A COMPREHENSIVE INVESTIGATION OF THE KUILS-EERSTE RIVER CATCHMENTS WATER POLLUTION AND DEVELOPMENT OF A CATCHMENT SUSTAINABILITY PLAN

Report to the

Water Research Commission

by

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DISCLAIMER

EXECUTIVE SUMMARY

BACKGROUND

This research, funded through the Water Research Commission, seeks to address issues regarding water quality arising from land cover type change and urban sprawl in a predominantly agricultural catchment in Cape Town. The Kuils River and Eerste River are two important rivers that run through the eastern part of the Cape Metropolitan Area (CMA). The Kuils River joins the Eerste River near Macassar forming a tributary to it. The Eerste River finally ends in False Bay. The Eerste-Kuils River estuary is one of the eleven estuaries draining into the False Bay located approximately 36 km south east of Cape Town. The two rivers form a bigger catchment with an area of 660 km^2. A portion of this bigger catchment falls within the boundary of the CMA and the rest falls in Stellenbosch municipality. Although these catchments form part of urban developments, significant portions of the Eerste-Kuils River catchment have agricultural lands; hence it has both urban and agricultural source of nonpoint source (NPS) pollutants. Typical techniques for determining the extent and magnitude of NPS pollution problems include long term surface water monitoring studies and computer based simulation modelling (hydrologic models). Due to the long time and high expenses associated with surface water monitoring techniques, computer simulation techniques (use of models) have been relied upon to provide needed information for the development and implementation of NPS management guidelines.

OBJECTIVES AND AIMS

This research, '*A Comprehensive Investigation of the Kuils-Eerste River Catchments Water Pollution and Development of a Catchment Sustainability Plan'*, aimed to assess nonpoint source (NPS) pollution in the Kuils-Eerste River Catchment through hydrologic experiments and modelling using Geographic information System (GIS). The major objectives which supported the overall aim were:

- Conducting hydrologic experiments (setting up of runoff plots) at selected locations for measuring surface runoff;
- Estimation of surface runoff through GIS modelling using curve number method;
- Assessment of runoff water quality over different land use types through sampling and generation of a water quality database (event mean concentrations);
- Collation of existing data on stream flow measurements and water chemistry of stream flow and surface runoff water;
- Generation of a GIS based hydrologic model (catchment loading model) capable of estimating
  - i) surface runoff using the NRCS Curve number method,
  - ii) pollutant concentrations and loading rates in the runoff water, and
  - iii) accumulated pollutant loading in the stream or river;
- Use of the above investigation to develop a working document for adapting the catchment into a sustainable system; and,
- To publish this work by means of scientific reports, conference papers and journals.

METHODOLOGY

The project was divided into four stages, corresponding to the major tasks that were carried out in the preparation of the input data for the models that were used to assess NPS pollution on the basis of the land cover types in the catchment. The acquisition of the relevant information, technology and expertise regarding water quality monitoring made up the main tasks during the initial stages of the research. Part of the work was accomplished by conducting literature reviews and evaluating available modelling tools. Literature regarding water quality assessment and guidelines was also reviewed.

The second part was focused on obtaining data that could be used for the application of the selected model of NPS pollution assessments. Kuils-Eerste River catchment was identified as a suitable study area because of the conditions in this catchment which are unique and are likely to reflect the situation experienced in many urbanising catchments. Most catchments situated close to urban areas would have similar inputs, for example, effluents from wastewater treatment works and industrial plants as well as nonpoint source pollution, which can originate from informal settlements, agricultural areas and other types of land uses. Data on the water quality of the surface water in these types of catchments are usually very limited, as was the case for the Kuils-Eerste River catchment before the start of this study. Land cover data was important in the development of the project hence a land cover map was developed with 36 land classes for the whole catchment as input data. Efforts were also made to acquire other data sets like annual rainfall, soil types and a digital elevation model.

The third stage involved preparation of input data tables of water chemistry in the form of Event Mean Concentration (EMC) obtained from the hydrological monitoring and runoff water sampling exercises carried out during the storm events that were experienced during the data collection period. These had to be prepared in formats that would make it possible to be uploaded into the system to estimate runoff, infiltration and pollutant loads. The SCS Curve Number method was selected for the estimation of runoff for the whole catchment because of the ease of preparing the limited number of input data sets needed and eases in implementing the method in a GIS.

The fourth study stage involved the application of GIS based hydrological models such as N-SPECT and RINSPE to simulate runoff, NPS pollutant loads and surface water quality in the catchment on the basis of the land cover types and soil information. N-SPECT (Nonpoint-Source Pollution and Erosion Comparison Tool) is a freely available ArcGIS based model provided by the NOAA Coastal Services Center to investigate potential water quality impacts from development, other land uses, and climate change. N-SPECT was initially developed as a decision support tool for coastal watershed managers in Hawaii and has since been applied in coastal areas around the U.S., the Caribbean, Central America, and the South Pacific. This tool operates accurately in medium-to-large watersheds having moderate topographic relief and is capable of providing maps of surface water runoff volumes, pollutant loads, pollutant concentrations, and total sediment loads. This model estimates runoff using the Curve Number (CN) method and it had limitations of not producing runoff at all in certain areas of urban catchments receiving lesser annual rainfalls because it estimates initial abstraction as a constant value of 20% of the potential maximum retention value (in reality this not the case in urban catchments). Therefore the runoff estimated using the CN method implemented in this model is a very negligible amount. This limitation necessitated the adjustment of the runoff estimation by inputting more accurate values of initial losses, which was achieved by developing the distributed parameter model called RINSPE (Runoff, Infiltration and Nonpoint Source Pollution Estimation) using ArcView GIS 3.2. The RINSPE was used to investigate non-point source pollution (NPS) problems in an urban river catchment.

RINPSE is an event-based or annual based model that can estimate runoff, infiltration and the pollutant loading from different land cover types within a catchment. Implementation of the RINSPE model within ArcView GIS 3.3 through Avenue programming facilitated better data analysis than conventional methods. It is a powerful, up-to-date tool that would be capable of monitoring and instantaneously visualizing the accumulation and loading of pollutants. RINSPE is a cell-based distributed parameter hydrologic model which requires several categories of information such as land use, topographical data in the form of a digital elevation model (DEM), event mean concentrations (EMC) of the pollutants to be investigated, soils data, annual or event based rainfall data, and is capable of generating both estimates of quantity and quality of runoff and infiltration from the catchment for a given storm event or annual rainfall. In this model, the extracted spatial and non-spatial data are generated too through the RINPSE model engine designed in ArcView GIS. The model reduces the time required to analyse the numerical output and enables users to identify critical areas of NPS pollution and furthermore, makes it possible to perform various "what if" scenarios to support the decision making processes such as Best Management Practices (BMP) for the catchment. The RINSPE model used to study pollutant concentrations and loadings easily generate large amounts of data for analysis even in a small catchment.

Using the above-mentioned input data sets, the RINSPE and N-SPECT models were successfully applied to the Kuils-Eerste River catchment and to estimate NPS pollutant loads of chosen variables such as nitrate, chloride, total nitrogen, and total phosphorous and total suspended solids. The success with which surface water variables such as concentrations and loads of nitrate, chloride, nitrogen, phosphorous and suspended solids may be simulated in surface water using the above two models depends largely on the quality of input data available such as rainfall, runoff distribution and digital elevation model.

RESULTS AND DISCUSSION

The results reveal that the accumulated loads of pollutants from the catchment increased substantially for all the pollutants for a two year period. Annual loads for all the parameters under study increased. This could be explained by the possible increased mobilisation of pollutants by urban sprawl, which also increased surface runoff between these two years. Rainfall interpolation results revealed that there was an increase in precipitation for a two year period. This slight increase in total rainfall is the possible cause of this increase in accumulated pollutant loads. Increased rainfall meant increased mobilisation and transportation of pollutants due to impacting by rain drops and the occurrence of higher volumes of surface runoff. Above all, the results confirm that surface water pollution is increasing at high rates in the catchment.

Runoff model simulations revealed that there was an increase in runoff discharge loads at the outh of the catchment for the study period. Changed land surfaces include compacted surfaces, channelized surfaces, constructions, which are some of the activities that increase the imperviousness of the surface thereby leading to more flows in the form of runoff and less underground recharge.

The results obtained show a distribution pattern that indicates high volumes of runoff in the eastern part of the catchment and lower values to the western side of the catchment.

Comparatively speaking, runoff volume for the two modelled scenarios on the basis of rainfall distribution, shows marked differences with the first scenario based on the rainfall gauges in the catchment and within the proximity of the catchment boundary registered volumes that ranges between 0,086 m^3 to 135.3 m^3, against the second model results of a range between 0.1 m^3 to 268.4 m^3.

The accumulated surface runoff distribution map also compares well to the one generated on the basis of the earlier rainfall distribution map though the values registered are different. The first model's results of total runoff volume using rainfall map of 2006 range from 0 m^3 to 112 million m^3 as compared to the second modelling results based on the radar estimates of long term average rainfall which indicates values that range between 0 m^3 and 194 million m^3. The estimated accumulated pollutant loads exiting from catchment (at the outlet point just before the estuary) using the long term average rainfall data are as follows: Nitrate 216.5 tons/Yr; Total Nitrogen 3551.61 tons /Yr; Total Phosphorus 190.7 tons /Yr; Chloride 6828.49 tons /Yr; Total Suspended Solids 18884.9 tons /Yr.

One of the outputs of the analysis by N-SPECT is the pollutant concentration grid. This is a map layer showing the spatial distribution of pollutants in the catchment and compares the contribution of each land use/cover to the observed pollution. A spatial observation of the pollutant distribution maps does not reveal any changes in the spatial extent to which pollutants are generated between the periods of study. The spatial distribution of pollutants on maps alone may not be enough to adequately interpret the actual prevailing scenarios. Statistical tables were used for better interpretation and conclusion of modelling results.

There were no noticeable variations in the percentages of pollutants that emanated from the land use classes when the classes are compared. This means that the change in precipitation did not influence the potential to generate pollutants so long as the surface conditions remained. With any change in the land characteristics, one would expect a corresponding response in terms of the potential to release chemical substances. The results show that the following land use classes, vineyards, industrial areas and the medium density residential areas contribute mostly towards the pollution in the catchments' streams and rivers. The vineyards contributed more than 40% of the entire load from classes followed by the industries and then the residential areas and open barren lands.

SUSTAINABILITY PLAN

A sustainability guideline is offered that focuses on the main activities that the catchment authorities can adopt for implementation with the following objectives:

- Restore and maintain degraded systems and habitats,
- Support sustainable human communities,
- Sustain biodiversity,
- Preserve natural ecosystems,
- Focus funding on the most effective strategies, and
- Teach about connections between individual actions and clean water.

CONCLUSIONS

The main and secondary aims of the study were achieved. Estimates of runoff, infiltration and pollutant loads were determined and can be useful as a management tool in the case of highly contaminated catchments. For urbanised catchments the two models would be able to estimate the surface runoff on the basis of the precipitation and land cover type. Runoff estimation on the basis of the hydrological soil groups and land use types, and estimation of pollutant accumulation and loading rates using a DEM on the basis of the runoff volume generated, Event Mean Concentrations in runoff, are the key aspects of the two models in generating results. The models however are dependent on input data and the modelled catchment should be well characterised, in particular, reliable hydrological data should be available. Broad management guidelines with predetermined guidelines and/or objectives for the surface pollution developed should be implemented to ensure that the water will be fit for its intended uses on a sustained basis.

RECOMMENDATIONS FOR FUTURE RESEARCH

A need exists for the implementation of a surface water quality programme in the catchment using the approach that is outlined in this study. The participation of the affected community of Kuils-Eerste River catchment in such a management programme is crucial for its success and the study should also explore various ways of involving the community.

ACKNOWLEDGEMENTS

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Name	**Organisation**
Dr Renias Dube	WRC
Dr W de Clercq	Stellenbosch University
Mr W Kamish	Ninham Shand
Dr S Adams	WRC
Mr W Nomquphu	WRC

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LIST OF ABBREVIATIONS

BMPs	Best Management Practices
CMA	Cape Metropolitan Area
DEM	Digital Elevation Model
DN	Digital Number
DWA	Department of Water Affairs
EMC	Event Mean Concentration
ETM	Enhanced Thematic Mapper
GIS	Geographic Information Systems
NPS	Non-Point Source
NRCS	National Resources and Conservation Services
NSPECT	Nonpoint Source Pollution and Erosion Comparison Tool
RINSPE	Runoff Infiltration Nonpoint Source Pollution Estimation
SPOT	Satellite Pour l'Observation de la Terre or Earth Observing Satellites
WRC	Water Research Commission (of South Africa)
WWTW	Waste Water Treatment Works

GLOSSARY

Effluent	That which flows out (usually waste water)
Eutrophication	The process, usually anthropogenic, whereby nutrients accumulate in a body of water
Hydrology	The study of water resources
Infiltration	Percolation (in this volume, percolation of water into the ground)
Natural environment	With regard to rivers, aquatic ecosystems and those ecosystems dependent on them
Non-point	Diffuse
Nonpoint source pollution	Distributed or dispersed discharges of pollutants from surface runoff or atmospheric sources
Nutrient	In aquatic biology an element whose scarcity can limit plant growth (e.g. compounds of nitrogen, phosphorus)
Orthophosphate	A form of soluble inorganic phosphate
pH	The negative log10 of the hydrogen ion activity: a measure of acidity (pH < 7) or alkalinity (pH >7)
Point source pollution	Discharges of pollutants from known discrete sources e.g. an effluent discharge from an industry. The volume and quantity of the discharge can normally be measured and quantified.
Pollutant	A substance that contaminates
Pollution	Defilement: unfavourable alteration of our surrounding, normally as a result of human actions; the presence of any foreign substance(s) that impair the usefulness of water bristle worms
Precipitation	Rainfall
Pristine	Unaffected by human activities
Receiving water	A water body receiving an effluent
Receiving water quality objectives	The water quality towards which a regulatory body will aim or strive
Riparian	Related to the river bank
TSS	Total suspended solids
Water quality	The value or usefulness of water, determined by the combined effects of its physical attributes and its chemical constituents, and varying from user to user
Water quality constituent	A biological or chemical (organic or inorganic) substance or physical characteristic that describes the quality of a water body. For the purpose of this report, water quality refers to water quality constituent, substance or property only.
Water quality guideline	According to the definition used in South Africa is that concentration, level or value of a particular water quality variable that would meet the needs of all water users in a specified river reach
Water quality standard	A rule authoritatively establishing, for regulatory purposes, the limit of some unnatural alteration in water quality that is permitted or accepted as being compatible with some particular intended use of water

1 INTRODUCTION AND OBJECTIVES

1.1 Background

The Kuils River and Eerste River are two important rivers that run through the eastern part of the Cape Metropolitan Area (CMA). The Kuils River joins the Eerste River near Macassar forming a tributary to it. The Eerste River finally ends in False Bay forming an estuary. The Eerste-Kuils River estuary is one of the eleven estuaries draining into the False Bay that is located approximately 36km south east of Cape Town. The catchments of these two rivers form a bigger catchment having an area of 660 km^2 (Fig 1). A portion of this bigger catchment falls within the boundary of the Cape Metropolitan Area and the rest falls within the jurisdiction of the Stellenbosch municipality. Historically both these rivers were highly seasonal and the estuary was closed during summer months by a wind and wave built sand bar and opened only with the first winter rains. The Macassar sewage works located on the western side of the estuary discharge their effluent into these rivers, which have changed the hydrological character of these rivers (Petersen, 2002). Now these rivers are perennial and the estuary is open throughout the year. As these rivers flow through highly urbanized areas they have been degraded to a great extent in both water quality and aesthetic value. It is assumed that the degradation is mainly due to polluted urban storm water runoff and the release of sewage effluent into these rivers (Petersen, 2002).

1.2 Problem Statement

Although the Kuils River and Eerste River catchments form part of urban developments, significant portions of these catchments have agricultural lands; hence it has both urban and agricultural source of Non-Point Source (NPS) pollutions. The potential loading from the Eerste-Kuils River catchments has great impact on the coastal waters near the Eerste River Estuary. Taylor (2000) has done a monitoring study of the river system and the estuary and their results indicate that large changes in flow regime and channel pattern have occurred in the Kuils River. The physical river system is in a poor state because of the discharge of sewage influent into the river and increase in vegetation encroachment along the river and in the river itself, which leads to eutrophication caused be the extra nutrients entering the river systems from the sewage works (Taylor, 2000). The density of vegetation along and in the river is not helping with the flushing of the river (Taylor, 2000) and hence the condition of water quality is not improving. It is generally believed that the quality of surface water and groundwater in urban environments is deteriorating through various urban activities and industrial activities and other land use practices.

In view of the above situations there is an urgent need to provide correct answers to the following questions/unknowns scenarios: whether the deterioration of Eerste-Kuils River water quality is mainly because of NPS pollution due to the present land use practices in the catchment or as a result of the combined effect of NPS pollution and the release of effluent into the river from the Macassar sewage treatment plant. In order to solve this there is a need to assess the pollutant loading rate and concentration reaching a point just above/behind the sewage treatment plant. Assessment of NPS pollution has been gaining recognition and importance in many countries over the last two decades. Many studies have already been conducted all over the world, especially in USA with efforts to identify and quantify NPS loads at catchment levels. Typical techniques for determining the extent and magnitude of NPS pollution problems include long term surface water monitoring studies and computer based simulation modelling (hydrologic models). Due to the long time and high expense associated with surface water monitoring technique, however, computer simulation techniques (use of models) have been relied upon more frequently to provide needed information for the development and implementation of NPS control programmes (Barry et al., 2002).

1.3 Aims and Objectives

The project aims to study and assess nonpoint source (NPS) pollution in the Kuils-Eerste River Catchment within the Cape Metropolitan Authority Area (CMA) through hydrologic experiments and modelling using a Geographic information System. The major objectives of this study are the following:

• Conducting hydrologic experiments (setting up of runoff plots) at selected locations for measuring surface runoff;
• Estimation of surface runoff through GIS modelling using the curve number method;
• Assessment of runoff water quality over different land use types through sampling and generation of a water quality database (event mean concentrations);
• Collation of existing data on stream flow measurements and water chemistry of stream flow and surface runoff water;
• Generation of a GIS based hydrologic model (catchment loading model) capable of estimating

i) surface runoff using the NRCS Curve number method,

ii) pollutant concentrations and loading rates in the runoff water, and

iii) accumulated pollutant loading in the stream or river;

• Use of the above investigation to develop a working document for turning around the catchment into a sustainable system; and,
• To publish this work by means of scientific reports, and papers in journals.

1.4 The Structure of the Report

This project report is organised into nine main chapters as follows:
Chapter 1 offers the introduction which will focus on the background of the research and stating of the problem statement, subsequently resulting in the highlighting of the aims and objectives. Chapter 2 focuses on the catchment description, which includes the description of the location, topography, and climate. Chapter 3 handles the preparation of the detailed land use/land cover map using an integrated approach and Chapter 4 focuses on water quality monitoring through runoff plots, storm water sampling and sampling techniques. Chapter 5 shows the database of stream flow measurement for the Kuils- Eerste Rivers and a discussion of the results obtained. Preparation of a database of Event Mean Concentration (EMC) values is covered. The application of GIS based runoff and NPS pollutant loading model is covered in Chapter 6 with an overview of the Runoff Infiltration Nonpoint Source Pollution Estimation (RINSPE) Model and its input data development being discussed too. The procedure for running the RINSPE Model for runoff estimation and runoff distribution map generation for the whole catchment is also covered in this chapter. Chapter 7 offers a detailed approach to modelling of NPS Pollution using NSPECT model with the model results for NPS Pollution being presented. Finally Chapter 8 presents the catchment management/sustainability Plan. Finally chapter 9 presents the conclusions and from the study and recommendations.

2 CATCHMENT DESCRIPTION

2.1 Location

The Kuils-Eerste River catchment is situated in the South-Western Cape coastal area of the Republic of South Africa between the Cape Fold Mountains (Cape Peninsula) and the Hottentots-Holland mountain belts near the Cape of Good Hope (Figures 1 and 2). The geographical extent of the study area is between latitudes 33º 50' and 34º 07' south of the equator and between longitudes 18º 30’ and 19º 05' east of Greenwich Meridian. A municipal boundary line divides the catchment into the two municipal jurisdictions namely Cape Town and Stellenbosch.

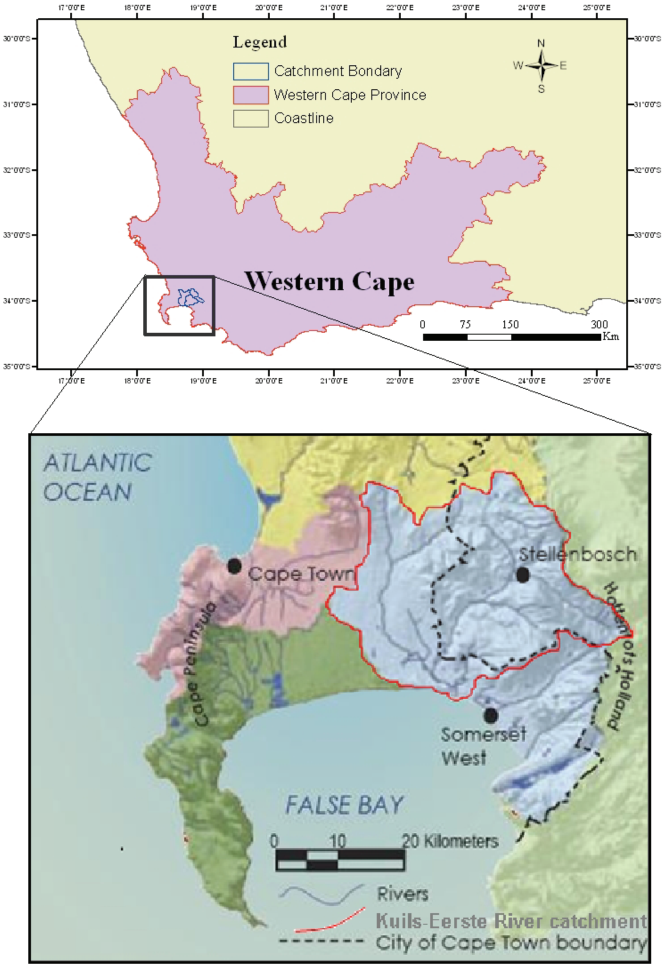


Figure 1 The location of the Kuils-Eerste River catchment in the South Western Cape region. (Modified from River Health Programme, 2005).

Figure 2 The location of Eerste-Kuils River catchment (Source, CMA website).

2.2 The Kuils-Eerste River System

The Kuils-Eerste River catchment is a large surface water network that drains The Cape Metropolitan Authority (CMA) and Stellenbosch Municipal area (Figure 2). These two highly urbanised and agriculturally advanced regions of the Western Cape adjoin the False Bay estuary to the south and the south east (Petersen, 2002). The catchment is characterised by urban land and agricultural land and consists of two perennial rivers, Kuils River and Eerste River. The Eerste River drains a comparatively larger surface area that extends into the Stellenbosch municipal area before joining Kuils River, at a location close to Macassar as shown in Figure 3.

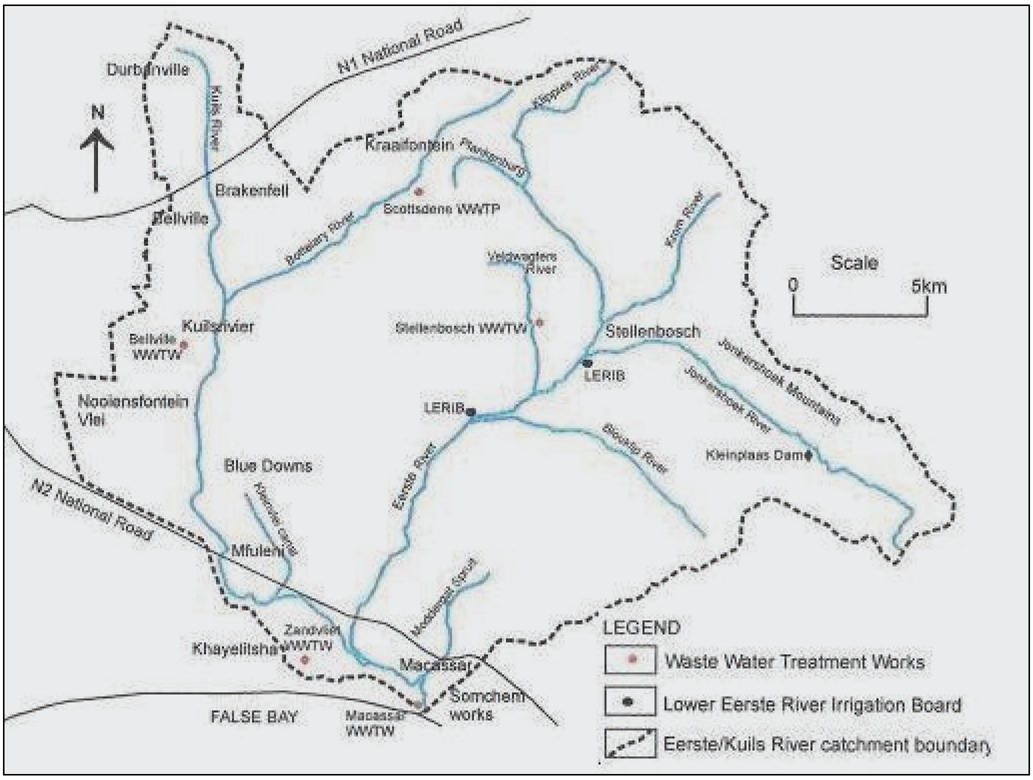


Figure 3 Location and Distribution of the stream network in the Kuils-Eerste River urban catchment area. Source: Petersen, 2002; Harrison, 1998; DWAF, 1993).

The Kuils River is a major tributary and it merges with the Eerste River approximately at 4 km north of the Eerste River mouth (Petersen, 2002). The Kuils River rises from the highlands of Durbanville near Kanonkop in the Tygerberg hills and runs south through the industrial and residential areas of Bellville and Kuilsrivier. It streams largely through the rural sandy plains of the Cape Flats, gushing through the N2 Freeway below the Driftsands Nature Reserve and curving east of the residential area of Khayelitsha to Macassar. In the lower course, the river has some wetlands, which are of high significance to the ecosystems diversity. This “once” highly seasonal river that only flowed strongly during summer became perennial due to the discharge of large volumes of treated sewage effluent from Scottsville, Bellville and Zandvliet Waste Water Treatment Works (WWTW).

The Eerste River originates in the Jonkershoek Forest Reserve, in its middle reaches it flows through mainly agricultural land and the town of Stellenbosch towards the confluence with the Kuils River (Wiseman and Simpson, 1989). After the confluence with the Kuils River in the Cape Flats region, the catchment has mainly underdeveloped and unmanaged open land where the Moddergat Spruit enters the river. The mouth of the Eerste River is characterised by an estuary. Two industrial plants, the Somchem factory and the Macassar Waste Water Treatment Works (WWTW) are located on the eastern and the western banks respectively (Wiseman and Sowman, 1992; Ninham Shand, 1999; Petersen, 2002). Therefore, beside surface runoffs, this river also receives chemical wastes from industrial drains and treated sewage effluent from a number of WWTW located in its catchment. In addition to the Macassar WWTW, the Stellenbosch WWTW discharges effluent via the Veldwagter River, into the Eerste River. Petersen (2002) outlined an approximate flow rate in terms of discharge contributed by both the Stellenbosch and Macassar WWTW plants as 13.5 MLday^{-1} and 14 MLday^{-1}, respectively. The total catchment area for both rivers is 660 km^2 of which approximately 45% belongs to the Kuils River (Morant, 1991; Harrison, 1998; Petersen, 2002) leaving an approximately 360 km^2 as the total catchment area occupied by the Eerste River.

Historically, both rivers were highly seasonal with low flows during summer and increased flows during winter months. But through the years, both rivers have changed from being seasonal to perennial (Harrison, 1998 and Petersen, 2002). This could be attributed to rapid urbanisation that have resulted in an increase in river flows from storm water runoff and treated sewage effluent (Petersen, 2002).

2.3 Catchment Characteristics

2.3.1 Topography

The topography of the study area varies greatly from high and steep mountain terrains to very flat regions near the coast. For example, the Jonkershoek area has a range of topographical features ranging from the steep mountain ridges, cliffs, ravines and spurs to the almost level ground of the main Jonkershoek Valley floor. The highest peaks range from 1220 m in the mountain peaks making up the larger Hottentots-Holland Height to about 120 m at lower height around Stellenbosch.

2.3.2 Climate

The climate of the Kuils-Eerste River catchment area is fairly typical of the south-western Cape which falls within the winter rainfall region of the country with a characteristic Mediterranean climate. Climate is generally influenced by the south Atlantic anti-cyclone and therefore in the south-easterly wind regime (Schulz *et al*., 2001; Petersen, 2002). The summers are dry, warm to very hot with strong south-easterly winds prevailing with daily temperatures reaching 40^{o}C. Winters are wet and cold, often with gale-force north-westerly winds that bring temperatures to as low as 0^{o}C often leaving the high peak valleys inundated with snow (Hendricks, 2003).

Orographic rainfall is the predominant forms of precipitation typically due to the mountainous topography making the area stand out with peak rainfalls of the highest in the whole Southern Africa. About 85% of the rainfall occurs within six months of the winter period, this is from April to September (Van Wyk, 1989). The highest mean monthly precipitation occurs in June as a consequence of cold fronts linked with the tropical cyclones, which traverse the Cape from the Atlantic Ocean.

The area is associated with high wind speeds during summer, particularly the "South-Easters" that blow from the south-east. Berg winds associated with hot and dry winds also occur in autumn. The highest wind velocities are recorded at Cape Point and the fringing mountains on the eastern side of False Bay creating a wind shadow over the Eerste River area (Petersen, 2002; Hendricks, 2003). For instance, the average rainfall over the area of the Cape Flats is about 600 mm per annum. This is much less than in the surrounding mountains but the mean annual precipitation increases to about 800 mm in the eastern hills due to the orographic effect (Wicht *et al.,* 1969). The mean annual rainfall in the Jonkershoek area of the catchment ranges from 1100 to 1400 mm, of which most occurs during the winter months.

2.3.3 Land use

NPS pollution comes through surface runoff occurring over different land use/land cover types. Land use is one of the important characteristics of the runoff processes as it affects infiltration, erosion and evapotranspiration rates (Melesse and Shih, 2002). Very often, NPS pollutants are occur as salts and trace elements from soils or they originate as a direct consequence of human activity like the application of pesticides and fertilizers in agriculture (Corwin and Wagenet, 1996). But irrespective of its source, generally, NPS pollution occurs as a consequence of land use activities (human activities such as agriculture), urban runoff, hydro modification, and resource extraction, etc. One step in understanding NPS pollution is to understand the correlation between land use, contaminant and runoff. Logically, land use determines the amount of and type of NPS contaminant that gets into surface waters by virtue of the release of typical contaminants from certain land use categories into the environment.

The Kuils-Eerste River is highly urbanized (residential, industrial, and commercial) along with agricultural development. The major land use types of the non-urbanized or agricultural developed areas are vineyards, deciduous fruits, lucerne, pasture and forest plantations (Oak, Pine, etc.). The major part of the cultivated land is being used for wine production. The remaining portion of the cultivated land is used for growing fruits, lucerne and pasture. The other land covers found are mainly fynbos vegetation, wetland vegetation, surface water bodies such as wetlands, vleis, ponds, lakes, reservoirs or dams.

2.3.4 Agriculture

Enough literature on this subject covering this area has not yet been attained. However, Schulz et al. (2001) revealed that, contamination levels in the closely neighbouring Lourens River were influenced by wastes from intensively cultivated orchards. Contamination in this example resulted from pesticide application on fruits just prior to the harvest season. Site specific details of the land use practices in the agriculture domain for the Eerste River catchment would necessitate intensive field evaluations and on the spot data acquisition from the farmers concerned since very little is published so far on the subject.

2.3.5 Residential Settlements

A few insights have been mentioned on some of the riverside settlements, mostly rural farm settlements in Hendricks (2003). Examples are the Zandvlei, the Malabos informal settlement, etc. These have been described to be characteristically low density population settlements with limited social basic facilities in supply. The sources of pollution therefore have been domestic resulting from ablution, sanitation, laundry and dumping. A couple of formal settlements exist with well-planned drainage and proper housing. The towns of Stellenbosch and environs, parts of Khayelitsha have an impact on the urban development distribution in this area.

2.3.6 Industry

The area has experienced significant industrial development. A number of waste water treatment works exist in the study area though only a few chemical plants (e.g. Somchem) are also found. The contribution of these industries and WWTP to surface water contamination is enormous.

2.3.7 The Jonkershoek Nature Reserve

Jonkershoek Nature Reserve lies approximately 9 km from the town of Stellenbosch in the Western Cape. It covers a total area of about 9800 ha and functions as mountain catchment area providing water for Stellenbosch and its surroundings. The reserve comprises of the imposing Jonkershoek Mountains and portions of the upper Jonkershoek valley through which flows the Eerste River. The Jonkershoek Mountains form part of the larger Boland mountain range and the Eerste, Berg, Lourens and Riviersonderend Rivers have their various sources high in these mountains. The lower reaches of the valley are a well-known wine-producing area.

Flora in the reserve comprises of very dense vegetation of two main vegetation types, fynbos and riparian forest. The former is the dominant type while the riparian forest is restricted to the banks of the Eerste River and adjoining streams. The natural vegetation of the Jonkershoek area is mainly mountain fynbos. More than 1100 plant species are known to occur, of which a number are rare and/or endemic to the area. Distinctive species are *protea repens*, *P. neriifolia*, mountain cypress, as well as various *ericas* and *restios*. Several relic forest communities occur in narrow, moist kloofs where they are relatively sheltered from fire. Dense riparian vegetation grows along the banks of the Eerste River. The riparian zone, as opposed to the in-stream vegetation, is the vegetation found along the river corridor (Fisher, 2003). These in other words are areas receiving surface water from the river. Oak trees, although not indigenous, have been allowed to remain in Assegaaibosch because of their special historical value. Large pine plantations are a distinctive feature of the valley and occur on property neighbouring the nature reserves.

2.3.8 River Channel Modifications

In the last decade, the Kuils River had been upgraded between Van Riebeeck Road and the Stellenbosch Arterial route to limit flood levels. The reach of the river between the R300 and Van Riebeeck Road was also upgraded, thus reducing any possibility of flooding. This was done by concrete-lining of some areas of the river that are within the Kuilsrivier Municipal Area.

The Kuils River has been affected by agriculture, urbanisation, canalization, invasion by introduced plants and extensive loss of natural vegetation. This has caused a sharp decrease in water quality in the river. The river system is severely degraded and very typical of an urban water body and as a result serves as a convenient and cost effective transport route for outputs from industries, recreation and disposal of storm and waste water (Hendricks, 2003), resulting in serious water quality degradation. Petersen (2002) confirms the above scenario to be true in the case of the Eerste River catchment with the major influence being sewage effluent, storm water runoff, general pollution and alien vegetation. This river receives storm water from storm water ways and treated sewage effluent from a number of waste water treatment plants along its course. For a couple of decades, concern has been placed on the poor quality of the river (Fisher, 2003 and Hendricks, 2003). The main reason for this deteriorating environment and loss in aesthetic value and recreational value of the river has been the impact of uncontrolled human encroachment in the catchment area that led to significant alterations in the river system. This in effect has rendered the river system unfit for domestic, agricultural and other aesthetic uses. The present state of water quality shows that bringing the Kuils River to a near pristine state, is a very difficult task as more urbanisation in the catchment will produce even more sewage effluent and storm water volumes.

PREPARATION OF LAND USE / LAND COVER MAP USING REMOTE SENSING AND GIS

2.4 Introduction

The Kuils and Eerste River catchments (also called as Kuils-Eerste River catchment) jointly cover an estimated surface area of over 650 square kilometres (Petersen, 2002 and Taylor, 2000). This catchment is a very complex one in terms of the diversity in surface characteristics (land use activities). The catchment is mostly urban in character and harbours various activities such as business, administrative, industrial and agricultural activities. The two major rivers viz. the Kuils and the Eerste Rivers, flow through urban areas and are therefore influenced in their quality by urban activities. For an assessment of the extent of the influence of these urban activities on the water quality of these rivers, a thorough determination of the surface characteristics or land use activities of the catchment has to be made. One of the products which could duly express the surface character of the catchment is the land use/land cover of the catchment. This chapter summarises in brief the main procedures that were followed during the process of creating a detailed land use / land cover map for the Kuils-Eerste River catchment.

2.5 Methodology and Results

The procedure that was used in this study for extracting land use/land cover information was generally based on a methodology/approach that was used by Thomas (2001) for Birmingham, UK. An integrated land use/land cover mapping procedure, based on a specially formulated land use/land cover classification scheme, was obtained through;

1. digital image classification of acquired remotely sensed digital images,
2. visual interpretation and manual on screen digitizing supported by local knowledge of the area and
3. use of other data that was readily available in GIS format and further GIS analysis and
4. Data conversion.
5. This approach also involved multiple image processing algorithms provided by different software packages to obtain the best results.

The following sections will explain in greater details how the above approaches were implemented for the Kuils-Eerste River catchment.

2.5.1 Spatial Data Acquisition and Evaluation

In the beginning of the project, a digital copy of generalised land use map was procured from the City of Cape Town but this map was found to be inappropriate for the use of the project mainly for two reasons: (1) the data covered just a portion of the catchment, i.e. the section that basically fell under the administrative jurisdiction of the Cape Town Metropolis. (2) The Stellenbosch municipality area was left out. (3) The nature of the map was not appropriate for the purpose of assessing pollutant fluxes emanating from the diverse activities in the catchment.

It was found that an improved and more detailed land use/land cover map is needed for assessing non-point source pollution. An alternative approach was to map land use/land cover for the catchment in an integrated approach suitable for pollutant flux modelling. Therefore, it was decided to formulate a detailed land use/land cover classification scheme in aid of delineating potential areas of non-point source pollution through runoff processes and use existing spatial data, satellite images and aerial photographs and extract land use features from them using various approaches. Some spatial data sets such as roads, railways etc were obtained from the City of Cape Town and Provincial Government and they were found to be suitable to make use in the land use map preparation. Satellite imagery was acquired from remote sensing satellites that retrieve images/imageries from digital data captured from platforms hundreds of kilometres above the Earth. These imageries have the advantage of covering an extensive surface area at a time or wide surface aerial coverage. They are also periodic, meaning the same surface could be captured several times during a year.

Digital images consist of an array of discrete picture elements (pixels) or grid cells, which are ordered in rows and columns. Each pixel has a digital number (DN) that represents the intensity of the received signal reflected or emitted by a given area of the Earth's surface. The size of the area belonging to a pixel is called the spatial resolution. The image also consists of spectral bands or layers created by the sensor and that collect energy in specific wavelengths of the electromagnetic spectrum. Therefore, variations in these reflection values will reflect variations on the local surface.

Two sets of multispectral satellite images were used during the process of production of a land cover/land use map for the catchment: Landsat-ETM images (2002 summer scene) and SPOT 5 images (2005 summer scene). Landsat imagery is acquired by the US (NASA) Satellite Remote Sensing programme. Landsat ETM (Landsat Enhanced Thematic Mapper) image captured by Landsat 7 sensors has a spatial resolution of 30 metres in all its seven bands. A SPOT image is provided by the SPOT (Satellite Pour l'Observation de la Terre or Earth Observing Satellites) programme set by France, Belgium and Sweden. SPOT incorporates a high resolution imaging instrument. The SPOT 5 image has very high resolution of 10 m in all 3 spectral bands in the visible and near infra-red ranges.

2.5.2 Digital Image Processing of Satellite Imagery

Digital image processing involves various steps: The major steps used in this project are the following: image rectification, image enhancement, image classification and post processing of classified images. Both Landsat and SPOT images were subjected to certain image processing techniques (rectification, projection changes, clipping and classification techniques) within different remote sensing software such as PCI Geomatica, ILWIS, ENVI and ArcView Image Analysis.

2.5.3 Digital Image Rectification/Ortho-rectification

Digital imagery mostly does not have the relationship between the rows/columns and the real world coordinates (UTM, geographic coordinates, or any other reference map projection). In order to use these images within a GIS along with other spatial data sets, it is necessary to correct and adapt them geometrically so that they have comparable resolutions and projections to other data sets. It becomes therefore very essential for the image to be converted from pixel coordinate system to map coordinate system or another pixel coordinate system in a process known as rectification. This is easily done by correcting the pixel geometry of the image with that of an existing map of that same coverage. In image rectification, a number of control points were used to transform the image from a pixel coordinate system to a map coordinate system. The ortho-rectification using an elevation layer (Digital Elevation Model or DEM) to account for the height difference of surface objects gives best rectified images, which do not have any geometric distortion. The ortho-rectification of the SPOT image was performed using PCI Geomatica OrthoEngine software with the help of digital topographic maps for ground control point selection and 90 m SRTM DEM data. The road network junctions and large building corners obtained from topographic maps were used as main control points for dereferencing. At various stages during this procedure, care was taken to keep the levels of error for control points on the georeferenced image, linked to points on the new image. These levels of error were expressed by the root mean square indices (RMS) of the image processing software. As general procedure, it is recommended that the RMS values remain below one for the rectification process to qualify as accurate. Around 25 well identifiable ground control points were chosen and a final RMS value of 0.6 was obtained while orthorectifying the satellite image covering Cape Town.

2.5.4 Digital Image Enhancement

Image enhancement techniques provide procedures for making a raw image more interpretable. In other words, these techniques improve the visual impact of the raw remotely sensed data for the human eye. Some image enhancement tools available in ArcView GIS were used to improve the appearance of the image by adjusting contrast and brightness and using various contrast-stretch methods such as standard deviation, histogram equalization, maximum-minimum and density slicing. In addition to this, selection and de-selection of the different combinations of red, green and blue bands of the multi spectral image in the display window using the legend editor tool of image analysis, revealed different visual results or false colour composites (FCC) scenes from the image. Selection of thermal infrared band as the ‘red band’, the near infra-red as the ‘green band’ and the red band as the ‘blue band’ in ArcView Image Analysis extension was found to be the most suitable display option for identifying and discriminating all cultural features, vegetation types, non-vegetated areas and all water features.

2.5.5 Classification of Satellite Imagery

Digital image classification is the means through which information on the relationship between land cover and measured reflection values from an image could be extracted. Two kinds of image classification approaches are available, viz. supervised image classification and unsupervised image classification. Supervised classification is the process of using samples of known identity (training samples) to classify pixels of similar identity/digital number while unsupervised classification is the identification of natural groups, or structures within multi- spectral data by the algorithms available in the remote sensing software. For performing supervised classification, the software is trained on the features or pixels identified earlier to look for similar pixels throughout the image during the classification procedure. These training sets are clusters of homogenous pixels that designate a particular feature on the ground. Therefore, identification of similar pixels in the image automatically identifies similar existing ground surface features. A prior knowledge of the area of interest is, however, very vital. Vital knowledge of the catchment characteristics was acquired through many ground-truthing field trips conducted. For unsupervised classification on the other hand, there is no need for identifying training site of the area under study. The operator is allowed to specify a number of categories desired and the software classifies the image data into a number of groups of likely similar pixels corresponding to the number of categories stated earlier. Both the supervised and the unsupervised methods of digital image classification have advantages and disadvantages over each other.

For this project, it was decided initially to use supervised image classification technique. As it was planned in the beginning to use the supervised approach in image classification, a set of training sites were selected following the land use classification scheme that was generated earlier as a guide to identify the class level from which these land use features would be selected. The classification of both Landsat and SPOT image using supervised approaches (classifier algorithms) in ENVI and ILWIS software was later found to be inappropriate or inaccurate after few trials of classification on the image. A couple of classified features were inappropriate to use because of their appearance in certain regions where they were not supposed to be. For instance, it was discovered that, most of high density residential areas appearing as water features on the map or some residential areas appear on the mountainous regions because of their similar spectral reflectance values; some agricultural crop plots could not be differentiated clearly.

To solve this problem of insufficient spectral differentiation of the image, a more integrated approach of image classification was used. This approach involved the use of both supervised and unsupervised methods, to select individual thematic layers or single land use features, and then add to other correct, existing, land use classes, detected by the previous classification attempts and by manual digitizing.

As such, using the 'Categorize menu/method' in ArcView image analysis extension, a categorisation of the pixel values in different satellite bands was carried out, which resulted in a single layer thematic grid data layer having a specified number of land use classes. The categorisation process in ArcView image analysis extension employs an unsupervised approach using the Iterative Self-Organizing Data Analysis (ISODATA) technique (ESRI, 1998).

Supervised approach was later used to correct all the errors that occurred in terms of inappropriate display or assigning of spectral values to certain thematic layers. Such problematic layers were selected using the 'Find Like Areas' algorithms in ArcView's Image Analysis extension which is a parallel piped classifier. During this method, a Seed tool is used to create a polygon-like graphic which identifies areas with similar characteristics in the image. The 'Find Like Areas' command is later applied on the imagery by which all pixels having similar DN values/ranges were identified from the whole imagery based on the values or ranges identified under the newly created polygon graphic, regardless of where they are located in the image.

The above techniques were applied on both Landsat ETM (2003) and SPOT5 (2005) image. By using visual inspection and comparing the results with available ground truth revealed errors in the classified image obtained from Landsat image. The classified layer derived from SPOT5 image is was later preferred to the Landsat image because it is having better resolution (10 m) and is also a more recent image that would better reflect current land cover/ land use trends in the catchment.

2.5.6 Post Processing of Classified Image

All the thematic layers accumulated by means of unsupervised and supervised classification algorithms were saved as tiff file format and then converted into grid file format for a final merge with previously extracted map features. All the classified layers and the other subsequently identified thematic layers in grid forms were merged into one land use/land cover grid map.

After applying the classification algorithms to the satellite images, it was found that pixels from the same ground surface feature were classified like different features. These have been termed as problematic pixels/layers and such pixels/layers were eliminated by simply regrouping the problematic pixels through a merging-routine. Problematic layers, which could not be properly distinguished during the classification processes, were merged to adjacent pixels within the same surface feature. This procedure was done using the 'merge' request and 'Con' request in the Map Calculator interface of ArcView Spatial Analyst extension. In doing this, individual grid codes were assigned to each layer and these codes later formed the basis through which these layers would be identified after the merging. The Avenue syntax for the 'Con' request is expressed in the ESRI online help menu as follows:

aGrid.Con (yesGrid, noGrid) Equation (2.1)

For a cell in a grid, this request returns the value found in yesGrid if aGrid is non-zero (TRUE), otherwise it returns the value found in noGrid. For instance the layers with grid cell value 6 in it (data layer 6 'commercial and industrial units' in the classified image) were merged into cells having values 2 as follows:

([landuse12cls] =6).Con (2.AsGrid, ([Landuse12cls]) Equation (2.2)

After eliminating all problematic spectral regions and layers, a Majority Filter request was applied on the merged grid map for minimising the speckled appearance of the data through the elimination of island pixels. These were isolated pixels that did not fall into the bigger class surrounding them. At the end of this process a total of 23 land use grid classes were generated. The Re-class command in ArcView Spatial Analyst extension was used to reclassify the resulting land use grid map into a new land use grid with a corresponding number of grid layers that would have all these cell values in sequence. The various thematic layers were later identified, labelled or assigned land class names using information obtained from ground truthing, and other reference spatial data documents like topographical maps of the area, aerial photographs and the Cape Town and Peninsular Street Guide document.

2.5.7 Extraction of Other Features to Complete Land Use Map

Image classification alone could not be used to successfully identify all the features that constitute the catchment area. Some of the linear features (minor roads, railway line, etc., 6-8 m wide) were too narrow to be grouped because of the image's spatial resolution and polygon features like industry and residential settlements, etc., could not be differentiated due to their very diverse spectral characteristics.

The linear features like the roads, railways and rivers were obtained in ESRI shapefile format from the City Council. These line features were all converted into polygon features using the buffering technique in ArcView. Different buffering distances were identified by measuring the road widths of different road types that exist in the study area. Similarly a unique buffer distance of 10m was chosen for buffering railway lines and major river channels. The polygon width that was attained was having a minimum width of 10 m to enable the final grid to have 10m grid cell size. All these buffered polygons were converted into grid layers by choosing a grid cell of 10m and assigned appropriate cell values for each layer using the reclassify command.

The different residential areas, industrial areas, commercial areas (institutional or mercantile) and most recreation areas that were identified in the image through visual interpretation were individually digitised by drawing polygons that define their boundaries. This was done using the Draw tool in ArcView. The resulting polygon features were saved as shapefiles in ArcView and were converted later into raster grid raster files. Water bodies were identified by doing a 'Find Like Areas' command on the SPOT2005 NDVI image of the area (ESRI, 1998). Using the NDVI vegetation index algorithms, water bodies could clearly be picked up from the satellite image. This image was saved as a shapefile layer; water body polygons and other polygons generated were edited in order to remove unwanted polygons and later converted into a grid layer in ArcView.

2.5.8 Final Merging of All Layers

In the end a total of thirty-six (36) land use and land cover types/features were generated after applying classification (supervised and unsupervised), manual on-screen digitisation and processing of shapefile data acquired from other sources. This formed the final database from which the final land use map for the area can be generated. But since the generation of this land use database was in different formats and compiled from different sources at also varying scales, a rigorous data integration effort was necessary to improve data consistency and quality. The land use class layers obtained from the SPOT satellite image was in UTM Zone 34 South projection and other vector layers obtained from other data analysis and data sources (e.g. City of Cape Town) were in a different projection (WGS 1984 Zone 19 and 21). Therefore before the final merging, the grids obtained from other means (digitisation from aerial photographs and buffered polyline vector layers) were re-projected to the projection of the satellite image. Each re-projected grid layer was merged with the grid layer generated from the satellite image using the merge command or Con request of ArcView Spatial Analyst extension. Finally, the grid cell values were given appropriate attribute descriptions in text form (as seen in Figure 4). The final land use grid having 36 land use/land cover classes (Figures 4 and 5) was finally achieved.

The area statistics of each land use/land cover unit is illustrated in Table 1. From the table it is evident that vineyards constitute over 35% of the total area followed by Fynbos (indigenous vegetation) (12.48%), open hard rock area (5.83%), riparian forest (5.21%), mountain forest (4.98%), scrubland (4.38%) and improved grassland (3.61%). The residential area is around 14% only. Roads contribute 3.36% of the total area.

2.5.9 Final Map Accuracy

The preparation of the Kuils-Eerste River land use / land cover map involved the use of remote sensing and GIS techniques which involved the use of multiple source digital data and other ancillary data sources supported by local knowledge of the area. The quality and accuracy of the output map will therefore be dependent on the quality and accuracy of the input data. However, care was taken to select the most accurate input data available. All the sources that were consulted for these data sets are accredited data distributors who perform high levels of data pre-processing and quality check before letting to the public for use. However, data layers that were deemed not suitable for use were duly eliminated or improved upon at certain instances.

The processing of data for the production of the detailed land use/land cover map for the Kuils-Eerste River area started in the year 2006 and great effort was made to acquire the most recent imageries at very good spatial and spectral resolutions. A 10 m resolution multispectral image, captured by SPOT5 satellite in November 2005, was the closest in time that could be procured. The latest products of topographic map sheets of 1:50,000 scale (large scale map) were employed during ground truthing. Equally, Garmap digital maps, which are integrated in GPS devices, served in the ground truthing process or evaluation of the final land use/land cover map. A general check of the output and available ground truthing data showed a perfect overlap confirming the judgements on grouping different land use/land cover units and the maximum accuracy during manual digitisation. A few field trips were conducted for identifying training sites and the ground truth data collected were compared with the image classification results.

A map accuracy check was performed using 98 randomly selected sampling points. Ground truth information for the sample points were identified, which were later displayed in ArcMap as an event layer. An error matrix was created using the ground truth information collected and map data information obtained from the table. The overall map accuracy or total map accuracy was calculated and an overall accuracy of 91% was obtained for the whole map from this exercise. The Kappa value (coefficient of agreement) for the final map as a whole was also calculated which came to 0.89683 (which means that the total map accuracy is 89.68%). The next sub section briefly describes the procedures that were used during map accuracy checks.

2.5.10 Procedure of Map Accuracy Estimation

The accuracy estimation was performed using 200 randomly sampled points generated in Excel spreadsheet using the Analysis ToolPak extension. Minimum and maximum values of *x* and *y* coordinates of the land use map were identified using ArcMap. Using these values as a range, random data points for 200 locations were generated (because there were thirty six land use classes and hoping that each class will have at least one accuracy check point) and displayed in ArcMap as an event layer (by adding the table as XY data). It was noticed that only 98 samples fell within the catchment boundary and 24 land use/land cover types were represented from the 98 locations identified. The event layer of sample points was exported as a shapefile and an additional field (value) created with a value of one given to all data points used for accuracy check. The ground truth information for the selected sample points were identified through field visits, conducted for accuracy check and previous ground-truthing. The new data point shapefile, the land use map and the ground truth information, were also converted into raster layers/grids. Using the Raster Calculator in Spatial Analyst extension, the raster accuracy check point location layer was multiplied by the land use grids and thus two grids of accuracy assessment data were created. The raster data accuracy check points extracted from the land use map was multiplied by a factor of ten and this grid was added to the raster data accuracy check points extracted from the ground truth layer (in raster form) and this operation done in Raster Calculator gave a new grid. The values of this grid showed the ground truth information and also the mapped data class. The attribute table was exported as a dbf file and displayed in Excel. An error matrix was generated using the ground truth information and map data information obtained from this table, and then the overall map accuracy was calculated for the whole map. The overall or total 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.

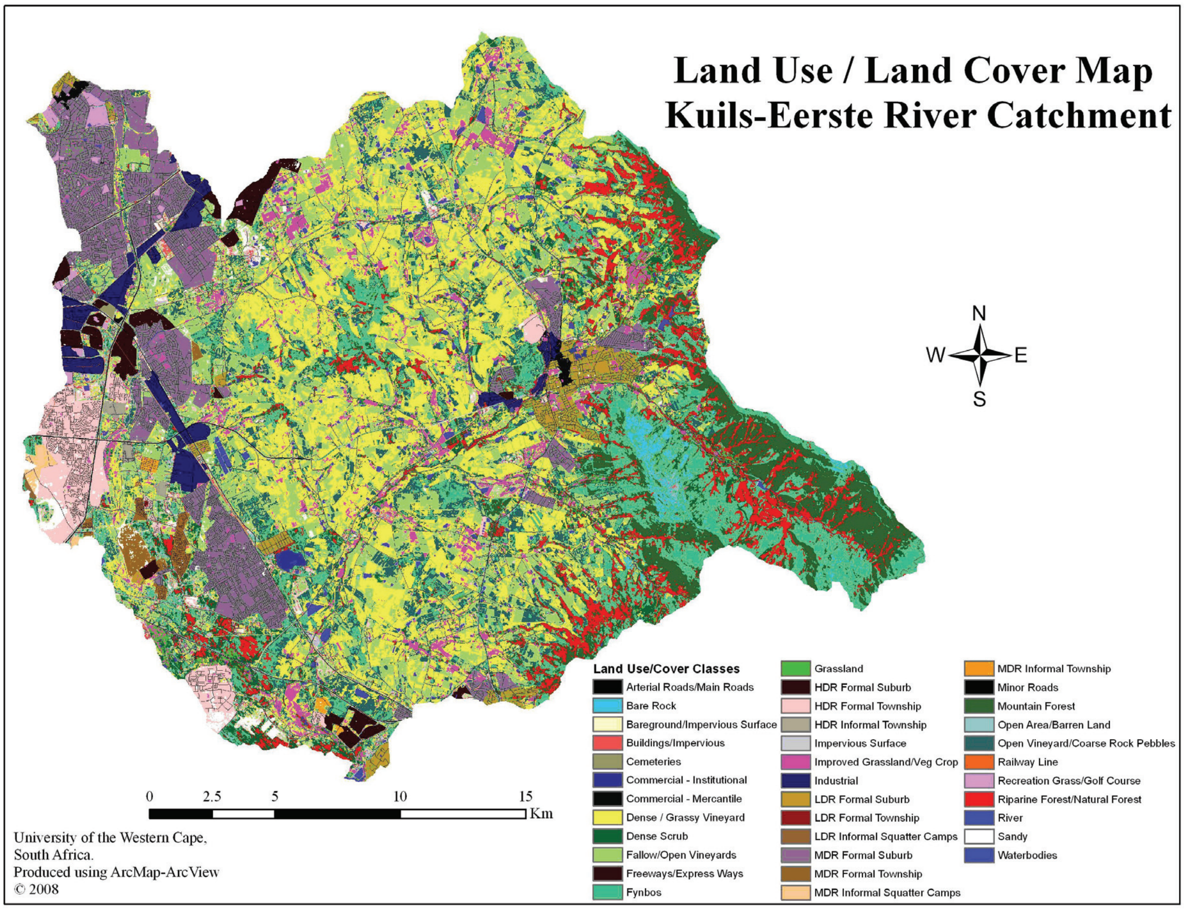


Figure 4 Land Use/Land Cover Map for the Kuils-Eerste River Catchment Area (prepared using an integrated approach).

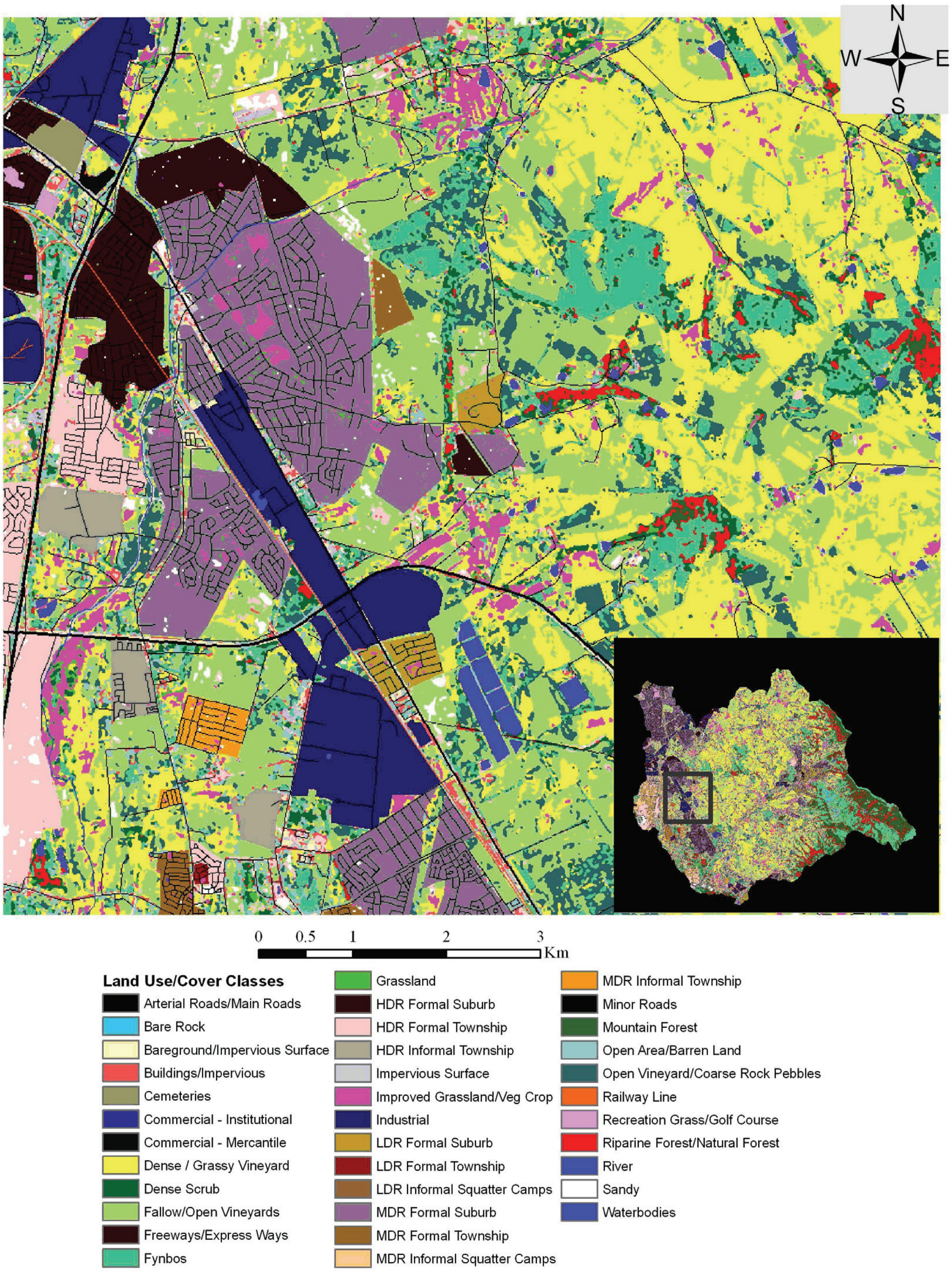


Figure 5 Kuils-Eerste River catchment area at closer view

Table 1 Total area and percentage area of land use/land cover units in the catchment.

Class No.	Land use type	Cell Counts	Area (m2)	% Area
1	Mountain Forest	324131	32413100	4.98
2	Riparian Forest/Natural Forest	339056	33905600	5.21
3	Dense Scrub	284897	28489700	4.38
4	Fynbos	812843	81284300	12.48
5	Grassland	115790	11579000	1.78
6	Impervious Surface	41335	4133500	0.63
7	Railway Line	8649	864900	0.13
8	Bare ground/Impervious Surface	35773	3577300	0.55
9	Bare Rock	36133	3613300	0.55
10	Open Vineyard/Coarse Rock Pebbles	379872	37987200	5.83
11	Open Area/Barren Land	116675	11667500	1.79
12	Improved Grassland/Vegetable	234823	23482300	3.61
13	Buildings/Impervious	49299	4929900	0.76
14	Dense/Grassy Vineyard	1329204	132920400	20.42
15	Fallow/Open Vineyard	937630	93763000	14.4
16	Recreation Grass/Golf Course	23781	2378100	0.37
17	Freeways/Express Ways	5206	520600	0.08
18	Arterial Road/Main Road	23538	2353800	0.36
19	Minor Roads	189969	18996900	2.92
20	Sandy	59206	5920600	0.91
21	Waterbodies	73820	7382000	1.13
22	HDR* Formal Suburb	94178	9417800	1.45
23	MDR* Formal Suburb	455611	45561100	7
24	LDR* Formal Suburb	93700	9370000	1.44
25	HDR Formal Township	217399	21739900	3.34
26	MDR Formal Township	34738	3473800	0.53
27	LDR Formal Township	236	23600	0
28	HDR Informal Township	9861	986100	0.15
29	MDR Informal Township	6701	670100	0.1
30	MDR Informal Squatter Camps	14990	1499000	0.23
31	LDR Informal Squatter Camps	4280	428000	0.07
32	Commercial- Mercantile	12426	1242600	0.19
33	Commercial- Institutional	14365	1436500	0.22
34	Industrial	115054	11505400	1.77
35	Cemeteries	2091	209100	0.03
36	Rivers	13572	1357200	0.21
	Total	6510832	651083200	100

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

2.6 Conclusion

A detailed land use/land cover map containing 36 classes that could be used for assessing non-point source pollution could be generated through an integrated approach involving use of remotely sensed data and further GIS analysis (Figs 4 and 5). The final land use/land cover map that was generated reflected the very complex land cover character of the catchment. It extends from urban and suburban settlement plus industrial and commercial activities in the west, through extensive open agricultural fields, mainly vineyards in the central parts of the catchment, to mainly forest tree plantation and naturally vegetated areas in the eastern section of the catchment. The relief is generally flat in the western part of the catchment, changing to gently undulating hills around the centre to extremely rugged relief with very high mountain ranges in the eastern part. One should take into consideration that, due to both human error and computer software limitations or shortcomings, there would certainly be some mis-representation in the assigning of certain identities to certain land classes.

3 WATER QUALITY MONITORING

3.1 General considerations

This chapter describes the water quality monitoring programme adopted and also presents the data acquired during the research period for the catchment. The water quality in the catchment was monitored in a systematic way for nearly three years covering most of the land use/land cover types and observed most quality parameters were falling within the limits adopted by the national authority on water quality control. In view of this consideration, the purposes of this chapter are to provide some background on water quality monitoring network design and programme evaluation, and to set the stage for the subsequent application of the model presented in the report.
A set of monitoring considerations includes the following issues:

- Monitoring objectives – why do we monitor?
- Monitoring network design – how do we monitor, including the essential components of where, when, and what do we monitor?
- Monitoring-programme evaluation – how will monitoring network procedures incorporate developing technologies and change in the future?

The sampling of runoff water in order to generate the required water quality data at several stream monitoring sites and land/use cover type was conducted during 2006 through to 2008. In the same exercise were collected other parameters also like water temperature and electrical conductivity at some sites. The principal goals of this monitoring programme was to characterize the surface runoff water, water from the rivers and streams of the Kuils-Eerste River Catchment and to track changes in water quality on the basis of the land use/ land cover type distribution; data obtained would then be used in the GIS models to characterise non-point source pollution in the catchment.

In conducting these activities all safety precautions were adhered to both in terms of sample collection, handling and management of samples including the safety of personnel engaged in the data collection.

Monitoring is defined by the International Organization for Standardization (ISO) as: “the programmed process of sampling, measurement and subsequent recording or signalling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives”. This general definition can be differentiated into three types of monitoring activities that distinguish between long-term, short-term and continuous monitoring programmes as follows:

- Monitoring is the long-term, standardised measurement and observation of the aquatic environment in order to define status and trends.
- Surveys are finite duration, intensive programmes to measure and observe the quality of the aquatic environment for a specific purpose.
- Surveillance is continuous, specific measurement and observation for the purpose of water quality management and operational activities.

“Water quality” is a term used here to express the suitability of water to sustain various uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water; for example limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities. Consequently, water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality. Quantity and quality demands of different users will not always be compatible, and the activities of one user may restrict the activities of another, either by demanding water of a quality outside the range required by the other user or by lowering quality during use of the water. Efforts to improve or maintain a certain water quality is often a compromise between the quality and quantity demands of different users. There is increasing pressure that natural ecosystems have a legitimate place in the consideration of options for water quality management. This is both for their intrinsic value and because they are sensitive indicators of changes or deterioration in overall water quality, providing a useful addition to physical, chemical and other information.

Water quality is affected by a wide range of natural and human activities. The most important of the natural influences are geological, hydrological and climatic, since these affect the quantity and the quality of water available. Their influence is generally greatest when available water quantities are low and maximum use must be made of the limited resource; for example, high salinity is a frequent problem in arid and coastal areas. If the financial and technical resources are available, seawater or saline groundwater can be desalinated but in many instances this is not feasible. Although water may be available in adequate quantities, its unsuitable quality limits its usefulness. Although the natural ecosystem is in harmony with natural water quality, any significant changes to water quality will usually be disruptive to the ecosystem.

3.2 Runoff Water Quality Monitoring

The Kuils-Eerste River catchment is a large surface water network draining the eastern part of Cape Town. This catchment is highly urbanized contributing to the degradation of the water bodies within it. It is assumed the degradation is mainly due to urban storm water runoff and the release of sewage effluents from the sewage works located within the catchment. A significant portion of the catchment area constitutes agricultural land hence is linked to non-point source (NPS) pollution.

In order to understand the water quality characteristics of the catchment, sampling activities were carried out from different sites as shown in Figure 6 representing the sampling sites. It is worth noting too that some areas in the catchment could not be accessed for water sampling due to the nature of the terrain, variation in rainfall distribution (no rainfall received in some areas during the sampling campaign) and/or lack of authority/permission to access certain areas. Water quality information reviewed here has been collected from several sites chosen throughout the Kuils-Eerste River catchment (Figure 6).

The range of water quality parameters that were measured at each site depended on the aims of the sampling programme. In most of the times, parameters like temperature, dissolved oxygen, pH, and electrical conductivity were measured in field sites using standard meters. River flow was determined using velocity and depth measurements across the river cross-section. Water samples were collected for laboratory analysis of nitrate nitrogen (NO_3-N), total nitrogen (TN), and total phosphorus (TP), total suspended solids (TSS). Samples were transported to the BemLab, an accredited laboratory in Somerset West, on the same day of sampling for analysis. Chemical and microbiological analyses were conducted using standard analytical techniques (BemLab Report 2008). The levels of recent detection limits in the laboratory for the chemical analyses of chosen parameters were as follows: for NO_3-N 0.002 mg/L; for TN 0.1 mg/L; for TP 0.005 mg/L, and for TSS 0.3 mg/L.

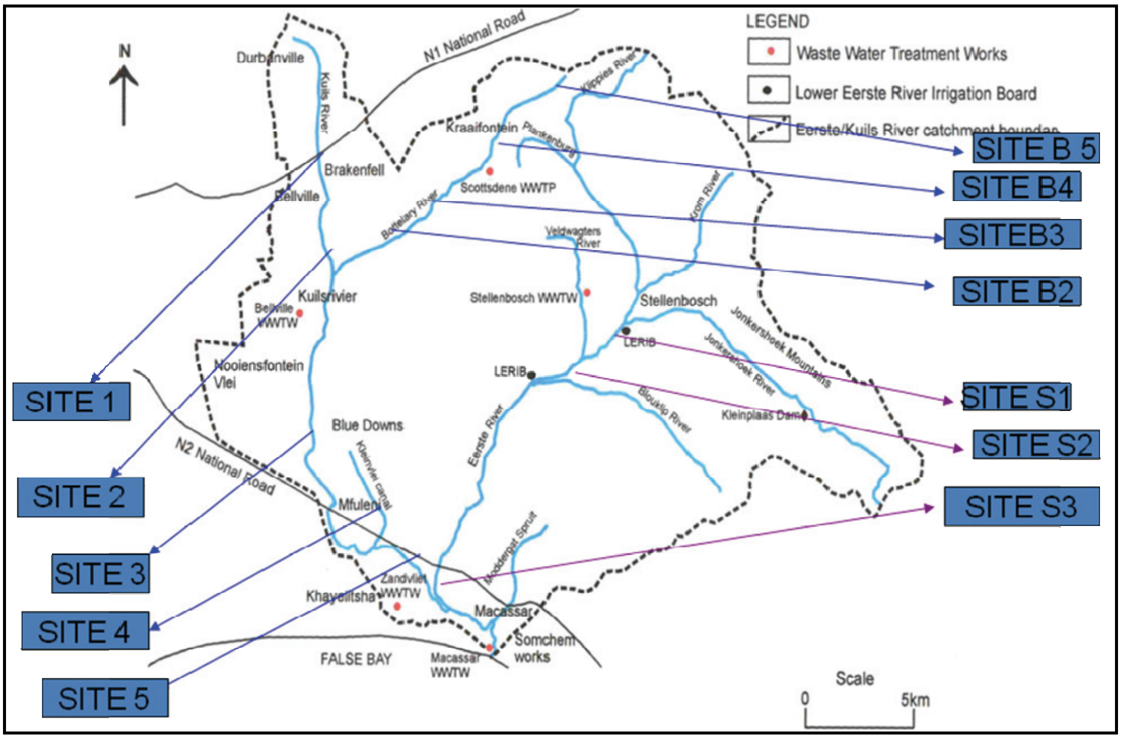


Figure 6 Sampling sites location along the river network

3.2.1 Sampling Procedures

The procedure of sampling was mainly grab sampling of surface runoff with the use of plastic scoops and discrete sampling along the course of the river where runoff samples were collected in one litre and 250 ml bottles. Specific land use / land cover types like residential areas, parking areas, streets and roads, and farming areas were targeted which were sampled at random as the storm continued in order to ensure extensive coverage of the area under study. In addition to surface runoff sampling, discrete river water sampling was conducted at specific intervals along the Kuils River and also along the Bottellary River (after October 2007 by the M.Tech student from the Cape Peninsula University of Technology).

The sampling team members were given training in sampling procedures and techniques during a storm event where all safety precautions were adhered to both in terms of sample collection, handling and management up to the safety of personnel engaged in the data collection. During the course of the reporting period, an agent of the supplier of the flow meter and automatic sampler made a visit to the Department in order to demonstrate on the operation of the automatic sampler.

For each sampling campaign all samples were collected between 9 am and 3 pm of the same day. At the end of each sampling campaign the samples were immediately taken to BemLab. In instances where the sampling procedure exceeded the working hours making it impossible to deposit them at the laboratory, the samples were temporarily preserved in a fridge under an optimal temperature of 5^{o}C.

3.2.2 Experimental Plots/ Runoff Plot Data Generation

Experimental plots/runoff plots for runoff water quality monitoring were set up on a farm (Skoonheid wine farm) located within the catchment to enhance the collection of data on surface runoff from specific land cover types within the catchment. The Skoonheid wine farm is located in Skoonheid area on the left side of Stellenbosch Arterial road (at 33° 57’ 26.59" South and 18° 43' 35.24" East). Permission was sought and granted by the owner of the farm, Mr Jaco van der Westhuizen, in October of 2006 in order to have the runoff plot set up on his farm. A reconnaissance survey was then undertaken to locate appropriate sites for runoff plots that would be representative of an agricultural setting in the area. Four experimental plots were set up on four different land use types and runoff and water quality data were collected from them. All plots conformed to a set of dimension specifications based on their locational parameters.

Runoff Plot I (Figure 7) was constructed on a land cover type representing grassland located in front of the farm house. The runoff plot covers a total surface area of 75 m^2 (15 m x 15 m). Three sides of the plot were sealed with 150 mm wide metal sheets driven into the soil to prevent runoff from entering or leaving the plot. At the lower side of the plot, a 5 m long PVC gutter was laid on the ground to collect runoff into a collection chamber. The collection chamber is a pit having a volume of 1 m^3 in which a 60 litre plastic barrel was kept. The barrel had a lid and it was connected to the gutter by a 1.8 m long PVC pipe of 75 mm diameter.

Figure 7 Runoff Plot 1 in a grassland area on Skoonheid farm.

The second runoff plot (Figure 8) was set up in a vineyard situated on a slope facing the farm house. This runoff plot was designed to assess runoff emanating from an agricultural land use setting. The first runoff plot has a surface area of just 60 m^3 (12 m by 5 m). This plot accounted for the agricultural activities of the farm, i.e. a vineyard. The rows of vines have been planted perpendicular to the down slope direction. The long edge of the rectangular plot was set parallel to the rows of vine plants and furrows. As a general observation, it was noted that, the rows and furrows have been cultivated to run across the slope gradient probably as a control measure against soil erosion.

Figure 8 Plate showing runoff Plot 2 on a NW facing slope. Notice the strips of metal on both long sides of the plot and the concrete gutter in front.

Galvanised metal strips (plates) of 15cm width were driven into the ground along the sides of the plot to cordon off any flow of water into or out of the plot. In this case, the side strips were buried just along the edge of the ridge on which the vines are growing. These sheets were cautiously driven deeply enough into the ground to prevent any subsurface escape or entry of surface water from beneath the sheets and at the same time, to avoid tampering with the root system of the plants. On the lower side of the plot, a 5 m concrete gutter was constructed in the ground to convey water that is collected into a collection chamber. The gutter of this runoff plot is constructed with concrete as opposed to PVC material, in order to allow easy access for the farmer's tractor to pass through so that normal farming activity can go on without causing any hindrance for the movement of the tractor or the farmer. The collection chamber is a plastic barrel, with capacity of 20 litres placed in an excavation (pit) of about 1 cubic metre. The barrel has a lid to cover it, thus preventing direct contributions from direct rain drops entering into it and preventing evaporation from it. A PVC pipe of 75 mm diameter links the concrete gutter to the collection chamber. The PVC pipe from the gutter runs into a barrel kept in the pit. The pit's size is sufficient enough to allow easy emptying of the barrel.

The third runoff plot was designed in woodland situated on the sloping face of a hill (Fig 9) in the same farm. This plot was meant to assess runoff emanating from the pine forest land cover. The sitting of the plot took into consideration other aspects relating to the quantity and amount of canopy cover over the plot. In order to effectively represent the role canopy plays in affecting the amount of rain water that would likely to reach the ground, the extent of the canopy coverage was determined through some photographs taken underneath the canopy in such a way that camera was facing towards the tree tops/sky.

Figure 9 Site set up for the construction of the Runoff Plot III

3.2.3 Runoff Monitoring in Experimental Plots

The experimental plots were set up to mimic natural processes in runoff production in an agricultural setting. During the winter rainy days these plots were constantly monitored for any runoff that accumulated. Weather forecasts for the region were closely noted in order to obtain predictions of the next rain events and their magnitudes. With this information in hand, the team used to visit the plots to prepare them for a proper sample collection. These activities included cleaning of the gutters through which runoff would smoothly flow into the barrel; cleaning of the barrels – getting rid of any unwanted matter that may have fallen into barrels; setting of the rain gauge on site etc.

After each rainfall event and sometimes during rains, the plots were visited and the barrels were checked for any runoff that might have collected from the rainfall event. The volumes of total runoff that was collected were first noted down (Table 2) and a sample was taken in a sample bottle for chemical analysis. Two simple approaches were employed in deducing the total volume of runoff that collects in the barrel. These methods included reading off the volume from graduated marks that represented the depth of runoff in the barrel or simply measuring of the volume of runoff with a measuring cylinder in the case where the total runoff collected is small.

Rainfall amounts received at these sites were measured as rainfall depths recorded from the rain gauges located inside the plot. In some instances the rain gauge had fallen down and the rainfall readings were collected from the farmer's rain gauge. In many cases, the barrel was found empty indicating no runoff from the plot even at times when the rain gauge showed that significant amounts of rain fell. Lack of runoff in some instances is due to the nature of the soil, which is sandy loam to sandy clayey loam, slope condition and higher initial

abstraction. Sandy loam soil textures possess high infiltration potentials and thereby do not produce much surface runoff but most of the rainfall infiltrates into the subsurface.
After collecting the data, the barrel is emptied and set again for subsequent episodes of rainfall to be monitored. It should be noted that, the samples that were collected in the barrels are representative composite sample of chemical constituents that were generated in the duration of the rainfall event. By definition, a composite sample is a mixed or combined sample that is formed by combining a series of discrete samples of specific volumes at specified intervals. In other words, these composite samples characterize the quality of a storm water discharge over the duration of the storm event.

Table 2 Runoff Volumes from Plot I and Plot II

Event Date	**Rainfall Depth (mm)**	**Runoff Depth (Litres)**	
		Plot 1	**Plot 2**
31-Aug-2007	20	3.25	
1-Sep-2007	1.5	1.8	
3-Sep-2007	5	0	0.75
13-Sep-2007	14	0	4
3-Oct-2007	9.5	0	6
23-Oct-2007		0.5	12
8-Nov-2007	12	0	0
21-Nov-2007	12	0.25	6
22-Nov-2007	10	0.52	4.8

3.3 Generation of Database of Runoff Water Quality (EMC Values)

3.3.1 EMC Properties

Estimated or Event Mean Concentrations (EMC) values are typical values of a pollutant expected in runoff from a particular land use (Naranjo, 1998) arising as a result of the build up and wash off processes (Butcher, 2003). Equation 4.1 defines EMC as a flow weighted average concentration of a pollutant over an entire storm event.

$$\text{EMC} = \frac{\sum (Ci * Qi)}{\sum (Qi)} \qquad \text{Equation 3.1}$$

Where C_i = concentration of runoff at interval i
Q_i = flow at time when sample was taken
The EMC value is usually estimated from a flow weighted composite sample collected in the field or calculated from discrete measurements and the runoff volume (Q) determined by way of field measurements as well as through estimation techniques such as the Natural Resources Conservation Service (NRCS) curve number (CN) method.

The CN method combines infiltration with initial losses to estimate rainfall excess, which would appear on the earth's surface as runoff (Thomas, 2001). The equation for total runoff excess in this technique is expressed in Equation 4.2 below:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad \text{Equation 3.2}$$

Where Q = total rainfall excess (runoff) for storm event
P = total rainfall for storm event
I_a = total initial loss
S = potential maximum retention capacity of the soil at the beginning of the storm

S is determined thus $S = \left(\frac{1000}{CN}\right) - 10$ Equation 3.3

CN in Equation 4.3 is the curve number value and it ranges between 0 (100% infiltration) and 100 (0% infiltration). This curve number is dependent on soil; land use and land cover information. The estimated runoff volume (Q) from Equations 4.2 and 4.3 is then incorporated into Equation 4.1 for estimating the EMCs.

During this study discrete runoff samples were collected from all the previously identified land use/covers (roads, grasslands, residential, industrial, car park, open area, etc) of Kuils-Eerste Rivers urban catchment. While sampling, it was not possible to measure the runoff volume or even the extent of land use area contributing to the runoff at a point of collection due to insufficient logistics. The runoff volume for the sampled land use types could not be estimated. Because of the above constrain the calculation of EMC values using the afore-mentioned equations could not be undertaken for such sampling sites. An alternative approach to estimate EMC value is to assume an arithmetic average value of concentrations of any number of samples collected from a site during a rainfall event using Equation 6.4 which defines the arithmetic average, EMC, as:

$$\text{Average EMC} = \frac{\sum_{j=1}^{m} EMCj}{m} \qquad \text{Equation 3.4}$$

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

Using the latter method discussed above, the arithmetic means of the chemical concentrations of nitrate (nitrate-nitrogen), total phosphorus, and chloride, dissolved oxygen, COD, total nitrogen, for the land use types that were sampled were calculated for each day of sampling. In building the database of EMC for the rest of 2007 and beyond, care was taken to minimize the reoccurrence of any land use type in the records gathered for a single event. In other words, for each rainfall event that was sampled, efforts were made to sample all representative land use types as well as to sample extensively within the perimeter of the catchment. In an occasion where one land use type was sampled more than once, a mean value was calculated for that land use by considering averaging all the records of that land us type irrespective of the position where it was collected in the catchment. Samples were collected from over 83 sites in the Kuils River catchment during the winter months of 2006, 2007 and 2008. A spatial distribution of the sample sites is shown in Figure 10. Table 3 contains the final EMC values calculated from the set of land use sites sampled in the catchment.

3.3.2 Generation of EMC Database from Runoff Plots

The purpose of the experimental plots in the Skoonheid wine farm was to simulate runoff processes that occur on selected land use types. During the rainy days, these plots were monitored and any runoff collected were analysed in the laboratory for the selected parameters.

The samples that were collected by means of runoff plots are flow-weighted composite aliquots or samples. The analysis of such samples characterises the quality of a storm water discharge over a period of time e.g. during the duration of an entire storm event. The results obtained from the analysis of the runoff samples collected from these experimental plots are expressed in the form of Event Mean Concentration (EMC) values and are presented in Tables 3 to 5. The sample field dates in Table 3 and 4 are basically the dates on which the samples were retrieved from the barrels. These dates might not necessarily be the same dates during which rainfall occurred. Most of the time, the samples were retrieved the next morning if there was an overnight rain event.

Effort was made to avoid contamination of the samples by collecting the samples very promptly, corking and storing them in a field box and sending to the laboratory for chemical analysis before any major internal chemical alterations may occur within the sample constituents. It should be noted also that, the sample dates that have been presented in the data table do not necessarily represent all the rainy days during the period of investigation. It was frequently noticed that, very small rainfall amounts was received, hence very little or no runoff was collected. This could be explained by the high infiltration capacity of the sandy clay loam soils that underlay the vegetation in the plots. This is also an indication that soil texture played a very important role in runoff generation on these sites but also that the contribution of nonpoint source pollution is controlled by the land use activity on the plot.

Two land use or land cover types are being presented by the plot data. Plot I represents grassy or shrubby vegetation type scenario, while Plot II represents environmental responses that occur in an agricultural setting (e.g. vineyard). During certain days of prolonged rainfall, some subsurface flow was observed as soil water oozed through the walls of the collection chamber and gradually filling the chamber. Such interflows were collected and also analysed. The chemical content of the barrel samples were considered to be the event mean concentrations (EMC) for every pollutant. Since the two plots represented land use/cover surfaces, their data was incorporated into the data table for the whole catchment. In this regard, the EMC readings for Plot I and Plot II were considered as the EMC data from grasslands and vineyards, respectively.

Table 3 Estimated Mean Concentrations values (in mg/l) obtained for samples collected in runoff plots 1 and 2 during 2007

		WATER QUALITY PARAMETERS						
DATE	**LAND USE/COVER**	**N**	**NO_3-N**	**P**	**Cl**	**SS**	**COD**	**DO**
19-May-07	PLOT I	No Data	0.04	0.37	6.20	158.00	22.00	7.90
	PLOT II	No Data	0.03	1.95	7.10	590.00	370.00	4.60
7-8 June 07	PLOT I	400.00	0.24	0.28	8.83	52.00	35.00	8.20
	PLOT II	257.00	2.03	0.63	8.20	89.00	113.00	6.20
25-Jun-07	PLOT I	120.00	0.00	0.11	8.83	51.00	4.00	7.60
	PLOT II	171.00	1.24	0.98	37.08	95.00	445.00	4.80
28-Aug-07	PLOT I	547.00	0.14	1.34	31.28	101.00	49.00	8.10
28-Aug-07	PLOT II	343.00	0.00	1.69	35.62	5.00	74.00	7.00
29-Aug-07	PLOT I SUB	310.00	0.00	0.93	34.75	41.00	38.00	8.20
31-Aug-07	PLOT I	360.00	0.54	1.88	26.93	41.00	139.00	6.10
31-Aug-07	PLOT I SUB	395.00	0.00	0.46	33.88	30.00	24.00	8.00
3-Sep-07	PLOT II	802.00	0.00	3.02	84.27	74.00	710.00	3.60
6-Sep-07	PLOT II	317.00	0.00	0.64	17.38	19.00	22.00	6.30
13-Sep-07	PLOT I	445.00	0.00	0.75	19.11	8.00	35.00	7.40
13-Sep-07	PLOT II	387.00	0.00	4.34	43.44	40.00	335.00	6.00

Concentrations (mg/l) for samples collected in runoff Plot2 during 2007.

Table 4 Estimated Mean Concentrations (mg/l) for samples collected in runoff Plot I during 2007

Plot I									
Event Date	**Rainfall (mm)**	**Runoff Volume (L)**	**N**	**NO_3-N**	**P**	**Cl**	**SS**	**COD**	**DO**
19-May-07	6.5	No records	No Data	0.04	0.37	6.2	158	22	7.9
08-Jun-07	1.5		400	0.24	0.28	8.83	52	35	8.2
25-Jun-07	5		120	0	0.11	8.83	51	4	7.6
28-Aug-07	14		547	0.14	1.34	31.28	101	49	8.1
29-Aug-07	9.5		310	0	0.93	34.75	41	38	8.2
31-Aug-07	20	3.25	360	0.54	1.88	26.93	41	139	6.1
31-Aug-07	20	No records	395	0	0.46	33.88	30	24	8
01-Sep-07	1.5	1.8							
03-Sep-07	5	0	No Data	No Data	No Data	No Data	No Data	No Data	No Data
06-Sep-07	12								
13-Sep-07	14		445	0	0.75	19.11	8	35	7.4
03-Oct-07	9.5	0	No Data	No Data	No Data	No Data	No Data	No Data	No Data
23-Oct-07		0.5							
08-Nov-07	12	0	No Data	No Data	No Data	No Data	No Data	No Data	No Data
21-Nov-07	12	0.25							
22-Nov-07	10	0.52							

Table 5 Estimated Mean Concentrations (mg/l) for samples collected in runoff Plot2 during 2007.

Plot II									
Event Date	**Rainfall Depth**	**Runoff Volume (L)**	**N**	**NO_3-N**	**P**	**Cl**	**SS**	**COD**	**DO**
19-May-07	20		No Data	0.03	1.95	7.1	590	370	4.6
08-Jun-07	8	2.25	257	2.03	0.63	8.2	89	113	6.2
25-Jun-07	5		171	1.24	0.98	37.08	95	445	4.8
28-Aug-07	14		343	0	1.69	35.62	5	74	7
01-Sep-07	1.5	N/A							
03-Sep-07	5	0.75	802	0	3.02	84.27	74	710	3.6
06-Sep-07	12		317	0	0.64	17.38	19	22	6.3
13-Sep-07	14	4	387	0	4.34	43.44	40	335	6
03-Oct-07	9.5	6							
23-Oct-07		12							
08-Nov-07	12	0							
21-Nov-07	12	6							
22-Nov-07	10	4.8							

3.4 Water Quality Monitoring in Kuils River

An attempt was made to sample water from the Kuils River on a weekly basis for a month (October 2007) and the results of analysis of river water samples are shown in Tables 6 and 14.

Table 6 Database of Sample Analysis for Pollution in the Kuils River Profile

Date	Reference	Lab No	NO_3-N mg/L	Cl mg/L	TSS mg/L	P mg/L	N mg/L	COD mg/L
02/10/07	KR07100201	14351	1.96	208.5	6	0.09	412	33
	KR07100202	14352	1.66	189.4	8	0.07	270	43
	KR07100203	14353	4.91	179	25	1.02	467	57
	KR07100204	14354	5.06	185.9	15	1	246	56
	KR07100205	14355	3.25	243.3	12	0.09	1542	58
	KR07100206	14356	4.84	134.7	8	2.55	1335	29
	KR07100207	14357	2.54	145.1	44	0.16	866	32
	KR07100208	14358	0.56	149.4	66	3.29	278	56
	KR07100209	14359	0.29	147.7	58	3.25	441	44

Table 7 Database of Sample Analysis for Pollution in the Kuils River Profile

Date	Reference	Lab No	NO_3-N mg/L	Cl mg/L	TSS mg/L	P mg/L	N mg/L	COD mg/L
03/10/07	KR07100303	14362	3.97	132.1	36	0.82	701	58
	KR07100304	14363	4.86	167.8	13	1.14	519	71
	KR07100305	14364	2.27	59.1	15	0.12	454	8
	KR07100307	14366	1.43	130.3	36	0.23	412	54
	KR07100308	14367	0.75	107.7	174	2.62	349	59
	KR07100309	14368	0.32	106.9	151	3.05	704	57
	KR07100310	14369	5.94	117.3	11	0.36	726	58
	KR07100311	14370	3.73	139.9	20	0.17	487	56
	KR07100312	14371	4.32	134.7	13	2.53	526	57

Table 8 Database of Sample Analysis for Pollution in the Kuils River Profile

Date	Reference	Lab No	NO_3-N mg/L^{-1}	Cl mg/L^{-1}	TSS mg/L^{-1}	P mg/L^{-1}	N mg/L^{-1}	COD mg/L^{-1}
10/10/07	KR0 7101001	15076	0.48	152.9	7	0.07	597	47
	KR0 7101002	15077	0.51	177.2	16	1.13	498	60
	KR0 7101003	15078	0.54	174.6	18	0.13	627	54
	KR0 7101004	15079	0.51	169.4	10	1.43	738	62
	KR0 7101005	15080	0.63	165.1	20	0.21	794	26
	KR0 7101006	15081	4.62	149.4	70	2.82	731	54
	KR0 7101007	15082	5.84	157.2	55	3.01	572	55
	KR0 7101008	15083	1.72	229.4	14	0.04	955	49
	KR0 7101009	15084	0.64	139	16	1.9	709	33

Table 9 Database of Sample Analysis for Pollution in the Kuils River Profile

Date	Reference	Lab No	NO_3-N mg/L^{-1}	Cl mg/L^{-1}	TSS mg/L^{-1}	P mg/L^{-1}	N mg/L^{-1}	COD mg/L^{-1}
16/10/07	KR 07101601	16237	1.25	198.1	3	0.16	451	13
	KR 07101602	16238	5.1	187.7	10	1.38	307	64
	KR 07101603	16239	1.69	176.4	9	0.18	324	63
	KR 07101606	16242	1.44	172.9	22	0.26	274	54
	KR 07101607	16243	1.72	152	58	2.78	305	64
	KR 07101608	16244	1.78	158.1	48	2.3	516	74
	KR 07101609	16245	2	244.1	16	0.09	634	68
	KR 07101610	16246	1.38	133.8	6	3.51	735	49

Table 10 Database of Sample Analysis for Pollution in the Kuils River Profile

Date	Reference	Lab No	NO_3-N mg/L^{-1}	Cl mg/L^{-1}	TSS mg/L^{-1}	P mg/L^{-1}	N mg/L^{-1}	COD mg/L^{-1}
23/10/07	KR07102301	16641	0.68	112.9	35	0.41	1014	75
	KR07102302	16642	4.01	192	45	1.54	1166	86
	KR07102303	16643	1.3	81.66	40	0.1	700	67
	KR07102304	16644	3.33	172.89	48	1.22	620	87
	KR07102308	16648	3.19	70.37	296	2.65	679	132
	KR07102309	16649	1.12	39.09	14	0.12	642	68
	KR071023010	16650	0.4	59.95	251	2.19	795	137
	KR071023011	16651	0.89	145.1	9	0.04	399	72
	KR071023012	16652	0.59	125.1	12	3.52	382	88

Table 11 Database of Sample Analysis for Pollution in the Kuils River Profile

Date	Reference	Lab No	NO_3-N mg/L^{-1}	Cl mg/L^{-1}	SS mg/L^{-1}	P mg/L^{-1}	N mg/L^{-1}	COD mg/L^{-1}
31/10/07	KR 07103101	0	178.9	4	0	8	31	9.6
	KR 07103102	11.47	173.8	19	0.02	7	30	8.8
	KR 07103103	4.25	180.7	19	0.83	6	17	9.4
	KR 07103104	4.46	183.3	8	0.66	8	50	9.9
	KR 07103105	1	107.7	12	0.17	9	77	9.5
	KR 07103106	2.26	147.7	17	0.09	10	43	9.4
	KR 07103107	3.39	146.8	27	3.46	5	51	8.6
	KR 07103108	2.32	148.6	43	3.33	4	42	9.5
	KR 07103109	2.06	271.9	13	0	8	44	9.8
	KR 07103110	2.82	123.4	18	3.26	2	34	8.9

Table 12 pH and Electrical Conductivity Database

Date	Ave Temp. ^oC	pH	EC$\mu S/m^{-1}$
16/10/2007	15.65	6.5	1016
	21.9	7	939
	20.5	7.3	980
	22.5	7.5	951
	29.25	8.5	827
	27.3	8	1195
	22.2	7.7	1048
	22.15	7.6	1047
	30.75	8.8	1237
	19.8	8.3	892

Table 13 pH and Electrical Conductivity Database

Date	Ave Temp. ^oC	pH	EC$\mu S/m^{-1}$
23/10/2007	17.45	7	631
	20.15	7.5	945
	19.4	7.5	394
	19.35	7.7	405
	19.5	7.4	340
	17.65	7.6	204
	21.85	8.1	413
	20.05	7.8	475
	23.15	8	425
	20	7.8	468
	24.3	8.5	254
	20	8.1	732

Table 14 pH and Electrical Conductivity Database

Date	Ave Temp. ^oC	pH	EC$\mu S/m^{-1}$
31/10/2007	18.55	8.1	934
	25.75	8.2	970
	27.5	8.1	929
	25.9	8.4	954
	29.7	8.7	707
	28.55	7.7	1075
	24.7	7.7	1051
	24.6	7.7	1051
	31.4	8.7	1306
	22.6	7.4	892

3.4.1 The EMC Database for the Whole Catchment

The team's dedication in acquiring adequate water samples ensured a unique dataset for runoff that could be used successfully. The EMC database for the whole catchment consists of all EMC values that were obtained from various sampling campaigns conducted for each of the thirty-six land cover types as determined by the land cove/use map that was developed for the project. Table 15 given below reflects the land use/land cover types seen in the catchment and the corresponding EMC values that were derived as average/mean of the EMC values determined from various the samples collected.

Table 15 Expected Mean Concentration derived from the analysis of surface runoff samples.

Value	Land use/Land Cover	Nitrate	Chloride	TSS	Total P	Total N	DO	COD
1	Mountain Forest	1.01	16.27	196.17	0.25	7.50	7.33	64.50
2	Riparian Forest/Natural Forest	1.01	16.27	196.17	0.25	7.50	7.33	64.50
3	Dense Scrub	1.01	16.27	196.17	0.25	7.50	7.33	64.50
4	Fynbos	1.17	16.24	45.80	0.19	5.80	7.20	76.80
5	Grassland	1.01	36.08	66.90	3.32	319.86	4.94	178.43
6	Impervious Surface	1.21	16.87	70.56	0.24	317.59	6.07	107.00
7	Railway Line	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Impervious Surface/Bare Ground	1.21	16.87	70.56	0.24	317.59	6.07	107.00
9	Bare Rock	1.21	16.87	70.56	0.24	317.59	6.07	107.00
10	Open Vineyard/Hard Rock	0.51	58.11	61.44	0.08	367.22	8.02	50.78
11	Open Area/Barren Land	0.69	159.80	68.00	0.03	50.00	6.80	43.00
12	Improved Grassland/Veg Crop	0.69	157.29	234.50	3.78	295.50	7.25	128.00
13	Buildings/Impervious	1.21	16.87	70.56	0.24	317.59	6.07	107.00
14	Dense / Grassy Vineyard	1.79	48.21	96.25	2.12	249.09	6.19	213.58
15	Fallow/Open Vineyards	1.79	48.21	96.25	2.12	249.09	6.19	213.58
16	Recreation Grass/Golf Course	0.03	261.60	9.00	0.12	565.00	7.30	120.00
17	Freeways/Express Ways	0.08	12.19	236.50	0.15	458.00	6.55	325.50
18	Arterial Roads/Main Roads	0.12	34.94	394.29	0.57	147.69	5.01	592.43
19	Minor Roads	0.13	29.40	75.00	0.58	329.34	4.94	521.00
20	Sandy	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	HDR Formal Suburb	0.23	33.43	99.67	1.27	420.33	5.80	608.67
23	MDR Formal Suburb	0.17	21.03	40.63	0.29	287.65	6.56	108.00
24	LDR Formal Suburb	0.17	21.03	40.63	0.29	287.65	6.56	108.00
25	HDR Formal Township	0.22	12.27	41.80	0.31	294.34	6.38	54.40
26	MDR Formal Township	0.22	12.27	41.80	0.31	294.34	6.38	54.40
27	LDR Formal Township	0.22	12.27	41.80	0.31	294.34	6.38	54.40
28	HDR Informal Township	0.10	13.62	35.07	0.39	177.00	3.09	179.17
29	MDR Informal Township	1.85	134.42	321.00	3.53	24.50	6.58	350.50
30	MDR Informal Squatter Camps	0.18	18.11	41.02	0.30	289.88	6.50	90.13
31	LDR Informal Squatter Camps	1.85	134.42	321.00	3.53	24.50	6.58	350.50
32	Commercial - Mercantile	6.65	26.25	112.18	0.31	258.14	5.40	228.73
33	Commercial - Institutional	0.12	11.04	108.00	0.16	337.27	6.00	104.50
34	Industrial	0.71	38.63	192.63	2.13	285.18	6.68	580.75
35	Cemeteries	0.69	16.78	506.00	0.14	3.00	7.40	104.00
36	River	5.59	150.45	24.84	1.80	383.17	8.06	62.76

The next chapter includes a description of the methods that were used in measuring stream discharge and discharge in other surface / open channels (engineered).

4 DATABASE OF STREAM FLOW MEASUREMENT

4.1 Introduction

Documenting and monitoring stream flow is an integral part of developing water budgets, conducting load calculations, evaluating the relationship between groundwater and surface water, and critical in evaluating impacts from urban runoff. Following the main activities contained in the schedule for the second year of data collection for the project, stream flow, and measurement along the Eerste River was scheduled as part of the main activities and the results herein reported correspond to the activities that were then realised. The work was carried out during January and September 2008 after careful consideration of the sites and all preliminary reconnaissance work was completed. The main objective of this set of activities was to generate a database of stream flow measurement from the Eerste River.

4.2 Methodology

There are a number of methods to document stream flow, but the most typical method for field evaluations is to develop a cross-section of a stream segment or channel. The volume of water that moves through the channel is then calculated by dividing the channel into smaller units of known or approximated areas (width * depth) and measuring the flow within each area (velocity – distance travelled over time). When these values, area * velocity, are multiplied together the result is discharge (length 3/ t^{-1}), expressed as velocity of flow in unit time m^3/s^{-1}.

4.2.1 Step 1: Selecting the Channel Location

All possible precautions were taken such that the section of the stream used for the measurement should be relatively stable, i.e. not actively down cutting or meandering. In addition, it was necessary to select a stream segment where the flow was not immediately after or before a meander or rapid. Three channel sites were selected on the Eerste River for the season (January and September). The first site lies just within the environs of Stellenbosch urban area and the second site lies just outside the urban built up area downstream of a bustling winery industry and the third lies in the lower section of the river where N1 crosses the river. The portions of the stream that were monitored are not braided sections of the stream or lie within meandering areas. The sections that were monitored had flow that is parallel to the stream channel orientation and not within a pool area or other area altered by structures that may create backwater areas or reverse the flow of the water. The sites are all easily accessible as shown in Figure 10.

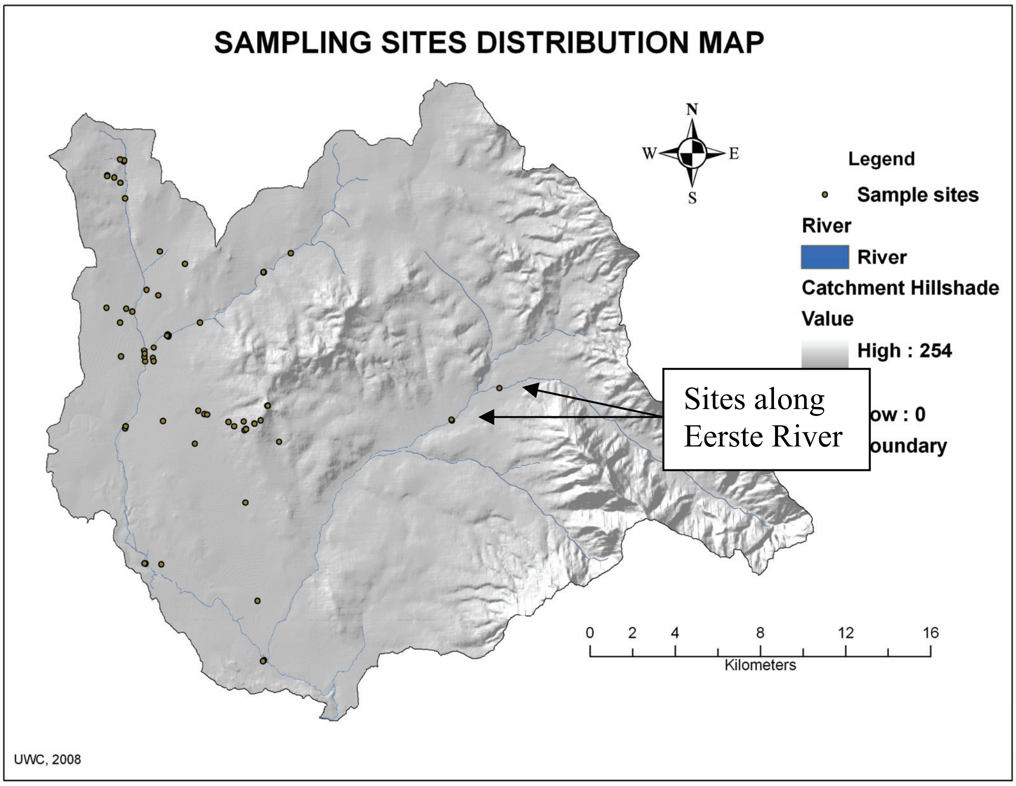


Figure 10 Map showing the location of Stream Flow Measurement sites along the Eerste River.

4.2.2 Step 2. Developing a Cross-Section of the Site and Establishing a Reference

These methods utilize a velocity-area approach to measure stream flow (or volume of water passing a set point in a given period of time). In order to determine stream flow, information about stream area was obtained from a cross-section developed identical on its course and the velocity of the water was measured at site (Figure 11).

When developing the cross-section, it was not possible to change the stream channel bottom material to create a more uniform surface as the river bed is lined with large stones, which were impossible to move. In this regard a suitable cross section point was identified were the river bed seemingly smooth and the channel almost straight. The cross-section was extended to a point located above the flood level for the stream.

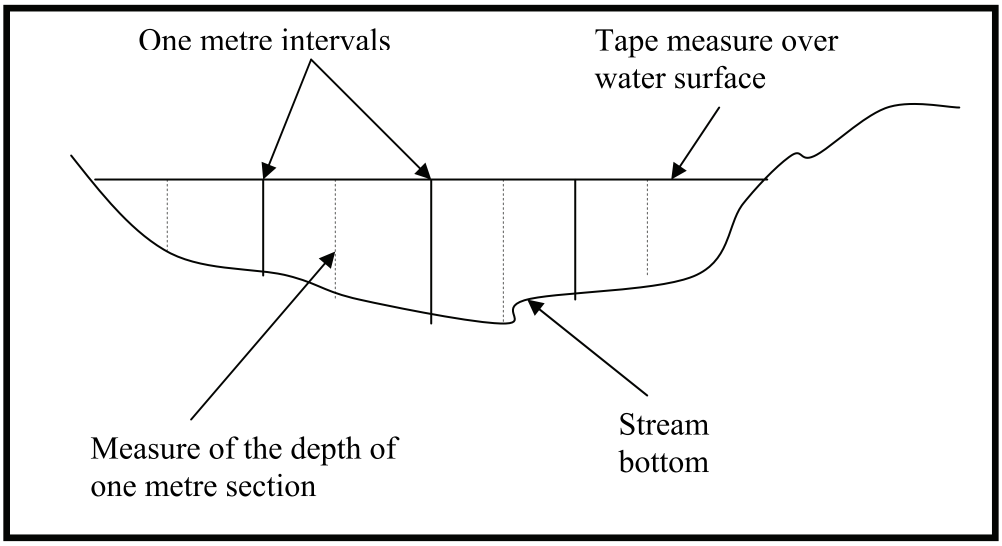


Figure 11 Cross-section model where measurement of stream flow was conducted.

4.2.3 Step 3. Setting of intervals for depth measurement

Field activity was designed to measure the area of the stream at the sites by measuring the width across the stream and the depth at several locations across the measured width. The procedure followed, was based on the standard hydrological approaches to stream flow measurement. The Eerste River had a width of nine meters at the first site, and 10 m at the second site, and three and a half meters for the third site. The interval used was of 1.9 m for the first site, and 2.15 m for the second site with, only 0.7 m for the last site.

The river was divided into rectangular grids (see Fig 11) and the flow was measured at 60% off the stream depth. It should be noted here that flow can be measured with a number of different flow measuring devices and in this case an electronic flow probe (current meter) was used to accurately determine stream flow. Measurements were also made of the river's width, depth, and speed (velocity) at ten horizontal and vertical points across the stream.

4.3 Equipment Used

Flow-measurement equipment used in the data gathering exercise included the following:

1. A flow meter, (in this case an electronic flow probe) that determines the average flow after it has been immersed into the current for at least 40 seconds,
2. wading rod (marked in tenths of a meter),
3. Tape measure (marked in tenths of a meter),
4. Field logbook, and
5. String for marking the cross section of the channel.

4.4 Methodology Followed

4.4.1 Determining the Number of Flow Cross Sections

The width of the stream was determined by stringing a measuring tape from bank to bank at right angles to the direction of flow. The total width of the section measured was about 9 m. this length warranted that, 10 vertical spacing at an interval of 0.9 m. On completion of this exercise, the spacing or width of the verticals was also determined. The verticals were spaced so that no subsection could have more than 10 per cent of the total discharge. If the stream width were less than 1.5 m, vertical spacing widths of 0.15 m would be used. If the stream width was greater than 1.5 m, the minimum number of verticals considered was 10. The preferred number of verticals though was 10 to 20.

4.4.2 Determining the Mid-Point of the Cross Section

To determine the mid-point of a cross section, the cross section width was divided in two, for example, if the total stream width were 10 m with 10 sections and each cross section width being equal to 1.9 m for the first site (Figure 2) and 1.15 meters for the second site. By dividing 1.9 m in half, the mid-point of the first section was determined to be 0.185 m. In this example, the tape at water's edge is set to zero meters. By adding 0.19 to zero, the mid-point of the first section is 0.19 m. Each subsequent mid-point is found by adding the section with (0.9 m) to the previous mid-point. For example, the first mid-point = 0.19 + 0.0 = 0.19 meters; the second mid-point = 0.19 + 0.9 = 0.28 m; the last midpoint = 8.1 + 0.9 = 9 m.

4.5 Measuring Velocity

Water velocity was measured using a Global Water Flow Probe FP101 and 201 instruments. These instruments can measure maximum and average velocities and displays the results digitally on a small computer screen mounted on one end of the rod. Instantaneous velocity is always displayed.

In measuring the average velocity the flow probe was kept vertical and the flow sensor, which has a propeller, was oriented directly into the flow using the arrow indicator aimed downstream. The flow probe was kept perpendicular to the tape rather than perpendicular to the flow while measuring velocity at each measuring point. The probe was held for several second and then removed, once removed the average velocity reading would hold once the propeller stopped turning. Measurements were also done with movement of the probe in a smooth vertical motion (as if painting with a brush) to attain the average velocity of a water column. The procedure was repeated up to the next vertical with repeat manoeuvres of the procedure reaching the opposite bank.

Water depth/velocity measurements were obtained horizontally across the river at 1.9, 2.8, 3.7, 4.6, 5.5, 6.4, 7.3, 8.2 and 9.1 m for the first site. At each location, measurements of velocity and total depth were obtained. Depending on the depth and flow conditions, one or more velocity reading(s) were obtained in each vertical.

In order to compute the total stream flow using the velocity of the water in the river, the stream flow for each channel segment area (Figure 12) was computed. Summing the stream flows for all the segment areas gave the total stream flow. The explanation given above is a simplified explanation of how stream flow is measured. When an actual measurement was made, measurements at 10 points across the stream were taken (Tables 16 to 20). The calculation for the Eerste River is shown in Table 16. The goal was to have one vertical cross-section containing more than 5 per cent of the total stream discharge.

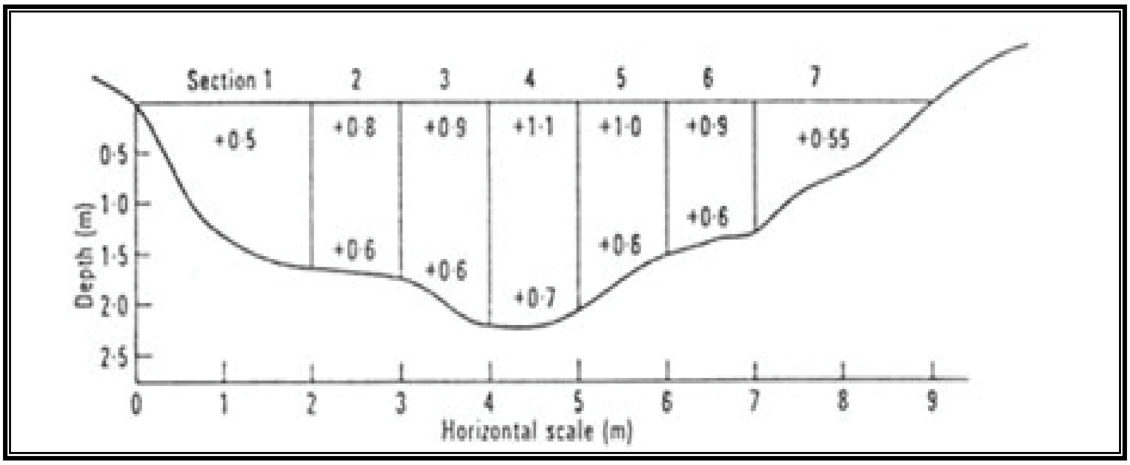


Figure 12 Estimating the flow in a river from measurement with a flow probe.

Table 16 Calculation of Stream Flow using a Flow Probe meter readings at Site 1 (September 2008).

1 Section	2 Mean Flow Velocity(m/s)	3 Depth (m)	4 Width (m)	5 Area(m^2)(3*4)	6 Discharge (m^3/s^{-1}) (5*2)
1	15.22	0.23	0.9	0.41	6.24
2	22.44	0.34	1.8	0.92	20.65
3	17.41	0.37	2.7	1.33	23.16
4	16.84	0.46	3.6	2.07	34.86
5	7.81	0.44	4.5	2.38	18.59
6	11.74	0.37	5.4	2.33	27.35
7	7.16	0.39	6.3	2.81	20.12
8	7.36	0.24	7.2	1.94	14.28
9	0	0	8.1	0	0
10	0	0	9	0	0
Total Discharge, $\sum Q(m^3/s^{-1})$					**165.25**

Table 17 Calculations of Stream Flow using Stream Flow Probe meter at Site 2(Sept 2008).

1 Section	2 Mean Flow Velocity (m/s^{-1})	3 Depth(m)	4 Width(m)	5 Area(m^2) (3*4)	6 Discharge (m^3/s^{-1})(5*2)
1	12.21	0.24	1.57	0.38	4.60
2	18.83	0.37	2.72	1.01	18.95
3	22.13	0.53	3.87	2.05	45.39
4	19.42	0.32	5.02	1.61	31.20
5	24.16	0.6	6.17	3.70	89.44
6	25.79	0.41	7.32	3.00	77.40
7	22.16	0.48	8.47	4.07	90.09
8	20.66	0.48	9.62	4.62	95.40
9	30.29	0.36	10.72	3.86	116.90
10	17.62	0.28	11.92	3.34	58.81
Total Discharge, ∑Q(m^3/s^{-1})					**628.18**

Table 18 Calculation of Stream Flow using a Flow probe meter readings at Site 1 (January 2008).

1 Section	2 Mean Flow Velocity (m/s-1)	3 Depth(m)	4 Width(m)	5 Area(m2)(3*4)	6 Discharge(m^3/s-)(5*2)
1	0.22	0.29	0.70	0.203	0.04
2	0.15	0.29	0.70	0.203	0.03
3	0.06	0.24	0.70	0.168	0.01
Total Discharge, ∑Q(m^3/s^{-1})					**0.08**

Table 19 Calculation of Stream Flow from a Flow Probe meter readings at Site 2 (January 2008)

1 Section	2 Mean Flow Velocity (m/s^1)	3 Depth(m)	4 Width(m)	5 Area(m^2) (3*4)	6 Discharge (m^3/s^{-1})(5*2)
1	0.05	0.22	1.38	0.3036	0.02
2	0.05	0.32	1.38	0.4416	0.02
3	0.13	0.30	1.38	0.414	0.05
4	0.02	0.39	1.38	0.5382	0.01
5	0	0.29	1.38	0.4002	0.00
6	0	0.14	1.38	0.1932	0.00
7	0.1	0.19	1.38	0.2622	0.03
8	0	0.13	1.38	0.1794	0.00
Total Discharge, ∑Q(m^3/s^{-1})					**0.13**

Table 20 Calculation of Stream Flow from a Flow Probe meter readings at Site 3 (January 2008)

1 Section	2 Mean Flow Velocity(m/s^{-1})	3 Depth(m)	4 Width(m)	5 Area(m^2)(3*4)	6 Discharge(m^3/$^{s-}$)(5*2)
1	0.48	0.26	0.75	0.195	0.09
2	0.32	0.21	0.50	0.105	0.03
3	0.33	0.19	0.50	0.095	0.03
4	0.22	0.18	0.50	0.09	0.02
5	0.12	0.12	0.50	0.06	0.01
6	0.1	0.12	0.75	0.09	0.01
Total Discharge, ∑Q(m^3/s^{-1})					**0.19**

4.6 Discussion of Results

The analysis of the data sets collected during two distinctive rainfall periods clearly indicates that discharge is not the same in the river during the two periods of study. Higher discharge values were observed during the winter months, which were associated with the rainfall season. The following readings for discharge were obtained from both during summer and winter months of 2008: 0.08 m^3/s^{-1} from upstream; 0.13 m^3/s^{-1} from down-stream and 165.25 m^3/s^{-1} from upstream respectively. The values obtained show clearly the influence of precipitation and the seasonal variability of the rainfall as it affects the amount of discharge in the river. Such variations are likely to influence the distribution of surface pollutants into the river network, as a high per cent of the discharge in the river originates from storm runoff that is channelled through the numerous storm drains. Part of this discharge is from flows after heavy precipitation and from other tributaries.

5 RUNOFF AND NPS POLLUTANT LOAD ESTMATION USING RINSPE MODEL

5.1 Introduction

Non-point source pollution may be defined as the introduction of impurities into surface or sub-surface water supplies, generally from indirect, intermittent or diffuse sources and often associated with storm, rainfall or snowmelt events (Warrington, 2000). Non-point source pollution results from a wide variety of human activities on land. It represents the cumulative effects of all of the land uses in a watershed and associated human activity. Owing to this complexity, models that try to reflect the actual processes require large quantities of data, which are rarely available. Thus, the most common method of approximating non-point source pollution uses long-term average contaminant loadings of common land uses. This approach is based on the National Urban Runoff Program called NURP (US EPA, 1984). The approach has also been followed in many other countries. The estimation of nonpoint source pollutants in the surface runoff and ground recharge is based on typical Event Mean Concentrations (EMCs). EMCs are standardized concentrations of a pollutant expected from a particular land use. They are assumed to be directly related to the land uses in the watershed and remain constant, independently of the duration and intensity of the rainfall events (Naranjo, 1998).

Rainfall is a key input for all hydrologic/water quality (H/WQ) models because it activates flow and mass transport. Accurate input of rainfall in time and space is crucial for modelling runoff and transport of non-point source pollutants using H/WQ models. Rudra *et al.* (1993) noted that failure to consider the spatial variability of rainfall, leads to serious errors in predicted results. An important issue of rainfall spatial variability relates to the size of catchment under consideration. Information about the effect of rainfall spatial variability on predicted runoff is limited for relatively larger catchment. Chaubey *et al.,* (1999) attempted to quantify the uncertainty in the predicted water quantity due to spatial variability of rainfall to a 159 km^2 catchment. They mentioned that large uncertainty in the model output could be expected if the spatial variability of rainfall is not properly taken into consideration.

Selection of a rainfall-runoff model is a compromise between model complexity and available input data. Loague and Freeze (1985) have questioned the reliability of more complex models although such models are expected to better represent the physical processes. They have shown that simpler, less data-intensive models provided as good or better simulations than physically-based models. A physically-based model is one that has a theoretical basis and whose parameters and variables are measurable in the field while an empirical model is a representation of data and has no real theoretical basis. Although In reality, many empirical relationships are used for parameter estimation by the “physically-based” models (Wilcox *et al*., 1990 and Beven, 1983). However, rainfall-runoff models need to be sophisticated enough to account for the routing of all precipitation in the form of surface runoff, infiltration, evapotranspiration, etc. In order to estimate it, some suitable method for estimating the areal distribution of rainfall losses through infiltration and runoff has to be chosen first. Possible models that can be adopted are the following: the rational method, NRCS Curve Number (CN) method, Horton’s model for infiltration capacity, Green-Ampt infiltration model etc.

The Curve Number (CN) model of United States National Resources and Conservation Services (NRCS) has been acclaimed to be the most successful runoff model used so far in runoff-pollutant flux estimations in the urban catchment (Graf, 1988). The NRCS-CN runoff equation is basically an empirical model developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981). It combines infiltration with initial losses (interception and detention storage) to estimate the rainfall excess, which would appear as runoff. The only major limitation of the curve number method is that rainfall intensity and duration are not considered, only total rainfall volume.

Recent developments in Geographic Information Systems (GIS) have provided advantages associated with the full utilization of spatial landscape characteristics, soil physical and hydraulic properties, and spatial and temporal precipitation in order to analyse hydrologic processes. Advances in computing have allowed the distributed watershed model to perform large-scale hydrologic simulation with reasonable resolution at a more detailed level (Seong-Joon *et al.,* 2003).

Surface runoff contains a variety of contaminants, such as chloride, phosphorous, nitrite and nitrogen, which can adversely affect the ecology of receiving environments and/or the human uses or values associated with them. However, receiving environments differ widely in their inherent sensitivity and their risk from surface runoff depends on a variety of factors apart from human activities and urban growth. The purpose of this report is to develop and validate a GIS-based map identifying and ranking sensitive receiving environments from surface runoff, and therefore assist in prioritising sections of the catchment that may require management strategies for their sustainability.

The following aspects are included in the methodology:
• Applicable both to rural and urban environmental setups.
• Conceptually simple, using a comparative (not absolute) assessment of distribution.
• GIS-based to facilitate regional application using nationally consistent datasets.

A key assumption to applying the method in the context of Kuils-Eerste River Catchment is that the particulate fraction of the pollutant load is the appropriate point of focus and consequently the primary factor determining the impact of this component of runoff is the degree to which the immediate receiving environment is depositional.

5.2 The Mechanisms of Runoff, Infiltration and Nonpoint Source Pollution

Runoff is what occurs when rain is not absorbed by the ground on which it falls and so then flows downhill. The amount of rainwater that runs off during/immediately after a rainfall event depends heavily on the amount of rainfall, ‘initial abstraction’ (i.e. initial loss was due to interception), and the type and condition of ground it lands on (i.e. infiltration characteristics of the soil, soil moisture, antecedent rainfall, impervious surface etc.). The most important factor in determining the quantity of runoff that will result from a given storm event is the per cent imperviousness of the land cover. Other factors include soil infiltration properties, topography, vegetative cover, and prevailing site conditions (US EPA, 1993). The most important is the soil water content at that time.

If the amount of water falling on the ground is greater than the infiltration rate of the surface, runoff or overland flow will occur. Runoff specifically refers to the water leaving an area of drainage and flowing across the land surface to points of lower elevation. It is not the water flowing beneath the surface of the ground. This type of water flow is called through flow. As the soil saturates, the infiltration rate decreases. Runoff involves the following events:

1. Rainfall intensity exceeds the soil's infiltration rate.
2. A thin water layer forms that begins to move because of the influence of slope and gravity.
3. Flowing water accumulates in depressions.
4. Depressions overflow and form small rills.
5. Rills merge to form larger streams and rivers.
6. Streams and rivers then flow into lakes or oceans.

Oceans make up 71% of the Earth's surface and the solar radiation received here powers the global evaporation process. In fact, 86% of the Earth's evaporation occurs over the oceans, while only 14% occurs over land. Of the total amount of water evaporated into the atmosphere, precipitation returns only 79% to the oceans and 21% to the land. Surface runoff sends 7% of the land based precipitation back to the ocean to balance the processes of evaporation and precipitation (Pidwirny, 2006).

Surface runoff occurs when rainfall exceeds a soil's maximum saturation level and all surface depression storage is filled to its capacity. The rate of runoff flow depends on the ratio of rainfall intensity to the infiltration rate. If the infiltration rate is relatively low, such as when a soil is crusted or compacted, and the rainfall intensity is high, then the runoff rate will also be high. High runoff rates can detach and transport large amounts of soil, as well as transport the associated nutrients and pesticides.

When runoff flows along the ground, it can pick up soil contaminants such as petroleum, pesticides (in particular herbicides and insecticides), or fertilizers that ultimately become part of stream discharge. When the soil is saturated and the depression storage filled, and rain continues to fall, the rainfall will immediately produce surface runoff.

The level of antecedent soil moisture is one factor affecting the time until soil becomes saturated. This runoff is saturation excess overland flow or saturated overland flow. After water infiltrates the soil on an up-slope portion of a hill, the water may flow laterally through the soil, and infiltrate (flow out of the soil) closer to a channel. This is called subsurface return flow or interflow. As it flows, the amount of runoff may be reduced in a number of possible ways: a small portion of it may evaporate; water may become temporarily stored in micro topographic depressions; and a portion of it may become run-on, which is the infiltration of runoff as it flows overland.

Urbanization increases surface runoff, by creating more impervious surfaces such as pavement and buildings, which do not allow percolation of the water down through the soil to the aquifer. The water is instead forced directly into streams or storm water drains, where erosion and siltation can be major problems, even when flooding is not. Increased runoff reduces groundwater recharge, thus lowering the water table and making droughts worse, especially for farmers and others who depend on water wells. When anthropogenic contaminants are dissolved or suspended in runoff, the human impact is expanded to create water pollution. This pollutant load can reach various receiving waters such as streams, rivers, lakes, estuaries and oceans with resultant water chemistry changes to these water systems and their related ecosystems.

In urban environments water pollution occurs from various sources such as precipitation (direct recharge); rivers, canals and lakes (indirect recharge); and from man-made activities such as irrigation and urbanisation. Development of a GIS based water pollution model, which could account for all sorts of pollution in an urban area, is a challenging task because of the complexities involved in the urban set up. However attempts were made in Birmingham, UK to develop GIS models for estimating direct or precipitation recharge, indirect recharge through seepage from surface water bodies, indirect recharge through mains leaks and indirect recharge through sewer leaks in a city on a regional scale (Thomas, 2001; 2004; 2005) and the same approach was used in the development of this model as applied to the Western Cape's Kuils-Eerste River catchment in South Africa.

The conceptual basis for the estimation of runoff, infiltration and pollution estimation is shown in Figure 13. Infiltration is the initial process of water entering the soil at the ground surface from precipitation or anthropogenic sources (US EPA, 1998a). Infiltration is a direct loss that governs the volume and rate of runoff, and thus it controls the shape of the runoff hydrograph (Tindal *et al*., 1999). Infiltration depends on the type of land use, soil type (texture class), vegetative cover, porosity and hydraulic conductivity, degree of soil saturation (moisture content), soil stratification, drainage conditions, depth to water table, and intensity and volume of rainfall. The amount of rainwater that runs off during / immediately after a rainfall event depends heavily on the amount of rainfall, 'initial abstraction' (i.e. the initial loss due to interception storage, depression storage, and surface storage), and the type and condition of soil it lands on (i.e. the infiltration characteristics of the soil, soil moisture, impervious surface etc.).

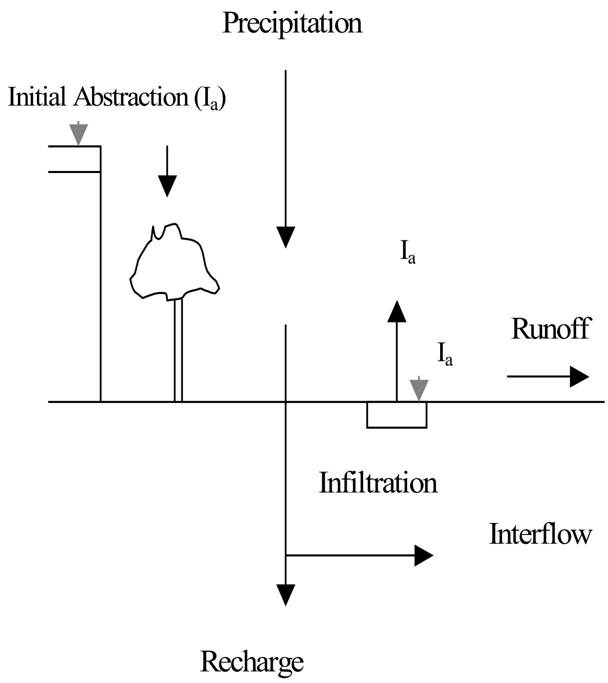


Figure 13 Conceptualisation of Runoff Processes

*NB: The term 'initial abstraction' (I_a) incorporates rainfall loss due to interception, depression and detention storage (not abstraction to groundwater).

After having infiltrated into the soil / vadose zone, the infiltrated water is subjected to redistribution in the vadose zone where part of the infiltrated water may be lost to the atmosphere through transpiration processes. The amount of infiltrated water left behind after the evaporative loss can be called potential recharge, which may again lose a certain portion through subsurface lateral flow, also called interflow. The amount of water infiltrated left behind after all these losses is available as actual recharge (Thomas 2001).

5.3 Estimation of Runoff through Modelling

Estimation of runoff can be done through field measurements or it can be estimated using a model. In this project, GIS based model for estimating runoff and infiltration from various land use/ land cover types was developed for the assessment of pollution in an urbanised and agricultural catchment. The model was developed taking into consideration that the model needed to be sophisticated enough to account for the routing of all precipitation in the form of surface runoff, infiltration and pollution loading. In order to estimate these parameters, some suitable method for estimating the areal distribution of rainfall losses through infiltration and runoff had to be chosen. There were other possible models that could be used and include the following: i) the rational method, ii) SCS CN method, iii) Horton's model for infiltration capacity, and iv) Green-Ampt infiltration model etc.

The runoff and infiltration estimation procedure needs information on areal precipitation, infiltration, runoff, and hydrologic soil group status as indicated earlier on and on the basis of this observation it is important to note that runoff and infiltration in any location can be estimated through the following equation:

Runoff = Rainfall – Initial abstraction – Infiltration (Equation 5.1)

After considering various available methods for infiltration and runoff estimation, the Runoff Curve Number (CN) method of the United States Department of Agriculture, Soil Conservation Service (SCS, now known as the Natural Resources Conservation Service, or NRCS) was chosen.

The SCS 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 (Figure 14). This model is relatively simple requiring few input parameters, and has been widely applied in the fields of soil physics and hydrology (US EPA, 1998a). The method is empirically based and is applicable to the situation in which amounts of rainfall, runoff, and infiltration are of interest (US EPA, 1998b).

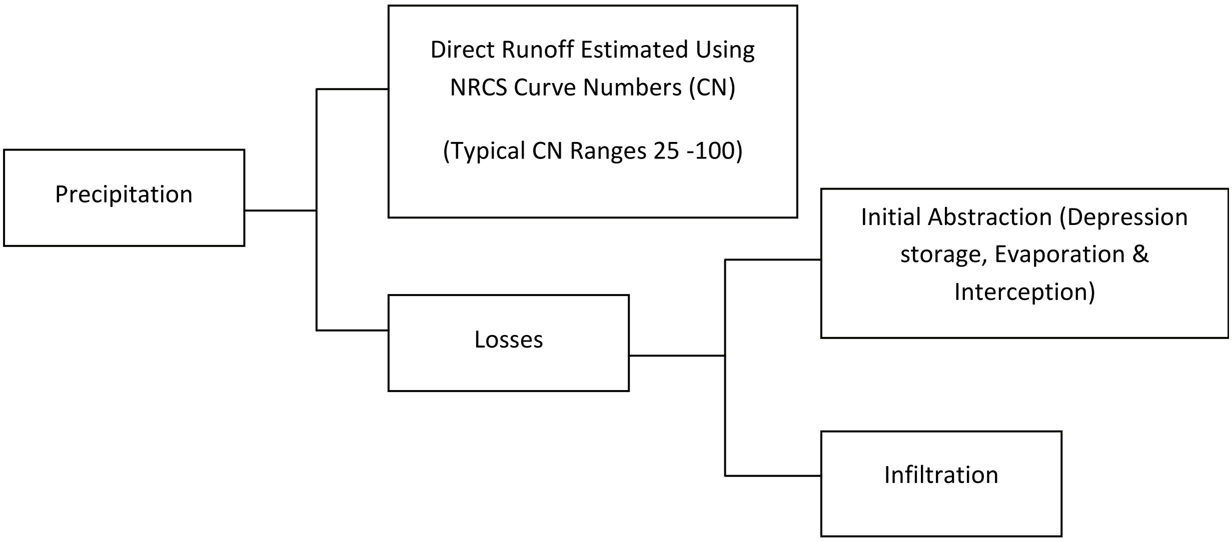


Figure 14 Conceptual components of rainfall in SCS Curve Method.

The USDA NRCS curve method predicts direct surface runoff using the following equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{(Equation 5.2)}$$

in which: Q = Total rainfall excess (runoff) for storm event (mm or inches) P = Total rainfall for storm event (mm or inches), Ia = Total initial loss or "initial abstraction" (inches) and S = Potential maximum retention capacity of soil at beginning of storm or maximum amount of water that will be absorbed after runoff begins (inches).

S, also called the retention parameter, is a statistically derived parameter related to the initial soil moisture content or soil moisture deficit (US EPA, 1998a). The value of S is determined based on the type of soil and the amount and kind of plants covering the ground (cover types). This is derived through its relationship to the value of the NRCS runoff curve number (CN). A curve number is a numerical description of the impermeability of the land in a watershed. This number varies from 0 (100% rainfall infiltration) to 100 (0% infiltration – e.g. road/concrete). The following relation relates the value of S to the 'curve number':

$$S = \frac{1000}{CN} - 10 \qquad \text{(Equation 5.3)}$$

CN = runoff curve number (0-100, based on the soil and land use information).

CN is determined through several factors. The most important are the hydrologic soil group (HSG), the ground cover type, treatment, hydrologic condition, the antecedent runoff condition (ARC), and whether impervious areas are connected directly to drainage systems, or whether they first discharge to a pervious area before entering the drainage system. Soils are extremely important in determining the runoff curve number. Soils are generally classified into four HSG's (hydrological soil groups: A, B, C, and D) according to how well the soil absorbs water after a period of prolonged wetting.

The term 'initial surface loss' incorporates rainfall loss due to interception, depression and detention storage. The value of I_a depends greatly on the cover types (the kind of plants covering the soil or land use), the kind of soil (hydrologic soil groups, its treatment, and hydrologic condition) and antecedent soil moisture of the area being studied. For a given drainage basin, the values of I_a are highly variable, but are generally correlated with soil and cover parameters. A major limitation for applying the SCS model lies in the values of the parameter I_a that must be evaluated with field data for each specific site.

5.4 Modelling of Nonpoint Source Pollution

Models that try to reflect the actual processes require large quantities of data, which are rarely available. Thus, the most common method of approximating non-point source pollution uses long-term average contaminant loadings for common land uses. This approach is based on the National Urban Runoff Program called NURP (US EPA, 1984). The approach has been followed in many other countries also. The estimation of nonpoint source pollutants in the surface runoff and recharge is based on typical Event Mean Concentrations (EMCs). EMCs are standardized concentrations of a pollutant expected from a particular land use type. They are assumed to be directly related to the land uses in the watershed and remain constant independently of the duration and intensity of the rainfall events (Naranjo, 1998). Literature based Estimated Mean Concentrations of pollutant constituents associated with land use are available (Lopes and Dionne, 1998; Delzer *et al*., 1996). The annual loading of the NPS pollution in the catchments is estimated as:

Pollutant Load = Runoff Flow * Pollutant Concentration, or
L (Mass/Time) = Q (Volume/Time) * C (Mass/Volume) (Equation 5.4)

5.5 Development of RINSPE Model for Assessing NPS Pollution

Using the Avenue programming language, (the objected oriented programming language/code of ArcView GIS) the above listed equations of runoff estimation and pollutant loading were programmed in a model called RINSPE (Runoff Infiltration Non-point Source Pollution Estimation) using the ArcView GIS 3.3. The RINSPE model is a water quality screening tool capable of predicting spatially distributed (raster based) runoff, infiltration and non-point source pollutants in a catchment. It compares the effects of different land cover and land use scenarios on total yields and has a user friendly graphical interface within ArcView 3.3. RINSPE was developed for estimating runoff and pollutant fluxes in an urbanised catchment (Thomas, 2008). The model has been demonstrated for an urbanised catchment in the Western Cape Province of South Africa. In this model, the estimation of surface runoff, infiltration and pollutant fluxes are performed through fourteen sub models that may be grouped into three major model types, viz. i) catchment runoff (NRCS Method), ii) Non-point source pollutant load/flux models and iii) catchment runoff (HOST Method). Within each of the major types, there are specific sub models, each of which deals with a specific type of attribute and or pollutant (Fig 15).

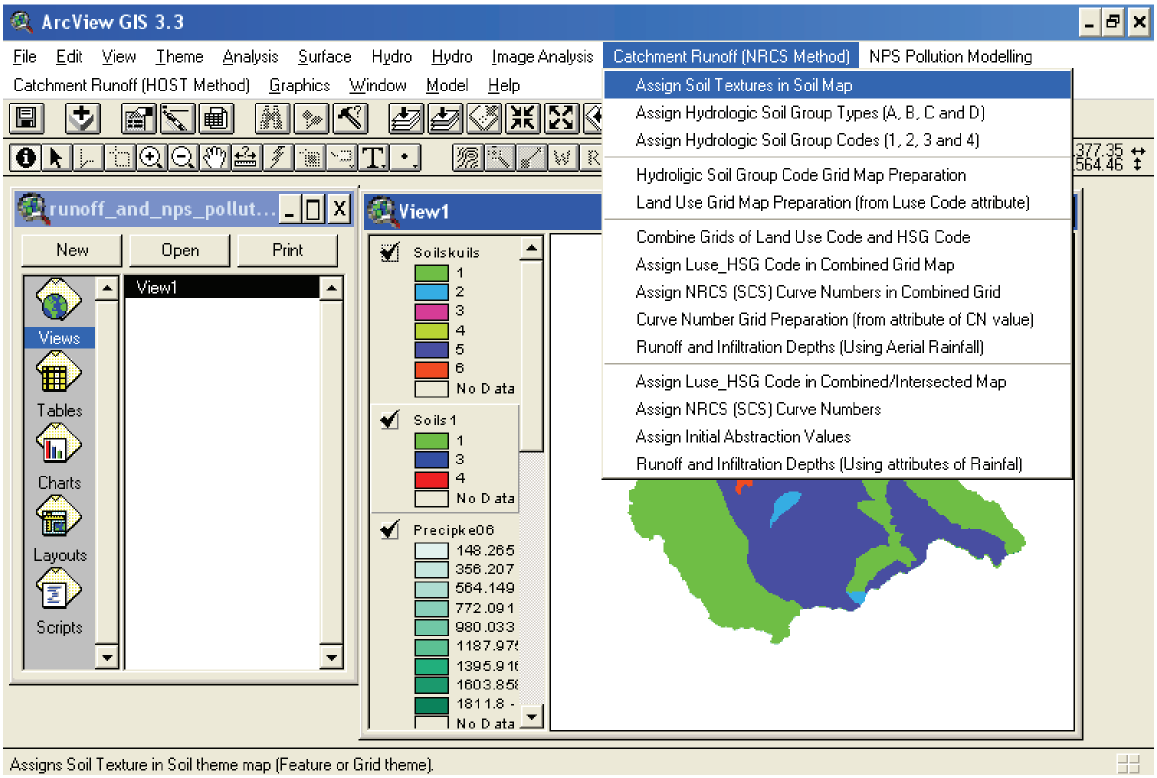


Figure 15 Interface of RINSPE Model

The major functions of the RINSPE model are to model rainfall-runoff on the basis of the Soil Conservation Service (SCS) curve number technique and to model the pollutants based on their Event Mean Concentration Coefficients (EMCs). Several processes characterise the model and they take into consideration topography which determines flow direction and slope; soil characteristics, land cover and precipitation, which determine runoff; runoff, land cover and pollutant coefficients, which determine pollutant loads.

The model operates on the assumptions that the following processes are omitted, Atmospheric deposition, groundwater processes, storm water drainage, stream diversions, snowmelt and landslides.

5.5.1 Input Data Needed for RINSPE Model

The input data required for the present RINSPE model are the following:

1. Land Use Data / Land Cover.
2. Soils Data / Hydrologic Soil Group (HSG).
3. Digital Elevation Model (DEM) / Topography.
4. Precipitation Grid.
5. Curve Numbers Table.
6. Initial Abstraction Table.
7. Event Mean Concentration (EMC) Table.

5.5.2 Model Output from RINSPE

The major outputs from the present model are estimates of surface runoff volume and depth distribution of cumulative infiltration pollutant loads in surface runoff, pollutant concentration of each chosen pollutant, final amounts of pollutants and final pollutant concentration reaching the river.

5.5.3 Working of the Surface Runoff Estimation in RINPSE Model

Due to the paucity of data regarding the controlling parameters and because of the complexities involved in assessing surface water bodies, a pragmatic approach was adopted for the estimation of runoff volume for a catchment scale assessment. In this model, the runoff volume from different land cover types is estimated and the important factors that can control surface runoff within the catchment are identified as: i) hydrologic soil group type ii) land use/land cover type iii) antecedent moisture conditions and iv) initial loss or initial abstraction. Each factor is accounted for in the model. The first three factors have a direct relationship with the surface runoff.

Using land use and soil hydrologic group themes, a map showing the area under various land uses on different hydrologic soil groups is generated by intersecting/combining these two maps with the GIS. A curve number value is assigned for each unit of this map, which leads to the preparation a runoff curve number map. The hydrologic soil group map can be generated by reclassifying the various soil units or lithological units (as defined by geological map) based on their drainage potential (textures of the sediments). The runoff and infiltration depths are calculated from the rainfall grid using the assigned CN values and initial abstraction values.

5.5.4 Input Data Needed for the Running of Runoff Estimation Model

1. The input data needed for the running of runoff estimation part of RINPSE model are the following:
2. Land Use Map (shapefile or grid)
3. Hydrologic Soil Group Map (shapefile or grid)
4. Rainfall data (grid)

The spatial input data needed for the generation of runoff grid are: land use grid, rainfall grid and hydrologic soil group grid map with attributes of specific group types and group codes. All calculations in this model use grid data. One of the outputs from this model is a spatially distributed surface runoff and which can be used in the second part of the modelling in order to produce an accumulated runoff and pollutant loads. Field scale measurement and monitoring of water balance components such as rainfall and its initial loss, surface runoff, infiltration, can help in validating the model predictions.

5.5.5 Working of the Nonpoint Source Pollution Estimation in RINPSE Model

Using ArcView GIS, a sub model called 'NPS Pollution Model' has been generated for estimating the pollutant loads of chosen constituents in surface runoff water. Fig.16 shows a screen shot of the drop-down menu of this add-on model. The Avenue script written in these programme/model associates or links EMC values of different pollutant constituents to the land use types. The input data for this model are: i) a grid of land uses of the catchment, ii) a grid of average annual runoff volume of the catchment iii) associated EMC values of chosen/selected pollutant constituents (in this study the following have been considered nitrate, chloride, phosphorous, nitrogen and total suspended solids) and iv) an elevation grid/DEM. This program creates an EMC grid (for selected pollutants) and multiplies it by a grid of accumulated average annual runoff in the basin. The result generated is the annual loading of the NPS constituent to each grid cell in the catchment. The accumulated runoff is estimated using a DEM and applying the 'flow direction' and 'flow accumulation' commands. The final output from this model consists of grids of pollutant concentrations distribution and predicted annual pollutant loading rates (e.g. mg/m^2/year^{-1}) for each land use type, which affects the catchment area.

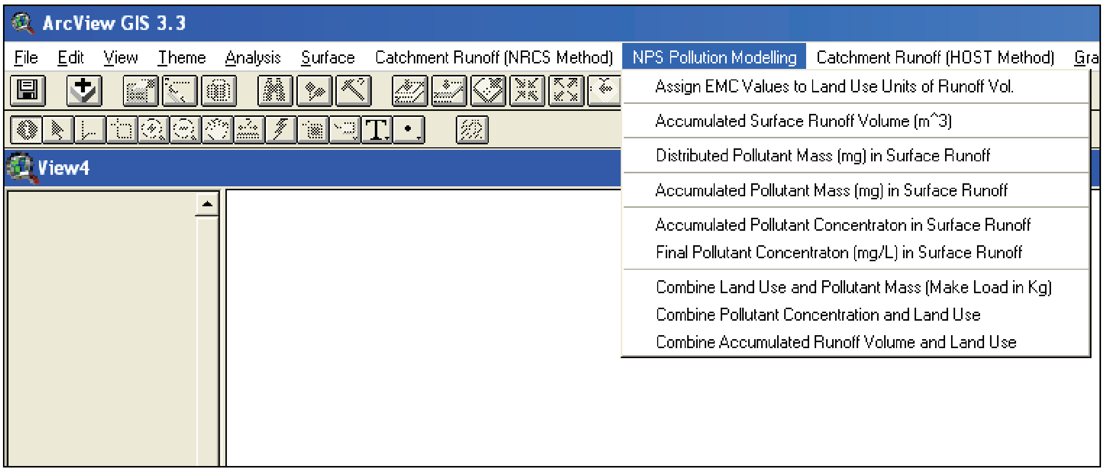


Figure 16 Screen shot of the RINSPE model's Interface of NPS Pollution Modelling.

5.5.5.1 Flow Direction Function

One of the key aspects to deriving hydrologic characteristics about the study area surface is the ability to determine the direction of flow from every cell in the elevation grid. This was done with the Flow Direction function. Flow direction is determined by evaluating the relative elevation of the eight cells surrounding the cell in question. The neighbouring cell with the least elevation is identified as the direction of outflow from the current cell. The value of the current cell in the output flow direction grid is assigned based on the value of the cell it flows into, as given in Figure 17 below, where the centre cell is being evaluated.

This function takes the elevation of study area as input and output a raster showing the direction of flow out of each cell. The output drop raster option can be chosen, and an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centres of cells.

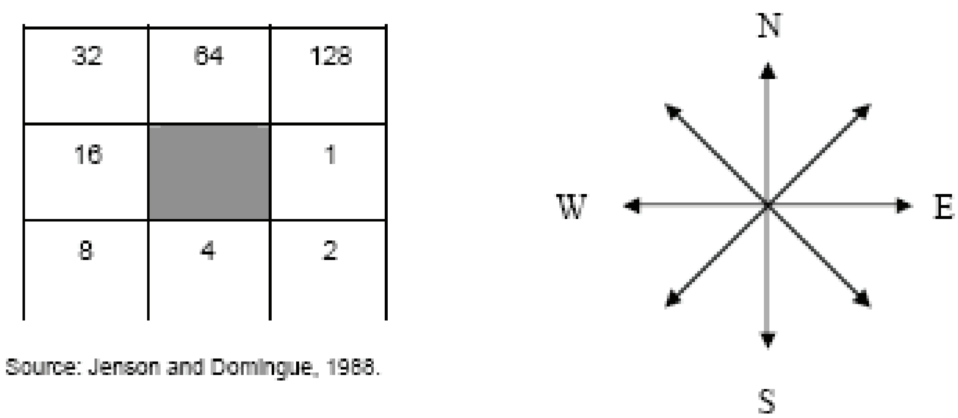


Figure 17 Assigning flow directions in an elevation grid.

There are eight valid output directions, as indicated in the illustration above (Figure 17) relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight direction (D8) flow model and follows an approach presented in Jensen and Domingue (1988).

For instance, a cell that flows into the cell to its immediate left would have a value of 16 in the resulting flow direction grid. Assuming that the above diagram is oriented in a north-south direction, the values of the output flow direction grid are given below:

- East – 1
- Southeast – 2
- South – 4
- Southwest – 8
- West – 16
- Northwest – 32
- North – 64
- Northeast – 128

The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell. This is calculated as:

Maximum drop = change in z-value / distance (Equation 5.5)

The distance is determined between cell centres. Therefore if the cell size is 1, the distance between two orthogonal cells is 1 and the distance between two diagonal cells is 1.414216, the square root of 2. If the maximum descent to several cells is the same, the neighbourhood is enlarged until the steepest descent is found. When a direction of steepest descent is found, the output cell is coded with the value representing that direction. If all neighbours are higher than the processing cell, the processing cell is a sink and has an undefined flow direction. Cells with undefined flow direction can be flagged as sinks using the Sink function. To obtain an accurate representation of flow direction across a surface, the sinks should be filled.

5.5.5.2 Flow Accumulation Function

The Flow Accumulation function calculates accumulated flow as the accumulated weight of all cells flowing into each down-slope cell in the output raster. The Avenue syntax for this command is as follows: *FlowDirectionGrid.FlowAccumulation (weightGrid).* When this is applied on a Flow Direction grid it returns a grid of flow accumulation. The *weightGrid* can be a Grid or Nil, and represents the weight to assign to each cell. If no weight raster is provided, a weight of one is applied to each cell, and the value of cells in the output raster will be the number of cells that Flow into each cell. Using this function the surface runoff can be accumulated using runoff grid as the weight raster. In the graphic given below (Fig 18) the top left image shows the direction of travel from each cell and the top right the number of cells that Flow into each cell. Cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Cells with a flow accumulation of zero are local topographic highs and may be used to identify ridges.

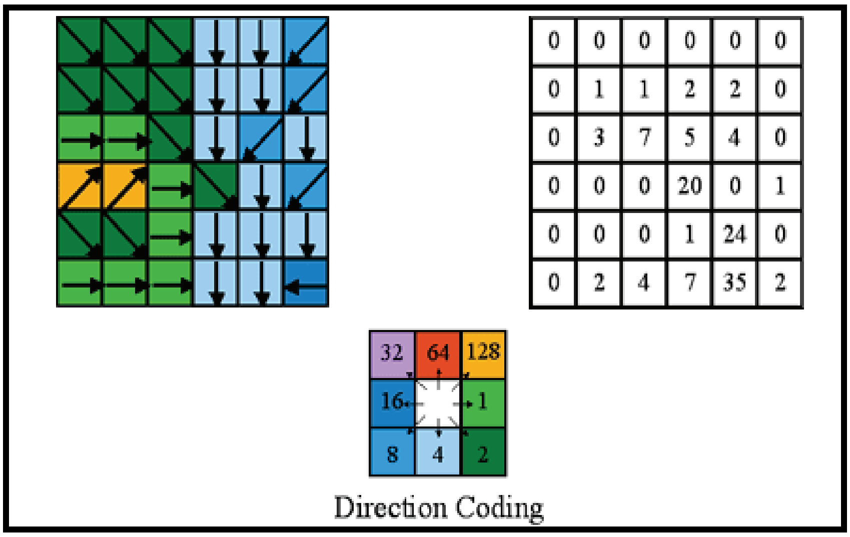


Figure 18 Flow Direction and Accumulation Model for the catchment

5.5.5.3 Flow Accumulation in a Catchment

A typical RINSPE run begins with a watershed identified from a DEM. Many of the grids driving RINSPE's functionality of pollution estimation are derived from the DEM and for this reason; it is perhaps the most important of these data sets. RINSPE needs a depression free DEM (having no sinks and other imperfections that are commonly found in raw topography data). The sinks in DEM can be removed using the FILL command or using the Fill Sinks menu in hydrological modelling extension. A flow direction grid is generated from the depression free DEM by calculating the downstream flow path of water leaving each cell.

The flow accumulation grid is created based on the flow direction grid and is used to derive a stream network. The values of the cells in a user-specified weight grid of runoff values are summed according to the hydrologic linkages represented by the flow direction grid. Each cell contains the total value of all upstream cells that flow through it along the flow paths dictated by the flow direction grid (Jenson and Domingue, 1988). RINSPE automatically sets the raster analysis environment to the parameters of the DEM file. This is an important step because it ensures that all grids produced have the same cell size, spatial reference, and extent. Otherwise, the cells of input and output grids may or may not overlay properly.

5.5.5.4 Estimating Pollutant Loads and Pollutant Concentrations

The accumulated runoff grid is created from the flow direction grid and the runoff volume grid using the 'flow accumulation' command. 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 a land use grid using a new set of pollutant coefficient or EMC values derived from local sampling data, where each cell is assigned a value based on its land cover classification. The pollutant coefficient value represents an average concentration (mg/L) for a given land cover classification. When the pollutant concentration grid is multiplied by the runoff volume grid, the result is a new grid that indicates the mass of the pollutant produced by each individual cell. This grid of pollutant mass does not take into account upstream contributions. The pollutant mass grid is accumulated using the flow direction grid, which yields an accumulated pollutant mass grid in which the value of each cell represents the total mass of pollutant that passes through that cell, including contributions from upstream cells. An accumulated pollutant concentration grid is derived by dividing the accumulated pollutant mass grid by the accumulated runoff grid. However, this grid does not include the pollutant mass and runoff volume generated at the current cell; instead it includes only the total value of all upstream cells that flow through the current cell. The final pollutant concentration grid is created by adding the pollutant mass grid and accumulated pollutant mass grid, then dividing this quantity by the sum of the runoff volume grid and the accumulated runoff grid.

5.6 Procedure for Running the RINSPE Model

The RINSPE model has certain menus through which the user has to go in order get estimates of runoff, infiltration, NPS pollution. Only four of the inputs (namely, the land use/land cover map, hydrologic soil group map, rainfall amount with or without rain gauge locations, and an elevation map) would be required to generate a runoff distribution map for the catchment under study. As a source of input data for the model these were acquired or developed within the laboratory at UWC where the subsequent model was developed and tested.
The runoff, infiltration and NPS pollution calculation is done using grid input maps of land use and hydrologic soil group.

The preliminary steps involved for running this model are:

1. Preparation of land use map and hydrologic soil group map in grid file format acceptable to the model;
2. Preparation of input data tables such as curve number (text file or dbf file) and meteorological data (text file) in a specified format needed for the model.

Once these input data are ready one can directly go to the 'Catchment Runoff (NRCS Method)' model for estimating runoff, infiltration, and NSP pollution through its various menus divided into four broad categories (Figure 19).

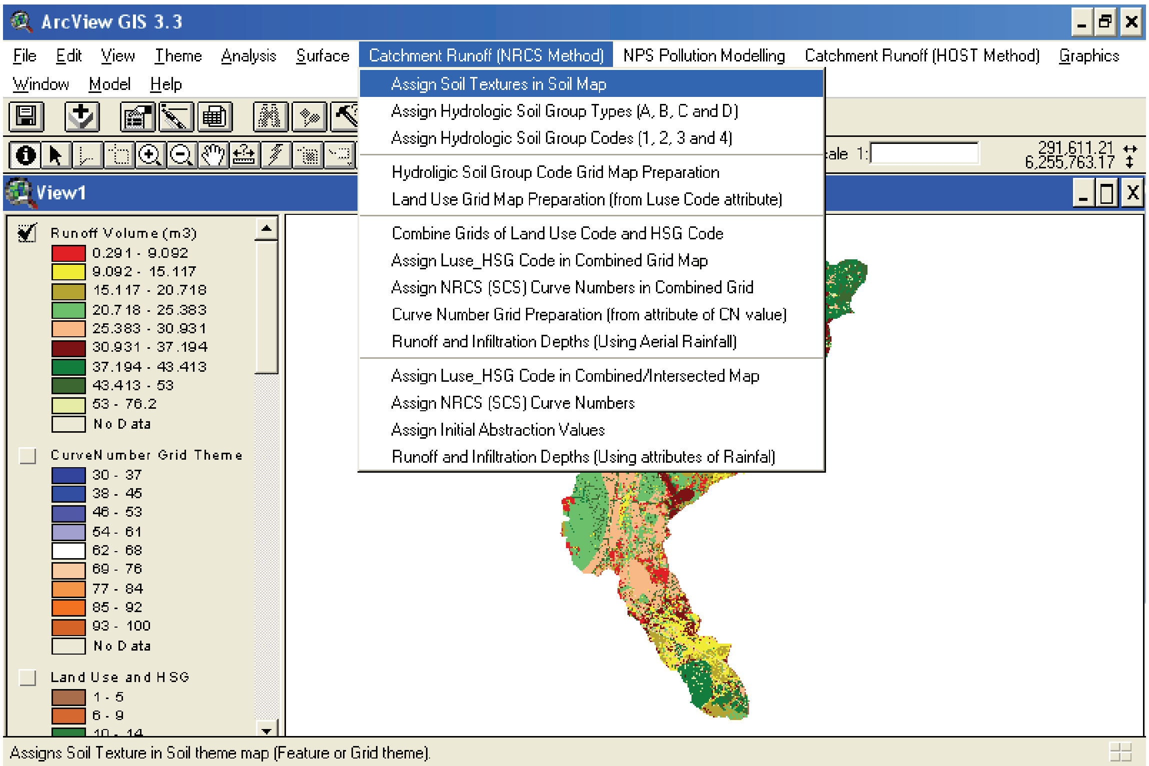


Figure 19 The model drop down menu attached to Catchment Runoff model in RINSPE.

The steps or submenus involved in runoff, infiltration, and NSP pollution estimation are the following:

Submenus 1 to 3

i) Assign Soil Texture in Soil Map
ii) Assign Hydrologic Soil Group types (A, B, C and D)
iii) Assign Hydrologic Soil Group Codes (1, 2, 3, and 4)

Submenus 4 to 5

i) Hydrologic Soil Group Code Grid Map Preparation
ii) Land Use Grid Map Preparation (From LUSE Code Attribute)

Submenus 6 to 10

i) Combine Grids of Land Use Codes and HSG Code
ii) Assign LUSE_HSG Code in Combined Grid Map
iii) Assign NRCS (SCS) Curve Numbers in Combined Grid
iv) Curve Number Grid Preparation (From Attribute of CN Value)
v) Runoff and Infiltration Depths (Using Aerial Rainfall)

Submenus 11 to 14 *(*for a single map having attributes of Land Cover Types, HSG and Rainfall)

i) Assign LUSE_HSG Code in Combined/ Intersected Map
ii) Assign NRCS (SCS) Curve Numbers
iii) Assign Initial Abstraction Values
iv) Runoff and Infiltration Depths (Using Attributes of Rainfall)

5.6.1 Inputting of Land Use Data

Land Use / Land Cover data is the foundation for runoff quantity and pollutant yield. An application of suitable land use grids in the RINSPE model to estimate runoff distribution necessitated the preparation of a land use land cover map that would be used to identify potential sources of runoff as well as pollution from surface sources (Figure 20). A detailed description of a land use / land cover map that was used during the surface runoff estimation was reported on in previous deliverables (Appendix).

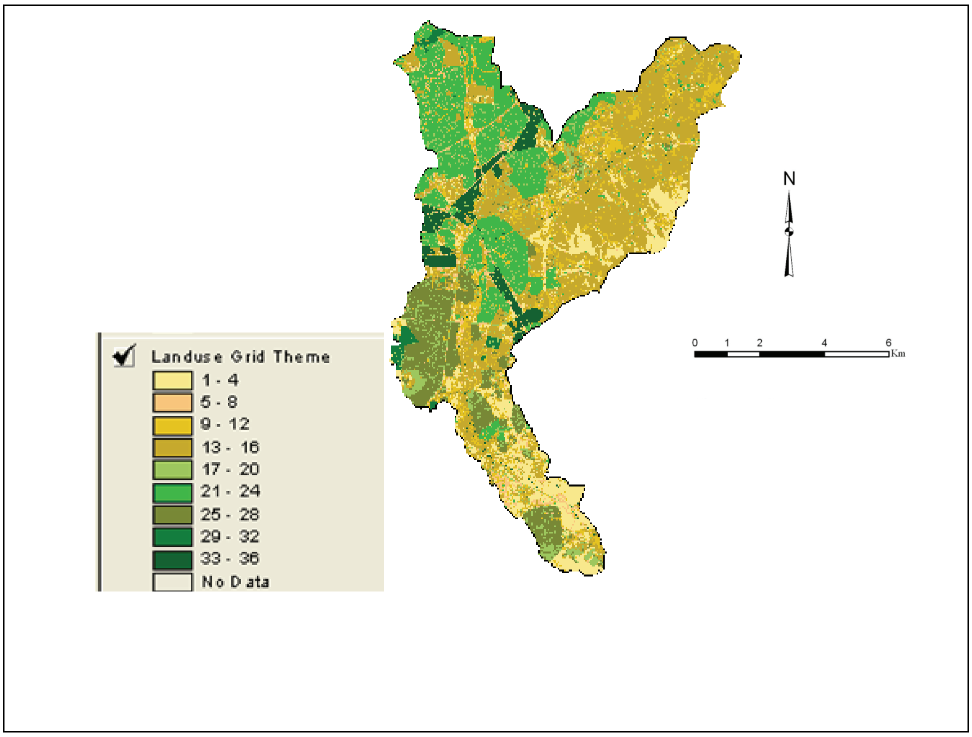


Figure 20 Land Cover Map of the Kuils River catchment

The RINSPE model requires land use data in specific data formats. The land use data in grid format contains predefined land use classes and are represented with codes values (Table 21). The attribute table for this data therefore contains a field 'type', which shows all the available land use classes in the study area, and the field 'luse_code' which shows the codes for each of these classes. This land use grid map can be generated through the sub menu 'Land Use Grid Map Preparation' under the 'Catchment Runoff (NRCS Method)' menu. The programme however, can accept the land use map in both shape file or grid file formats. If in the shape file format and the 'Luse_code' field is absent, the land use classification script/programme will create such a field and write the code values based on the text values available in its field 'Type'. Finally, the land use classification script will convert the shape file format data into a grid map having the code values and land use types as shown in Table 21.

Table 21 Typical Land Use Types and the Codes Applicable to RINSPE Model.

VALUE	COUNT	LAND USE	LUSE_CODE
1	321783	Mountain Forest	1
2	330731	Riparine Forest/Natural Forest	2
3	268895	Dense Scrub	3
4	778580	Fynbos	4
5	114064	Grassland	5
6	37964	Impervious Surface	6
7	7822	Railway Line	7
8	33393	Impervious Surface/Bare Rock	8
9	35750	Bare Rock	9
10	372671	Open Vineyard/Coarse Rock Pebbl	10
11	105086	Open Area/Barren Land	11
12	233472	Improved Grassland/Veg Crop	12
13	45552	Buildings/Impervious	13
14	1317394	Dense / Grassy Vineyard	14
15	916792	Fallow/Open Vineyards	15
16	20989	Recreation Grass/Golf Course	16
17	4002	Freeways/Express Ways	17
18	22638	Arterial Roads/Main Roads	18
19	181464	Minor Roads	19
20	55073	Sandy	20
21	72494	Waterbodies	21
22	83024	HDR Formal Suburb	22
23	448277	MDR Formal Suburb	23
24	86253	LDR Formal Suburb	24
25	187955	HDR Formal Township	25
26	33851	MDR Formal Township	26
27	236	LDR Formal Township	27
28	9861	HDR Informal Township	28
29	6701	MDR Informal Township	29
30	11243	MDR Informal Squatter Camps	30
31	1593	LDR Informal Squatter Camps	31
32	12371	Commercial - Mercantile	32
33	8762	Commercial - Institutional	33
34	106300	Industrial	34
35	2091	Cemeteries	35
36	13572	River	36

5.6.2 Acquisition and Preparation of Soils Data (Hydrologic Soil Group)

The soil information was derived from the Land Capability map of South Africa, which has information on the soil textures (Figure 21). The soil texture classes were reclassified based on their drainage potential, which formed the hydrologic soil group map (Figure 22).

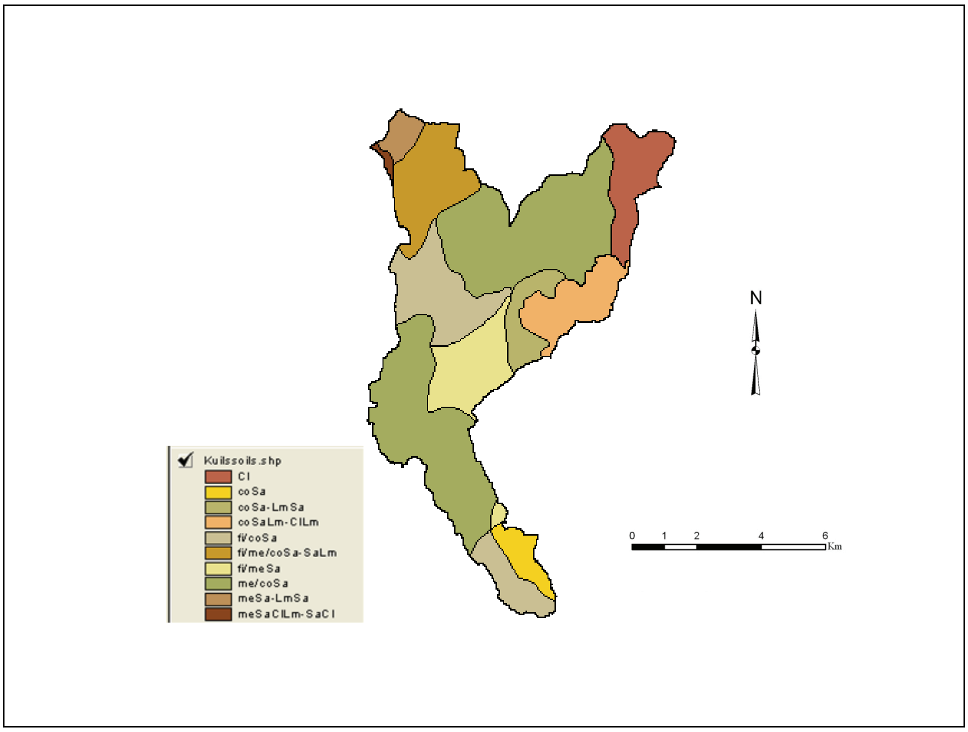


Figure 21 Soils Distribution Map of the Kuils River Catchment

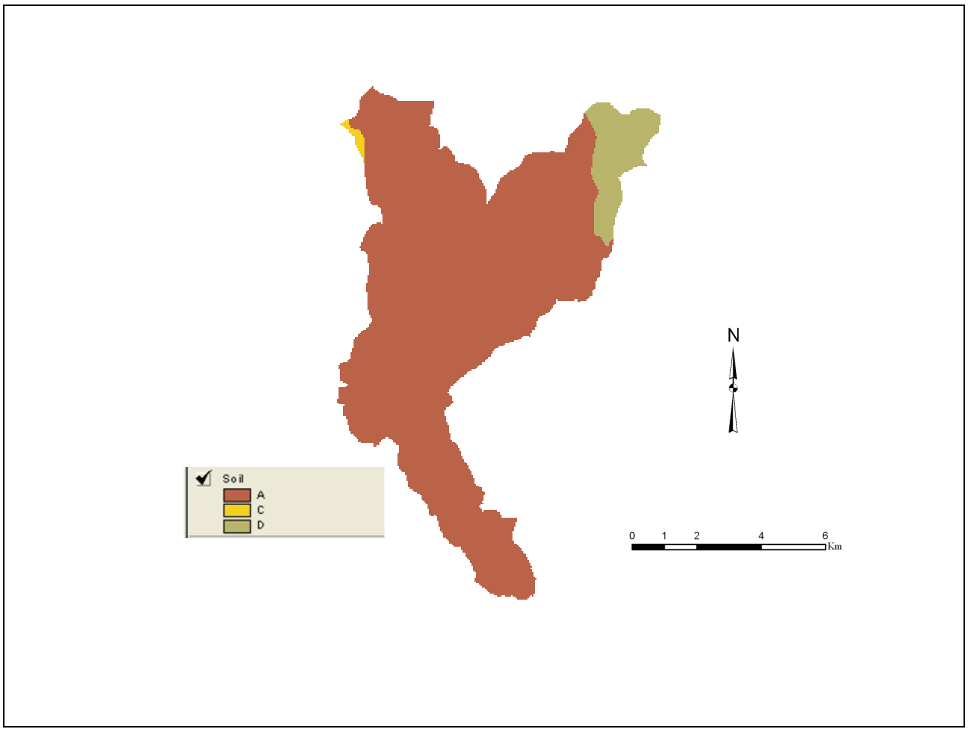


Figure 22 HSG Grid Theme for the Kuils River catchment

5.6.3 Preparation of Elevation Layer / Digital Elevation Model (DEM)

Digital elevation models (DEM) represent the existing topography and they are available in different levels of resolution. However, higher resolution DEMs result in increased processing times during modelling runs. Topography of the catchment was represented by a 30m digital elevation model (DEM), which was resampled to 10 meters (Figure 23) as the land use map was also of the same resolution. It is this topography data that defines flow direction, stream networks, and catchments and sub catchments. The entire runoff and pollutant routing process is based on flow direction and flow accumulation grids derived from the elevation grid. The resolution of the data set impacts processing speed and file size and in this case a 10m resolution was considered ideal for optimum rendition and results. Because DEMs are the basis for flow routing and quantifying, it became very necessary to ensure that the grid cells of the DEM and all other grid data sets are aligned to each other. This was accomplished by setting the "snap to extent" feature to the DEM data set in the ArcGIS™ Spatial Analyst options menu. In general, all input data layers that are used during modelling must be converted to a common projection; in the case of this study, the projection reference that is used is UTM Zone 34S with datum WGS84. On further examining the above elevation layer by creating a flow direction, flow accumulation and stream network it was found that this layer had some errors in the cell values, as the simulated stream network did not follow the existing streams. Therefore an attempt was made to procure an accurate DEM for the hydrologic modelling purpose.

5.6.4 Processing of Elevation Data (DEM) for Hydrologic Modelling

A 20m DEM layer (named 'eerste20m') was procured from COMPUTAMAPS (a private firm that supplies digital spatial data) based in Cape Town. The above DEM was generated from the 10 m and 20 m contour maps and looked much better than the 30 m one. New projection parameters (coordinate information) were assigned to the DEM by deleting the projection file for the DEM in Windows Explorer and then defining another using the Define Projection tool of ESRI's ArcToolBox. With the spherical coordinates defined, the DEM was then projected to WGS84_UTM34S using the Project Raster tool of ESRI's ArcToolBox. In order to derive a unique catchment boundary that would be used to define the boundaries of all other grids (a precondition for a successful model run), a catchment delineation analysis was performed on this DEM. The results from catchment delineation process showed a gross miss match between the flow accumulation path derived from the DEM and the actual path of the river channels, which were manually digitised from satellite imagery, therefore indicating errors inherent in the DEM. Attempts to use other available DEM data were problematic as well, as these data sets were of an early origin and did not reflect current flow mechanisms for the catchment. For example, the defined flow accumulation grid for these data sets showed both the Kuils and the Eerste Rivers to have separate mouths at False Bay whereas current conditions show these two rivers form a confluence about 4km upstream of the pour point at False Bay.

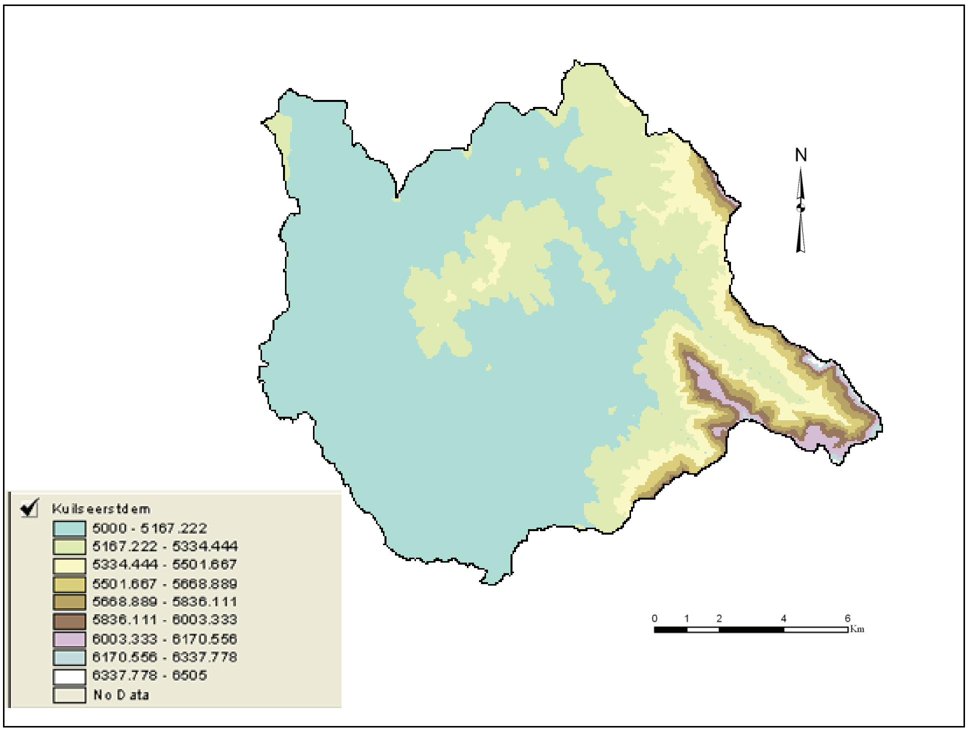


Figure 23 A 20 m DEM of the Kuils-Eerste River Catchment

In order to correct this mismatch in the DEM and the stream layers, an extra and prior process described by Oliveira (1996) was added to the preparation of the DEM. This procedure consisted of burning-in the digitized rivers/streams that have been observed in the catchment. This burning-in 'Burndem' process produces an improved DEM that is created by raising the elevation of all the cells in the DEM but for those that coincide with the digitized rivers/streams. By doing this, water is forced to remain in the stream valleys once it gets there; although it may not be forced to flow downstream if the stream values are incorrect. However, Oliveira (1996) confirms that, if successful, streams delineated using this improved methodology represents much better the real stream network. A stepwise illustration of the burn in process was carried out as follows (Oliveira 1996):

- Converting the line coverage of digitized streams into a grid (with value 1 in the stream cells and NODATA elsewhere).
- Making sure that this grid presents continuous streams (no gaps), they do not involve short circuits, and that they extend out of the study area.
- Adding a constant value to the DEM (e.g. 5000, which is much higher than the max elevation value).
- Merging the two grids, keeping the stream grid on top of the modified elevation grid, to obtain the burned-DEM.

Following these steps, the standard methodology for hydrological analysis described above was applied to the burned-DEM. The next step was a step-by-step description of the methodology used during burning in of the Streams (Oliveira 1996). This process consisted of modifying the DEM, by burning-in the streams and by filling the sinks, so that the ArcView hydrologic functions imbedded in the model could be implemented. Both the river grid and the DEM layer were loaded into the ArcMap window.

Firstly, the river grid was divided by itself so that all the cells could be assigned value 1, by using the Spatial Analyst/Raster Calculator and entering the corresponding map algebraic expression (mathematical operation, [river]/ [river],) in the Raster Calculator dialog box. The result was automatically added to the map window as a layer (called Map Calculation 1) with values of 1 or NODATA corresponding to on-stream and off-stream cells, respectively. By right-clicking this new stream grid and opening the layer properties dialog, this layer was later renamed 'Unitriver' under the general tab of the layer properties dialog window so that it could easily be referenced in the next step.

Secondly, using the Spatial Analyst raster calculator, the Unitriver grid was Multiplied by the DEM, by typing in the following mathematical expression into the raster calculator dialog box: [unitriver]*[dem]. Following the same procedure as above, the resultant grid was renamed to 'Demstrm' because it stores the DEM value in the stream cells. An appropriate colour scheme was assigned to this layer for better visualisation of the layer features.

Thirdly, a fixed constant value was added (5000 m was an arbitrarily chosen figure) to the DEM grid using the Spatial Analyst/Raster Calculator and entering the corresponding mathematical operation [dem] + 5000 in the raster calculator dialog box. This grid layer was named Demplus because it stored the DEM value increased by 5000 m.

Lastly, the two grids were merged into a single grid layer using the merge command algebraic syntax, merge ([aGrid], [bGrid],[etc.]), in the raster calculator. The purpose of this expression was to take the Demstrm grid as aGrid and Demplus as bGrid and then to merge them in the order aGrid merged into bGrid. The effect of this was the insertion in the raised DEM (demplus), the elevation values of the actual DEM in those cells lying along the stream (demstrm). The order of input in the grid list Raster Calculator determines the priority of the raster, with the last raster listed having the lowest priority. Since demplus was artificially raised by 5000 m, this created a narrow trench wherever there was a stream and forced the flow direction grid to follow this trench in subsequent processing. The elevation increment of 5000 m was an arbitrary figure and would have no real significance in subsequent calculations.

A few important hints were taken into account during the merging process: Both categorical and continuous rasters could be entered as input rasters during a merge and the result would be a floating-point raster if the input raster were a floating-point raster. Otherwise, the result would be of the integer type. The extent and cell size of the output raster were determined by the current analysis environment, which were set using the Spatial Analyst Option's dialog. The default settings would result in an undesirable output raster with an extent equal to the minimum bounding rectangle of all inputs and a cell size equal to the coarsest resolution of all inputs.

For the floating-point input rasters (of different resolution) it was recommended to RESAMPLE all the data using BILINEAR interpolation or CUBIC convolution before running Merge command/function. Otherwise, the Merge function would automatically resample the rasters using NEAREST neighbour (which was not appropriate for the continuous type of data) and the current cell-size setting in the current analysis environment and then perform the merge. The default cell size was set to the Maximum of Inputs. With that unchanged, the function would resample the finer raster(s) to the coarsest resolution.

When typing a Map Algebra expression into the Spatial Analyst Raster Calculator, if the input raster dataset is a grid and resides in the working directory (usually set on the General tab of the Options dialog), type the name of the grid directly into the expression: e.g. merge (demstrm). On the other hand, if the grid dataset does not reside in your working directory, the path to the grid dataset on computer disk is typed into the raster calculator: merge (c:\SpatialData\Demstrm). The above criterion only applies to grid data sets. All other raster datasets (for example, TIFF) cannot be accessed directly from disk. Alternatively, all raster inputs (including grids) could be simply added first as layers to ArcMap. Such layers will then be displayed automatically in the Layers list of the Raster Calculator from where they are easily selected during a map algebraic exercise. Lastly, when entering the raster into a Map Algebra expression it must be surrounded by square brackets: e.g. merge ([Demstrm]).

Zooming in on the new 'burndem' grid and using the 'Identity' tool to check the cell values, one could see how the procedure has produced a stream network imbedded in the DEM. The quality of success in the burn in process was checked by performing a preliminary hydrologic analysis of the newly improved dem During this stage, the Burndem was filled using the Hydrology Fill sink tool in ArcToolBox. This operation has the effect of filling the artificial pits created in the landscape when it is represented by a DEM. If these pits are not filled they interrupt the subsequent functions by stopping the water "flow" at intermediate points in the landscape. Flow direction and the flow accumulation grids were later derived using the corresponding hydrology commands in ArcToolBox. The cells of higher flow accumulation obtained from above the hydrologic processes were perfectly aligned/matching with the digitized stream layer features. The prepared DEM is now ready for incorporation into ArcView GIS for further hydrologic modelling.

5.6.5 Sub catchment Delineation Using Hydrology Extension

Sub-catchments from a DEM can be delineated using the Hydrology Extension of ArcView 3.3. In order to determine or delineate the watershed using the Hydrology Extension, hydrological properties had to be defined and the drop-down menu on the hydrology analysis option was used. Taking full advantage of the Hydrologic Modelling extension, including the use of W (watershed) and R (flow path) buttons and the Hydro/Watershed function, the name of the flow-direction and flow-accumulation grids are then entered in the Hydro/Properties dialog box. Once the name of these grids has been entered, the buttons and the function become active. After making active the filled Burndem grid-theme clicking the R enables the flow-path function. Clicking on any point of the view display area generated a flow path line that runs from the point to its pour point or out of the analysis area. Clicking on the W button again with the filled burndem grid theme enables the watershed function. Clicking on any point of the View display area will generate a watershed grid for the selected point. The confluence of the Kuils River with the Eerste River was identified from the flow direction grid and by clicking on this point just above the merger of the Kuils River resulted in generating a catchment for the Kuils River. The elevation layer was later clipped using this identified sub catchment, which formed the input layer of elevation (Figure 24) for the Kuils River catchment. Similarly all other input rasters were clipped using this sub catchment identified for the Kuils River which could be used for further modelling work.

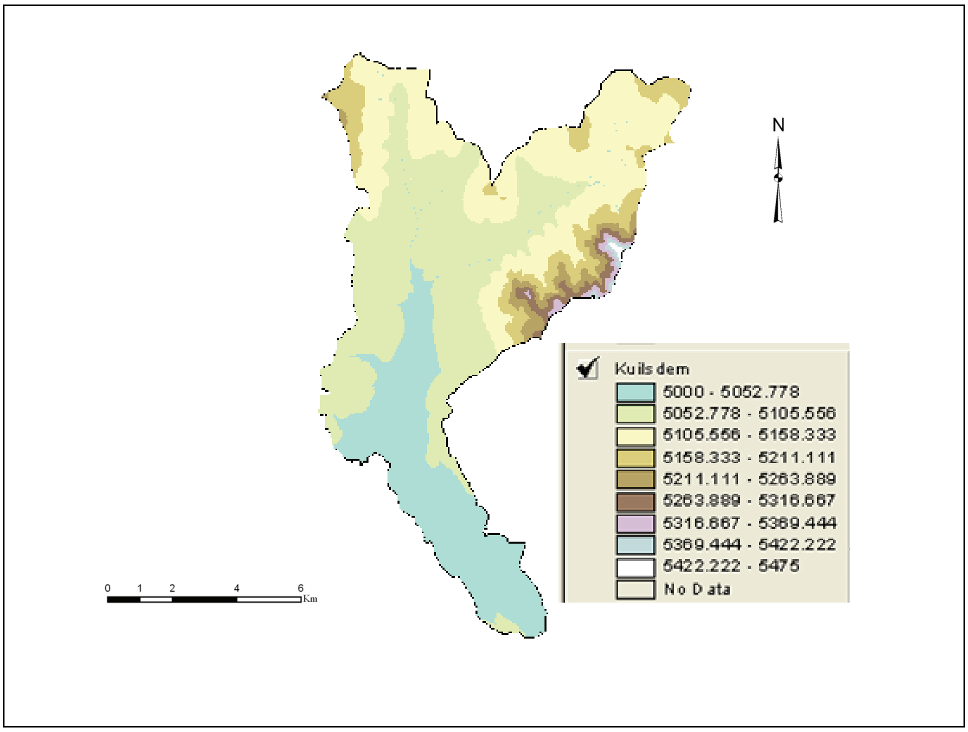


Figure 24 Digital Elevation Model of the Kuils River catchment

5.7 Preparation of Precipitation Grid

5.7.1 Acquisition of rainfall data and preparation of rainfall grid layers

The runoff component of RINSPE is driven by the precipitation grid. The South African Weather Service (Weather SA) and the South African Department of Water and Forestry (DWAF) are the primary repository for precipitation data collected in weather stations that are located all over the Republic of South Africa. Monthly and annual rainfall records for stations in the vicinity of the Kuils-Eerste River catchment were interpolated as grids based on the procured precipitation data. Annual Precipitation totals for the year 2006 and 2007 were extracted from annual rainfall records collected from six rain gauges that occur at some sites in the catchment. Interestingly, there existed a greater number of rain gauges in the catchment but a number of such stations were no longer functional and there existed points with missing data in the rainfall table. Initially, a wide range of rain fall stations were sampled but the number of stations that were considered for rainfall interpolation were reduced because some points were considered too distant to influence rainfall distribution in the Kuils River area (Table 22). The Smirnov-Kolmogorov Regression Model was used to correct for missing data points.

Table 22 Rainfall Input Data

Stn_ID	Stn_Name	Lon	Lat	2O06	2O07
G1E001	Wellington	19.0158	-33.6500	662.1	729.0
G1E002	Vogel Vallij @ Voelvlei dam	19.0408	-33.3417	569.5	659.6
G1E003	Zachariashoek @ Nemmershoek dam	19.0825	-33.8333	715.3	768.9
G1E006	Assegaaibos	19.0658	-33.9417	1669.0	1483.6
G1E009	Withoogte @ purifiction works	18.6678	-33.0672	464.3	522.3
G2E001	Brakke Fontein @ Atlantis Sewage	18.4825	-33.6083	400.9	515.2
G2E003	Higgovale Cape Town @ Molteno	18.4117	-33.9375	772.2	968.5
G2E004	Tafleberg	18.4033	-33.9792	1440.0	1761.0
G2E005	Tafelberg @ Newlands	18.4492	-33.9667	1266.0	1756.0
G2E007	Malan DF Airport	18.5992	-33.9667	436.1	680.6
G2E008	Stellenbosch @ Welgevallen	18.8700	-33.9417	486.2	630.6
G2E011	Jonkershoek @ Biesievlei	18.9492	-33.9833	1360.7	1796.3
G2E013	Jonkershoek @ Manor House	18.9286	-33.9639	1093.0	1330.0
G4E001	Kogel Baai @ Steenbrasdam-Lower	18.8514	-34.1797	996.5	959.0
OO212303	Altydgedacht	18.6330	-33.8330	488.0	651.4
OO21550	Maitland	18.5860	-33.9200	484.1	614.1
0021417A0	Skoonheid	18.7333	-33.95	463.0	679.0

5.7.2 Generation of Precipitation Grid

A number of steps were followed during generation of annual precipitation grids from data that was procured from both Weather SA and DWAF. These data were outlined in table format on a Microsoft Excel™ spreadsheet and later saved as a database (dbf IV) file in Microsoft Excel. The function Add X-Y Data in ArcMap Tools was used to add the precipitation (dbf IV) data into ArcMap GIS window as an event layer feature. The event layer was later converted into a shapefile of point feature type. Using ArcGIS' 'Define Spatial Reference' tool under ArcCatalog application, the event layer shapefile was assigned Universal Transverse Mercator Zone 34 South (UTM34S) projection coordinates which is the reference coordinates that exists on all other GIS data layers involved in the research project. In an Alternative procedure to assign the projection, the rainfall data (dbf IV) table was added as an event layer to ArcMap window that already contained a spatially referenced layer (e.g. BoundaryUTM34S) so that the resultant event point data layer assumes the existing spatial reference coordinates in the ArcMap window 'on the fly'. A shapefile was made out of the event layer by using the export function that is reached by right-clicking on the event layer name to export the event point data layer as an ESRI shapefile.

The ArcGIS Spatial Analyst Surface interpolation function was used to create a continuous (or prediction) surface from sampled point values in the point feature shapefile. The resulting continuous surface was a representation of annual rainfall predictions for all locations in the raster dataset whether or not a measurement had been taken at the location. A number of interpolation algorithms, including Inverse Density Weighted (IDW) and Spline were experimented for the best annual rainfall distribution display during the interpolation process and it was found that, the Spline algorithm produced a smooth surface of annual rainfall distribution map for the Kuils River catchment area. The Inverse Distance Weighted (IDW) and Spline methods of interpolation assign values to locations based on the surrounding measured values using specific mathematical formulae that determine the smoothness of the resulting surface. The default values of 12 points were used in the Spline method based in

ESRI's Spatial Analyst Interpolation to Raster algorithms to determine the annual rainfall amounts for each grid cell. The Tension method which creates a less-smooth surface but with values more closely constrained by the sample data range was chosen during the Spline operation in preference to the Regular method which samples even values that fall out of the sample range. Finally, the resultant grid was later trimmed to the extent of the Kuils River boundary using Extract By Mask tool in ArcToolBox' Spatial Analyst Tools. Figure 25 and Figure 26 show the annual rainfall maps for Kuils River Catchment area for year 2006 and 2007 deduced using the procedures that have been discussed above.

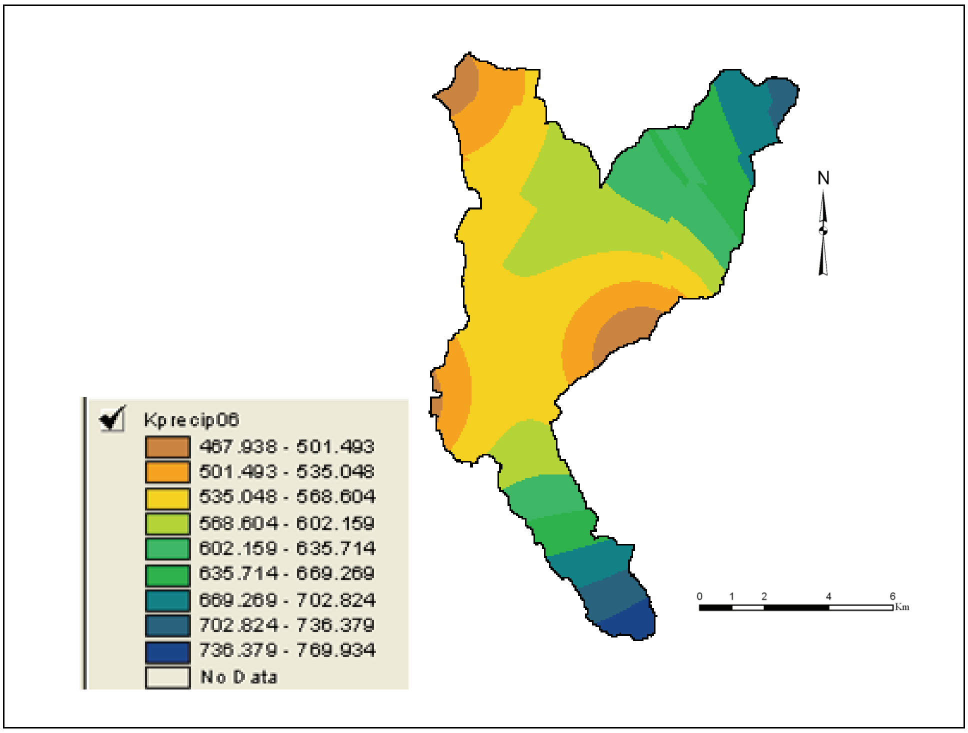


Figure 25 Precipitation Grid for Kuils River Catchment for the year 2006.

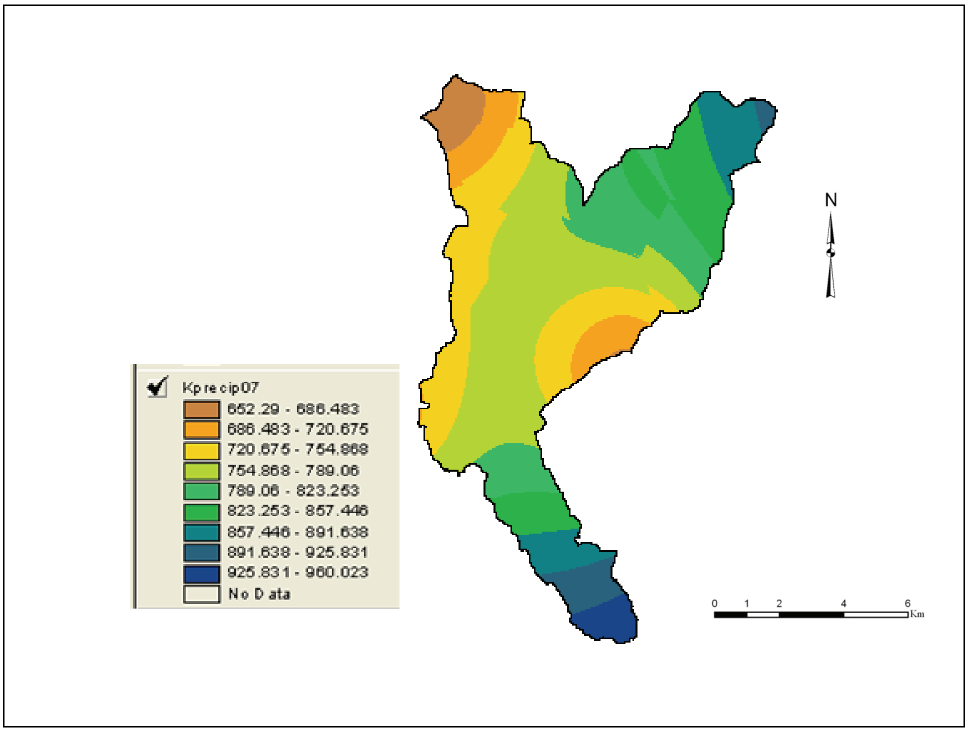


Figure 26 Precipitation Grid for Kuils River Catchment for the year 2007.

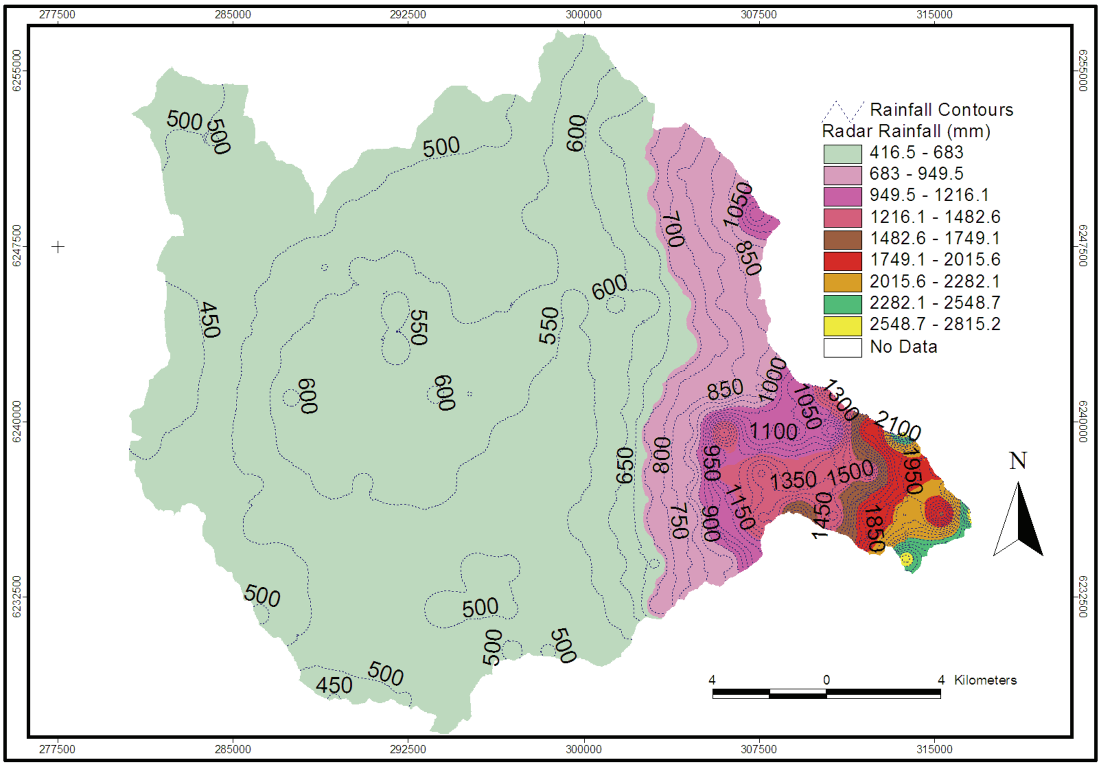


Figure 27 Annual Precipitation Grid the Catchment

A new rainfall data set for the catchment was obtained (Schulze *et al*., 1996). This dataset had monthly rainfall information in a point feature shapefile format covering the whole

Western Cape Province (in decimal degrees/geographic coordinate system). All monthly rainfall amounts were added in its attributes table in order to get annual rainfall amounts. Later this dataset was projected to UTM projection 34S and interpolated to get a rainfall distribution map (Figure 27) covering the catchment under study. The resultant grid shows the distribution of rainfall values that are decreasing as one approach the western part of the catchment and a high concentration of high rainfall values along the Jonkershoek River in Stellenbosch area. The distribution of rainfall has a direct influence on the amount of runoff registered in the catchment and also the quantity of pollutants that are moved over different land cover types.

5.8 Curve Numbers Table

Runoff curve numbers represent the infiltration capacity of the soil and range from 0 to 100, with 0 being no runoff and 100 indicating no infiltration. Curve numbers play an important role in RINSPE’s runoff depth estimation calculations. The USDA Urban Hydrology for Small Watersheds: Technical Release 55 is the primary reference for more information on determining appropriate curve numbers for other land cover classes. For instances in a situation in which a dual hydrologic group is assigned (e.g. A/D, B/D, C/D), the highest curve number of the two components will be used. For instance, B/D areas will be assigned a value of D for that land cover class. Higher curve numbers are given for landscapes with more impervious cover, surface soils with high clay content, or lands with low soil cover. Table 6.3 shows Kuils River catchment land use / land cover classes and the corresponding curve number values for each of the four hydrologic soil types. Figure 27 is the resulting curve number map after assigning CN values to various hydrologic soil groups characterised by various land use/land cover types.

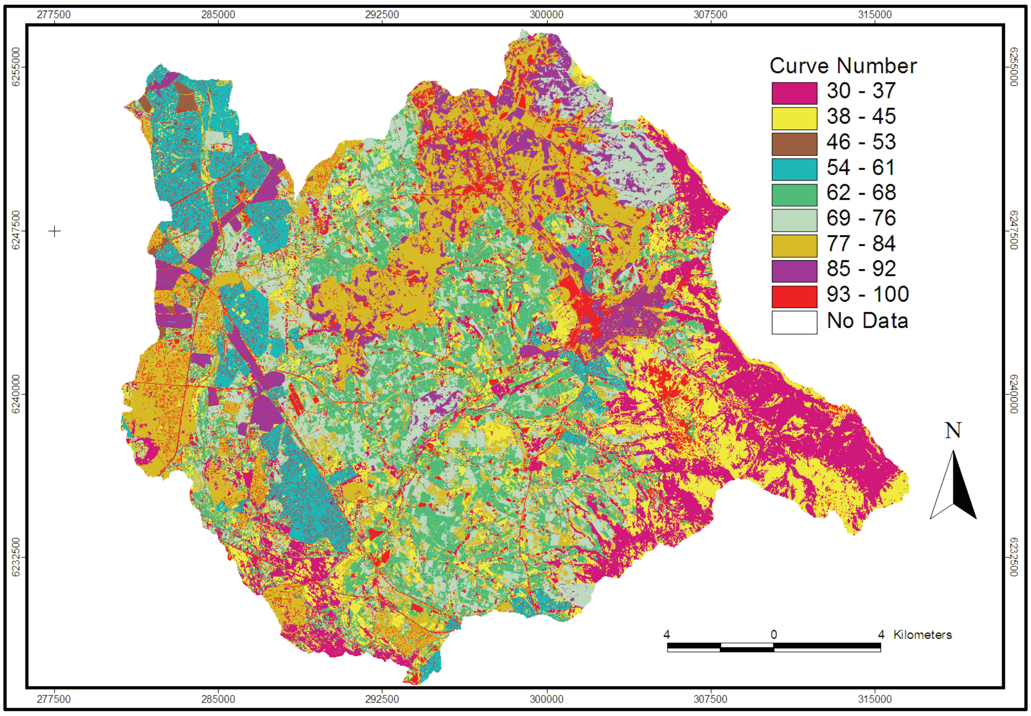


Figure 28 Curve Number (CN) Grid Theme for Catchment.

5.9 Preparation of Initial Abstraction Table

The initial abstraction ratio (I_a/S); (initial abstraction I_a expressed as fraction of potential maximum retention S) plays an important role in the calculated runoff depth, the hydrograph peak and the time distribution of runoff. It largely depends on climatic conditions (Ponce and Hawkins, 1996) and is the most ambiguous assumption and requires considerable refinement. When initial abstractions were estimated as 0.2S, it was found that for certain urban land use types the runoff predicted using the Curve Number method is zero or very negligible whereas in reality there were higher amounts of runoff were observed in field. Therefore, it has been investigated in many studies (Jiang, 2001; Hawkins *et al*., 2002; Mishra and Singh, 2004; Mishra *et al.,* 2004, 2005, 2006). This ratio was assumed in its original development to be equal to 0.2S. Mishra *et al.* (2006), employing a large dataset of 84 small watersheds (0.17 to 71.99 ha) in USA, investigated a number of Ia-S-relations incorporating antecedent moisture (M) as a function of antecedent precipitation. Hawkins *et al.,* (2002) using data sets that covered a plethora of rainfall/runoff events in USA, suggested changing the coefficient from 0.2 to 0.05 for use in runoff calculations. Mishra and Singh (2004) examined the applicability of a versatile SCS-CN model to long-term hydrological modelling and found that the model efficiency is at maximum when the ratio is in the order of 0.01.

For the determination of the initial abstraction ratio (I_a/S), in Kuils River Catchment in Western Cape Province, the measured rainfall/runoff events were analysed, but fewer storm events and conclusions were drawn regarding the change in ratio value. Attempts were also made to calculate Ia as 20% of the potential maximum retention value using the curve number approach and the calculated Ia values were quite high which actually resulting in producing no runoff in certain pixels (representing low curve numbers). Therefore a literature search was made for identifying observed typical values of initial abstraction values in other areas in US, UK and other countries for different land use/ land cover type of the catchments and table of realistic initial abstraction was thus finally prepared. The final values of initial abstraction for the different land cover types are adjoined to Table 23.

Table 23 Curve Numbers for Hydrologic Soil Group and Initial Abstraction Values

		Curve Numbers for Hydrologic Soil Group				
Value	Land use/Land Cover	A	B	C	D	Initial Abstraction
1	Mountain Forest	30	55	70	77	10.0
2	Riparian Forest/Natural Forest	36	60	73	79	10.0
3	Dense Scrub	36	60	73	79	8.0
4	Fynbos	39	61	74	80	8.0
5	Grassland	39	61	74	80	5.5
6	Impervious Surface	98	98	98	98	3.0
7	Railway Line	54	70	80	85	2.5
8	Impervious Surface/Bareground	77	86	91	94	3.0
9	Bare Rock	98	98	98	98	2.5
10	Open Vineyard/Hard Rock	77	86	91	94	5.0
11	Open Area/Barren Land	68	79	86	89	5.5
12	Improved Grassland/Veg Crop	39	61	74	80	7.5
13	Buildings/Impervious	98	98	98	98	2.5
14	Dense / Grassy Vineyard	43	65	76	82	5.5
15	Fallow/Open Vineyards	74	83	88	90	5.0
16	Recreation Grass/Golf Course	49	69	79	84	7.5
17	Freeways/Express Ways	98	98	98	98	2.0
18	Arterial Roads/Main Roads	98	98	98	98	2.0
19	Minor Roads	98	98	98	98	2.0
20	Sandy	36	60	73	79	2.0
21	Water bodies	0	0	0	0	0.0
22	HDR Formal Suburb	77	85	90	92	4.1
23	MDR Formal Suburb	61	75	83	87	4.5
24	LDR Formal Suburb	57	72	81	86	5.1
25	HDR Formal Township	81	88	91	93	4.1
26	MDR Formal Township	77	85	90	92	4.5
27	LDR Formal Township	57	72	81	86	5.1
28	HDR Informal Township	89	92	94	95	5.1
29	MDR Informal Township	77	85	90	92	5.1
30	MDR Informal Squatter Camps	81	88	91	93	5.1
31	LDR Informal Squatter Camps	61	75	83	87	5.1
32	Commercial - Mercantile	89	92	94	95	3.0
33	Commercial - Institutional	81	88	91	93	3.0
34	Industrial	86	91	93	94	3.0
35	Cemeteries	59	74	83	87	5.5
36	River	0	0	0	0	0.0

5.10 Model Results

The results of the application of the RINSPE model for estimating runoff for the Kuils River Catchment are presented in Figure 29. The flow direction grid generated by the RINSPE model while running the pollutant loading programmes is shown in Figure 30. Estimates of NPS pollutant loads based on a database of site mean EMC values prepared are shown in figures 31 to 38.

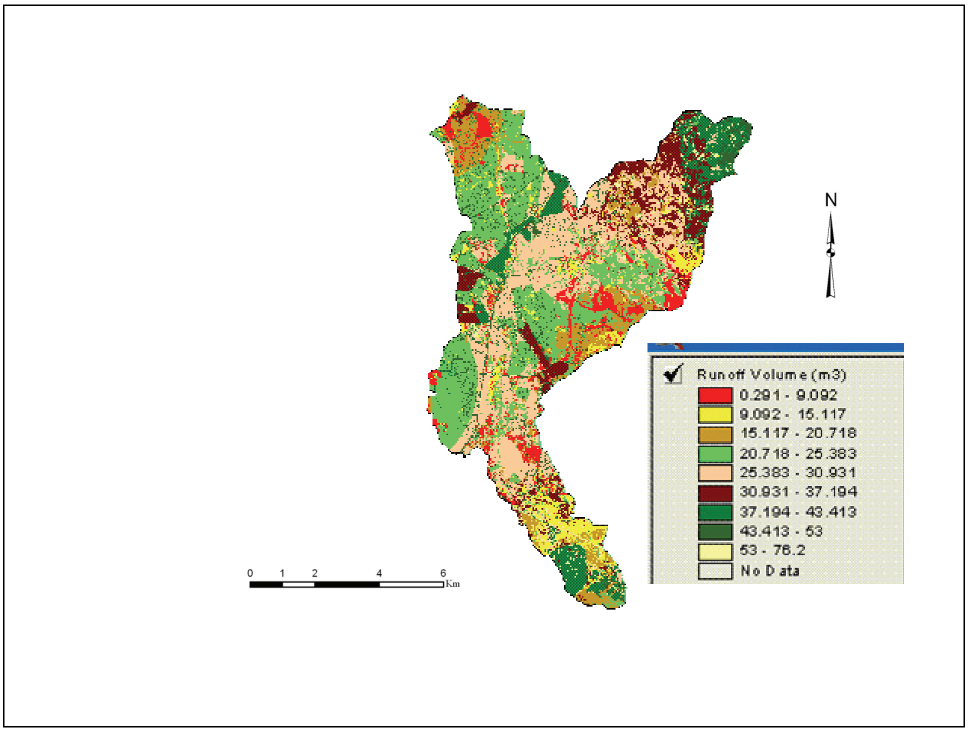


Figure 29 Runoff Volume (m^3) year 2006.

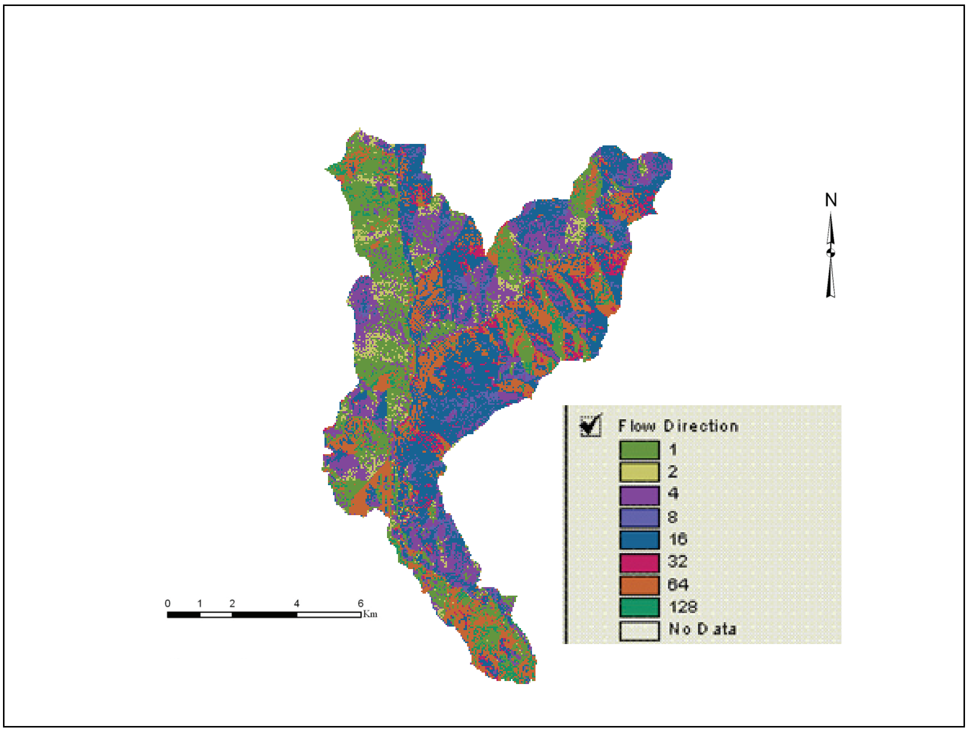


Figure 30(a) Flow direction map generated for the Kuils River catchment.

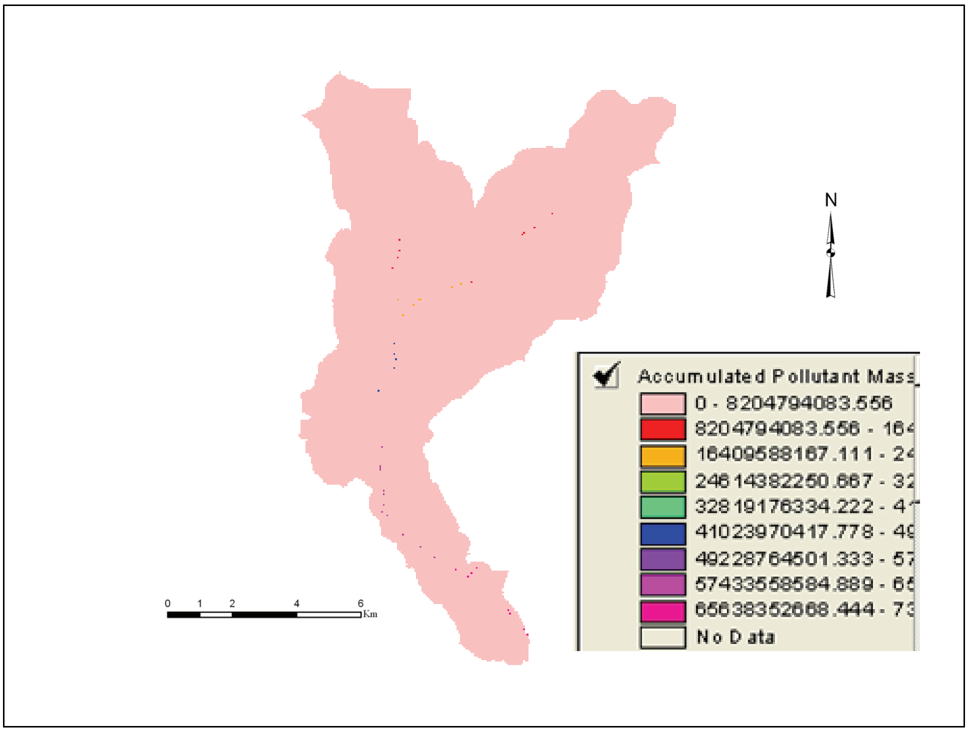


Figure 30(b) Accumulated Pollutant Mass (Nitrate).

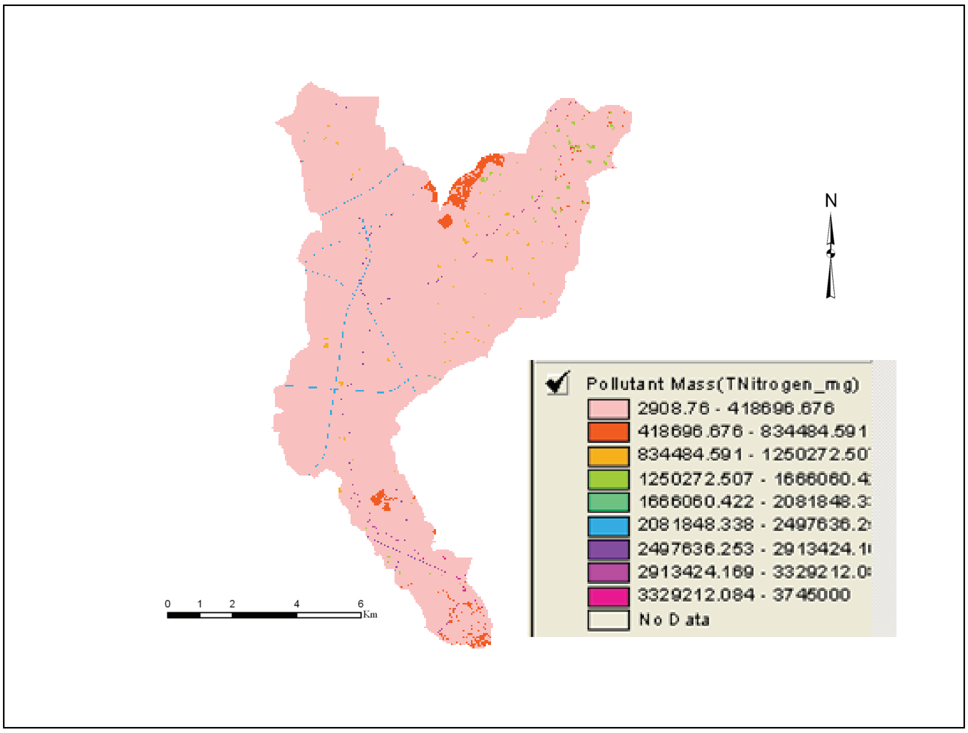


Figure 31 Pollutant Mass (T Nitrogen mg)

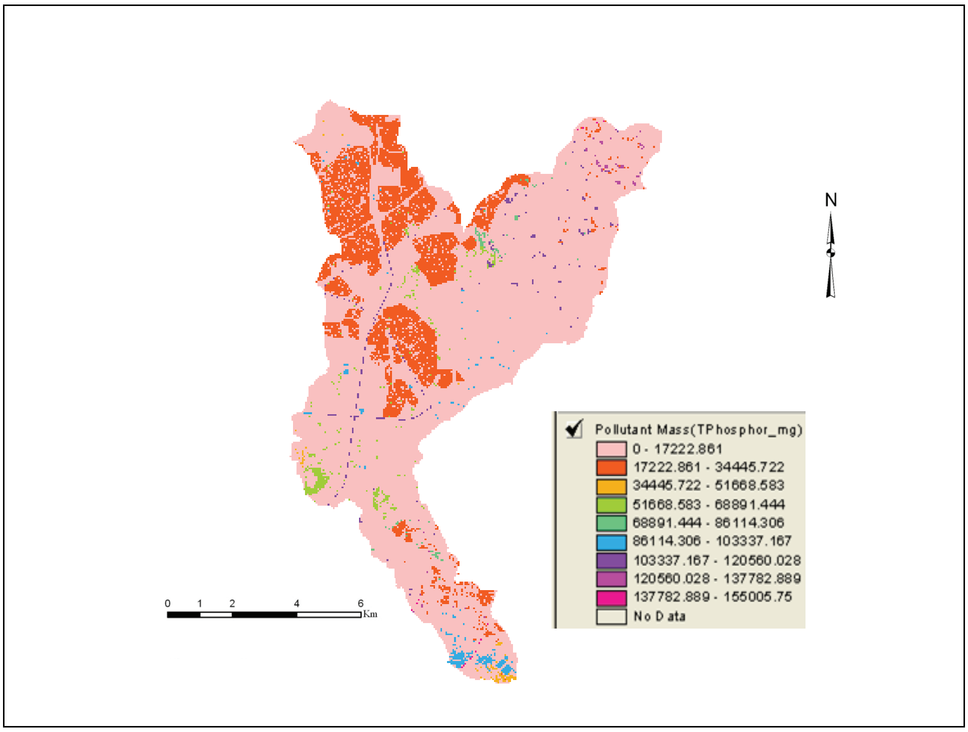


Figure 32 Pollutant Mass (T Phosphorous mg)

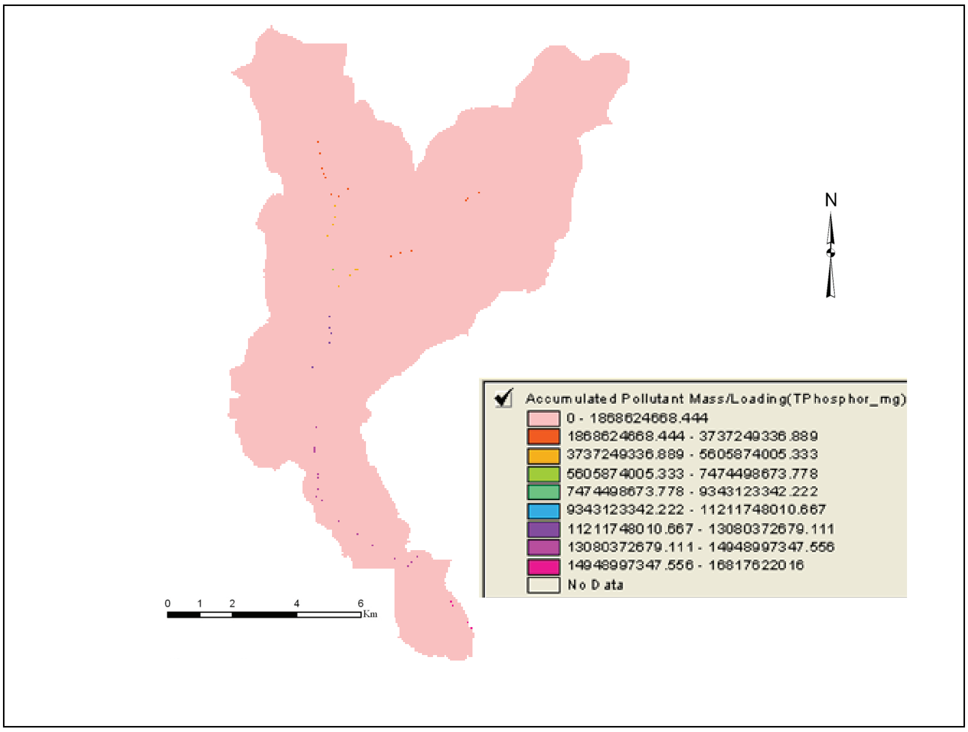


Figure 33 Accumulated Pollutant Mass (T Phosphorous mg))

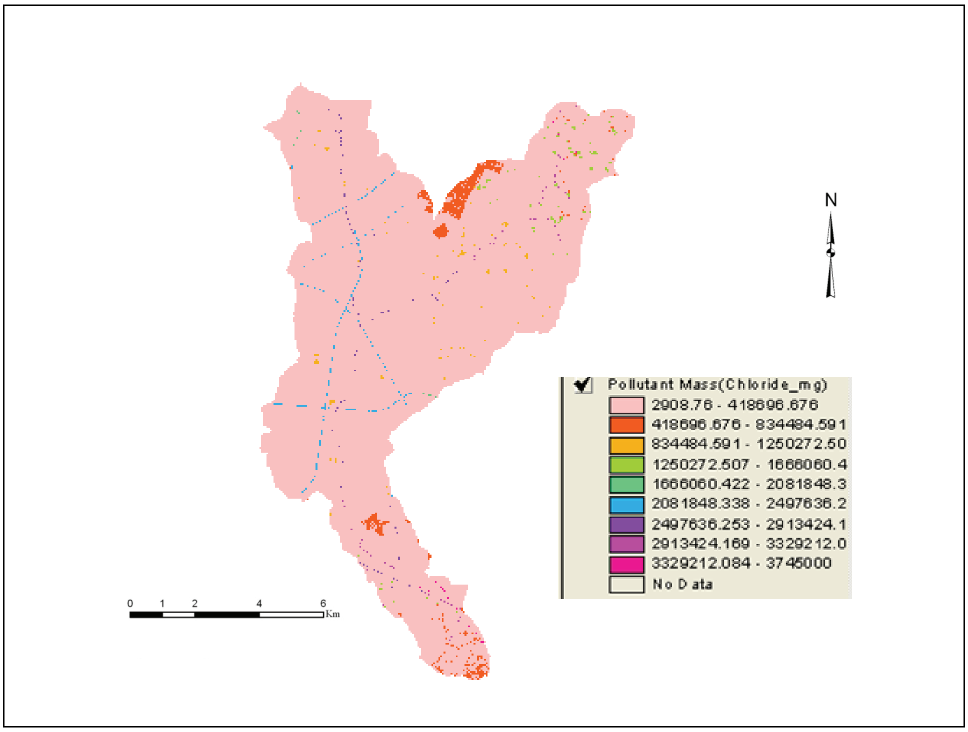


Figure 34 Pollutant Mass (Chloride mg)

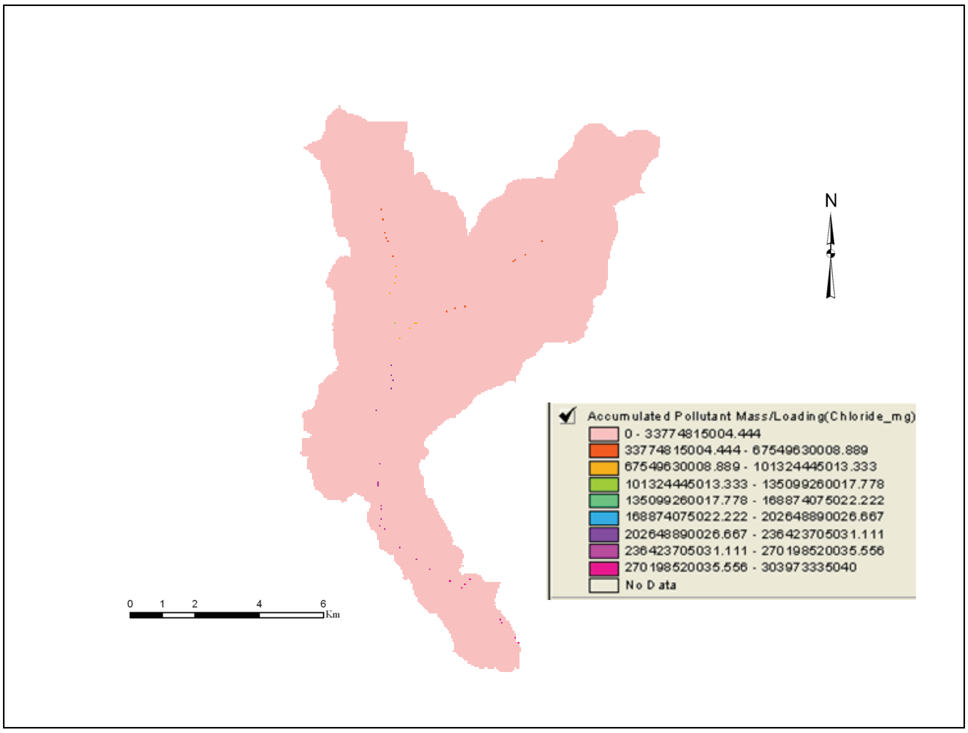


Figure 35 Accumulated Pollutant Mass (Chloride mg))

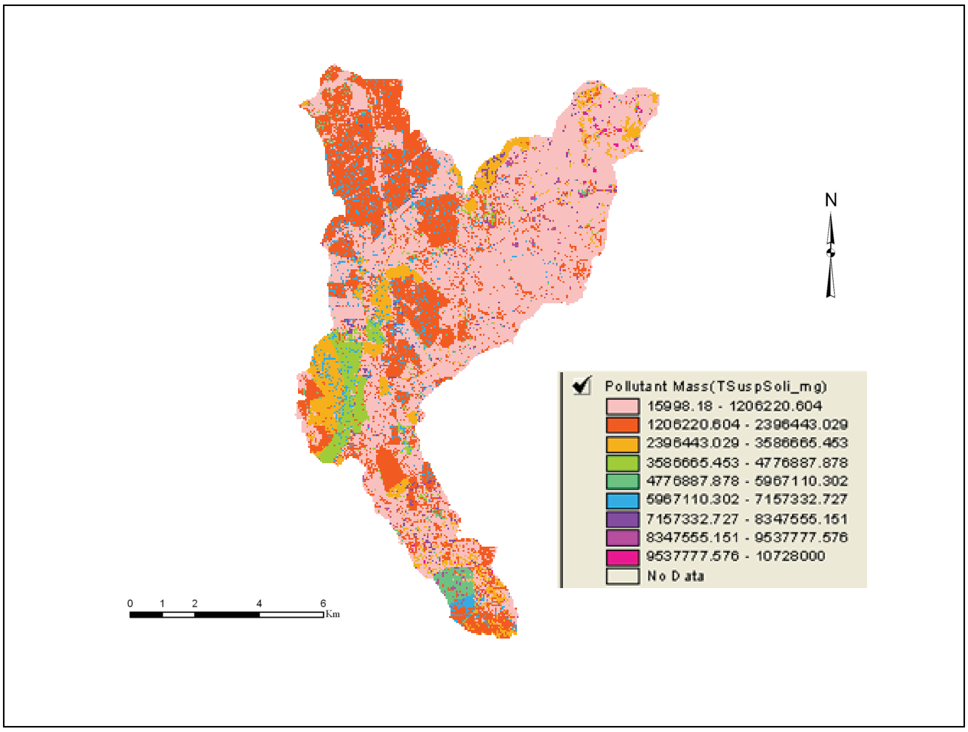


Figure 36 Pollutant Mass (TSS mg)

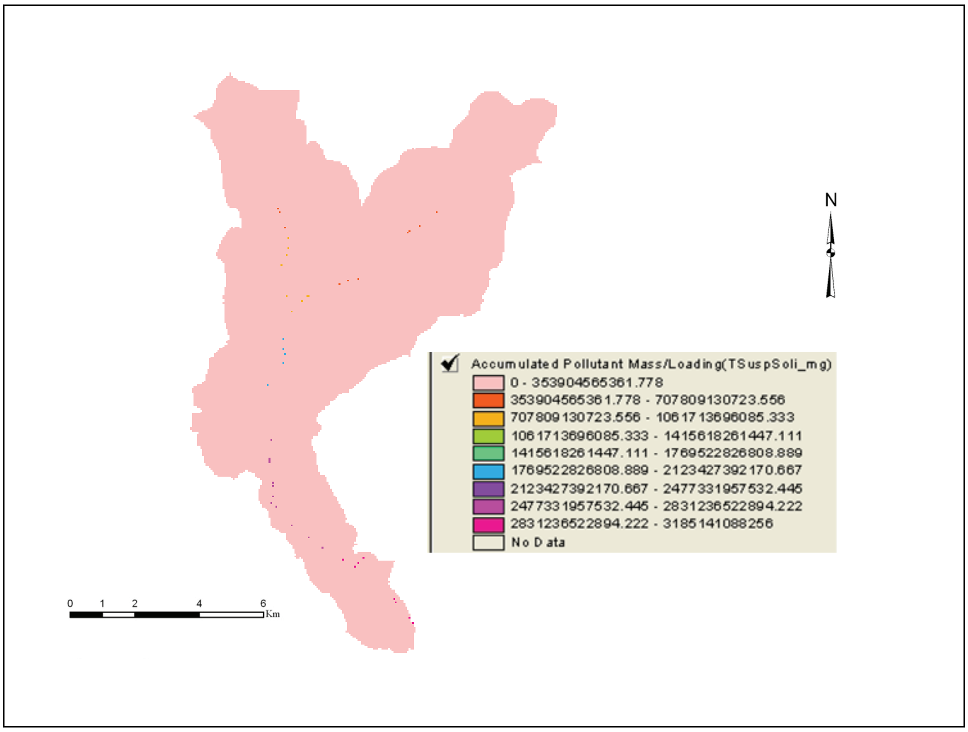


Figure 37 Accumulated Pollutant Mass (TSS (mg)

5.10.1 Runoff Distribution Map for the Whole Catchment

The same methodology of running the runoff estimation in RINSPE model which was used for the sub catchment of Kuils River was followed for the whole catchment delineated for

Kuils and Eerste Rivers using the input maps of Land use / Land Cover, HSG, Curve Number, and Rainfall (Figures 38 and 39), and the flow direction, flow accumulation and finally the runoff accumulation grids, culminating in the runoff predicted by RINSPE is shown in Figure 45.

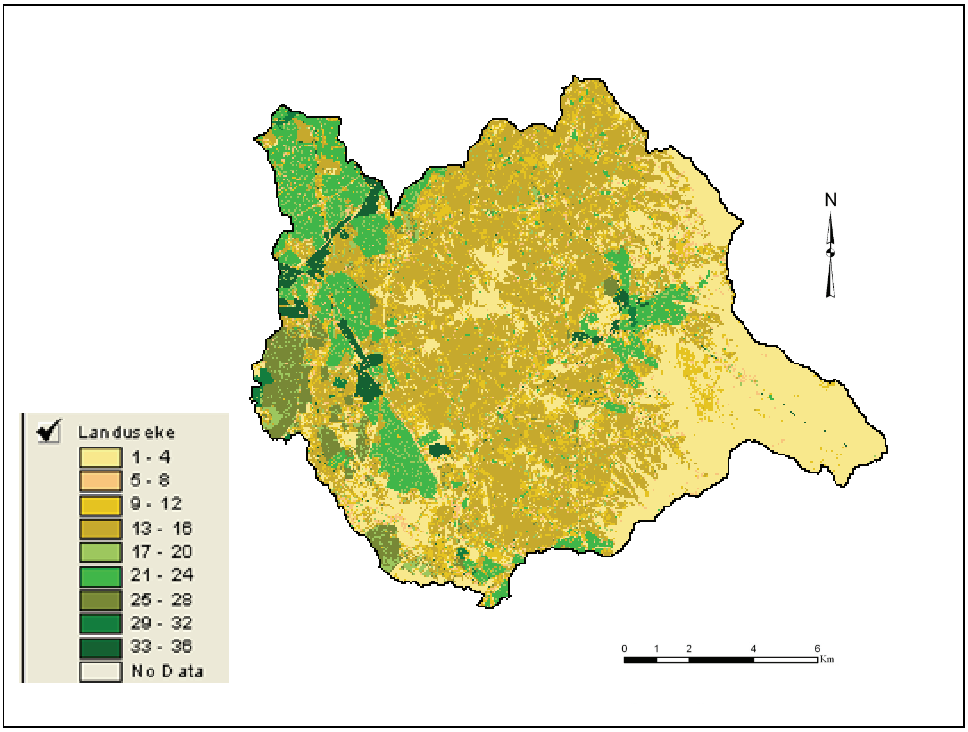


Figure 38 Land Use Grid for the Kuils-Eerste River Catchment.

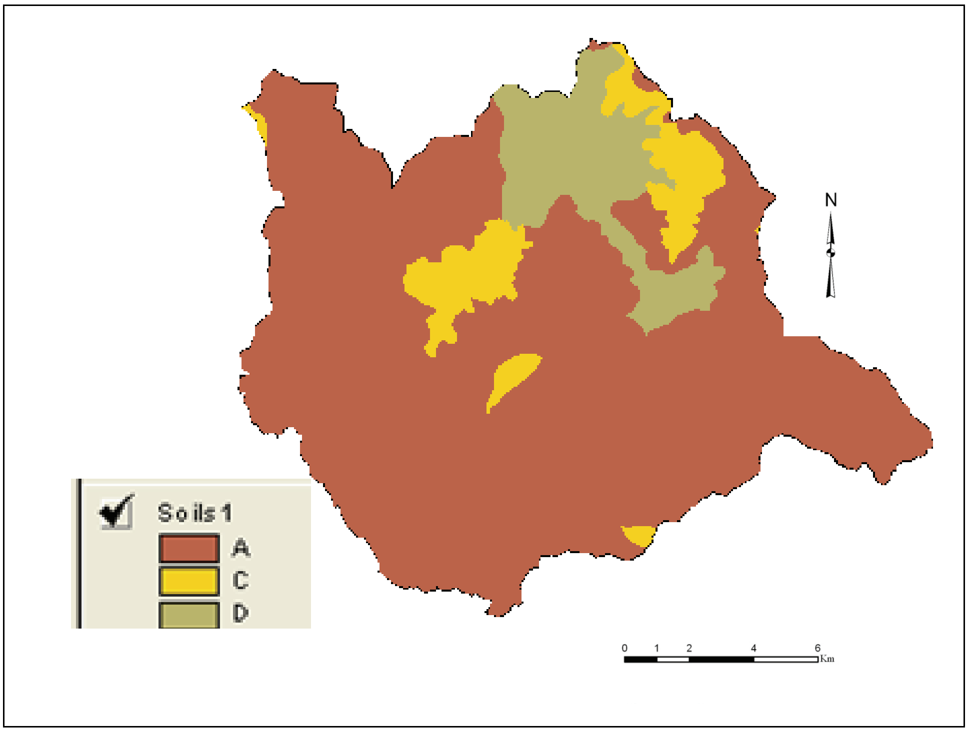


Figure 39 HSG grid for the Kuils-Eerste River Catchment.

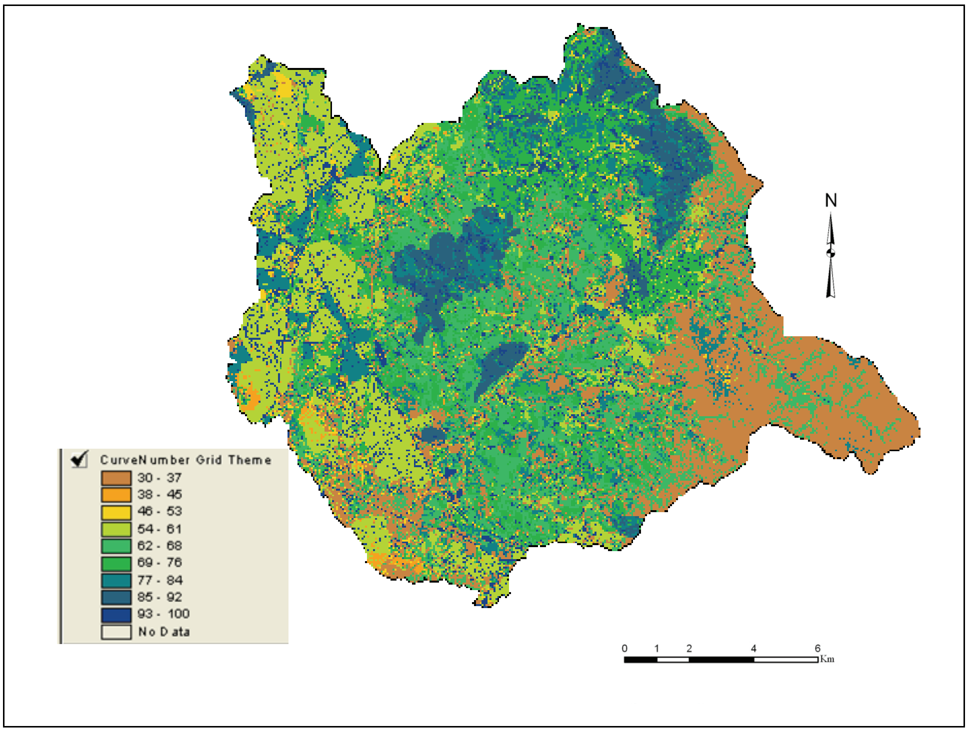


Figure 40 Curve Number (CN) Grid Theme for the whole catchment of Kuils-Eerste River.

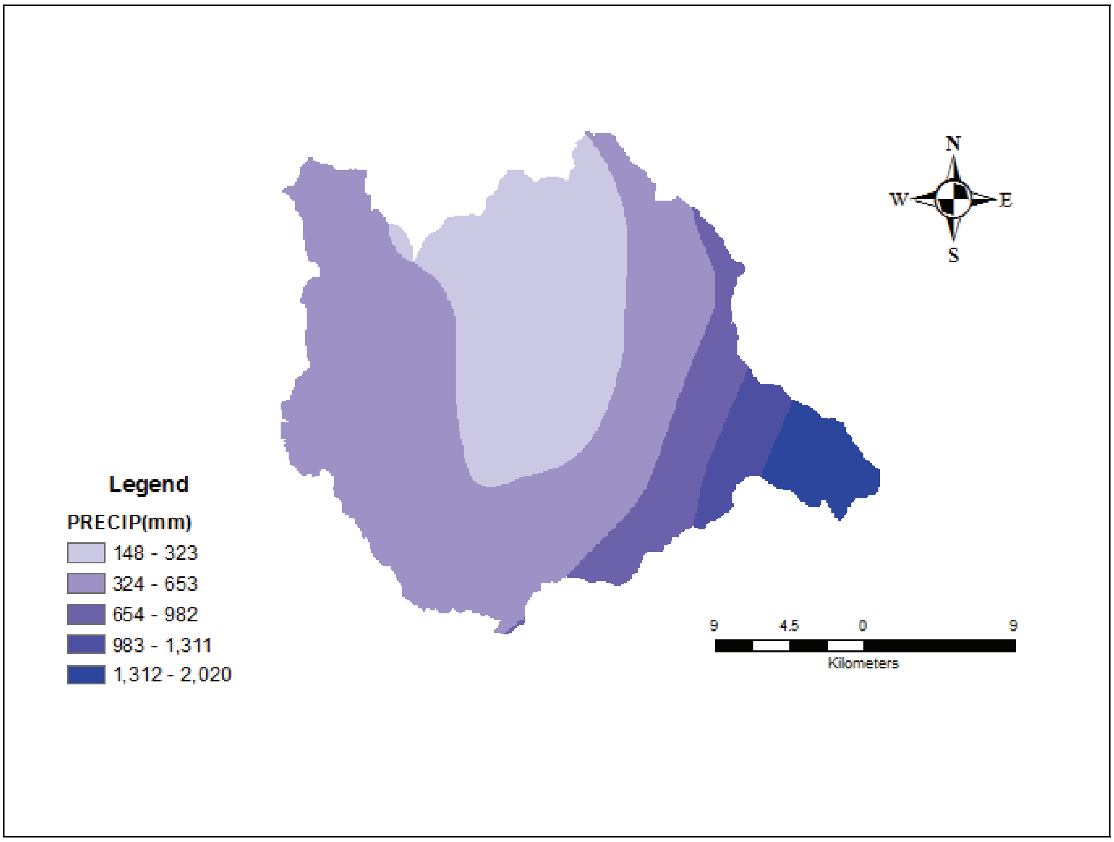


Figure 41 Precipitation 2006 grid for the Kuils-Eerste River Catchment.

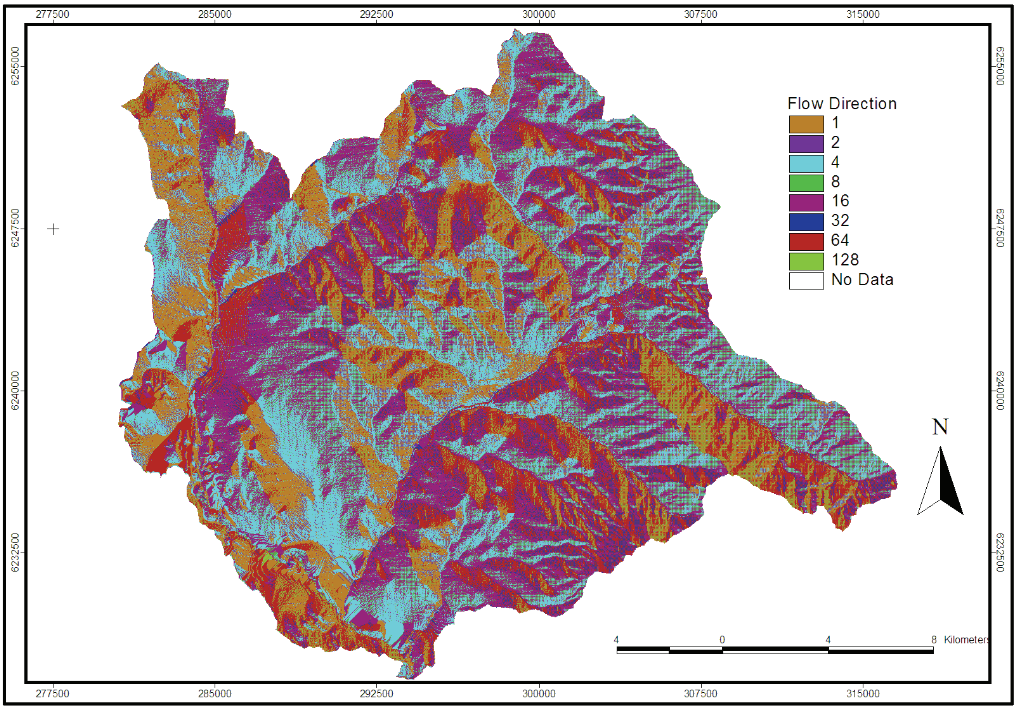


Figure 42 Flow direction grid of the catchment

The modelled flow accumulation using unit rainfall distribution shows a gradual increase from the upper reaches of the river network to the mouth of the river system with values ranging between 0 and 6252993 m^3 (Fig 43).

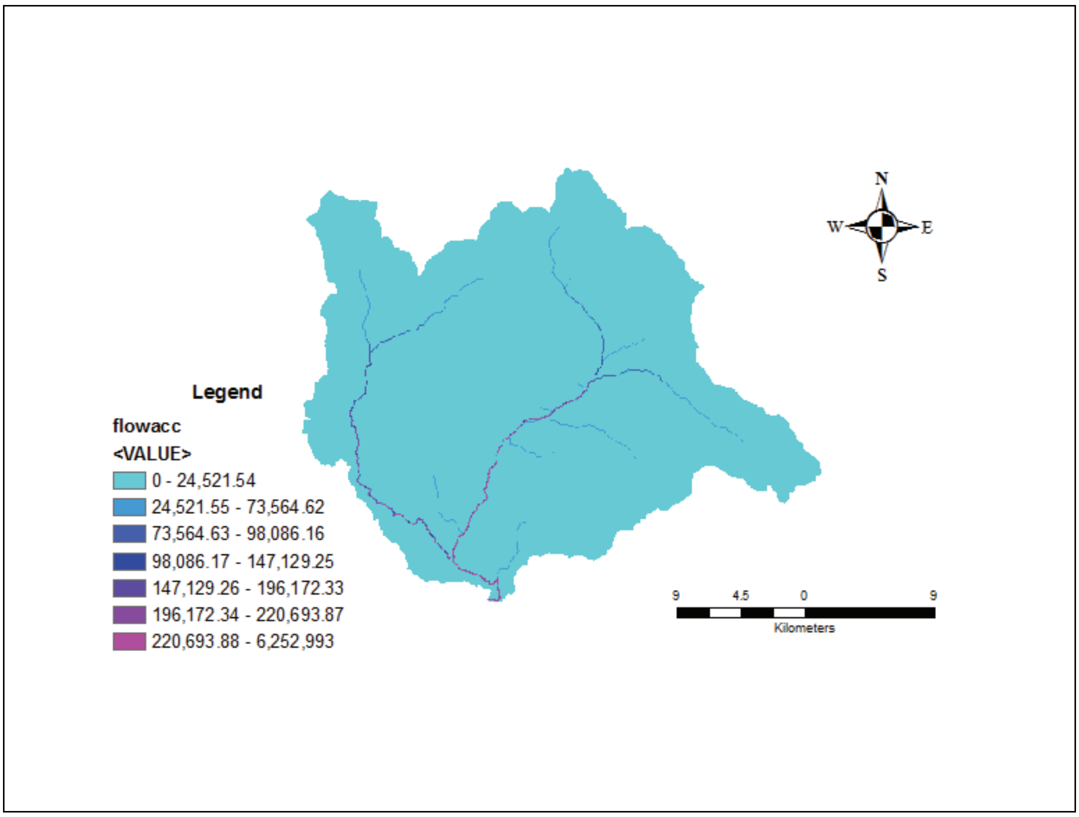


Figure 43 Flow accumulation grid for the catchment

The accumulated runoff grid generated by using the flow accumulation command on the above runoff map also shows a distribution ranging from 0 to 112489216 m^3 with higher volume values along the Eerste River as compared to the Kuils River (Fig 44).

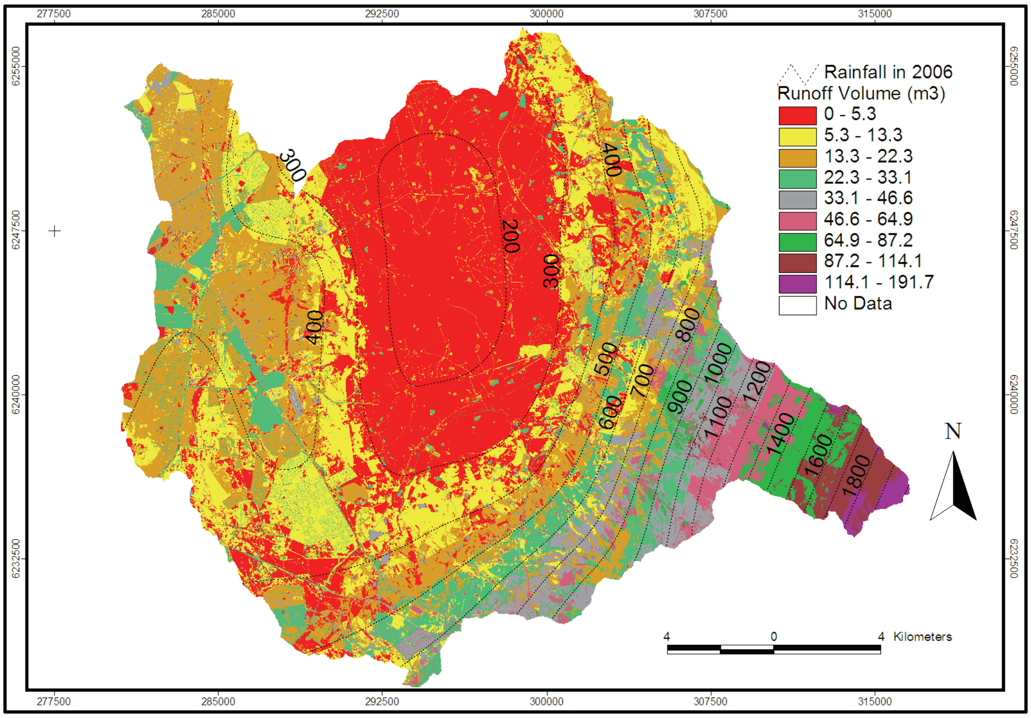


Figure 44 Runoff Volume for the Kuils-Eerste River Catchment for the year 2006.

On examining Figure 45 one can see that in general the eastern and south eastern section of the catchment has higher potential for runoff than the western and central sections of the map. In the north eastern part of the catchment soil permeability generally is less, and precipitation typically is lower. The spatial distribution of potential contributing areas within individual land cover types shows considerable variability. Land use in Kuils River catchment is predominantly urban with vineyards and grassland covering the northern section of the catchment. The spatial pattern of land use cover types varies between and within the different parts of the catchment. Potential runoff contributing areas with high percentages of vineyard and or urban land uses would be expected to have higher potential for runoff compared to similar areas with high percentages of grassland and or woodland. Implementation of BMP's in potential runoff contributing areas with high percentages of vineyards and or urban land uses is likely to be more effective at reducing runoff compared to similar areas with high percentages of grassland and woodland. The spatial distribution of potential contributing areas in combination with the superimposed land use patterns, maybe used to help identify and prioritize areas for the implementation of BMP's to reduce runoff and nonpoint source pollution propagation.

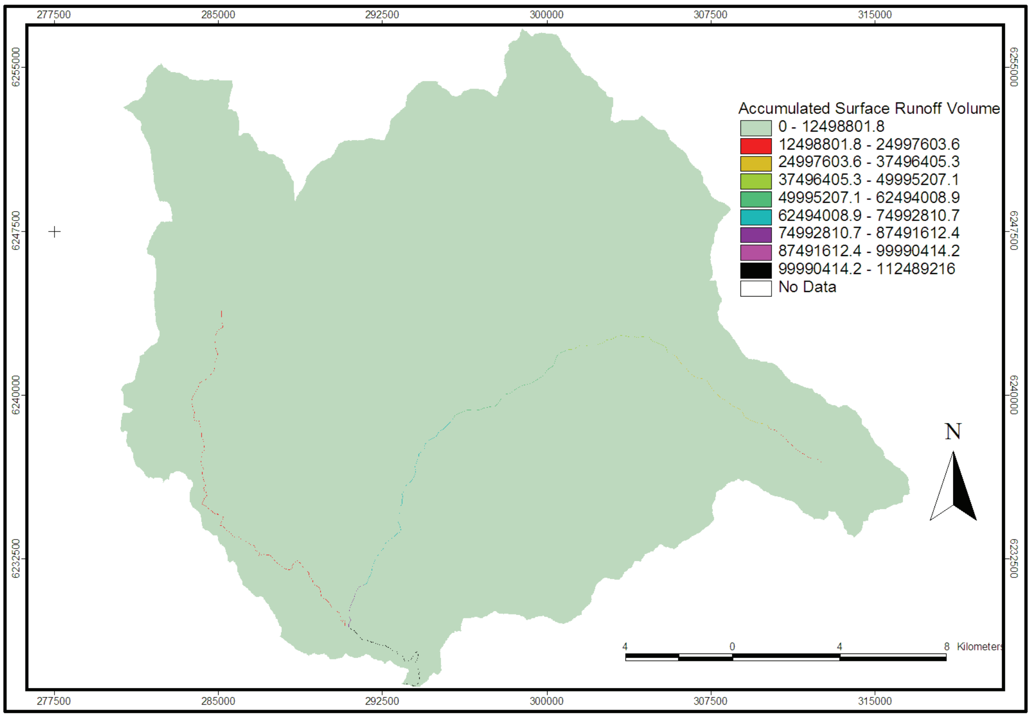


Figure 45 Accumulated surface Runoff

The model generates a table showing calculated parameters that are related to the modelling procedure of the surface runoff of the catchment. A sample of the results (Table 24) is given in this section with a complete data base Appendix1 being included at the end of the report.

Table 24 Table generated by the model showing runoff volume of the catchment

TotRain_vol	TotRunof_vol	Sum_Area	Name	RainRate.mm	RunoffRate.mm
36024519.2	14067944.9	32136900	Mountain Forest	1121	438
25506440.7	7719834.7	33063500	Riparine Forest/Natural Forest	771	233
14164218.5	3213886.9	26887200	Dense Scrub	527	120
56668865.3	21731976.6	77762400	Fynbos	729	279
5558664.5	1661096.0	11407300	Grassland	487	146
1536783.3	1061950.2	3796900	Impervious Surface	405	280
275982.7	116545.9	783200	Railway Line	352	149
1265213.3	690124.1	3340200	Water/Roads	379	207
3466860.6	3091463.0	3570100	Bare Rock	971	866
14586951.1	5702937.3	37262400	Open Vineyard/Hard Rock	391	153
4318131.4	1374997.0	10515200	Open Area/Barren Land	411	131
8641833.7	927518.3	23352300	Improved Grassland/Veg Crop	370	40
1752720.1	1273673.9	4559300	Buildings/Impervious	384	279
44438960	10642270.3	131735700	Dense / Grassy Vineyard	337	81
33253408.2	11316618.6	91687100	Fallow/Open Vineyards	363	123
951202.3	124245.7	2108600	Recreation Grass/Golf Course	451	59
174021.8	139970.5	400100	Freeways/Express Ways	435	350
921392.3	728688.3	2264500	Arterial Roads/Main Roads	407	322
7476588.7	5931501.6	18158200	Minor Roads	412	327
2163934.9	750687.9	5514600	Sandy	392	136
2630106.6	2630106.6	7254200	Waterbodies	363	363
3318067.9	1531279.3	8318500	HDR Formal Suburb	399	184
18972810.1	6744287.1	44838100	MDR Formal Suburb	423	150
4228027.9	1837179.6	8619900	LDR Formal Suburb	490	213
7344684.6	3477971.2	18835600	HDR Formal Township	390	185
1280663.4	485963.4	3384800	MDR Formal Township	378	144
9074.4	2136.1	23600	LDR Formal Township	385	91
387829.4	163979.2	986100	HDR Informal Township	393	166
304130.2	131363.1	670100	MDR Informal Township	454	196
447239.6	170070.0	1128100	MDR Informal Squatter Camps	396	151
65731.5	17978.1	165100	LDR Informal Squatter Camps	398	109
524702.6	351302.8	1236900	Commercial - Mercantile	424	284
311223.9	169115.0	877100	Commercial - Institutional	355	193
4141252.7	2498391.9	10641700	Industrial	389	235
87120.5	21668.8	209100	Cemeteries	417	104
650990.4	650990.4	1357200	River	480	480

Fig 46 shows the distribution of the accumulated nitrate across the catchment. The highest values of loads are associated with the Eerste tributary of the catchment where values are highest with a total of 3901,16 kg/year exiting the catchment

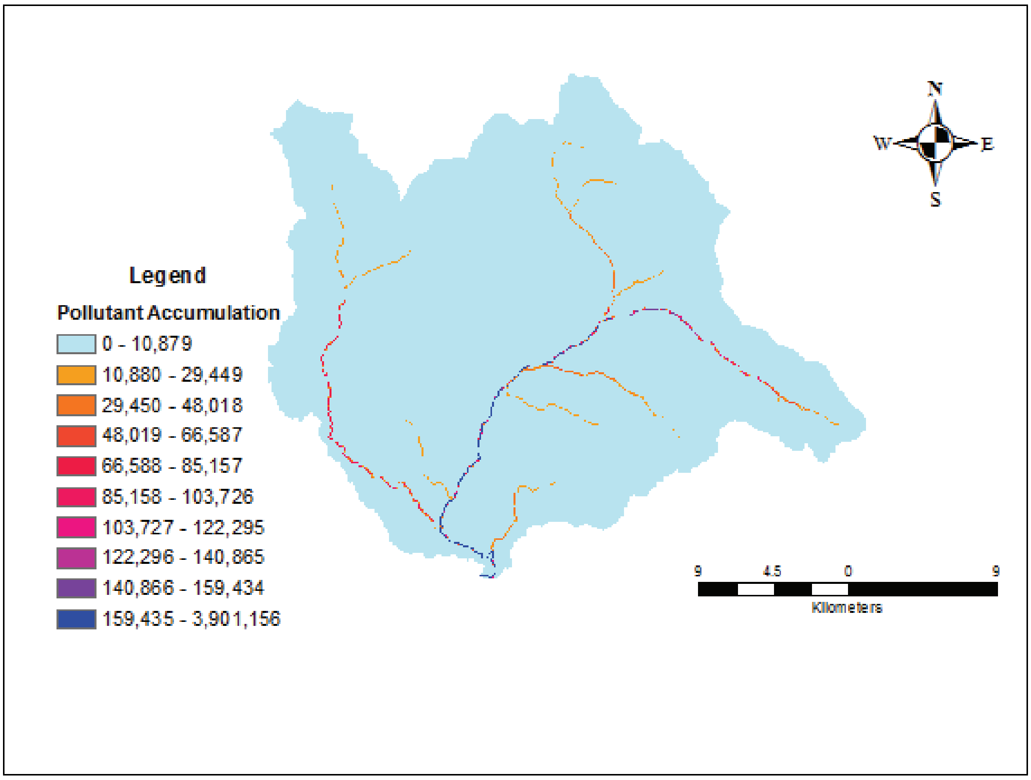


Figure 46 Nitrate accumulation in the catchment

Table 25 summarises a few selected points on the catchment showing the quantity of runoff volumes and accumulated pollutant loads estimated by the model.

Table 25 Selected points within the catchment and the values of pollutant accumulation

Watershed ID	**Precipitation (mm)**	**Runoff Accumulation (m^3)**	**Nitrate Accumulation (Kg/year)**	**Land use Code**	**Curve Number**
11992	644	12938158	22.9925808	36	100
7174	353	195566075904	327581.06	36	74
11995	No data	No data	3901155.5	No data	No data
11995	639.36	2431244304384	3900799.5	11	86
10959	489	12560079872	1971216	14	36
10958	489.7	213136.9	No data	14	36
11066	489.6	152337170432	232851.6	14	36
11989*[k]	594.51	2242040037376	3609757.25	36	100
11952*[e]	594.31	184064720896	282288.16	12	74
11987*[d]	596.16	2426390970368	3892523.75	3	73
11995		2431425183744			

Note: *k= Kuils River last grid cell into the confluence
*e= Eerste River last grid cell into the confluence
*d= Downstream last grid cell after the confluence

The result obtained from the runoff map in the last grid of the mouth of the river gave a value of the runoff as 2431425183744 m^3. Table 24, shows that there is significant variation in terms of the quantity of pollutant accumulated for the different grid cells selected.

5.10.2 Results from RINSPE model using Radar derived rainfall for the whole catchment of Kuils-Eerste River

Further modelling was done using rainfall data (Fig 27) that was acquired at a later stage and the following results were generated for the catchment. The results when compared to the first modelled results where the rain gauge based rainfall distribution gird was applied shows clearly the distribution of such runoff values is not the same

The distribution of rainfall across the catchment shows high values in the eastern part of the catchment and low values for the western section of the catchment. The data is radar derived rainfall amounts and these were interpolated with the isohyets showing the values plotted over the catchment. The highest values are registered around Jonkershoek with an annual value of 2815.2 mm. The values gradually decrease with the larger part of the catchment receiving only between 416.5 mm to 683 mm.

The rainfall distribution based on the radar derived amounts varies greatly with the one generated using the available rain gauge stations within and near the catchment described in section 6.7. It is noteworthy to mention that the radar derived rainfall amounts gives a near representation of the reality in terms of the rainfall pattern of the area.

Following the development of the rainfall grid on the basis of the radar generated values, it then was possible to model the runoff volume for the catchment using the same algorithm as described earlier though using the new rainfall grid. The results are illustrated in Fig 48 and show a distribution pattern that indicates high volumes of runoff in the eastern part of the catchment and lower values to the western side of the catchment. This follows closely on the pattern of rainfall distribution given in Fig 27. Comparatively speaking runoff volume for the two modelled scenarios shows marked differences as the first scenario registers volume that ranges between 0,086 to 135.3 m^3 against the second model results of a range between 0.1 to 268.4 m^3 (Fig 48).

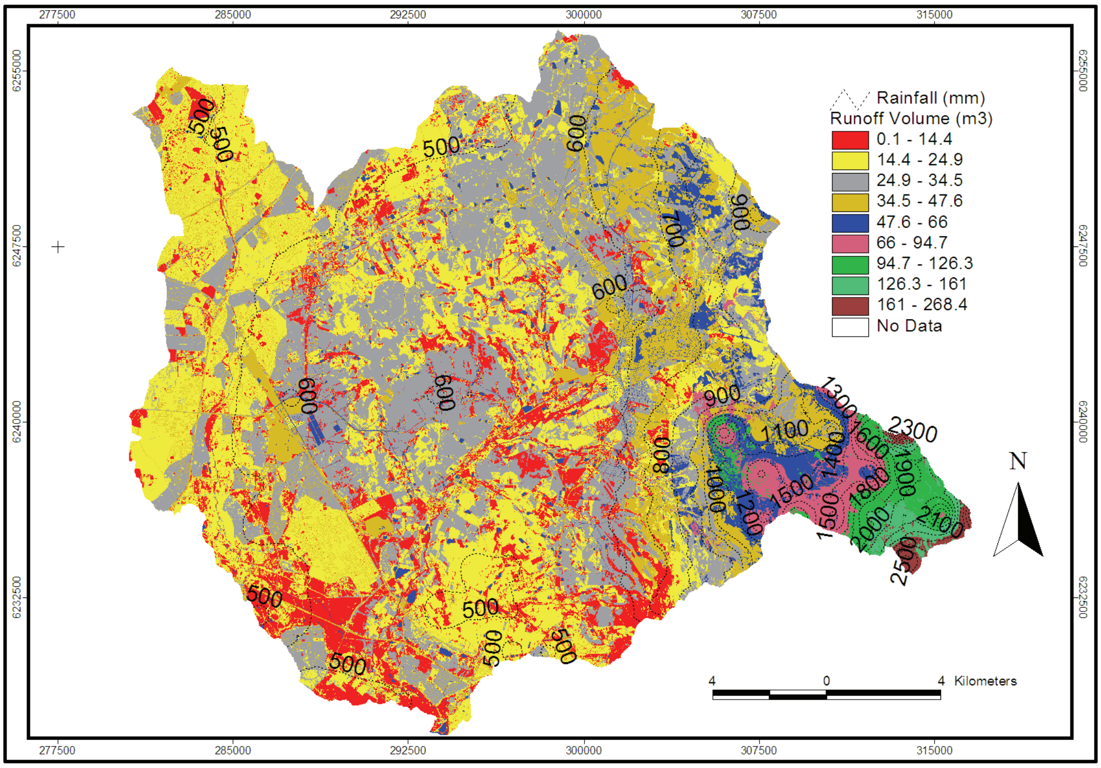


Figure 47 Surface runoff volume modelled using RINSPE model.

The accumulated surface runoff distribution map compares well to the one generated on the basis of the earlier rainfall distribution map though the values registered are different. The first map gave results that range from 0 to 2,4310m^3 as compared to the second modelling results (Fig 49) which indicates values that range between 0 and 194050864 m^3.

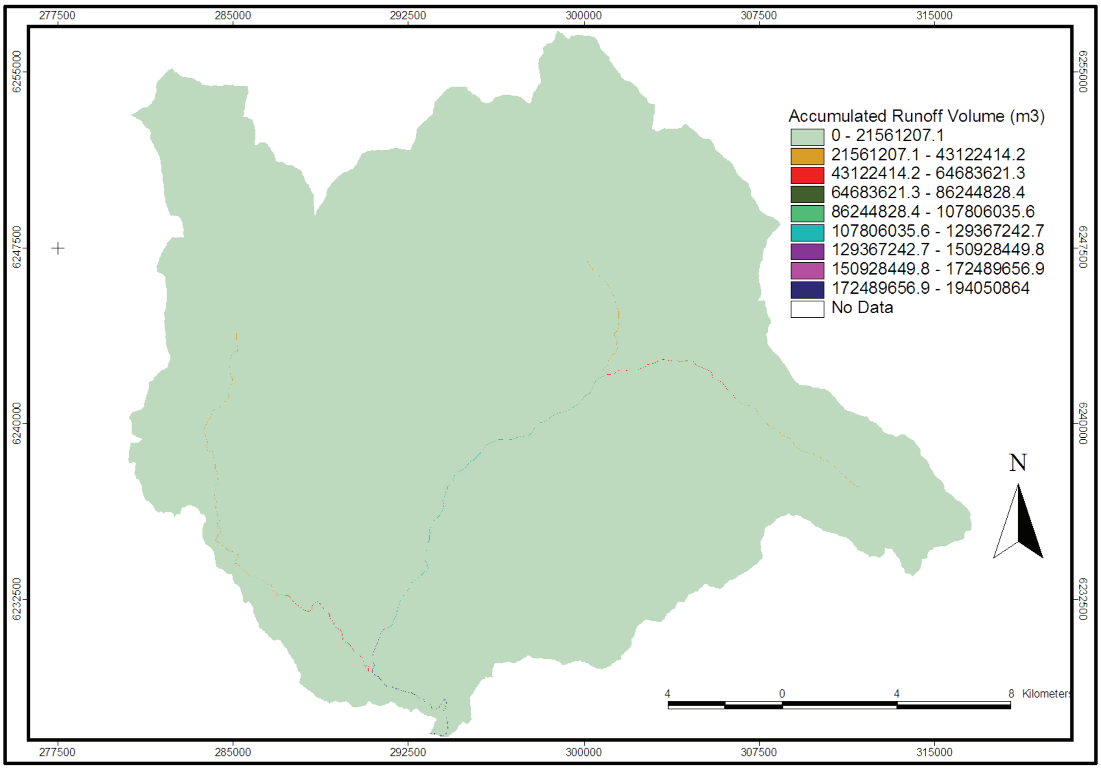


Figure 48 Accumulated surface runoff

Each land cover type was analysed in terms of the quantity of pollution it could generate given the input parameters of the model and the resultant output were specific pollutant maps showing the extent and magnitude of the phenomenon. Fig 50 shows the distribution of Nitrate mass across the catchment with the highest values being registered as 116889 mg and the lowest being 0 mg. Figure 51 shows the distribution of nitrate across the catchment. During the year the accumulated values of nitrate were also estimated using the model and the values also range from 0 to 216538.3 kg/yr.

The second pollutant to be considered is nitrogen. Nitrogen as one of the pollutants estimated using RINSPE model and shows a distribution pattern that reflects the manner in which rainfall is distributed (Fig 50). The phenomenon is spread widely though, with a higher mass in the eastern section of the catchment. The values range between 0 and 92508207.3 mg. High values are confined to the eastern part of the catchment with values as high as 92508207.3 mg. Otherwise the central part of the catchment shows values that range between 6669190.2 to 10651946.3 mg. The lowest values though occupy the area around Stellenbosch town and its environs in the eastern section of the catchment.

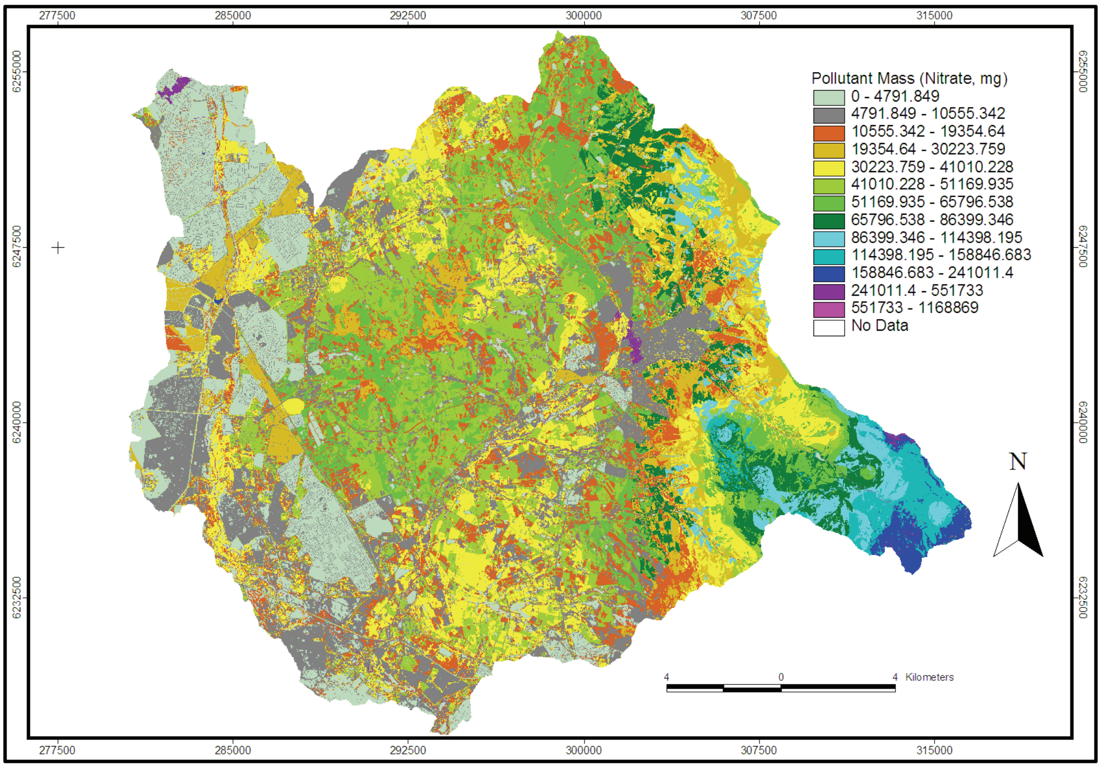


Figure 49 Nitrate mass distribution in runoff waters of the catchment

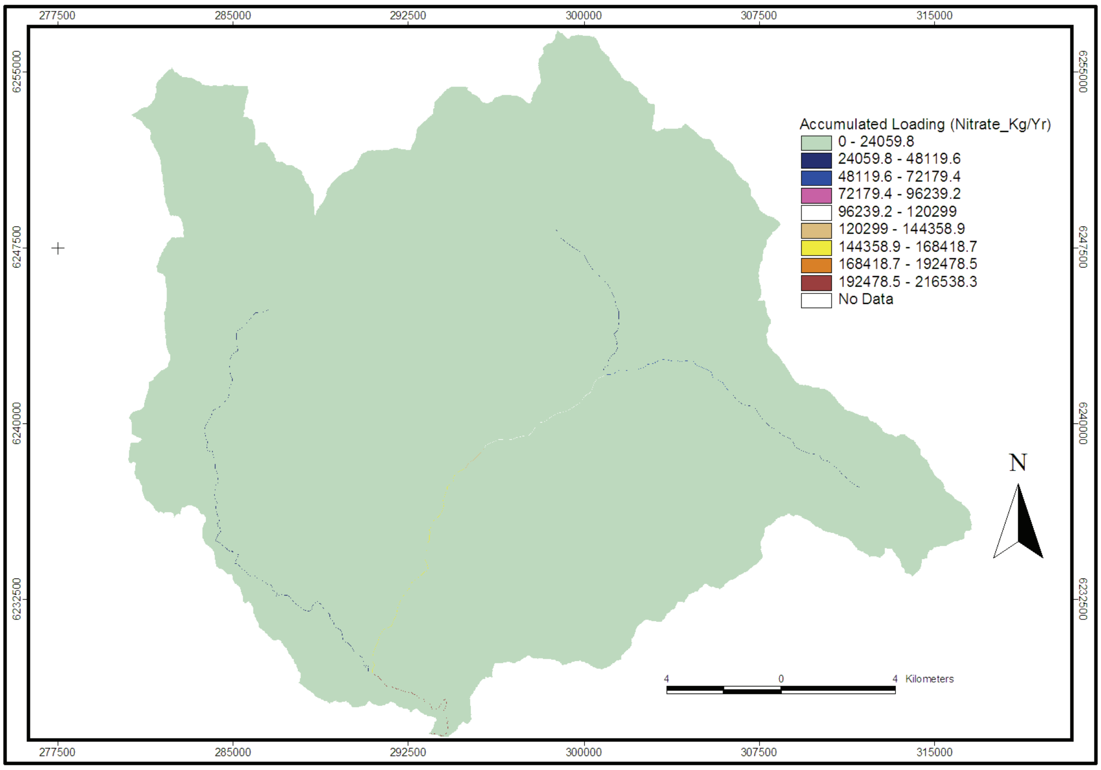
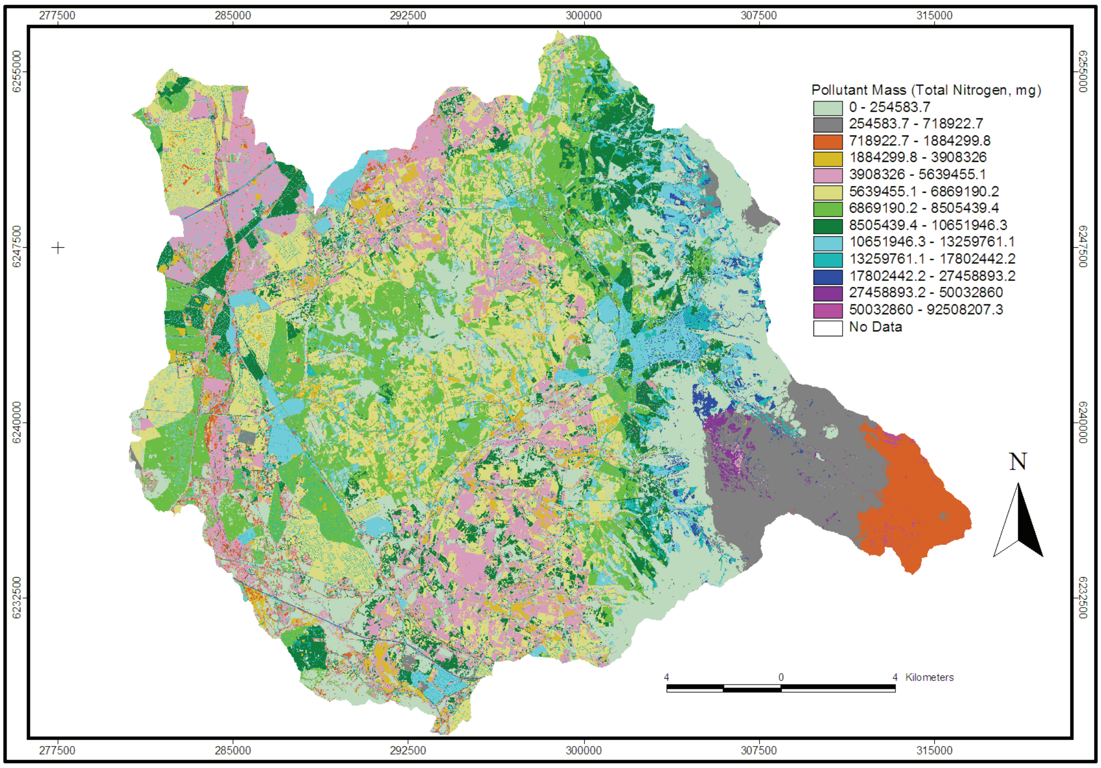
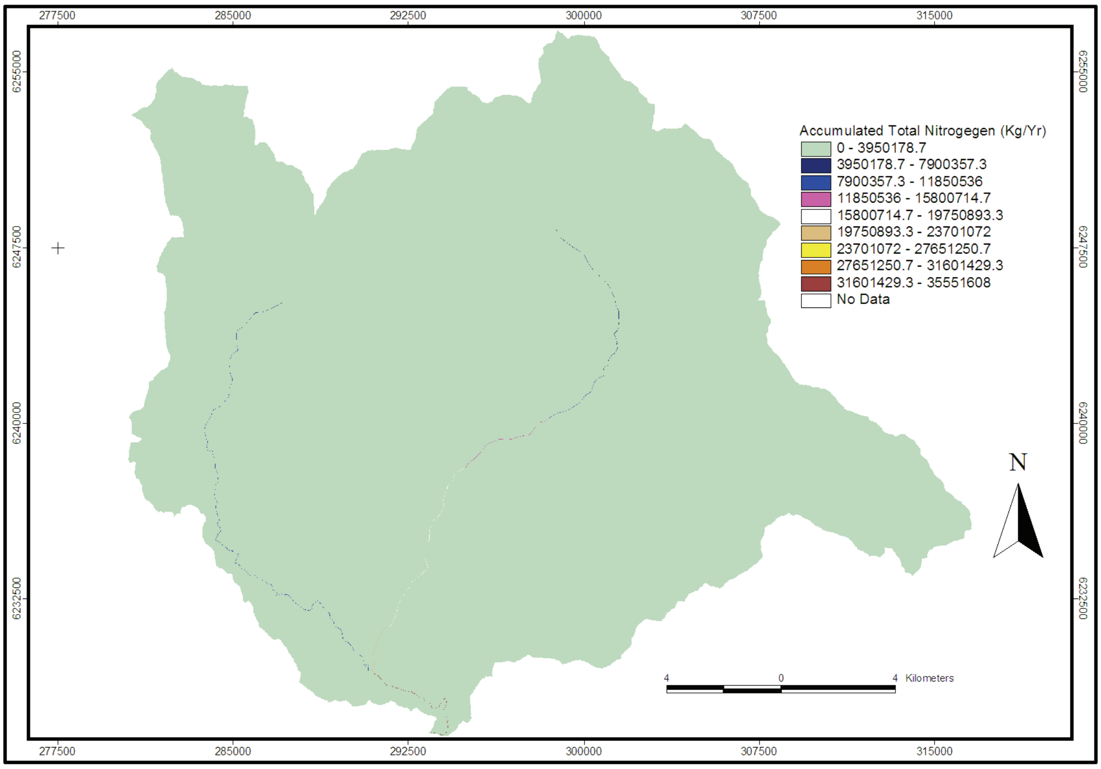


Figure 50 Accumulated Nitrate mass distribution



(a)



(b)

Figure 51 Distribution of Total (a) and accumulated (b) nitrogen in runoff waters in the catchment

The distribution of nitrogen along the river also shows a pattern that increases in value from source to mouth. The high loads of nitrogen in the river are observed after the confluence of the two rivers, Kuils and Eerste where the values range between 31601429.3 to 3551608 Kg/Y^{-1}.

Like the other pollutants, phosphorus distribution in surface runoff varies across the catchment, with the central region and western part of the catchment showing values that range between 3908326 mg to 8505439.4 mg. interestingly; the lowest values are registered in the Stellenbosch area Fig 53.

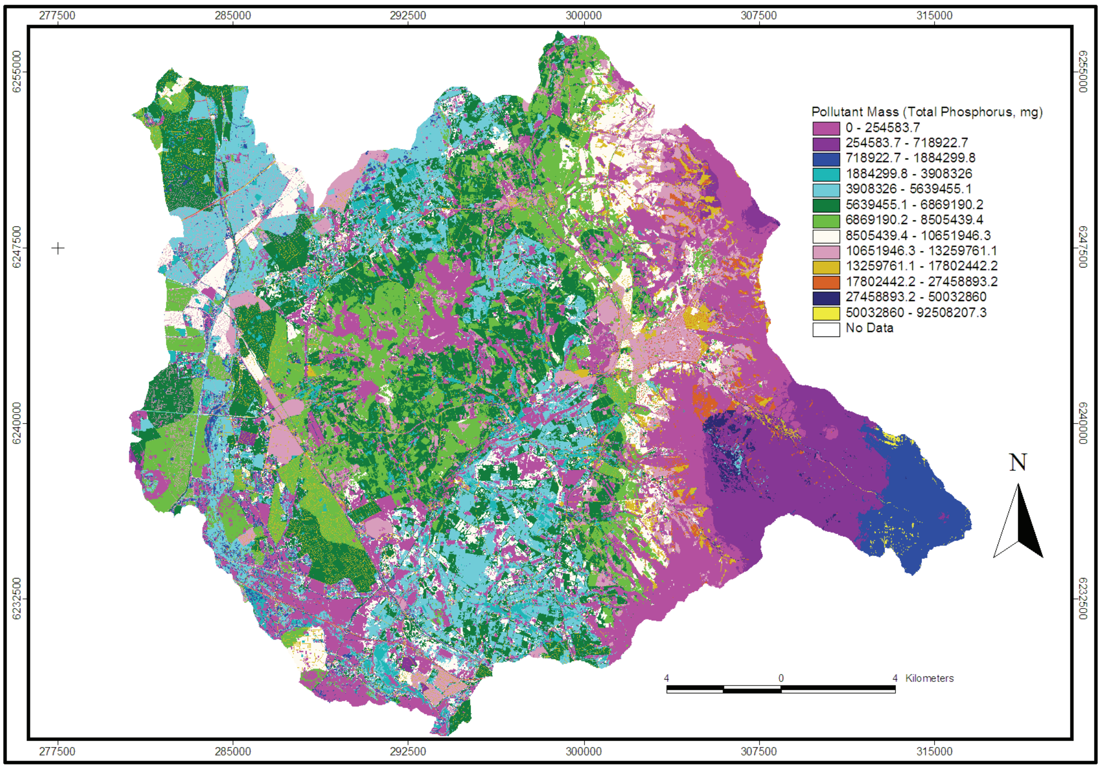


Figure 52 Phosphorous distribution in runoff waters in the catchment

Figure 54 shows the phosphorus load in the runoff waters of the catchment with values ranging between 0 Kg/Yr to 190723.1 Kg/Yr.

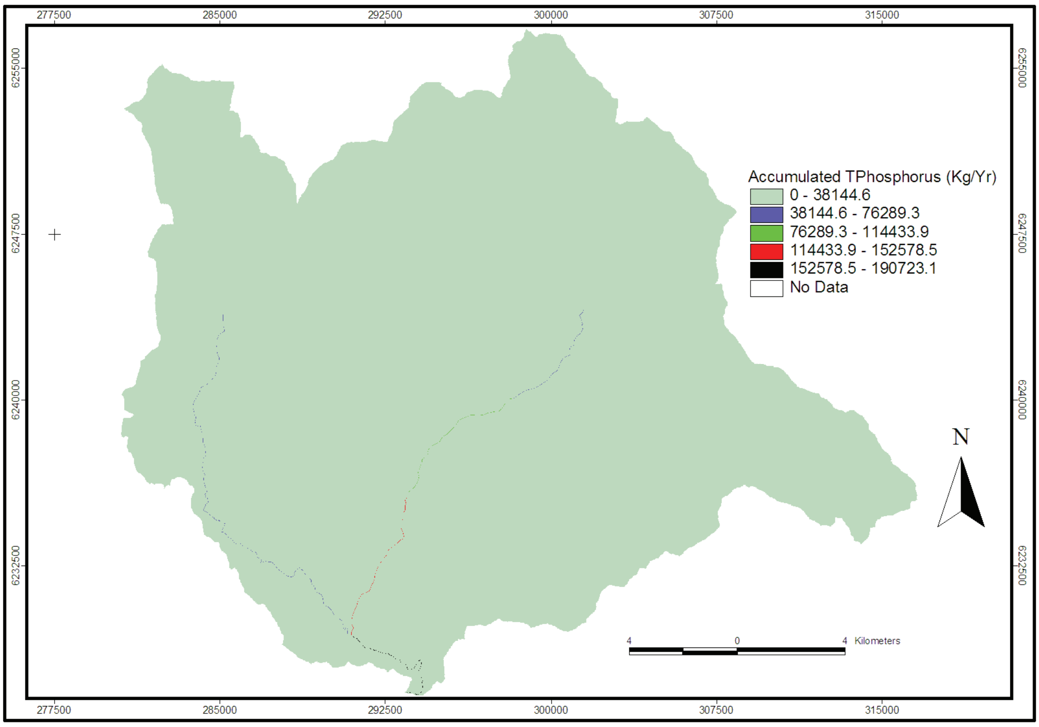


Figure 53 Phosphorus load in the runoff waters of the catchment

Chloride distribution in runoff waters is represented in Fig 55 and it shows that there are two prominent areas that show values ranging between 491223.5 mg to 782912 mg.

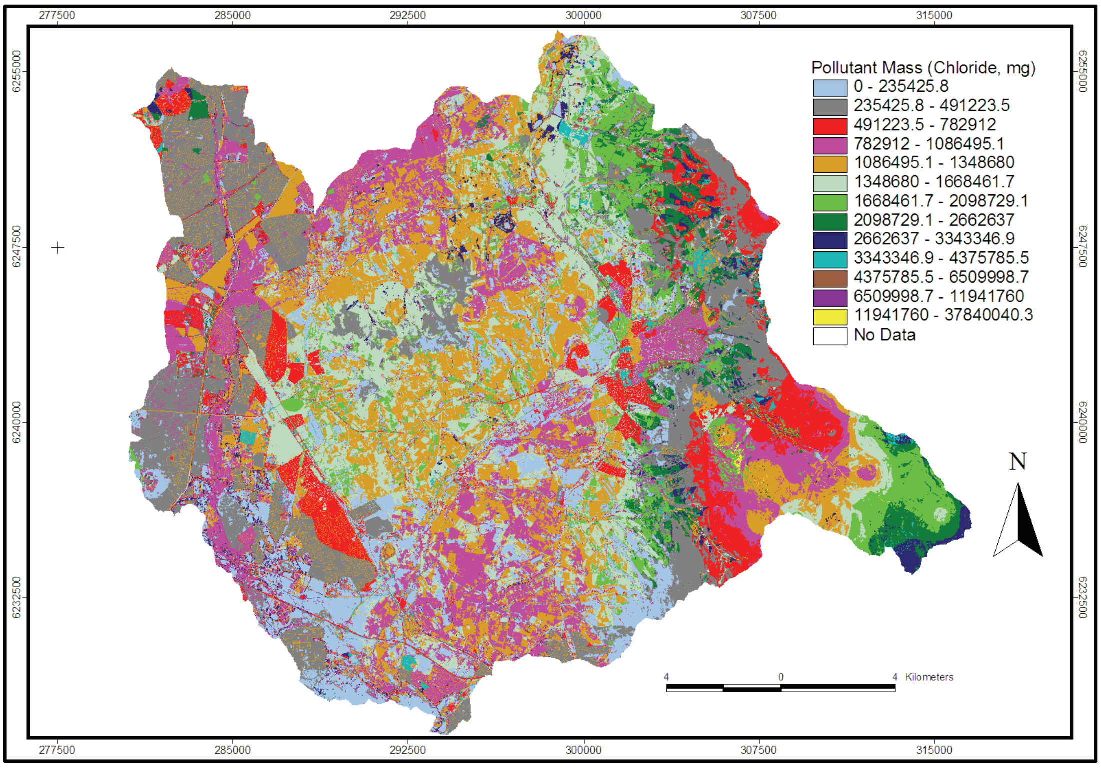


Figure 54 Chloride mass distribution in runoff waters of the catchment

The accumulated value of chloride in the runoff waters (Fig 56) shows that, close to the confluence of the two rivers, the value ranges between 4552322 Kg/Y^{-1} to 5690402.5 kg/Y^{-1} and drop immediately after the confluence, probably due to dilution from the Kuils River contribution.

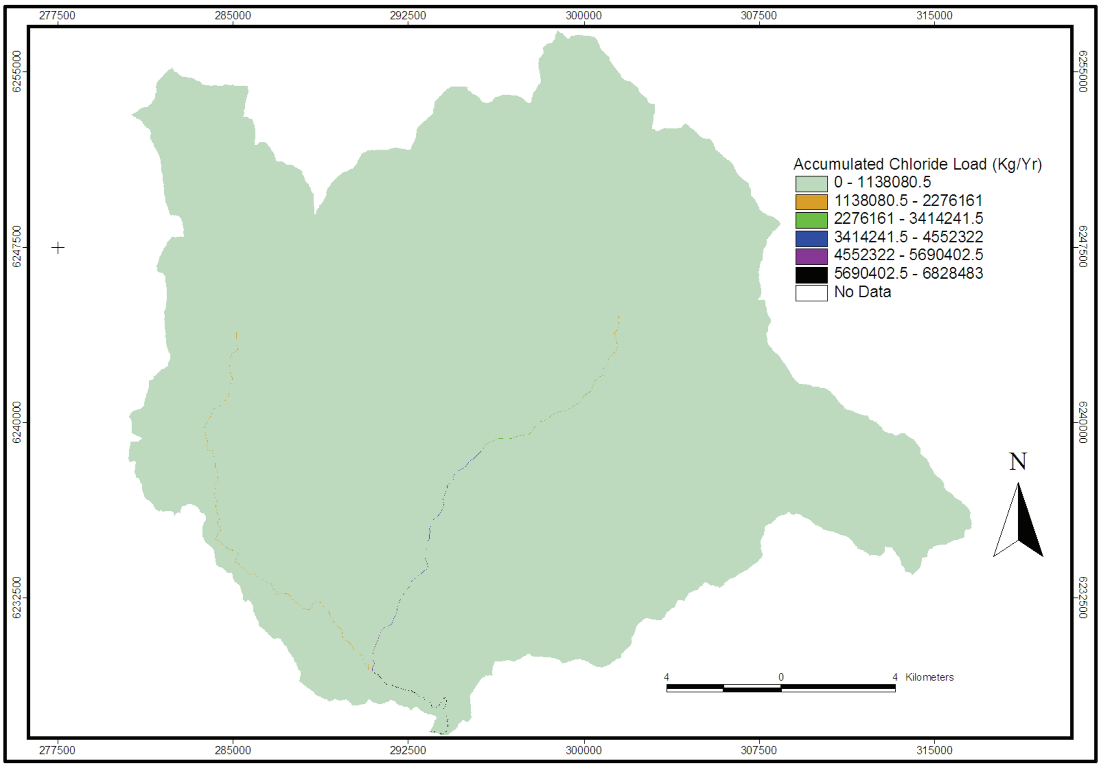


Figure 55 Accumulated chloride in the runoff waters of the catchment

Figure 57 shows the distribution of total Suspended Solids (TSS) across the catchment and the area that draws one's attention mostly is the central region where the values recorded range between 1338392 mg to 4326692.4 mg. the rest of the catchment in terms of areal distribution shows smaller areas as having concentrations especially the eastern tip of the catchment which registers the highest vales ranging between 25460264.2 mg to 38026132.8 mg

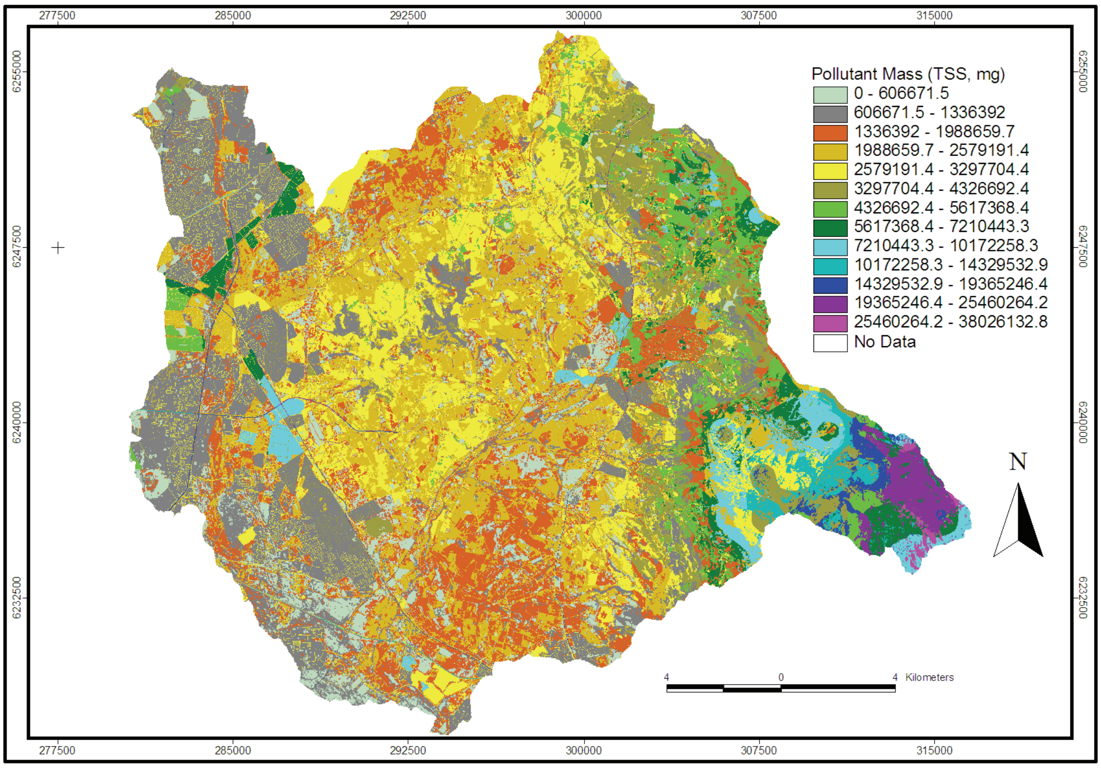


Figure 56 TSS distribution in Runoff waters of the catchment

The accumulated TSS values increases immediately from the 9442428 Kg/Y^{-1} along Eerste River to 16524249 Kg/Y^{-1} at the confluence with Kuils River. The contribution from the Kuils River appears to be constant along the greater part of the river until the confluence. The total load registered for the catchment is 18884856 Kg/Y^{-1}.

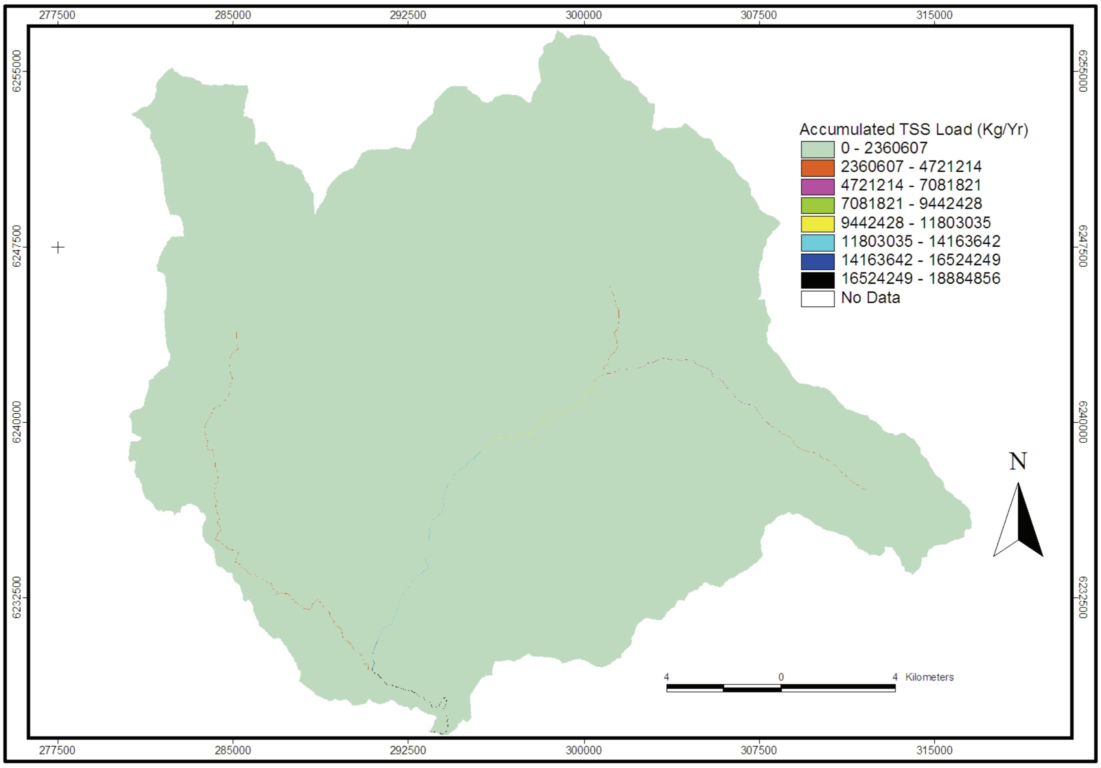


Figure 57Accumulated TSS in runoff waters of the catchment

5.11 Other Applications or Uses of RINPSE Model

The developed models can be used for predicting the net change in surface runoff and pollutant distribution due to change in rainfall amount (e.g. climate change), construction of "permeable pavements", and change in land use. Urban cover permeability alteration is achieved by either increasing the amount of paved areas (concrete or asphalt cover) or by replacing the paved areas by materials, which allow more infiltration of rainwater, for example bricks. Increasing the permeability of the paved areas is useful in helping to reduce peak flow rates in the drainage systems. Land use change in urban areas occurs for example due to increasing demand for housing facilities. Examples of land use changes are conversion of agriculture areas to residential area or erection of more residential buildings in open areas or low-density residential areas.

The developed model can be used to model surface runoff and pollutant distribution over a given period of time (e.g. 2007-2008) in an urban area provided all the input data are available for the period chosen for modelling. Current land use and the typical concentration associated with each land use would be quite different. However the geology, and hence the HSG would be the same. The rainfall data for a period back in time might be available however EMC data may well not be available.

Nonpoint source pollution aspects related to contaminated land cover types were covered in the study conducted at UWC. Consequently, the RINPSE model could be used to estimate the pollutant loading from the contaminated land cover types. In principle, the model runs in pollution assessment mode, can be repeatedly run with input parameters sampled from user-defined land cover type variations and rainfall variations, in order to obtain an idea of the likely surface runoff pollution distributions. However, this requires necessary data input and reliable computer resources.

A model run with a uniform EMC across the area would quickly indicate the vulnerable land cover types in the catchment, and hence be of some use for environmental management and planning. The result is used to compare the output of the model and more standard approaches and in establishing the levels and magnitude of pollution as per land cover type within the catchment.

Although the model is primarily developed for the Kuils-Eerste River catchment, it can also be extended to other similar developing cities in Southern Africa or anywhere in the world, provided all the basic inputs (mainly land use, hydrologic soil group, surface elevation (DEM grid), rainfall data, and EMC values of the surface water) are available. In particular, Cape Town has many similarities to a number of African cities in their basic land use description. In some respects Cape Town is similar to all other cities in South Africa, and therefore the developed method could be applied or used where the basic inputs of land use, soils, rainfall data, EMC values, surface elevation (DEM), are available.

5.12 Major Limitations of the RINPSE Model

Although the RINPSE model is not very sophisticated, it does take into account the principal processes involved, and as it is incorporated in a GIS environment, it allows for the complexities of spatial heterogeneity to be investigated. A major limitation is in the way that time is dealt with. It is assumed that land use and land use-related properties do not vary within the 'time-slice' or period being considered by the model. Annual rainfall estimations are undertaken, and summed over the user-specified period. Within this period, steady-state conditions are assumed for the movement of water and pollutants over the surface.

In nonpoint source pollution assessment, all units of the same land use type are assumed to have the same Event Mean Concentrations (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 a number of factors. From the variations of the topography and land cover types to soils and rainfall amounts, release of the pollution into surface water is possible due to present human activities e.g. accumulation of waste material, agricultural activity, industrial activity and or residential zone type.

5.13 Prediction Accuracy

The different sub models in RINPSE make use of many input parameters (both spatial and non-spatial data) and the accuracy of their predictions is dependent on the assumptions made in each sub model and the accuracy of the input data used.

5.14 Uncertainty Aspects

Environmental models are simplified representations of systems in reality, and uncertainty is always associated with their representations. In many cases the systems, especially urban hydrologic systems, are heterogeneous, where a wide range of parameters with a wide range of possible values for them control the complex behaviour of the system. In the case of surface runoff and pollutant transport simulations of urban environments, the hydraulic and transport parameters are never known in sufficient detail. If the input parameters, used in the present GIS based urban pollutant estimation models, are based on literature based typical inputs, the predictive runs and the results obtained from them are subject to much uncertainty in relation to the complex heterogeneity of the urban system being modelled. There may be additional uncertainty relating to whether the conceptual model with simplified analytical equations is fully applicable to the field situation in an urban area.

5.15 Model Running Issues

The simulation of the fate and transport of pollutants in the NPS pollution model involves combining of five grids into a single grid. The input grids needed are the following: DEM grid, land use grid, rainfall grid, soils grid, and EMC values. After combing these grids, the value fields of respective grids are queried and text values of land use types, soil type names and rainfall are assigned to the combined grid. This grid combining, querying grid codes and assigning of various text attributes, takes time and the speed of completion of these tasks really depends on the processor speed of the computer.

5.16 Summary and Conclusions

Estimation of infiltration, runoff and nonpoint source pollutant is challenging because of the complexity of urban hydrogeological systems and is a complex spatial environmental problem. GIS is an appropriate tool for such environmental analysis. The urban surface runoff (being spatially variable), the best way to model them is through an integrated modelling approach involving use and analysis of various thematic data (aerial photographs, satellite imagery and various vector and raster maps) and other attribute information within a Geographic Information System. An ArcView GIS based methodology developed herein can provide reasonable estimates of infiltration, runoff and pollutant loads in urbanizing catchments. This study could develop a GIS based urbanizing catchment and pollution source distribution model and a GIS based runoff model for selected pollutants viz. nitrate, chloride nitrogen, phosphorous and total suspended solids.

The model described herein has attempted to address the process of infiltration; runoff and pollutant loading from different land cover types of an urbanizing catchment. It essentially combines the normally separated disciplines of contaminant water quality and water resources hydrology, examining catchment scale contaminant issues in urbanizing areas. The model presented is an abstraction of reality, so errors will always be present. However, the model provides a way to better understand a problem and to test alternatives. Using the above methodology, clearly, it was not possible to develop a definitive representation of urban runoff processes, but a framework was set up, which will allow investigation of the main issues. With this initial framework, it will be possible and appropriate for progressive upgrading in future studies. This model can provide information on the quantity and quality of surface runoff, potentially of South Africa to help the various administrative bodies in formulating decisions on the management of urban stormwater. It can also be used to identify the risks of stormwater on a regional scale.

Digital topographic, soil and land use cover type information was used to estimate runoff in the catchment. Rainfall data and soil infiltration values and initial abstraction values were used to represent the threshold conditions at which infiltration- excess overland flow may occur. The potential contributing areas for infiltration excess and saturation excess overland flows provide understanding of how spatial distribution of such areas may change in response to change in environmental conditions. Under low potential runoff conditions characterised by low antecedent soil moisture and low rainfall intensity, potential contributing areas for infiltration excess and saturation excess overland flows are limited to areas of lower soil permeability and saturated areas adjacent to rivers and streams, respectively. As antecedent soil water and rainfall intensity increase, the spatial distribution of the contributing areas increases for both infiltration excess and saturation excess overland flows. Under high potential runoff conditions, characterised by high antecedent soil moisture and high rainfall intensity, the distinction between infiltration excess and saturation excess overland flow, becomes less meaningful as the ground becomes increasingly saturated and the potential contributing areas for both runoff processes coalesce.

These results obtained from the model runs has some limitations in that the potential runoff contributing areas may over or under estimate actual contributing areas for a particular location and precipitation event. A number of factors account for the differences between potential and actual contributing areas, which include vegetation (type and density), soil compaction, impervious surfaces, and climatic variability. Such factors were not addressed in this report.

6 MODELLING OF NPS POLLUTION USING N-SPECT

6.1 Introduction

In recognition of the importance of NPS pollution in degrading the quality of the nation's water resources, a number of models have been developed that simulate the production, transport and the fate of NPS pollutants. These models help assess the environmental impacts of sediments, nutrients and chemical pollutants on surface water quality. Though some of these models are capable of simulating pollution production over a long period of time, efficient application of these models could be restricted to event specific pollution assessment because, data required for long term simulations are highly complex. But this direction of development is problematic as water quality management assessment requires the understanding and modelling of the long-term impacts. In a comparison between a simple and a complex model, Chandler (1994) justified that both simple and complex models could be applicable in modelling of non-point source load estimates although complex models do have a slight quantitative quality advantage over simple models. However, the use of simple models was more justified when it comes to estimating pollutant loads for long time scales (e.g. monthly or annual scales). For this study, a simple model has been selected since both monthly and annual loads as well as event based estimates were ear-marked to be estimated for the catchment.

NPS pollution has geospatial characteristics because potential pollution production varies with land use characteristics (Ventura and Kim, 1993; Novotny and Olem, 1994; Bhaduri et al., 2000) and at the same time, pollution generation is greatly influenced by prevailing hydrologic and meteorological properties of the watershed (Gilliland and Baxter-Potter, 1987, Bhaduri et al., 2000). GIS on the other hand, is a powerful and time efficient tool that can provide the suitable platform to create and manage data sets required as inputs of hydrologic/water quality models (Tim et al., 1992; Novotny and Olem, 1994; Adamus and Bergman, 1995; Bhaduri et al., 2000). Therefore, integrating GIS and NPS pollution modelling in environmental and resource management, would identify environmentally sensitive areas in terms of NPS pollution potential based on the model results, produce useful information on changes in water quality following implementation of pollution reduction approaches, evaluate alternative management strategies and improve NPS pollution control in a cost effective manner (Gilliland and Baxter-Potter, 1987; Tim et al., 1992; Ventura and Kim, 1993; Adamus and Bergman, 1995; Bhaduri et al., 2000).

6.2 Overview of the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) Model

The Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT), was originally developed by the NOAA Coastal Services Center to accompany the Waianae Ecological Characterization. The tool is an extension to ESRI's ArcGIS software package and it can be used to examine relationships between land cover, Nonpoint source pollution, and erosion. N-SPECT is useful for understanding and predicting the impacts of management decisions on water quality, and, potentially, on coral health. It allows the user to investigate the impact of land use change on storm water runoff and water quality, in general. The tool 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.

6.2.1 The N-SPECT Model setup

N-SPECT is delivered free with data sets specific to the Wai'anae region of Oahu, and very little user interaction is required to run a basic analysis for this area. However, applying the tool in other regions requires the specific attention in preparing the appropriate input data such as:

- Digital elevation model (DEM)
- Land cover grid
- Rainfall grid
- Soils shapefile
- R-factor grid (annual erosion)
- Local pollutant coefficients
- Water quality standards

Many of the grids driving N-SPECT's functionality are derived from the DEM and for this reason; it is perhaps the most important amongst the data sets. N-SPECT automatically sets the raster analysis environment to the cell size and boundary parameters of the DEM file. This is an important step because it ensures that all grids produced have the same cell size, spatial reference, and extent. Otherwise, the cells of input and output grids may or may not overlay properly.

6.2.2 Runoff Estimation in N-SPECT Model

The following section discusses the general principles that are used in N-SPECT to calculate or estimate runoff depth and runoff volume. There is no user interface within N-SPECT that is directly related to the estimation of runoff; these calculations are the basis of many of the other N-SPECT functions and processes. N-SPECT uses the USDA NRCS Curve Number method (USDA, 1986) as the basis for its runoff estimation. The Curve Number (CN) method is an empirical set of relationships between rainfall, land use characteristics, and runoff depth. CN values range from 0 to 100, and these represent land surface conditions. In other words, they are a function of land use, hydrologic soil group (or soil permeability) and the antecedent moisture condition (USDA, 1986). Retentions, initial abstraction (I_a), and runoff depth (Q) are all derived according to equations 7.3, 7.4, 7.5 and 7.6:

$$Q = \frac{(P - Ia)^2}{[(P - Ia) + S]} \qquad \text{Equation 6.1}$$

$$Ia = 0.2 * S \qquad \text{Equation 6.2}$$

$$S = \frac{254000}{CN} - 254 \qquad \text{Equation 6.3}$$

Therefore,

$$Q = \frac{(P - 0.2S)^2}{[(P + 0.8S) - 254)]}$$ Equation 6.4

Where:

Q	=	Runoff depth (mm)
P	=	Precipitation or rainfall depth (mm)
S	=	Potential maximum retention after runoff begins (mm)
Ia	=	Initial abstraction (mm)
CN	=	Runoff curve number

When the initial abstraction at a given cell is greater than the rainfall at that cell ($P \leq 0.2$ S), N-SPECT sets runoff depth to zero, i.e. if ($P - I_a$) = 0, then Q = 0. This prevents the reintroduction of no data cells to the runoff analysis output grid. Originally, specific retention S, is represented as [(1000/CN) – 10] when S, P, and Q are expressed in inches. Alternatively, S, P and Q may also be expressed in SI metric units. The expression for specific retention (S) is given as [(254000/CN) – 254] in Equation 7.6 above.

Figure 59 represents an overview of the runoff estimation process resulting in three sets of data at the end of the runoff calculation process. These are runoff volume, runoff depth and runoff curve number. The last two data sets are temporary data that are produced in the process but are not reported by N-SPECT as layers whereas the runoff volume grid is used as an input to the calculation pollutant concentration in N-SPECT.

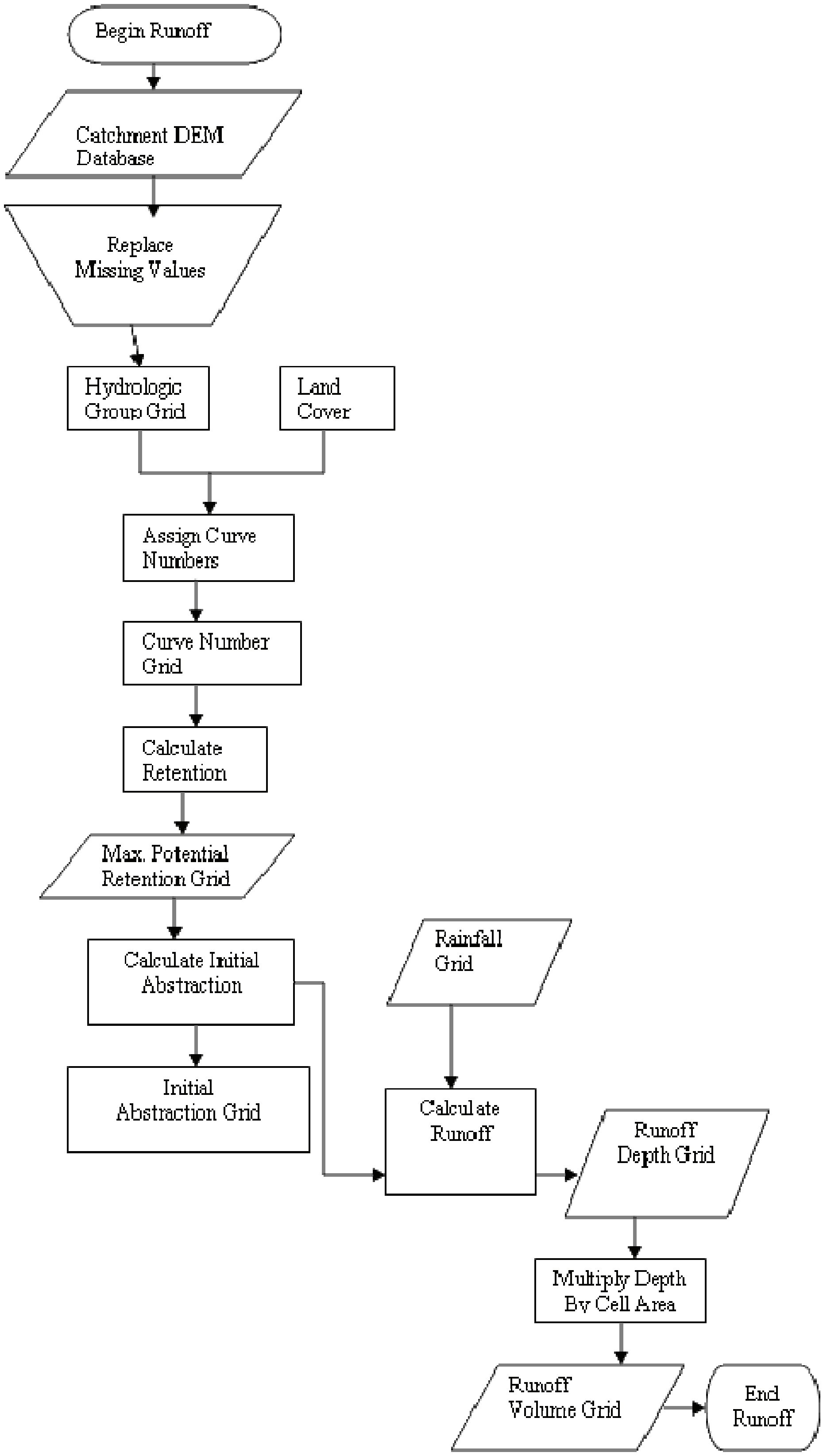


Figure 58 An overview of the runoff estimation process. (Source: N-SPECT Technical Guide, 2004).

6.2.3 Calculating Runoff in N-SPECT Model

This section of the model description defines the processes that occur behind the scenes when N-SPECT estimates runoff depth and volume.

Step 1: Create the Curve Number Grid
Runoff curve numbers were developed by NRCS based on soil properties and represent overall permeability. This number varies from 0 (100 per cent rainfall infiltration) to 100 (0 per cent infiltration— i.e. pavement) and is used to estimate runoff depth. N-SPECT generates a curve number grid based on the combination of land cover and hydrologic soil group at each cell within a given analysis area.

Step 2: Calculate Maximum Potential Retention
Retention represents the ability of the soil to absorb or retain moisture. Precipitation that is absorbed or retained by the soil does not contribute to runoff. N-SPECT calculates retention at each grid cell as shown in Equation 7.7 below:

Retention = $\dfrac{254000}{CurveNumber} - 254$ Equation 6.5

Step 3: Calculate Initial Abstraction
Abstraction refers to the losses that occur before runoff begins. This can include water stored by surface depressions and water intercepted by vegetation, evaporation, and initial infiltration. N-SPECT calculates abstraction at each grid cell as shown in equation 7.8. The units associated with the abstraction grid are millimetres.

Abstraction = $(0.2 * \mathrm{Re}tention)$ Equation 6.6

Step 4: Precipitation Grid
The next step is to either choose a pre-existing input precipitation grid or create a new precipitation grid using a Geographic Information System (GIS). This grid is assigned units in millimetres, as the Technical Release 55 equation for estimating runoff assumes precipitation inputs are in millimetres.

Step 5: Calculate Runoff
Event-based runoff depth is estimated according to Equation 7.9 taken directly from Technical Release 55:

Runoff Depth = $\dfrac{\textbf{(Rainfall – Abstraction)}^{2}}{\textbf{(Rainfall – Abstraction) +Retention}}$ Equation 6.7

N-SPECT checks for instances where abstraction is greater than rainfall and sets runoff to zero. This method is designed for average conditions, does not explicitly account for rainfall intensity or duration, and is less accurate when precipitation is 0.5 inches or less.

Annual runoff depth is estimated based on the average number of days it rains per year. The estimated abstraction and retention are multiplied by the number of rain days, thus reducing estimated runoff as expressed in the following equation:

$$\text{Runoff Depth} = \frac{[\text{Rainfall} - (\text{Abstraction*Rain Days})]^2}{[(\text{Rainfall} - (\text{Abstraction*Rain Days})) + (\text{Retention*Rain Days})]}$$

Equation 6.8

Step 6: Convert Units

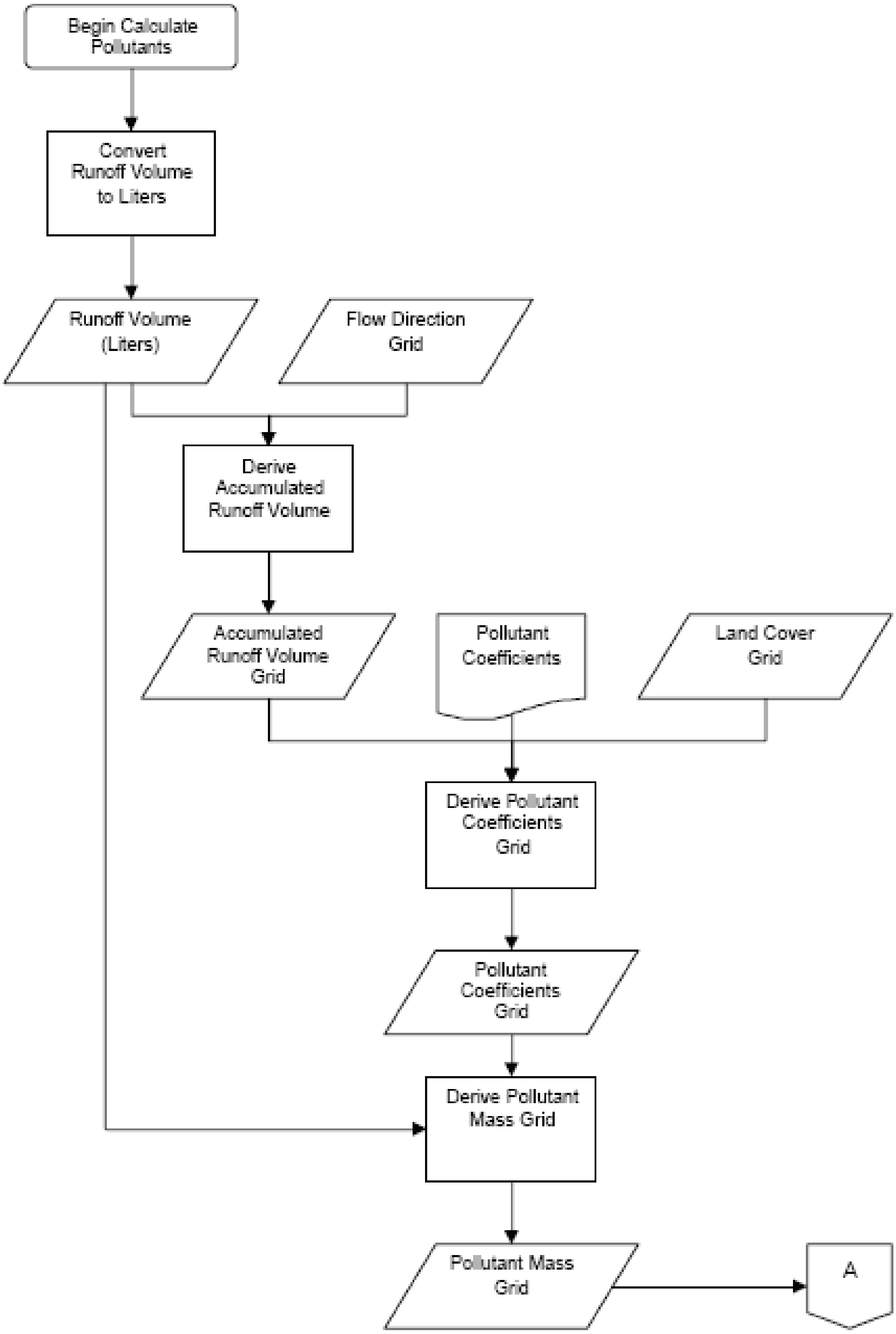
The next step in the runoff estimation process is to convert the runoff depth grid to runoff volume and to other units that will be used as inputs to subsequent processing. Because the Technical Release 55 runoff equation yields the depth (inches) of excess water that runs off the landscape for a given total rainfall depth, this grid must be multiplied by the cell area in order to produce a true runoff volume grid. The cell area is simply the length times the width of the cell.

6.2.4 Pollutant Concentration Estimation in N-SPECT Model

N-SPECT estimates pollutant concentrations in a step by step basis by utilizing various input datasets of land use, soil, rainfall and elevation grids and other input parameters prepared for the catchment in study (Kuils-Eerste River catchment). This is accomplished by applying runoff coefficients and pollutant contribution coefficients (in other words, EMCs) to the Kuils-Eerste Rivers land use / cover classes and then introducing a runoff volume grid. This procedure does not take into account the intensity or duration of rainfall. The following inputs were used during the estimation of pollutant concentration using the N-SPECT Model:
i) Precipitation grid (units);
ii) Digital elevation model (m);
iii) Land cover grid, and
iv) Rasterized soils data set (hydrologic group attribute).

Figure 59 is a diagrammatic representation of the processes involved during the estimation of pollutants concentration in N-SPECT model. First, the runoff volume grid is converted to litres by multiplying each cell by a conversion factor. Next, the accumulated runoff grid is created from the flow direction grid and the new 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 either the default pollutant coefficients or a new set derived from local sampling data where each cell is assigned a value based on its land cover classification. The pollutant coefficient value represents an average concentration (mg/L) for a given land cover classification.

When the pollutant concentration grid is multiplied by the runoff volume grid, the result is a new grid that indicates the mass of the pollutant produced by each individual cell. This grid does not take into account upstream contributions. The pollutant mass grid is accumulated using the flow direction grid, which yields an accumulated pollutant mass grid in which the value of each cell represents the total mass of pollutant that passes through that cell, including contributions from upstream cells. An accumulated pollutant concentration grid is derived by dividing the accumulated pollutant mass grid by the accumulated runoff grid. However, this grid does not include the pollutant mass and runoff volume generated at the current cell, instead including only the total value of all upstream cells that flow through the current cell. The final pollutant concentration grid is created by adding the pollutant mass grid and accumulated pollutant mass grid, then dividing this quantity by the sum of the runoff volume grid and the accumulated runoff grid.


Begin Calculate Pollutants
Convert Runoff Volume to Liters
Runoff Volume (Liters)
Flow Direction Grid
Derive Accumulated Runoff Volume
Accumulated Runoff Volume Grid
Pollutant Coefficients
Land Cover Grid
Derive Pollutant Coefficients Grid
Pollutant Coefficients Grid
Derive Pollutant Mass Grid
Pollutant Mass Grid
A

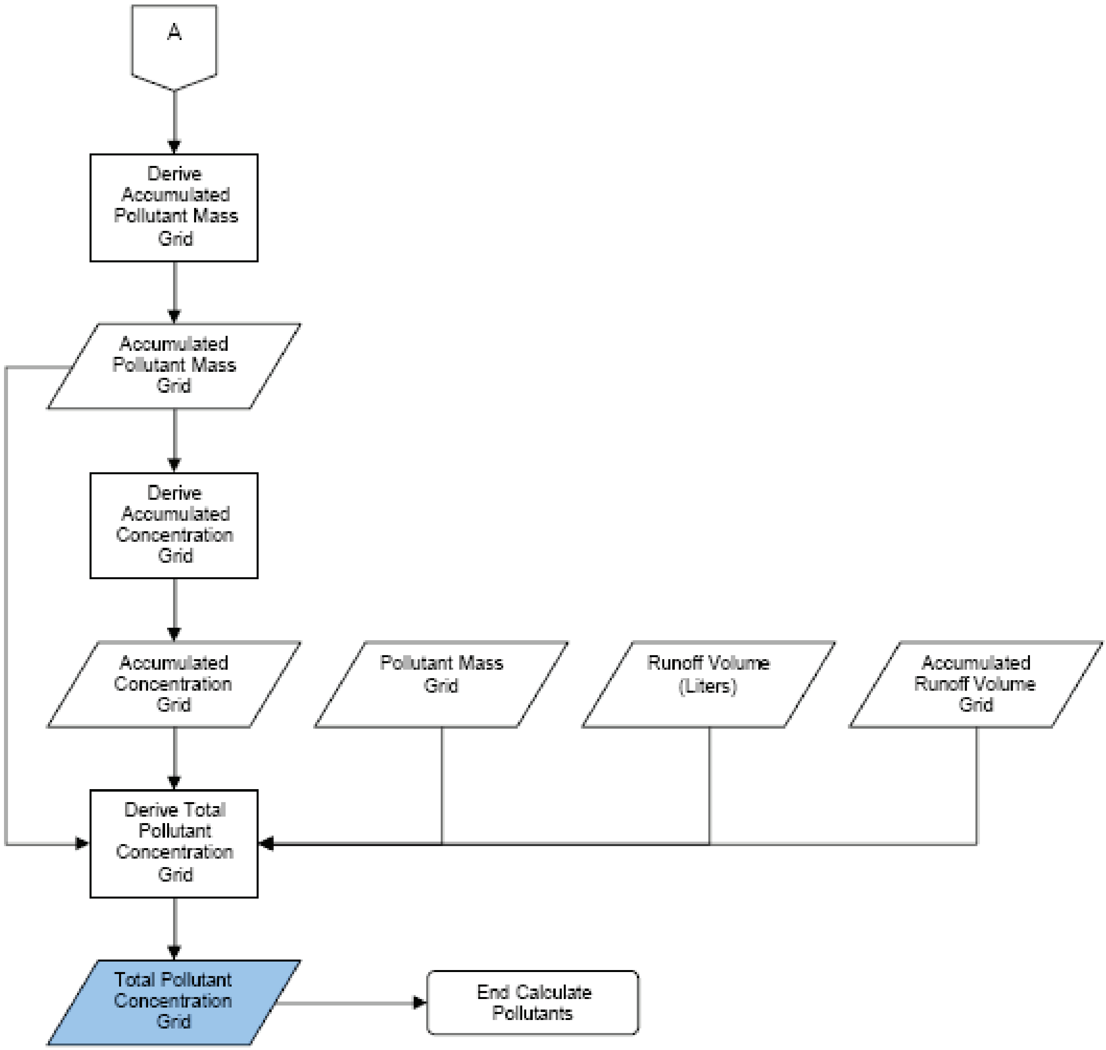


Figure 59 Pollutant Concentration Estimation Process. Source: N-SPECT Technical Guide, 2004. (NB: Shading indicates output data set.)

The output data sets that are produced after a pollutant concentration analysis include, Accumulated Pollutant (kg), Pollutant Concentration (mg/L^{-1}), and Comparison to Pollutant Standard (exceeds standard or below standard) grid for each pollutant specified in the initial analysis setup (Figure 60). The resulting grid represents the expected pollutant concentration value if a sample were taken at a given cell location. At times a local effect analysis could be performed and the resultant grids 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.

6.3 Input Data Sets for Use in Hydrologic Modelling

N-SPECT uses a variety of data sets, but only four data sets viz. Elevation, Soil, Rainfall and Land Use/Cover are required for basic analyses of Runoff and NPS Pollution. All spatial data input layers that are used during modelling must be converted to a common projection; in the case of this study, the projection reference that is used is UTM Zone 34 South with datum WGS84. The following section provides an overview of the methodology adopted for the preparation of the required input data sets and associated attribute information.

6.3.1 Elevation Data

The entire runoff and pollutant routing process is based on flow direction and flow accumulation grids derived from the elevation grid. Elevation grid data that is employed in the runoff model is a digital elevation model (DEM) shown in Figures 61 and 62. DEMs represent the existing topography and they are available in different levels of resolution. However, higher resolution DEMs result in increased processing times during modelling run. Because DEMs are the basis for flow routing and quantifying, it became very necessary to ensure that the grid cells of the DEM and all other grid data sets are aligned to each other.

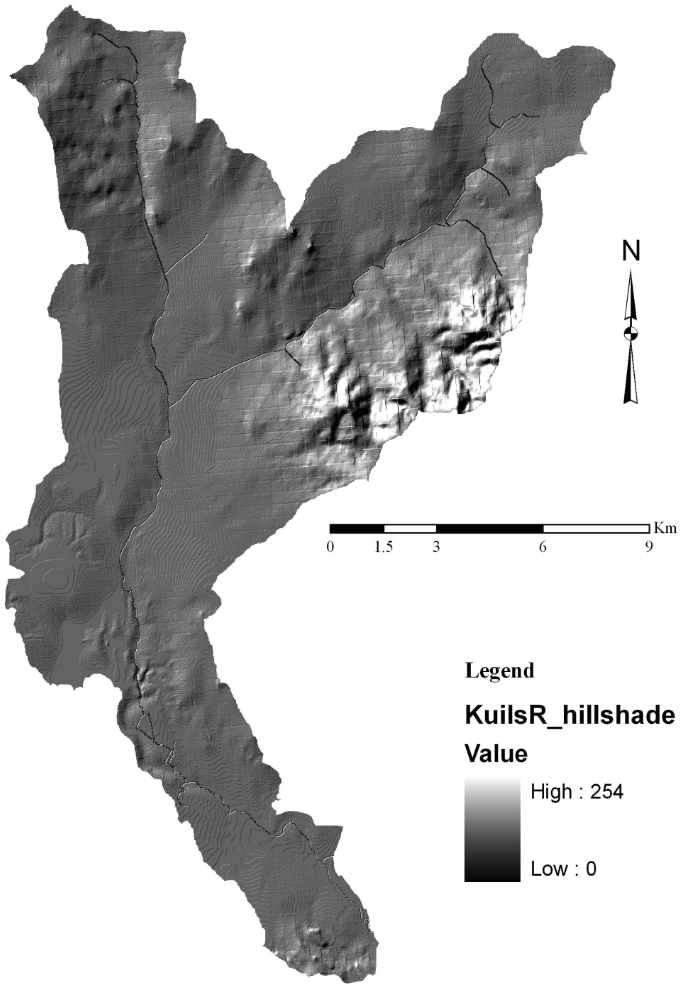


Figure 60 Hill-shade or sun-illuminated view of the topography of the Kuils River catchment.

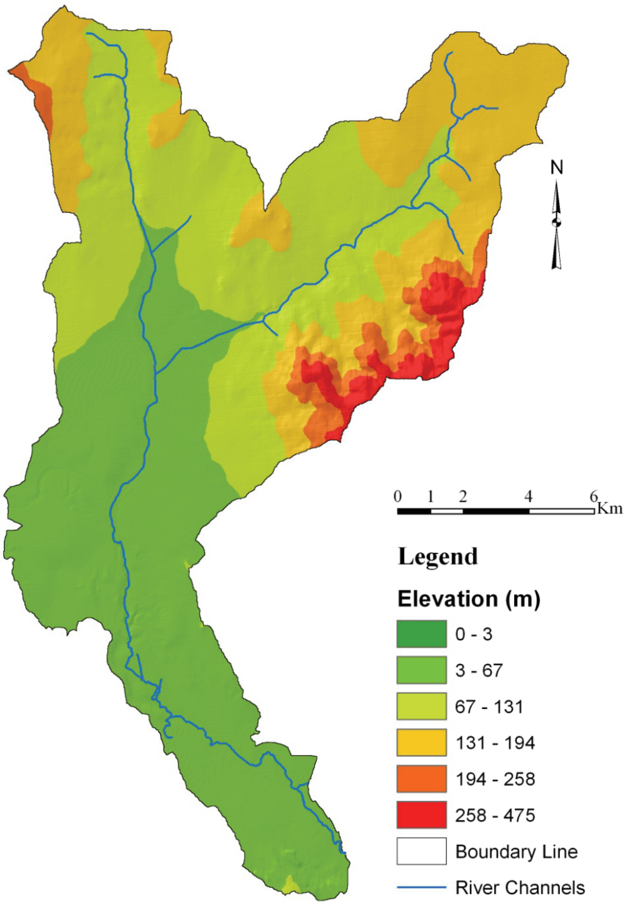


Figure 61 Digital Elevation Data (10m) showing variation in height.

6.3.2 Soils Data

The soils data that was used during this study was obtained from the ARC-ICSW data. This is a small scale (1:250.000) data set which contains soil type distribution for the whole of South Africa. A few modifications were necessary in order to make this data suitable for use in the N-SPECT model. This soil data was procured in a land type folder that contained soil polygons in Arc Info coverage format, Arc Info interchange files and shape files. However, soil data input that is used in the N-SPECT model is needed in shape file format. In addition to the polygon shape file representing soil units, two soil data attributes (tables) were required to satisfy the requirements for running N-SPECT. These attributes are the Soil Erodibility (k-factor) values and the Hydrologic Soil Group (HSG) attributes. Soil polygons that underlie water bodies do not have k-factor as well as HSG data to define them. As a general rule, in instances where there is no k-factor or HSG values available in the soil attribute data, conservative data were used to populate these fields. The k-factor was set to 0 and the hydrologic soil group to D, unless prior knowledge indicates that other values are more appropriate. K-factor and hydrologic soil group were then introduced in to the modelling by using N-SPECT Advanced Settings tool. The next two sub sections define HSG and k-factor in more detail and describe the procedures that were involved in preparing these values.

6.3.3 Preparation of the Hydrologic Soil Group Inputs

The hydrologic soil group (HSG) defines the soil infiltration capacity (infiltration rates) and the hydrologic group attribute is used to assign runoff curve numbers when working with new land cover data sets or classes. The soil data contained only the textural descriptions of soil units but fell short of defining the hydrologic characteristics of these soil units. Therefore it became very necessary to define these hydrologic characters for the soil units in order to apply in the hydrologic model. The procedure that was used to define the HSG for the soil data was as follows:

Firstly, a field was created in the soil attribute table and a texture descriptive name (US_TEXTURE in Table 26) was assigned to the soil units by extracting information available in soil texture descriptions column (TEXTURE in Table 26), that were symbolised in the original soil layer table. Soil texture descriptions for each of the soil units enabled the classification of these units into sandy, sandy clay, sandy clay loam, and sandy loam and clay texture classes. Secondly, based on the soil texture classes acquired from the previous procedures, four hydrologic soil group categories were defined. HSGs exist in four categories, A, B, C and D, based on decreasing infiltration rates (A= high infiltration, D=very slow infiltration) (e.g. see US_HSG field in Table 26). Tables 26 and 27 contain descriptive information that guided the categorisation of the soil units. Water bodies and urbanised areas with unclassified severely disturbed soils, were coded as hydrologic soil group D. The HSG of each soil cover was based on the soil texture characteristics in the various Kuils River catchment land covers, as guided from Table 26. Lastly, the individual HSG were converted to specific numeric codes acceptable to the model as follows: polygons coded as A became 1, B became 2, C became 3, and D became 4; all codes inferred from Table 28.

Table 26 Land Type Data Showing Textural Descriptions

ISCW_ID	BROAD	LANDTYPE	AVR_CLAY	SERIES	HORIZON	TEXTURE	US_TEXTURE
15959	Db	Db54	7.8	Es41Lo20	E	meSa-LmSa	Sand
15961	Ac	Ac27	17.7	We22We13	B	meSaClLm-SaCl	Sandy Clay Loam
15976	Hb	Hb15	3.0	Es21Es42	E	me/coSa	Sand
15999	Db	Db53	6.8	Ss25Ss22Ss23Ss21Sw31	A	fi/me/coSa-SaLm	Sand
16008	Db	Db52	16.5	Va32Ka20	B	Cl	Clay
16083	Ga	Ga10	3.6	Fw21Fw20Fw22	A	fi/coSa	Sand
16114	Fa	Fa919	18.5	Av25Av26	B	coSaLm-ClLm	Sandy Clay
16120	Ca	Ca30	6.4	R	B	coSa-LmSa	Sandy Loam
16130	Ga	Ga16	3.6	Fw11Fw10	A	fi/meSa	Sand
16143	Hb	Hb13	3.3	Ms22	A	me/coSa	Sand
16268	Ha	Ha7	3.2	Fw20Fw21Fw22	A	fi/coSa	Sand
16297	Ca	Ca134	5.6	Wa30Kd22	E	coSa	Sand

Table 27 Hydrologic Soil Group Definitions.

Hydrologic Soil Group	Soil Group Characteristics
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well- excessively –drained sands and gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep and moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having a slow infiltration rate when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow rate of infiltration when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential ,soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils

Table 28 Table of Hydrologic Soil Group Codes Based On Texture.

Hydrologic Soil Group	HSG Code (Recls_Code)	Soil Texture
A	1	Sand, loamy sand, and sandy loam High infiltration (low runoff) Infiltration rate >0.3 inch/hr when wet
B	2	Silty loam and loam Moderate infiltration (moderate runoff) Infiltration rate 0.15-0.3 inch/hr when wet
C	3	Sandy clay loam Low infiltration (moderate to high runoff) Infiltration rate 0.05 – 0.15 inch/hr
D	4	Clay loam, Silty clay loam, Sandy clay, Silty clay, and Clay Very low infiltration (high runoff) Infiltration rate 0 – 0.05 inch/hr

6.3.4 Soil Erodibility (k-factor) Inputs

Soil Erodibility factor is a measure of the ease with which soil particles could be dislodged from the original soil mass and carried away due to external factors. It is derived from the amount of soil loss per unit of erosive energy during rainfall, assuming a standard research plot. Soil Erodibility is a function of the infiltration capacity and structural stability of the soil. A low infiltration capacity would cause more surface runoff, and the surface is less likely to be ponded, making it more susceptible to splashing. Some soils properties that create a high k-factor are high contents of silt and clay or impervious soil layers. The soil erodibility factor was taken from literature that explained the successful use of such data inputs for similar studies elsewhere in the world. Some soils that were extremely disturbed, e.g. urban soils were, considered as not having any k-factor values. For such soil polygons, a k-factor value of 0.30 was used. The erodibility factor for the rest of the soil layer polygons were assigned after careful consideration of the textural composition and the organic contents of the soil as expressed in Table 29.

The final soil data produced had the soil textural characteristics (US_TEXTURE), HSG (GROUP) and erodibility (K-FACT) attributes as shown in Table 30. Figure 63 is a spatial display showing the distribution of the various classes of soil that are present in the Kuils River catchment.

Table 29 Soil Erodibility Factor, K of Different Soil Textures.

	Organic Matter Content		
Textural Class	0.50%	2.00%	4.00%
Fine sand	0.16	0.14	0.1
Loamy sand	0.12	0.1	0.08
Sandy loam	0.27	0.24	0.19
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Loamy very fine sand	0.44	0.38	0.3
Very fine sandy loam	0.47	0.41	0.33

Table 30 Soil Data Table for Kuils River Catchment.

ISCW_ID	LANDTYPE	TEXTURE	US_TEXTURE	US_HSG	HSG_CODE	GROUP	K-FACT
15959	Db54	meSa-LmSa	Sand	A	1	1	0.12
15961	Ac27	meSaClLm-SaCl	Sandy Clay Loam	C	3	3	0.28
15976	Hb15	me/coSa	Sand	A	1	1	0.16
15999	Db53	fi/me/coSa-SaLm	Sand	A	1	1	0.47
16008	Db52	Cl	Clay	D	4	4	0.28
16083	Ga10	fi/coSa	Sand	A	1	1	0.16
16114	Fa919	coSaLm-ClLm	Sandy Clay	C	3	3	0.27
16120	Ca30	coSa-LmSa	Sandy Loam	A	1	1	0.12
16130	Ga16	fi/meSa	Sand	A	1	1	0.16
16143	Hb13	me/coSa	Sand	A	1	1	0.16
16268	Ha7	fi/coSa	Sand	A	1	1	0.16
16297	Ca134	coSa	Sand	A	1	1	0.16

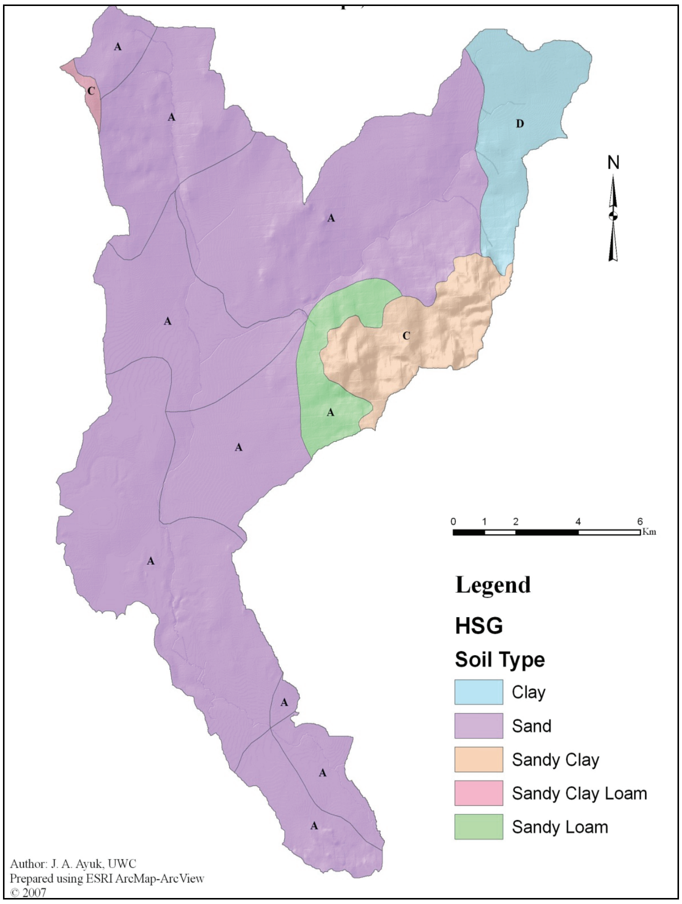


Figure 62 Soil Map showing the spatial distribution of the soil groups in the Kuils River Catchment.

6.3.5 Rainfall Data

The runoff component of N-SPECT is driven by the precipitation grid. The South African Weather Service (Weather SA) and the Department of Water Affairs and Forestry (DWAF) are the primary repository for precipitation data collected in weather stations that are located all over the Republic of South Africa. Monthly and annual rainfall records for stations in the vicinity of the Kuils River catchment were interpolated as grids based on the procured precipitation data. Annual Precipitation totals for the year 2006 and 2007 were extracted from annual rainfall records collected from seventeen rain gauges located in the catchment (Table 31). Interestingly, there existed a greater number of rain gauges in the catchment but a number of such stations were no longer functional and there were also points with missing data in the available rainfall tables. However, attempts were also made to fill in values for these missing data points by using estimates generated by the Smirnov-Kolmogorov Regression Model. This is a linear model ($y = 34.74332+0.630337\ X$) with a correlation coefficient (R) of 0.56. Figure 63 shows a wide range of rain stations of Cape Region from where rainfall data was initially procured but the number of stations that were considered for rainfall interpolation were reduced because some points were considered too distant to influence rainfall distribution in the Kuils River area.

Table 31 Annual Rainfall Data Collected from Available Rain Gauge Points in the Cape Region.

Stn_ID	Stn_Name	Lon	Lat	2OO6	2OO7
G1E001	Wellington	19.0158	-33.6500	662.1	729.0
G1E002	Vogel Vallij @ Voelvlei Dam	19.0408	-33.3417	569.5	659.6
G1E003	Zachariashoek @ Wemmershoek Dam	19.0825	-33.8333	715.3	768.9
G1E006	Assegaaibos	19.0658	-33.9417	1669.0	1483.6
G1E009	Withoogte @ purifiction works	18.6678	-33.0672	464.3	522.3
G2E001	Brakke Fontein @ Atlantis Sewage	18.4825	-33.6083	400.9	515.2
G2E003	Higgovale Cape Town @ Molteno	18.4117	-33.9375	772.2	968.5
G2E004	Tafleberg	18.4033	-33.9792	1440.0	1761.0
G2E005	Tafelberg @ Newlands	18.4492	-33.9667	1266.0	1756.0
G2E007	Malan DF Airport	18.5992	-33.9667	436.1	680.6
G2E008	Stellenbosch @ Welgevallen	18.8700	-33.9417	486.2	630.6
G2E011	Jonkershoek @ Biesiesvlei	18.9492	-33.9833	1360.7	1796.3
G2E013	Jonkershoek @ Manor House	18.9286	-33.9639	1093.0	1330.0
G4E001	Kogel Baai @ Steenbras Dam-Lower	18.8514	-34.1797	996.5	959.0
OO212303	Altydgedacht	18.6330	-33.8330	488.0	651.4
OO21550	Maitland	18.5860	-33.9200	484.1	614.1
0021417A0	Skoonheid	18.7333	-33.95	463.0	679.0

6.3.6 Preparation of Precipitation grid

Figure 64 shows the distribution of 13 rain gauges in the Cape region. Interestingly, none of these stations were located in the Kuils River catchment area. In order to predict rainfall amounts within the catchment, an interpolation approach was used. ArcGIS Spatial Analyst Surface interpolation function was used to create a continuous (or prediction) surface from sampled point values in the point feature shapefile. The result was a continuous surface that represented annual rainfall for all locations in the catchment whether or not a measurement had been taken at these locations. A number of interpolation algorithms, including Inverse Density Weighted (IDW) and Spline, were experimented for the best annual rainfall distribution display. Both the Inverse Distance Weighted (IDW) and Spline methods of interpolation use ESRI's Spatial Analyst Interpolation to Raster tools to assign values to locations based on the surrounding measured rainfall using specific mathematical formulae that determine the smoothness of the resulting surface. As the number of rainfall gauges in the catchment were low and the variation of measured rainfall amounts were high due to the topographic differences, the resulting interpolation algorithms did not produce satisfactory rainfall distribution. It was found that IDW algorithm with one rain gauge point produced the most satisfactory annual rainfall distribution map (like a Thiessen polygon approach) for the Kuils River catchment area. Finally, the resultant grid was later trimmed to the extent of the Kuils River boundary using Extract By Mask tool in ArcToolBox' Spatial Analyst Tools. Figures 65 and 66 show the annual rainfall maps for Kuils River Catchment area for year 2006 and 2007 deduced using the procedures that have been discussed above.

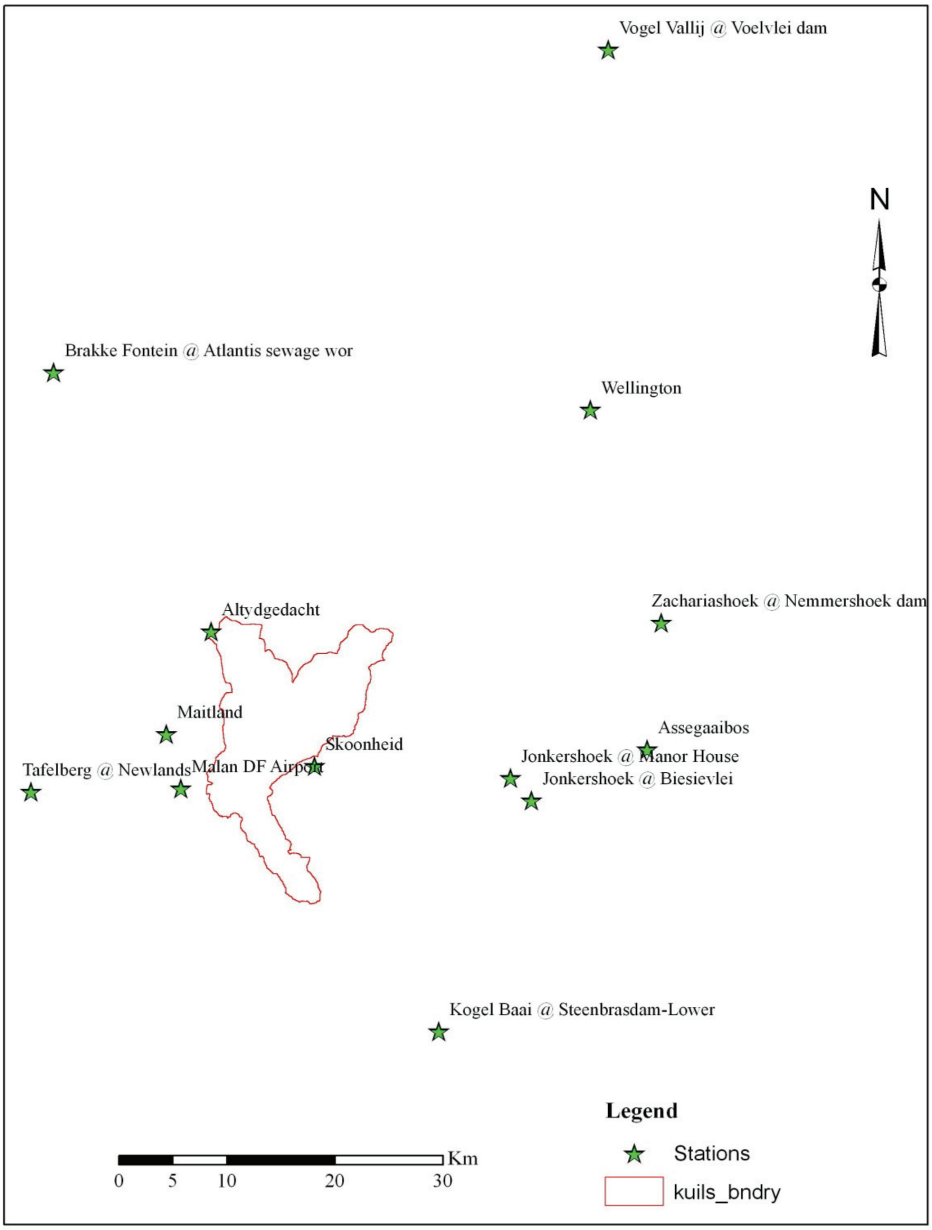


Figure 63 Location of rain gauges in the Cape region

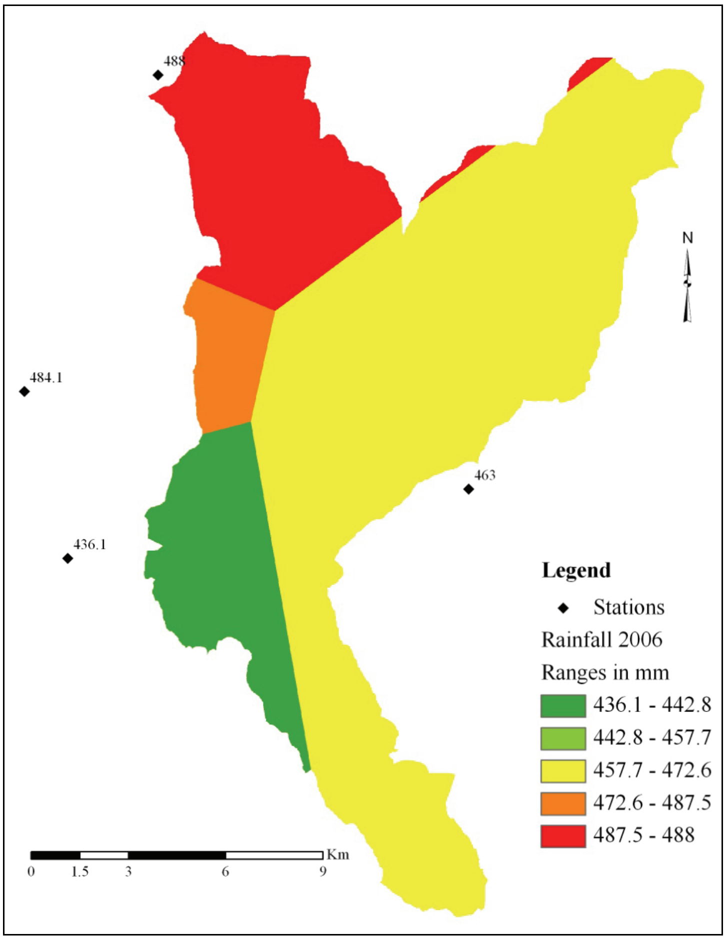


Figure 64 Rasterised annual rainfall distribution map for the year 2006.

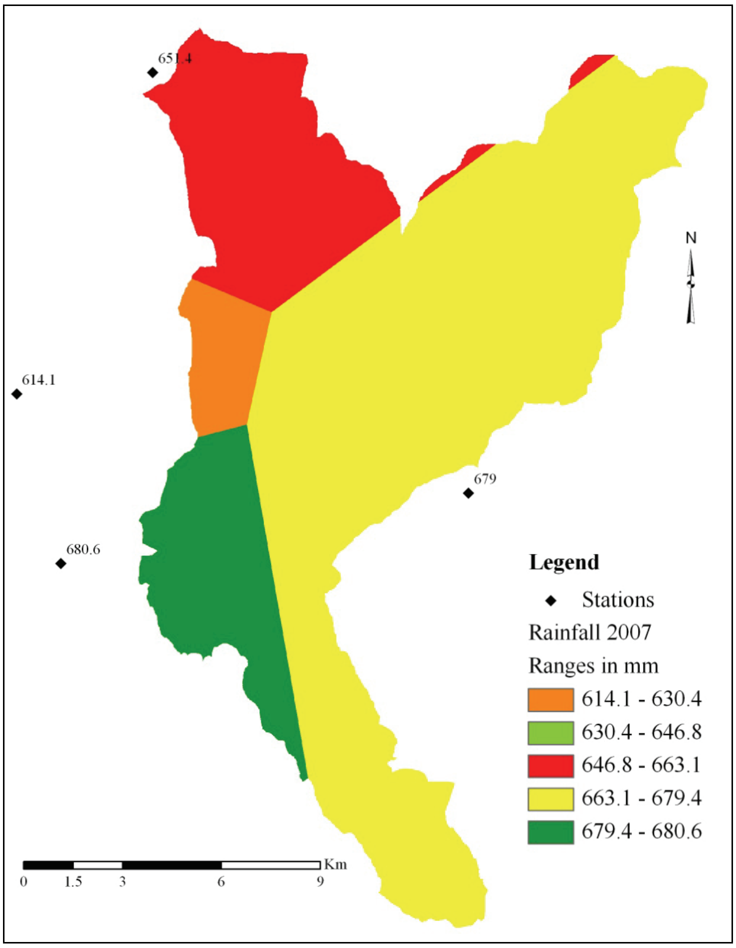


Figure 65 Rasterised annual rainfall distribution map for the year 2007.

The results from the rainfall interpolation show that there was a general increase in overall rainfall from 2006 to 2007 which could be the result of varying climate patterns. The pattern of distribution of rainfall varied tremendously. In 2006, the Durbanville (NW) area received the highest amounts of rainfall (above 480 mm) as compared to southern western areas showing readings below 450 mm. This pattern was reversed in the year 2007 accompanied by overall increases in rainfall totals in all stations as mentioned earlier. The possible explanation to these patterns is that rainfall around the Cape Peninsula, the Cape Flats and the Boland varies greatly in space. Newlands receives very high annual rainfall (1266 mm in year 2006, 1756 mm in year 2007) while the Cape Flats (Airport), which is 30 km away from Newlands receives far lesser rainfall (436 mm in 2006, 680 mm in 2007). Jonkershoek area near Stellenbosch also receives very high rainfall (1360 mm in year 2006, 1796 mm in year 2007). The peninsula receives frontal rain closer to the mountains; orographic rain is common, causing a gradient away from the mountains.

Additionally long term average data was procured through Schultze *et al*., (1996) which was processed showing annual mean values across the province. The catchment was clipped from this data set and the resultant rainfall grid map is shown in Fig 67.

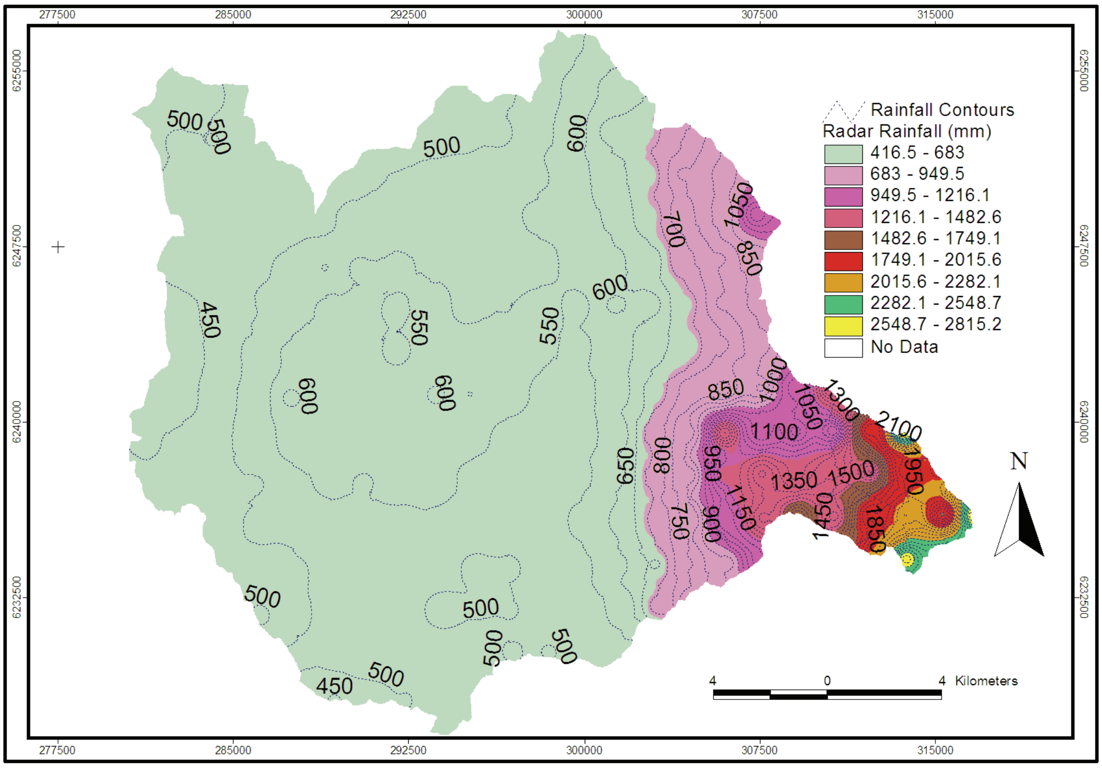


Figure 66 Rainfall distribution across the catchment derived from the radar estimated long term averages (Schultze *et al*., 1996)

In comparison the two rainfall data sets show marked differences in the way rainfall is distributed across the catchment. The second data set is a more reliable representation of the distribution though, as it gives an average distribution pattern. Alternatively in making a historical study that is not related to the time frame of other parameters it then would render more reliable and accurate results since this would be the average rainfall for the area and not event based rainfall values.

6.3.7 Land Cover Data

The land use/cover data was selected for the Kuils River catchment and re-projected to the common projection of all the other data inputs using the suitable projection tools in GIS. In ArcGIS, an analysis mask is specified, e.g. the soils shapefile or the DEM, (Spatial Analyst/Options) and the Raster Calculator are used to create a new land cover grid clipped to DEM or soils data. Care was taken to make sure that the grid cells of the DEM and land cover data sets (and all other grid data sets) match. This is accomplished by setting the “snap to extent” feature of the ArcGIS Spatial Analyst options menu to the DEM data set.

A detailed description of the preparation of a detailed land use / land cover map for Kuils River and other close areas has been described in Chapter 3. This is a 10 m raster grid map containing 36 land use / cover classes and it is projected to WGS 84 UTM Zone 34 South. A boundary of the catchment had been defined through catchment delineation from the local DEM. Using ArcGIS Extract By Mask tools, this boundary shape was then used as the mask to extract the land use/cover grid covering the Kuils River catchment. The Kuils River catchment covers an area of over 203 km^2 appropriately distributed between 36 Kuils-Eerste

River classes as shown in Figure 68 and Table 30. However, in order for N-SPECT to successfully simulate the influence of these Kuils-Eerste River types on the hydrologic processes in the catchment, additional descriptive information about the surface properties of the different land uses/ land cover units (attribute information) must be added to the layer.

6.3.8 Runoff Curve Numbers (CN) Deduced for Kuils River Catchment

Runoff curve numbers represent the infiltration capacity of the soil and range from 0 to 100, with 0 being no runoff and 100 indicating no infiltration. Curve numbers play an important role in N-SPECT's runoff depth estimation calculations. N-SPECT CN values are employed as percentage fractions of the actual designated CNs (as runoff coefficients). The USDA Urban Hydrology for Small Watersheds: Technical Release 55 (USDA, 1986) is the primary reference for more information on determining appropriate curve numbers for other land cover classes. Higher curve numbers are assigned for landscapes with more impervious cover, surface soils with high clay content, or lands with low soil cover. Table 32 shows Kuils River catchment Kuils-Eerste River classes and the corresponding curve number values for each of the four hydrologic soil groups are shown in Table 33.

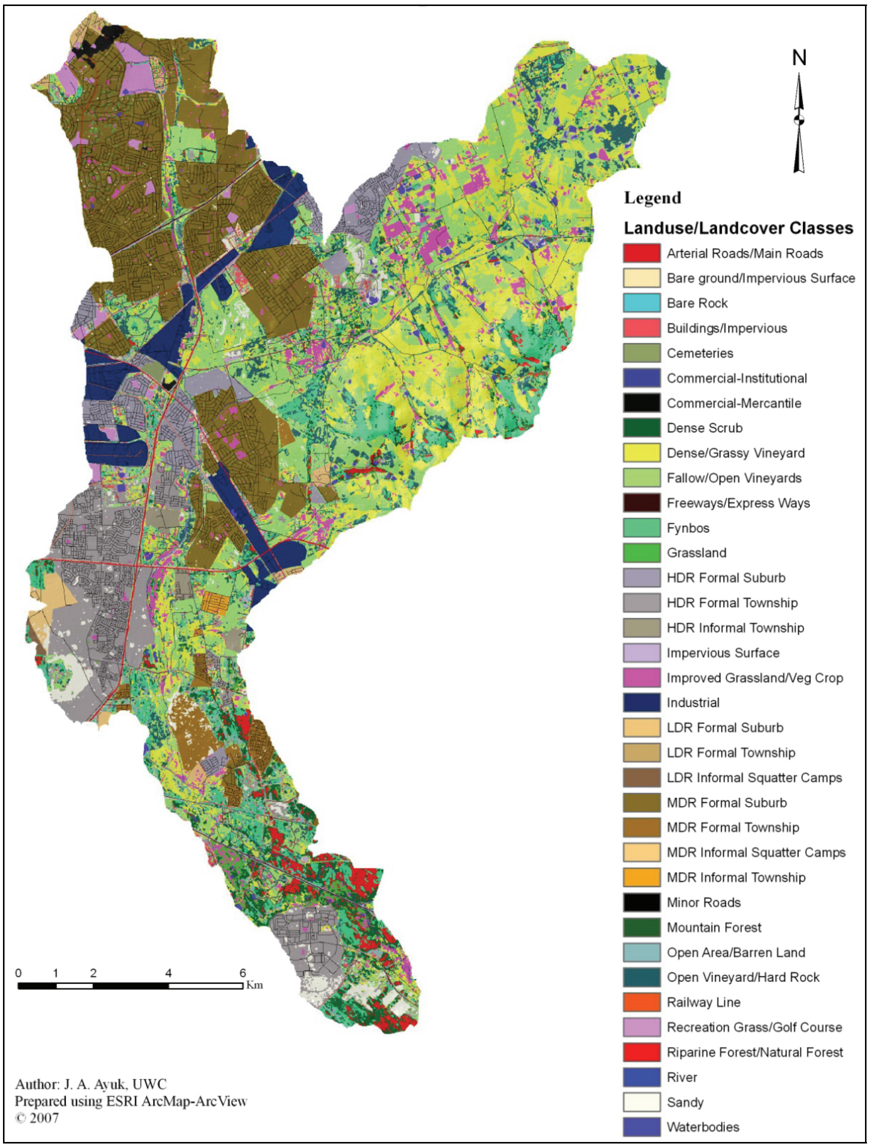


Figure 67 Kuils-Eerste River map of Kuils River Catchment in the Western Cape Province of South Africa.

Table 32 Land use/cover percentage contributing area in the Kuils River Catchment.

Value	Count	Name	Area (m^2)	Area (Km^2)	Percentage Cover
1	4564	Mountain Forest	456400	0.46	0.2
2	32045	Riparine Forest/Natural Forest	3204500	3.20	1.6
3	71640	Dense Scrub	7164000	7.16	3.5
4	122812	Fynbos	12281200	12.28	6.0
5	26411	Grassland	2641100	2.64	1.3
6	14926	Impervious Surface	1492600	1.49	0.7
7	2737	Railway Line	273700	0.27	0.1
8	16270	Bare ground/Impervious Surface	1627000	1.63	0.8
9	4	Bare Rock	400	0.00	0.0
10	84510	Open Vineyard/Hard Rock	8451000	8.45	4.2
11	53778	Open Area/Barren Land	5377800	5.38	2.6
12	74855	Improved Grassland/Veg Crop	7485500	7.49	3.7
13	23284	Buildings/Impervious	2328400	2.33	1.1
14	324516	Dense/Grassy Vineyard	32451600	32.45	16.0
15	307574	Fallow/Open Vineyards	30757400	30.76	15.1
16	20989	Recreation Grass/Golf Course	2098900	2.10	1.0
17	2598	Freeways/Express Ways	259800	0.26	0.1
18	10789	Arterial Roads/Main Roads	1078900	1.08	0.5
19	96821	Minor Roads	9682100	9.68	4.8
20	44483	Sandy	4448300	4.45	2.2
21	14035	Waterbodies	1403500	1.40	0.7
22	65691	HDR Formal Suburb	6569100	6.57	3.2
23	300817	MDR Formal Suburb	30081700	30.08	14.8
24	10353	LDR Formal Suburb	1035300	1.04	0.5
25	156317	HDR Formal Township	15631700	15.63	7.7
26	29127	MDR Formal Township	2912700	2.91	1.4
27	236	LDR Formal Township	23600	0.02	0.0
28	9859	HDR Informal Township	985900	0.99	0.5
29	3311	MDR Informal Township	331100	0.33	0.2
30	11243	MDR Informal Squatter Camps	1124300	1.12	0.6
31	1593	LDR Informal Squatter Camps	159300	0.16	0.1
32	5740	Commercial-Mercantile	574000	0.57	0.3
33	24	Commercial-Institutional	2400	0.00	0.0
34	79343	Industrial	7934300	7.93	3.9
35	2091	Cemeteries	209100	0.21	0.1
36	6104	River	610400	0.61	0.3
TOTALS			**203149000**	**203.15**	**100**

The Kuils River catchment grid consists of 36 different land use/cover classes. The value column refers to specific codes assigned to each class. The count column shows the cell count within each land use/cover class. The name column contains names of all land use/cover classes present while the area column shows the areal extent in square metre and square kilometre units. The percentage cover column shows what proportion of the overall catchment area each class comprises. It is seen that over 30% of the area is being used for commercial farming followed by about 20% used for Formal residence purposes. The rest of this area is divided amongst industry, commercial, natural vegetation, open land and informal settlement areas.

Table 33 Curve Numbers for the land use / land cover types in the Kuils-Eerste River Catchment

		Hydrologic Soil GroupCurve Numbers			
Value	**Land use/Land Cover**	**A**	**B**	**C**	**D**
1	Mountain Forest	0.3	0.55	0.7	0.77
2	Riparine Forest/Natural Forest	0.36	0.6	0.73	0.79
3	Dense Scrub	0.36	0.6	0.73	0.79
4	Fynbos	0.39	0.61	0.74	0.8
5	Grassland	0.39	0.61	0.74	0.8
6	Impervious Surface	0.98	0.98	0.98	0.98
7	Railway Line	0.54	0.7	0.8	0.85
8	Bare ground/Impervious Surface	0.77	0.86	0.91	0.94
9	Bare Rock	0.98	0.98	0.98	0.98
10	Open Vineyard/Hard Rock	0.77	0.86	0.91	0.94
11	Open Area/Barren Land	0.68	0.79	0.84	0.89
12	Improved Grassland/Veg Crop	0.39	0.61	0.74	0.8
13	Buildings/Impervious	0.98	0.98	0.98	0.98
14	Dense/Grassy Vineyard	0.43	0.65	0.36	0.82
15	Fallow/Open Vineyards	0.74	0.83	0.88	0.9
16	Recreation Grass/Golf Course	0.49	0.69	0.79	0.84
17	Freeways/Express Ways	0.98	0.98	0.98	0.98
18	Arterial Roads/Main Roads	0.98	0.98	0.98	0.98
19	Minor Roads	0.98	0.98	0.98	0.98
20	Sandy	0.36	0.6	0.73	0.79
21	Water bodies	0	0	0	0
22	HDR Formal Suburb	0.77	0.85	0.9	0.92
23	MDR Formal Suburb	0.61	0.75	0.83	0.87
24	LDR Formal Suburb	0.57	0.72	0.81	0.86
25	HDR Formal Township	0.81	0.88	0.91	0.93
26	MDR Formal Township	0.77	0.85	0.9	0.92
27	LDR Formal Township	0.57	0.72	0.81	0.86
28	HDR Informal Township	0.89	0.92	0.94	0.95
29	MDR Informal Township	0.77	0.85	0.9	0.92
30	MDR Informal Squatter Camps	0.81	0.88	0.91	0.93
31	LDR Informal Squatter Camps	0.61	0.75	0.83	0.87
32	Commercial-Mercantile	0.89	0.92	0.94	0.95
33	Commercial-Institutional	0.81	0.88	0.91	0.93
34	Industrial	0.86	0.91	0.93	0.94
35	Cemeteries	0.59	0.74	0.83	0.87
36	River	0	0	0	0

6.3.9 Water Quality Standards/Criteria

The South African Water Quality Guide for Aquatic Ecosystems is in essence a specification document describing Target Water Quality Ranges (TWQR). The aquatic guide developed by DWAF (1996) is meant for the protection of the health and the integrity of aquatic ecosystems and guidelines for the protection of the marine environment. Target water quality ranges (TWQR) are threshold within which no measurable adverse effects are expected on the aquatic ecosystem. Beyond these ranges quality could become chronic or acute. The procedure used in classifying or evaluating the effects of nutrients in the aquatic environment was the change of trophic status, from local natural conditions. The standard used as the benchmark for evaluating non-toxic inorganic constituents is the change from local nutrients which affect ecosystem structure and functioning. Water quality criteria are given as numerical values associated with a level of risk of acute or chronic toxicity effects.

Since this study was primarily based on assessing the resultant effects of runoff pollutant to the water quality of the Kuils River, it was decided that the water quality standards and criteria that focus on aquatic systems be used as bench marks for quality assessments in the Kuils River DWAF (1996). The South African Water Quality Guide for Aquatic Ecosystems was consulted but it was very difficult to come to conclusive values for most of the quality inputs. It became very necessary now to consult other literature for examples of water quality standard limits and thereafter to consider implementing water limits for the present analysis. Tables 34 to 37 are examples of proposed water quality standards for different organisations with different interest.

Table 34 Chemical characteristics and their recommended limits for no risk (Lin et al., 2004) after DWAF, DOH and WRC (1998).

Element	**Unit**	**Limit**	
Temperature	^oC	N/A	
Electrical Conductivity	mS/Cm	<700	
Dissolved Oxygen	mg/L^{-1}	N/A	
Total Nitrogen	mg/L^{-1}	<6	
Nitrates	mg/L^{-1}	<26	
Total Phosphates	mg/L^{-1}	<1	
Chemical Oxygen Demands	mg/L^{-1}	N/A	
E.coli	/100ml	0	
Chlorides	mg/L^{-1}	0-200	No effect
		200-600	Tasty with no health risk
		600-1200	Tasty
		>1200	Unhealthy

Table 35 Classification of water quality for the development of Universal Water Quality Index (UWQI) US EPA, 1986.

Parameter	Unit	Class I Excellent	Class II Acceptabl	Class III Polluted	Remarks
Nitrate-Nitrite	mg/L^{-1}	5	10	20	Chemicals from agriculture
Dissolved Oxygen	mg/L^{-1}	8	6	3	
pH	mg/L^{-1}	6.5-8.5	5.5-6.4 8.6-9.0	<5.5 >9	Operational levels
Biochemical Oxygen Dema	mg/L^{-1}	<3	<5	<7	Indicators of organic pollutio
Total Phosphates	mg/L^{-1}	0.02	0.16	0.65	
Total Nitrogen	mg/L^{-1}	0		87.15	

Table 36 Water Quality Standards from the South African National Standards 241.

Water Quality Standards (SANS 241)	
Parameter	Limits
Chlorides	< 200 mg/L^{-1}
Chlorides	200 mg/L^{-1}
Phosphates	5 mg/L^{-1}
N	26 mg/L^{-1}
TSS	110 mg/L^{-1}
Nitrate	10 mg/L^{-1}

Table 37 DWAF Volume 7 Aquatic Ecosystems should not exceed AEV.

Parameter	Value (mg/L)	Source
Nitrate	<0.5	DWAF
Chloride	0.2	"
TSS	<100	"
Phospshor	<5	"
Total Nitroger	<6	"

6.4 Modelling Process in N-SPECT

6.4.1 Setting up of Input Parameters

Using the Advanced Settings menu (Figure 69) that is provided by the model, data inputs that have been prepared for the Kuils River catchment area was incorporated in to the model.

First, using the Options menu in the Land Cover Type window of N-SPECT, a new land cover data was defined by creating a land cover type for the Kuils River area. The new Land Cover Type name was designated as ‘Kuils Eerste Land Use’ and the appropriate description of the layer was written in the Description column. The land use codes and the Kuils-Eerste River types were respectively entered under the Value and Name fields of the Classification column. The curve numbers that were derived for Kuils River catchment were entered into the respective fields as directed in the SCS Curve Numbers column.

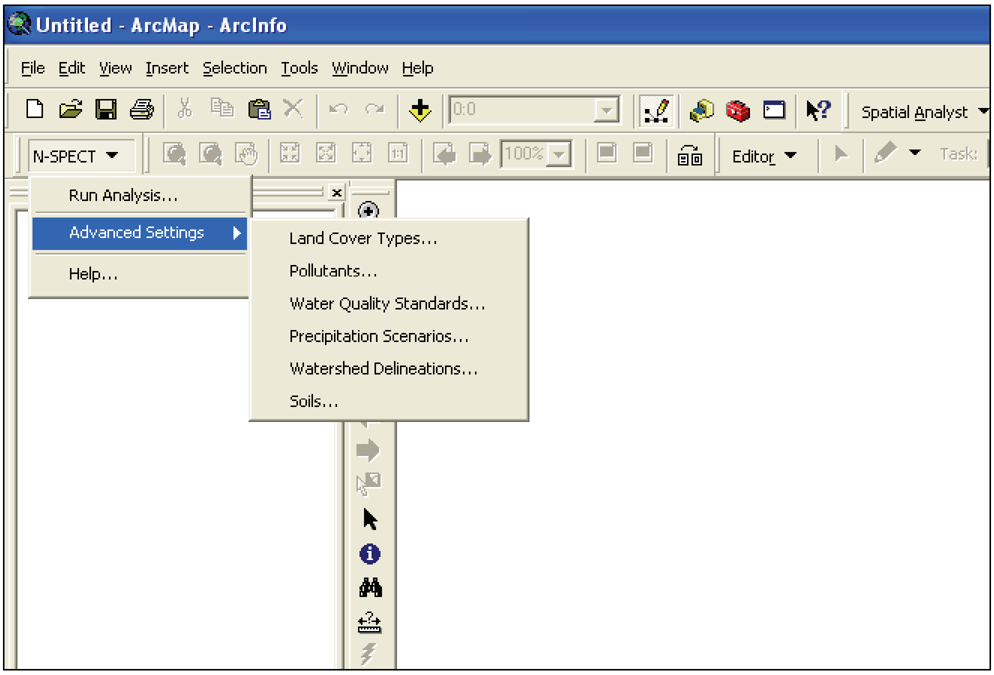


Figure 68 Screen shot of model input parameters in N-SPECT's Advanced Settings menu.

The Cover Factor and the Wet columns were ignored because these inputs are geared towards the calculation of erosion using the Revised Universal Soil Loss Equation (RUSLE) which is not a major objective of this study. Alternatively, the land type data table consisting of all values, land use types and curve numbers, could be directly imported into the New Land Cover Type window. The imported file would be an ASCII file containing a header row, followed by a row of comma-separated values for each of the cover classes. The header row would contain the name of the land cover type and a description, separated by a comma (no space). Also, an export function in the Land cover type window allows users to share their data tables with other users.

Secondly, pollutant coefficients of each water quality parameter in the study were loaded into the Pollutants window. These coefficients are the local water quality values that were derived through runoff sampling. The pollutant menu was repeatedly used to add new pollutants and the Coefficient menu also used to create new coefficient sets every time values for another pollutant were to be loaded in to the window. A Coefficient Set was defined for every pollutant input using the following naming format: '*pollutant name* Set' in naming the pollutant coefficient set.

The water quality standards that would be used to assess the water quality were specified in the model. Using the options menu in the Water Quality Standards dialog box, new inputs were created, deleted or exported as deemed necessary. The threshold value for each water quality standard is entered in microgram per unit litre (µg/L) units. The following threshold values were entered as water quality standards for NPS parameters under investigation:

Total Nitrogen, 26000 µg/L; Total Phosphorus, 150 µg/L; Nitrates, 60 µg/L; Chloride, 19 µg/L; Total Suspended Solids, 20 µg/L.

Next was the introduction of the precipitation scenarios. This layer is necessary to calculate runoff. Again from the options menu of the Precipitation Scenarios window, a new precipitation scenario was created, the scenario named, a description of the data provided, and the rain fall grid that had been prepared earlier was loaded as the precipitation grid as shown in Figure 70. The grid units of the precipitation layer are similar to those of the DEM data (10m) and the precipitation units were in centimetres. The time period of the precipitation data is annual precipitation data of the Cape Flats-Boland regions and the rainfall type or rainfall distribution Type I was chosen for the study area.

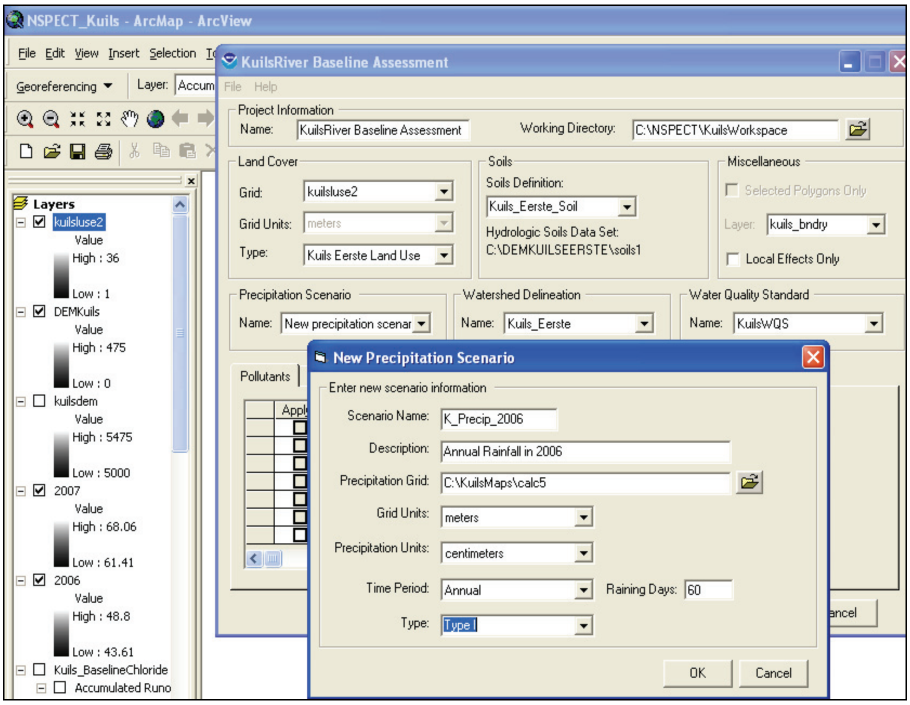


Figure 69 Precipitation scenario window for loading up rainfall layers.

Using the Options menu in the Advanced Settings window, a new watershed was created for the analysis. A name was assigned for the watershed, and the DEM grid was loaded as the DEM grid. A medium size sub watershed was chosen for any newly delineated watershed, the units were defined to be in metres and the algorithm was allowed to perform a hydrological correction of the DEM grid by automatically filling up all sinks before any further analysis in N-SPECT. During the process of input of the DEM, a hydrologic process was set off aimed at creating n watershed polygons layers and in the process, a flow direction grid, a flow accumulation grid , vector watersheds layer, and length (LS) factor grid were all generated.

The final input layer to be loaded was the soils data layer. Through the Options menu of the N-SPECT Advanced Settings, a new soil configuration was added in the Soil Setup window. The layer was named, and the Kuils River DEM layer was chosen as the DEM grid. The Kuils River soils layer was then selected as the Soils Dataset and the corresponding fields that contained attributes of the hydrologic soil group and the soil Erodibility were assigned.

6.4.2 The N-SPECT Run

A typical N-SPECT run begins with watershed delineation. N-SPECT removes artificial sinks and other imperfections that are commonly found in raw topography data sets using the FILL command. Next, a flow direction grid is generated from the DEM by calculating the downstream flow path of water leaving each cell.

Flow direction is determined by evaluating the relative elevation of the eight cells surrounding the cell in question. The neighbouring cell with the least elevation is identified as the direction of outflow from the current cell (Jenson and Domingue, 1988). The value of the current cell in the output flow direction grid is assigned based on the value of the cell it flows into, as given in Figure 71, where the centre cell is being evaluated. For instance, a cell that flows into the cell to its immediate left would have a value of 16 in the resulting flow direction grid. Assuming that the diagram is oriented in a north-south direction, the values of the output flow direction grid are given as follows: Southeast 2, South 4, Southwest 8, West 16, Northwest 32, North 64, and Northeast 128.

32	64	128
16		1
8	4	2

Figure 70 Flow Direction Grid Values. Source: Jenson and Domingue, (1988).

The flow accumulation grid is created based on the flow direction grid and is used to derive a stream network. The values of the cells in a user-specified weight grid are summed according to the hydrologic linkages represented by the flow direction grid. Each cell contains the total value of all upstream cells that flow through it along the flow paths dictated by the flow direction grid (Jenson and Domingue, 1988). The maximum value from the flow accumulation grid is multiplied by one of the predefined threshold values (0.001, 0.01, 0.1), which correspond to small, medium, and large watershed sizes, respectively.

N-SPECT then extracts a stream network by giving all cells in the flow accumulation grid that exceed the defined threshold (0.1%, 1%, 10% of total flow accumulation) a numeric value, and coding all other grid cells as NoData. Therefore, the number of upstream grid cells flowing into a given cell must be greater than the threshold percentage of the total flow accumulation to be classified as part of the stream network.

The STREAMLINK command partitions the larger stream network into links where one or more reaches come together. The WATERSHED command delineates all of the cells that flow directly into each of the individual stream links. The resulting grid is the basis for the watershed polygons that are the primary product of N-SPECT's watershed delineation process. The results of the water quality assessment are reported using these watershed polygons or a user-defined polygon data layer.

In low-lying areas where there is no significant relief as they are nearly flat, flow occurs mostly as sheet flows and digital elevation models are not precise enough to represent these subtle changes in elevation. This typically results in the omission of significant areas of the study area from the final watershed delineation and prevents the watersheds from reaching the actual outfall. This is because these cells are not connected, via the flow direction grid, to any grid cells identified as part of the larger stream network.

6.4.3 Upstream and Local Effects

N-SPECT allows users to examine both local and upstream contributions to pollutant loads. "Local effects" refers to pollution generated by a single cell or group of cells with no input from upstream sources. Upstream effects include local effects but also incorporate pollutants flowing into the current cell from upstream cells according to the flow direction grid. Local effects are simple to calculate within a grid environment, but upstream effects present a challenge. In order to accurately estimate upstream pollutant contributions for a given cell, N-SPECT needs to be able to easily determine all of the cells that flow into the current cell (N-SPECT, 2004).

The BASIN command delineates the major drainage basins within a given DEM. This is accomplished by identifying ridge lines and watershed pour points, and then using the flow direction grid to determine all cells that drain the same area. N-SPECT executes the BASIN command on the DEM and converts the resulting grid to a shapefile. Intersecting this basin shapefile with a user-defined area of interest (polygon shapefile) yields an approximation of the upstream contributing area and the relevant polygons from the basin layer are used to clip the DEM and other input grids. Although this approach is not ideal, it provides a reasonable estimate of contributions from upstream sources (N-SPECT, 2004).

6.5 Discussion of Model Outputs

A basic run of N-SPECT was performed using the customized data sets for the Kuils River area and the results that were obtained from the analysis were just baseline approximations of surface runoff, and pollution mobilization caused by surface runoff. In total, nine output data sets (maps) were produced during the analysis and were organised within a group layer and the project named as 'N-SPECT_Kuils'. The output data sets that were produced during the analysis are the following: Accumulated Runoff (L), Total Phosphorus concentration (mg/l), Total Nitrogen Concentration (mg/l), Nitrate Concentration (mg/l), Chloride Concentration (mg/l), Total Suspended Solids Concentration (mg/l), Accumulated Loads of Total Nitrogen, Nitrates, Total Phosphorus, Chlorides, TSS, Limits raster for Total Phosphorus, Total Nitrogen, Chlorides, Nitrates, TSS. Figures 72 to 93 are the output grids that were generated after the model run on Kuils River Data. The layers have been displayed in pairs to ease comparison between conditions in the year 2006 and 2007.

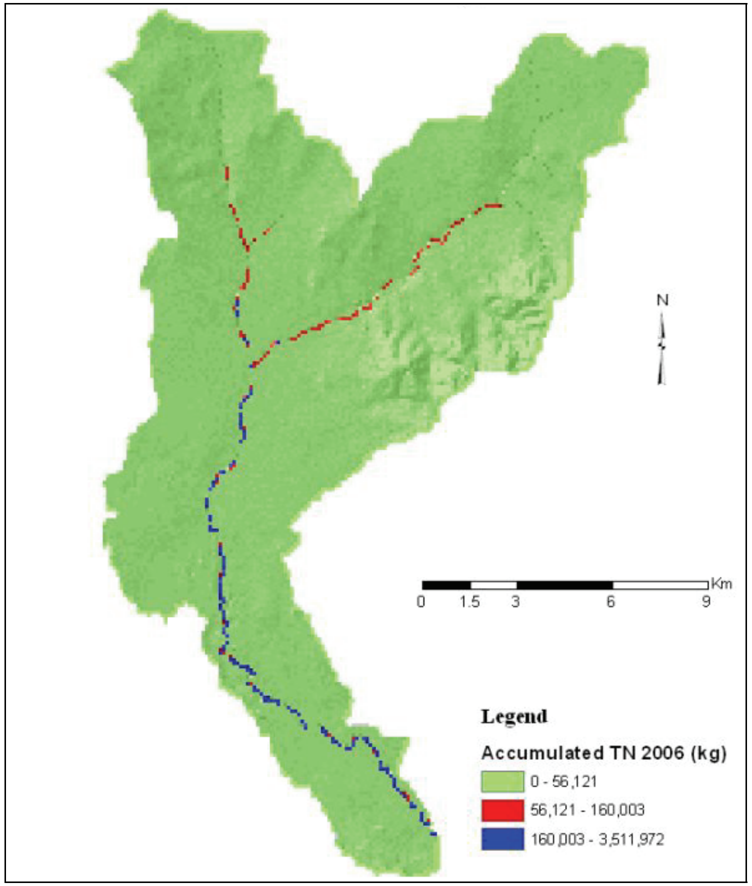


Figure 71 Map showing the Total Nitrogen accumulated in the year 2006.

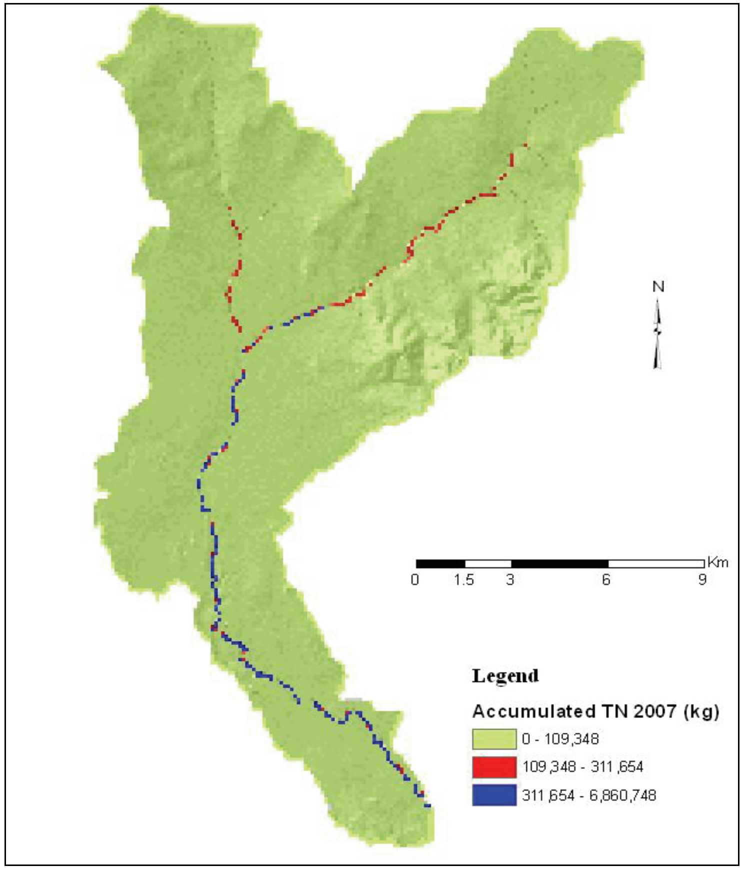


Figure 72 Map showing Total Nitrogen load accumulated in the year 2007.

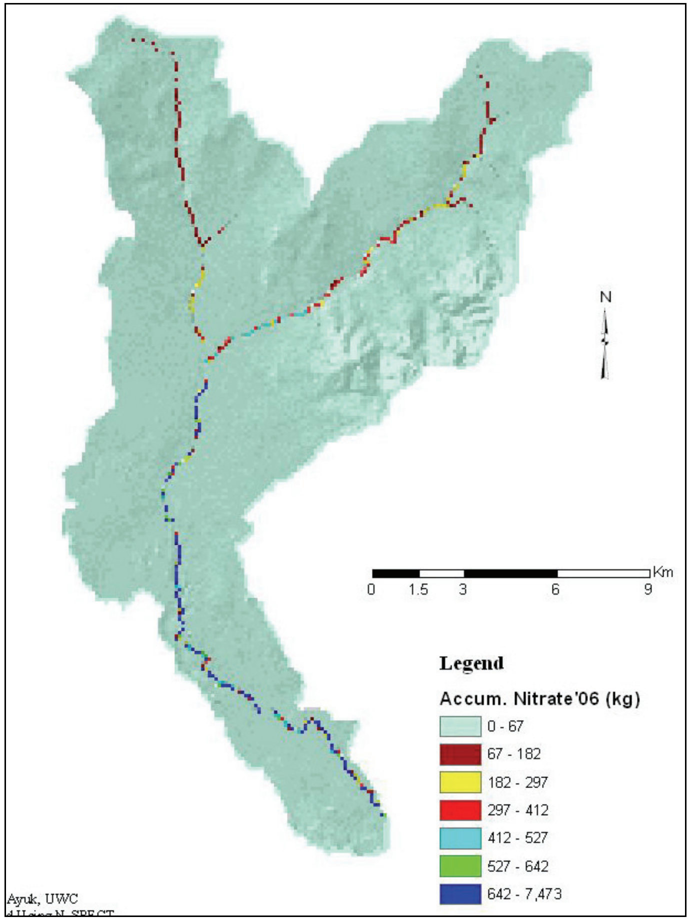


Figure 73 Map of Nitrate load accumulated during 2006 in the Kuils River catchment.

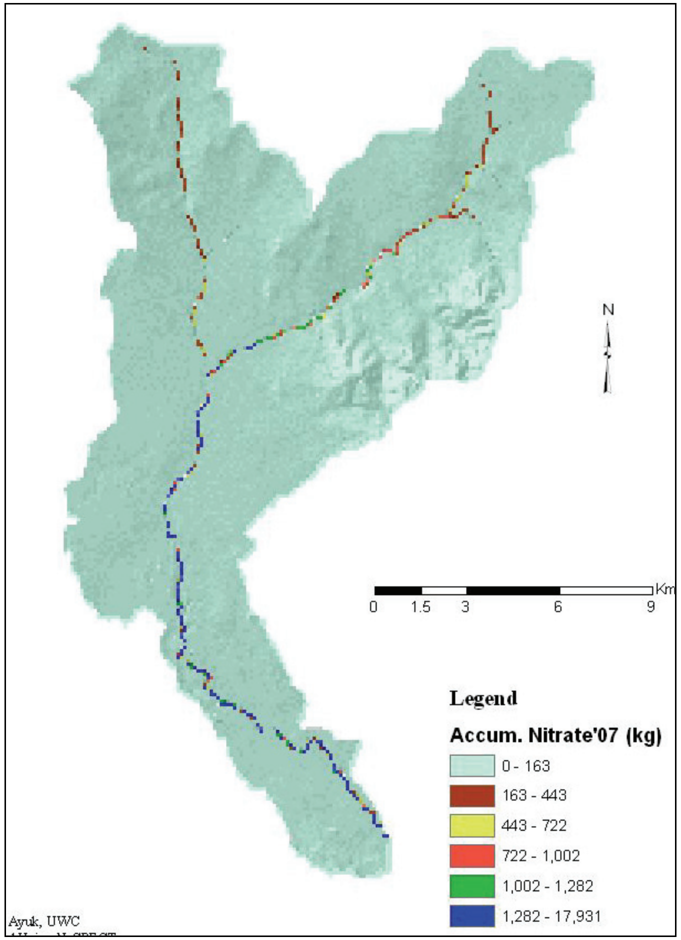


Figure 74 Map showing the Nitrate load accumulated in the year 2007.

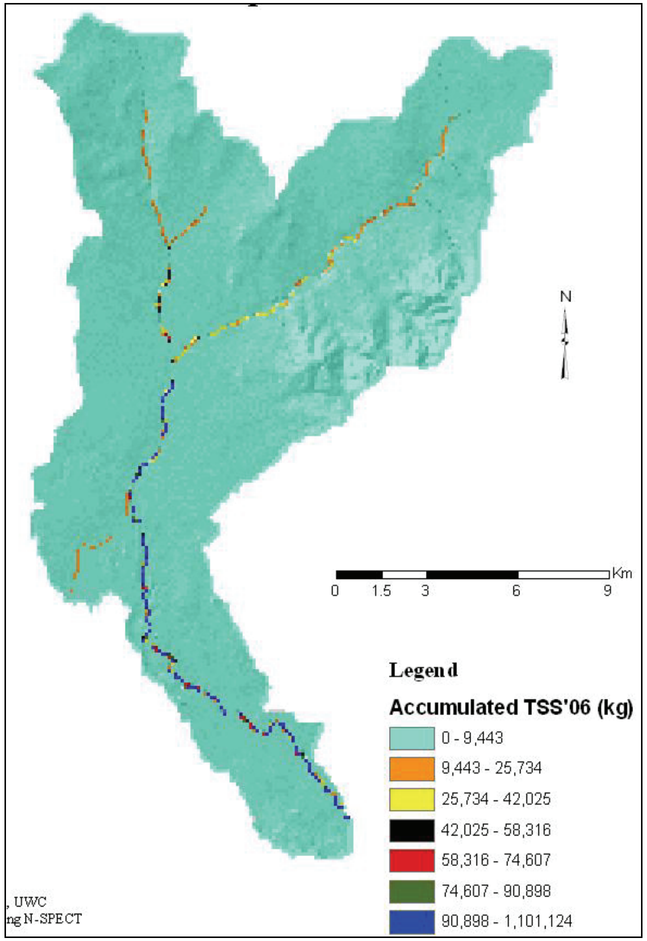


Figure 75 Total Suspended Solids Loads accumulated during 2006 in the Kuils River catchment.

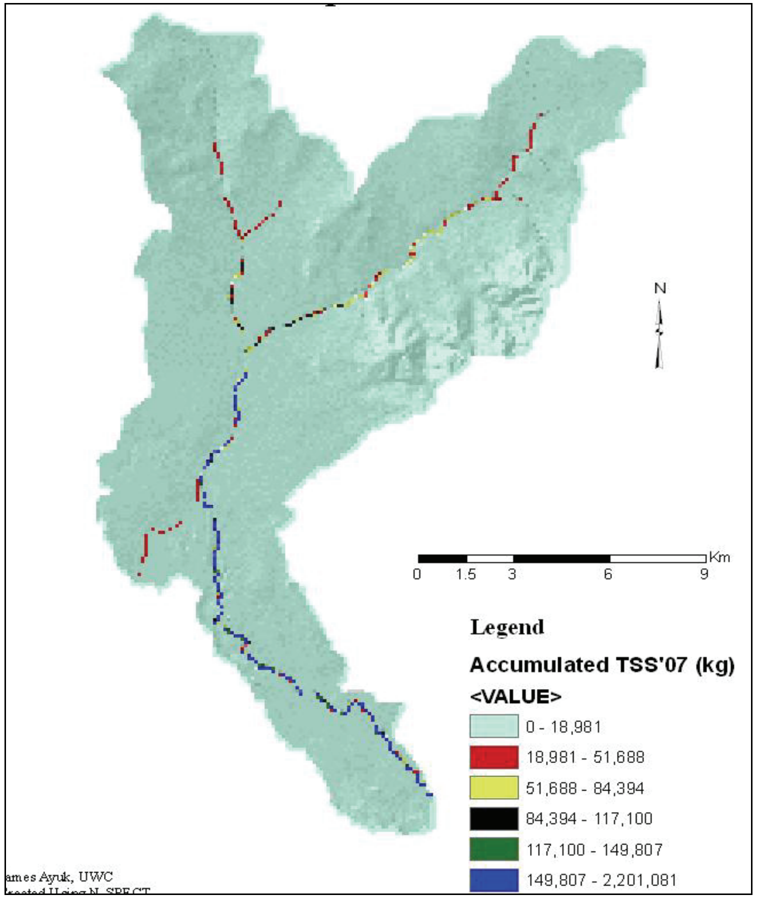


Figure 76 Total Suspended Solids Load accumulated during 2007 in the Kuils River catchment.

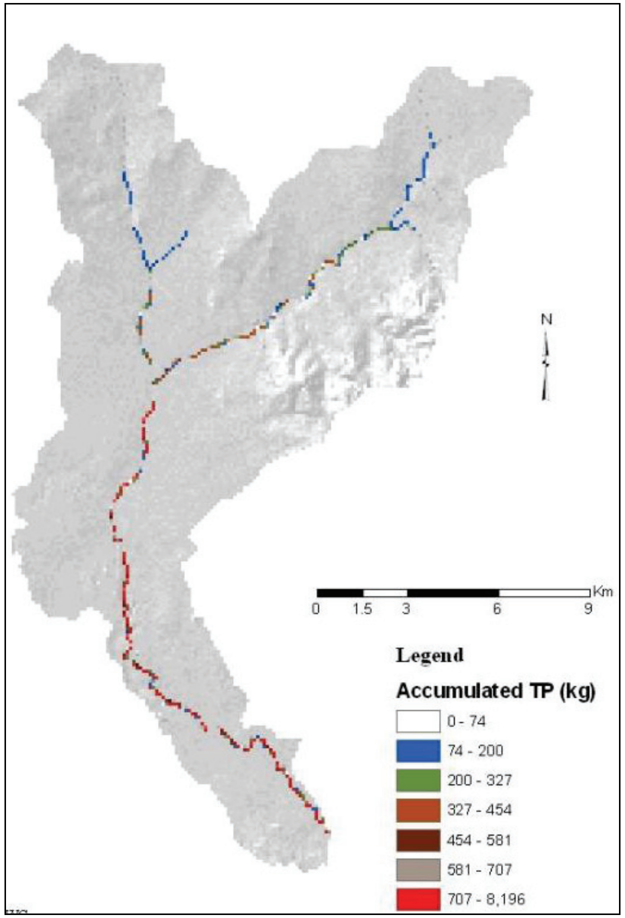


Figure 77 Total Phosphates accumulated loads in 2006

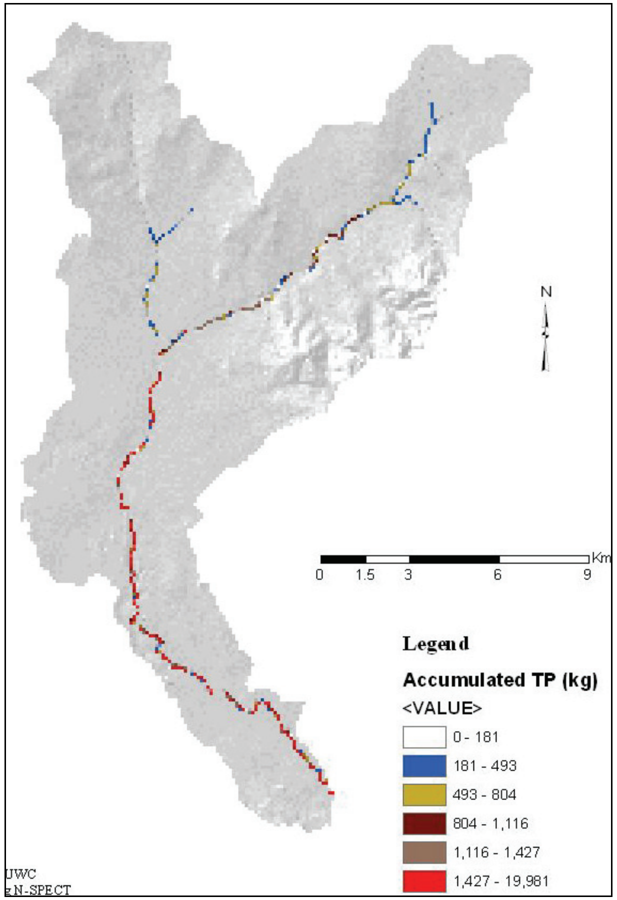


Figure 78 Total Phosphates accumulated loads 2007.

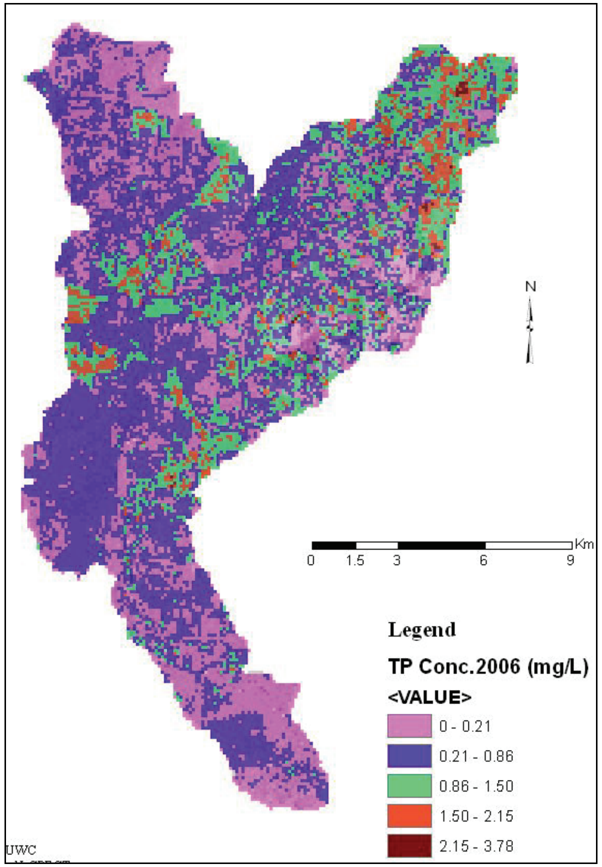


Figure 79 Distribution of TP in Kuils River catchment for 2006.

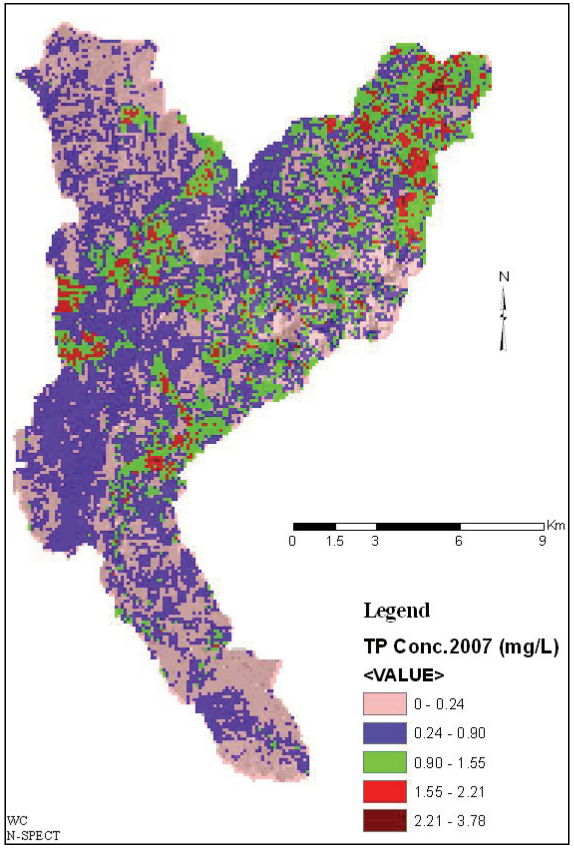


Figure 80 Distribution of TP in Kuils River catchment for 2007.

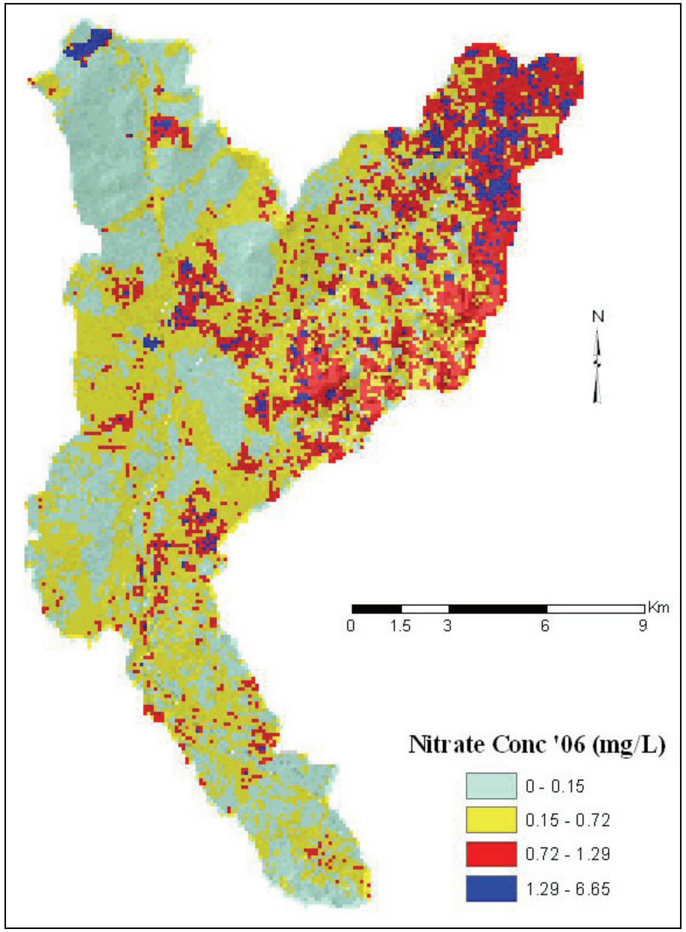


Figure 81 Nitrates map of the Kuils River catchment in 2006.

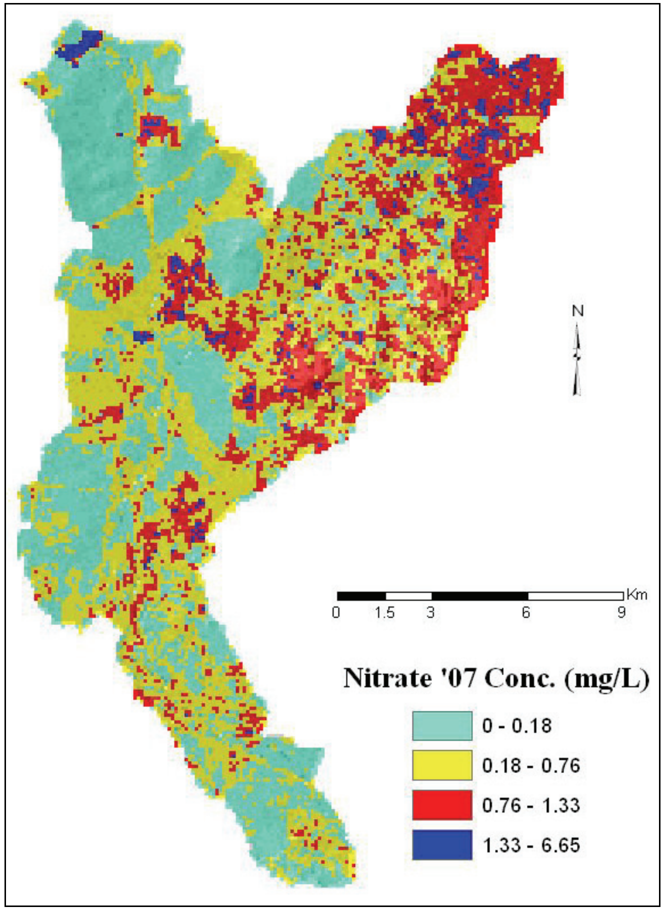


Figure 82 Nitrates map of the Kuils River catchment in 2007.

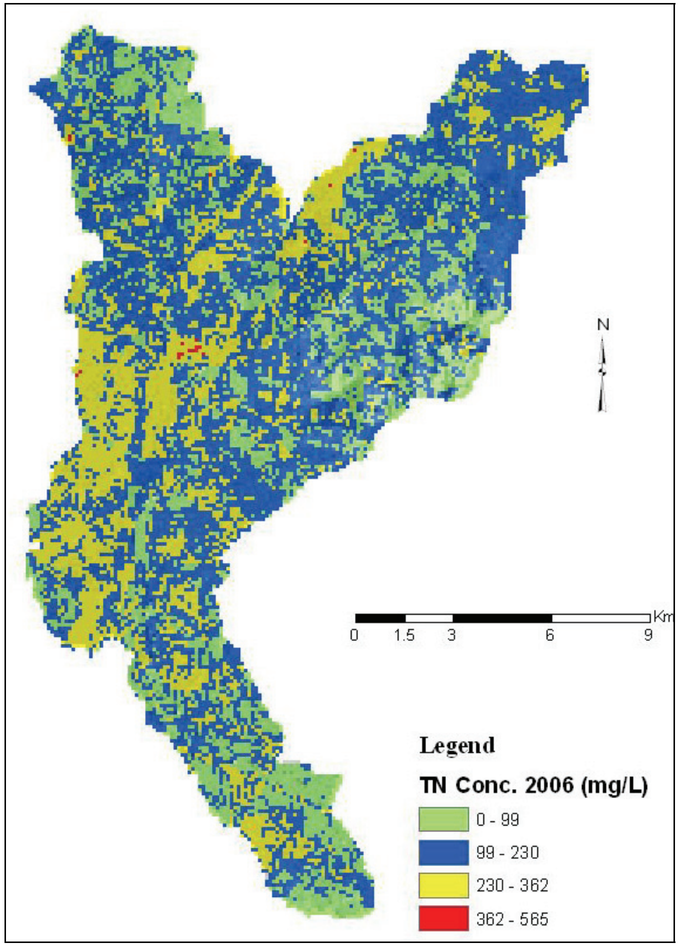


Figure 83 Nitrates map of the Kuils River catchment in 2006.

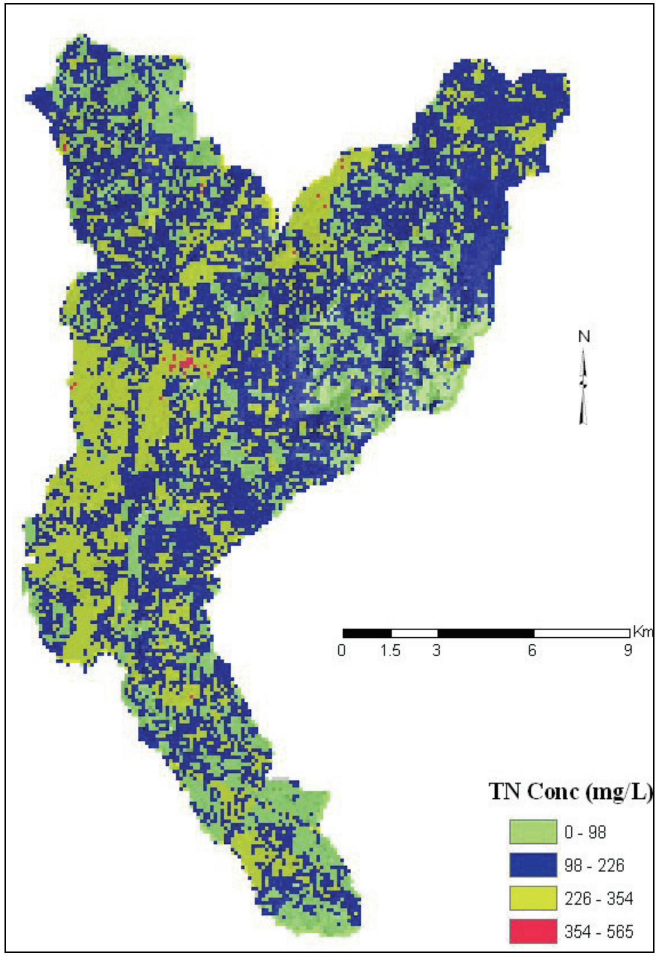


Figure 84 Nitrates map of the Kuils River catchment in 2007.

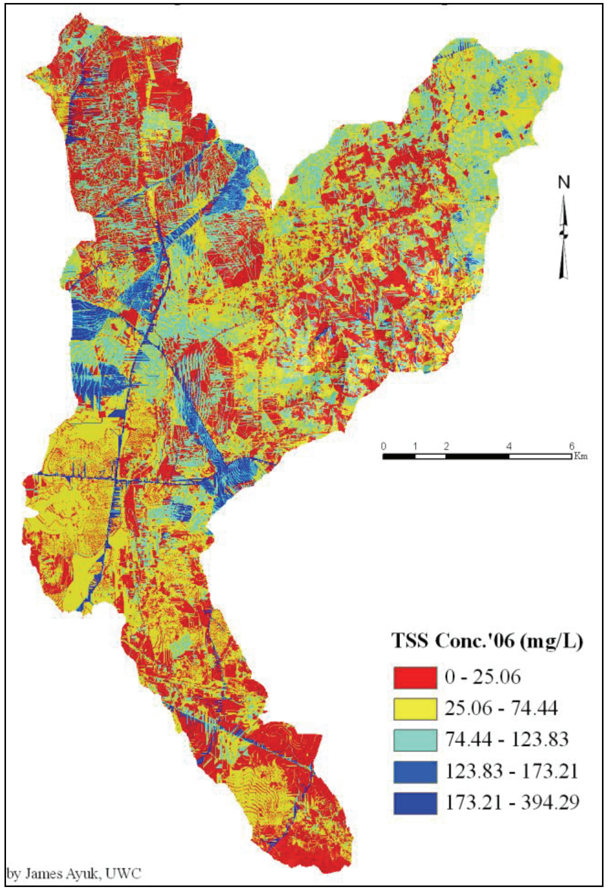


Figure 85 Distribution map of TSS in 2006.

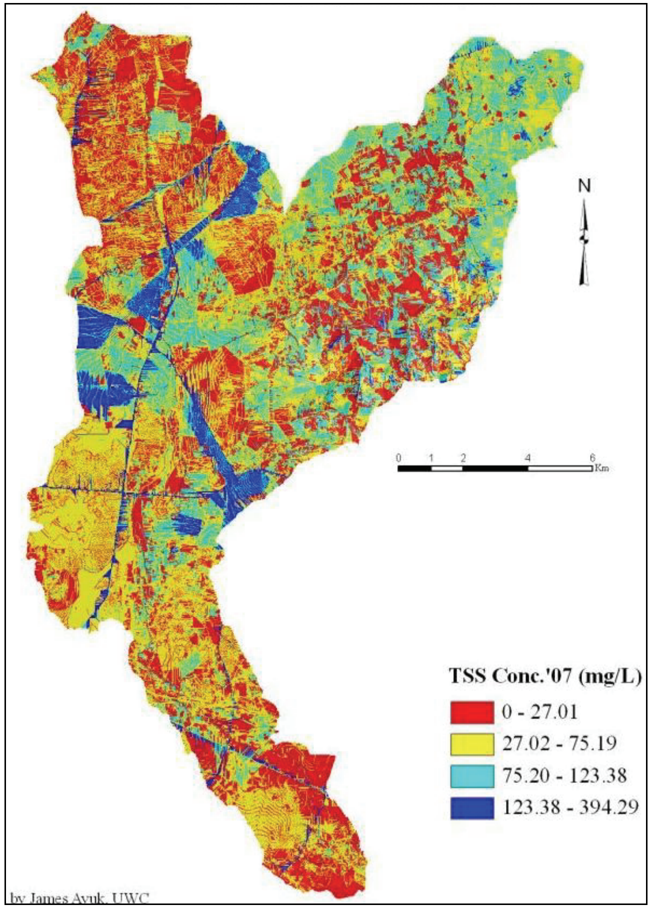


Figure 86 Distribution map of TSS in 2007.

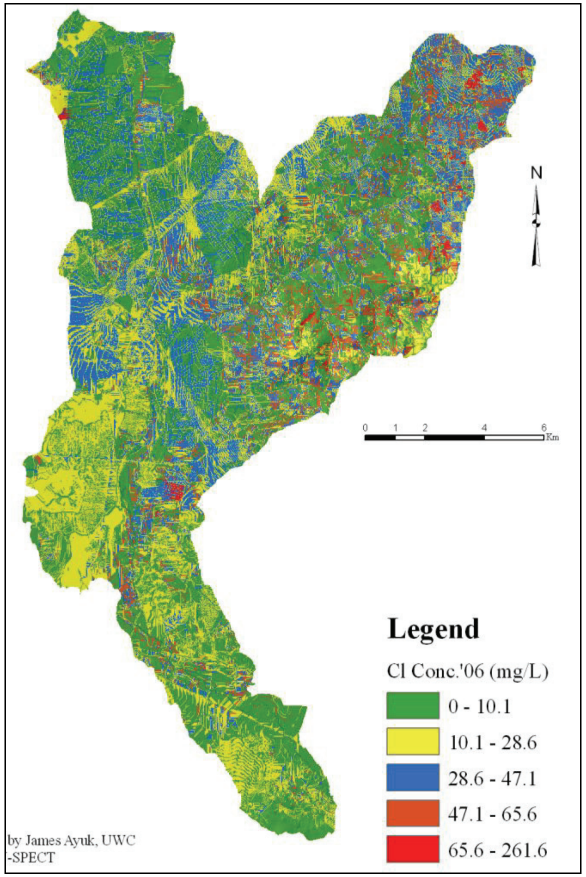


Figure 87 Distribution map of Chlorides in 2006.

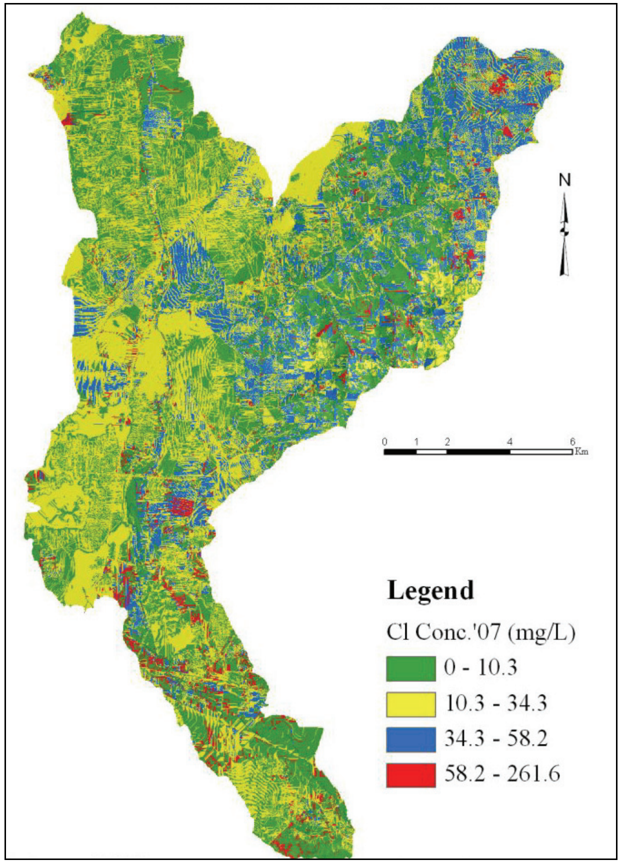


Figure 88 Distribution map Chlorides in 2007

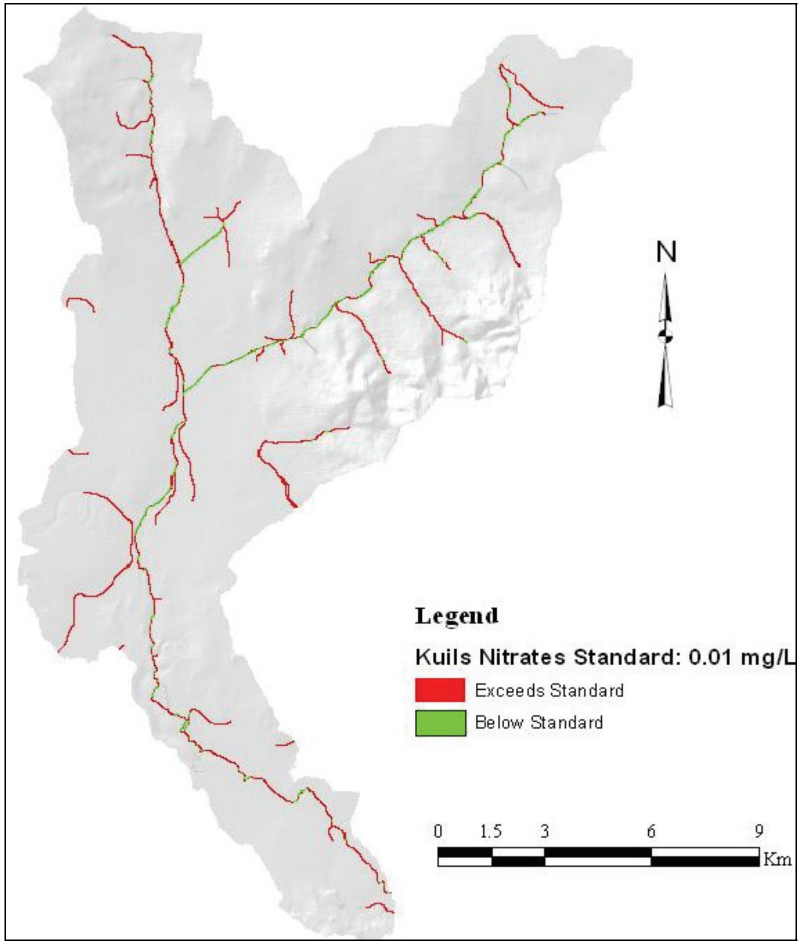


Figure 89 Map of nitrate contamination levels in the Kuils River

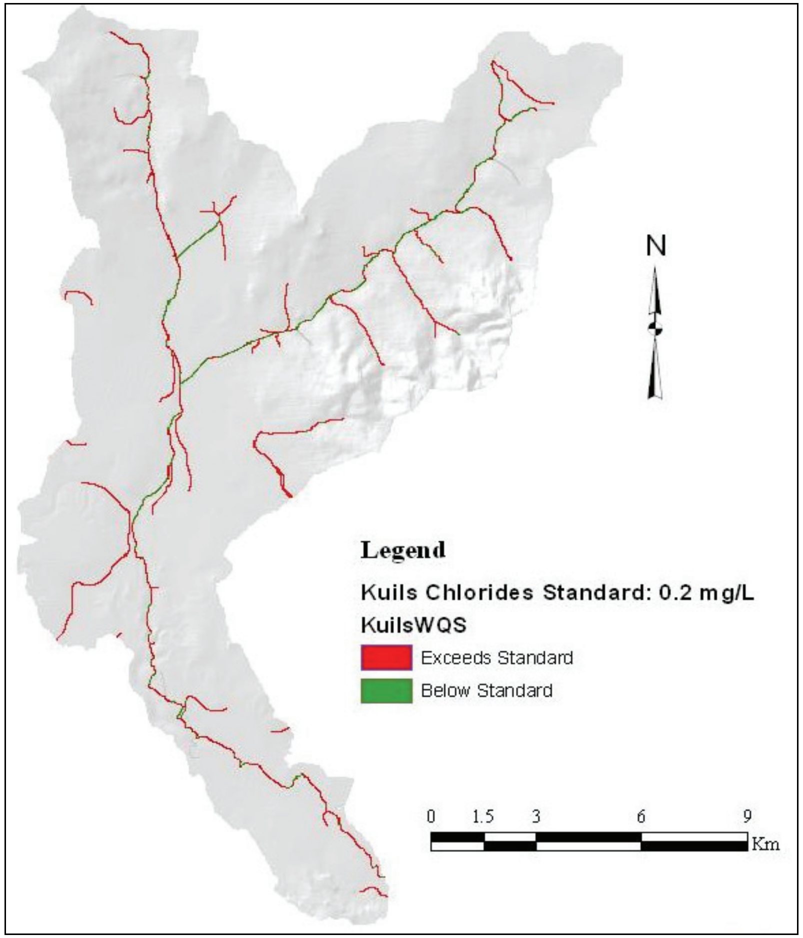


Figure 90 Map of chloride pollution levels in the Kuils River system.

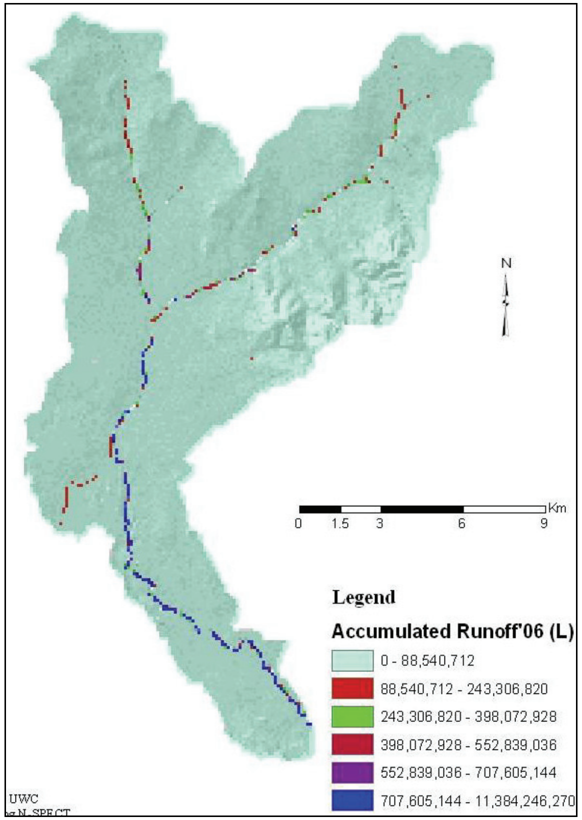


Figure 91 Accumulated runoff (L) in Kuils River during 2006.

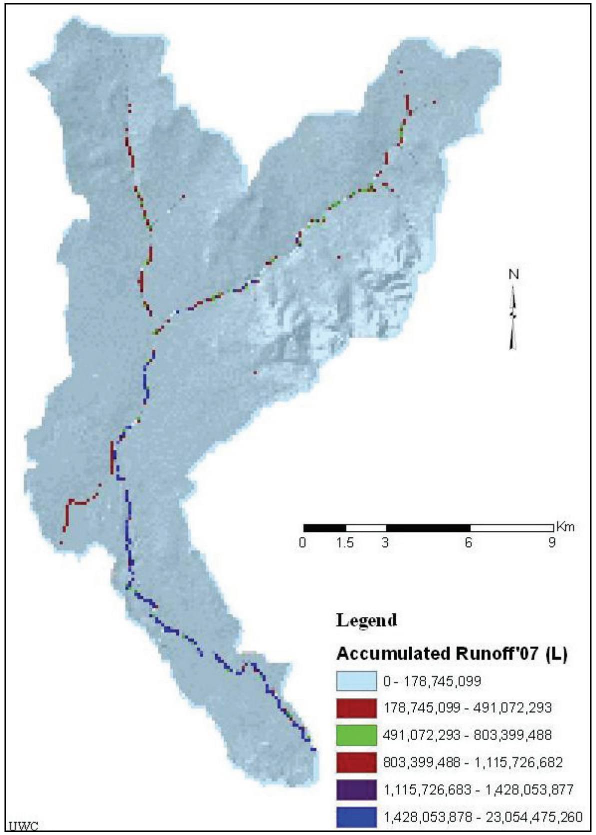


Figure 92 Accumulated runoff volume in the Kuils River channel during 2007.

The results reveal that the accumulated loads of pollutants from the catchment increased substantially for all the pollutants from the year 2006 to the year 2007. Figures 72 and 73 show annual Nitrogen loads increased from 3,511,972 kg (3511.972 t^{-1}) in 2006 to 6,860,748 kg (6860.748 t^{-1}) in 2007. Similarly, annual Nitrates loads increased from 7,473kg (7.473 t^{-1}) to 17,931kg (17.931 t^{-1}) (Figures 74 and 75), TSS loads from 1,101,124 kg (1101.124 t^{-1}) to 2,201,081 kg (2201.081 t^{-1}) (Figures 76 and 77), TP from 8,196 kg (8.196 t^{-1}) in 2006 to 19, 981 kg (19.981 t^{-1}) in 2007 (Figure 78 and 79), etc. This could be explained by the possible increase mobilisation of pollutants by increased surface runoff between these two years. Rainfall interpolation results revealed that there was an increase in precipitation between 2006 and 2007 (Table 7.6). This slight increase in total rainfall amounts is the possible cause of this increase in accumulated pollutant loads because increased rainfall meant increased mobilisation and transportation of pollutants due to impacting by rain drops and the occurrence of higher volumes of runoff on the surface. Above all, the results confirm that surface water pollution is in an upward trend and at incredible rates in the catchment.

In related results, the model simulations revealed that, there was an increase in discharge loads at the mouth of the catchment from 2006 to 2007. Runoff volumes in 2006 were estimated to be 11384200 m^3 in total per annum whereas discharge was estimated at 23054500 m^3 in the following year 2007 (Figures 80 and 81). This increase could also be tied to the effects of increased discharge and to some extend a possible increase in the amount of runoff generated from the continuous increase in disturbed (impervious) surfaces in the catchment. Disturbed land surfaces include compacted surfaces, channelized surfaces, constructions, which are some of the activities that increase the imperviousness of the surface thereby leading to more flows and less underground recharge.

One of the outputs of the analysis by N-SPECT is the pollutant concentration grid. This is a map layer showing the spatial distribution of pollutants in the catchment and compares the contributions of each land use/cover to the observed pollution generated. A spatial observation of the pollutant distribution maps does not reveal any changes in the spatial extent to which pollutants are generated between the two years (Figures 92 and 93). But the N-SPECT model provides a program through which catchment parameters (characteristics) could be calculated. These calculations run in VBScript or avenue script environment. These scripts could calculate the perimeter and the area of the catchment and immediately use the above to calculate the basin/catchment shape. The basin shape is a ratio of the basin perimeter and the square of the basin area. It is a very important characteristic in that it influences the time of concentration and the magnitudes of peak discharge for any precipitation event. Lower values represent more compact basins and higher values represent more elongated basins. Elongated basins exhibit more sustained hydrographs than rounded basins resulting in a steady input to the outlet.

The basin shape could not be deduced through the program of N-SPECT due to some fault in PC system that harboured the model. The VBScript that is necessary for the above was absent or defective. But efforts were made to manually measure the perimeter of the catchment which measured to approximately, 96,060 m (96 km).The area of the catchment was extracted from the attribute table of the land use grid data layer, 201,126,600 m^2. Computing basin shape using these two values as follows:

Basin shape = Perimeter/ [area] $^{\mathbf{2}}$ Equation 6.9

The basin ratio is an infinitesimally small quotient which confirms that the catchment is a constrained one with possibly low time of concentration or rapidly peaking hydrographs exhibiting rapid discharge rates after an event. Furthermore, the river has been prone to flash floods on account of the effects of large impervious surfaces and extensive channelization of water ways making concentration times to be very short as a result.

6.5.1 Extracting land use specific pollutant contributions

ArcGIS Spatial Analyst was used to perform Zonal statistical analysis on the land use layer using the available pollutant data produced during earlier analysis. The zone data set was the land use of Kuils River (Kuils) grid, the zone field was the <Name>, and the value raster was chosen as the respective output layers of N-SPECT baseline analysis using the Kuils River inputs data. The results from these calculations occur in tables that summarize the pollutant load raster values for each land use class in the Kuils River catchment and using the "join output table to zone layer" command in the Zonal Statistics window, the land use class layer data is joined to the statistical values. The Zonal Statistics tool was used to summarize raster values for each unique land use / land cover class in the Kuils River data layer and the contribution of specific land uses to total pollution was assessed using the results that were obtained from baseline analysis in the Kuils River catchment using N-SPECT model. The statistical value for each class was created in tables and later linked (joined) to the original raster classes. During Zonal statistics analysis extra care was taken to automatically add output tables to the zone layer and the results achieved displayed quantitatively using the symbology scheme in a GIS map window. Figures 55 to 72 show the spatial distribution of pollutants but these maps alone may not be enough to adequately interpret the actual prevailing scenarios. Statistical tables become handy aids for better interpretation of modelling results.

Table 38 shows the percentage contribution of each land use class to each pollutant investigated. The table also includes the contribution to runoff by each of the available land uses. A spatial distribution map alone would not be sufficient for a qualitative analysis of the contribution of land use activities to pollution. The Zonal statistics table (Table 39) further reveals that, built up/impervious areas and the vineyards were the most prominent suppliers of TSS to the overall TSS load, followed by density formal MDR and informal HDR formal township residential areas.

Table 38 Percentage contribution of each land use to the concentration of pollutants.

NAME	CODE	COUNT	AREA m2	% TSS'06	% TSS'07	% TP'07	% TP'06	Nitrate'07	Nitrate'06	Runoff '07	Runoff'06	% Cl '06	% Cl'07	% TN'06	% TN'07
Mountain Forest	1	4564	456400	0.18	0.28	0.12	0.12	0.26	0.26	0.16	0.16	0.16	0.16	0.11	0.11
Riparine Forest/Natural Forest	2	32045	3204500	0.92	0.97	0.44	0.44	0.84	0.84	6.02	6.02	0.76	0.76	0.59	0.59
Dense Scrub	3	71640	7164000	2.25	2.49	1.25	1.25	2.28	2.28	17.14	17.14	2.92	2.92	1.72	1.72
Fynbos	4	122812	12281200	4.13	4.43	2.67	2.67	6.66	6.66	8.30	8.30	5.86	5.86	3.39	3.39
Grassland	5	26411	2641100	0.79	0.82	0.66	0.66	0.66	0.66	5.94	5.94	0.83	0.83	0.78	0.78
Impervious Surface	6	14926	1492600	0.98	0.97	0.38	0.38	1.06	1.06	1.80	1.80	0.51	0.51	1.02	1.02
Railway Line	7	2737	273700	0.22	0.22	0.18	0.18	0.15	0.15	0.07	0.07	0.15	0.15	0.18	0.18
Bare ground/Impervious Surface	8	16270	1627000	1.29	1.23	0.56	0.56	1.16	1.16	4.71	4.71	0.71	0.71	1.20	1.20
Bare Rock	9	4	400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Open Vineyard/Hard Rock	10	84510	8451000	4.17	4.22	2.46	2.46	4.63	4.63	2.35	2.35	7.19	7.19	6.44	6.44
Open Area/Barren Land	11	53778	5377800	2.31	3.27	1.55	1.55	3.38	3.38	7.19	7.19	7.88	7.88	2.55	2.55
Improved Grassland/Veg Crop	12	74855	7485500	2.90	2.93	3.49	3.49	2.44	2.44	9.63	9.63	3.66	3.66	2.37	2.37
Buildings/Impervious	13	23284	2328400	1.24	1.23	0.55	0.55	1.74	1.74	1.81	1.81	0.75	0.75	1.56	1.56
Dense/Grassy Vineyard	14	324516	32451600	12.58	12.71	18.44	18.44	19.64	19.64	21.86	21.86	15.67	15.67	11.58	11.58
Fallow/Open Vineyards	15	307574	30757400	20.66	20.41	34.83	34.83	36.03	36.03	2.96	2.96	23.06	23.06	18.64	18.64
Recreation Grass/Golf Course	16	20989	2098900	0.48	0.47	0.29	0.29	0.27	0.27	0.13	0.13	0.57	0.57	0.59	0.59
Freeways/Express Ways	17	2598	259800	0.34	0.33	0.04	0.04	0.06	0.06	0.12	0.12	0.07	0.07	0.24	0.24
Arterial Roads/Main Roads	18	10789	1078900	2.33	2.21	0.41	0.41	0.28	0.28	0.47	0.47	0.56	0.56	0.49	0.49
Minor Roads	19	96821	9682100	5.10	5.05	3.57	3.57	1.69	1.69	1.52	1.52	4.21	4.21	6.45	6.45
Sandy	20	44483	4448300	1.27	1.23	1.12	1.12	1.11	1.11	0.60	0.60	1.06	1.06	1.64	1.64
Waterbodies	21	14035	1403500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HDR Formal Suburb	22	65691	6569100	4.85	4.77	4.71	4.71	1.35	1.35	1.01	1.01	3.66	3.66	6.12	6.12
MDR Formal Suburb	23	300817	30081700	9.19	8.95	5.83	5.83	2.69	2.69	2.06	2.06	7.43	7.43	11.11	11.11
LDR Formal Suburb	24	10353	1035300	0.27	0.26	0.18	0.18	0.18	0.18	0.08	0.08	0.23	0.23	0.34	0.34
HDR Formal Township	25	156317	15631700	7.60	6.88	4.29	4.29	3.42	3.42	3.14	3.14	4.72	4.72	11.47	11.47
MDR Formal Township	26	29127	2912700	1.12	1.06	0.71	0.71	0.59	0.59	0.10	0.10	0.79	0.79	2.04	2.04
LDR Formal Township	27	236	23600	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02
HDR Informal Township	28	9859	985900	0.30	0.29	0.28	0.28	0.11	0.11	0.04	0.04	0.26	0.26	0.43	0.43
MDR Informal Township	29	3311	331100	0.53	0.58	0.55	0.55	0.34	0.34	0.01	0.01	0.55	0.55	0.12	0.12
MDR Informal Squatter Camps	30	11243	1124300	0.44	0.41	0.26	0.26	0.21	0.21	0.08	0.08	0.39	0.39	0.84	0.84
LDR Informal Squatter Camps	31	1593	159300	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.02	0.02	0.03	0.03
Commercial-Mercantile	32	5740	574000	0.46	0.45	0.13	0.13	2.47	2.47	0.03	0.03	0.25	0.25	0.35	0.35
Commercial-Institutional	33	24	2400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industrial	34	79343	7934300	11.03	10.83	10.01	10.01	4.28	4.28	0.68	0.68	5.11	5.11	5.56	5.56
Cemeteries	35	2091	209100	0.03	0.03	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
River	36	6104	610400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 39 Example of Zonal Statistics Table for Total Suspended Solids in 2006

VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM		% Contr	Wt Area
1	4564	456400	0.00	394.29	394.29	41.12	53.55	187664	101819166.47	0.18	0.00
2	32045	3204500	0.00	394.29	394.29	29.27	52.32	937964	101819166.47	0.92	0.00
3	71640	7164000	0.00	394.29	394.29	31.96	52.63	2289900	101819166.47	2.25	0.00
4	122812	12281200	0.00	394.29	394.29	34.21	41.31	4201630	101819166.47	4.13	0.00
5	26411	2641100	0.00	394.29	394.29	30.60	54.29	808168	101819166.47	0.79	0.00
6	14926	1492600	0.00	359.38	359.38	67.00	45.94	1000100	101819166.47	0.98	0.00
7	2737	273700	0.00	394.29	394.29	81.38	70.16	222747	101819166.47	0.22	0.00
8	16270	1627000	35.07	393.89	358.81	80.68	74.10	1312650	101819166.47	1.29	0.00
9	4	400	0.00	35.28	35.28	26.46	15.28	106	101819166.47	0.00	0.09
10	84510	8451000	30.72	392.26	361.54	50.27	23.42	4248710	101819166.47	4.17	0.00
11	53778	5377800	0.00	394.29	394.29	43.79	57.20	2355010	101819166.47	2.31	0.00
12	74855	7485500	0.00	394.29	394.29	39.49	56.38	2956240	101819166.47	2.90	0.00
13	23284	2328400	0.00	365.67	365.67	54.14	29.98	1260560	101819166.47	1.24	0.00
14	324516	32451600	0.00	394.29	394.29	39.46	46.09	12804400	101819166.47	12.58	0.00
15	307574	30757400	35.07	394.25	359.18	68.40	21.36	21037700	101819166.47	20.66	0.00
16	20989	2098900	0.00	394.29	394.29	23.44	45.59	491960	101819166.47	0.48	0.00
17	2598	259800	65.57	229.21	163.63	132.17	32.31	343388	101819166.47	0.34	0.00
18	10789	1078900	45.74	383.24	337.50	219.82	70.31	2371690	101819166.47	2.33	0.00
19	96821	9682100	0.00	361.64	361.64	53.64	25.19	5193080	101819166.47	5.10	0.00
20	44483	4448300	0.00	394.29	394.29	29.09	45.60	1294180	101819166.47	1.27	0.00
21	14035	1403500	0.00	0.00	0.00	0.00	0.00	0	101819166.47	0.00	0.00
22	65691	6569100	0.00	391.42	391.42	75.22	27.12	4941010	101819166.47	4.85	0.00
23	300817	30081700	0.00	394.29	394.29	31.11	45.24	9358360	101819166.47	9.19	0.00
24	10353	1035300	0.00	394.29	394.29	26.16	39.86	270808	101819166.47	0.27	0.00
25	156317	15631700	8.57	391.31	382.74	49.53	41.40	7742920	101819166.47	7.60	0.00
26	29127	2912700	20.90	392.21	371.31	39.15	21.94	1140290	101819166.47	1.12	0.00
27	236	23600	0.00	75.00	75.00	58.93	26.79	13907	101819166.47	0.01	0.00
28	9859	985900	17.53	336.19	318.65	30.64	14.20	302105	101819166.47	0.30	0.00
29	3311	331100	38.05	316.54	278.49	162.04	74.54	536518	101819166.47	0.53	0.00
30	11243	1124300	20.51	283.53	263.02	40.01	17.06	449877	101819166.47	0.44	0.00
31	1593	159300	0.00	75.00	75.00	10.36	21.82	16497	101819166.47	0.02	0.00
32	5740	574000	56.09	291.29	235.20	82.20	24.49	471816	101819166.47	0.46	0.00
33	24	2400	54.00	75.36	21.36	69.23	7.94	1662	101819166.47	0.00	0.03
34	79343	7934300	0.00	386.55	386.55	141.52	42.14	11228700	101819166.47	11.03	0.00
35	2091	209100	0.00	192.63	192.63	12.84	41.85	26850	101819166.47	0.03	0.00
36	6104	610400	0.00	0.00	0.00	0.00	0.00	0	101819166.47	0.00	0.00

For instance, Figure 82 shows that the nitrate distribution in the catchment is not uniform. A high percentage of nitrates originate from the eastern ‘horn’ of the catchment where Bottellary River drains mainly medium density residential areas and agricultural lands. Results from the Zonal statistics table (Table 39) confirms this observation, as it shows that about 55.5% of the total nitrate contribution comes from the vineyards and the remainder almost proportionately distributed amongst the remaining 32 classes in the catchment.

6.5.2 Water Quality Limits

Amongst the output grids that were generated after a complete N-SPECT run is a grid of water quality limits. This grid shows the accumulated levels of contaminants in the flow channels in excess of an area specified threshold or water quality standards. Figure 90 and Figure 91 are the water quality limits outputs for nitrates and chlorides, respectively. Looking at both maps shows that the distribution of reaches of the catchment that show water quality exceedance or still within the limits of previously defined water quality standards does not show any variation between the two figures. The same pattern of pollution occurs for all other pollutants that were investigated using the model. The uniformity in these results might simply be interpreted as evidence of the pollution levels in those reaches or it could still be error cause by some bug in the algorithms. However, Figures 90 and 91 shows that the main stream remains within acceptable limits of water quality whereas the contributing streams are beyond the limits. This could be explained by the fact that surface discharges from polluted surface maintain high concentrations but upon entry in the main stream channels that contains higher flows volumes, the inputs from these contributing input streams become diluted and less concentrated. This pattern might also continue downstream with intermittent sections that exceed limits due to increased pollution inputs and alternate dilution effects further downstream. 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.

Proper verification of the efficacy of the model required the use of regular flow observation data for the Kuils River. Such regular readings were never accessed during this study. Therefore attempts were made to gather such data by sampling the stream at selected point and measuring flow from time to time. The procedures that were involved to achieve this aim have been explained in previous chapters.

6.5.3 Local Effect Analysis

Using N-SPECT model, a catchment scale analysis was performed on small catchment that was defined from a point where stream flow measurements were undertaken. The purpose of this procedure was to compare the model estimates with the observed estimates that were measured in the field and by so doing attempt an evaluation of the model results. Figure 94, shows a small catchment that was defined from the point where stream flow was measured on the Kuils River channel. Then on the basis of catchment shape, a local effects analysis was performed using N-SPECT model. The results from these analyses gave a total annual runoff accumulated at the selected point to be 8,449,979,712 or 8.5×10^9 litres. Compared with the observed readings in Table 40 which are discharges computed from flow measurements undertaken at the same point during winter of 2007, it was found that the observed figures were much higher at about 1.23×10^{13} litres.

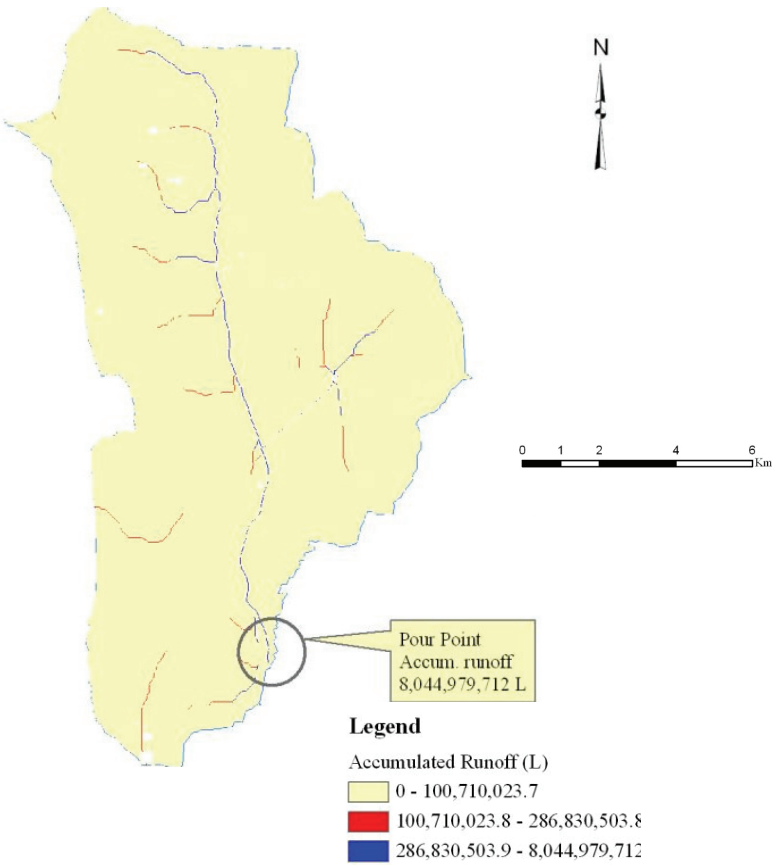


Figure 93 Accumulated runoff from small catchment in Kuils River

Table 40 Annual discharge estimates for selected points on the Kuils River.

Annual Discharge Computations for Selected Points of Measurement				
Catchments	Date	Discharge (m^3/s)	Discharge (Litres/Year)	Data Source
Sonstaal Upper	18.05.2007	1.51×10^{-4}	4761936	Table 11
Sonstaal Lower	18.05.2007	9.8×10^{-4}	30905280	Table 12
Sonstaal Upper	23.07.2007	0.132	4162752000	Table 13
Sonstaal Lower	23.07.2007	0.185	5834160000	Table 14
Sonstaal Upper	27.07.2007	0.354	11163744000	Table 15
Sonstaal Lower	27.07.2007	0.655	20656080000	Table 16
Fairtrees Dr	27.07.2007	0.205	6464880000	Table 19 & 20
Fairtrees Dr downstream	27.07.2007	0.415	13087440000	Table 22
Kuils R (channelised)	13.08.2007	391.72	12353281920000	Table 23
Kuils R (channelised)	14.07.2007	436.58	13767986880000	Table 24

This means that the simulations have not entirely accounted for all the runoff resulting from the catchment to the channel. However, it is important to note that stream discharge was measured just once after an event and the results extrapolated to yearly estimates whereas results from model simulations represent an annual picture where the total rainfall was averaged between 60 rainy days. The above discrepancy in the field and simulated results might even suggest adjustment in the curve number inputs to improve the simulation estimates (i.e. generate more runoff). On the whole, these results remain very inconclusive due to insufficient regular flow data inputs from the stream for verification and calibration of model.

6.6 Conclusions

Between 2006 and 2007, there were no noticeable variations in the percentages of pollutants that emanated from the land use classes when the classes are compared together. This means that the change in precipitation did not influence the potential to generate pollutants so long as the surface conditions remained. With any changes in the land characteristics, one would expect a corresponding response in terms of the potential to emit chemical substances. The results do show that the following classes, vineyards, industrial areas and the MDR residential areas, contribute the most towards the pollution in the catchments' streams and rivers. The vineyards contribute an average of over 40% of the entire load from classes followed by the industries and then the residential areas and open barren lands (see Table 37).

7 WATER QUALITY MANAGEMENT PLAN / GUIDELINES

7.1 Preamble

Even though the City of Cape Town has been working on controlling nonpoint sources of pollution for many years, it has only been in the last five years that a comprehensive focused approach was developed. Prior to that, controlling point sources of pollution was a priority for the different municipal authorities and other state agencies. It was assumed that reducing polluted flows that came out of the end of a pipe would go a long way to solve the city's water quality problems. It did, but another source of pollution then became more obvious.

After a majority of point source discharges were controlled, the City of Cape Town still suffered from water quality degradation. What were these other causes of water quality problems? They were nonpoint sources of pollution. The city's environmental department has long realized that controlling these sources requires a different approach than controlling point sources. Nonpoint pollution is inextricably tied to local land uses and individual actions. City of Cape Town's first Water Quality Plan to control nonpoint source pollution was published in April 2000. In that plan, the City of Cape Town obligated itself to update the nonpoint source pollution every five years by analysing programmes and progress in achieving plan results. This rewrite of the nonpoint source pollution plan recognizes the problem of trying to manage local land uses and individual actions from the Municipality's perspective. The distinguishing characteristic of this plan is to support sustainable communities through the creation and preservation of relationships with local entities. This plan recognizes the role that local governments play in water quality improvements and the importance of public participation in understanding and addressing nonpoint source pollution.

This plan does not capture every activity the City of Cape Town performs to address nonpoint source pollution problems. For instance, it does not contain lengthy descriptions of existing programmes, and makes recommendations about how they should proceed. Instead, the plan focuses on Kuils-Eerste River catchment.

7.2 A Summary of Water Quality in Kuils-Eerste River Catchment

7.2.1 Introduction

The purpose of this summary is to identify catchment-wide problem areas and to identify the reasons for water quality problems. The summary for each sub-catchment contains demographic information, listed problem areas, a list of impacted designated uses, and the programmes and plans in place to control nonpoint sources of pollution. Information has been compiled and synthesized into a series of problem statements describing the nonpoint source pollution problems that have identified. City of Cape Town (CCT) can use this information to understand the range and extent of water quality degradation, to help determine priority areas, and to develop projects and programmes needed to solve those problems.

7.2.1.1 Population Growth

The most startling change in demographics is the growth in population in the city. The CCT area has a population of approximately 3.2 million people with a growth rate of approximately 2% (ICLEI, 2006). This comprises a natural growth rate of 1.1% and an in-migration rate of approximately 1% (Dorrington, 2000).

7.2.1.2 Urban sprawl

The former CCT Spatial Planning Department received a total of 17 applications for land use changes beyond the urban edge during 1999. During 2000, five applications were received from the former Metropolitan Local Councils (MLC's), two were supported and three not supported. These applications excluded applications on the urban edge which were not referred to the former Cape Metropolitan Council (CMC) for metropolitan comment. The total growth on the edge of development for the period 1993 to 1996 was 3.8 km^2. The extent and delineation of the urban edge, as a 20- year outer extent of urban development has been defined. Difficulty has been in quantifying this indicator and no more recent data is available.

What does population growth have to do with nonpoint source pollution? Simply stated, a major factor is the increase of impervious surfaces associated with increases in housing, roads, and business areas. When pavement, roofs, and other hard surfaces replace forests, meadows, and other natural areas they generate stormwater runoff. Stormwater runoff picks up oils, grease, metals, yard and garden chemicals, dirt, bacteria, nutrients, and other pollutants from paved areas, and carries them to streams, rivers, wetlands, and other water bodies.

The current City of Cape Town State of the Environment Year 3 (2000) Report documented the increase in impervious surfaces within the urban area.

7.2.1.3 Land Use and Nonpoint Source Pollution

Nonpoint pollutants are introduced into water through runoff. Rainfall washes off pollutants from the land into rivers, streams, lakes, oceans, and underground aquifers. Land use is strongly correlated to nonpoint pollution. Therefore, to manage nonpoint pollution, we must focus on land use activities.

The intensity of environmental impact from each land use differs. For example, Dense/Grassy Vineyards and fallow/Open Vineyard, making up about 40.6 per cent of the land cover, are generally under the highest contributors of surface water pollutants. Agricultural and forestry land uses account for approximately 61.3 per cent of land in the catchment, which may give an initial impression that the catchment has large land areas that do not contribute much pollution (Figure 95).

However, nonpoint source problems associated with land uses vary from none to very extensive, depending upon location and control programmes in place. The land use that covers the smallest land area (urban areas) may pose the greatest threat to surface water quality by means of stormwater runoff. The major sources of nonpoint pollution can be divided into five categories as shown in Table 41.

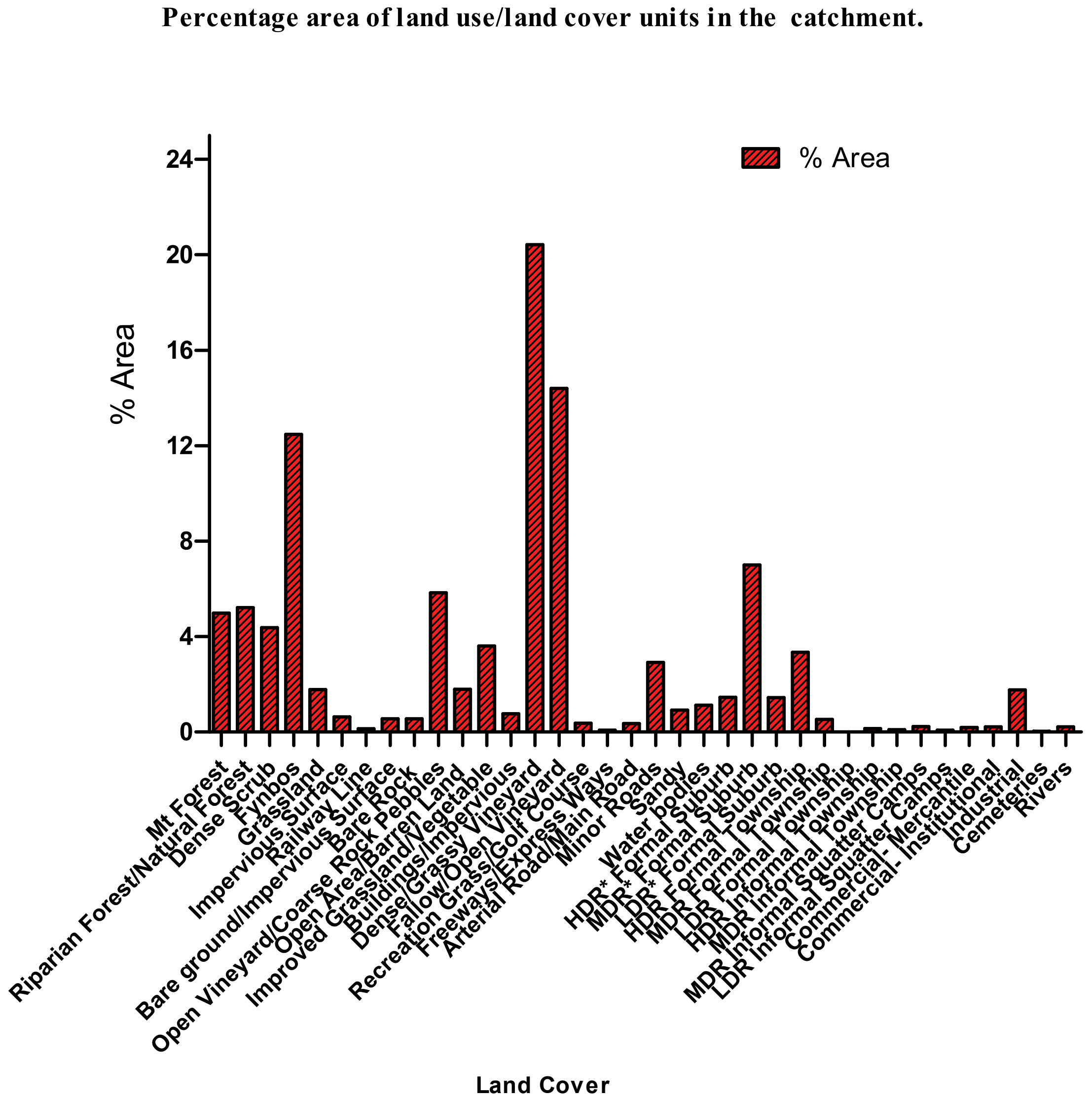


Figure 94 The intensity of environmental impact from each land use differs.

Table 41 Categories of the major sources of nonpoint pollution

Categories	Associated Land Use
Agriculture	Livestock keeping, dry-land and irrigated crops, grazing, non-commercial agricultural
Forest Practices	Road construction and maintenance; harvesting; chemical applications
Urban/Suburban Growth	Storm water runoff; on-site sewage systems; hazardous materials; construction and maintenance of roads and bridges; residential use of fertilizers and pesticides.
Habitat Alteration	Filling of wetlands and alteration of riparian areas; shoreline development, stream channelization.
Recreation	Marinas and boats, off-road vehicles

7.2.2 What is the Quality of Kuils-Eerste River Catchment Water?

7.2.2.1 Water Quality Assessment

According to City of Cape Town: State of the Environment Year 3 (2000) Report the most common water pollution problems in Kuils-Eerste River Catchment have most of their indicators revealing a marked deterioration, notably in the stormwater and marine water quality as well as an increase in the number of algal blooms. Most of these problems are caused by nonpoint source pollution, which is the primary source of pollution in rivers, lakes, and ground water.

The typical pollutants from nonpoint sources and their relative frequency of detection in the Kuils-Eerste River Catchment are shown in Figure 95. It should be noted that the water quality assessment is not a full accounting of the water quality problems in the Kuils-Eerste River Catchment.

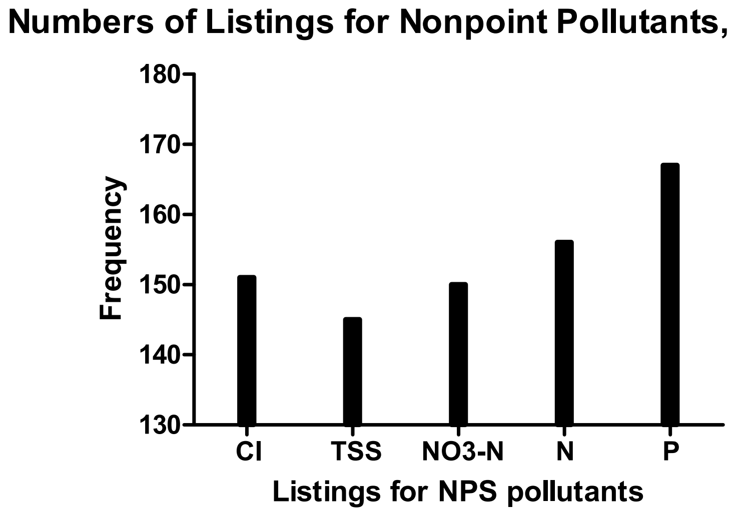


Figure 95 Typical pollutants from nonpoint sources and their relative frequency of detection

The assessment helps to use municipal resources more efficiently by focusing limited time on water bodies that need the most work and to address the problem pollutants that show up most often. The list of water bodies in the assessment reflects local government, and community recognition of water quality problems in the Kuils-Eerste River Catchment – demonstrating community interest in, and commitment to, clean water.

7.3 The Nonpoint Source Pollution Problem

7.3.1 Introduction

Section 8.2 summarized demographic and environmental information from the Kuils-Eerste River Catchment. The summary showed obvious problems associated with the causes and control programmes for nonpoint source pollution. When the City of Cape Town Management Plan was written in 2000, equal emphasis was placed on all the potential sources of nonpoint source pollution: agriculture, urban areas, recreation, and loss of aquatic ecosystems (including hydromodification). However, after some years of programme implementation, coordination of activities, biennial meetings and looking at nonpoint problems with a critical eye, problem areas, some more apparent than others, have appeared.

7.3.1.1 Lessons Learned from the GIS assessment

Nonpoint source pollution is linked to local land uses and individual actions. In order to control water quality impairments resulting from nonpoint sources of pollution, there is need to continue efforts to understand the connections that land use activities have to water quality and to make sure that people living in the catchment understand them, too. There is also, need to coordinate closely with the municipality and other groups. This is the only way it is possible to effectively achieve water quality improvements, create sustainable communities, and maintain the environment that benefits all that live in the catchment.

From the years of implementing management plan in Cape Town, several lessons were learned that it takes time and effort to coordinate implementation activities among the various responsible entities as reflected by the reports reviewed. It has been noted too that Cape Town Metropolitan City and provincial agencies need to work more closely with municipalities to effectively implement nonpoint source pollution programmes. Thus, creating, sustaining, and improving relationships among provincial, municipal, and local entities will be a hallmark effort during the implementation of the guidelines proposed herein.

7.3.1.2 The Way land is used in the catchment

The way land is used is the major contributing factor to nonpoint source pollution. The following chart shows the relative geographic area covered by the different land uses in the Kuils-Eerste River Catchment (Figure 96). By far the largest land use category is Dense/Grassy Vineyard (20.4%). The second largest land use category is Fallow/Open Vineyard (14.4%). The land use that had the largest growth in the last five years is urban use. Even though it has the smallest land base, urban uses cause the greatest impacts. It has been evident for some time that urban and suburban development cause serious water quality problems. Because of the increased area covered by impervious surfaces and the concentration of people, nonpoint pollution through individual actions is well defined.

There is still concern with recreational activities, especially boats and marinas, as contributors to water quality impairment, and there is concern with the loss of aquatic habitat. Intact riparian areas and wetlands are essential for treating storm water runoff before it enters a water body. However, the major focus here is on how land use practices lead to water quality impairments.

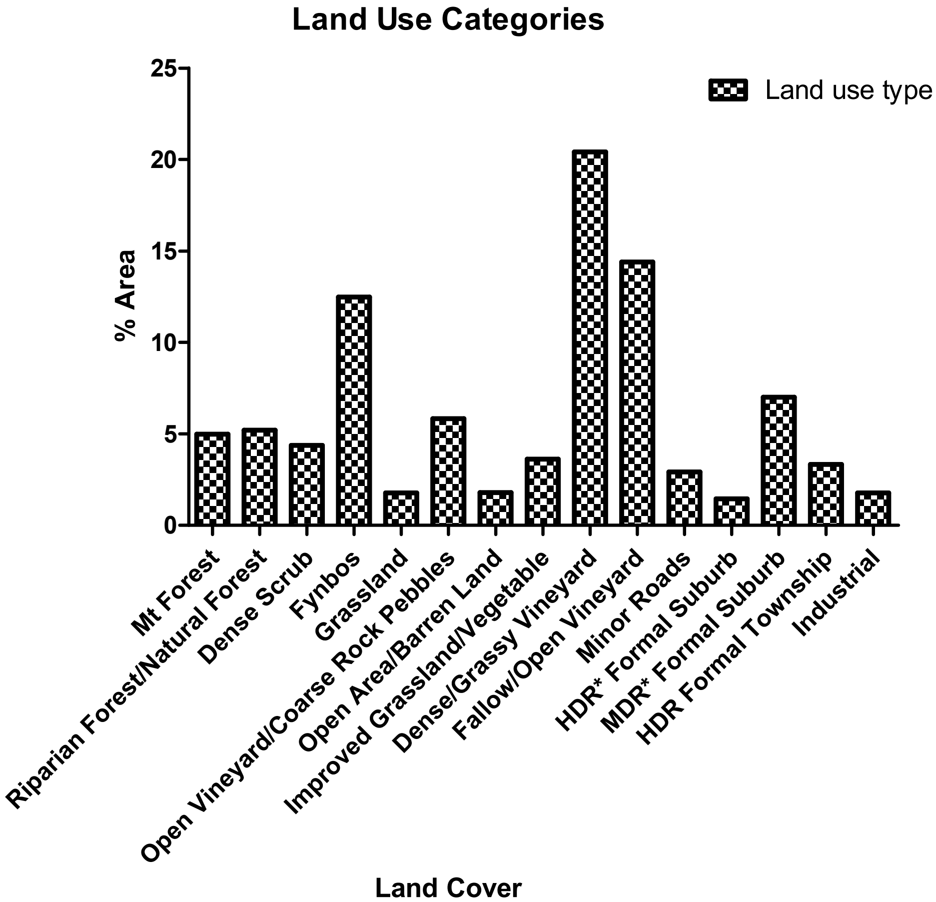


Figure 96 The relative geographic area covered by the different land uses in the Kuils-Eerste River Catchment.

7.3.2 The Impacts of Land Use Practices

7.3.2.1 Agriculture

For the purposes of this document, agriculture is defined as the production of crops or livestock for commercial sale and/or personal benefit. Agriculture in the Kuils-Eerste River catchment is a diverse industry that encompasses a wide range of activities and products; it includes large commercial operations that cultivate and harvest acres of vineyards and small farms that raise and sell poultry products and market gardening. Agricultural activities in the catchment represent a significant sector of the City's economy. It is also a highly diverse business, with one major crop grown, vineyards.

Plant-based agriculture in the catchment includes cut flowers, vegetables, fruits, nursery and landscaping stock, and vineyards. Commercial livestock operations in the catchment include cattle feedlots, and sheep, poultry and piggery operations. In addition, livestock operations can also include the breeding and keeping of horses, goats, geese/ducks, rabbits. Livestock grown strictly for personal use also comprises a significant portion of the total livestock numbers in the catchment.

7.3.3 Water Quality Impacts from Agriculture

Catchment wide, agricultural activities are a leading cause of impaired waters. Most of the degradation is attributed to loss of riparian corridors. The results are increased high temperature, and excessive nutrients. The most common agricultural activities leading to impairment are those associated with livestock access to riparian areas which are common in the low catchment section around Macassar. Those activities lead to faecal coliform bacteria from manure, increased sedimentation, and loss of trees in riparian areas that result in increased surface water temperatures. In addition to degradation of surface waters, agriculture activities can cause groundwater pollution when fertilizers (manure or synthetic) and pesticides (herbicides, insecticides, and fungicides) are improperly applied to fields and other cropland.

Irrigated agriculture practices especially in the Bottellary sub catchment contributes to surface water quality degradation. Erosion of sediments causes water quality problems by degrading and decreasing water clarity. Irrigation return flows draining these agricultural areas carries pesticides and fertilizers to rivers and streams. Irrigation also increases the potential for leached materials, such as pesticides and fertilizers, to reach ground water.

Grazing and rangeland management activities also create a significant potential for water pollution, particularly in estuarine zone of Zandvlei. Cultivating crops and grazing livestock too close to stream banks can cause increased erosion rates, increased temperature, and other water quality problems.

Ambient monitoring has shown that impairment to water quality exists in the Kuils-Eerste River catchment's dry-land agricultural areas, particularly where soils erode easily, such as in the Bottellary sub-catchment. Stream corridors associated with agricultural and forested lands are especially susceptible to degradation of water quality due to pressures from animals foraging and drinking near or within waterways. Other detrimental activities include improper management of manure and wastewater confinement area runoff, excess surface runoff from overgrazed pastures, trampling of streamside vegetation, and direct access to streams by animals. Effects on surface and ground water quality from these types of activities can include high levels of faecal contamination, increased nutrient loads, and sedimentation.

Both point and nonpoint sources of water pollution from livestock are controlled through permitting processes, implementation of BMPs, and the implementation of educational and outreach efforts. Nutrients from dairies and other livestock operations are regulated through livestock nutrient management programmes that are currently co-administered by the Environmental Management Department of the Cape Town Metropolitan Area. These programmes work to protect water quality from livestock nutrient discharges through the combination of clear guidance, education, and technical assistance, as well as through coordination with related agencies, industry, and other stakeholders.

7.3.3.1 Urban/Suburban Growth

The sources of nonpoint pollution in the urban/suburban category include on-site sewage disposal systems, storm water runoff, fertilizers, and household wastes, and all of these are magnified by increasing urban and suburban development.

Natural vegetative cover once protected much of the Kuils-Eerste River catchment's land by intercepting rainfall, reducing erosion, and recharging ground water. The trees and shrubs held much of the moisture, and the forest duff layer absorbed runoff, releasing it slowly and steadily to the streams. However, with the advent of human development patterns, some hydrologic regimes have been forever altered.

One of the major problems currently facing the Kuils-Eerste River catchment is the high growth rate the catchment experienced in the 1990s, and continuing into the 2000s. The City of Cape Town as a whole has an estimated 640 000 units of a range of types of units with formal and informal housing (CCP: State of the Environment Year 3(2000)). The estimated backlog for 2000 was 240 000 units. The increase from 1999 (220 000 units) is largely due to better monitoring and data availability than a substantial increase in housing requirement.

During the 1990s, a lot of people moved into the catchment area each year. That, combined with the birth rate, forced an increase in construction and development and thus a change in land cover. Most of this growth originally centred in urban districts associated with metropolitan Cape Town. More recently, however, growth has spread throughout the catchment, with high rates of annual growth in the rural northern part of the catchment.

Land clearing for buildings, parking lots, and landscaped areas is now occurring at a rapid rate. Soils that allowed water to infiltrate are being paved over. With increased impervious surfaces, rainfall runs quickly and directly into streams, dramatically increasing volume and peak flows. In addition, development encroachment into riparian corridors and modifications to the surface water drainage network all work together to increase runoff and pollution. Storm water runoff may contain high concentrations of silt, petroleum products, nutrients, and pesticides.

7.4 Being in a State of Clean Water

7.4.1 Introduction

Even though the preceding sections have shown that the overall quality of water in the Kuils-Eerste River catchment is less than optimum, it is possible to have clean water. It is possible indeed to have clean water for every designated use determined by law. It only takes a determined will. Having a splendid quality of life and the freedom to enjoy the environment is the right of every citizen in the province. It starts with a clean water attitude. Some people think that it is impossible ever to have clean water; some people think that it is—the resultant state of clean water depends upon the residents of the catchment's collective attitudes. Thus, the goal of this water quality plan is to:

- Protect and restore water quality by creating a culture in the Kuils-Eerste River Catchment that values ecosystem health and biodiversity.

In developing this strategy, numerous conversations with agencies, local government, and the general public were considered. The discussion always led to clean water. There were abundant ideas on ways to achieve clean water because it was clear that was what everyone wanted. This plan will identify both technical fixes for those things that are broken and educational opportunities to teach people about their connections to the land.

When natural systems are properly functioning, they have the ability to filter contaminants, stop contamination from entering water bodies, and then restore themselves. For example, a properly functioning wetland will filter contamination before releasing water to either surface or ground sources. This ability of nature, when given a chance, becomes the impetus for developing the following set of objectives.

7.4.2 Objectives of Water Quality Plan

The Objectives of this Water Quality Plan are:

- Restore and maintain degraded systems/habitats
- Support sustainable human communities
- Sustain biodiversity
- Preserve natural ecosystems
- Focus funding on the most effective strategies
- Teach about connections between individual actions and clean water

7.4.2.1 Restore and maintain degraded systems/habitats.

Many Kuils-Eerste River Catchment habitats need to be restored. Preeminent among them are riparian areas and wetlands. Properly functioning riparian areas and wetlands can trap stormwater runoff and filter contaminants. They provide wildlife habitat and places where people can enjoy nature. Properly functioning natural systems provide many benefits to the human community.

7.4.2.2 Support sustainable human communities

Sustainable development is a strategy by which communities seek economic development approaches that also benefit the local environment and quality of life. Sustainable development provides a framework under which communities can use resources efficiently, create efficient infrastructures, protect and enhance quality of life, and create new businesses to strengthen their economies. It can help create healthy communities that can sustain generations, as well as those that follow Department of Energy, (2004). Examples of sustainable human communities include non-traditional planning and land use, landscape scale analysis, and low impact development.

7.4.2.3 Sustain biodiversity

Western Cape Province is situated in a region with a rich natural biological diversity (biodiversity). Biodiversity refers to the variety of life forms at all levels of species organization—from molecular to landscape. Biodiversity is usually quantified in terms of numbers of species, which is defined as richness. This richness in species diversity is due to the tremendous variety of habitats within the province translating all its richness into smaller areas too including the Kuils-Eerste River catchment.

In 2001 the City of Cape Town provided leadership in addressing biodiversity conservation by passing The Environmental Policy of the City of Cape Town 2001, a policy relating to an integrated metropolitan environmental policy for the city of Cape Town (IMEP). IMEP requested a comprehensive review of the city's needs for a sectoral approach in addressing specific environmental issues. But above all the South African Constitution (Act 108 of 1998) guarantees everyone the right to an environment that is not harmful to their health or well-being. Further the Constitution commits all levels of government to sustainable development so as to ensure that the environment is protected for present and future generations. Local government's constitutional roles and responsibilities reinforce the commitments of local governing bodies to these principles.

7.4.2.4 Preserve natural ecosystems.

Functioning, natural ecosystems should be protected because they are critical for a healthy environment. Some of these include critical areas, riparian zones, healthy fynbos habitats, and wetlands. Why is it important to preserve natural ecosystems? There are a number of reasons, but perhaps the most important is the services natural ecosystems provide to humanity. These services maintain biodiversity and the production of ecosystem goods, such as food, fibre, and many pharmaceuticals. In addition to the production of goods, ecosystem services support, Issues in Ecology (1997):

- Purification of air and water.
- Mitigation of droughts and floods.
- Generation and preservation of soils and renewal of their fertility.
- Detoxification and decomposition of wastes.
- Aesthetic beauty and intellectual stimulation that lift the human spirit.

7.4.2.5 Focus funding on the most effective strategies

Even though there is movement toward sustainability, there is an apparent need to solve problems effectively and prevent problems from happening. To do this takes time and money. However, financial managers at both the provincial and municipal levels are getting impatient for the city municipality to show achievable results. It is imperative that the Cape Town Metropolitan Municipality fund projects that "will get the job done." That places much responsibility on both the local recipients of funds and fund administrators to make sure that when projects are chosen for funding, measurable outcomes are identified and achieved.

7.4.2.6 Teach about connections between individual actions and clean water

There is an old statement that natural philosophers use that claims, "Everything is connected to everything else." This statement is pertinent when we look at how the land is used in the Kuils-Eerste River catchment and the resultant environmental degradation. Conversion of agricultural land to residential, commercial, and industrial uses results in loss of habitat. However, habitat degradation also occurs when landowners do not care for their land in ways that are environmentally protective. Usually this happens because someone truly does not understand their connection to the land and how their actions impact the landscape. To teach about these connections becomes crucial to the successful implementation of this nonpoint plan in the Kuils-Eerste River catchment.

The City of Cape Town is aware of the importance of environmental outreach, and has also established an Environmental Education, Training and Awareness Strategy. This aims to guide decisions regarding environmental education and training in the city of Cape Town, to address issues and concerns to do with environmental education and training, and to ensure that good practices are maintained. Several flagship environmental programmes have been established. The Youth Environment Schools (YES) Programme for example brings together over 35,000 school children from various parts of the city to participate in one of South Africa's largest environmental education programmes, and has recently been expanded to include all of the city's environmental initiatives throughout the year.

7.4.3 How to Achieve These Objectives

There are several ways that the objectives will be fulfilled. The most important way will be to continue building and sustaining relationships with the city authorities, provincial, and local entities and to create understanding about the cause and effect of water quality impairments. The following strategy is proposed to achieve the objectives.

Sustain Relationships – measures will be pursued to build on the relationships between agencies and groups working to address nonpoint pollution problems. The realization that no one agency can get the job done is understood and part of that understanding is to respect the role of the “other” and to share with them results, issues, and other pertinent information about water quality. In addition, activities will be done which will demonstrate the need to work in cooperative ventures to solve problems.

Local Problem Solving – The best solutions are often developed by the people closest to the problem. Since most nonpoint source pollution is generated by local land uses and individual actions, local people are the best ones to solve most water quality problems. City of Cape Town environmental management department is encouraged to work closely with local problem solvers, both agencies and citizens, and to help in their efforts through technical, financial, and educational assistance.

Innovative Approaches – The municipality needs to continue developing innovative approaches for agricultural BMPs, new sources of funding, riparian protection and habitat enhancement, septic system repairs, low impact development, storm water alternatives, and any other number of solutions for nonpoint source pollution control. Innovations, to test results, and determine if a new idea actually works should be pursued also.

Environmental Education – Environmental education about nonpoint sources of pollution is a vital tool to prevent pollution before it happens. Developing educational programmes, involving the public, increasing public understanding about pollution, and promoting volunteerism are ways this important element can be achieved. Teaching about connections to the land, the value of biodiversity, and what it means to be sustainable human communities are all imperatives if this plan is to be successful.

Scientific Knowledge – The need to increase understanding through scientific knowledge and increased monitoring is essential to solving the nonpoint source problem. By its very nature, it is difficult to pinpoint specific causes of nonpoint source pollution and because of that; it is difficult to determine effectiveness of programmes. Nonpoint sources of pollution should be understood as a system-wide issue. Effectiveness monitoring, ambient/trend monitoring, and targeted monitoring studies to identify and solve specific pollution problems are key components of this element.

Financial Assistance – catchment authorities are encouraged to streamline their financial assistance programmes to provide equitable and reliable funding to nonpoint source pollution efforts. Focused funding on the most manageable problem areas and shared funding should be emphasized in the period in which the project runs.

Implement BMPs – Cape Town implements an Integrated Metropolitan Environmental Policy (IMEP). This is a statement of intent, a commitment to certain principles and ethics and a set of high order commitments to the environment based on 15 key sectors. Sectoral strategies have been established to give effect to these higher order commitments and principles. These strategies establish the targets, programmes and actions needed to ensure sustainable resource use and management of Cape Town’s unique environment, for the benefit of all communities.

Enforcement – the city municipalities will be encouraged to use their enforcement capabilities in a more effective fashion observing the provisions of the law and mechanisms for monitoring legislative implementation.

7.5 Roles in Implementation: Water Quality Partners – Working With City Of Cape Town, Local, and Municipal Agencies

7.5.1 Introduction

The complexities of CCT's environments and the mandates of various agencies to protect water quality and other resources are many. Even though sub catchments have individual mandates, it is imperative that these agencies work together to solve water quality problems. Many of the programmes identified in this plan call for joint efforts. This section details the individual nature of the agencies as well as the reason a unified approach is necessary.

7.5.2 Local Administration

Since the early 1990s, Cape Town has been increasing its capacity to deal with environmental and sustainability issues, within the city, nationally and internationally. Initially, the city was involved in many environmental projects without an overall focus. However, in 1996, Cape Town adopted its first Environmental Policy, which aimed to establish an environmental framework for the city. In the late 1990s, the city embarked on a process to establish a comprehensive environmental policy for the city, well researched and widely consulted with the public. The first step in this process, which was cyclical, was to commission a State of the Environment Report based on key environmental indicators in the city.

In October 2001, the city adopted its first Integrated Metropolitan Environmental Policy (IMEP). It established strategies for sectors such as coastal zone management, energy and climate change, air quality management, environmental education and training, heritage and biodiversity management. Many of these strategies, while dealing with local issues, also protect global common goods such as air and water. With the establishment of the Unicity in December 2000 and the attendant transitional local government restructuring a number of policies, programmes and projects have been put on hold and data have been difficult to obtain in certain areas.

7.5.3 Enabling Legislation for Local Government

New legislation in South Africa has created new responsibilities for local government; foremost amongst these are public participation, transparency, accountability and access to information. The State of the Environment therefore provides an important mechanism for monitoring legislative implementation.

The Local Government: Municipal Systems Act 32 of 2000 is designed, amongst other things, to enable municipalities to move progressively towards the social and economic upliftment of local communities, and to ensure universal access to essential services that area affordable to all. The Act further deals with the principles and mechanism giving effect to developmental government. A key tool identified in the Act is Integrated Development Planning (IDP). This is a process whereby the municipality has to prepare a strategic plan outlining key development priorities in the municipality, its vision and development objectives, development strategies, identification of projects and its operational budget.

The Municipal Structures Act of 1998 gives effect to chapter 7 of the Constitution and creates the new Unicity structure, the City of Cape Town, incorporating the former Cape Metropolitan Council (CMC) and the six former Metropolitan Local Councils (MLCs). Local government is now firmly established by these national Acts as an autonomous sphere of government having specific functions defined by the Constitution.

The Access to Information Act (95 of 2000) aims to promote transparency, accountability and effective governance of all public and private bodies, by educating everyone to , amongst other things, effectively scrutinise, and participate in, decision- making by public bodies that affect their rights.

The Promotion of Administrative Justice Act (96 of 2000) aims to give effect to section 33 of the Constitution. Thus local government can be held responsible for its actions and decisions by the public and is required to act in an efficient and transparent manner.

The greatest impact of state agencies on public policy is from the ability to use a consensus based problem-solving approach to address challenging natural resource issues with other vested stakeholder; regulations they promulgate; their technical assistance programmes; and from the grants they award, to carry out tasks mandated by statutes.

The complexities of CTC government and the differing authorities of the several agencies responsible for controlling nonpoint source pollution have made cooperative efforts difficult. Staff time is usually at a premium and efforts to participate with other agencies are often a low priority. However, the need to share resources, efforts, and programmes is recognized as essential. The creation of one Unicity administration, effective from 5 December 2000 has provided opportunities for integration.

7.6 Activities and Milestones

7.6.1 Activities Table

This plan's activities are divided into two broad categories. The first are those programmes that are currently being implemented by CCT. This plan assumes that all existing programmes will continue.

The second category includes programme that is proposed for the Kuils-Eerste River catchment (Tables 42 to 47). In either case, these actions are designed to enhance the current state of nonpoint source controls by implementing the full array of plan objectives. New programme additions have not necessarily received funding or administrative blessings, but it is hoped that implementing agencies will work toward that end.

Implementation actions are organized by nonpoint source pollution category. Where activities are related to another major planning process in the Kuils-Eerste River catchment, this has been indicated. The responsible organization for each activity has been listed with the lead agency underlined. A list of acronyms for each agency is found in the front of the plan.

It should be noted that not every action will lead to a measurable outcome. Some actions will lead to qualitative outcomes, which are not measurable, but it is anticipated that the action will lead to water quality improvements. For example, an action to provide outreach and education to a targeted group of people on riparian area functions will not lead directly to measurable water quality outcomes, but is an important nonpoint source pollution control action to undertake.

Table 42 Proposed Actions to Manage Nonpoint Pollution in the Kuils-Eerste River Catchment through Agricultural Activities (2009-2014)

Objectives to be fulfilled	**Through these Agricultural Activities**	**Lead Entity-** Co-operators	**Measurable Outcome**
IMEP Implementation	CCT has an IMEP with the responsibility for developing and implementing a stormwater management program that reduces pollutants in stormwater to the maximum extent practicable.	CCT	Improved quality of water
Restore and maintain habitats	Continue to refine and update regulatory programme for pesticide applications.	Catchment management committee	Reductions in sediment.
Restore and maintain ecosystems	Provide technical assistance on proper use of pesticides to ensure compliance with pertinent regulations.	CCT	
Restore and maintain ecosystems	Continue to research, develop, test, and evaluate agricultural best management practices.	CCT	
Support sustainable Human communities	Actively engage producer groups in implementing new best management practices.		Reductions in sediment.
Focus funding on most effective strategies	Use SRF low interest loans to help agricultural commodity groups with development and installation of BMPs that water pollution, air pollution, and water use.		Number of Educational events, participants and acres affected.
Focus funding on most effective strategies	Continue to implement the IMEP.		Reductions in sediment
Teach about connections	Provide outreach and education to the agricultural community on riparian area function and management related to agricultural land uses and continue with efforts intended to change behaviour and those intended to inform the public about water resources. These efforts include implementation of IMEP, brochures, public presentations, school programmes, Earth Day activities, and other outreach efforts.	CCT and Kuils-Eerste River Catchment management committee	Number of educational events, participants and acres affected.
Support sustainable human communities	Implement the Irrigation Efficiencies programme state-wide		Reduction in sediment.
Teach about connections	Implement the IPM certification program state-wide.		Number of agricultural Landowners served. Number of workshops offered.

Table 43 Proposed Actions to Manage Nonpoint Pollution in the Kuils-Eerste River Catchment through Urban and Suburban Activities (2009-2014).

Objectives to be fulfilled	**Through these Urban and Suburban Activities**	**Lead Entity--** Co-operators	**Measurable Outcome**
Support sustainable Human communities	Continue to provide road maintenance guidelines and technical assistance to local communities in the catchment.		
Support sustainable human communities	Continue to promote low impact development (LID) to communities through assistance, research, and demonstration projects, and by providing assistance to revise existing ordinances and development standards to allow for low impact development.		Number of local municipalities with ordinances that allow for or encourage LID
Restore and maintain habitats	Continue to manage runoff from state highways using the updated highway runoff manual.		
Support sustainable human communities	Identify and participate in a low impact project and research the applicability of low-impact techniques to regional hydrogeology, soils, and climactic conditions.		Credits for LID techniques updated in Ecology stormwater manual.
Restore and maintain habitats	Develop methods and procedures for watershed based runoff, stream-flow, and water quality mitigation measures, with a goal of resource recovery in place of patchwork, incremental mitigation as practiced in the past.		
Support sustainable human communities	Develop a model clearing and grading ordinance to include low impact development. Partner with resource agencies to utilize regional staff in updating ordinances. Implement a series of workshops around the state on legal obligations of land use planning.		

Objectives to be fulfilled	**Through these Urban and Suburban Activities**	**Lead Entity-- Co-operators**	**Measurable Outcome**
Preserve natural ecosystems	Update guidelines and models for consideration by catchment management team on inclusion of Best Available Science and giving special consideration to resource conservation in the catchment.		
Support sustainable human communities	Continue to research storm water technology design, cost benefit and know-how to effectively address storm water problems. Educate key audiences about new findings, etc.		
Support sustainable human communities	Educate key audiences in the best available science in CCT storm water management and low impact development techniques.		
Support sustainable human communities	Promote adoption of IMEP and other elements of a comprehensive storm water programme.		Number of local communities assisted. Number of developers and consultants served.
Preserve natural ecosystems	Assess the impacts of urban and highway storm water runoff on the quality of sediments as well as biological resources and habitat, with particular emphasis on urban embayment in False Bay.		Number of local communities adopting IMEP
Preserve natural ecosystems	Develop pilot programme to address water quality violations associated with onsite sewage systems in sensitive areas.		Number of acres impacted.

Table 44 Proposed Actions to Manage NPS Pollution in the Kuils-Eerste River Catchment through Habitat Alteration Activities (2009-2014).

Objectives to be fulfilled	**Through Habitat Alteration Activities**	**Lead Entity-** Co-operators	**Measurable Outcome**
Restore and maintain degraded ecosystems	Prioritize and coordinate restoration projects on a sub catchment basis.		Miles of riparian areas restored.
Sustain biodiversity	Provide critical information, technical guidance, and maps to support local municipalities' revisions to their IMEP		
Sustain biodiversity	Provide outreach and educational materials on the State of the Environment (SoE)		Number of workshops.
Sustain biodiversity	Train local, staff on SoE Guidelines.		Number of staff trained.
Teach about connections	Continue to develop and disseminate educational materials in multi-media formats on the benefits and methods of riparian restoration.		
Restore and maintain degraded ecosystems	Develop additional needed SoE Guidelines		
Restore and maintain degraded ecosystems	Continue to implement the SoE		
Sustain biodiversity	Conduct wetland training workshops for local communities to assist them in implementing local wetland regulatory programmes.		Number of workshops.
Sustain biodiversity	Develop wetland guidance documents based on the best available scientific information for use by local communities in developing wetland protection regulations under the SoE and the IMEP.		
Preserve natural ecosystems	Develop new guidance on wetland mitigation plans		
Focus funding	Develop a compliance tracking and enforcement programme for agency permitted wetland mitigation projects		
Preserve natural ecosystems	Prevent, control, and monitor the spread of aquatic nuisance species and increase the capacity of catchment groups to do the same.		Reduction in areas where nuisance species exist.
Teach about connections	Provide technical assistance to local communities on functions and processes of near shore habitat.		
Support sustainable human communities	Provide technical assistance and education to support Shoreline Master Programme updates.		

Table 45 Proposed Actions to Manage Nonpoint Pollution in the Kuils-Eerste River Catchment through Educational Activities (2009-2014).

Objectives to be fulfilled	**Through These Educational Activities**	**Lead Entity- -** Co-operators	**Measurable Outcome**	**Major Program Linkage**
Teach about connections	Organize a biennial conference on nonpoint pollution	CCT	Number of participants	Biennial Symposium on Urban Catchment Management
	Continue to develop, upgrade, and enhance environmental learning canters across the catchment.		Number of Students participating.	
Teach about connections	Develop and implement catchment-wide training programmes for the public and specific interest groups, such as real estate professionals, conservation district staff, planners, catchment group members, developers, and agriculture professionals.		Number of educational events, participants and acres affected.	
Support sustainable human communities	Support existing community outreach		Number of educational events, participants and acres affected.	Programmes in support of river upgrade projects
Teach about connections	Develop water quality outreach programmes to smaller sub catchments.			
	Develop and present water quality education in classrooms and events as requested			Millennium Mural Competition
Support sustainable human communities	Develop a water quality component for the continuing education programme for local officials.		Number of workshops.	Water Week and South African Youth Water Prize.
	Educate and engage the public in activities to correct and prevent nutrient pollution.		Number of educational events, participants and acres affected.	

Table 46 Proposed Actions to Manage Nonpoint Pollution in the Kuils-Eerste River Catchment through General Programme Activities (2009-2014).

Objectives to be fulfilled	**Through These General Programme Activities (Programmes that have multiple impacts or are administrative in nature)**	**Lead Entity--** Co-operators	**Measurable Outcome**
Preserve natural ecosystems	Continue to emphasize phase 1 and phase 2 catchment planning efforts to control nonpoint source pollution.		
Support sustainable human communities	Continue to promote local catchment planning and implementation		
Restore and maintain degraded ecosystems	Continue to develop catchment and detailed implementation plans to address waters impacted by nonpoint source pollution		Number of catchment-based plans supported under this plan
Restore and maintain degraded ecosystems	Continue to emphasize catchment management planning to address nutrient and sediment enrichment, and de-emphasize the use of chemicals for pest control.		
Restore and maintain degraded ecosystems	Propose and Implement the Kuils-Eerste River Sediment Reduction Plan		
Support sustainable human communities	Create a toolbox for solutions to nonpoint source problems that includes grant project reports and products as well as agency products, and make the toolbox available on the internet.		
Support sustainable human communities	Develop clean water indicators for sustainable communities. Work with communities to forward their adoption.		
Restore and maintain degraded habitats	Support local corrective actions and programmes to reduce human related pollution and nutrient input into Kuils-Eerste River catchment to address the low dissolved oxygen problem		Number of corrective actions.
Restore and maintain degraded habitat	Develop a social marketing for clean water project for catchment-wide application. Use the campaign to increase citizen's awareness of how their actions affect water quality and what they can do to improve water quality.		

Table 47 Proposed Actions to Manage Nonpoint Pollution in the Kuils-Eerste River Catchment through Enforcement Activities (2009-2014).

Objectives to be fulfilled	**Through Monitoring and Enforcement Activities**	**Lead Entity--** Co-operators	**Measurable Outcome**
Teach about connections	Develop protocols for performing nonpoint source monitoring throughout CCT.		
Focus funding on most effective strategies	Monitor the effectiveness of corrective actions for nonpoint source pollution, BMPs, and other catchment based plans.		
Restore and maintain degraded systems	Monitor nitrates and pesticide runoff from agricultural lands.		
Teach about connections	Continue to implement ground water pesticide monitoring to support and water quality and toxicological assessments.		
Restore and maintain degraded systems	Continue to monitor the implementation of forest practice rules catchment -wide.		
Teach about connections	Using existing monitoring data identify water bodies high in phosphorus, nitrates, and sediments.		List of water bodies.
	Report to the public on monitoring trends in Kuils-Eerste River catchment through the CCT Monitoring Programme and IMEP.		List of reports issued and copies distributed.
Restore and maintain degraded ecosystems	Increase compliance and enforcement activities for nonpoint source pollution.		Number of Enforcement actions.
Restore and maintain degraded ecosystems	Investigate agricultural related complaints and assist in development and implementation of farm plans.		Number of Complaints attended.

7.7 Water Quality Monitoring For Assessing NPS Pollution

As noted in section 8.6, each year, the City of Cape Town is asked to answer specific environmental questions about the effectiveness of its programmes by a wide array of people and groups, including the legislature, and the public. The questions vary depending on who is asking, for example:

1. What is the amount (in tons) reduction in nitrogen, phosphorus, and sediment in city's waters?
2. How many watersheds in the state that were polluted are now meeting water quality standards?
3. Are the management practices recommended effective?
4. What is the project outcome and was it worth the money value spent

Similar questions are asked because it should be known whether the money and time spent on implementing best management practices and doing restoration projects is actually improving water quality, and to fine-tune the practices used, if necessary.

These are a lot of important questions to answer, so Cape Town's IMEP and various strategies are funded by core funds from the city who are also working with Department of Environmental Management to design an effectiveness monitoring strategy that could make available the information needed to answer questions about programme effectiveness and help keep improving catchment programmes over time.

At this point, there is uncertainty as to what the strategy would look like, but there are some initial thoughts. Since it is not possible to monitor everything everywhere, there is a need to be strategic about where the catchment management team should monitor to ensure that answers to the questions that are important are obtained. Some possible ideas to consider are:

- Does ambient monitoring provide answers to the questions? If not, can the programme be redesigned so as to answer?
- Should effectiveness be tested in certain sub catchments because the nonpoint problems to be fixed are particularly difficult to address?
- Should results be compared in two or more different sub catchments where they have implemented the same array of practices, and suspect that the results would not be the same?
- Should the effectiveness of different arrays of practices be tested?
- Should the effectiveness of an innovative practice be tested?
- Should the effectiveness of a single practice across two or more ecoregions be compared?
- Should areas in which the municipality has spent a lot of money be tested?

As part of the Basin Management Action Plan (BMAP), stakeholders could design a strategy for monitoring water quality and measuring pollutant loads. This strategy builds on the integrated environmental monitoring plan's (IEMP's) existing water quality monitoring resources. The strategy would address monitoring parameters, quality assurance / quality control (QA/QC), data management, and data evaluations to measure progress in achieving the annual loads, while allowing for evaluation and feedback that better refine the monitoring strategy and provide information to better define how to achieve the annual loads. The specific objectives of this monitoring strategy are as follows:

- Determine if positive trends in water quality conditions are being observed;
- Improve our ability to evaluate water quality conditions by enhancing flow measurements;

- Continue to improve source identification efforts; and
- Provide sufficient data to support the development of future management actions.

Information provided by the monitoring network will be useful in evaluating the cost-effectiveness of load reduction strategies, modifying existing and selecting future load reduction strategies, coordinating agency/group monitoring efforts to reduce duplication and conserve resources, and increasing the understanding of the relationship between pollutant loads and water-body response.

One initial idea is to assess the water quality trend in a set of representative sub catchments in the Kuils-Eerste River catchment, and to try to figure out whether water quality is getting better or worse, and why. The sub catchments selected would be primarily urban, agricultural, or forested, to assess trends for those three major kinds of land uses. While this is a question about water quality trends, we would also want to design a strategy that would give us information about why the trend is going the way it is, whether the trend is the same throughout the catchment and why or why not, and identify pollution sources that are still a problem and sources that have been controlled. This would lead to other questions, like "are the BMPs being used effective," and "are there sources of pollution that are not addressed by any of the best management practices?" It is likely that it could be found out that the problem is not with the practices, but with the level of implementation.

However, the first thing needed to be done is to get clear about what kind of monitoring data would help make management decisions and improve the programmes.

7.8 Implementation Strategy

This plan's strategy includes implementation activities in two broad categories: The first are the assessments of the levels of pollution which programmes can be proposed upon and that could be implemented in the catchment. This has been successfully completed in the study and reported in chapter 4 to chapter 7 of the thesis.

The second category includes the proposed programmes to deal with identified nonpoint plan, 'Control Nonpoint Source Pollution' in Kuils-Eerste River catchment. This is the proposed programme to be implemented in the Kuils-Eerste River catchment. In addition, Tables 42 to 47 identifies specific activities that the municipality could attempt to fund and staff. What is the strategy to implement nonpoint plan activities, and how would those activities be funded?

7.8.1 Implementation Strategy for Local Governments

Chapters 4 to 7 of the study of the nonpoint pollution in the catchment provide a series of summaries that profile of the catchment. The information contained in the chapters can be used to better understand the relationships between demographics, land-use activities, and water quality problem areas. Data from the chapters can be used to help support water quality and catchment-based planning efforts. Subsequently, the Kuils-Eerste River catchment plan that can be incorporated into the proposed catchment management guideline can be adopted and be referenced as part of Kuils-Eerste River catchment's overall water quality plan.

7.8.1.1 Technical Assistance

CCT provides technical assistance to local municipalities and to each other in the implementation of environmental programmes. Many municipalities have extensive programmes that provide in-kind technical assistance. In some cases, they must provide technical assistance before taking an enforcement action.

7.8.1.2 Enforcement

CTC has actively sought delegation to implement municipal programmes and legislation from the provincial government in an effort to maintain municipal control of resource management concerns. Examples of such legislature have been cited in this report. Enforcement is used by several agencies and by local government to ensure compliance with water quality regulations. Though many programmes rely initially on working with people to encourage cooperation, the regulatory support is needed for polluters whose compliance cannot be achieved any other way.

7.8.1.3 Implementation Strategy for State Agencies

This document, proposed management guidelines of the nonpoint source pollution in the Kuils-Eerste River catchment, contains the management strategies to implement the programme designed to fulfil the goals and objectives outlined in Section 8.4. Tables 42 to 47 are the Kuils-Eerste River catchment list of activities. It is derived from both the on-going activities within the catchment and the site-specific need identified through the assessment process conducted.

Once an activity is adopted into the annually updated Table (e.g. Table 45), it is up to catchment management team to find funding, if none has been previously available, and to implement and report on the activity.

7.8.1.4 Progress Review

Progress toward meeting the goals and objectives of the plan will be evaluated and discussed by the management committees of the catchment and the municipality. Members of this workgroup have access to their agencies' data, programmes, and activities at the local level. They will work closely to align activities and support each other in the broader direction of plan activities.

7.8.1.5 Five Years from Now

The actions identified in the plan will require a long-term commitment from provincial, municipal, and local resources. There is no quick fix to pollution that is as endemic as nonpoint pollution. Although the scope of this plan covers actions to be taken within five years, the framework and efforts established in the plan will continue for many more years. During the five years of this plan, the focus of many agencies will be to develop the necessary programs to implement the actions in the plan. The management team will determine its own timeline for the actions, and report the timeline to the municipal environmental management department.

As programmes are developed, they will be implemented on the ground by the appropriate groups, as needed. For example, landowners will put in place BMPs, catchment management team will provide technical and financial assistance when possible. In addition, the various planning processes such as local catchment plans will continue to investigate and identify water quality problems across the state. This plan will provide a toolbox of programmes to be used in these areas to address the identified problem.

In summary, during the next five years of this plan, catchment management team will develop the programmes necessary to implement the actions identified in the plan, and implement where possible. Beyond five years, programmes will be implemented to the maximum extent needed and where possible within the catchment and additional programmes will be developed and implemented to manage future identified needs. Every five years this plan will be updated, including another analysis of management measures. The need for major changes in strategy will be identified at that time.

The actions of the plan, when taken as a whole, will focus resources in a manner that widens programme implementation, improves programme effectiveness, and attends to problems not previously addressed. Through increased coordination and cooperation, it is possible to improve the quality of the catchment's waters, and maintain and improve the quality of life.

8 CONCLUSIONS AND RECOMMENDATIONS

The main findings of this study are that an assessment of nonpoint source (NPS) pollution in the Kuils-Eerste River Catchment in the Cape Metropolitan Authority Area (CMA) through hydrologic experiments and modelling using a Geographic information System has been achieved. The major objectives of this study have been also achieved with the following work having been accomplished with satisfactory results:

One of the critical components of this study was to conduct hydrologic experiments (setting up of runoff plots) at selected locations for measuring surface runoff within the catchment given that this would allow the generation of the needed data for the GIS models used in the study area to estimate runoff, infiltration and nonpoint source pollution.

This study further proposed and achieved the estimation of surface runoff through GIS modelling using curve number method; this was considered one of the major outputs of the project.

Subsequently, further activities carried out made it possible to conduct an assessment of runoff water quality over different land use types through sampling and generation of a water quality database (event mean concentrations). Collation of existing data on stream flow measurements and water chemistry of stream flow and surface runoff water was conducted and the results used also in the models that were applied to further understand the behaviour and variation of water quality parameters in relation to the various land cover types that characterise the catchment. The values obtained show clearly the influence of precipitation and the seasonal variability of the rainfall as it affects the amount of discharge in the river. Such variations are likely to influence the distribution of surface pollutants into the river network as a high per cent of the discharge in the river is originates from storm runoff that is channelled in through the numerous storm drains. Part of this discharge is contribution from return flows resulting from heavy precipitation and from other tributaries.

Generation of a GIS based hydrologic model (catchment loading model) capable of estimating surface runoff using the NRCS Curve Number method, pollutant concentrations and loading rates in the runoff water, and accumulated pollutant loading in the stream or river was achieved resulting in the development of the RINSPE model.

Using the above approaches a working document for turning around the catchment into a sustainable system has been developed. In developing this strategy, numerous conversations with agencies, local government, and the general public were considered.

It should be noted also that the project was not meant to solve a water balance issue and that future work should incorporate subsurface component in order to capture that element of the water cycle and account for its contribution to runoff.

This study recommends further work to assess the influence and contribution of base flow into the quality of water in the rivers and hopefully bring out the real situation of nonpoint source 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 also 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 approaches used in this study have shown that the land use data are a good background for the calculation 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 on a bigger part of the catchment such as balanced fertilization, reduction in soil tillage. Such effective measures as planting of forests on arable land would reduce pollution in the catchment.

Nonpoint source pollution has geospatial characteristics because potential pollution production varies with land use type and characteristics, including the amount of impervious area, and the nature of the urban, agricultural, industrial, and construction activities occurring on the site (Ventura, and Kim, 1993; Novotny and Olem 1994; Bhaduri *et al* ., 2000). This study has also shown that NPS pollution is significantly influenced by the hydrologic and meteorological properties of the catchment. In environmental and resource management, a GIS can be a powerful and time-efficient tool to create and manage data sets required as input of hydrologic/ water quality models, such as soil information, pollutant source area and transport routes, and component and parameters of NPS pollution generation (Tim *et al*., 1992; Novotny and Olem 1994; Bergman 1995; Bhaduri *et al*., 2000).

This study used a framework for assessing NPS pollution in an urbanising catchment. The approach is consistent with the model limitations and data available and allows direct quantitative comparison between model estimates obtains obtained using the two models; RINSPE and N-SPECT.

A parameter sensitivity analysis demonstrated that the most important model parameters were land cover type and rainfall and depending on how these varied the amount of runoff and pollutants would vary too. The contribution of rainfall in the pollutant output and runoff volume is variable within the catchment. Parameter sensitivity analysis is useful for identifying parameter interdependencies in the catchment and also indicates which parameter should be focused on in an effort to reduce the negative effects of pollution and design of mitigation strategies. On the other hand these observations about the variations could contribute to the future development of modelling procedures for use in nonpoint source pollution studies and management. The main challenge of using these models is the relevance of the original data sources with respect to the temporal attributes and the role of the parameters in influencing model outputs. Even if current temporal data sets such as land cover type for estimation purposes are used in the future, problems of not being 'real time data' will always be experienced. The alternative approach is to continue updating the land cover data and rainfall data in order to estimate real time effects of runoff and surface pollution.

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 use type and meteorological data the models would estimate the parameters with little difficulty. It stands to reason that improving the data bases of spatial data and revision of the pollutant parameters estimation approaches for the most critical areas would be made with greater efficiency.

While in a broader sense the focus of the study was on NPS pollution in the Kuils Eerste River catchment, the analyses were based on a number of examples. It is therefore important to extend similar studies to other countries within the region. These would contribute to a better understanding of how NSP pollution varies from region to region in Africa and from country to country too. However, sources of data are not always easy to access and therefore improvements in the effective management and sharing of data are necessary for regional modelling studies.

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. These issues must be addressed if an important aim of developing water quality issues is to encourage more widespread criticism of data and water quality models in Africa, which will create avenues for further research. 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 whole 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. The choice seems to lie therefore between modifying existing techniques to make better use of existing data and collecting data to support the existing techniques.

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APPENDIX

Appendix Table 1 Rainfall volume, Runoff rate and Runoff volume computed by the RINSPE Model

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
1	173273	84037	27508	159
2	101076	48921	15965	158
3	72197	35016	28870	400
4	57758	27897	9076	157
5	101076	48820	40216	398
6	86636	41932	34558	399
7	14439	6960	2257	156
8	14439	6974	1167	81
9	129954	62638	43289	333
10	101076	48617	33569	332
11	57758	27724	19125	331
12	43318	20749	14301	330
13	346545	165649	62855	181
14	317667	151209	57079	180
15	158833	76875	29617	186
16	245470	118562	45563	186
17	360985	172190	65168	181
18	274348	130041	48832	178
19	288788	136597	51159	177
20	86636	41845	28946	334
21	187712	88600	33095	176
22	245470	115616	43071	175
23	28879	14006	14006	485
24	72197	34943	24193	335
25	14439	6916	5399	374
26	202151	96022	36152	179
27	259909	122157	45386	175
28	202151	94607	34960	173
29	202151	94203	34620	171
30	202151	93798	34281	170
31	187712	86535	31362	167
32	202151	92585	33268	165
33	202151	91979	32763	162
34	202151	91372	32260	160
35	28879	12967	1797	62
36	231030	102808	35531	154
37	375424	165937	56812	151
38	57758	25298	10423	180
39	57758	25067	10206	177

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
40	86636	37254	10827	125
41	101076	43058	17102	169
42	332106	139817	52283	157
43	57758	24085	6595	114
44	43318	10353	151	3
45	57758	13804	965	17
46	14439	3451	0	0
47	173273	84037	13197	76
48	28879	13977	6241	216
49	28879	13948	2162	75
50	57758	27724	22807	395
51	43318	20749	17062	394
52	28879	13804	2068	72
53	57758	27493	4063	70
54	86636	41152	6039	70
55	274348	127572	46755	170
56	187712	86911	31676	169
57	173273	79705	28804	166
58	245470	109970	38360	156
59	375424	165562	56503	151
60	43318	18930	7777	180
61	86636	37514	15228	176
62	72197	30972	8962	124
63	129954	55231	15699	121
64	288788	121580	38771	134
65	57758	24027	6548	113
66	72197	17183	228	3
67	14439	3437	1920	133
68	14439	3422	1102	76
69	28879	6844	0	0
70	43318	10266	123	3
71	57758	13689	888	15
72	14439	7003	4853	336
73	433182	208360	79670	184
74	418742	200578	76304	182
75	72197	34149	4940	68
76	14439	6801	6801	471
77	187712	88037	32621	174
78	231030	107891	39760	172
79	216591	98982	35464	164
80	144394	65555	23282	161
81	57758	26049	11132	193
82	245470	108988	37550	153
83	28879	12707	10249	355

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
84	404303	176680	59525	147
85	360985	156306	51969	144
86	490939	210122	68685	140
87	462060	195914	63150	137
88	216591	90968	28905	133
89	375424	155801	48598	129
90	57758	13631	850	15
91	72197	17038	184	3
92	86636	20360	196	2
93	14439	3393	2166	150
94	14439	3393	232	16
95	57758	13573	813	14
96	332106	160075	61362	185
97	404303	194065	74016	183
98	86636	41066	5984	69
99	72197	34005	4849	67
100	86636	40632	5710	66
101	187712	86723	31519	168
102	202151	92788	33436	165
103	129954	58480	24925	192
104	259909	116179	40401	155
105	245470	108743	37348	152
106	418742	184247	62680	150
107	433182	188867	63423	146
108	375424	162183	53743	143
109	303227	128265	41198	136
110	187712	78651	24900	133
111	216591	89669	27865	129
112	101076	23652	201	2
113	57758	13458	100	2
114	14439	3364	2137	148
115	14439	3364	0	0
116	43318	10093	634	15
117	101076	23551	1295	13
118	43318	10396	753	17
119	43318	10440	181	4
120	43318	10526	213	5
121	14439	3523	77	5
122	28879	7075	165	6
123	14439	3567	94	7
124	28879	13977	2495	86
125	57758	27839	22923	397
126	72197	34077	4895	68
127	57758	26973	3734	65

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
128	28879	13400	4098	142
129	14439	6671	1025	71
130	43318	19753	2898	67
131	158833	71951	25479	160
132	173273	77973	5035	29
133	14439	6440	6440	446
134	389863	171150	58037	149
135	418742	182153	60967	146
136	389863	168031	55493	142
137	375424	160306	52220	139
138	288788	121868	39004	135
139	303227	126749	39980	132
140	101076	23450	151	1
141	101076	23348	128	1
142	72197	16677	959	13
143	14439	3335	2108	146
144	57758	13342	669	12
145	28879	6700	352	12
146	43318	10310	695	16
147	14439	3451	273	19
148	43318	10483	197	5
149	28879	7104	623	22
150	14439	3581	333	23
151	14439	7003	1258	87
152	14439	6815	553	38
111	216591	89669	27865	129
112	101076	23652	201	2
113	57758	13458	100	2
114	14439	3364	2137	148
153	14439	6787	540	37
154	72197	33788	4713	65
157	28879	13226	1969	68
158	202151	92181	32931	163
155	72197	33644	4623	64
156	14439	6657	1015	70
159	14439	6483	6483	449
160	173273	77280	26791	155
161	389863	170760	57718	148
162	129954	56400	45340	349
163	389863	167641	55176	142
164	418742	178384	57906	138
165	173273	72255	22707	131
166	43318	9963	546	13

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
167	43318	9920	0	0
168	72197	16533	863	12
169	28879	6613	19	1
170	72197	16533	62	1
171	28879	6613	300	10
172	72197	16605	76	1
173	28879	6758	388	13
174	28879	6931	110	4
175	14439	3523	291	20
176	14439	3581	372	26
177	14439	7003	2705	187
178	28879	13717	11259	390
179	43318	20360	2882	67
180	72197	33427	27282	378
181	14439	6657	2015	140
182	187712	84283	29489	157
183	231030	102808	41490	180
184	303227	131601	43901	145
185	375424	161057	52828	141
186	418742	177965	57568	137
187	259909	108122	33853	130
188	57758	13284	436	8
189	86636	19840	0	0
190	57758	13169	566	10
191	28879	6584	4129	143
192	115515	26222	1066	9
193	72197	16389	770	11
194	57758	13053	500	9
195	43318	9877	30	1
196	14439	3307	0	0
197	43318	9963	475	11
198	14439	3350	202	14
199	28879	6815	6815	236
200	28879	6960	522	18
201	14439	3523	2007	139
202	14439	3552	350	24
203	14439	3567	361	25
204	14439	7018	1109	77
205	144394	69887	10903	76
206	43318	20706	8628	199
207	28879	13429	1831	63
208	14439	6685	6685	463
209	14439	6642	2003	139
210	28879	13198	3938	136

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
211	14439	6555	6555	454
212	202151	91170	32092	159
213	28879	12822	5375	186
214	101076	23045	43	0
215	28879	6555	181	6
216	14439	3263	145	10
217	101076	22742	28	0
218	14439	3249	0	0
219	28879	6498	0	0
220	57758	12938	10	0
221	57758	12938	438	8
222	57758	12995	469	8
223	14439	3249	3	0
224	43318	9790	17	0
225	43318	9833	23	1
226	14439	3292	0	0
227	14439	3465	284	20
228	14439	3523	328	23
229	14439	3538	339	23
230	14439	3567	322	22
231	28879	14064	7055	244
232	14439	7018	2304	160
233	43318	21053	9443	218
234	57758	28012	9944	172
235	43318	20013	2666	62
236	57758	26568	21653	375
237	14439	6555	956	66
238	72197	32561	26416	366
239	245470	108988	43855	179
240	72197	16317	479	7
241	43318	9747	237	5
242	14439	3249	89	6
243	28879	6469	4014	139
244	43318	9660	356	8
245	14439	3220	0	0
246	72197	16100	7	0
247	28879	6411	221	8
248	43318	9617	283	7
249	101076	22540	713	7
250	14439	3263	3	0
251	14439	3494	306	21
252	14439	3509	317	22
253	14439	3538	301	21
254	28879	14064	11606	402

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
255	28879	14035	11577	401
256	28879	13920	2454	85
257	57758	26800	3626	63
258	14439	6628	1992	138
259	14439	6584	1958	136
260	14439	6541	949	66
261	173273	77973	27364	158
262	173273	76760	30795	178
263	173273	71562	22154	128
264	14439	3234	83	6
265	28879	6440	0	0
266	115515	25760	7	0
267	86636	19233	4	0
268	115515	25529	698	6
269	28879	6382	204	7
270	72197	15956	1	0
271	72197	15883	0	0
272	28879	6353	160	6
273	14439	3263	0	0
274	14439	3408	0	0
275	14439	7046	3315	230
276	28879	14064	7546	261
277	14439	7018	2099	145
278	28879	14035	10999	381
279	14439	7003	1182	82
280	72197	34871	3121	43
281	28879	13255	5563	193
282	57758	26337	10838	188
283	14439	6541	6541	453
284	101076	44777	13738	136
285	202151	88744	35178	174
286	28879	6440	1	0
287	72197	16028	314	4
288	14439	3206	0	0
289	173273	38293	1	0
290	14439	3177	60	4
291	101076	22136	514	5
292	72197	15811	0	0
293	28879	6324	173	6
294	101076	22035	0	0
295	28879	6324	6324	219
296	14439	3177	94	7
297	14439	3191	0	0
298	14439	3278	1474	102

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
299	14439	3292	0	0
300	14439	7032	3868	268
301	28879	14035	7708	267
302	14439	7018	3250	225
303	28879	14006	3831	133
304	28879	13948	5861	203
305	28879	13689	13689	474
306	14439	6657	880	61
307	28879	13226	10769	373
308	28879	13140	4221	146
309	43318	19580	4697	108
310	28879	12880	3008	104
311	57758	25529	7801	135
312	28879	12649	1693	59
313	14439	5949	566	39
314	259909	105783	31993	123
315	57758	12822	2	0
316	86636	19060	317	4
317	72197	15883	0	0
318	101076	22136	0	0
319	28879	6296	100	3
320	86636	18887	262	3
321	28879	6296	0	0
322	115515	25067	484	4
323	28879	6267	143	5
324	57758	12533	0	0
325	14439	3162	0	0
326	14439	3177	0	0
327	14439	3249	369	26
328	28879	6527	6527	226
329	14439	3350	437	30
330	28879	14006	7489	259
331	14439	7003	1518	105
332	28879	13977	4142	143
333	28879	13948	6213	215
334	28879	13891	11433	396
335	43318	20619	16932	391
336	28879	13660	11202	388
337	72197	34077	27932	387
338	57758	25875	3556	62
339	173273	76413	30474	176
340	173273	75720	29832	172
341	202151	83084	25524	126
342	303227	123110	37086	122

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
343	259909	104223	30765	118
344	57758	22814	5565	96
345	173273	38120	0	0
346	43318	9487	0	0
347	43318	9443	0	0
348	101076	21933	275	3
349	57758	12533	0	0
350	144394	31189	351	2
351	28879	6238	6238	216
352	43318	9313	173	4
353	101076	21731	0	0
354	72197	15522	242	3
355	28879	6238	0	0
356	14439	3133	0	0
357	28879	6324	3870	134
358	14439	3177	1949	135
359	14439	3220	1	0
360	14439	3234	2	0
361	14439	7003	1691	117
362	14439	6989	3259	226
363	28879	13977	3355	116
364	28879	13775	2245	78
365	28879	13746	2331	81
366	14439	6555	2098	145
367	86636	37080	10683	123
368	288788	118403	36234	125
369	231030	93567	28074	122
370	101076	40430	10143	100
371	129954	51202	14673	113
372	86636	18973	289	3
373	43318	9400	0	0
374	14439	3133	45	3
375	129954	27940	280	2
376	28879	6180	6180	214
377	86636	18454	225	3
378	101076	21529	0	0
379	72197	15450	0	0
380	28879	6180	0	0
381	57758	12476	0	0
382	14439	3119	54	4
383	14439	3379	0	0
384	14439	7003	3840	266
385	101076	48921	26779	265
386	14439	6974	1237	86

CATCHMENT	AREA_M^2	RAINFALLVO	RUNOFFVOL_	RUNOFFRATE
387	28879	13833	2275	79
388	57758	27608	4743	82
389	28879	13660	2186	76
390	43318	20403	16716	386
391	28879	12707	5266	182
392	28879	12216	1321	46
393	43318	17717	4663	108
394	72197	29168	951	13
395	158833	63374	18552	117
396	101076	39723	11334	112
397	101076	22035	0	0
398	86636	18627	0	0
399	14439	3104	0	0
400	86636	18540	0	0
401	144394	30756	239	2
402	101076	21529	0	0
403	14439	3061	24	2
404	43318	9183	0	0
405	57758	12187	134	2
406	129954	27420	0	0
407	43318	9140	83	2
408	57758	12245	0	0
409	14439	3061	0	0
410	14439	3090	0	0
411	14439	3292	8	1
412	43318	20619	3345	77
413	14439	6541	5312	368
414	14439	6498	1545	107
415	231030	94260	28621	124
416	259909	104743	31174	120
417	187712	74709	21779	116
418	57758	22641	2235	39
419	115515	44704	12417	107
420	202151	43260	384	2
421	231030	48978	329	1
422	28879	6093	40	1
423	101076	21226	102	1
424	158833	33355	0	0
425	43318	9097	0	0