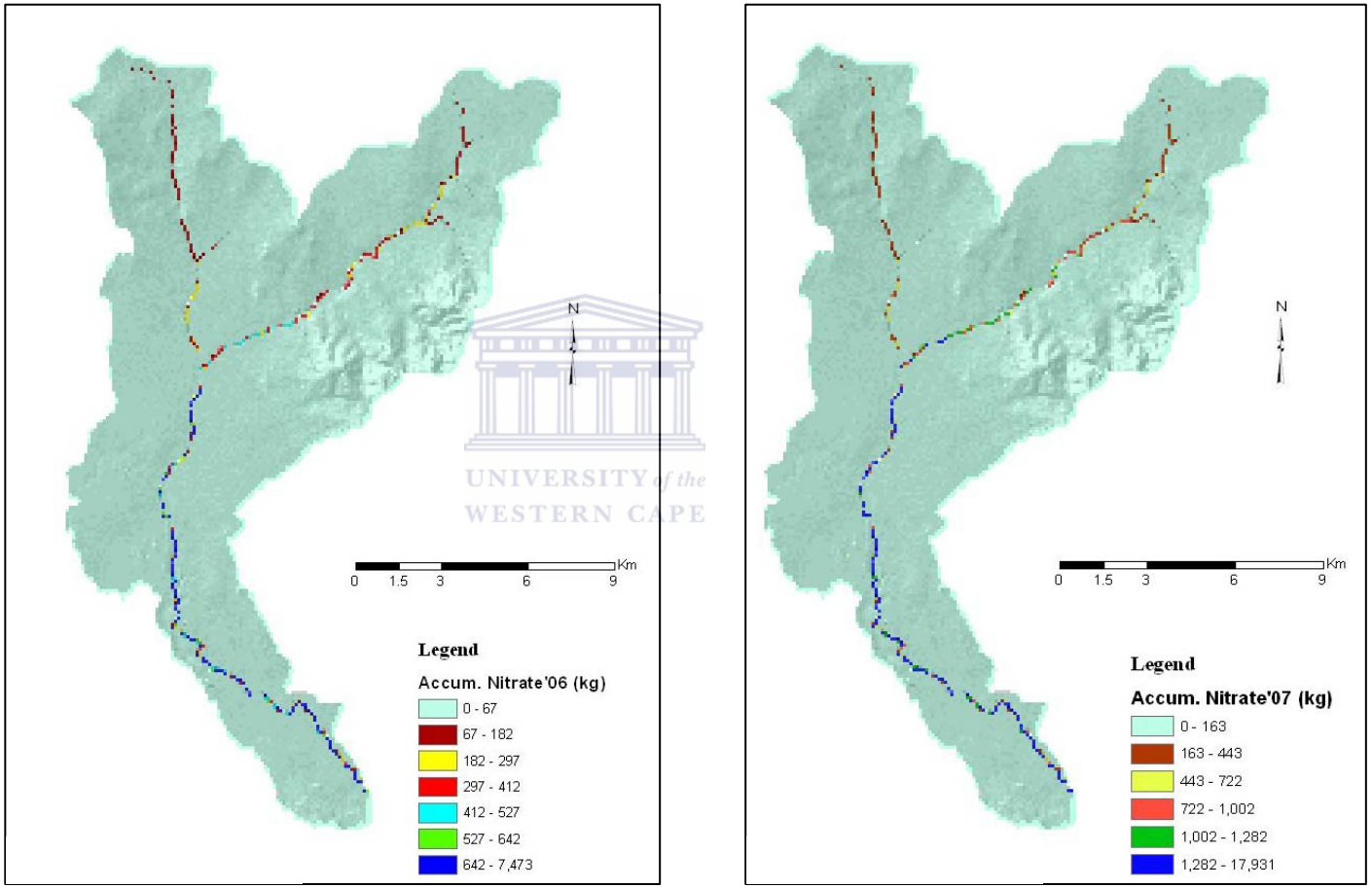


Figure 7. 19: Model output results showing nitrate accumulations in the Kuils River for the years 2006 and 2007

TSS loads for 2007 are twice as much as those for the year 2006. The concentration values range from 1, 1 x 10^6 kg to 2, 2 x 10^6 kg (Figures 7.20). The annual values indicate there is generally an increase with more vineyard production and conversion of agricultural land into built up urban areas contributing to the changes that are taking place in the catchment.

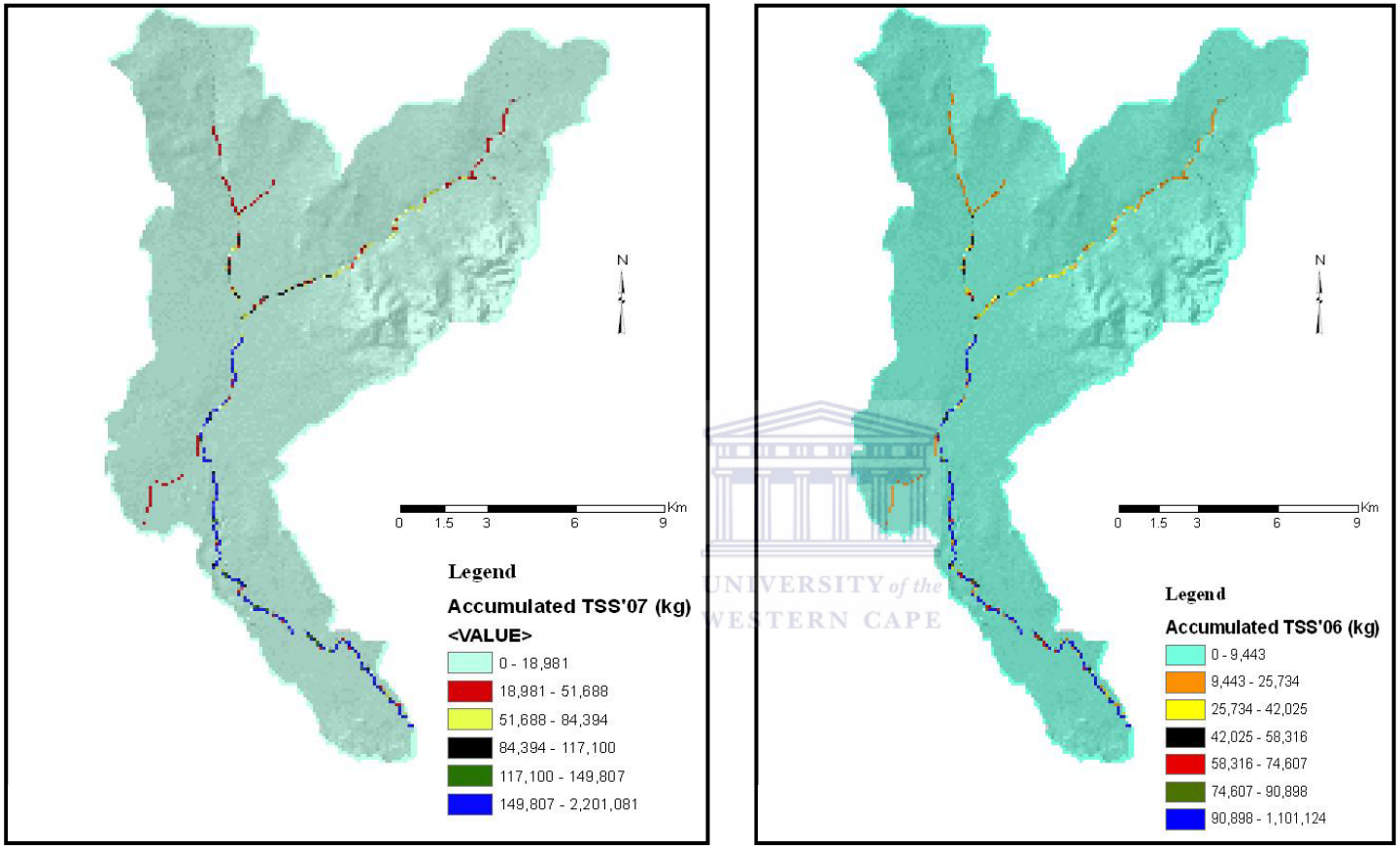


Figure 7. 20: Model output results showing total suspended solids accumulations in the Kuils River for the years 2006 and 2007

Total phosphorus concentrations were distributed unevenly throughout the years and 2007 had higher values of concentrations compared to 2006. This could be explained by the variation of rainfall amount (see Table 3.4) received which contributed to the significant levels of washoff generated. Values of the pollutant range from 0 kg to 8.19 kg for 2006 and 0 kg to 19.98 kg for the year 2007 (Figure 7.21). This explains the role played by the increased rainfall amounts received leading to the mobilisation of pollutants by increased surface runoff. Rainfall results (see Table 3.4) revealed that there was an increase in precipitation between 2006 and 2007. This increase in total rainfall amount is the possible cause of this increase in accumulated pollutant loads. Increased rainfall means increased mobilisation and transportation of pollutants due to higher volumes of runoff on the surface.

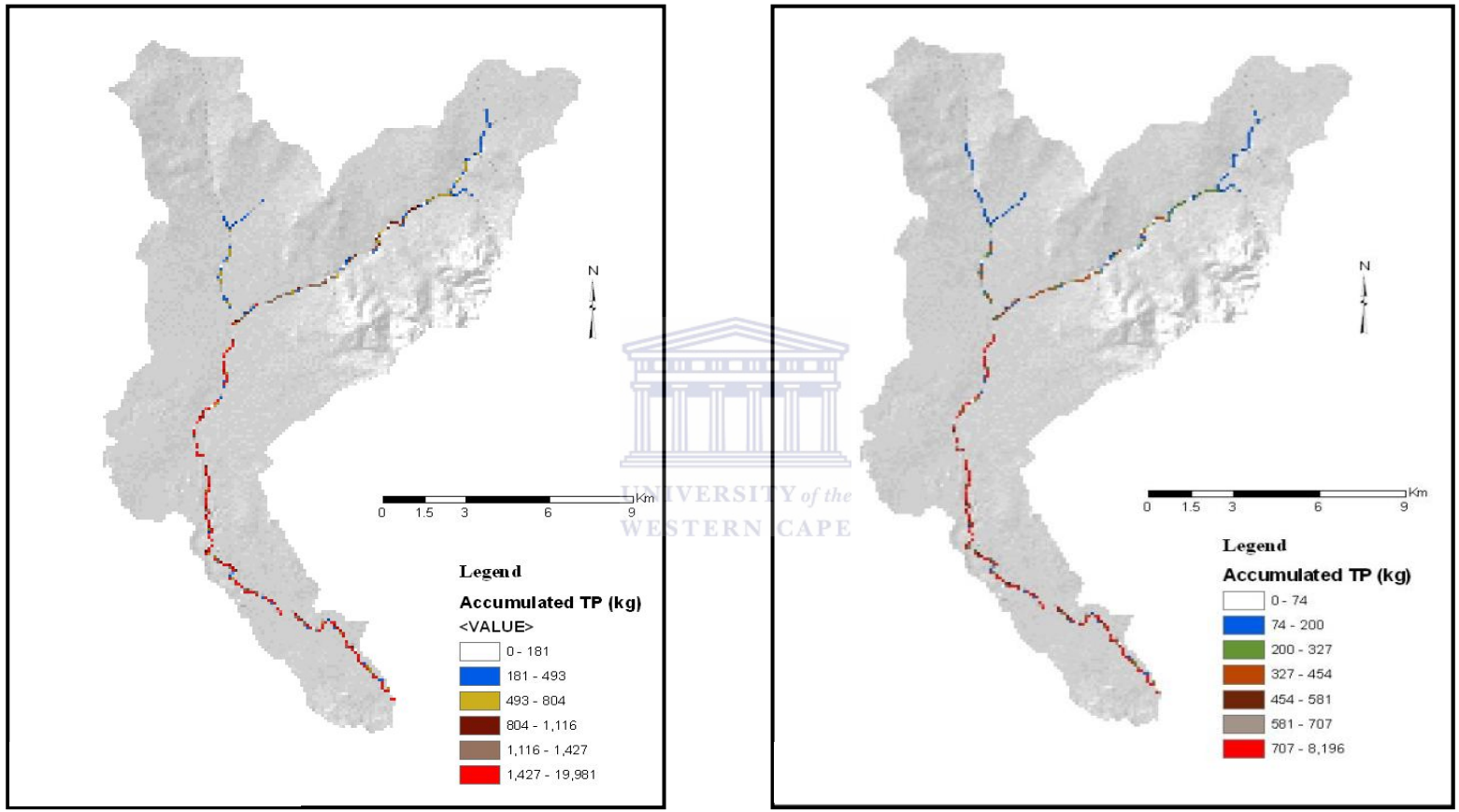


Figure 7. 21: Model output results showing pollutant loads in the Kuils River for the years 2006 and 2007

It is important to note that while the model produced the spatial distribution and river accumulation of pollutants in the catchment, the important factor that really determined the spatial pattern of concentration of the pollutants is rainfall and also land-cover type. An understanding of the distribution pattern of surface runoff into the river is important in order to appreciate fully whether the results obtained are within the stipulated standards or they exceed these. The mean annual runoff of the Kuils River has been estimated as 22 x 10^6 m^3 at Kuils - Eerste River confluence (Heydorn and Grindley 1982). Development of the undeveloped area zoned for urban use was projected to increase the mean annual runoff to approximately 27 x 10^6 m^3 and year to year variations in runoff were considerable with occasions where mean annual runoff was as low as 1 x 10^6 m^3 with a recurrence interval of 10 years (Heydorn and Grindley 1982). To achieve a holistic understanding of runoff behaviour and water quality within the catchment the runoff was modelled for the two years of study and the results are graphically shown in Figure 7.22. Rainfall results show that there was an increase in rainfall from the 2006 annual total to the 2007 amount received. The increase in total rainfall received is capable of increasing the values of accumulated pollutants in the river.

For each land-cover type values of accumulated runoff indicate that for 2006 the values range between 0 m^3 to 11,384 x 10^3 m^3. The following year 2007 shows accumulated runoff to have higher values that range between 0 m^3 and 23,054 x 10^3 m^3. In comparison to the earlier studies (Heydorn and Grindley, 1982), there is an increase in runoff estimated. The type of land-cover that dominates in the catchment is responsible as the catchment is urbanising. There was a corresponding increase in compacted surfaces as opposed to areas under agricultural activity. For each pollutant, the GIS-model was applied to calculate runoff volume per grid cell, which was then coupled with an *EMC* value appropriate to the land-use, so as to generate a pixel load. Observed pollution data to test the validity of these loadings is not available (a motivation behind the model development), but results are within the range of observed unit area load's reported in the literature for South Africa.

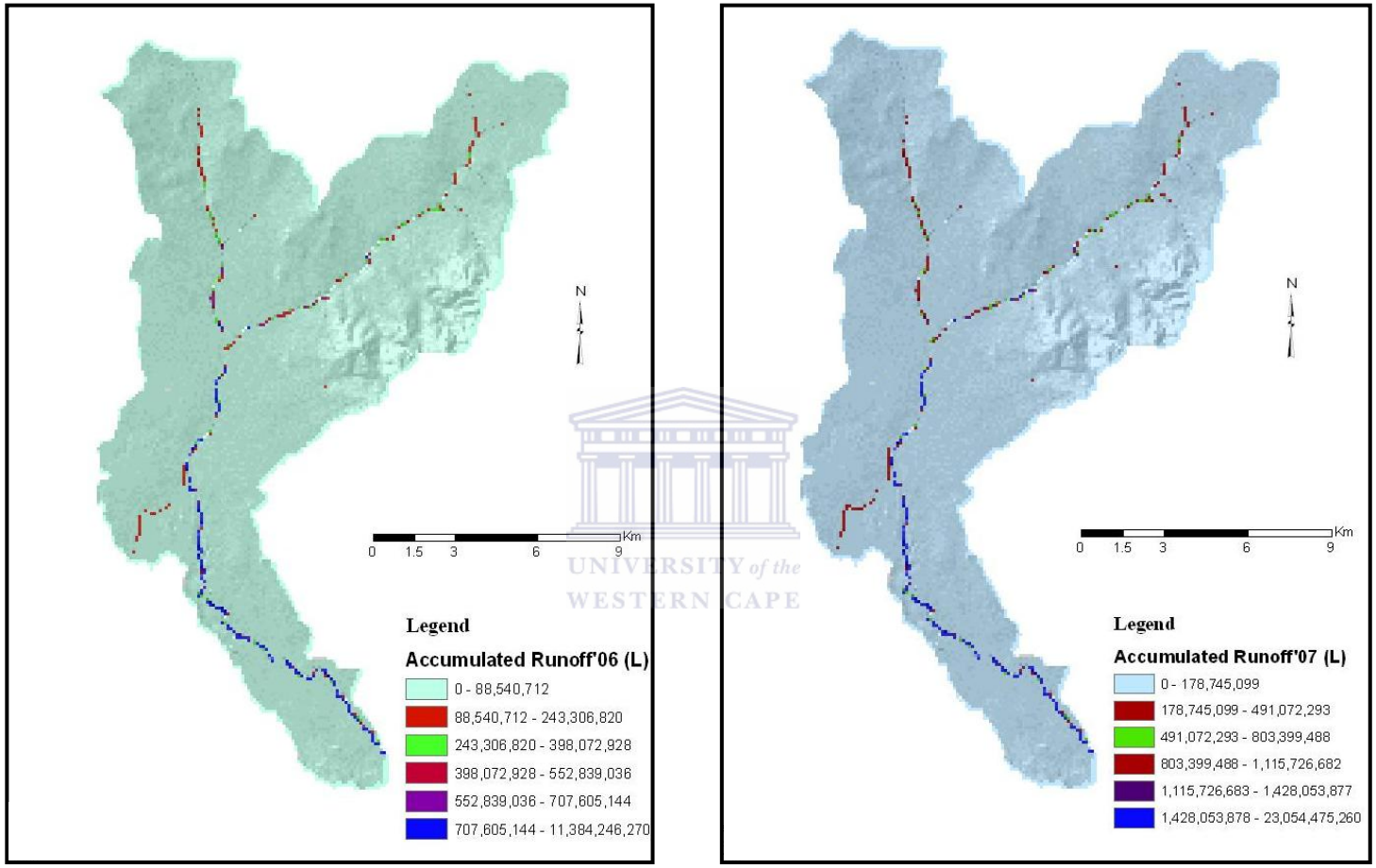


Figure 7. 22: Model output results showing accumulated runoff distribution in the Kuils River during the years 2006 and 2007

7.5.3 Discussion

The results presented in this chapter indicate variability in the levels of concentration and distribution of pollutants and runoff in the catchment. While the pictorial presentation of spatial data draws the attention of the reader to the way in which the pollutants are distributed, the use of figures only would not show the extent of the spatial variation of the phenomenon and the magnitude of pollutant diffusion. The results from the calculations are presented in a table that summarizes the pollutant load values for each land-cover class. Annex 7.1 shows the percentage contribution of each land-cover class for each pollutant studied. Nitrate distribution is not uniform. A high percentage of nitrates originate from the eastern 'horn' of the catchment where Bottelary River drains mainly medium density residential areas and agricultural lands. Annex 7.2 shows that 55.5 % of the nitrate contribution comes from the vineyards and the remainder is distributed amongst the remaining 32 classes. Such a high percentage value points to the fact that the area is predominantly agricultural, with the application of fertilizers contributing to the high concentration values.

Grasslands are important nitrate sources that have been reported previously (Hart *et al.* 1993; Holloway and Dahlgren, 2001) and attributed to asynchrony within nutrient cycling. Instead of continuous nitrogen feedback among senescing plants, their soils, and new growth (biotic uptake), nitrogen in grasslands is mineralized and accumulates in soils during the dry summer months (Hart *et al*. 1993). With the onset of winter rains, water begins to flow through the upper soil horizons, mobilizing the accumulated nitrate (Holloway and Dahlgren, 2001) before new growth can uptake nutrients. As such, grasslands are inherently leaky systems with respect to nitrate. The pollutant with notable variations in concentration is the total suspended solids, which for the two years shows variation as indicated in Figure 7.23. A total of 11 land-cover types showed variations: dense scrub, fynbos, bare ground/impervious surfaces, open area/ barren land, dense/ grassy vineyard, fallow/ open vineyard, arterial roads/ main roads, high density residential (HDR) formal townships, HDR formal suburb, medium density residential (MDR) informal Township and industrial areas. The variations are due to the effects of the conversion of agricultural land into urban settlement including current agricultural activities.

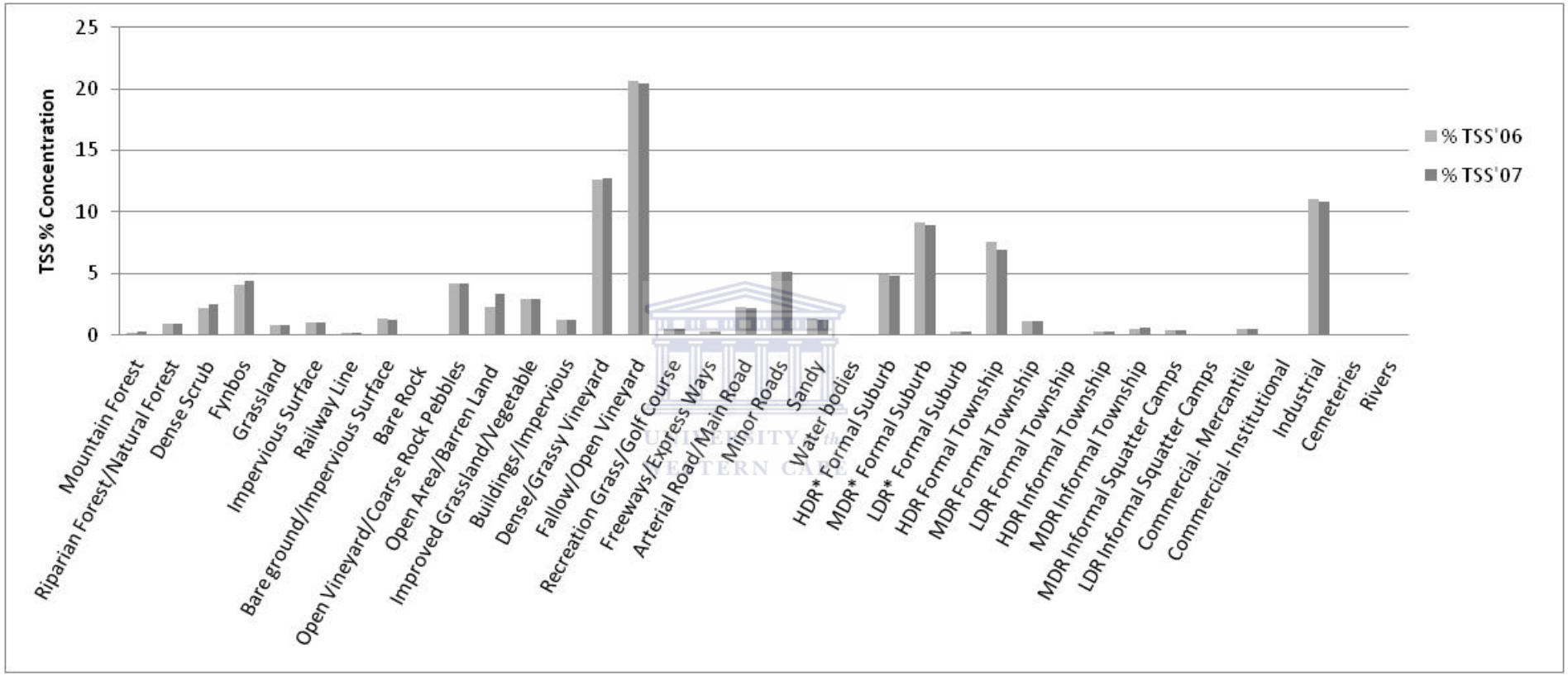


Figure 7.23: Comparison of the concentration values and distribution of total suspended solids across the catchment in 2006 and 2007.

7.5.3.1 Effects of changes in total rainfall on pollutant loads

Studies of runoff estimation and pollution loading in different types of catchments have been conducted (Tsihrintzis *et al.,* 1997). This study applied the methodology based on *RINSPE* and *N-SPECT* models. Irrespective of the method used for runoff, and pollutant loading estimation, it is difficult to tell which of the two model parameters most influences model output and hence the need for sensitivity analysis. Multiple runs of the models were done using nitrate, chloride, and rainfall and land-cover type data. The output includes a range of statistics comparing each model result with observed data sets and visual displays of the distribution and accumulation values of the pollutant concentration. The results were used to determine the effects of change of total rainfall on pollutant load above the water quality guideline limit by varying the rainfall parameters. The focus was on the nitrate and chloride found on similar land-cover types.

Amongst the output maps generated using *N-SPECT* are maps of water quality limits showing the accumulated levels of contaminants in the rivers. Figure 7.24 shows the water quality guideline limit outputs for nitrates and chlorides, respectively. The distribution of nitrates and chloride in the river segments indicates water quality levels above or below the DWA guideline limit.

The estimates were generally based on two categories, whether the segment of the river exceeded or was below the guideline limit required of the pollutant in the water. Due to the nature of the analysis, the results shown on the maps are presented in two categories only (those that exceed guideline limit and those that are below the guideline limit). This provided a preliminary ranking of the river segments requiring management in the catchment.

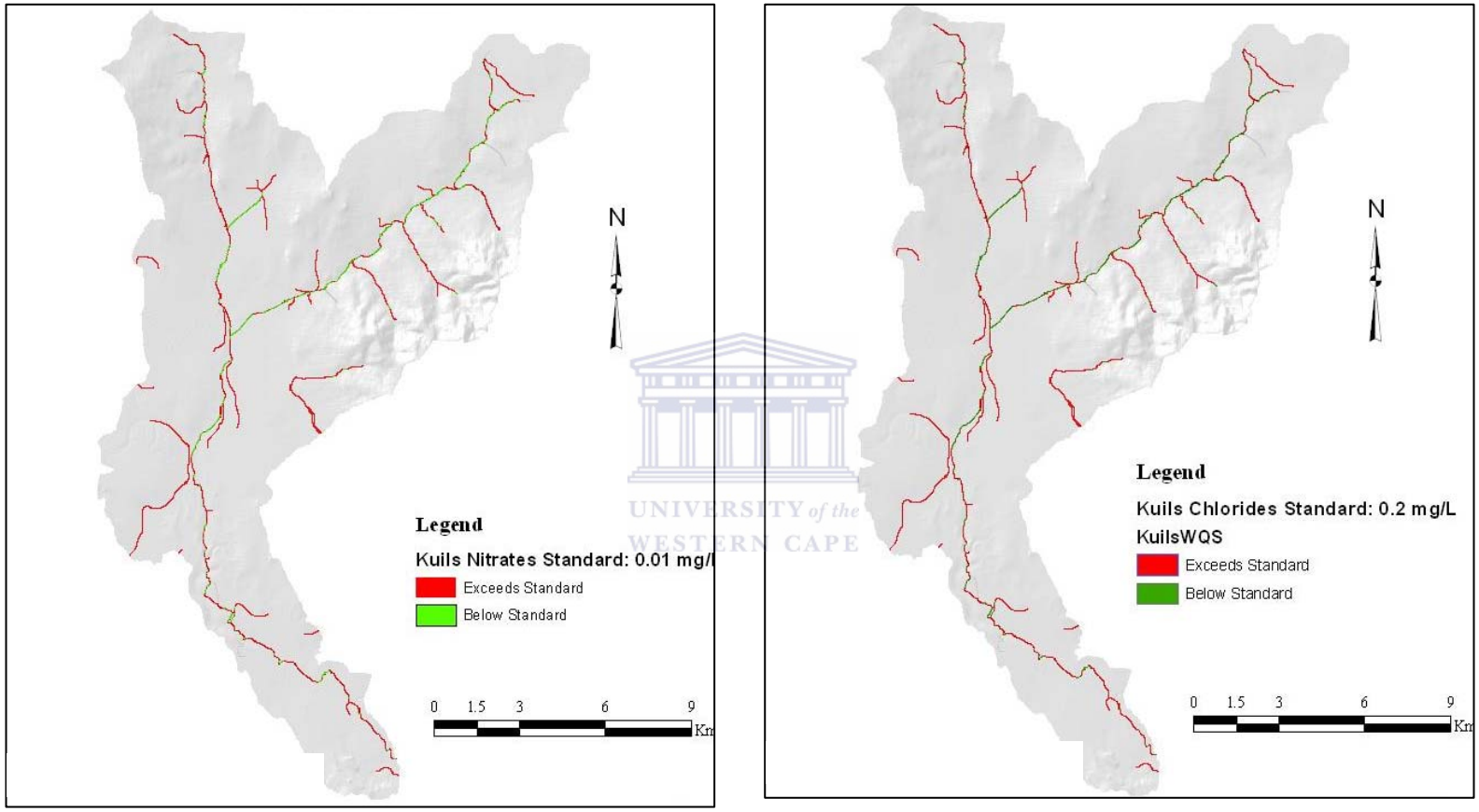


Figure 7. 24: Model output results showing water quality guideline limit outputs for nitrates and chlorides in the Kuils River catchment

However, the main stream remains within acceptable limits of water quality whereas the contributing streams exceed the limits. This indicated the fact that surface discharges from polluted surfaces maintain high concentrations but upon entry into the mainstream channels that contain higher flow volumes, the inputs from these contributing streams become diluted and less concentrated. This pattern also continued downstream with intermittent sections that exceed guideline limits due to increased pollution inputs and alternate dilution effects. The activities of aquatic plants (eutrophication) that utilise e.g. nitrates and phosphates in aqueous medium is a major explanation for some observed purification of the river at certain stages.

7.6 Summary

Between 2006 and 2007, noticeable concentration variations in space and time in pollutants from the land-cover classes are shown on the maps produced by the model. With any changes in the land characteristics, one would expect a corresponding response in terms of the potential to produce polluting substances from the different land-cover types. The results show that the following classes: vineyards, industrial areas and the medium density residential (MDR) areas, contribute the most towards pollution in the catchments' streams and rivers. The vineyards contribute an average of over 40 % of the entire pollutant load from classes followed by the industries and then the residential areas and open barren lands (see Annex 7.1).

In general, the central and southern section of the catchment recorded higher surface runoff than the north-eastern section of the map. In the north eastern part of the catchment soil permeability generally is low, and precipitation typically is low. The spatial distribution of pollutants within individual land-cover types shows considerable variability. Land-cover in the Kuils River catchment is predominantly urban with vineyards and grassland-covering the northern section of the catchment. The spatial pattern of land-cover types varies between and within the different parts of the catchment.

The application of a model within the ArcView GIS platform for the estimation of pollution loads and runoff volumes using land-cover knowledge was investigated.

The results of the model indicate pollutants for a particular location in relation to the precipitation event. A number of factors account for the variability in terms of the land-cover contribution to pollution which include vegetation (type and density), soil compaction, impervious surfaces, and rainfall variability. This research does not address such factors since the objective of this chapter was to determine the quality of surface runoff originating from each of the land-cover type.

CHAPTER 8

APPLICATION OF WATER QUALITY GUIDELINES FOR IMPROVING MANAGEMENT OF WATER QUALITY

8.1 Introduction

This chapter addresses the objective of identifying measures for improving management of water quality for those areas where this is necessary.

The main issue dealt with in this study was a focus on explaining how water quality of surface runoff varied on different land-cover types and to provide guidelines for minimizing water pollution that may occur in the Kuils-Eerste River catchment. The first issue to be dealt with is the establishment of the types, distribution of land-cover types within the catchment, and secondly the determination of how the quality of surface water varied with land-cover, and finally the estimation of the pollutant loads at the catchment scale. To conclude the chapter, a set of management strategies are proposed based on water quality guideline results.

The management of water resources by the City of Cape Town does not only focus on efficient supply of potable water, and removal, treatment and disposal of wastewater, but includes management of storm water systems including rivers, vleis, wetlands, groundwater and the impacts of land-based activities on our coastal waters (City of Cape Town State of Environment Report Year 5, 2002).

A number of inland water bodies (vleis) are used for a variety of recreational purposes (e.g. sailing, canoeing, water-skiing, fishing and swimming). Although not formally recognised for recreational use, wading in rivers is common. The challenge is for the city to monitor and ensure that the inland aquatic systems have water quality suitable for their uses.

8.2 The South African Water Quality Guidelines

The South African Water Quality Guidelines serve as the primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of the health of aquatic ecosystems.

The Department of Water Affairs (DWA) considers fresh water aquatic ecosystems to be "the base from which the [water] resource is derived" (White Paper, on Water Supply and Sanitation, 1994). Humans depend on many services provided by healthy aquatic ecosystems, namely:

- Maintaining the assimilative capacity of water bodies for certain wastes through self-purification;
- Providing an aesthetically pleasing environment;
- Serving as a resource used for recreation;
- Providing a livelihood to communities dependent on water bodies for food; and
- Maintaining biodiversity and providing habitats to that biota dependent on aquatic ecosystems.

Aquatic ecosystems, as the resource base, must therefore be effectively protected and managed to ensure that South Africa's water resources remain fit for agricultural, domestic, recreational and industrial uses on a sustained basis (DWA 1996).

There are several approaches for protecting and maintaining the health of aquatic ecosystems compared to the approach used to determine the requirements of other water uses. This indicates that there is some measure of uncertainty regarding the vulnerability of aquatic ecosystems to changes in water quality, and that there are very few options for mitigating the effects of poor water quality. As a consequence, the consideration of a precautionary approach is required to protect the health of aquatic ecosystems. This approach means that active measures are taken to avert or minimise potential risks of undesirable impacts on the environment. Part of the precautionary approach is to minimize risk to the environment in all the decision making steps involved in water quality management. This precautionary approach has been followed in the development of water quality guidelines in South Africa.

The South African Water Quality Guidelines for Aquatic Ecosystems are used for water quality management. However, the information provided is more detailed, and not only provides information on the water quality requirements for the management and protection of aquatic ecosystems but in addition provides background infor-

mation to help users of the guidelines to make informed judgements on the likely impacts of water quality on the health and integrity of aquatic ecosystems (Dallas and Day, 1993; DWA 1996).

In keeping with the goal of upholding the health and integrity of aquatic ecosystems in the catchment, the different water quality criteria and objectives provided in these guidelines are used in this study to develop management strategies for the Kuils-Eerste River catchment. The City of Cape Town has developed a catchment management strategy which emphasises the following:

- An integrated and co-ordinated catchment-based planning approach founded on an understanding of local needs and values. Decisions now incorporate water quantity, water quality and socio-economic considerations in support of broader city objectives. It is further recognised that there is a strong interrelationship between human health, the environment and development.
- Protection of urban water resources; including rivers, wetlands, vleis, subsurface and coastal waters from the potentially harmful impacts of development through the reduction of pollutant loads as near to source as possible.
- Development of innovative infrastructure solutions that are cost effective, sustainable in terms of future maintenance requirements, environmentally sensitive and maximise social and amenity value.
- Involvement of communities and other stakeholders in the management of river systems through catchment forums. This includes efforts to promote other beneficial uses of storm water and river systems through educational programmes and capacity building initiatives.

8.3 Application of Water Quality Guidelines in Management

The precautionary approach was followed in this study in setting up the water quality objectives based on the water quality criteria. The water quality objectives were not necessarily set at a level which might not adversely affect the resilience of aquatic ecosystems. The resilience of a system refers to its ready ability to recover structure and behaviour in the face of external forces since loss of this resilience might well limit options for future development of water resources. In keeping with the goal of

assuring the health and integrity of aquatic ecosystems, the different water quality criteria and objectives provided in the DWA guidelines are used in this study taking into account the three criteria levels in the following ways:

- The Target Water Quality Range (TWQR) as a management objective is used to specify the desired or ideal concentration range and/or water quality requirements for a particular constituent.

- The Chronic Effect Value (CEV) as a criterion was used in certain special cases where the TWQR is exceeded. The setting of water quality requirements or objectives at the CEV protects aquatic ecosystems from acute toxicity effects.

- The Acute Effect Value (AEV) as a criterion was used to identify those cases requiring urgent management attention because the aquatic environment is threatened, even if the situation persists only for a brief period. The AEV was also used to identify those cases in need of urgent mitigatory action.

8.4 Water Quality Constituents and Management Applications

Five pollutant constituents were used in the study, namely, total phosphorus, chloride, total nitrogen, total suspended solids, and NO_3-N. The results are analysed using the guideline limit associated with selected ranges of pollutant concentrations and environmental conditions. The comparative relationship between concentration and land-cover type is used as an indicator in understanding the water quality of the land-cover scenarios. Table 8.1 shows the selected range of concentration of pollutants and the targeted water quality range.

Table 8. 1: Illustration of typical symptoms associated with selected ranges of nitrogen and phosphorus concentrations as proposed by DWA (1996) Water Quality Guidelines.

Nitrogen concentration (mg L^{-1})	Phosphorus concentration (mg L^{-1})	Effects
<0.5	<5	Oligotrophic conditions; usually moderate levels of species diversity, usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or the presence of blue-green algal blooms.
0.5 -2.5	5 - 25	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algal blooms seldom toxic.
2.5 - 10	25 -250	Eutrophic conditions; usually low levels species diversity; usually highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, wildlife and livestock.
>10	>250	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, animals and wildlife.

Table 8.2 shows the different land-cover types and the concentration levels of each pollutant. The parameters that exceed the guideline values of pollutant concentration are indicated also.

Table 8. 2: Water quality guideline limits and expected mean concentration derived from the analysis of surface runoff samples. The shaded areas indicate all parameters that are above the limit of acceptable concentration for each pollutant per land-cover type.

Water quality guideline limits and expected mean concentration derived from the analysis of surface runoff samples show that agricultural land had high pollutant concentrations. Urban land-covers show varying amounts. For all five of the studied pollutants in the surface water, the model estimated phosphorus as being the only pollutant that was below the limit of the guidelines in the catchment. TSS ranked as the

pollutant from land-cover types that had concentration values above the guideline limit. The data in Table 8.2 indicate that the variables were generally within the target water quality range for aquatic ecosystems (DWA, 1996). The dominant land-cover types are dense grassy vineyards which occupy 20.4 % of the land, fallow/open vineyard covering 14.4 %, fynbos 12.5 %, MDR formal suburbs take up 7 % while 5.8 % is covered by open vineyard/ hard rock. Mt forest and riparian/natural forest take up 5% and 5.2 %, respectively. The land-cover types that are likely to change due to the high urbanisation taking place and currently have recorded high concentration values of pollutants are dense grassy vineyards, fallow/ open vineyards, 5.8 % open vineyard and riparian forest. The focus on any management strategies should deal with these land-cover types as they are of concern as the quality of water is bad. In Natal, South Africa Simpson and Kemp (1982) carried out similar studies focusing on the quality and quantity of storm water runoff from commercial land-use catchment and their results inform some of the findings of this study too. Of the land-cover containing high values of nitrate concentration above the water quality guideline limit of 0.5 mg L^{-1}, commercial mercantile had the highest concentration of 6.65 mg L^{-1} any management strategy should be directed at dealing with this land-cover type.

8.4.1 Nitrogen and NO_3-N

Nitrogen (N) is essential for increasing yields of crops. Applying too much nitrogen to cropland, however, could have adverse effects on the environment. Achieving optimum yields without applying excessive nutrients should therefore be a goal for all farmers. Excess nitrogen in surface waters causes eutrophication (excess algae growth) in surface waters and health problems in humans and livestock as a result of high intake of nitrogen in its nitrate form.

Nitrogen management on these land-cover types should be prioritised especially considering that dense/grassy vineyard and fallow/ open vineyard contribute in terms of percentage value the highest amounts of the nitrogen (Annex 7.1).

Nitrogen management strategies frequently involve a one year or longer time frame; proposals should be environmentally sound if they also involve a number of short-

term decisions that account for plant growth, water availability, soil physical factors and climatic conditions. In the Kuils-Eerste River catchment the production of vineyards is the dominant agricultural activity. As such, short term decisions are considered ideal to reduce the accumulated effects on surface flow.

Because nitrate in surface water is a potential health hazard and contributes to current eutrophication problems (evident where Kuils River crosses the road to Stellenbosch), fertilizer must be used prudently on all vineyards in the catchment. Farmers are encouraged to consider the following techniques for guarding against the possibility of unused nitrate contaminating surface water.

- Reduction of quantities to be applied and variation of the times of application. Proper timing ensures maximum daily nitrogen uptake and minimizes the likelihood of unused nitrogen leaching below the plant roots.

In the dense/grassy vineyard and fallow/open vineyard the application of small amount of nitrogen to crops should be adopted. The need for additional nitrogen can be determined and applied before the crop matures.

This study proposes that significant reductions in nitrate accumulation can be achieved for the affected land-cover types by reducing fertilizer application rates and changing the timing of application. Examples of such achievements are found in the USA, where, for example, 9 % reduction in nitrate losses was achieved when switching from fall to spring application (Nangia *et al*., 2008). The application of fertilisers by farmers and residents of the catchment on their lawns and horticulture plots indicate that it is possible to reduce quantities without cutting down on output.

If current practices continue, nonpoint pollution of surface waters in the low density residential areas (LDR), informal squatter camps, commercial mercantile land-cover, and medium density residential (MDR) and informal townships is virtually certain to increase in the future. Such an outcome is not inevitable, however, because a number of technologies, land-use practices, and conservation measures are capable of decreasing the flow of nonpoint nitrates into surface waters.

Further proposals indicate that nonpoint source pollution of surface waters with nitrates could be reduced by cutting down on surplus nutrient flows in agricultural systems and processes, reducing agricultural and urban runoff by diverse methods, and eutrophication (where Kuils River crosses the road to Stellenbosch) can be reversed by decreasing input rates of phosphorus and nitrogen to aquatic ecosystems, but rates of recovery are highly variable among water bodies (Carpenter *et al.*, 1998). In studies carried out in the Great Lotus catchment in South Africa, Grobicki (2001) states that attenuation of external loading could have a positive effect on the severely impaired state of the water through the control of phosphorus in sewage, industrial wastewaters and diffuse pollution.

Management programmes should be improved, where necessary, to better utilize the fertilizer applied, or fertilizer rates should be reduced to coincide with anticipated yields. In addition, farmers can adopt side dressing programmes in which most of the nitrogen fertilizer is applied after the crop emerges. It is easier to determine potential yield once planting date and plant stand have been established. This approach can aid in developing nitrogen rates for potential yields and should reduce accumulations of excess nitrate.

8.4.2 Total suspended solids

The increased values of total suspended solids may also result from anthropogenic sources, which could include of the following:

- discharge of domestic sewage especially in the informal settlements and townships,
- discharge of industrial effluents in the commercial mercantile land-cover types, and
- Physical perturbations from road, and bridge construction throughout the catchment which in a way is an urbanising catchment.

Some management options that should be considered for the Kuils-Eerste River catchment land-covers, taking into account the affected land-cover types and the levels of TSS concentration, should include the establishment of vegetative filter strips

along Kuils River and the built up area where the river is passing through. These have proved to be a crucial part of best management practices (Fares *et al*., 2009). The term vegetative filter strips is often interchangeably used in the scientific literature with other terms, such as buffer zones, buffer strips, vegetative buffers, or riparian buffers. Buffer zones are perennial, cultivated grasslands adjacent to watercourses, streams bordering farmlands, agricultural lands, or urban areas.

In the medium density residential (MDR) informal townships, low density residential (LDR) informal squatter camps, commercial mercantile, commercial institutional and the industrial land, storm-water management practices should emphasize centralized treatment facilities such as dry and wet detention ponds. Practices that disconnect both rooftop and ground surface impervious cover from a direct conveyance off site and instead direct it to pervious areas where it is either infiltrated into the soil or filtered by vegetation should be put in place. This can be achieved by considering the land-cover to promote overland vegetative filtering or providing bio-retention areas on small residential or commercial lots. In terms of water quality, wet detention ponds and having a permanent pool, have been seen as being more beneficial to water quality than dry detention ponds. Large structural facilities such as detention ponds have more recently been associated with problems of their own. A study in Delaware observed no improvement in downstream water quality metrics provided by detention ponds.

Another management strategy that can be considered for the MDR informal townships, LDR informal squatter camps (Khayelitsha for example), and commercial mercantile and commercial institutional land-cover types (UWC campus) is the disconnection of rooftop runoff with a greater percentage of rooftop areas not being directly connected to the drainage system. That is, runoff from the roof is directed to a pervious surface where it can either infiltrate into the soil or filter through vegetation.

Some examples of recommended site design practices to incorporate within this management strategy are:

- Construction of narrower roads as the freeways/express ways and arterial roads/main roads have contributed large quantities of TSS beyond the acceptable limits (2.36 mg L^{-1} and 3.94 mg L^{-1}, respectively).

- Construction of smaller cul-de-sac or cul-de-sac with ‘green middles’ especially in LDR areas.
- Provision of pervious road shoulders, parking areas and driveways
- Development of reduced parking lot ratios especially at shopping malls like Tygervalley Mall.
- Development of angled one-way parking

8.4.3 Phosphorus

Phosphorus can occur in numerous organic and inorganic forms, and may be present in waters as dissolved and particulate species. Elemental phosphorus does not occur in the natural environment. Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates are found in natural waters. The forms of phosphorus in water are continually changing because of processes of decomposition and synthesis between organically bound forms and oxidised inorganic forms. The phosphorus cycle is influenced by the exchange of phosphorus between sedimentary and aqueous compartments. In turn this is affected by various physical, chemical and biological modifying factors such as mineral-water equilibrium, pH, sorption processes, oxygen-dependent redox interactions, and the activities of living organisms.

Phosphorus is an essential macronutrient, and is accumulated by a variety of living organisms. It has a major role in the building of nucleic acids and in the storage and use of energy in cells. In un-impacted waters it is readily utilized by plants and converted into cell structures by photosynthetic action. Phosphorus is considered to be the principal nutrient controlling the degree of eutrophication in aquatic ecosystems (DWA 1996).

In South Africa, phosphorus is seldom present in high concentrations in unimpacted surface waters because it is actively taken up by plants (DWA, 1996). Results from the study show that for the Kuils-Eerste River catchment phosphorus concentration levels are not above the water quality guideline limit; no management strategies are to be proposed since the catchment conditions are within acceptable limits. Elevated

levels of phosphorus may result from point-source discharges such as domestic and industrial effluents and from diffuse sources (non-point sources) in which the phosphorus load is generated by surface and subsurface drainage. Non-point sources include atmospheric precipitation, urban runoff, and drainage from agricultural land, in particular from land on which fertilizers have been applied.

8.4.4 Chloride

The concentrations of chloride observed in the Kuils-Eerste River catchment are high enough to induce a variety of effects within both aquatic and terrestrial ecosystems. These effects include acidification of streams, mobilization of toxic metals through ion exchange, changes in mortality and reproduction of aquatic plants and animals, altered community composition of plants in riparian areas and wetlands.

Consequently, broad management strategies need to be designed to cope with the pollution challenges.

The effects of high values of concentration of chloride include among others, inhibition of plant growth, impaired reproduction, and reduced diversity of organisms in streams. Sources of chloride in water in the catchment include wastewater treatment plants, failed septic systems especially from the residential areas, and farming operations that do not use good practices especially from all land-cover types that deal with agricultural activities.

The high concentrations of chlorides are due to several factors. The rate of water uptake by the plants, evaporation from the soil surface, soil type, and rainfall amount and distribution are among some of the factors to consider. Excessive chloride may accumulate in low-lying, poorly drained soils. Management strategies like the improvement of drainage are targeted at land-cover types that deal with agricultural activities since these have shown that levels of chloride concentration is above the water quality guideline limit.

8.5 Discussion

The concentration values obtained in the study indicate that there is a need to consider management strategies since some values are not acceptable within the DWA guideline limit. However, when the same results are compared with those obtained in studies conducted by the City of Cape Town, there is need to focus on the areas where the city has indicated presence of high values. The annual median value of phosphorus concentration is 1.876 mg L^{-1} for the built up areas of the city (City of Cape Town 2004) which compares well with the result obtained in this study of 1.8 mg L^{-1}.

The City of Cape Town has adopted Integrated Catchment Management as a process and established a Catchment Management Department. Catchment Management Plans and the establishment of broadly representative Catchment Management Forums have been set up to prioritise catchment management issues and strategies. Such forums have been established for the Kuils River catchment.

As a preliminary step, the concentration levels of phosphorus in water for each land-cover indicate that the mean concentration of phosphorus exceeds the annual median values limit for surface waters of 1.876 mg L^{-1} over 7 land-cover types. The contribution is likely to continue in the future with urbanisation this assumption provides a useful index of time against which the effects of catchment-scale implementation of strategies to reduce nutrient loading may be based.

Society accepts a certain degree of impact and degradation in selected systems as a trade-off for economic benefits accruing from those activities that are leading to pollution of the resource (DWA, Nov 2004) as a result there is the need for implementation of integrated water resource management (IWRM) by catchment authorities.

Due to the intimate connection between water resources and land-use, the sustainable development of either requires their management to be integrated (Görgens *et al.*, 1998), which creates more challenges since a different style of management to that traditionally used for resource exploitation is needed for resource protection. Local Authorities are both impactors and regulators as in the case of Cape Town city (Van

Zyl, 2005). Water serves many different purposes, functions and services and therefore requires holistic management on demands and threats to it (Mazibuko, 2004).

The first management option evaluated for the catchment is the reduction of all fertiliser applications on six land-cover types, a move advocated by Addiscott and Powlson (1989) as a means of reducing pollutant concentrations in surface waters draining agricultural land. All land-cover types related to agricultural activities are the majority (grassland, improved grassland/vegetation crop, dense/ grassy vineyard, and fallow vineyard). To improve water quality in the selected land-cover types, some land should be retired from agricultural use and restoration efforts also should be needed, as suggested by Mitsch and Gosselink (2000).

Rapid urbanization poses a clear potential for future water quality problems. MDR informal townships and LDR informal squatter camps within the catchment are responsible for the production of more than 3.0 mg/L of phosphorus within their respective jurisdictions. Therefore, the essential management focus for the catchment currently must be placed on controlling nonpoint sources.

Meals *et al.*, (2008) suggest that nutrient load reductions using targeted management are greater than those using random management; therefore cost-effective management should target the land areas at greatest risk of nutrient losses like the grassland (3.32 mg L^{-1}) and improved grassland/ vegetation crop (3.78 mg L^{-1}). The results are in accordance with a study that found targeted watershed management to be more effective in achieving water quality protection than voluntary adoption of best management practices (Mankin *et al.*, 2005). Targeted retirement of land from agricultural production and the restoration of wetlands are suggested as feasible management actions.

Vegetation management should consider land-cover and harvest method as indicators of the amount of crop residue and cover left on a field during the non-growing season to protect the soil surface from phosphorus movement.

The management of the Kuils-Eerste River catchment as a contribution towards achievement of water quality objectives is possible through a holistic approach that

would focus on the nutrient management plan which the authorities could adopt. Nhapi (2004) in a study of options for water management in Harare Zimbabwe made several observations that also have a bearing on what the Kuils-Eerste River catchment has experienced. A nutrient management plan is a set of conservation practices designed to use fertilizer and/or manure effectively while protecting against the potential adverse impacts of manure, erosion and organic by-products on water quality. On the other hand, serious consideration of other pollution prevention options should be prioritized. Pollution prevention practices include low impact development techniques, installation of green roofs and improved chemical handling (e.g. management of motor fuels and oil, fertilizers and pesticides). Runoff mitigation systems include infiltration basins, bio-retention systems, constructed wetlands, retention basins and similar devices. Some of the land-cover types should not be promoted in the catchment like the LDR informal squatter camps, MDR informal squatter camps, HDR informal townships and MDR informal townships. These land-cover types have contributed significantly to diffuse pollution as indicated by the concentration values recorded.

Since there are a number of informal settlements, informal townships and other forms of residential structures being developed in the catchment, these should be formalised and proper sanitation and storm water drainage infrastructure should be put in place. Use of the results presented here should enable city planners to include runoff mitigation systems in the designs for built up infrastructure in the catchment.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This chapter aims to synthesize the main findings of this study, relate them to the stated aims and objectives, and outline some recommendations for further work. The major objectives of this study, as stated at the beginning of the thesis, have been achieved with the establishment of the types and spatial distribution of land-cover types within the Kuils-Eerste River catchment. From the land-cover map there is a suggestion that with 14.3 % of the catchment being taken up by residential areas. This figure is likely to increase resulting in more agricultural land being lost to urban sprawl. This is a common trend in South Africa and hence diffuse pollution management has to be considered as one critical area. Furthermore, one of the critical components of this study was to conduct hydrological experiments (setting up of runoff plots) at selected locations for measuring surface runoff within the catchment in order to inform the basis upon which a catchment wide analysis of the pollution problem could be studied. The generation of the necessary data, for the GIS models used in the study area to estimate runoff, infiltration and NPS pollution, was then made possible through the results obtained from the experimental plots.

The estimation of surface runoff was realised through a GIS model based on the curve number method. Further activities carried out, made assessment of runoff water quality achievable through sampling and generation of a water quality database (event mean concentrations). The RINSPE AND N-SPECT models offered a better understanding of water quality parameters in relation to the various land-cover types that characterise the catchment.

The approaches used in this study have shown that the land-cover data are a good background for the estimation of pollutant inputs to the river system and other water bodies and for planning the measures to reduce them. The most effective measures for pollution mitigation are those that can be applied, such as the application of bal-

anced fertilization in all agriculture related land-cover types. Such effective measures as planting of forests on arable land would reduce pollution in the catchment.

This study has also shown that NPS pollution is significantly influenced by the hydrological and meteorological properties of the catchment. As a framework for assessing NPS pollution in an urbanising catchment, the approach used in this study allows comparison between model estimates obtained using the two models *RINSPE* and *N-SPECT*.

The study demonstrated that the most important parameters were land-cover type and rainfall, and depending on how these varied, the amount of runoff and the type of pollutants also varied. Using the knowledge gained through this study, management guidelines for pollution control in the catchment have been proposed.

The following broad conclusions have been drawn from the study:

I. A detailed land-cover type map containing 36 classes, used for assessing NPS pollution, was generated using an integrated approach, based on the use of remotely sensed data and GIS analysis. The final land-cover type map generated, reflected the complex nature of land-cover characteristics of the catchment. Results obtained showed that the land-cover type characteristics of the catchment extended from urban and suburban settlement including industrial and commercial activities in the western part of the catchment, with extensive open agricultural fields, mainly vineyards, in the central part of the catchment, and included forest tree plantation and naturally vegetated areas in the eastern section. The contribution of each land-cover type, towards the quality of surface water in the catchment has been clearly shown. The differences amongst the land-cover type have contributed significantly to the variation of water quality meriting in some instances the proposal of management strategies to reduce those pollutants that were of above acceptable standards. Land-cover classification has shown that a greater percentage (40 %) of the land-cover in the catchment is predominantly agricultural.

II. Results from the analysis of the data revealed that water quality varied with different land-cover types. However, the variations of pollutant loads in the plots are worth noting with nitrogen registering highest values in vineyards and grassland, NO_3-N in grassland and vineyards, phosphorous in grassland and vineyards while chloride was highest in grassland and vineyards and finally for TSS highest values were recorded in vineyards and mountain forest. These results confirm the existence of variability of water quality with land-cover type, the same noted with the catchment wide analysis.

III. The approach has shown that catchment specific data is appropriate in understanding the dynamics of pollution behaviour in agreement with what NOAA Coastal Services Center (2004); Line *et al*. (2002); Oki (2003); and City and County of Honolulu (2007) have found out in similar studies. The summary of outcomes from the study undertaken include; 1) the development of a water quality profile for Kuils-Eerste River catchment for an overall evaluation of the catchment and the different land-covers that contribute to the pollutant loading; 2) the identification of the various sources of contamination to allow for the implementation of appropriate management strategies; 3) the identification of sources of pollution which cause and sustain poor water quality in the catchment; and 4) the development of a critical nonpoint monitoring programme for the Cape Town Metropolitan Authorities for the monitoring, management and mitigation of pollutant inputs in the catchment. The Event Mean Concentration (*EMC*) was derived as the flow-weighted mean concentration of contaminant. Individual storm *EMC* values were then summarised as either the arithmetic mean, the flow-weighted mean (total load from storm events divided by total discharge volume), or the median of event *EMCs*. Since the assessment of urban overland flow quality of Kuils-Eerste river catchment required a consideration of different types of land-cover, it was represented by the event mean concentration (*EMC*) value. The *EMC* determined, represent the concentration of a specific pollutant contained coming from a particular land-cover type within the catchment. The aim of the study was fulfilled which sought to explain how the quality of surface runoff varied on dif-

ferent land-cover types and to provide guidelines for minimizing water pollution that may be occurring in the Kuils-Eerste River catchment.

IV. GIS technology has been applied to establish the contribution of each land-cover type to the pollutant loads at the catchment scale.

9.2 Recommendations

Based on the outcomes of this study, the following recommendations are suggested:

- The study recommends that further work to assess the *RINSPE* and *N-SPECT* model structures in the face of the temporal changes that are taking place in urban sprawl within the catchment be conducted as an ongoing research focus. The modelling approach presented in this study was based on model data input structure that only considered annual output results and subsequent estimation of parameters through an a priori approach using annual rainfall, soils and pollutant properties. In-depth studies could also be undertaken to understand the interaction between urban water quality and quantity; the interaction of urban water supply, sanitation (including grey water), storm water, groundwater and urban streams; as well as into the development and use of more sophisticated models that, wherever appropriate, take into account sociological and ecological concerns.

- This study recommends further work to assess the influence and contribution of base flow into the quality of water in the rivers and bring out the real situation of NPS pollution in the catchment, which does not necessarily consider surface runoff only, but other components of the hydrological cycle. In view of this, the development of a model that would improve on the present and focus on the base flow contribution to stream flow and the related pollution scenarios could enhance the understanding and management of the pollution issues in the catchment.

- The study recommends that there is need to continuously update land-cover data as the level of urbanisation in Cape Town is high and the agricultural

land is being converted to residential area of varying densities. If a high level of confidence can be expressed in the information available on topography, soil types, land-cover type and meteorological data the *RINSPE* and *N-SPECT* models would estimate the parameters with little difficulty. It makes sense that improving the databases of spatial data and revision of the pollutant parameters estimation approaches for the most critical areas would be made with greater efficiency.

It is intended that if the understanding of NSP pollution is to be advanced within South Africa, and the region an appropriate conceptual structure and practical methods are required for handling NSP pollution modelling. If the aim of developing water quality standards is to encourage more widespread criticism of data and water quality models in Africa, which will create avenues for further research, then more should be directed towards understanding how diffuse pollution behaves. In addition, efforts to improve estimation capabilities, improvements in spatial databases, and quantifying the spatial temporal aspects in catchments are needed. However, in practice, there will always be challenges even if efforts are made to reduce these and therefore there is need for parallel approaches to incorporate aspects that are not attended to by the other approaches. Unless the input information base is improved, neither the development of new models, nor improving the application methodology of existing models is likely to improve the situation.

REFERENCES

Acutis, M., Donatelli M. 2003. SOILPAR 2.00: Software to estimate soil hydrological parameters and functions. *European Journal of Agronomy*, 18, 373–377

Addiscott, T.M., Powlson D.S., 1989. Laying the ground rules for nitrate. *New Science*, 122, 28-29.

AFDEC. 2006. *WATER: A Shared Responsibility*. World Water Assessment Programme, Country Report.

AFRICOVER. 1998. *Technical Document on the AFRICOVER Land-cover Classification Scheme: A Dichotomous, Modular-Hierarchical Approach.* FAO Research, Extension and Training Division, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Ahearn, D.S., Sheibley R.S., Dahlgren R.A., Anderson M., Jonson J., Tate K.W. 2005. Land-use and land-cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. *Journal of Hydrology*, 313, 234–247.

Allan, J.D., Erickson D.L., Fay J. 1997. The influence of catchment land-use on stream integrity across multiple spatial scales. *Freshwater Biology*, 37, 149–161.

Allen, R.B., Herold C.E. 1988. *Vaal River system analysis: Water quality modelling*. DWA Report No PC000/00/7086, Pretoria, South Africa.

Anderson, J. R., Hardy E. E., Roach J. T., Witmer W. E. 1976. *A land-cover and land-cover classification system for use with Remote Sensing data*. USGS Professional Paper, 964, 138– 145. Reston, Virginia' U.S. Geological Survey.

ANZECC. 1992. *Australian Water Quality Guidelines.* Australian and New Zealand Environment & Conservation Council, Melbourne, Australia.

Bailey, A. 2008. *Water resources simulation model for Windows, Theory Document*, PWMA 04/000/00/6107. (DWA, WRC, SSI).

Bailey, G.W., Swank R. 1983. Modelling Agricultural Nonpoint Source Pollution: A Research Perspective. In: Shaller, F. W. and G. W. Bailey (Eds.), *Agricultural Management and Water Quality*. The Iowa State University Press, Ames, Iowa, 27-47.

Baltas, E.A., Dervos N.A., Mimikou M.A. 2007. Determination of the SCS initial abstraction ratio in an experimental watershed in Greece. *Hydrology and Earth System Sciences,* 11, 1825–1829.

Bhaduri, B., Harbor J., Engel B., Grove M. 2000. Assessing Catchment-Scale, Long-Term Hydrological Impacts of Land-Use Change Using a GIS-NPS Model. *Environmental Management,* 26, (6), 643–658.

Boyacioglu, H. 2006. Surface water quality assessment using factor analysis, *Water-SA*, 32, (3), 23-57

Brown, C., Magoba R., (Eds). 2009. *Rivers and Wetlands of Cape Town caring for our rich aquatic heritage.* Water Research Commission, Report No TT376/08, Pretoria, South Africa.

Burke, L. 2006. *Land-cover change and catchment based catchment- impacts to the Mesoamerican Reef*. An analysis under the ICRAN partnership. World Resources Institute.

Butcher, J.B. 2003. Build-up, Wash-off and estimated Mean Concentrations. *Journal of the American Water Resources Association*: 39, (6), 234-285

Carpenter, S.R., Caraco N.F., Correll D.L., Howarth R.W., Sharpley A.N., Smith V.H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*. 8, 559-568.

CCREM. 1987. *Canadian Water Quality Guidelines*. Prepared by the Task Force on Water Quality Guidelines of the Canadian Council of Resource and Environmental Ministers. Ontario, Canada.

Chow, M.F., Yusop Z. 2008. *A Review of Event Mean Concentration (EMC) for Urban Storm water Runof.,* International Conference on Environmental Research and Technology (ICERT 2008).

Chow, V. T, Maidment D. R., Mays L. W. 1988. *Applied Hydrology*. McGraw-Hill, Inc.

City and County of Honolulu. 2000. *Department of Permitting and Planning*. Wai‘anae Sustainable Communities Plan. http://honoluludpp.org/planning/Waianae/Wai5.pdf. Accessed June 15, 2010.

City of Cape Town. 2004. *Catchment, storm water & river management 2003-2004.* Cape Town, South Africa.

City of Cape Town. 2004. *Water services development plan of the city of Cape Town, Comprehensive WSDP*. Chapter 6: Environmental Issues, www.capetown.gov.za/water/wsdp. Accessed July 07 2009.

Cude, C. 2001. Oregon Water Quality Index: a tool for evaluating water quality management effectiveness. *Journal of American Water Resources Association,* 37 (1), 125-137.

Cullis, J., Görgens A., Rossouw N. 2005. *First order estimate of the contribution of agriculture to non-point source pollution in three South African catchments: Salinity, Nitrogen and Phosphorus.* Water Research Commission, Report No 1467/2/05, Pretoria.

Dabrowski, J. M., Peall S. K., Niekerk C., Van A., Reinecke A. J., Day J. A., Schulz R. 2002a. Predicting runoff-induced pesticide input in agricultural subcatchment surface waters: linking catchment variables and contamination. *Water Air Soil Pollution,* 135, 265–283.

Dabrowski, J.M., Peall S.K.C., Reinecke A.J., Liess M., Schulze R. 2002b. Runoff-related pesticide input into the Lourens River, South Africa: basic data for exposure assessment and risk mitigation at the catchment scale. *Water Air Soil Pollution,* 135, 265–283.

Dallas, H.F., Day J.A. 1993. *The Effect of Water Quality Variables on Riverine Ecosystems: A Review*. Water Research Commission Report No. TT 61/93. Pretoria.

De Bie, C. A., van Leeuwen J. A., Zuidema P. A. 1996. *The Land-cover Database; a Knowledge-Based Software Program for Structured Storage and Retrieval of User-Defined Land-cover Datasets.* ITC, FAO, WAU.

Debels, P., Figueroa R., Urrutia R., Barra R., Niell X. 2005. Evaluation of water quality in the Chillan River (Central Chile) using physicochemical parameters and a modified water quality index. *Environmental Monitoring Assessment,* 110, 301-322.

Deksissa, T., Meirlaen J, Ashton P. J., Vanrolleghem P. A. 2004. Simplifying dynamic river water quality modelling: A case study of inorganic nitrogen dynamics in the Crocodile River (South Africa). *Water Air and Soil pollution*, 155, 303-320.

Department of Water Affairs (DWA). 1996. *South African Water Quality Guidelines Volume 7 Aquatic Ecosystems.* Pretoria, South Africa.

Department of Water Affairs (DWA). 1996. *South African Water Quality Guidelines (second edition). Volume 7: Aquatic Ecosystems*. Pretoria, South Africa.

Fares, A., Deb S.K., Ryder M.H. 2009. *Use of Filter Strips for Improved Surface Water Quality Soil and Crop.* College of Tropical Agriculture and Human Resources (CTAHR) Management.

Feio, M.J., Norris R.H., Graca M.A.S., Nicholas S. 2008. Water Quality assessment of Portuguese streams: Regional or national predictive models? *Ecological Indicators*, 9, (4), 791-806.

Fennessey, L.A.J., Hawkins R.H. 2001. *The NRCS Curve Number, a New Look at an Old Tool.* Proceedings of the 2001 Pennsylvania Storm water Management Symposium, Re-thinking Comprehensive Storm Water Management—Integrating Quality, Volume and Peak Controls, October 17-18, 2001.

Fisher, R. C. 2003. *The Impacts of Channelization on the Geomorphology and ecology of the Kuils River, Western Cape, South Africa*. Unpublished Master's Thesis submitted to the University of the Western Cape, Bellville. Cape Town, South Africa.

Francey, M., Fletcher T. D., Deletic A., Duncan H. 2010. New insights into the quality of Urban Storm Water in South Eastern Australia. *Environmental Engineering.* 136, (4), 381-390.

Gascho, G.J., Wauchope R.D., Davis J.G., Trueman C.C., Dowler C.C., Hook J.E., Sumner H.R., Johnson A.W. 1998. Nitrate-nitrogen, soluble, and bio available phosphorus runoff from simulated rainfall after fertilizer application. *Soil Science Society American Journal,* 62, 1711–1718.

Gergel, S. E., Turner M. G., Miller J. R., Melack J. M., Stanley E. H. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic Sciences*, 64, 118–128.

Gimtnez, D., Perfect E., Rawls, W.J., Pachepsky Ya. 1997. Fractal models for predicting soil hydraulic properties: A review, *Engineering Geology*, 48, 161-183.

Goel, P.K. 2006. *Water pollution- Causes, effects and control.* New Delhi. New Age International.

Gosselink, J. and Turner, R. 1978. The role of hydrology in freshwater ecosystems. In: R. Good, D. Wigham, and R. Simpson (Eds.). *Freshwater wetlands: Ecological processes and management potential.* Academic Press, New York. 63–78.

Green, I.R.A., Stephenson D., Lambourne J.J. 1986. *Urban hydrology and drainage: Storm water pollution analysis*. Water Research Commission, Report No115/10/66, Pretoria, South Africa.

Grobicki, A. 2001. *Integrated catchment management in an urban context the Great and Little Lotus Rivers, Cape Town.* Water Research Commission, Pretoria, Report No 864/1/01, Pretoria, South Africa.

Grunwald, S., Norton, L. D. 1999. An AGNPS-Based Runoff and sediment field model for two small watersheds in Germany. *Transactions of the ASAE,* 42(6), 1723-1731.

Gui, D., Lei J., Zeng F., Mu G., Zhu J., Wang H., Zhang Q. 2010. Characterizing variations in soil particle size distribution in oasis farmlands. A case study of the Cele Oasis, *Mathematical and Computer Modelling Journal*.

Hansen, M. C., Defries R. S., Townshend J. R. G., Sohlber G. R. 2000. Global land-cover classification at 1 km spatial resolution using a classification tree approach. *International Journal of Remote Sensing,* 21, (6 & 7), 1331–1364.

Hart, S.C., Firestone M.K., Paul E.A., Smith J.L. 1993. Flow and fate of soil nitrogen in annual grassland and a young mixed conifer forest. *Soil Biology and Biochemistry,* 25, 431–442.

Hartanto, H., Prabhu R., Widayat A. S.E., Asdak C. 2003. Factors affecting runoff and soil erosion: plot-level soil loss monitoring for assessing sustainability of forest management, *Forest Ecology and Management,* 180, 361–374.

Hatt, B. E., Fletcher T. D., Walsh C. J., Taylor S. L. 2004. The Influence of Urban Density and Drainage Infrastructure on the Concentrations and Loads of Pollutants in Small Streams. *Environmental Management,* 34, (1), 112–124.

Hawkins, R. H. 1998. *A comparison of predicted and observed runoff curve numbers.* Proceeding of Special Conference Irrigation and Drainage Division, Flagstaff Arizona, ASCE, New York, NY.

Hawkins, R. H., Jiang R., Woodward D.E., Hjelmfelt A.T., Van Mullem J.A., Quan Q.D. 2002. *Runoff Curve Number Method: Examination of the Initial Abstrac-*

tion Ratio. Proceedings of the Second Federal Interagency Hydrologic Modelling Conference, Las Vegas, Nevada, U.S. Geological Survey, Lakewood, Colorado, ASCE Publications.

Heathwaite, A.L. 2003. Making process-based knowledge useable at the operational level: A framework for modelling diff use pollution from agricultural land. *Environmental Modelling Software*, 18, 753–760.

Hendricks, Y. 2003. *The Environmental Health Impacts Associated with Flooding and Pollution of Riverine Environments: A case study of the Kuils and Eerste Rivers*. Unpublished MA Thesis. University of the Western Cape, Bellville.

Herold, C. E., van Eeden P. H. 2001. *The feasibility of using low cost modelling techniques to relate river water quality and diffuse loads to a range of land-covers.* Report No 796/1/01, Water Research Commission, Pretoria, South Africa.

Heydorn, A.E.F., Grindley J.R. 1982. *Estuaries of the Cape, part II: Synopses of available information on individual systems*. Report No 16, Eerste (CSW6) CSIR Research Report 415, Stellenbosch, South Africa.

Hill, A.R. 1981. Stream phosphorus exports from watersheds with contrasting land-uses in southern Ontario. *Water Resources Bulletin*, 17, 627–634.

Hoffmann, J. R. 1994. *Non-point source pollution in the Hennops River valley*. Water Research Commission, Pretoria, South Africa.

Holloway, J.M., Dahlgren R.A. 2001. Seasonal and event-scale variations in solute chemistry for four Sierra Nevada catchments. *Journal of Hydrology*, 250, (1–4), 106–121.

Hu, Y.F., Liu J.Y. Zhuang D.F., Cao H.X., Yan H.M. 2005. Fractal dimension of soil particle size distribution under different land-use/land-coverage. *Acta Pedologica Sinica*, 42, (2), 36-339.

Huai-en, L., Joseph I., Hun-Wei LEE., Ming C. 2003. Nutrient load estimation methods for rivers. *International Journal of Sediment Research*, 18, (4), 346-351.

Huang, G.H., Zhang R.D. 2005. Evaluation of soil water retention curve with the pore-solid fractal model, *Geoderma*, 127, 52-61.

Huber, W.C., Dickenson R.C. 1988. *Storm water management model: User's manual, Version 4.* EPA 600/3-88/001a, US EPA, Athens, GA.

Hughes, D.A., Metzler W. 1998. Assessment of three monthly rainfall-runoff models for estimating the water resource yield of semi-arid catchments in Namibia. *Hydrological Science Journal,* 43(2), 283-297.

Hughes, D.A., van Ginkel C. 1994. Nutrient loads from developing urban areas, a simulation approach and identification of information requirements. *WaterSA,* 20,(2), 139-150.

Hunsaker, C. T., Levine D.A. 1995. Hierarchal approaches to the study of water quality in rivers. *BioScience,* 45, 193-203.

Jabro, J.D. 1992. Estimation of saturated hydraulic conductivity of soils from particle size distribution and bulk density data. *Transactions ASAE,* 35, (2), 557-560.

Johnson, L.B., Richards C., Host G.E., Arthur J.W. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems, *Freshwater Biology*, 37, 193–208.

Joseph, R. 2003. *The Causes and Effects of Solid Waste Pollution of Rivers in an Urban Environment: A Case Study of the Eerste River, Cape Town, South Africa*. Unpublished M.A Thesis. University of the Western Cape, Bellville.

Kang, Y. T., Bartholic J. 1994. *A GIS-based agricultural nonpoint source pollution management system at the catchment level*. ASPRS/ACSM.

Khan, F., Husain T., Lumb A. 2003. Water quality evaluation and trend analysis in selected watersheds of the Atlantic Region of Canada. *Environmental Monitoring and Assessment,* 88, 221-242.

Kienzel, S.W., Lorentz S.A., Schulze R.E. 1997. *Hydrology and water quality of the Mgeni Catchment.* Report No TT87/97, 88, Water Research Commission, Pretoria, South Africa.

Kleinman, P.J.A., Srinivasan M.S., Sharpley A.N., Gburek W.J. 2005. Phosphorus leaching through intact soils columns before and after poultry manure application. *Soil Science,* 170,153–166.

Kloppers, W.S. 1989. *Urban storm water runoff: a water quality study*. CSIR Research Report No. 685, Ematek, Stellenbosch, South Africa.

Konrad, C. P., Booth D. B. 2005. *Hydrological Changes in Urban Streams and Their Ecological Significance.* American Fisheries Society Symposium 47, 157–177.

Laws, E.A. 2000. *Aquatic pollution: An introductory text*. New York. John Wiley and Sons.

Lenz, R.M., How C.F.H. 2000. *Modelling in an urban park environment: a water quality modelling case study in Central Park.* 4th International Conference on Integrating GIS and Environmental Modelling (GIS/EM4): Problems, Prospects and Research Needs. Banff, Alberta, Canada, September 2 - 8, 2000.

León, L.F., Soulis E.D., Kouwen N., Farquhar G.J. 2000. Nonpoint Source Pollution: A Distributed Water Quality Modelling Approach. *Journal of Water Research*, 35, (4), 997-1007.

Line, D.E., White N.M., Osmond D.L., Jennings G.D., Mojonnier C. B. 2002. *Pollutant export from various land-uses in the Upper Neuse River Basin.* Water Environment Research.

Liou, S.M., Lien S., Wang S.H. 2004. Generalized water quality index for Taiwan. *Environmental Monitoring and Assessment*, 96, 35-52.

Liu J., Liao W., Zhang Z., Zhang H., Wang X., Meng N. 2007. Effect of Phosphate Fertilizer and Manure on Crop Yield, Soil P Accumulation, and the Environmental Risk Assessment. *Agricultural Sciences in China*, 6, (9), 1107-1114.

Lord, D. A., Mackay H. M. 1993. *The effect of urban runoff on the water quality of the Swartkops estuary.* Water Research Commission, Pretoria, South Africa.

Magadza, C.H.D. 1997. Water pollution and catchment management in Lake Chivero. In: N. A. G. Moyo (Ed.) *Lake Chivero, a Polluted Lake, International Union for the Conservation of Nature and Natural Resources*. University of Zimbabwe Publications, Harare, Zimbabwe, 13–26.

Magadza, C.H.D. 1994. An evaluation of eutrophication control in Lake Chivero using multivariate analysis of plankton samples. In: H. Dumont, J. Green & H. Masundire (Eds), *Studies in the Ecology of Tropical Zooplankton.* Kluwer Academic Press, London. 277– 92.

Mankin, K.R., Tuppad P., Devlin D.L., McVay K.A. 2005. Strategic targeting of watershed management using water quality modelling. *Transactions on Ecology and the Environment*, 83, 327–337.

Matji, M.P., Görgens A.H.M. 1999. *A comparative study of phosphorus production simulation models in rural catchments of the Western and Eastern Cape*. Ninth

SA National Hydrological Symposium, Western Cape, South Africa, 29-30 November, 1999.

Mazibuko, G., Pegram G. 2004. *Evaluation of the opportunities for cooperative governance between catchment management agencies and local government*. Pegasus Strategic Management, Project No. K5/1433, Water Research Commission, Pretoria, South Africa.

Meals, D.W., Cassell E.A., Hughell D., Wood L., Jokela W.E. 2000. Dynamic spatially explicit mass balances modelling for targeted watershed phosphorus management: II Modelling application. *Agriculture Ecosystems & Environment*, 127,(3–4), 223–233.

Mengistu, D.A., Salami A.T. 2005. Application of Remote Sensing and GIS in Land-cover mapping and change detection in a part of south western Nigeria. *African Journal of Environmental Science and Technology*, 1, (5), 99-109.

Mishra, S. K., Jain M. K., Pandey R. P., Singh V. P. 2005. Catchment area-based evaluation of the AMC-dependent SCSCN-inspired rainfall-runoff models. *Journal of Hydrological Process*, 19, (14), 2701–2718.

Mishra, S. K., Jain M. K., Singh V. P. 2004. Evaluation of the SCSCN- based model incorporating antecedent moisture. *Journal of Water Resources Management*, 18, 567–589.

Mishra, S. K., Sahu R. K., Eldho T. I., Jain M. K. 2006. An Improved Ia-S Relation Incorporating Antecedent Moisture in SCS-CN Methodology. *Journal of Water Resources Management*, 20, 643–660.

Mishra, S. K., Singh V. P. 2003. *Soil Conservation Service Curve Number (SCS-CN) Methodology*. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mishra, S. K., Singh V. P. 2004. Long-term hydrological simulation based on the Soil Conservation Service curve number. *Journal of Hydrological Process*, 18, 1291–1313.

Mitsch, W. J., Gosselink J. G. 2000. The values of wetlands: importance of scale and landscape setting. *Ecological Economics*, 35, (1), 25–33.

Montero, E. 2005. Rényi dimensions analysis of soil particle-size distributions. *Ecological Modelling*, 182, 305-315.

Moolman, J., Quibell G., Hohls B. 2003. A qualitative (GIS Based) Model of non-point source areas (Modelling suspended sediment in the Olifants river catchment) In: G. Quibell, G.C. Pegram, J. Moolman, M.P. Matji, B. Hohls and A.H.M. Görgens (Eds). *Development of a nonpoint source assessment guide: Test case studies*. Report No 696/2/03, Water Research Commission, Pretoria, South Africa.

Nangia, V., Gowda P.H., Mulla D.J., Sands G.R. 2008. Water Quality Modelling of Fertilizer Management Impacts on Nitrate Losses in Tile Drains at the Field Scale. *Journal of Environmental Quality*, 37, 296-307.

Naranjo, E. 1998. *A GIS based non point pollution simulation model*. http://www.esri.com/library/userconf/europroc97/4environment/E2/e2.htm. Accessed 5 July 2008,

Návar, J., Synnott T.J. 2000. Surface Runoff, Soil Erosion, And Land-cover In North-eastern Mexico. *TERRA*, 18, (3), 46-67

Nhapi, I. 2004. *Options for water management in Harare, Zimbabwe*. PhD Thesis, Wageningen University, Wageningen, The Netherlands.

Niehoff, D., Fritsch U., Bronstert A. 2002. Land-use impacts on storm-runoff generation: scenarios of land-use change and simulation of hydrological response in a meso-scale catchment in SW-Germany. *Journal of Hydrology,* 267, 80–93.

NOAA Coastal Services Center. 2004. *Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) Technical Guide Version 1.0* Release 1, November 2004.

Novotny, V. 1992. Unit pollution loads- their fit in abetment strategies. *Water Environment & Technology,* 4, (1), 40-43.

Oki, D.S. 2003. *Surface water in Hawaii.* US Geological Survey Fact Sheet 045-03, Honolulu. I.

Osborne L.L., Wiley M.J. 1988. Empirical relationships between land-use cover and stream water-quality in an agricultural watershed. *Journal of Environmental Management,* 26, 9–27.

Pearce, M. W., Schumann E. H. 1997. *The effects of land-cover on Gamtoos Estuary water quality*. Water Research Commission, Pretoria, South Africa.

Pegram, G. C., Görgens A. H. 2001. *A guide to nonpoint source assessment, to support water quality management of surface water resources in South Africa.* Sigma Beta Consulting Engineers, Report No. TT142/01, Water Research Commission, Pretoria, South Africa.

Pegram, G. C., Görgens A. H., Quibell C. 1990. *A framework for implementing nonpoint sources management under the National Water Act*. DWAF Report No WQP0.1 and Report No. TT115/99, Water Research Commission, Pretoria, South Africa.

Petersen, C. 2002. *Rapid Geomorphological Change in an urban Estuary: a case study of the Eerste River, Cape Town, South Africa*. Unpublished Master's Thesis University of the Western Cape, Bellville.

Pote, D.H., Daniel T.C., Sharpley A.N., Moore P.A., Edwards D.R., Nicholas D.J. 1996. Relating extractable phosphorus to phosphorus losses in runoff. *Soil Science Society American Journal*, 60, 855–859.

Quenzer, A.M. 1998. *A GIS Assessment of the Total Loads and Water Quality in the Corpus Christi Bay System.* Center for Research in Water Resources, [http://version0.neonet.nl/itc/education/larus/landuse/manual.html]. Accessed 24 July 2007.

Quibell, G., Pegram G. C., Moolman J., Matji M.P., Hohls B., Görgens A. H. M. 2003. *Development of a nonpoint source assessment guide: test case studies.* Report No. 696/2/03, Water Research Commission, Pretoria, South Africa.

Reichert, P., Borchardt D., Henze M., Rauch W., Shanahan P., Somlyody L., Vanrolleghem P.A. 2001, *River Water Quality Model No. 1 (RWQM1).* Scientific and Technical Report, IAWQ, London.

Sargaonkar, A., Deshpande V. 2003. Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. *Environmental Monitoring Assessment*, 89, 43-67.

Schapp, M.G., Leij F.J., van Genuchten M.T. 2001. Rosetta: A computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. *Journal of Hydrology*, 251, (3), 163–176.

Schmitz, P.M.U., de Villiers G. du T. 1997. *The development of an urban component of the ACRU model*. Report No. 424/1/97, Water Research Commission, Pretoria, South Africa.

Schulze, R.E., Maharaj M., Lynch S.D., Howe B.J., Melville-Thomson B. 1996. *South African Atlas of Agrohydrology and – Climatology*. Report No. TT 82/96, Water Research Commission, Pretoria, South Africa.

Sharpley, A.N., Kleinman P.J.A. 2003. Effect of rainfall simulator and plot scale on overland flow and phosphorus transport. *Journal of Environmental Quality*, 32, 2172–2179.

Sharpley, A.N., McDowell R.W., Weld J.L., Kleinman P.J.A. 2001. Assessing site vulnerability to phosphorus loss in an agricultural catchment. *Journal of Environmental Quality*, 30, 2026–2036.

Showalter, P., Silberbauer S., Moolman M., Howman J., 2000. *Revisiting Rietspruit: Land-cover change and Water Quality in South Africa.* Proceedings of the ICRSE 28th International symposium on Remote Sensing of environment and the Third AARSE Symposium, Cape Town, South Africa, 27 to 31 March 2000.Technical Session 11. [http://www.dwaf.gov.za/iwqs/rietprt/showaltr1.pdf]. Accessed 14 August 2009.

Simeonov, V., Einax J.W., Stanimirova I., Kraft J. 2002. Environmetric modelling and interpretation of river water monitoring data. *Analytical and Bio analytical Chemistry*, 374, 898-905.

Simpson, D. E. 1998. *Collection and evaluation of runoff water quality from a disused feedlot in KwaZulu-Natal*. Report No. 498/1/98, Water Research Commission, Pretoria, South Africa.

Simpson, D. E., Stone V. C., Hemens J. 1998. *Water pollution aspects of storm water runoff from a commercial land-cover catchment in Pinetown, Natal*. National Institute of Water Research of the Council for Scientific and Industrial Research, South Africa.

Simpson, D.E. 1986. *A study of runoff pollution from an urban catchment*. Unpublished MSc Thesis, University of Natal, South Africa.

Simpson, D.E., Kemp P. 1982. Quality and quantity of storm water runoff from a commercial land use catchment in Natal, South Africa. *Water Science Technology*, 14, 323-338.

Smart, R.P. Soulsby C., Neal C., Wade A., Cresser M.S., Billett M.F., Langan S.J., Edwards A.C., Jarvie H .P., Owen R. 1998. Factors regulating the spatial and temporal distribution of solute concentrations in a major river system in NE Scotland. *The Science of the Total Environment,* 221, 93–110.

SouthAfrica.Info. 2010. *Gateway to the Nation map,* Media publications, [www.southafrica.info]. Accessed: 24 June 2010.

Srinivasan, M.S., Gburek W. J., Hamlett J.M. 2002. Dynamics of storm flow generation: A field study in east-central Pennsylvania. *Hydrological Processes*, 16, 649–665.

Swank, W. T., Bolstad P.V. 1994. Cumulative effects of land-cover practice son water quality. In: Illim, N.E, Peters R.J., V.V., Tsirkunov (Eds). *Hydrochemistry 1993: hydrological, chemical and biological processes affecting the transformation and transport of contaminants in aquatic environments*. Proceedings of the Rostv-on-don Symposium, May 1993, 409-421, IAHS Publication 219.IAHS Press, Oxfordshire, UK.

Taylor, V. 2000. *A study of the influence of the Kuils/Eerste Rivers on the people of Zandvlei and environment.* Rocknews 2000. Geological Society, University of the Western Cape, Bellville, Cape Town.

Thomas, A. 2001. *A Geographic Information System methodology for Modelling urban groundwater recharge and pollution*. Unpublished PhD Thesis. The School of Earth Sciences, The University of Birmingham, Birmingham, United Kingdom.

Thomas, A., Chingombe W., Ayuk J., Scheepers A.T. 2010. *A comprehensive investigation of the Kuils-Eerste River catchments water pollution and development of a catchment sustainability plan.* Project No K5/1692, Water Research Commission, Pretoria, South Africa.

Thornton, J.A. 1980. A comparison of the summer phosphorus loading in three Zimbabwean water supply reservoirs of the varying trophic sates. *WaterSA,* 6, (4), 163-170.

Treitz, P., Rogan J. 2004. *Remote Sensing for mapping and monitoring land-cover and land-use change. An introduction*. Progress in Planning, Elsevier Ltd.

Tsihrintzis, V. A., Fuentes H. F., Gadipudi R. K. 1997. GIS-Aided Modelling of Nonpoint Source Pollution Impacts on Surface and Ground Waters. *Water Resources Management,* Kluwer Academic Publishers.11, 207–218.

Tsihrintzis, V. A., Hamid R. 1997. *Modelling and Management of Urban Storm water.*

UN Population Division. 1997. *Urban and Rural Areas, 1950–2030 (The 1996 Revision)*. New York: United Nations.

USEPA. 1986. *Quality Criteria for Water - 1986.* United States Environmental Protection Agency Office of Water Regulations and Standards, Report No. 440/5-86-001, Washington DC, 20460.

Van Ginkel, C.E., O'Keeffe L., Hughes D.A., Herold J.R., Ashton P.J. 1996. *A situation analysis of water quality in the catchment of the Buffalo River, Eastern Cape with special emphasis on the impacts of low cost, high-density urban development on water quality*. Report No 405/2/96, Water Research Commission, Pretoria, South Africa.

Van Wyk, D.B. 1987. Some effects of afforestation on stream flow in the Western Cape Province, South Africa, *WaterSA,* 13, 1.

Van Zyl, F. 2005. *Water Service Perspectives*. Presentation at Local Authority IWRM workshop. Project K8/611, Water Research Commission, CSIR, Pretoria, South Africa.

Vieux, B. E., Needham S. 1993. Non Point Pollution Model Sensitivity to Grid Cell Size. *Journal of Water Resources Planning and Management*, 119, 2.

Wang, D., Fu B.J., Zhao W.W., Wang Y.F. 2008. Multifractal characteristics of soil particle size distribution under different land-use types on the Loess Plateau, China. *Catena,* 72, 29-36.

Weddepohl, J.P., Meyer D.H. 1992. *Utilisation of models to simulate phosphorus loads in southern African catchments*. Report No. 197/1/92, Water Research Commission, Pretoria, South Africa.

Weng, Q. 2001. Modelling Urban Growth Effects on Surface Runoff with the Integration of Remote Sensing and GIS. *Environmental Management,* 28, (6), 737–748.

Wimberley, F.R., Coleman T.L. 1993. The effect of different urban development types on storm water runoff quality: A comparison between two Johannesburg catchments. *WaterSA,* 19, 4, 325-330.

Wimberley, F.R. 1992. *The Effect of Polluted Storm water Runoff from Alexandra Township on the Water Quality of the Jukskei River*. Unpublished M.Sc. Thesis, University of the Witwatersrand, Johannesburg, South Africa.

Wright, A. Kloppers W., Fricke A. 1993. *A hydrological investigation of the storm water runoff from the Khayelitsha urban catchment in the False Bay area, South Western Cape.* Report No. 323/1/93, Water Research Commission, Pretoria, South Africa.

Wright, A. 1987. *Quality of urban storm water runoff in Three Anchor bay*. Report to steering Committee for the re-use of water and water pollution in the Cape Province. Document 6.2, NIWR Report.

Wright, A. 1991. *The artificial recharge of urban storm water runoff in the Atlantis coastal aquifer*. Unpublished MSc Thesis, Rhodes University, Grahamstown, South Africa.

Young, R.A., Onstad C.A., Bosch D.D., Anderson W.P. 1987. *AGNPS, Agricultural Non-Point-Source Pollution Model: A Catchment Analysis Tool.* U.S. Department of Agriculture, Agricultural Research Service, Conservation Research Report 35, Washington, D.C.

Yuan, F., Sawaya K., Brian E., Loeffelholz C., Bauer M. E. 2005. Land-cover classification analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat Remote Sensing. *Remote Sensing of Environment,* 98, 317-328.

Zietsman H.L., Volk A.C., Nel I. 1996. *The identification of irrigation land in an intensively cultivated agricultural area in the south-western Cape by means of satellite Remote Sensing*. Water Research Commission, Report No. 440/1/96, Pretoria.

ANNEXURE

Annex 3. 1 Land-cover classification scheme used in creating land-cover grid

1. Forest/Woodland

1.1. Coniferous forest

1.1.1. Mature Coniferous forest (Closed Canopy Wood)

1.1.2. Young Coniferous forest (Open Canopy Wood)

1.2. Deciduous Forest

1.2.1. Mature Deciduous

1.2.2. Young Deciduous

1.3. Evergreen Trees

1.3.1. Mature Evergreen

1.3.2. Young Evergreen

1.4. Open Forest/Clear Felled

1.4.1. Burnt Forest

1.4.3. Clear felled

1.5. Degraded Forest

1.6. Mixed Forest

1.7. Forest Plantations

1.7.1. Eucalyptus

1.7.2. Pine

1.7.3. Acacia

2. Grassland

2.1. Pasture/Meadow/Natural Grassland

2.2. Recreation Grass/Golf Course

2.3. Degraded Grassland

2.4. Improved Grassland/Lawn

2.5. Parks/Gardens

2.6. Playgrounds/Sports Fields

2.7. Wooded Grassland

3. Thicket, Bush land, Shrub land/Scrubland

3.1. Fynbos

3.2. Acacia

3.3. Thicket/bushes

3.4. Herb land

4. Cultivated Lands/Agricultural/Horticultural Areas

4.1. Cultivated Irrigated

4.2. Cultivated Non-Irrigated

4.3. Cultivated Temporary

4.4. Dry land/Fallow land etc.

4.5. Orchards

4.6. Vineyards

4.7. Nurseries

4.8. Strawberry

5. Water Bodies

5.1. Inland Natural Water Bodies

5.1.1. Rivers/Streams

5.1.2. Lakes/Permanent pans

5.1.3. Ponds/Pools

5.1.4. Estuary

5.1.5. Wetland/Temporary Pans

5.1.6. Reed Marsh

5.1.7. Swamps

5.1.8. Vleis/Shallow lakes

5.2. Artificial Water Bodies

5.1.1. Reservoirs

5.1.2. Irrigation dams

5.1.3. Canals

5.1.4. Drains

5.1.5. Swimming pools

6. Urban/Built Up Area and Developed Land

6.1. Residential

6.1.1. High Density Residential

6.1.1.1. Formal Suburbs

6.1.1.2. Flatland

6.1.1.3. Formal Townships

6.1.1.4. Informal Townships

6.1.1.5. Informal Squatter Camp

6.1.2. Medium Density Residential

6.1.2.1. Formal Suburbs

6.1.2.2. Flatland

6.1.2.3. Residential, Mixed

6.1.2.4. Formal Township

6.1.2.5. Informal Township

6.1.2.6. Informal Squatter Camps

6.1.3. Low Density Residential

6.1.3.1. Formal Suburbs

6.1.3.2. Flatland

6.1.3.3. Mixed

6.1.3.4. Formal Township

6.1.3.5. Informal Township

6.1.3.6. Informal Squatter Camps

6.2. Commercial

6.2.1. Commercial Mercantile

6.2.1.1. Retail (Supermarkets, Petrol Stations, Building Materials, etc.)

6.2.1.2. Wholesale (Warehouses/Depots)

6.2.1.3. Services (Finance/Real Estate/Insurance)

6.3.2. Commercial Institutional

6.3.2.1. Governmental/Educational/Medical/Religious)

6.3.2.2. Services (Repairs/Automotive)

6.3.2.3. Water Treatment/Sewage Treatment

6.3.2.4. Hotels/Lodging

6.4. Industrial

6.4.1. Heavy industries

6.4.1.1. Chemical; metal; electrical; automotive; PowerStation)

6.4.2. Medium industries

6.4.2.1. Raw material processing and preparation

6.4.2.2. Food & drink processing

6.4.3 Light industries

6.4.3.1. furniture/wood processing/warehouse

6.5. Transportation

6.5.1. Railway transport facilities

6.5.1.1. Train stations

6.5.1.2. Railway lines

6.5.2. Road transport facilities

6.5.2.1. Taxi Ranks

6.5.2.2. Bus Stations

6.5.3. Airport Transport Facilities

6.5.3.1. Airport

6.5.3.2. Freight/Cargo/Warehouses

6.6. Pavement/Pedestrian Footpath

6.6.1. Pavement Brick Surfaced

6.6.2. Pavement Concrete Surfaced

6.6.3. Pavement Asphalt Surfaced

6.7. Open Urban Area

6.7.1. Public Open Space (for Cultural/Social Events)

6.7.2. Cemeteries

6.7.3. Construction sites

6.7.4. Open Derelict Land (Brown fields)

6.8. Roads

6.8.1. Freeways/Express Roads

6.8.2. Arterial Roads/Main Roads/Minor Roads

6.8.3. Minor Roads

7. Bare Land/Bare Rock & Soil

7.1. Bare Rock & Soil (Erosion: Dongas/Gullies)

7.2. Bare Rock & Soil (Erosion: Sheet)

7.3. Open sandy area/Barren land

8. Mines/Quarries/Waste Dump Site

8.1. Mines & Quarries (surface-based mining)

8.2. Mines & Quarries (mine tailings/Waste dumps)

8.3. Urban waste dump/landfill

Annex 3. 2 Comparison of water quality variables analysed in other urban hydrological studies

Variable	Three Anchor Bay Kloppers (1989)	Three Anchor Ba Wright et.al.,(198	Atlantis Wright(1991)	Pinetown Study Simpson (1986)	Johannesburg Green et.al., (1986)	Khayelitsha Urban Catchment Wright(1993)	Present Stud
Physical			EC	EC,TSS	EC,TSS	EC	EC,TSS
Inorganic major ions			Calcium, magnesium, sodium, potassium, Sulphate chloride, Alkalinity, sulphate, chloride, pH.		Bicarbonate, Chloride pH	Calcium, magnesium, sodium, potassium, alkalinity, sulphate, chloride, pH	Chloride , pH
Trace Metals	Zinc, lead, iron, manganese, chromium, cadmium copper, hydrocarbo		Zinc, lead, iron, manganese, chromium, cadmium, copper	Zinc, lead, iron, cadmium, copper			
Organic nutrients			DOC, nitrate, ammonia, orthophosphate	DOC, nitrate, phosphate	Nitrate	DOC, nitrate, ammonia, phosphate	nitrate, phosphate, nitrogen
Micro-biological		Faecal coliform, streptococci coli-form, coliphages	Total coliforms, Faecal coliform, streptococci coliform, coliphages			Faecal coliform, streptococci coliform, coliphages	

Annex 7.1 Percentage contribution of each land-cover to the concentration of pollutants.

	Land-cover Type	% TSS'06	% TSS'07	% TP'07	% TP'06	% Nitrate'07	% Nitrate'06	% Cl '06	% Cl'07	% TN'06	% TN'07	Runoff '07	Runoff'06
1	Mountain Forest	0.2	0.3	0.1	0.1	0.3	0.3	0.2	0.2	0.1	0.1	0.2	0.2
2	Riparian Forest/Natural Forest	0.9	0.9	0.4	0.4	0.8	0.8	0.8	0.8	0.6	0.6	6	6
3	Dense Scrub	2.2	2.5	1.3	1.3	2.3	2.3	2.9	2.9	1.7	1.7	17.1	17.1
4	Fynbos	4.1	4.4	2.7	2.7	6.7	6.7	5.9	5.9	3.4	3.4	8.3	8.3
5	Grassland	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	5.9	5.9
6	Impervious Surface	1	1	0.4	0.4	1.1	1.1	0.5	0.5	1	1	1.8	1.8
7	Railway Line	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1
8	Bare ground/Impervious Surface	1.3	1.2	0.6	0.6	1.2	1.2	0.7	0.7	1.2	1.2	4.7	4.7
9	Bare Rock	0	0	0	0	0	0	0	0	0	0	0	0
10	Open Vineyard/Coarse Rock Pebbles	4.2	4.2	2.5	2.5	4.6	4.6	7.2	7.2	6.4	6.4	2.3	2.3
11	Open Area/Barren Land	2.3	3.3	1.6	1.6	3.4	3.4	7.9	7.9	2.6	2.6	7.2	7.2
12	Improved Grassland/Vegetable	2.9	2.9	3.5	3.5	2.4	2.4	3.7	3.7	2.4	2.4	9.6	9.6
13	Buildings/Impervious	1.2	1.2	0.5	0.5	1.7	1.7	0.8	0.8	1.6	1.6	1.8	1.8
14	Dense/Grassy Vineyard	12.6	12.7	18.4	18.4	19.6	19.6	15.2	15.2	11.6	11.6	21.9	21.9
15	Fallow/Open Vineyard	20.7	20.4	34.8	34.8	36	36	23.1	23.1	18.6	18.6	3	3
16	Recreation Grass/Golf Course	0.5	0.5	0.3	0.3	0.3	0.3	0.6	0.6	0.6	0.6	0.1	0.1
17	Freeways/Express Ways	0.3	0.3	0	0	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1
18	Arterial Road/Main Road	2.3	2.2	0.4	0.4	0.3	0.3	0.6	0.6	0.5	0.5	0.5	0.5
19	Minor Roads	5.1	5.1	3.6	3.6	1.7	1.7	4.2	4.2	6.4	6.4	1.5	1.5
20	Sandy	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.6	1.6	0.6	0.6
21	Water bodies	0	0	0	0	0	0	0	0	0	0	0	0
22	HDR* Formal Suburb	4.9	4.8	4.7	4.7	1.4	1.4	3.7	3.7	6.1	6.1	1	1
23	MDR* Formal Suburb	9.2	8.9	5.8	5.8	2.6	2.6	7.4	7.4	11.1	11.1	2.1	2.1
24	LDR* Formal Suburb	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.1	0.1
25	HDR Formal Township	7.6	6.9	4.3	4.3	3.4	3.4	4.7	4.7	11.5	11.5	3.1	3.1

26	MDR Formal Township	1.1	1.1	0.7	0.7	0.6	0.6	0.8	0.8	2	2	0.1	0.1
27	LDR Formal Township	0	0	0	0	0	0	0	0	0	0	0	0
28	HDR Informal Township	0.3	0.3	0.3	0.3	0.1	0.1	0.3	0.3	0.4	0.4	0	0
29	MDR Informal Township	0.5	0.6	0.6	0.6	0.3	0.3	0.6	0.6	0.1	0.1	0	0
30	MDR Informal Squatter Camps	0.4	0.4	0.3	0.3	0.2	0.2	0.4	0.4	0.8	0.8	0.1	0.1
31	LDR Informal Squatter Camps	0	0	0	0	0	0	0	0	0	0	0	0
32	Commercial- Mercantile	0.5	0.5	0.1	0.1	2.5	2.5	0.3	0.3	0.4	0.4	0	0
33	Commercial- Institutional	0	0	0	0	0	0	0	0	0	0	0	0
34	Industrial	11	10.8	10	10	4.3	4.3	5.1	5.1	5.6	5.6	0.7	0.7
35	Cemeteries	0	0	0	0	0	0	0	0	0	0	0	0
36	Rivers	0	0	0	0	0	0	0	0	0	0	0	0
	Total	100	100	100	100	100	100	100	100	100	100	100	100

Annex 7. 2 Example of Zonal Statistics Table for Total Suspended Solids in 2006.

VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	% Contr
1	4564	456400	0.00	394.29	394.29	41.12	53.55	187664	0.18
2	32045	3204500	0.00	394.29	394.29	29.27	52.32	937964	0.92
3	71640	7164000	0.00	394.29	394.29	31.96	52.63	2289900	2.25
4	122812	12281200	0.00	394.29	394.29	34.21	41.31	4201630	4.13
5	26411	2641100	0.00	394.29	394.29	30.60	54.29	808168	0.79
6	14926	1492600	0.00	359.38	359.38	67.00	45.94	1000100	0.98
7	2737	273700	0.00	394.29	394.29	81.38	70.16	222747	0.22
8	16270	1627000	35.07	393.89	358.81	80.68	74.10	1312650	1.29
9	4	400	0.00	35.28	35.28	26.46	15.28	106	0.00
10	84510	8451000	30.72	392.26	361.54	50.27	23.42	4248710	4.17
11	53778	5377800	0.00	394.29	394.29	43.79	57.20	2355010	2.31
12	74855	7485500	0.00	394.29	394.29	39.49	56.38	2956240	2.90
13	23284	2328400	0.00	365.67	365.67	54.14	29.98	1260560	1.24
14	324516	32451600	0.00	394.29	394.29	39.46	46.09	12804400	12.58
15	307574	30757400	35.07	394.25	359.18	68.40	21.36	21037700	20.66
16	20989	2098900	0.00	394.29	394.29	23.44	45.59	491960	0.48
17	2598	259800	65.57	229.21	163.63	132.17	32.31	343388	0.34
18	10789	1078900	45.74	383.24	337.50	219.82	70.31	2371690	2.33
19	96821	9682100	0.00	361.64	361.64	53.64	25.19	5193080	5.10
20	44483	4448300	0.00	394.29	394.29	29.09	45.60	1294180	1.27
21	14035	1403500	0.00	0.00	0.00	0.00	0.00	0	0.00
22	65691	6569100	0.00	391.42	391.42	75.22	27.12	4941010	4.85
23	300817	30081700	0.00	394.29	394.29	31.11	45.24	9358360	9.19
24	10353	1035300	0.00	394.29	394.29	26.16	39.86	270808	0.27
25	156317	15631700	8.57	391.31	382.74	49.53	41.40	7742920	7.60
26	29127	2912700	20.90	392.21	371.31	39.15	21.94	1140290	1.12
27	236	23600	0.00	75.00	75.00	58.93	26.79	13907	0.01
28	9859	985900	17.53	336.19	318.65	30.64	14.20	302105	0.30
29	3311	331100	38.05	316.54	278.49	162.04	74.54	536518	0.53
30	11243	1124300	20.51	283.53	263.02	40.01	17.06	449877	0.44
31	1593	159300	0.00	75.00	75.00	10.36	21.82	16497	0.02
32	5740	574000	56.09	291.29	235.20	82.20	24.49	471816	0.46
33	24	2400	54.00	75.36	21.36	69.23	7.94	1662	0.00
34	79343	7934300	0.00	386.55	386.55	141.52	42.14	11228700	11.03
35	2091	209100	0.00	192.63	192.63	12.84	41.85	26850	0.03
36	6104	610400	0.00	0.00	0.00	0.00	0.00	0	0.00

DISSEMINATION AND PUBLICATION

1. **Wisemen Chingombe** & Abraham Thomas 2009, *Influence of land-use on overland flow pollution: Case study of Kuils-Eerste river catchment.*

Abstract:

Two rivers, Kuils River and Eerste River flow through urban built up areas and agricultural areas with their waters being perceived to be pullulated through nonpoint source (NPS) pollution. NPS pollution represents the cumulative effects of all Land-covers in a catchment and associated human activity/ environmental modifications present making the phenomenon exceedingly complex. Owing to this complexity, models that try to reflect the processes require large quantities of data, which are rarely available. This study aims to assess the quality of overland flow pollution and to determine NPS pollution rates using Geographic Information systems (GIS) based modelling. The study further makes assessment of overland flow water quality over different land-cover types through sampling and generation of a water quality database and subsequently modelling in a GIS. Land-cover activities affect water quality by altering sediment, nutrient, chemical loads, and catchment hydrology. They also serve as nutrient detention zones or as nutrient transformation zones as dissolved or suspended nutrients or sediments move overland. This study reports on the effects of individual Land-cover types, and their joint contributions of multiple land-cover activities in overland flow pollution. The methodology to assess the relationships between land-cover complex and nonpoint source (NPS) pollutants is examined through the Kuils-Eerste catchment which was delineated, and its Land-cover types classified, with contributing zones being identified using GIS analysis tools. Water samples collected from the catchment were analysed for selected chemical and physical parameters whose threshold limits were determined for classification purposes. Based on the contributions of the NPS pollutants, a linkage model was applied. This linkage model relates Land-cover with the pollutant levels in overland flow water. Linkage models were constructed and evaluated at two different scales: (1) the catchment scale; (2) the contributing land-cover type scale. The contributing land-cover type linkage model suggests that the phenomenon of NPS pollution is well defined in the catchment and merits development of some environmental management strategies to minimise the effects. Land-cover types are then ranked in terms of their contribution to the loading effect of NPS pollutants into the water system. The model can help in examining the relative sensitivity of water quality variables to alterations in land-cover made and also shows the importance of land-cover type management, which are key to maintenance of overland flow water quality. The linkage model is

vital in the integration of GIS and ecological models. It is hopped the model would be used by local and regional land managers in the formulation of plans for catchment level management.

2. **W Chingombe**, James Ayuk, Abraham Thomas & Dominic Mazvimavi 2009, *Runoff, infiltration and nonpoint source pollution assessment of the Kuils-Eerste River catchment, Western Cape Province, South Africa.*

Abstract:

The amount of pollution from nonpoint sources flowing in the river network of the Kuils-Eerste River in Cape Town is estimated by a GIS based method using rainfall, topographic, surface runoff quality and land-cover data. A fine grid of cells 10 m in size is laid over the landscape. For each cell, mean annual runoff is estimated from rainfall, and expected pollutant concentration is estimated from the land-cover. The product of runoff and concentration gives expected pollutant loading from that cell. These loadings are accumulated going down downstream to give expected annual pollutant loadings in the Kuils-Eerste River system. By dividing these accumulated loadings by the similarly accumulated mean annual runoff, the expected pollutant concentration from nonpoint sources is determined for each location/ and cover in the catchment. Observed pollutant concentrations in the basin are averaged at each sample point and compared to the expected concentrations at the same locations determined form the grid cell model. Results for phosphorus indicate that nonpoint source pollution in the Kuils-Eerste River catchment, which is largely urban and agricultural land-cover, is at relatively low levels in the 0 – 0.2 mg/l range, and is consistent with observed concentrations.