Cape Peninsula
University of Technology

Land-use impacts on water quality of the Bottelary River in Cape Town, Western Cape.

By

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Dissertation submitted in partial fulfilment of the requirements for the degree Master of Technology: Environmental Management in the Faculty of Applied Sciences at the Cape Peninsula University of Technology

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DECLARATION

I, Elie Fereche Itoba Tombo, declare that the contents of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed :   Date:

ABSTRACT

Freshwater scarcity and river pollution has become a serious challenge for governments and scientists. Worldwide, governments have a responsibility to provide their populations with enough clean water for their domestic needs. Scientists will have an enormous task to find a way to purify polluted water, because of its vital role in human lives and an increasing demand for water consumption due to population growth. Although the water from the Bottelary River is used on a daily basis for farming activities, its pollution level as well as spatial distribution of effluents in the catchment is unknown. In the present study, I took monthly water samples from six sampling points for laboratory analysis. The laboratory determined concentration levels of phosphorous, chloride, nitrate, and nitrate nitrogen (NO_3^-N), as well as the chemical oxygen demand (COD) and suspended solids from the samples. On the same occasion's pH, dissolved oxygen, electrical conductivity and temperature were measured in-situ using a multi-parameter reader. The results were then compared with the South African Water Quality Guidelines for Aquatic Ecosystems and for irrigation (DWAF, 1996a, 1996c). The non-point pollution source (NPS) model was used to generate predictions of the pollution level from the land-uses and use the data obtained from the field to validate the model predictions. Finally, I performed a two-factorial A One-way Analysis of Variance (ANOVA) without replication to assess the spatial and temporal variation of the measured variables along the river.

The findings of the study have shown that the concentration levels of some compounds are below the Target Water Quality Range (TWQR) set by the Department of Water Affairs and Forestry (DWAF, 1996a, 1996b, 1996c) while, the concentrations of chloride, total nitrogen and water quality variables such as electrical c onductivity, suspended solids, are higher than the TWQR (DWAF, 1996a, 1996b, 1996c). Based on the above findings water of the Bottelary River can have negative effects on the environment and human lives because of the concentration level of these compounds. It was therefore recommended that, environmentally friendly measures and practices must be undertaken in order to decrease the pollution and avoid further pollution of the river.

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DEDICATION

To the late Mr Tombo Francois and Apendi Marthe, my parents who did not have the opportunity to see their son achieve what they always told him to strive for.

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Chapter 1: Introduction

1.1. Background Information

The Earth is covered by 95.96% saline water, while fresh water represents only 4.04% (Berner & Berner, 1996; Grotzinger, Jordan, Press & Siever, 2007). Fresh water is generated by evaporation from oceans. After its condensation in the atmosphere, the water is released as precipitation and stored in rivers, lakes, glaciers, snowcaps on mountains, ice-caps at the poles and aquifers. Although fresh water comes from several resources, its availability for human beings is limited and the resources are becoming depleted due to factors such as drought and desertification, and its quality is deteriorated through multiple pollutions (GWP Technical Advisory Committee, 2000). Humans use this natural resource for their survival. Water is a precious resource that needs to be preserved and managed carefully, to allow the availability of water for domestic use. Good management of the surface water resources available as rivers depends on proper management of urban, semi-urban and rural areas.

Internationally, good management of a catchment or watershed becomes paramount because it concentrates on the treatment technologies of point source pollution and on a watershed specific priority of water quality problems as well as their integrated solutions (MacGillivray, Hamilton, Strutt & Pollard, 2006; Foran, Brosnan, Connor, Delfino, Depinto, Dickson, Humphrey, Novotny, Smith, Sobsey & Stehman, 2000). In Europe the DPSIR identified key hazards in a watershed based on the driving forces such as population growth, pressures (sewer discharge), state (increased nutrient load), impacts (anthropogenic eutrophication), and policy response (discharge control) (MacGillivray *et al*, 2006; Impress Management-EU Commission, 2002).

Population growth and its consequence of rapid urbanization have impacts on rivers throughout the world and in Africa. The impacts of population growth and rapid urbanisation constitute a major issue in Africa and South Africa. Rapid urbanization and human activities in urban and rural areas pose a serious threat to water quality in rivers due to an increased chance for pollution. This also applies to rivers in Cape Town, and those of the eastern catchment or the river basin east of Cape Town. The eastern catchment encompasses the following rivers: Kuils River, Bottelary River, Eerste River, Plankenburg River, Kromme River, Jonkershoek River, Blaauwklippen River, Bonte River, Lourens River, Sir Lowry's Pass River and Steenbras River (DWAF, 2005). Many streams in the river basin east of Cape Town, including the Bottelary River, have been modified by human activities. Thus, very few are still maintaining their natural condition (Wetzel, 2001).

The Bottelary River, which is a tributary of the Kuils River, is amongst the streams of the Eastern catchment which are exposed to several kinds of pollution, such as solid waste, industrial waste, storm water and spilled oil (DWAF, 2005). These kinds of pollution may constitute the greatest threats to human health and the environment. Microbial contamination can cause illnesses such as cholera. The decomposition process of bulk organic matter such as sewage and manure renders the water anoxic, which causes the death of many organisms (Davies & Day, 1998). Furthermore, the anaerobic decomposition process can produce many toxic and bad smelling compounds.

River pollution sources can be classified into two major groups: non-point and point sources of pollution. Non-point sources of pollution are those with a multitude of locations from which pollutants are generated. Often these pollutants reach the stream system through many ways such as agricultural runoff, urban runoff, livestock manure, human waste precipitation, drainage, interflow, seepage, groundwater flow, etc. These effluents are characterized by a variable occurrence because of weather effects (Abel, 1996; Pegram & Gorgens, 2001). As a result of rain, runoff is formed and pollutants are transported by surface water runoff and enter the river in large quantities (Arms, 1994). Non-point sources of pollution are difficult to measure and regulate because of their dispersed nature and the quantity of pollutants generated (Feng, 2005).

Point sources of pollution are from identified and fixed places which generate pollutants that enter into the stream system through specific points, such as drainpipes, ditches, channels and factory outfalls releasing organic loads, heavy metals or nutrients (Cunningham & Saigo, 1990; Abel, 1996; Pegram & Gorgens, 2001). They are relatively easy to identify, monitor and regulate.

This study, which is limited to the Bottelary River catchment, will provide an assessment of the concentrations of pollutants in the river and their spatial distributions. The evaluation of chemical levels of pollutants and their relationship with the non-point sources of pollution from the river catchment will culminate in management advice on how to decrease the pollution of the stream system. This study intends to answer questions concerning river pollution due to a multitude of land-use components along the catchment of the Bottelary River.

1.2 Research Problem

A speedy growth of the population in South Africa in general and in Cape Town in particular combined with booming industrial activities have put significant pressure on the Bottelary River system (Nieuwoudt, 2003). The river flows from the Durbanville Mountains to the Kuils River, in the Kuils River area near Bellville. The stream flows through farmland, a golf course and residential areas. Urban and agricultural surface runoff enters the Bottelary River system (Ma, 2005). During the winter season, rain storms wash pollutants into the catchment, while overflowing dams discharge their contents into the stream (Feng, 2005). Many consequences result from the presence of pollution in the river, such as a disappearance of indigenous vegetation, a decrease in water quality, a disappearance of fishes and invertebrates (Davies & Day, 1998; McConkey, 2007).

Apart from the replacement of indigenous vegetation by alien vegetation, river pollution can also have an impact on several organisms and macrophytes along the river channel. Macrophytes for example absorb pollutants and chemicals from water through their roots submerged in sediments (Biernacki *et al.,* 1996; Salt, Smith & Raskin 1998; Dean *et al.,*1972; Dietz, 1973; O'Keeffe, 1986; Erikson & Mortimer, 1975; Tremp & Kohler, 1995). These macrophytes can be used as indicators of metal pollution in freshwater ecosystems (Abo–Rady, 1980; Franzin & McFairlane, 1980; Mortimer, 1985; Ray & White, 1976). Several organisms such as mosses and periphyton, fish and vascular plants were successfully utilized in determining environmental pollution in water bodies (Porvari, 1995; Zurayk *et al.,* 2001).

Previous researches on pollution of the Bottelary River were broadly focused on water pollution caused by point sources of pollution and heavy metals such as zinc, copper, aluminium, lead. (Van Driel, 2003; Feng, 2005; Ma 2005; Rui Li, 2005). None of these preceding studies looked at the effects of pollutants generated from non-point sources of pollution (NPS). Therefore, a study on non-point source pollution in the Bottelary River is needed to fill the gap left by previous researchers.

As non-point source pollution is a spatial phenomenon, a use of GIS based non-point source pollution models is appropriate because it uses map overlay techniques in the identification and mapping of the catchment and the areas that have an impact on the water quality within the catchment (Foster & McDonald, 2000; Fuest, Berlekamp, Klein & Matthies, 1998; Lytton, Howe, Sage & Greenway, 2003; Sivertun & Prange, 2003; Osowski, Swick, Carney, Pena, Danielson & Parrish, 1999; Wickham & Wade, 2002).

The need to know the concentration levels of non-point source pollutants in the river and their distribution within the Bottelary River catchment motivated the selection of a few specific pollutants, such as chloride, nitrate-nitrogen, total-nitrogen, phosphorus, and other water quality indicators such as electrical conductivity, dissolved oxygen, chemical oxygen demand, pH and total suspended solids.

The motivation for the choice of these indicators is based on their relationship to water quality, especially on their influence on water quality in the catchment. For example, electrical conductivity and chlorides shed light on the degree of salinisation, high nutrient concentration on the level of eutrophication and chemical oxygen demand on the dissolved organic matter level in the catchment. Suspended solids contribute to the siltation in the river (DWAF, 1996a & 1996b; Alloway & Ayres, 1997; Withers & Lord, 2002). Establishing the link between water pollutants in the river and their sources in the catchment will help to prevent and decrease water pollution in the entire catchment. It would also help identify source areas that would need management intervention.

1.3 Research Questions

The main research questions addressed in this project are:

1. What impacts do different land-uses have on the water quality of the Bottelary River?
2. What is the quantity of each pollutant that gets into the river?
3. Which types of land-use in the river catchment contribute to the pollution?
4. What is the spatial distribution of the pollutants in relation to land-use?

1.4 Aims and Objectives

The main aim of this research is to study the effects of land-use on the water quality of the Bottelary River. Thus, a land-use map will help to comprehend the distribution of the sources of river pollution.

The objectives of this research are:

1. To determine the concentration levels of the selected chemical compounds in the Bottelary River.

2. To compare the concentration levels with the South African Water Quality Guidelines.

3. To identify the different types and sources of pollutants that get into the stream.

4. To assess the relationship between land-use and the contamination of the water in the stream.

5. To compare the results generated with a GIS model with the results measured in the field.

Chapter 2: Literature Review

2.1 Introduction

South Africa is a semi-arid country with most of its western part covered by the Kalahari. It is a water scarce country that receives less than 20 mm of rainfall annually. South Africa is facing a scarcity of water resources, compared to other countries such as the Republic of Congo in Central Africa or Brazil in South America that are situated in a tropical and humid climate where annual rainfall exceeds evaporation rates. The rivers from a tropical and humid climate flow throughout the year and water resources are abundant (Grotzinger *et al*, 2007; Saayman & Adams, 2002; Frame & Killick, 2004).

Sustainable management of the rivers around the world and in South Africa in particular is a big challenge due to the pollution of rivers system. Worldwide the degradation of the rivers is so intense that many rivers are no longer in their natural condition (Wetzel, 2001; Ngonye & Machiwa; 2004). Thus, sustainable management of the rivers requires a regular assessment of the hazards to the quality of water resources within a catchment as part of a permanent water safety programme (UKWIR, 2003; Umweltbundesamt Water Safety Conference, 2003; WHO, 2003; MacGillivray *et al*, 2006).

Such a programme must focus on the development and implementation of water safety plans based on the application of risk frameworks and risk tools such as the hazard analysis and critical control points (HACCP) in order to monitor water pollutants from the river to a household, farm, factory, etc (WHO, 2002; Fewtrell & Bartram, 2001; Dewettinck, Van Houtte, Geenens, Van Gege & Verstraete, 2001; Hellier, 2000).

Water pollution can be defined as any process that contributes to a direct or indirect alteration of the physical, chemical or biological properties of a water resource (National Water Act, 1998). According to the Water and Rivers Commission (1997), water pollution of rivers occurs when substances which degrade the quality of water enter the waterways and alter their natural condition.

Pollutants are waste materials that pollute water, soil and air. Water pollution is often dominated by chemical products, such as fertilizers, pesticides, herbicides, and urban toxic chemicals. All the above mentioned chemical compounds generated by both non-point and point sources of pollution are considered as serious environmental threats facing rivers in the world (Cunningham & Saigo, 1990; Botkin & Keller, 2000).

2.1.1 Non-point Sources of Pollution

Non-point sources of pollution, also called diffuse sources, are those with a multitude of locations or places from which pollutants are generated. Often these pollutants reach the stream system through many ways such as agricultural runoff, urban runoff, livestock manure, animal or human waste, atmospheric deposition, precipitation, drainage, interflow, seepage, groundwater flow and river source modification (Abel, 1996; Pegram & Gorgens, 2001). Human activities are responsible for pollutants generated by non-point sources that enter the rivers and streams through runoff (agricultural runoff or urban runoff), leaching, direct dumping, livestock manure, drainage and interflow. All these pollutants can be classified according to their origin. Urban pollutants result from municipal, industrial and domestic activities. In urban areas agricultural wastes are generated by farming activities (Kupchella & Hyland, 1989). Agricultural waste products, such as fertilizers, pesticides, wood preservatives, animal wastes from intensive pork, beef and poultry production, compost and manure are considered important non-point sources of pollutants (Alloway & Ayres, 1997).

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Due to their dispersed nature on the ground and their variable occurrence because of weather effects, non-point pollution sources are increasingly difficult to measure and regulate (Arms, 1994; Feng, 2005). In addition, because they may cover vast areas and there are many ways through which contaminated runoff enter into the stream, non-point pollution sources can be considered as major sources of pollution. They are causes for concern in the water purification process and sustainable supply of clean water (Arms, 1994; Feng, 2005; McConkey, 2007).

2.1.2 Point Sources of Pollution

Point sources of pollution occur at identified and fixed places which generate pollutants that enter into the stream system through specific points, such as drainpipes, ditches, channels, and factory outfalls releasing organic loads, heavy metals or nutrients (Cunningham and Saigo, 1990; Abel, 1996; Pegram & Gorgens, 2001). They are relatively easy to identify, monitor and regulate unlike non-point sources of pollution.

2.1.3 Water Quality in South Africa's Rivers

In South Africa several rivers deteriorate at a high rate, with the consequence of compromising the health of aquatic ecosystems, as well as the wellbeing and livelihoods of water users (Ray & White, 1976; Abo–Rady, 1980; Franzin & McFairlane, 1980; Mortimer, 1985; O'Keeffe, Uys & Bruton, 1992). Some of the water quality problems of South African rivers and their tributaries are eutrophication, increased salinity, increased turbidity, acidification and bacterial contamination, due to the diversity of land-uses they are flowing through (Ngwenya, 2006). Some scientists believe this problem will decrease South Africa's capability to provide fresh water of good quality to the population and to ensure the availability of this commodity for future generations (Otieno & Ochieng, 2004).

There is a direct relationship between the pollution loads of the rivers and the discharge into the rivers. An increase of the river pollution that causes salinization, the bloom of algae (eutrophication) and a proliferation of alien aquatic plants can obstruct the flow of water. The stream flow transports pollutants from upstream to downstream. Therefore, it is important to discuss both aspects (river pollution and river discharge) together (DWAF, 1996).

The presence of pollutants and solid waste increase the salinity and the silting up of the river systems and the withdrawal of water from rivers by farmers or other land-users within the catchment contributes to a decrease in the discharge of the rivers in South Africa (McConkey, 2007). According to Naidu (2006) the water availability in the Mgeni River catchment near Durban in Kwazulu Natal is predicted to decrease by 157.8 million cubic meters during the period from 2070 to 2100; i.e. at a rate of 5.26 million cubic meters per year due to urban demand, agricultural demand and climate change. Thus, the decrease of water availability will contribute to a decrease in agricultural productivity in the area. The decrease of water resources combined with a high level of pollutants in the rivers and aquifers will result in a lack of water and being unsuitable for irrigation and livestock. This could cause the population to leave the drier and polluted area to go to others areas where water resources are more abundant and of a better qality.

Reports revealed that in the Olifants River catchment in the Western Cape water resources are overused (Holtzhausen, 2006). The over-usage of water resources contributed to a deficit of about 55 million cubic meters every year. A continuous decrease in fresh water in the catchment constitutes a serious challenge for farming activities. Thus, a sustainable management of this natural resource is under pressure because farmers at present do not have sufficient water for irrigation and there will be very little water available for farming in the future (Holtzhausen, 2006).

Throughout the country the decrease of the discharge in the rivers becomes severe during the dry season. The decrease of the discharge has a consequence on formerly perennial rivers becoming intermittent because of insufficient rainfall (Preston-White

& Tyson, 2000). Thus, in the Northern Cape, tributaries of the Clanwilliam River, such as Kransvlei River, Kranshoek Rivers, the Dwars River & the Jan Dissels River, all formerly perennial rivers, have become seasonal (Holtzhausen, 2006).

In addition, there has been an increase in non-point source pollution into the rivers throughout the country. The increase of non-point source pollution varies from one province to another in relation to land-uses changes around the catchment. Thus, in Gauteng province, for example, the river pollution situation has worsened because of an increase of the population, mining activities and industrial developments. Due to a high density of mining activities in the province, the sulphate and salinity levels are highest along the central mining belt of the Blesbokspruit, Klip River, Wonderfonteinspruit and Suikerbosrand river, while faecal coliform levels are high in the Pienaars-, Hennops-, Klip- and Suikerbosrand rivers (DWAF, 2006). Pollutants from the mining activities around the Gauteng province that forms part of the total river flow used downstream in other provinces such as North West, Limpopo, Mpumalanga and Free State can carry some of the pollutants into those provinces. In the Northern Cape Province, for example, the non-point source pollution into the rivers results from the mining activities around Kimberley. The pollutants observed in the rivers are sulfate, lead and a high salinity.

In the Kat River catchment in the Eastern Cape Province the predominant human activities are agriculture and game farming. As a consequence, the pollution of the river is characterized by high salinity which is a result of surface runoff from soil irrigation, soluble salts as well as accelerated weathering of minerals such as feldspar and biotite and silting up of the river caused by land erosion (Van Vuuren, 2005; Plummer, Mcgeary & Carlson, 1999; DWAF, 2006; Grotzinger *et al,* 2007).

In the Western Cape Province the main land-use activities are farming and industry while urban areas are larger. Rivers in the Eastern Catchment of Cape Town are polluted by non-point source pollution because of the land-uses. Rivers such as the Eerste River, Kuils River, Kromme River and Bottelary River, for example, are exposed to a high level of pollution such as salinity, eutrophication due to farming activities, industrials activities and housing developments along these catchments (McConkey, 2007; Van Driel, 2005; Ninham, 1979).

DWAF (1993) compared the water quality data of the upper reaches and the lower reaches of the Eerste River and showed that there was a steady decline in water quality. The decline was linked to point and non-point sources of pollution in the catchment. Rivers are flowing through several land-uses that impact negatively on their water quality (DWAF, 1993; Hendricks, 2003; Joseph, 2003). Thus, Carpenter, Caraco, Correll, Howarth, Sharpley & Smith (1998) suggested that non-point pollution with nitrogen and phosphorus due to agricultural runoff urban runoff, and industry causes the water quality to deteriorate.

Van Driel (2005) observed that there have been some evident changes in the water quality of the Eerste River and the Bottelary River characterized by a high level of salinity, eutrophication and solid waste over the years. According to Feng (2005), the water quality in the Bottelary River has deteriorated due to inorganic chemical pollutants, especially nitrogen, phosphorus, cadmium, copper and zinc. Although some previous researchers have linked the deterioration of the water quality in the Bottelary River to chemical pollutants from both point sources and possibly non-point sources, they failed to further their studies on the non-point sources of pollution and the concentrations of pollutants in the stream.

Generally, the natural variation of water quality in space and time is greatly affected by land based activities in different river catchments and this is also the case with the Bottelary River (Buck, Niyogi & Townsend, 2004). The water used in industries, golf courses and agriculture (for irrigation) flows back to the stream and pollutes it. The volume of water in the river rises during the rainy season due to the input from the tributaries and the surface runoff. On the other hand, the surface runoff mobilizes and transports pollutant matter from both natural and anthropogenic sources into the river (Ngwenya, 2006).

The concerns about the water quality of the rivers in South Africa are the reasons for the government of the country and water authorities to establish the guidelines and procedures that regulate the use of this natural resource. In the water guidelines, the Department of Water Affairs and Forestry (DWAF, 1996) has set Target Water Quality Ranges (TWQR) for variables and compounds that can affect the quality of water and be harmful to human health and environment if exceeded.

2.1.4 Legislation Overview

Water is a human right as acknowledged by the World Health Organization (WHO) which gives a standard of 20-50 liters of water per person per day (World Bank, 1994). Water is so vital to human life that the Government of the South Africa has decided to include it in the constitution of the country. The government of the Republic in its section 27 (1) of the Bill of Rights acknowledges that everyone in South Africa has a right to sufficient clean water (South Africa, 1998). Accordingly, the government has adopted the policy to grant each household 6000 litres of free water per month. In addition, the National Water Act, No 36 of 1998 serves as a control tool that regulates the water resources and establishes reserves by defining them as follows: 1) The quantity and quality of water satisfies the basic human needs by securing a basic water supply; 2) The water supply will, in a reasonably near future, be relied upon as a relevant water reserve; 3) A water reserve covers both the basic human needs reserve and the ecological reserve. The basic human needs reserve provides for essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene. The ecological reserve relates to the water required to protect the aquatic ecosystem of the water resource. Moreover, the Act makes provision for the protection of aquatic ecosystems in order to secure ecologically sustainable development and the use of relevant water resources (NWA, 1998).

The protection of the quality of water is paramount because it affects its availability and use. When the quality of water is poor, there will be less water available to support various uses (DWAF, 2004b). Any usage of water resources should be promoting water conservation and sustainability.

2.1.5 Conclusion

Based on previous findings, it appears that there is a continual deterioration of the water quality in the rivers of South Africa. The state of the rivers throughout the country generally and within the Kuils-Eerste River catchment and the Bottelary River in particular is critical. The decrease of the water quality which is a result of natural and anthropogenic causes has put pressure on our rivers' capacity to supply fresh water to people for their needs and activities. A decrease in fresh water supply for human daily needs is a major concern. Thus, the concern for the well-being of the population, the economy and the conservation of the environment motivated a general fresh water awareness that resulted in the creation of rivers and groundwater management guidelines and standards. The aim of the guidelines and standards is to regulate the exploitation of this natural resource. For example, the adoption and implementation of the National Water Act, 1998 as well as the Department of Water Affairs and Forestry (1996) guidelines for water quality are assessment tools for water protection and conservation.

Chapter 3: Study Area

3.1 Bottelary catchment

The Bottelary River is a tributary of the Kuils River in Cape Town. Both rivers are part of the Eerste-Kuils River catchment (Eastern River catchment). The Eerste-Kuils River catchment, which covers an area of 588 km^2, spans all river basins from the Kuils River to the Steenbras River (Figure 3.1). The Bottelary River catchment is a relatively short, wide catchment of approximately 80 km^2 (Van Driel, 2003; Feng, 2005).

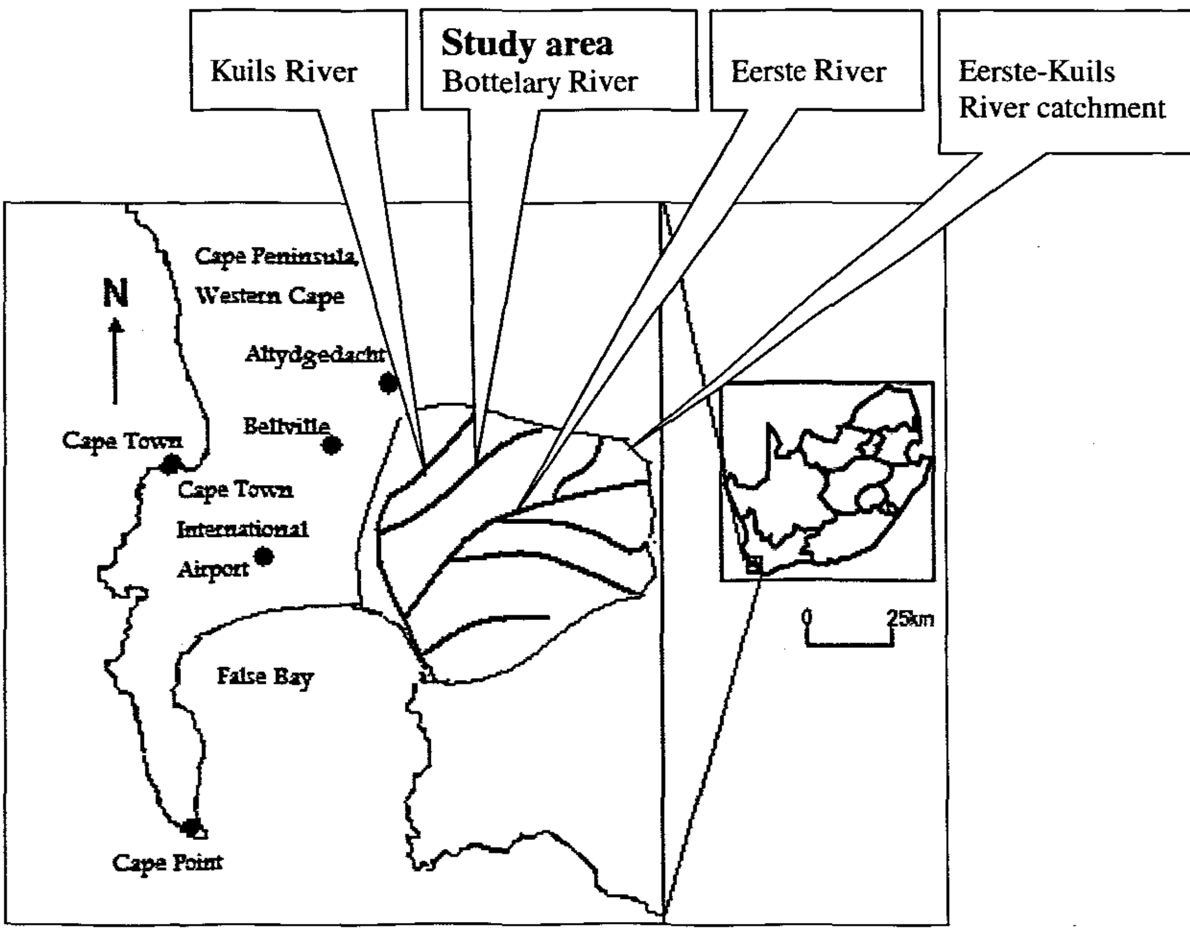

Figure 3.1: Study area in the Kuils- / Eerste River catchment.

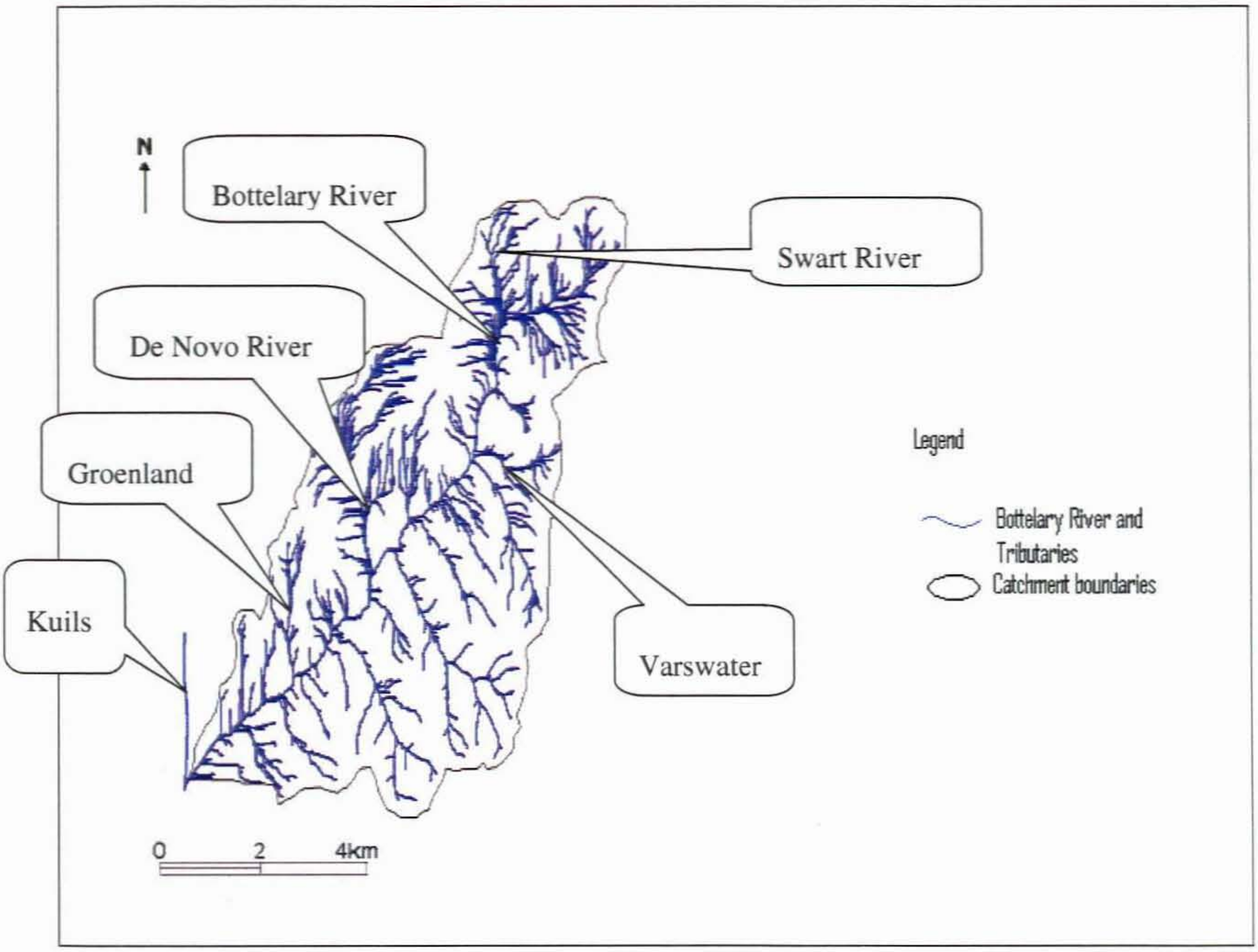

Figure 3.2: Bottelary stream system

The river banks are protected by solid concrete along certain segments of the river course as it runs through the residential areas of Kraaifontein and Kuils River (Plate 1 & 2) while at other segments of the river, the river banks are not artificially channelled. The stream is characterized by sandy banks that are covered by riparian grasses (Plate 4, Appendix 2). Most of the river bed and banks are covered by riparian grasses (Plate 6, 7; Appendix 2 & 3).

The river extends from Kraaifontein down to its confluence with the Kuils River, where the stream channel is open and the water is shallow (Plates 1 and 4).

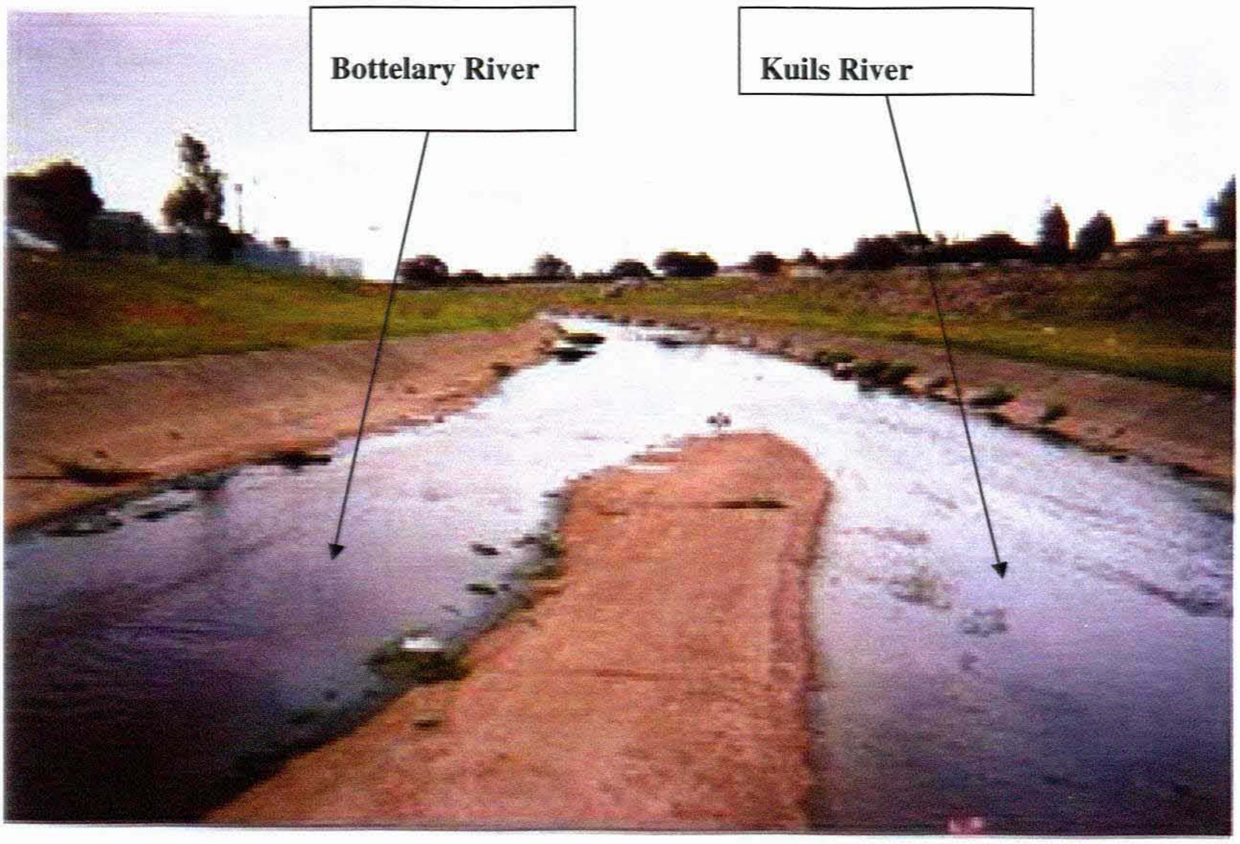

Plate 1: Confluence of Kuils River and Bottelary River

Plate 2: Bottelary River (under the bridge at Amandel Road)

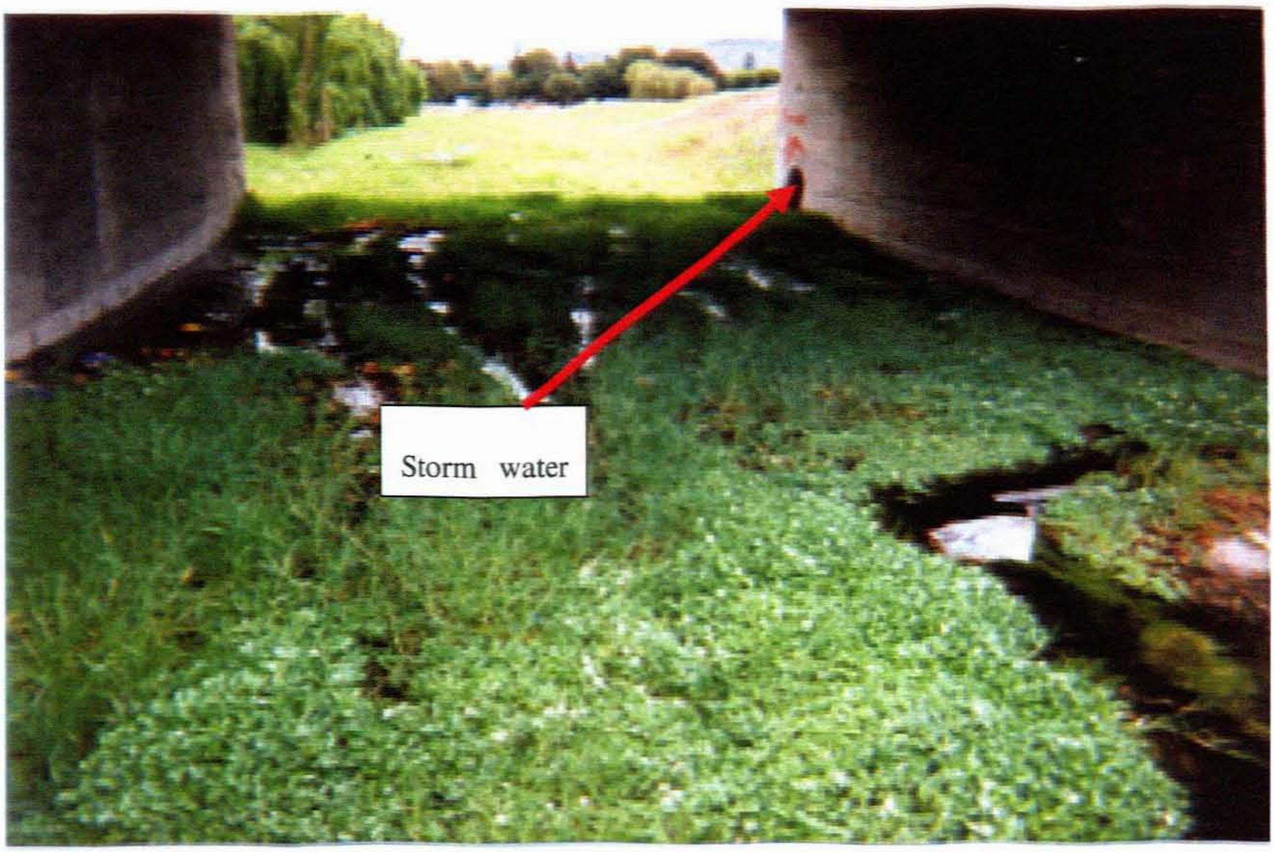

Plate 3: Storm water drain under the bridge at Amandel Road

Plate 4: Bottelary River (downstream of the bridge at Amandel Road); one of the sampling points is at this location

Plate 4: Bottelary River (downstream of the bridge at Amandel Road); one of the sampling points is at this location

Plate 5: Bricks factory next to the Bottelary River

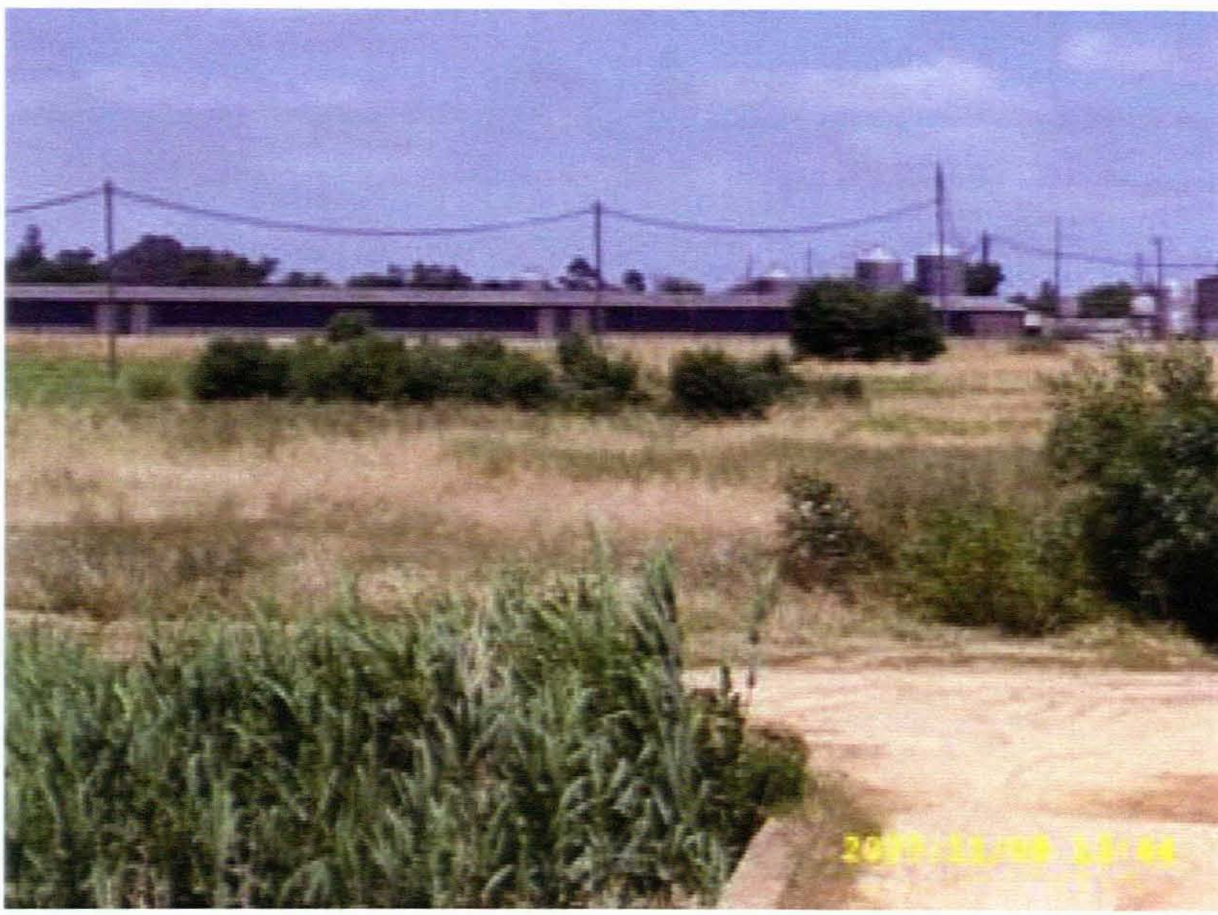

Plate 6: Rainbow chicken farm next to Bottelary River

Plate 7: De Novo (tributary of the Bottelary River) opposite the brick field showing market gardening activities in the background

3.5 Land-use/Land-cover

The catchment of the Bottelary River is characterized by a variety of land-use activities which include among others farming, brick fields, a golf course, residential areas and factories. There are farming activities in the rural and semi-urban areas (Figure 3.4). According to Van Driel (2005) there are approximately 80 farms in the Bottelary catchment. These farms are located from the Stellenbosch mountains next to the source of the river to Kraaifontein.

Within the Bottelary River catchment there is also a small Waste Water Treatment Plant (WWTP) of Scottsdene located upstream on the De Novo River (tributary of the Bottelary River). The Scottsdene WWTP is registered with the DWAF under permit No. 896 B (Cape Wastewater Consultants, 1999; Ninham Shand & Gibb, 2001). This small wastewater treatment plant has a capacity of about 4.5 Ml/day to 7.5 Ml/day. With a service area that covers approximately 350 ha, the Scottsdene WWTP receives wastewater from the urban areas such as Wallacedene, Scottsdene and a part of Kraaifontein (Cape Wastewater Consultants, 1999; Feng, 2005).

The Kuilsriver golf course which is located on the Bottelary road is an open course along vineyards. It is approximately 5819 meters wide and Rating: 70 and par: 70 (long).

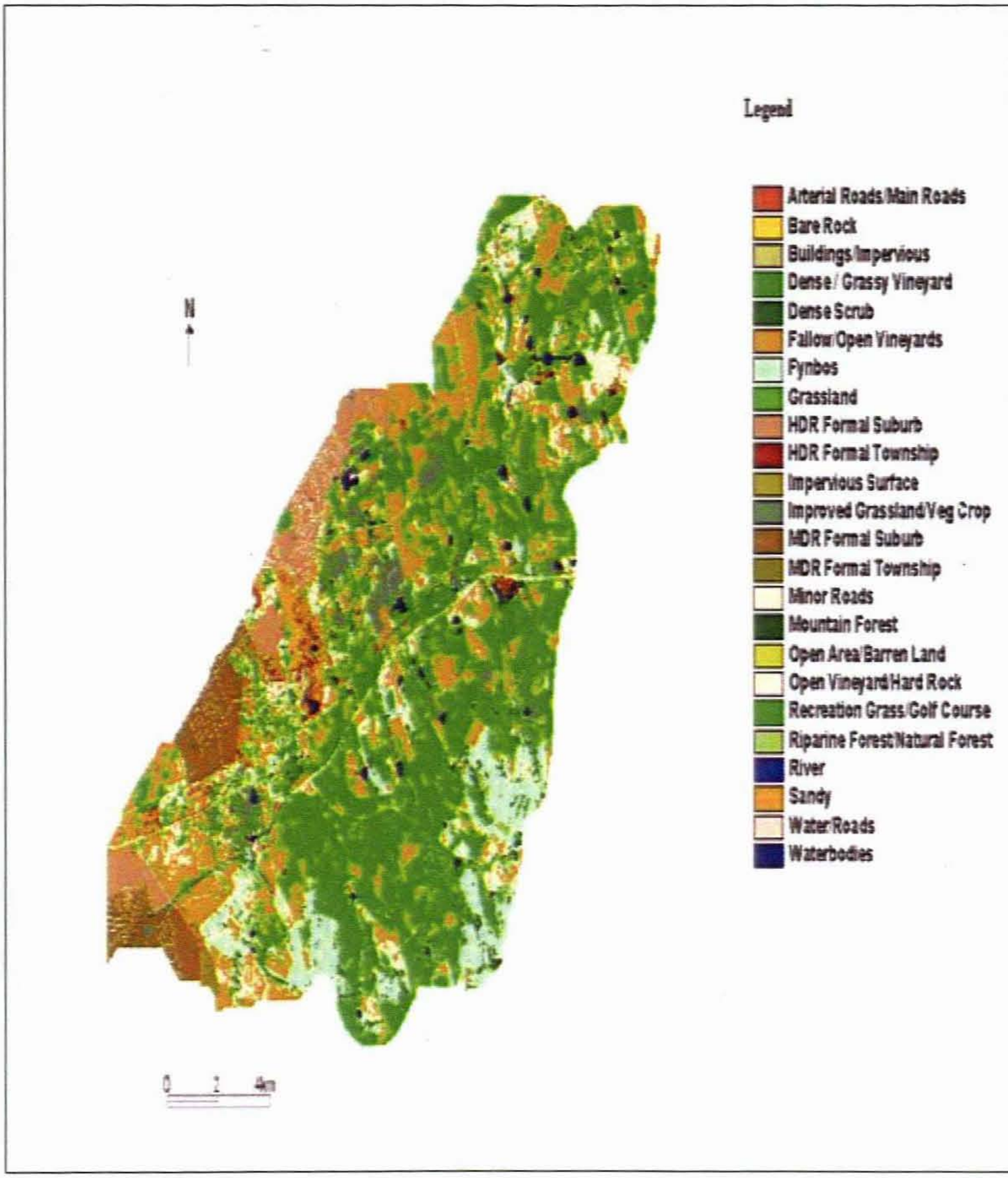

Figure 3.3: Land-use distribution within the Bottelary River Catchment (Thomas and Ayuk, 2005).

Chapter 4: Methodology

4.1 Introduction

Field sampling was conducted on a monthly basis. The pH, dissolved oxygen, water conductivity and temperature of the stream were measured *in situ* using a portable multi-parameter reader (HACH SENS 1 ON 156 and HANNA - HI 991301) during six month period (from the 08 November 2007 to the 11 April 2008). A flow probe (model FP 201 of Global Water) was used to measure stream flow velocity. Stream discharge was obtained through calculation. In addition, a Global Positioning System (GPS) Garmin GPSmap 60 CS was used to obtain geographic coordinates of the sample sites.

The water samples collected were analyzed in the BEM laboratory to determine the chemical composition of the stream by measuring the concentration levels of chemical elements and other contaminants, such as phosphorous, nitrate-nitrogen, chloride, suspended solids, and the chemical oxygen demand. Microsoft Excel was used to obtain the concentration level chart of each compound and determine the variation of the compound concentrations within sections of the Bottelary River. Finally, GIS modelling was used to estimate surface runoff pollutant loads from non-point pollution sources (NSPECT).

4.2 Identification of sample points using a Topographic Map.

A topographic map of Cape Town (scale of 1:50 000) was used for the identification of the possible sample points in the Bottelary River catchment. A total of seven sample points were chosen along the river. These sample points were chosen in relation to the accessibility of the stream at a particular point and their location near a particular land-use carried out along the river or its tributaries. The first two sampling points are located within the residential areas, while the remaining five sample points are in the semi-urban and agricultural areas.

4.3 Location of the sampling points

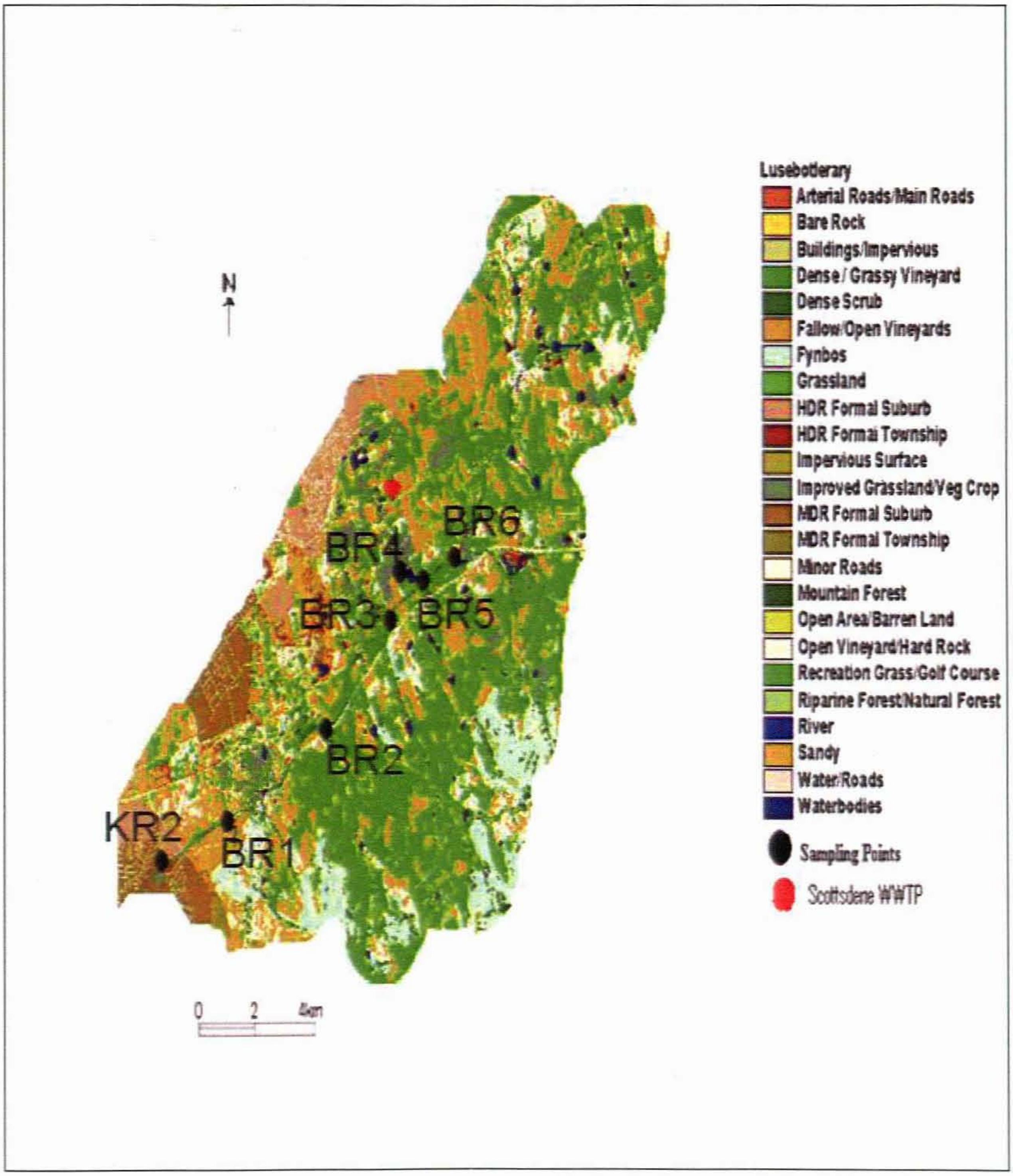

Figure 4-1: Sampling points along the Bottelary River

4.4 Description of sites

A site is a sampling point or a specific place along the river where a water sample was collected. The sample points identified are as follows:

- KR2: It is located in the residential area of Kuils River, on the Bottelary River and about five meters upstream of the confluence point between the Kuils River and the Bottelary River.

- BR1: It is situated two meters downstream the bridge at Amandel Road and about five meters downstream a storm water drain under the bridge in the residential area of the Kuils River.

- BR2: It is situated near the Rainbow Chicken Farm, under the bridge of the road that gives access to the chicken farm.

- BR3: It is located half a meter upstream of a brick factory, about three meters downstream of the confluence point between the Bottelary River and its De Novo tributary.

- BR4: It is under the bridge, about three meters upstream the confluence point of the Bottelary - De Novo and near Grape fields.

- BR5: It is situated on De Novo stream approximately five meters upstream from the confluence point between De Novo and Bottelary Rivers.

- BR6: It is about two meters downstream the confluence point between the Bottelary River and Varswater River.

Coordinates of the sampling points are given in Table 4.1.

Table 4.1: Geographic coordinates of sampling points along the Bottelary River

Sample Site	Longitude	Latitude	Elevation (m)
KR2	E018.67576°	S33.92229°	38
BR1	E018.68750°	S33.91613°	49
BR2	E018.70433°	S33.91091°	58
BR3	E018.73721°	S33.89043°	79
BR4	E018.73737°	S33.89027°	78
BR5	E018.73722°	S33.89021°	79
BR6	E018.75128°	S33.88231°	92

4.5 Fieldwork Scheme

The fieldwork scheme of this research project is given in Table 4.2.

Table 4.2: Fieldwork scheme

Sampling dates	Materials Used	Field work
Tues 06 Nov 2007	Garmin GPS map 60 CS	Identification of sample points.
Thurs 08 Nov 2007	1.Multi parameter reader type HACH SENS 1 ON 156. 2. White plastic bottles (Kartell) of 250 ml capacity.	1. Reading of water pH, temperature, dissolved oxygen, electrical conductivity. 2.Collection of samples.
Tues 20 Nov 2007	1.Multi parameter reader type HACH SENS 1 ON 156. 2. White plastic bottles (Kartell) of 250 ml capacity.	1.Reading of water pH, temperature, dissolved oxygen, electrical conductivity . 2.Collection of samples.
Wed 28 Nov 2007	1.Multi parameter reader type HACH SENS 1 ON 156. 2. White plastic bottles (Kartell) of 250 ml capacity.	1.Reading of water pH, temperature, dissolved oxygen, electrical conductivity . 2.Collection of samples.
Tues 04 Dec 2007	1.Multi parameter reader type HACH SENS 1 ON 156. 2.White plastic bottles (Kartell) of 250 ml capacity. 3.Stream flow Probe FP101 & 201	1.Reading of water pH, temperature, dissolved oxygen, electrical conductivity . 2.Collection of samples. 3. Stream Flow Measurement
Wed 12 Dec 2007	1.Multi parameter reader type HACH SENS 1 ON 156. 2.White plastic bottles (Kartell) of 250 ml capacity.	1.Reading of water pH, temperature, dissolved oxygen, electrical conductivity . 2.Collection of samples.
Tues 22 Jan 2008	1.Multi parameter reader type HACH SENS 1 ON 156. 2.White plastic bottles (Kartell) of 250 ml capacity.	1.Reading of water pH, temperature,electrical conductivity . 2.Collection of samples.
Tues 19 Feb 2008	1.Multi parameter reader type HANNA - HI 991301. 2.White plastic bottles (Kartell) of 250 ml capacity. 3.Strem flow Probe FP101 & 201.	1.Reading of water pH, temperature, total suspended solids, electrical conductivity. 2.Collection of samples. 3. Stream flow measurement.
Frid 14 Mar 2008	1.Multi parameter reader type HANNA - HI 991301. 2.White plastic bottles (Kartell) of 250 ml capacity.	1.Reading of water pH, temperature, total suspended solids, electrical conductivity. 2.Collection of samples.
Frid 11 Apr 2008	1.Multi parameter reader type HANNA - HI 991301. 2.White plastic bottles (Kartell) of 250 ml capacity. 3.Stream flow Probe FP101 & 201.	1.Reading of water pH, temperature, total suspended solids, electrical conductivity. 2.Collection of samples. 3. Stream flow measurement.

4.6 The Sampling Procedure

Clean white plastic bottles (Kartell) of 250 ml capacity were used to collect water samples from the river. After rinsing it, the plastic container was plunged into the stream and filled up with water. The bottle was closed very tightly to avoid any air intake into the bottle.

In cases where it was impossible to reach the river surface and plunge the plastic bottle into the water to collect a sample, a scoop was used to collect water from the river and fill the plastic container. After collecting the sample, the container was placed into a wooden box to avoid exposure to solar radiation. The samples where taken to the laboratory (BEM Lab) where the samples were analyzed for P, total N, NO_3-N, Cl, dissolved oxygen, suspended solids and COD.

4.7 Water Quality Testing using a Multi Parameter Reader

A multi-parameter reader (HACH SENS 1 ON 156) was used to collect readings of pH, temperature, electrical conductivity and dissolved oxygen at each sample point from November 2007 to January 2008. After that, due to the fact the multi parameter reader HACH SENS 1 became faulty, another multi parameter reader (HANNA - HI 991301) was used to collect readings of pH, temperature, and suspended solids at each sample point from February 2008 to April 2008, while readings of electrical conductivity were not possible.

4.8 Stream Flow Measurement Using a Flow Probe

Stream flow velocity was measured using a Global Water Flow Probe. The average velocity over a column is measured by slowly moving the velocity meter's propeller up and down for a period of 20 to 40 seconds. Stream flow velocity is not usually equal across a streams cross-section. The stream was therefore divided into three subsections (Fig. 4-2). At each section the depth of the stream and the stream velocity were measured.

The depth was directly read on a Global Water flow probe which is scaled in millimetre, centimetre and meter. The stream width was obtained using a measuring tape.

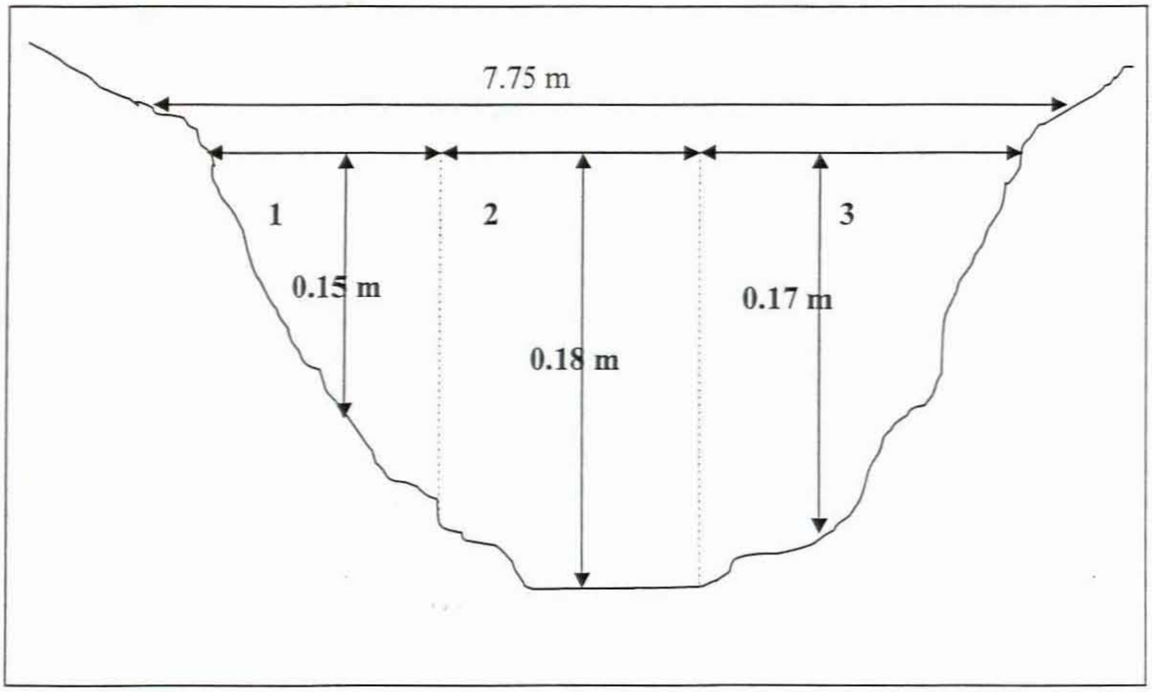

Figure 4-2: Channelled segment of the river where the stream flow measurement was done.

4.9 Description of the Water Flow Probe (FP201)

The Water Flow Probe is 5 feet to 15 feet long. The handle is constructed of anodized aluminium for light weight and long life. The Flow Probe may be easily extended up to 25 feet in length using standard PVC pipe and an electrical xextension cable for long measurements. The instrument has three main parts: Digital Readout Display, Turbo-Prop propeller sensor and a three (3) foot mylar coated staff gauge (Global Flow Probe, 2004)

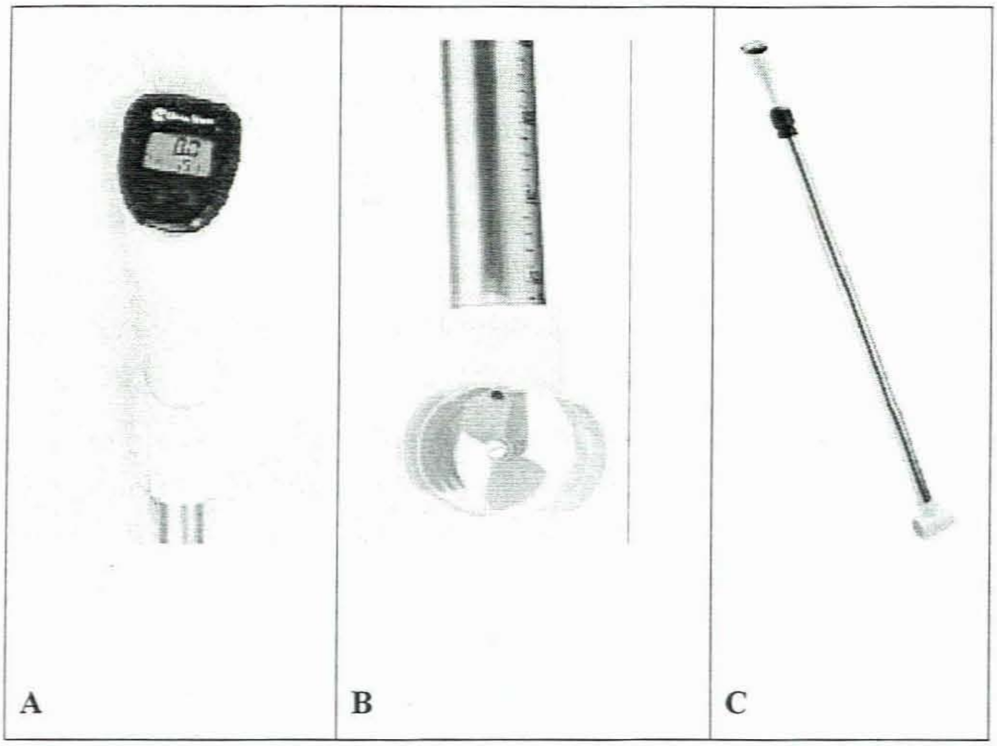

Figure 4-3: Global Water Flow Probe (Global Flow Probe, 2004)

A: Digital Readout Display

The Digital Readout Display receives an electrical signal from the propeller, amplifies the signal, and converts the reading to feet per second (or meters per second, depending on programming).

B: Turbo-Prop propeller sensor

The flow meter propeller is attached to the lower section of the flow probe. Once introduces in a stream water it rotates freely on its bearing shaft with no mechanical interconnections for minimal friction. Magnetic material in the propeller tip passes a pickup point in the water velocity meter handle producing electrical impulses that are carried to the readout display by an internal cable.

C: A 3-foot mylar coated staff gauge

A 3-foot mylar coated staff gauge is graduated in hundredths of a foot and centimeters. A mylar coated staff gauge is attached to the lower section of the water flow probe.

The water depth measurements is done by holding the flow probe vertically with the lower section of the instrument (a mylar coated staff gauge) is inserted in the water and the depth is obtained in centimeter from the instrument. We have decided to convert the depth from centimeters to meters for consistency and harmony. It is better to have the units in meters because it is a standard unit used to determine a discharge of the river (Global Flow Probe, 2004).

Figure 4-4: Handling of Water Flow Probe

4.10 Stream Discharge and Flux (loading rate)

The stream discharge is defined as the quantity of water that passes through a particular point at a given time. It is obtained as the result of a cross section (depth multiplied by width) assuming that the river's cross section is rectangular and multiplied by average stream velocity (Grotzinger *et al*, 2007). Total stream discharge is the sum of all the subsection discharges. I n order to determine the discharge and flux of the chemical compounds two sampling points (KR2 and BR1) were used.

Discharge D $(m^3/s) = A\ (m^2)\ .\ V\ (m/s)$

Where,

D: Is the total discharge (m^3/s)

V: Is the average velocity at each subsection (m/s).

A: Is the average area at each subsection (m^2).

Flux: Is the instantaneous rate at which a quantity of compound is passing a particular point of the river (g/s).

Flux (F) $= D\ (m^3/s)\ .C\ (mg/l)$

Where,

F: Is a loading rate of each compound (g/s).

D: Is the discharge (m^3/s).

C: Is the concentration level of each compound *(mgl)*.

4.11 Use of Global Positioning System (GPS)

A GPS receiver handset (Garmin GPSmap 60 CS) was used to get the geographic coordinates of all the sample points along the Bottelary River.

4.12 Laboratory Analysis Protocol

Laboratory procedures for the analysis of chemical elements (phosphorous, total N, nitrate-N, chloride, electrical conductivity, chemical oxygen demand, dissolved oxygen) in the Bottelary River samples were as follows:

4.12.1 Determination of electrical conductivity (EC)

The following equipments and solutions are needed:

Beakers, 100 ml capacity, conductivity meter fitted with a suitable cell and temperature probe, certified calibration standards 141.3 μs/m and 12.88 ms/m, Merck or equivalent, and deionised (or distilled) water.

The calibration is done by transferring a portion to a beaker. Then, the cell is immersed and the temperature probed. The reading is left to stabilize and the results are recorded in the conductivity column on the water information form.

4.12.2 Determination of chemical oxygen demand (COD) in waste water

When determining the chemical oxygen demand in waste water refers to Clesceri, Greenberg and Eaton (1998) and Merete (2001).

4.12.3 Determination of chloride, total nitrogen and nitrate-nitrogen

The equipments and solutions needed for the determination of chloride and the determination process are done according to the standard practices (Clesceri *et al.*, 1998).

4.13 Statistical Analysis

Prior to proceeding with statistical analysis of the data, the Bottelary River was divided into five sections starting from upstream to downstream as follows:

- Section 1: between BR6 and BR5.
- Section 2: between BR5 and BR4.
- Section 3: between BR4 and BR3.
- Section 4: between BR3 and BR2.
- Section 5: between BR2 and BR1.

The tables of each compound concentration were obtained by subtraction of the compound concentration at sample point A from the concentration at B. Thus, we have the increase or decrease of the compound concentration over a section (between A and B). Statistical analysis of data was done by using a two-factor ANOVA without replication, with the factors time and section.

4.14 Development of land-use / land-cover map of the catchment

In order to produce the land-use map one needs a land-use classification system. A land-use classification system is a structured collection of land-use class definitions (Thomas, 2006). Land-use classification systems come in two basic formats: hierarchical and non-hierarchical. The hierarchical system of classification was used for this work. It is a flexible system that allows different levels of land-use information to be accommodated, starting with broad level classes structured to allow further subdivisions to account for more detailed subclasses (Thomas & Tellam, 2004).

The topography used to develop a land-use / land-cover map is based on several sources of information, such as aerial photographs, satellite images and other data related to land-use activities that are taking place in the study area. Remote sensing and GIS software were used to produce a catchment map and a land-use map (Thomas, 2006). The method of developing a classification scheme land-use / land-cover capable of delineating possible sources of non-point source pollution helped in preparing a map that could be used in the model for pollution assessment. The catchment boundary of the Bottelary River was delineated using a 20 m Digital Elevation Model (DEM) using GIS.

4.15 Chemistry of Land-use / Land-cover of the Bottelary River catchment

The chemistry or Concentration (C) of the land-use/land-cover was obtained by computer calculation. The estimated Concentrations (C) 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). The C is a flow weighted average concentration of a pollutant over an entire storm event.

Several methods or approaches can be used to estimate the mean concentrations in storm runoff. It is mostly estimated from a flow weighted composite samples in the field or calculated from discrete measurements. A mathematical approach estimates C using the following equation:

$$\mathbf{C}\ (mg/l) = \frac{\sum (Ci\ (mg/l) \, . \, Qi\ (\mathrm{m}^3))}{Qi\ (\mathrm{m}^3)}$$

Where,

Ci = concentration of runoff at interval i

Qi = runoff volume at time when sample was taken

When the C is multiplied by the runoff volume, an estimate of the loading to the receiving water is provided. The runoff volume (Q) can be 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 as runoff (Thomas, 2001, Ayuk, 2008).

The C value can also be obtained through calculation of the arithmetic average concentrations for a samples collected during a rainfall event or a river flow. The arithmetic average C is defined as equation:

$$\text{Average } C\ (mg/l) = \frac{\sum_{j=i}^{m} Cj}{m}$$

Where,

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

The C represents the means the arithmetic average values of the concentration levels of the compounds analysed in this study and other aspects of water quality, such as total suspended solids (TSS), chemical oxygen demand (COD), dissolved oxygen (DO) of all land-use / land-cover types within the Bottelary River catchment. The C of the land-use/land-cover types within the Bottelary River catchment varies from one land-use to another, as it is represented in Table 5.3.

4.16 Modelling

The model used to determine the non-point source pollutants load in this study was developed by Thomas (2006). The model creates a runoff simulation and determines non-point source pollutant loads on the types of soil within the catchment. It assigns Standard Percentage Runoff (SPR %) to a map of hydrology of soil type classification.

The Non-point source pollution (NPS) model functionality depends on several grids that are derived from a Digital Elevation Model (DEM). A DEM used during this study was created by the service provider; the Directorate of Surveys and Mapping of the Department of Land Affairs in Mowbray. The model automatically sets the raster analysis environment to the parameters of the DEM file. The first run of the model begins with the watershed delineation. By using the FILL command, there will be a removal of all artificial sinks and other imperfections that are often found in raw topography data sets. The following step will be the creation of the flow direction grid from the DEM that will result in the calculation of the downstream flow path of water leaving each cell. After that step, there will be the creation of flow accumulation grid based on the flow direction grid. The flow accumulation grid will be used to derive the stream network (NOAA, 2004).

In addition, there will be the creation of precipitation grid, soil grid, and a land-use/land-cover grid. All grids that were created constitute a set of input data. The input tables (C table, curve number table and initial surface loss table) must be prepared as well. Once, the input data and input tables are ready, and then click on Catchment Runoff (NRCS Method) on the computer's tool bar, finally on NPS Pollution Modelling which is the last phase. The advantage of this model is that it produces maps or output layers that display the estimations of runoff, pollutant mass load of the catchment (Table 5.2). These maps will help water authorities and every department or organization involved in water resources management to make good and sustainable decisions regarding water quality.

Chapter 5: Results

5.1 Stream Flow: Discharge

After the calculation of the stream velocity under the bridge at Amandel Road an average of measurements on the day helped to determine the discharge. The result represents the amount of water that passes through BR1 (under the Bridge at Amandel Road). There is no tributary between BR1 and KR2. KR2 is the last point downstream the Bottelary River. It is located next to the confluence of the Bottelary and the Kuils Rivers. The discharge values measured in December 2007, February 2008 and April 2008 at the BR1 and KR2 vary. An observation of these values shows that the discharge is low in December 2007 (0.09 m^3/s at KR2); while it increases in February 2008 (0.25 m^3/s at KR2 and 1.22 m^3/s at the BR1) and April 2008 (21.57 m^3/s at the BR1).

December month receives an average of 17.5 mm of rain (SA Weather Service, 2009). The rainfall increases the volume of the water flow into the Bottelary River through its tributaries, runoff, subsurface flow and underground flow. While, the rainfall decreased during the last months of the study period (from January 2008 to April 2008) in contrast, the stream flow discharge measured during these months increased. The increase of the stream flow discharge could be due to the supply of water into the river by subsurface flow, underground flow and irrigation return flows. The water stored in the soil and underground during the rainy months of October, November and December 2007 is released into the Bottelary River through subsurface flow and underground flow.

5.2 Flux of the Compounds

Although the discharges were similar at KR2 and BR1, the amount of the chemical compound that passes through these two points is different (Table 5.1). For example, the flux of nitrate that passes BR1 during December 2007 is low (0.29 g/s). The mass increased to 5.82 g/s during February 2008 and 248.49 g/s during April 2008. The mass of the same chemical compound (NO_3^-) that reached KR2, which is the last point downstream was 0.44 g/s during December 2007, 248.49 g/s during February 2008 and 169.80 g/s during April 2008.

Chloride's flux also shows a low quantity of 1.42 g/s in December 2007, it increases to 203.86 g/s in February 2008 and to 3610.82 g/s during April 2008. In addition, the quantity of the phosphorus that flows past these two points is low: 0.11 g/s in December 2007 at KR2 and BR1, increases to 41.85 g/s in April 2008 at BR1. At KR2; a flux of phosphorus is low at 0.09 g/s in February 2008. It increases during December 2007 to 0.11g/s and in April 2008 to 41.85 g/s.

The instantaneous rate of total nitrogen at the BR1 and the KR2 varied from one month to the other during the study period. Thus, a broad observation of these fluxes show the same pattern between BR1 and KR2 for the mass flow of nitrate (NO_3^-), chloride (Cl^-) and phosphorus (P), i.e. low quantities in December 2007 in both points and an increase from February 2008 to reach their high point in April 2008. While, in the total nitrogen case the situation is different. During December 2007 in both points (BR1 and KR2) a flux is high, and it decreases during February 2008 and finally increases again in April 2008. The table below shows the variation in the discharge and chemical compounds at BR1 and KR2.

Table 5.1: Discharge and Flux of Chemical Compounds

			flux (g/s)			
Dates	**Sites**	**Discharge (m^3/s)**	**NO_3^-**	**Cl^-**	**P**	**N**
2007/12/04	KR2	0.09	0.44	5.79	0.11	36.36
2008/02/19	KR2	0.25	1.11	40.9	0.9	2
2008/04/11	KR2	17.38	169.8	2695.65	25.2	2346.3
2007/12/04	BR1	0.08	0.29	1.42	0.11	38.47
2008/02/19	BR1	1.22	5.82	203.86	0.9	19.52
2008/04/11	BR1	21.57	248.49	3610.82	41.85	1747.17

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2008/04/11	KR2	17.38	169.8	2695.65	25.2	2346.3
2007/12/04	BR1	0.08	0.29	1.42	0.11	38.47
2008/02/19	BR1	1.22	5.82	203.86	0.9	19.52
2008/04/11	BR1	21.57	248.49	3610.82	41.85	1747.17

5.3 Chemistry of Land-use/Land-cover of the Bottelary River catchment (obtained from the NPS model and observed data)

The chemistry or Concentration (C) of land-use/land-cover within the Bottelary River catchment varies from one land-use to another. The concentration values of the land-use/land-cover obtained from the modelling (table 5.2) are different from those obtain from calculation of observed data (table 5.3). The chemistry of the mountain forest obtained from the modelling are; 1.23 mg/l (C Nitrate), 55.00 mg/l (C TSS), 10.00 mg/l (C Chloride). While, the observed data of the mountain forest are 1.01 mg/l (C Nitrate), 196.17 mg/l (C TSS), 16.27 mg/l (C Chloride), as represented in the following tables:

Table 5.2: Concentration (C) of Land-use/Land-cover within the catchment obtained from the NPS modelling (Thomas, 2001).

Luse_code	Landuse/Land-cover	Nitrate (mg/l)	Total Nitogen (mg/l)	Total Phosphorus (mg/l)	Chloride (mg/l)	TSS (mg/l)
1	Mountain Forest	1.23	10	2.4	10	55
2	Riparian Forset/Nat. Forest	1.89	20	1.8	20	149
3	Dense Scrub	2.12	15	0.9	15	97
4	Fynbos	1.84	15	0.9	15	70
5	Grassland	1.83	15	0	15	135
6	Impervious Surface	4.06	0.91	0	0.91	145
9	Bare Rock	0.5	0.91	0.2	0.91	100
10	Open Vineyard/Hardrock	0.9	0.91	0	0.91	70
11	Open Area/Barren Land	0.8	15	0	15	100
12	Improved Grassland/Veg. Crop.	0.59	0.91	0	0.91	6
13	Buildings/Impervious	0.59	0.91	0	0.91	6
14	Dense/Grassy Vineyard	0.59	0.91	0	0.91	6
15	Fallow/Open Vineyard	0.59	0.91	0	0.91	6
16	Recreation Grass/Golf Course	0.59	0.91	0	0.91	6
18	Arterial Roads/Main Roads	6	50	2.4	50	70
19	Minors Roads	0.5	0.91	0.2	0.91	140
20	Sandy	1.23	10	2.4	10	55
21	Water bodies	1.89	20	1.8	20	149
22	HDR Formal Suburb	2.12	15	0.9	15	97
23	MDR Formal Suburb	1.84	15	0.9	15	70
25	HDR Formal Township	4.06	0.91	0	0.91	145
26	MDR Formal Township	1.83	0.91	0	0.91	70
36	River	8	50	0	50	6

Table 5.3: Concentration (C) of Land-use/Land-cover within the catchment obtained from observed data collected during the study.

Value	Land-use / Land-cover	Nitrate (mg/l)	Chloride (mg/l)	TSS (mg/l)	Phosphorus (mg/l)	Total Nitrogen (mg/l)	DO (mg/l)	COD (mg/l)
1	Mountain Forest	1.01	16.27	196.17	0.25	7.5	7.33	64.5
2	Riparian Forest/Natural Forest	1.01	16.27	196.17	0.25	7.5	7.33	64.5
3	Dense Scrub	1.01	16.27	196.17	0.25	7.5	7.33	64.5
4	Fynbos	1.17	16.24	45.8	0.19	5.8	7.2	76.8
5	Grassland	1.01	36.08	66.9	3.32	19.86	4.94	178.43
6	Impervious Surface	1.21	16.87	70.56	0.24	17.59	6.07	107
9	Bare Rock	1.21	16.87	70.56	0.24	17.59	6.07	107
10	Open Vineyard/Hard Rock	0.51	58.11	61.44	0.08	67.22	8.02	50.78
11	Open Area/Barren Land	0.69	159.8	68	0.03	50	6.8	43
12	Improved Grassland/Veg Crop	0.69	157.29	234.5	3.78	295.5	7.25	128
13	Buildings/Impervious	1.21	16.87	70.56	0.24	17.59	6.07	107
14	Dense / Grassy Vineyard	1.79	48.21	96.25	2.12	49.09	6.19	213.58
15	Fallow/Open Vineyards	1.79	48.21	96.25	2.12	49.09	6.19	213.58
16	Recreation Grass/Golf Course	0.03	261.6	9	0.12	565	7.3	120
18	Arterial Roads/Main Roads	0.12	34.94	394.29	0.57	47.69	5.01	592.43
19	Minor Roads	0.13	29.4	75	0.58	29.34	4.94	521
20	Sandy	0	0	0	0	0	0	0
21	Water bodies	0.2	1	1	0,13	0.81	0.3	0.1
22	HDR Formal Suburb	0.23	33.43	99.67	1.27	20.33	5.8	608.67
23	MDR Formal Suburb	0.17	21.03	40.63	0.29	87.65	6.56	108
25	HDR Formal Township	0.22	12.27	41.8	0.31	94.34	6.38	54.4
26	MDR Formal Township	0.22	12.27	41.8	0.31	94.34	6.38	54.4
36	River	5.59	150.45	24.84	1.8	383.17	8.06	62.76

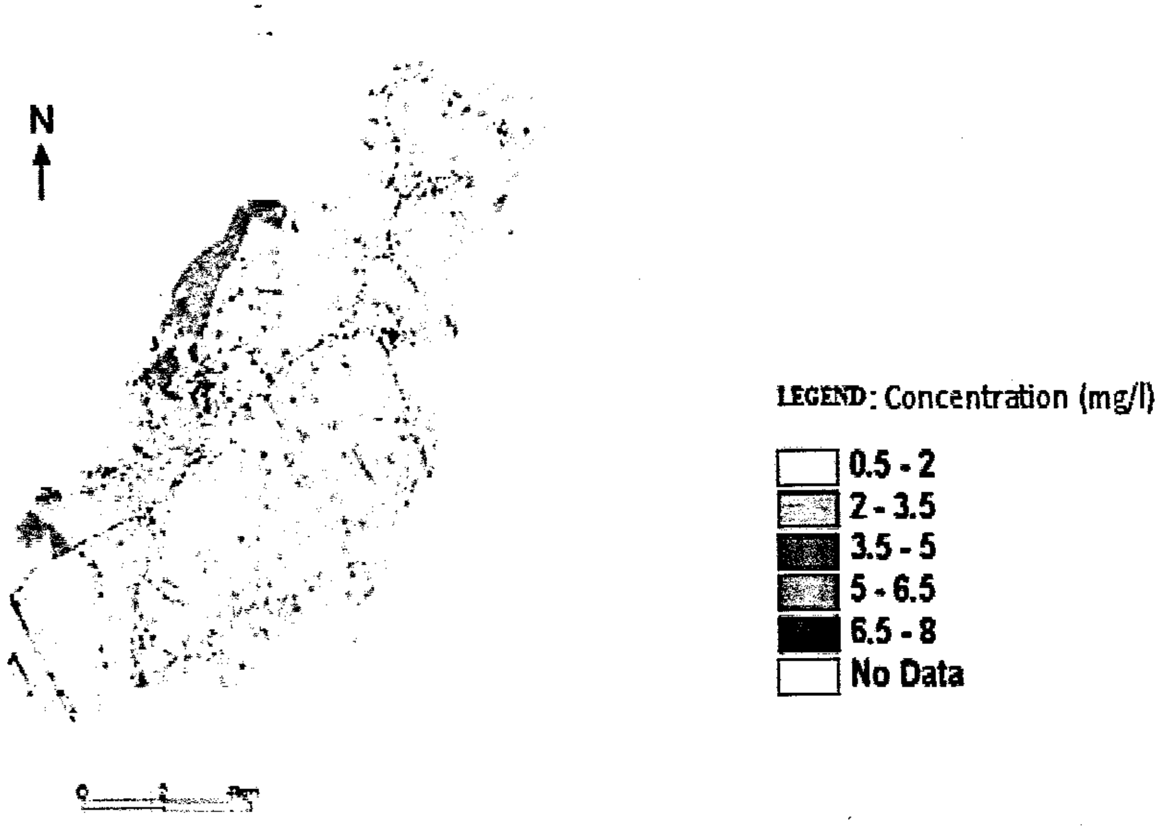
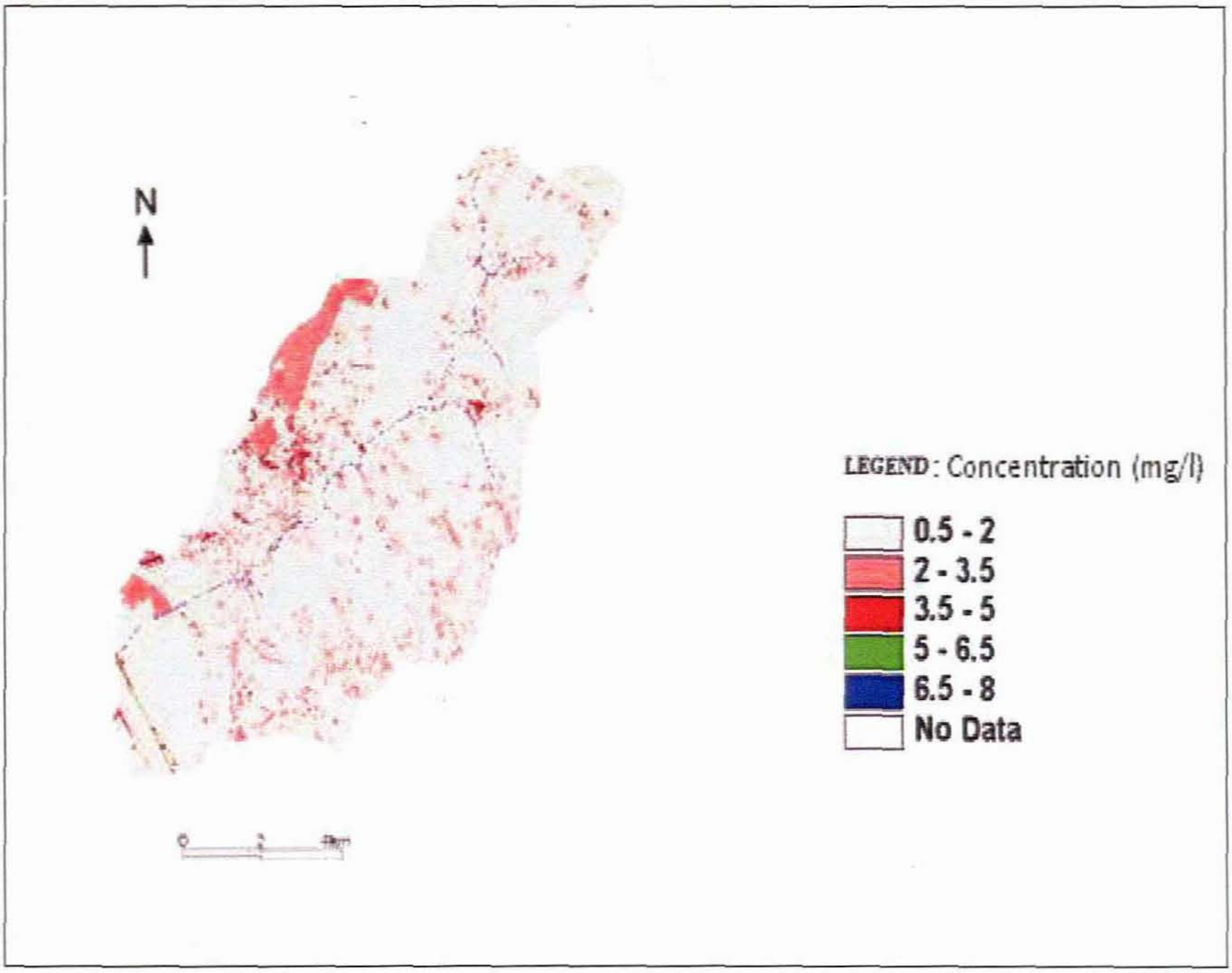


Figure 5.1 : Pollutant Concentration (C) Nitrate

5.4.2 Pollutant Concentration (C) Total Nitrogen

Pollutant concentration (C) Total Nitrogen throughout the study area varies from 0.91 mg/l – 50 mg/l (Figure 5.2). The peaks in total nitrogen (Figure 5.17) coincide with a valley (low value) in nitrate (Figure 5.18).



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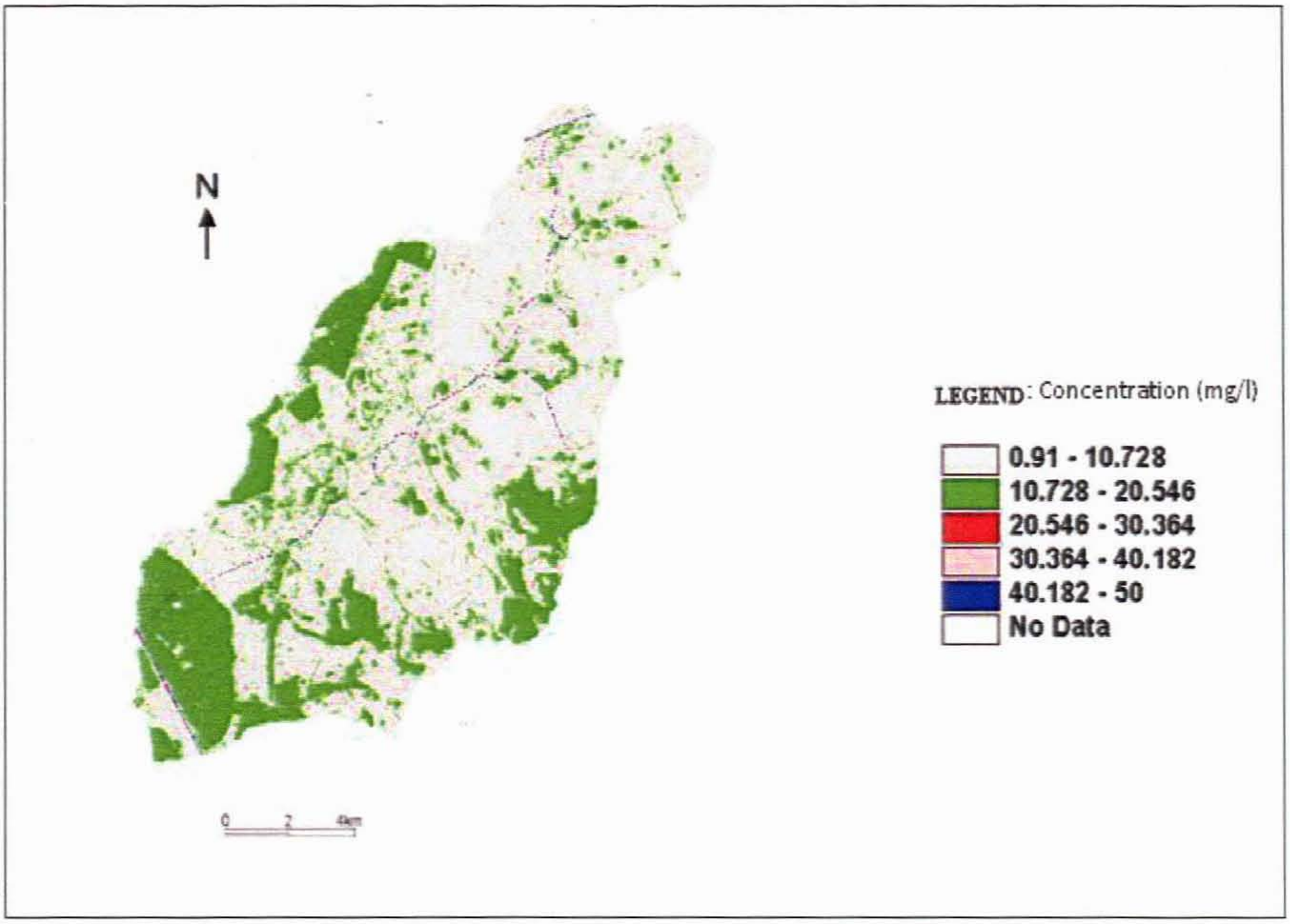

Figure 5.2 : Polluant Concentration (C) Total Nitrogen

5.4.3 Pollutant Concentration (C) Total Phosphorus

Pollutant concentration (C Total Phosphorus) within the study area varies from 0 mg/l – 2.4 mg/l (Figure 5.3). However, the quantity of the total phosphorus from observed data varies from 0.36 mg/l – 5, 85 mg/l (Figure 5.19).

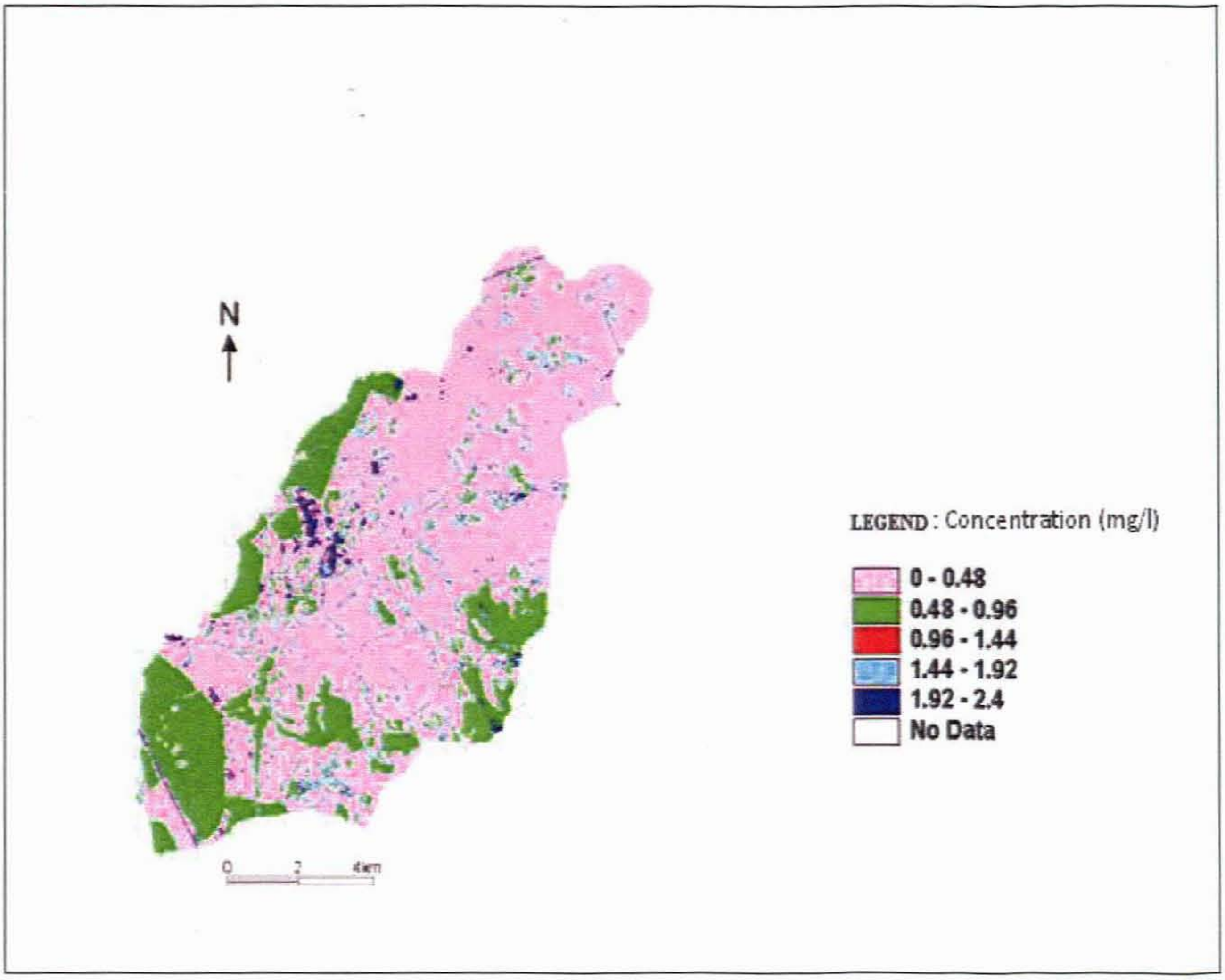

Figure 5.3: Pollutant Concentration (C) Total Phosphorus

5.4.4 Pollutant Concentration (C) Chloride

The concentration level of Chloride yielded by NPS modelling ranges between 0.91 mg/l – 50 mg/l (Figure 5.4). Chloride high concentrations are found along the land-uses such as River, Waterbodies (Figure 4.1). A decrease in chloride is observed during the December month (Figure 5.10).

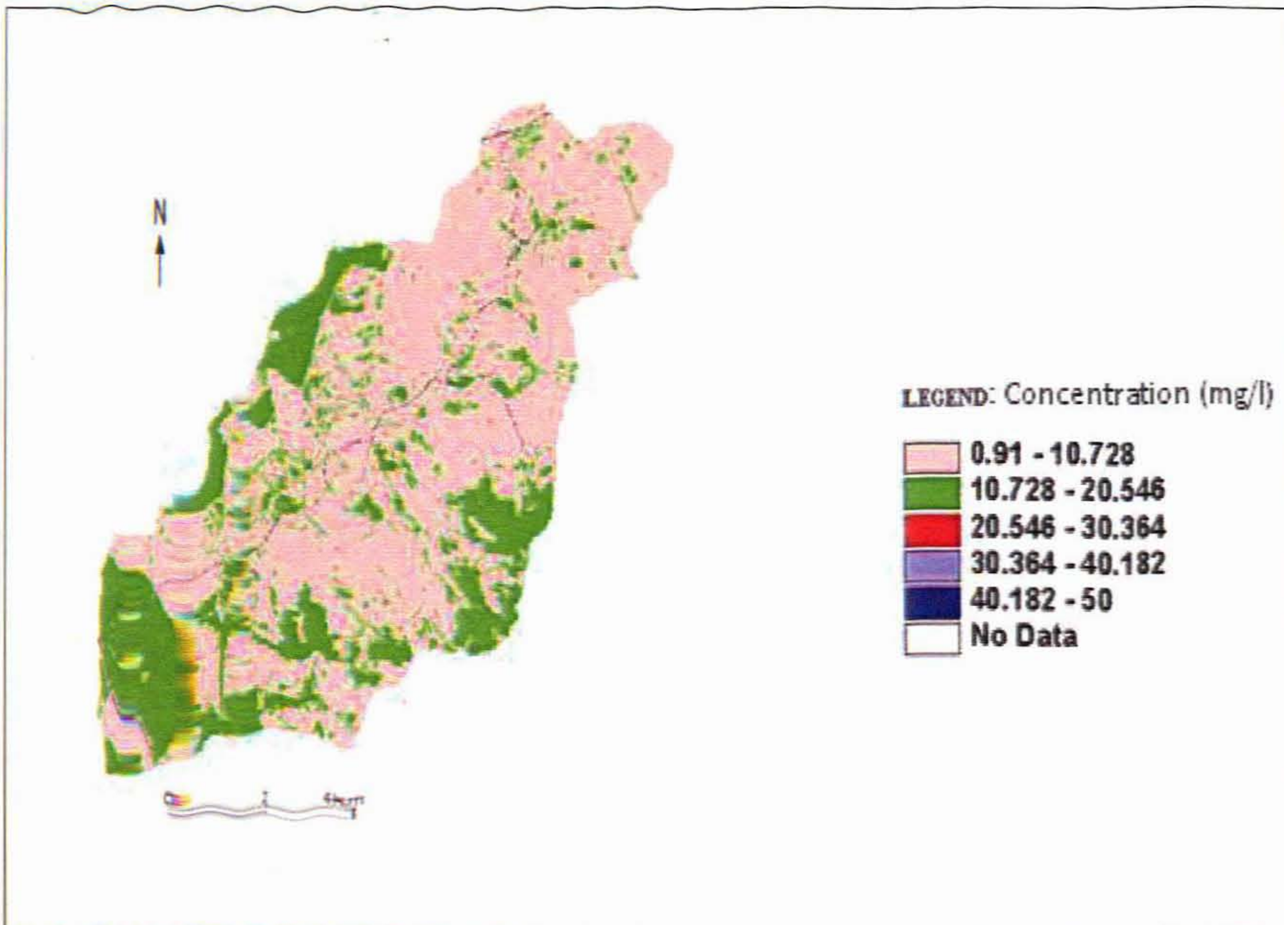

Figure 5.4: Pollutant Concentration (C) Chloride

5.4.5 Pollutant Concentration (C) TSS

Total Suspended Solids are spread all over the Bottelary River catchment and within all land-use/land-cover (Figure 5.5). The concentration of total suspended solids obtained through NPS modelling ranges between 6 mg/l – 149 mg/l (Figure 5.5). The concentrations of TSS from observed data ranges from 3 mg/l – 126 mg/l (Figure 5.9). The peak in TSS is similar to the peak in Chemical Oxygen Demand (Figures: 5.13; 5.14).

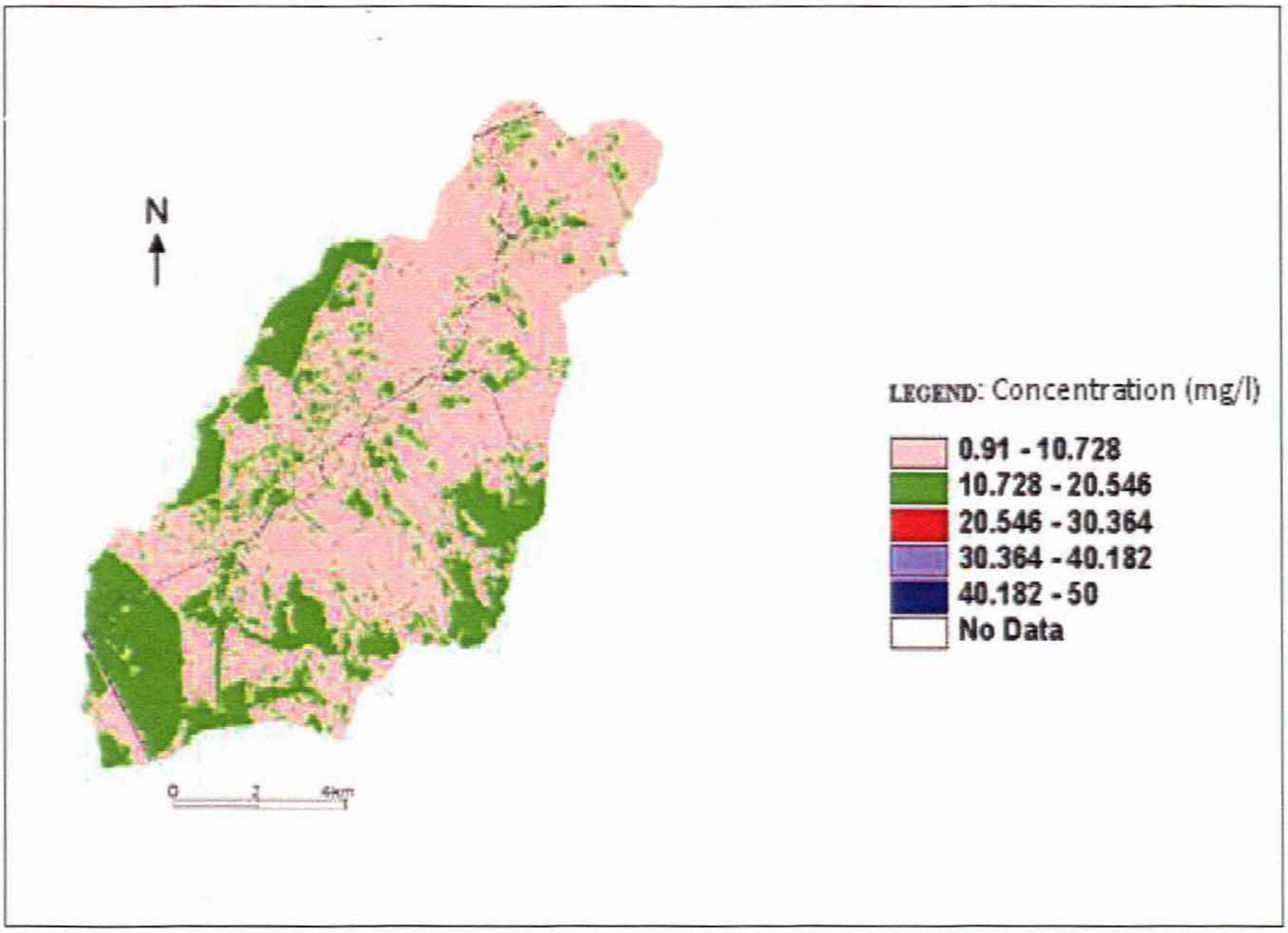

Figure 5.4: Pollutant Concentration (C) Chloride

5.4.5 Pollutant Concentration (C) TSS

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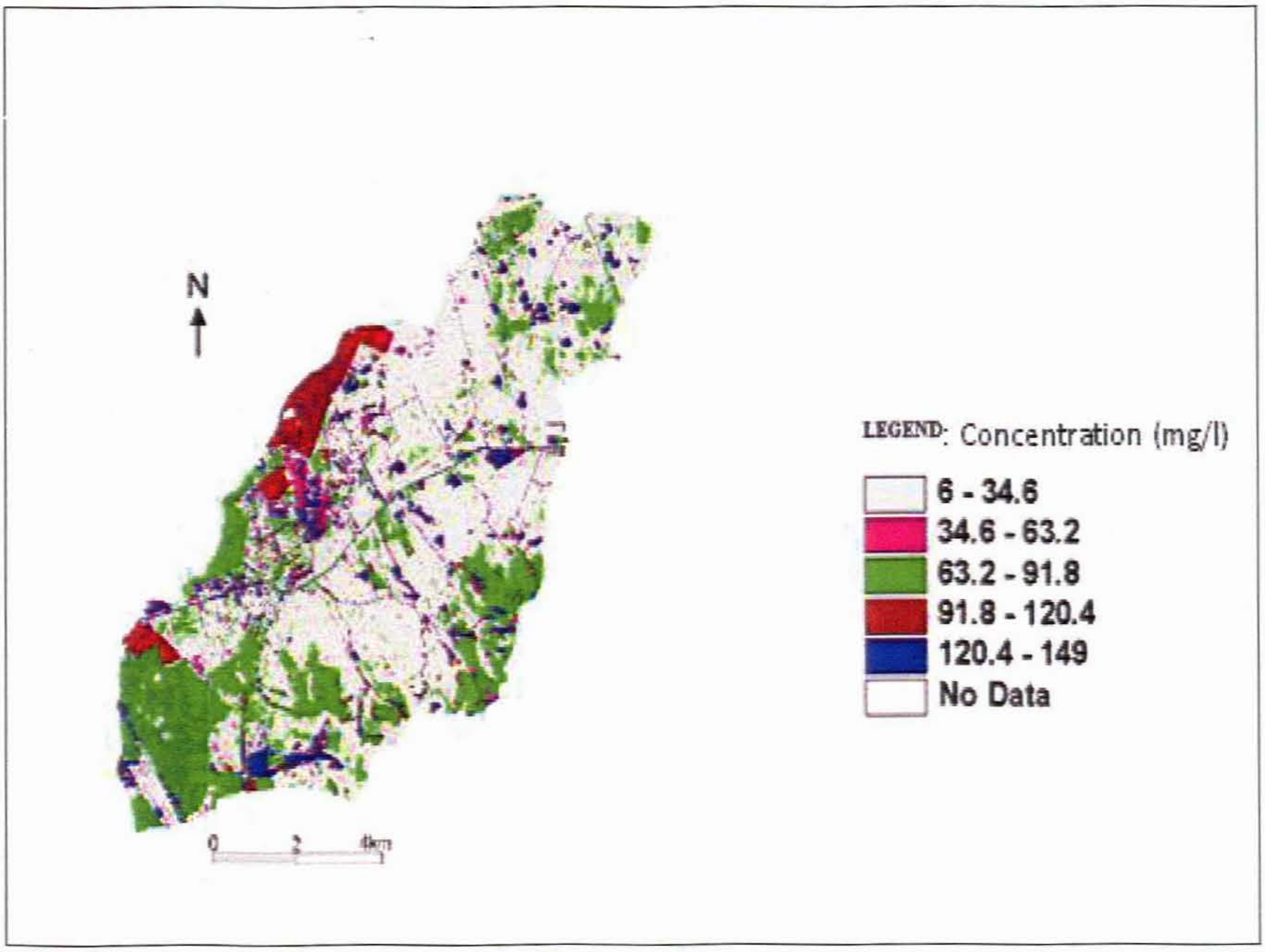

Figure 5.5: Pollutant Concentration (C) TSS

5.5 Distribution of Compounds

This subsection will explore the distribution of chemical compounds within the Bottelary River catchement obtained from data collected in the field.

5.5.1 Distribution of Chloride

This study has revealed that a concentration level of chloride into the Bottelary River ranged between 17.4 - 255.94 mg/l. Chloride effects on species depend on the concentration. A low concentration of less than 70 mg/l is acceptable for species of trees with a high absorption rate of chloride such as citrus, stone fruits, almonds and it is also suitable for animal species such as sheep, cattle, and poultry. However, at the concentration ranged between 70 - 105 mg/l chloride can cause foliar damage to Grape, Plum, and Apricot. At the concentration of 175-350 mg/l crops such as Pepper, Potato and Tomato can be damaged DWAF (1996a, 1996b).

An observation of the distribution of chloride along the Bottelary River shows a similar pattern of the concentrations of the chemical compound throughout the study period. However, that normal behaviour of chloride is characterized by a peak (high concentration) at BR2 (255.94 mg/l) in December 2007, and a sudden decrease (lowest value) at BR1 (17.4 mg/l) during the same month.

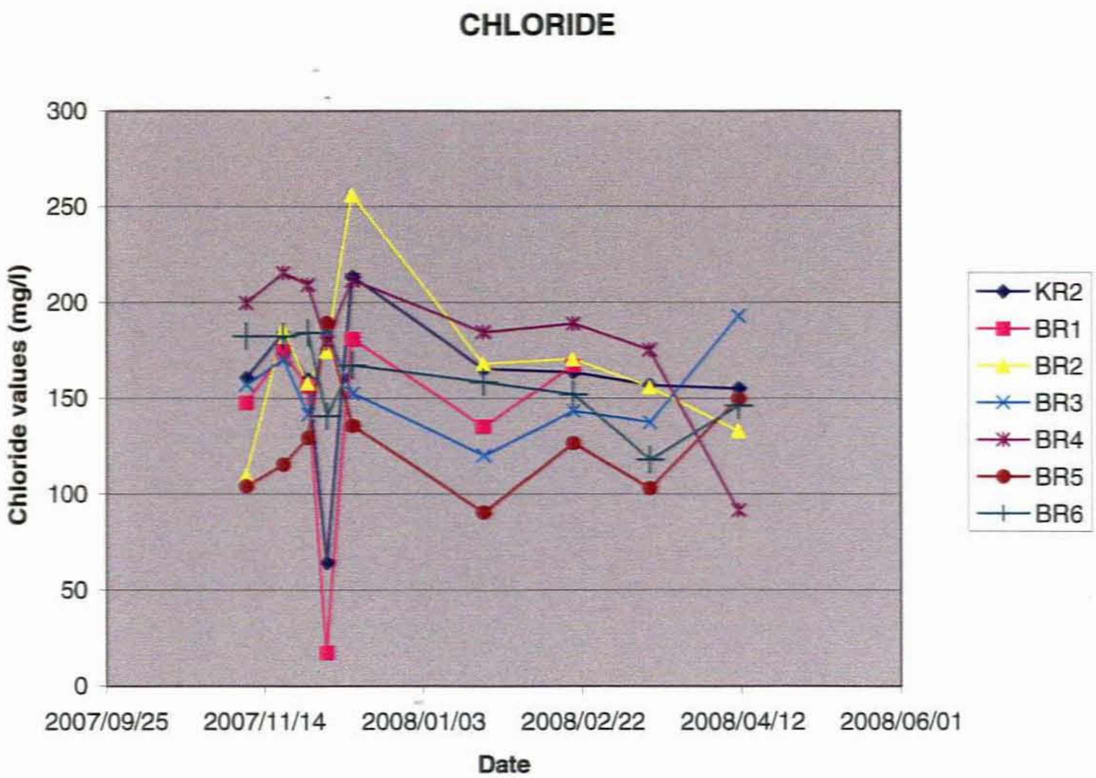

Figure 5.6: The distribution of chloride along the stream from October 2007 to April 2008

5.5.2 Distribution of pH

The level of pH within the Bottelary River ranged from 5.28 - 8.40. These values fall more or less within the pH range of raw waters of 6.5-8.5 given by DWAF (1996).

Figure 5.7 shows that at certain sampling points the stream water is acidic, while it is alkaline at other sampling points. The distribution of pH along the Bottelary River shows a variation in time along the sampling points. The abrupt drop in pH from January 2008 onward could be due to the change of instrument or an increase in toxicity due ionisation of ammonia, carbon dioxide and hydrogen DWAF (1996c).

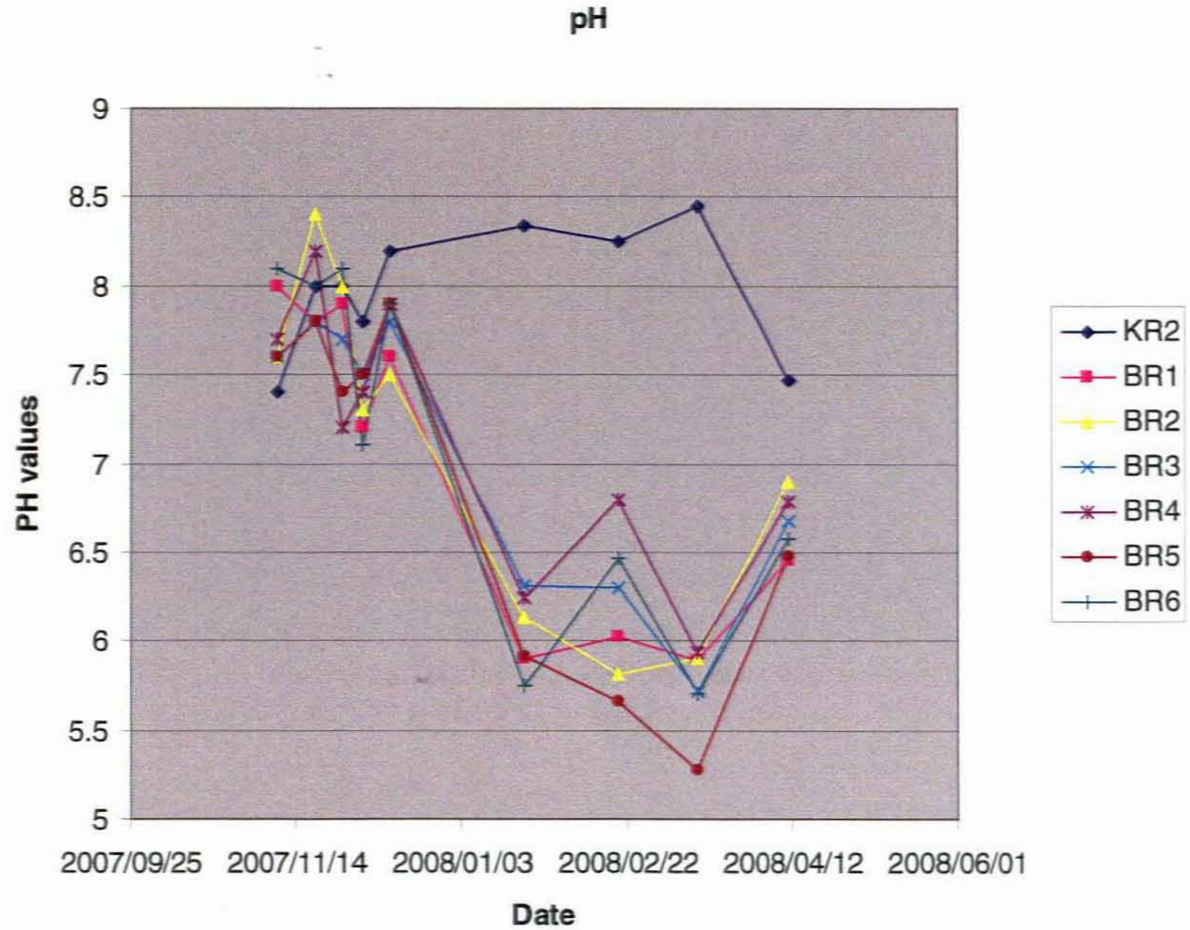

Figure 5.7: The distribution of the pH along the stream from October 2007 to April 2008

5.5.3 Distribution of Electrical Conductivity

The distribution of the Electrical Conductivity (EC) along the Bottelary River is showing a regular pattern except a peak at BR3 in November. The values of Electrical Conductivity vary from 39.9 to 161µS/cm wide range.

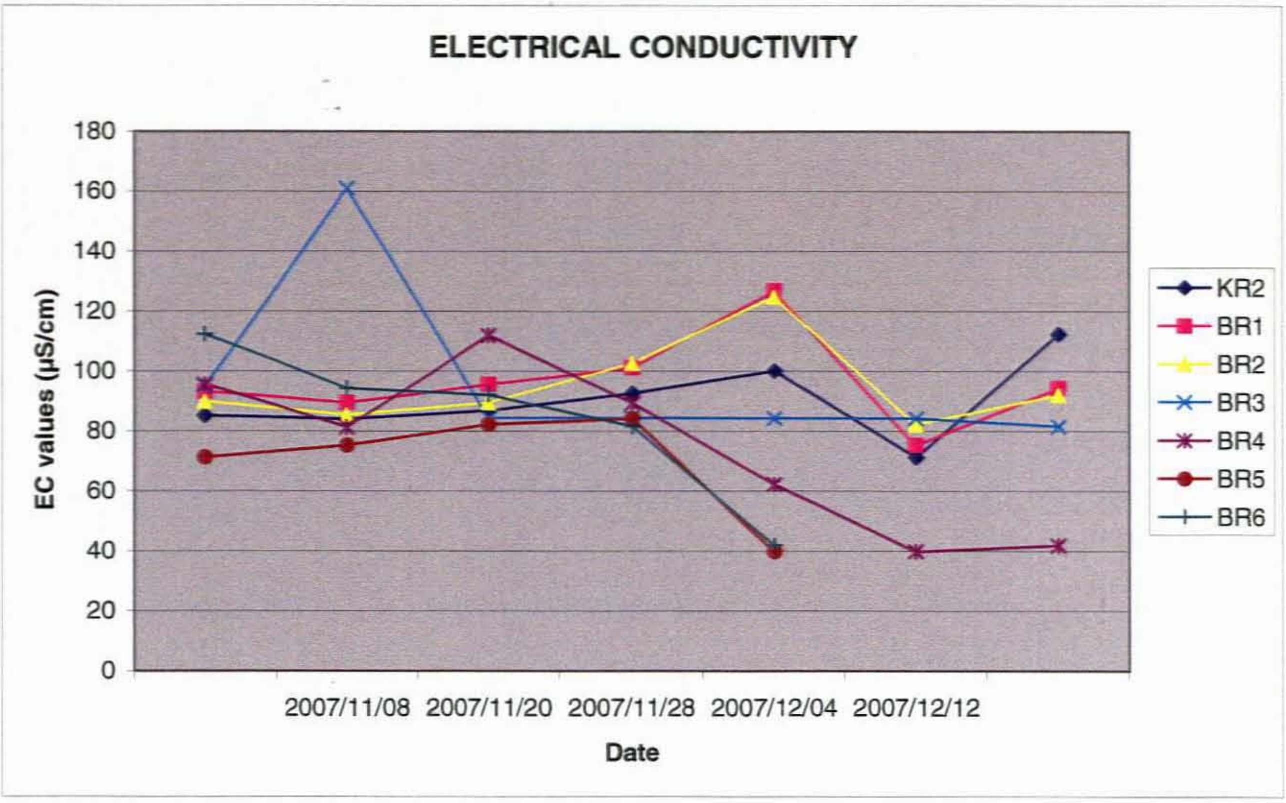

Figure 5.8: The distribution of the Electrical Conductivity along the stream from October 2007 to December 2007

5.5.4 Distribution of Suspended Solids

The concentration level of suspended solids along the Bottelary River is characterized by a regular distribution pattern except for a peak of 126 mg/l at BR4 on 2007/11/28. The concentration values of all sampling sites ranged from 3 mg/l to 126 mg/l.

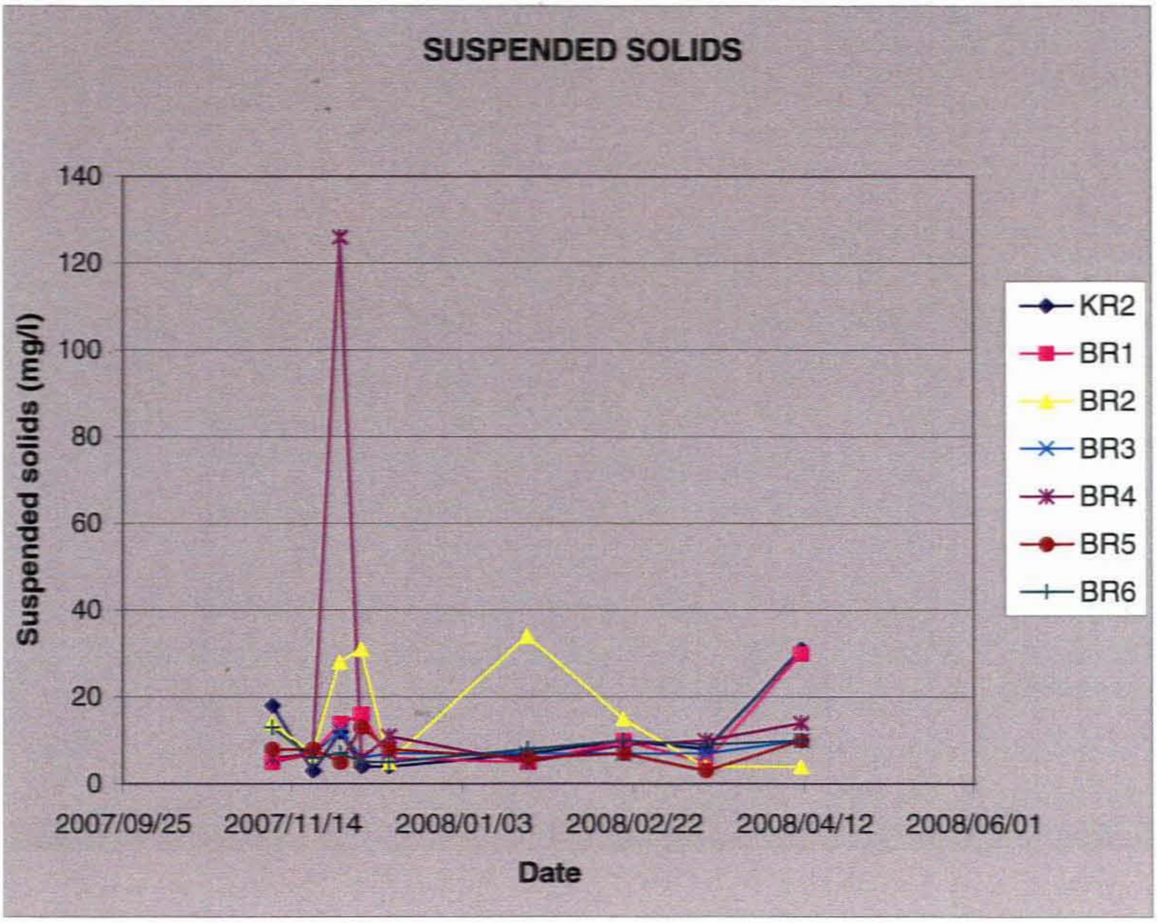

Figure 5.9: The distribution of the suspended solids along the stream from October 2007 to April 2008

5.5.5 Distribution of Chemical Oxygen Demand (COD)

The Chemical Oxygen Demand distribution along the stream shows a similar pattern to the suspended solids. It is characterized by a peak at the BR4 during the November month. The values of the COD are ranging from 22 mg/l at the BR1 to 129 mg/l at the BR4.

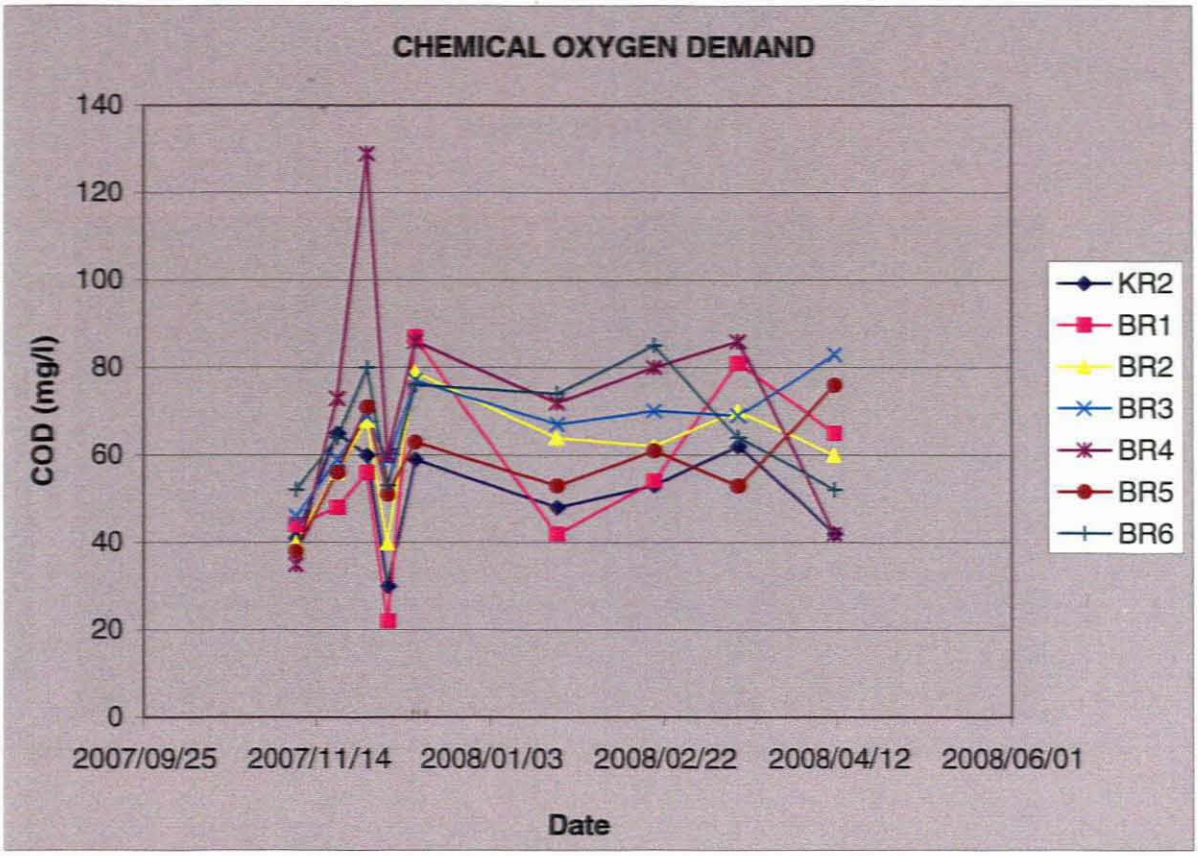

Figure 5.10: The distribution of the Chemical Oxygen Demand along the stream from October 2007 to April 2008

5.5.6 Distribution of Dissolved Oxygen (1): Measured in the field (stream).

An observation of the distribution of dissolved oxygen measured in the Bottelary River shows a pattern different to the one determined in the laboratory (Figures: 5.15 and 5.16). The distribution of dissolved oxygen from field samples shows a scattered pattern. The values recorded are ranging from 3.3 mg/l at the BR6 to 12.86 mg/l BR5. The highest concentration of dissolved oxygen determined in the laboratory is 10.4 mg/l, while the value obtained from the river is 12.86 mg/l.

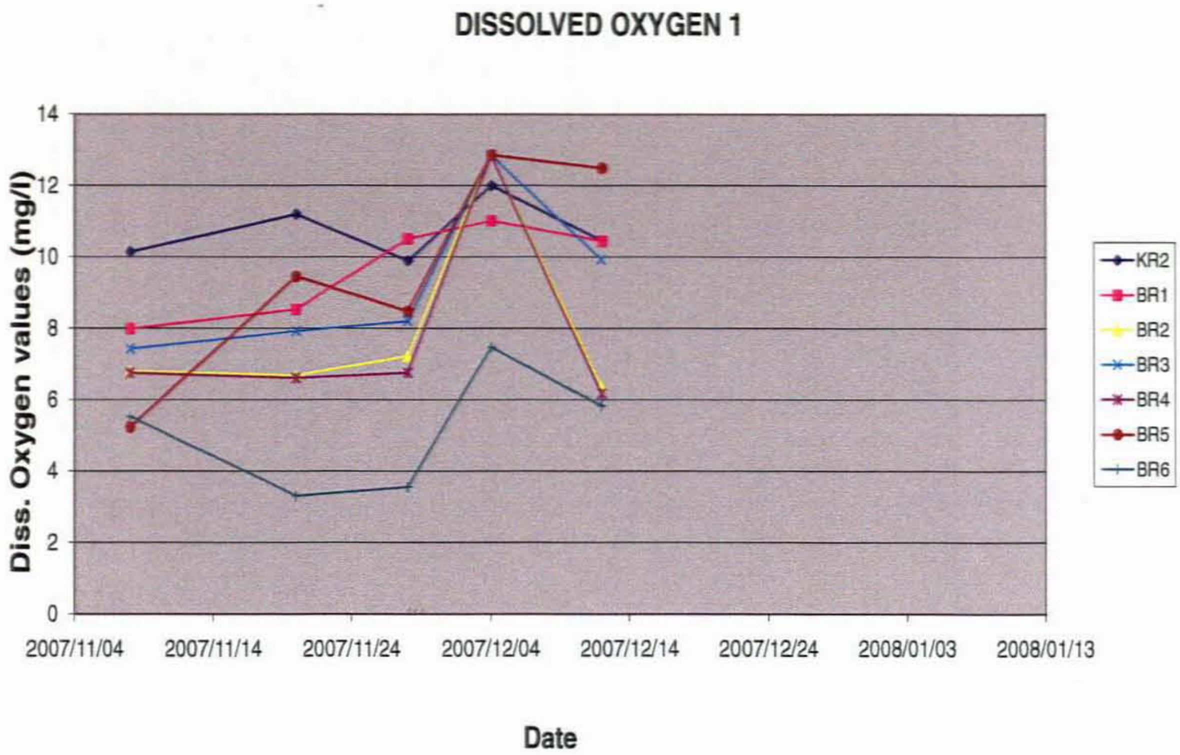

Figure 5.11: The distribution of Dissolved Oxygen along the stream from October 2007 to April 2008

5. 5.7 Distribution of Dissolved Oxygen (2): Determined in the laboratory

The distribution of dissolved oxygen along the Bottelary River shows a regular pattern along the river throughout the study period. The values of dissolved oxygen ranged from 4.4 mg/l to 10.4 mg/l.

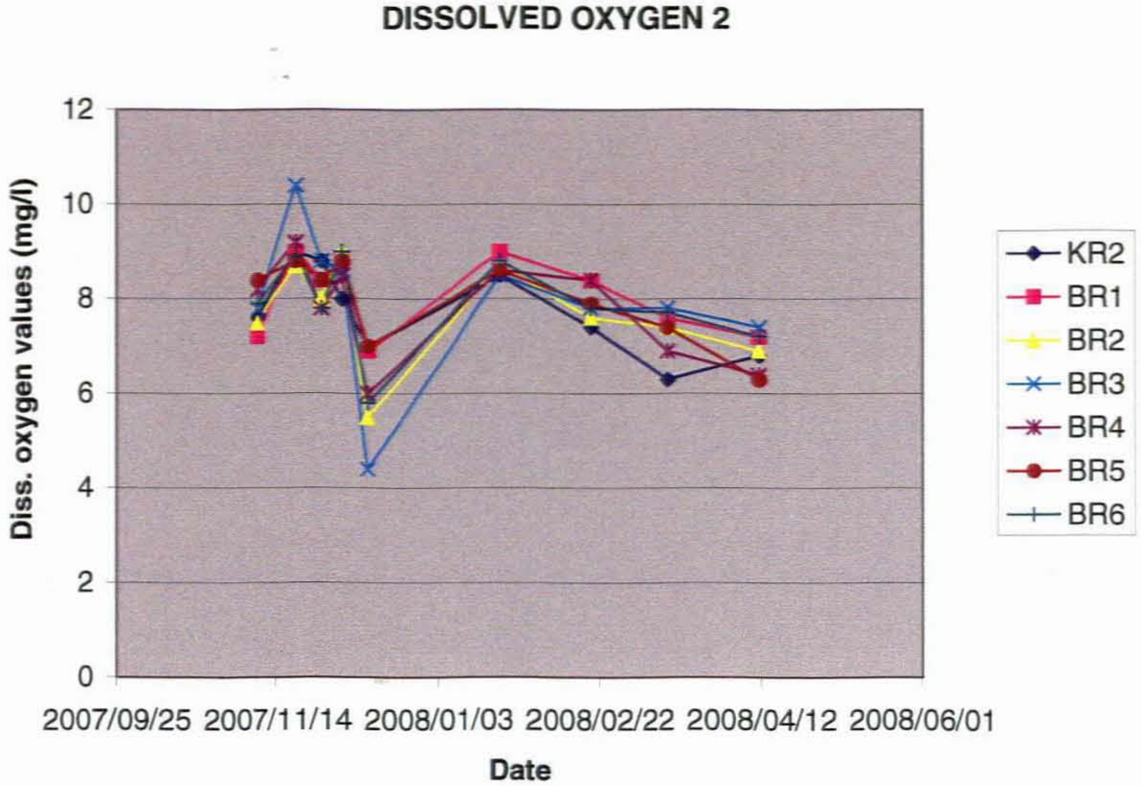

Figure 5.12: The distribution of Dissolved Oxygen determined in the laboratory from October 2007 to April 2008

5.5.8 Distribution of Total nitrogen

An observation of the distribution of total nitrogen shows an irregular pattern which is characterized by highest concentration level at the BR4 (639mg/l) on, 28/11/2007 at the BR5 (638 mg/l), then a sudden decrease (4 mg/l) on 12/12/2007. The value remains low around 4 mg/l until it rises again to 10 mg/l BR2 during February 2008.

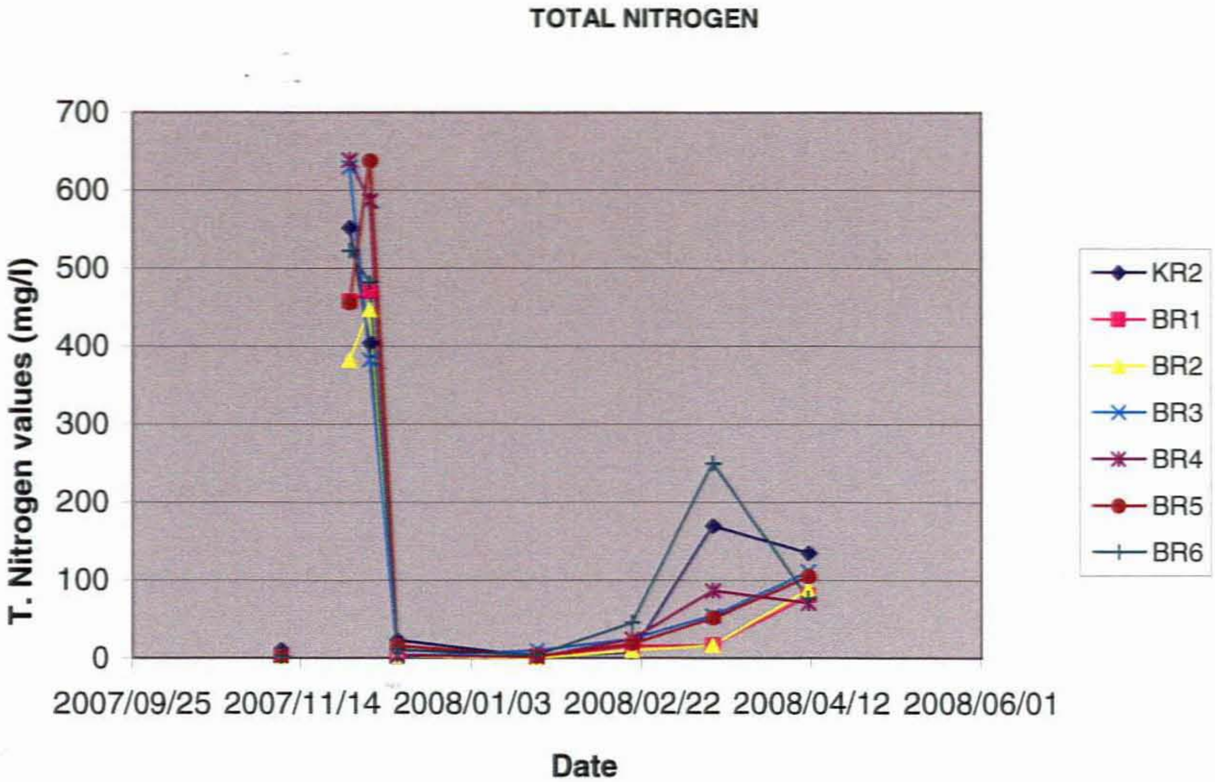

Figure 5.13: The distribution of Total Nitrogen along the stream from October 2007 to April 2008

5.5.9 Distribution of Nitrate

In the DWAF (1996) guidelines for agriculture and livestock, the nitrate norms are based on the toxicological effects of the chemical compound in the water used for livestock. Although there are no direct effects caused by the presence of nitrate in the water, a target water quality range recommended is 0-100 mg/l DWAF (2006).

An observation of the distribution of nitrate in the stream shows a regular pattern except for a peak at BR6 (53.6 mg/l) on February 19th, 2008. The distribution of nitrate along the Bottelary River showed a concentration level ranging between 0- 53.6 mg/l.

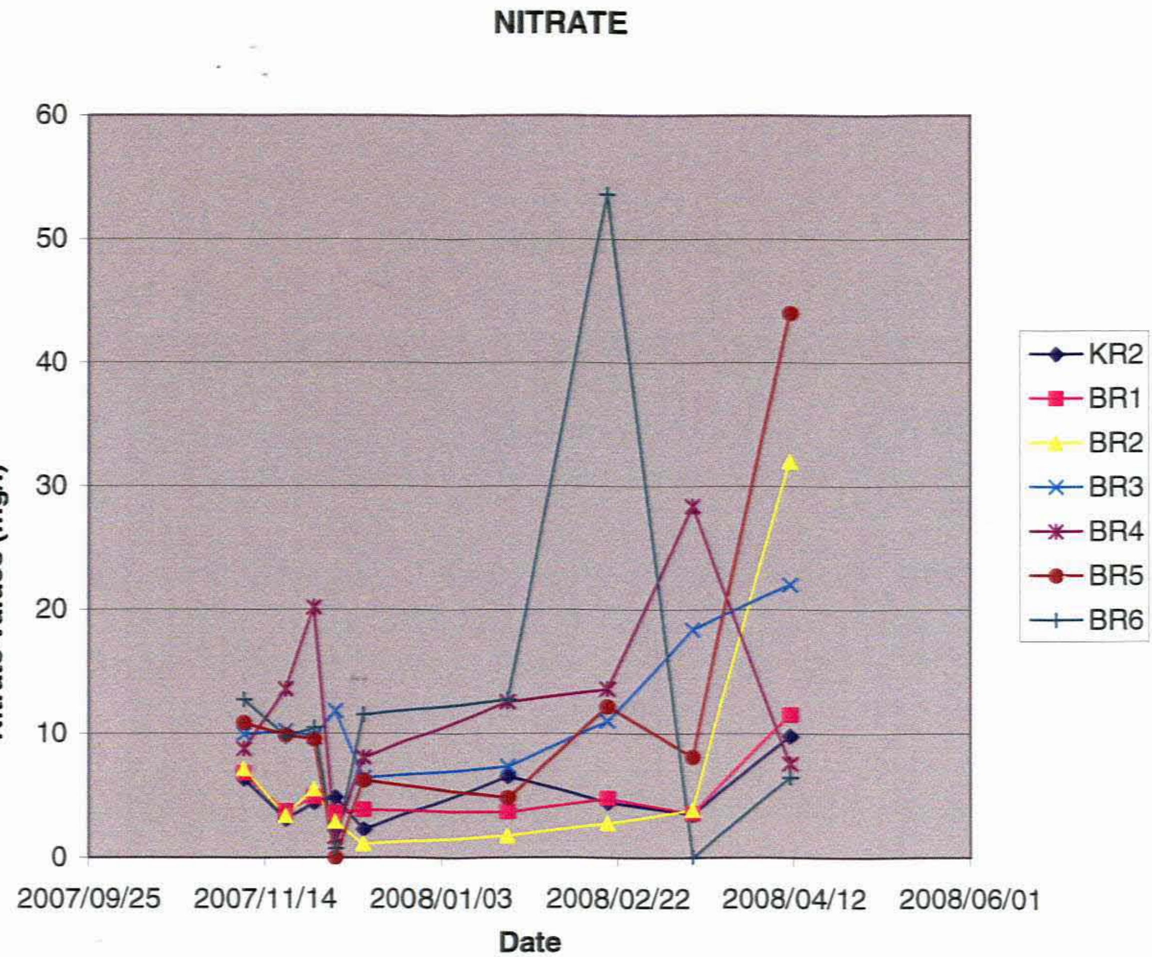

Figure 5.14: The distribution of Nitrate Nitrogen along the stream from October 2007 to April 2008

5.5.10 Distribution of Phosphorus

Phosphorus concentration level along the Bottelary River is ranged from 0.36 μg/l to 5.85 μg/l. This concentration range is below the target water quality range of 10 -50 μg/l of the phosphorus for aquatic ecosystems DWAF (1996).

The distribution of the phosphorus within the Bottelary River shows two patterns. The first distribution pattern at the BR1 and KR2 is regular along all sampling sites and throughout the study period. While, the second distribution pattern at the BR3 and BR5 is an irregular pattern.

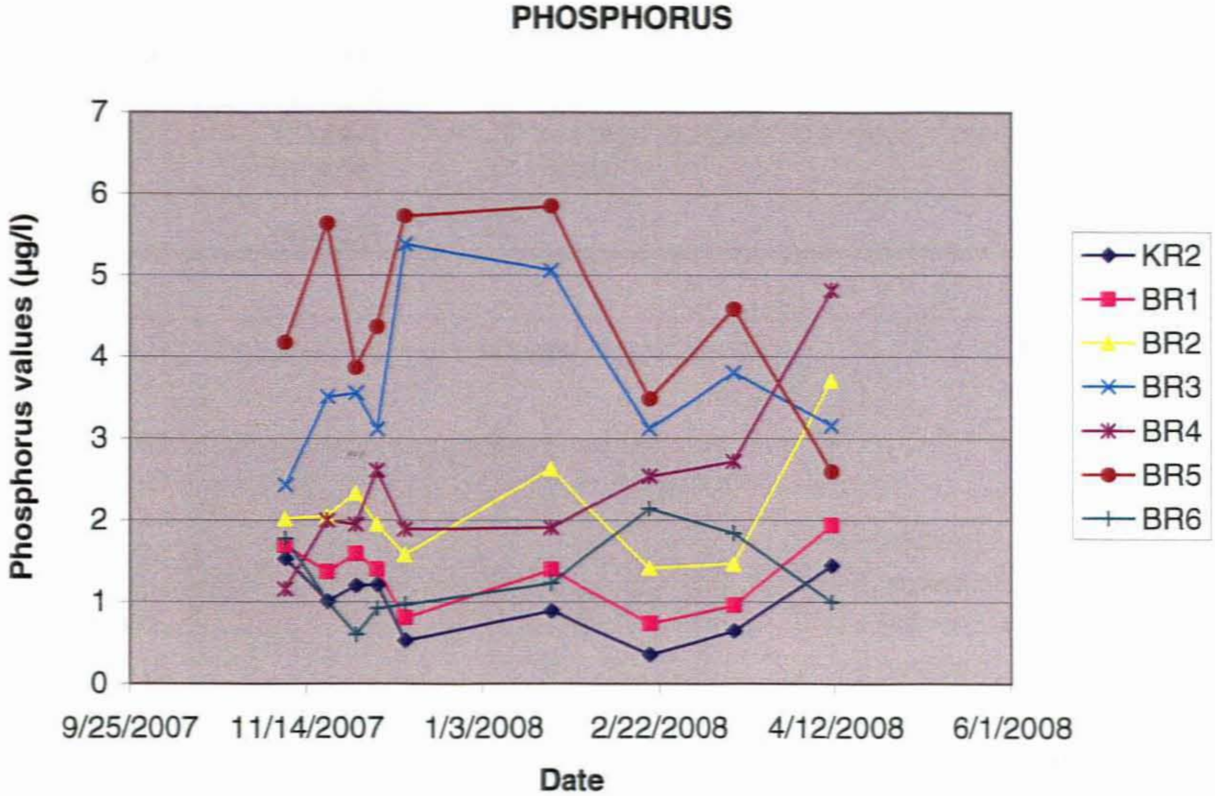

Figure 5.15: The distribution of the phosphorous along the stream from October 2007 to April 2008

5.6 Concentration changes between sampling points

5.6.1 Concentration changes in nitrate

Concentration changes in nitrate along the sections were not significant (Table 5.4; Figure 5.16). Generally, the distribution of nitrate throughout the sections is below zero.

All sections show a similar distribution pattern although there is a decrease in section 1 around February 2008 and an increase in March/April 2008 (Fig. 5.16).

Table 5.4: Variation in concentration of nitrate along the stream from October 2007 to April 2008

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Time	421.0903	8	52.63629	0.275827	0.969269	2.244396
Sections	179.6347	4	44.90867	0.235332	0.916359	2.668437
Error	6106.594	32	190.8311			
Total	6707.319	44				

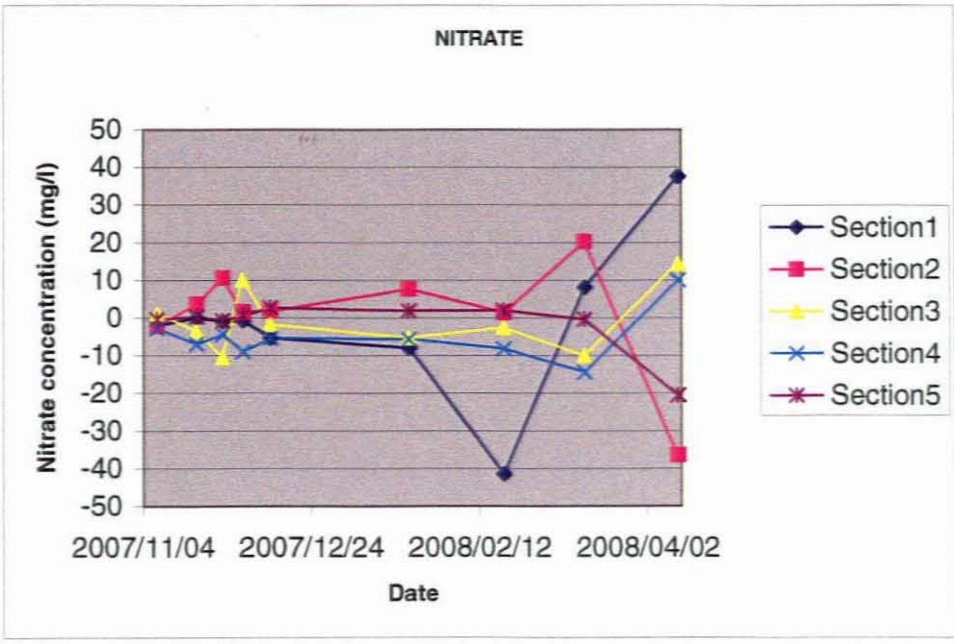

Figure 5.16: The variation in concentration of nitrate along the stream from October 2007 to April 2008

5.6.2 Concentration changes in chloride

There is a significant effect of section on changes in the concentration of chloride along the Bottelary River but not of time (Table 5.5). Chloride concentrations within sections vary continuously. The concentration increases in sections 2 and 4, while the other sections are characterised by concentration decreases for most of the time (Figure 5.16).

Table 5.5: Variation in concentration of chloride along the stream from October 2007 to April 2008

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Time	3506.563	8	438.3204	0.134264	0.997086	2.244396
Section	51566.51	4	12891.63	3.9489	0.010249	2.668437
Error	104467.6	32	3264.612			
Total	159540.7	44				

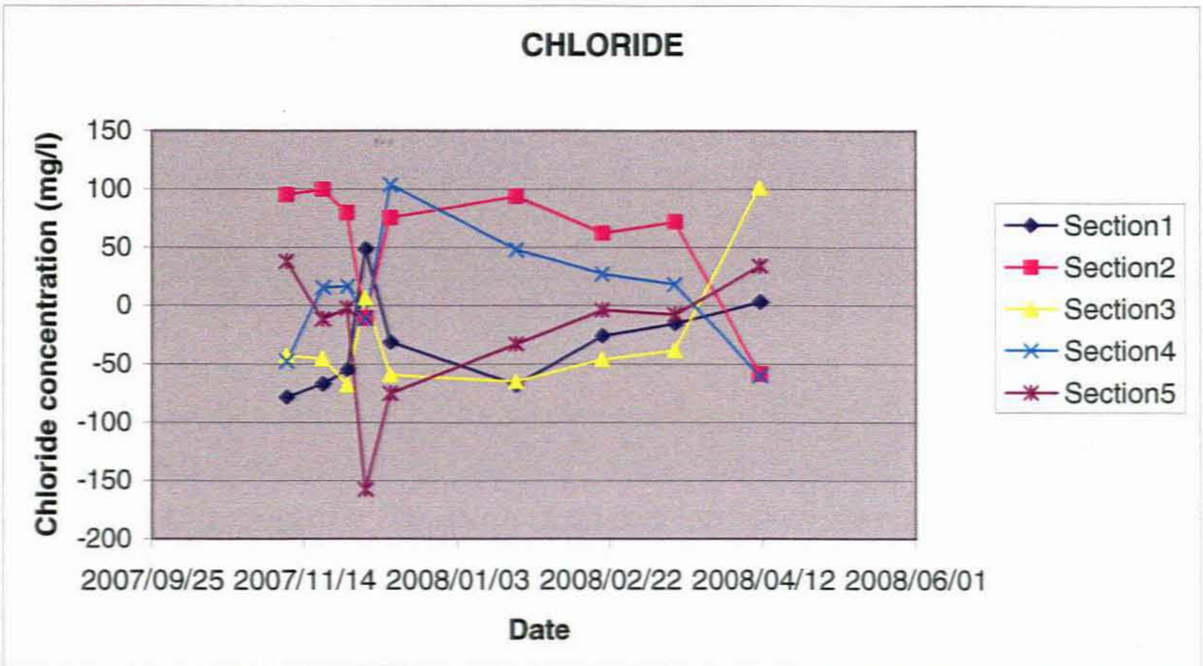

Figure 5.17: The variation in concentration of chloride along the stream from October 2007 to April 2008

5.6.3 Concentration changes in suspended solids

Changes in amounts of suspended solids along the Bottelary River sections are not significant (Table 5.6). The peak and valley in November (section 2 and 3 resp.) are attributable to one single exceptional sample and should therefore be regarded as outliers (Figure 5.18).

Table 5.6: Variation in concentration of suspended solids along the stream from October 2007 to April 2008

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Time	118.3111	8	14.78889	0.017285	0.999999	2.244396
Section	4296.222	4	1074.056	1.255353	0.307775	2.668437
Error	27378.58	32	855.5806			
Total	31793.11	44				

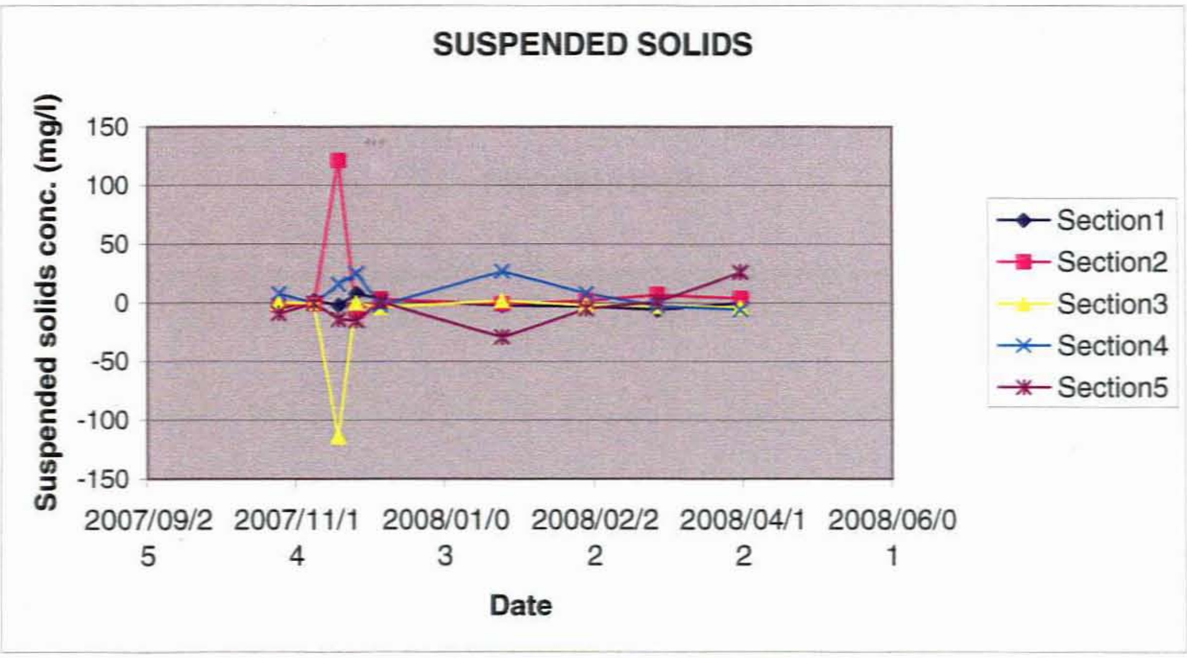

Figure 5.18: The variation in concentration of suspended solids along the stream from October 2007 to April 2008

5.6.4 Concentration changes in phosphorus

Phosphorus concentration changes along the stream. There is a highly significant effect of section but not of time (Table 5.7). On average the phosphorus concentration increases in section 1 and 3, while it decreases in all other sections (Figure 5.18).

Table 5.7: Variation in concentration of phosphorus along the stream from October 2007 to April 2008

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Time	1.001151	8	0.125144	0.053742	0.999898	2.244396
Section	173.7259	4	43.43148	18.6514	5.3E-08	2.668437
Error	74.51492	32	2.328591			
Total	249.242	44				

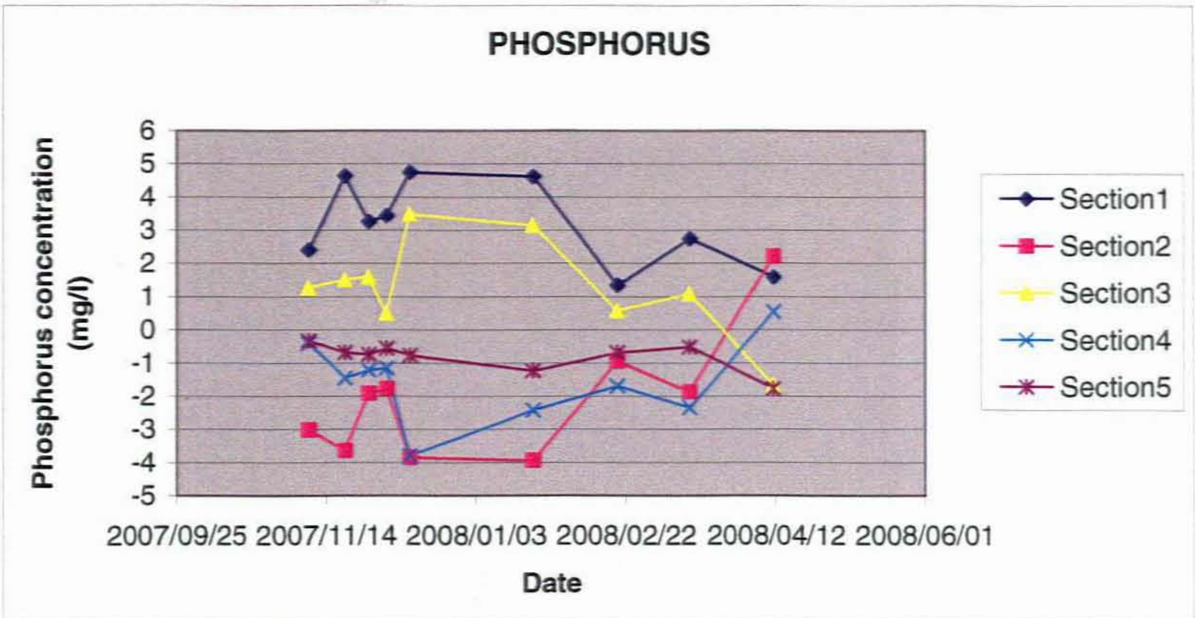

Figure 5.19: The variation in concentration of phosphorus along the stream from October 2007 to April 2008

5.6.5 Concentration changes in total nitrogen

A variation of total nitrogen's concentration along the Bottelary River is insignificant, because its P-value in both values of time and section are above 0.05 (Table 5.8). Despite the peaks and lows of total nitrogen within section 1, 2 and 4, its concentration changes pattern is more or less similar throughout the sections (Figure 5.20).

Table 5.8: Variation in concentration of total nitrogen along the stream from October 2007 to April 2008

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Time	9249.6	8	1156.2	0.183815	0.991506	2.244396
Section	14047.7778	4	3511.944	0.558336	0.69447	2.668437
Error	201280.622	32	6290.019			
Total	224578	44				

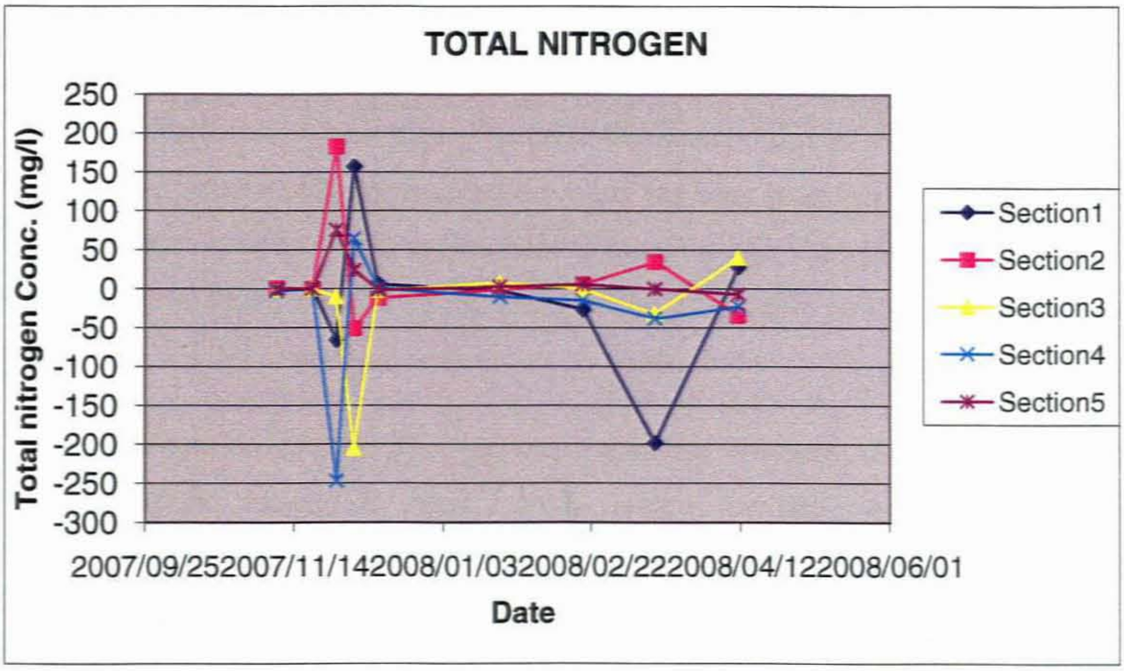

Figure 5.20: The variation in concentration of total nitrogen along the stream from October 2007 to April 2008

Chapter 6: Discussion

6.1 Stream flow: Discharge

Rainfall records have shown an increase during the October, November and December 2007 months and a decrease during the last months of the study period from January 2008 to April 2008 (SA Weather Service, 2009). Normally, as the rainfall increases during those last months of 2007, runoff within the catchment and stream flow increase as well (De Villiers, 2007).

Stream discharge measured during the first three months of the year 2008 was higher than the discharge measured during the three last months of the year 2007 (Table 5.1). We assume that that increase of the discharge can be attributed to the geology of the area and human activities within the catchment. Regarding the geology of the area, the water input that increased the discharge depends on the nature of the soil within the Bottelary River catchment. The soil of our study area has the characteristics of the sandy and loamy soils that are found within the Kuils- and Eerste Rivers catchments (DWAF 2005). These types of soils are permeable, which means that the rainwater infiltrates easily into the soil. Therefore, the percolated water from earlier rains has been stored in the saturated zone and then releases later on during summer and autumn through subsurface flow, interflow and underground input, because of the rising of the water table and the gradient of the terrain.

In addition, irrigation contributes to an increase of the discharge. Due to the lack of rainfall during the January to April months farmers use more water for irrigation purposes. Thus, an increase of the irrigation by farmer will generate a surface runoff and a subsurface flow that will supply water to the stream and increase the discharge. In December 2007 farmers did not irrigate their crops due to the abundance of the rainfall.

6.2 Flux of the Chemical Compounds

A flux of pollutants (nitrate, chloride, phosphorus and total nitrogen) varied from BR1 to KR2 during the study period. Thus, the variation in concentration of nitrate, total nitrogen and phosphorus that varied between BR1 and KR2 can be due to their dilution or conversion. The remarkable quantity of chloride may come from farming activities upstream, the households and shops amongst around this residential area.

The concentration levels of chloride, nitrate and total nitrogen were high during the April month. The causes for the increase of the quantities of these pollutants can be due to a continual release of pollutants from the Waste Water Treatment Plant, farming activities, shops and households and the decrease of rainfall that can dilute the pollutants. Thus, the decrease in rainfall has resulted in less dilution of the chemical compounds within the river.

6.3 Distribution of Compounds and water quality variables

6.3.1 Distribution of compounds and water quality variables Using NPS Model and observed data collected during the study

A broad interpretation of the results obtained from the NPS model and observed data is showing some difference. For example, the concentration (C) values of the following compounds and water quality variables obtained from the model are ranging: C nitrate-nitrogen (0.50 mg/l – 8 mg/l. Table 5.2; Figure 5.1), C total nitrogen (0.91 mg/l – 50 mg/l. Table 5.2; Figure 5.2), C total phosphorus (0.13 mg/l- 2.40 mg/l; Table 5.2; Figure 5.3), C chloride (0.91 mg/l – 50 mg/l. Table 5.2; Figure 5.4), C TSS (6 mg/l – 149 mg/l. Table 5.2; Figure 5.5). While C values of the same compounds and water quality variables obtained from the field measurement are: C nitrate- nitrogen (0.2 mg/l – 5.59 mg/l), C total nitrogen (0.81 mg/l – 420.33 mg/l), C total phosphorus (0.13 mg/l – 3.78 mg/l), C chloride (1 mg/l – 261.6 mg/l), C total suspended solids (1 mg/l – 394.29 mg/l) (Table 5.3).

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An assessment of these results has shown huge difference in the concentration level of compounds and water quality variables. The concentration of the compounds and water quality variables measured on the field are higher than the concentrations obtained from the NPS model. The highest concentration obtained from the field measurement are: chloride (261.6 mg/l) at the land-use/land-cover of Recreation Grass/ Golf Course, concentration TSS (394.29 mg/l) at the land-use/land-cover Arterial Roads/Main Roads and concentration total nitrogen (420.33 mg/l) at the land-use/land-cover HDR Formal Suburb (Table 5.3). While the highest concentration of the same compounds and water quality variables generate by the NPS model are: Concentration chloride (50 mg/l) at the land-use/land-cover River, Concentration TSS (149 mg/l) at the land-use/land-cover Water bodies, Riparian Forest/Natural Forest as well and concentration total nitrogen (50 mg/l) at the land-use/land-cover River (Table 5.2).

Although there are significant difference between the concentrations of chloride, TSS and total nitrogen as mentioned above, the concentration nitrate-nitrogen and phosphorus obtained both from the NPS model and the field measurement have shown minor difference. The highest concentrations obtained from the field are: C nitrate (5.59 mg/l) at the land-use/land-cover River and C phosphorus (3.78 mg/l) at the land-use/land-cover Improved Grassland/vegetated crop. While, the NPS model generated the following highest concentrations of the same compounds: C nitrate (8 mg/l) at the land-use/land-cover River and C phosphorus (2.40 mg/l) at the land-use/land-cover Sandy, Arterial Roads/Main Roads, Mountain Forest.

6.3.2 Distribution of compounds and water quality variables between the sections of the Bottelary River

The distribution of compounds and water quality variables along the Bottelary River varied from one section of the river to another and from one land-use/land-cover to another. The C nitrate-nitrogen is high in the land-use/land-cover River from upstream to downstream at 8 mg/l (Table 5.2) and at 5.59 mg/l (Table 5.3).

The high level of nitrate-nitrogen could be due to the presence of the Scottsdene Waste Water Treatment Plant (WWTP) upstream of the De Novo River and the multitude of farming activities along the De Novo River and upstream of the sampling point on the Bottelary River. The pollutants generated from the WWTP and the land-uses along the De Novo are transported by sewage drain and surface runoff into the river where it flows downstream the Bottelary River (Van Driel, 2003; Moeletsi, Mazema & Halday, 2004). This argument is justified by the amount of rainfall recorded during the November month which received a monthly average of rainfall of 38.9 mm (SA Weather Service, 2009).

The rise of the quantity of nitrate-nitrogen can also be due to the abundance of organic manure and fertilizer rich with nitrate used by farmers located along the River. During the rainfall events these nitrate rich fertiliser, organic matters and organisms they contain are transport into the Bottelary River (Davies & Day, 1998; DWAF, 1996a; De Villiers, 2007).

However, Nitrate-nitrogen decreases within the following land-uses/land-covers: Minor roads, Bare Rock at 0.50 mg/l (Table 5.2) and at Recreation Grass/Golf Course at 0.03 mg/l (Table 5.3). The causes of the decrease could be its absorption by aquatic plants and organisms within along the river (Davies & Day, 1998; Biernacki, Lovett-Doust & Lovette-Doust, 1996; Dean, Bosqui & Lanouette, 1972; Dietz, 1973; Erikson & Mortimer, 1975; Tremp & Kohler, 1995).

The concentration level of chloride increases (50 mg/l) within the land-use/land-cover River of the sections 1, 2 and 3. The rise of chloride is likely due to the presence of the Waste Water Treatment Plant (WWTP) located upstream of De Novo River which is a tributary of the Bottelary River (Van Driel, 2003). While, a decrease in chloride at 0.91 mg/l within the section(s) 4 and 5 is observed at the following land-use/land-cover: MDR Formal Township, HDR Formal Township, Minors Roads, Recreation Grass/Golf Course, Fallow/Open Vineyard, Dense/Grassy Vineyard, Buildings/Impervious, Improved Grassland/Vegetated Crop. The causes of a decrease of chloride concentration are linked to the location of the two sections downstream.

The concentration of phosphorus is low throughout the sections of the Bottelary River and within the land-uses/land-covers of the Bottelary River catchment. It highest values recorded within the sections 1, 2 are as follow; 3.78 mg/l at the land-use/land-cover Improved Grassland/vegetated Crop, 3.32 mg/l at the Grassland (Table 5.3) and 2.40 mg/l at the land-uses/land-cover Mountain Forest (Table 5.2). The rise of phosphorus level at these land-uses/land-covers could be due to the abundance of organic manure used by farmers and golf course located within the Bottelary River catchement (Davies & Day, 1998; Benjamin & Philip 2005; DWAF, 1996a; De Villiers, 2007).

However, the concentration level of TSS increases within the land-uses/land-covers: Arterial Roads/Main Roads at 394.29 mg/l, Improved Grassland/Vegetated Crop at 234.5 mg/l (Table 5.3) and within the Water bodies, Riparian Forest/Natural Forest at 149 mg/l (Table 5.2). The increase in TSS within the sections of the river could be due to heavy rainfall of November 2007 month that received a total amount of 38.9 mm of rainfall that transport sediments into the river. There are several activities along the De Novo River and within the Bottelary River catchment as well. Due to human activities such as agriculture, housing development, brick factory and the Waste Water Treatment Plant along De Novo River, large quantities of suspended solids enter the stream before being transported downstream into the Bottelary River (Van Driel, 2003, Bvi, 2003). There is a decrease in concentration of TSS at 6 mg/l in the land-uses/land-covers such as Recreation Grass/Golf Course, Fallow/Open Vineyard, Dense/Grassy Vineyard and Improved Grassland/vegetated Crop (Table 5.2), 5.8 mg/l in a land-use/land-cover Fynbos, 7.5 mg/l in the land-uses/land-covers Dense Scrub, Riparian Forest/Natural Forest and Mountain Forest (Table 5.3), 0.91 mg/l within the land-uses/land-covers: MDR Formal Township, HDR Formal Township, Minors Roads, Recreation Grass/Golf Course etc (Table 5.2) and at 9 mg/l in the Recreation Grass/Golf Course (Table 5.3). The causes of a decrease of TSS are the lack of sufficient rainfall (Van Driel, 2003; Bvi, 2003). A low concentration can also be related to the covering of the soil by grasses or crops that protect the soil from water and wind erosion. A low concentration of TSS could also be due to the location of certain land-uses/land-cover downstream the Bottelary River and the lack of a source of pollutants such as WWTP (DWAF, 1996a;

Davies & Day, 1998; Biernacki *et al.,* 1996); Dean *et al.*, 1972; Dietz, 1973; Erikson & Mortimer, 1975; Tremp & Kohler, 1995).

The total nitrogen concentration is high within the land-uses/land-covers: HDR Formal Suburb at 420.33 mg/l, River at 383.17 (Table 5.3) and Arterial Roads/Main Roads, River at 50 mg/l (table 5.2). The causes of the increase of total nitrogen could be due to the presence of the Scottsdene Waste Water Treatment Plant (WWTP) upstream of the De Novo River and the multitude of farming activities along the De Novo River. (Van Driel, 2003; Moeletsi *et al*, 2004). It is important to indicate that the high concentrations of total nitrogen obtained from data collected on the field (Figure 5.13) are above the norms of domestic wastewater. However, it is difficult to find the correct explanation to these unlike concentrations, because the analysis was done at the laboratory.

Chapter 7: Summary

7.1 Summary

Managing rivers is very important because they are sources of fresh water. Good management of rivers requires a clear understating of the river catchments, and their impacts on the water quality of the river. The following water quality variables and compounds with their TWQR given by DWAF (1996a, 1996b, 1996c) were used to assess the water quality of the Bottelary River: Electrical Conductivity (40 ms/m), Suspended solids (50 mg/), Nitrate and Total nitrogen (100 mg/l), pH (6.5-8.4), Chloride (100 mg/l), Phosphorus, chemical oxygen demand and dissolved oxygen (TWQR was not available). During the study seven sampling points were selected along the river. The seven sampling points within the river were divided into five sections in order to evaluate the spatial changes in concentration level of the compounds and variables from one point to another.

The aim of this study was to investigate the land-use impacts on the water quality of the Bottelary River over a period of six months. The findings of this research have shown that the water quality of the Bottelary River is deteriorating due to a high level of certain compounds and water quality variables. The concentration level of electrical conductivity, total suspended solids, total nitrogen and chloride is above the target water quality range stated in the water quality guidelines from the Department of Water Affairs and Forestry for agricultural water use: Irrigation DWAF (1996a) and in the water quality guidelines from the Department of Water Affairs and Forestry for agricultural water use: Livestock Watering DWAF (1996b). High concentration level of these compounds constitutes a serious pollution to the water quality of the Bottelary River because of their harmful impacts on the environment and human health.

For example chloride's concentration obtained in the field with a maximum of 255 mg/l (Figure 5.6) at the BR2 during December 2007 is above the TWQR set by DWAF (1996a). An excess of chloride can have negatives effects in agriculture and livestock such as: decreased food and water intake, weight loss, a decline in productivity, osmotic disturbances, hypertension, dehydration, renal damage and salt poisoning while, a high concentration (deposition) of suspended solids on the soil can result in the formation of a depositional surface on the river banks that reduces the river surface, disturbs the stream flow and inhibits water infiltration. The high concentration level of suspended solids (deposition) inhibits seedling emergence, reduces soil aeration and smothers habitat of aquatic organisms DWAF (1996b).

In addition, when used for irrigation a high level of electrical conductivity decreases the growth and productivity of sensitive crops and soils' ability to sustain crops. Finally, an excess concentration of total nitrogen can be harmful to crops growth, quality, maturation and the ecosystem by accelerating the growth of alien plants and green algae DWAF (1996a, 1996b).

The pollution of the Bottelary River is mostly from non-point sources of pollution, because it is transported by surface runoff from the multiple land-uses/land-covers such as a HDR Formal Suburb by total nitrogen at 420.33 mg/l (Table 5.3), Recreation Grass/Golf Course from chloride at 261.6 mg/l (Table 5.3), Arterial Roads/Main Roads by TSS at 394.29 mg/l (Table 5.3) and 149 mg/l (Figure 5.5) along the Bottelary River. However, the pollution of the river from the Scottsdene waste water treatment plant which constitutes a major point source of pollution cannot be neglected because of the amount of pollutants such as suspended solids and chloride generate by the plant. The presence of these compounds in the river both during the summer and winter season is a confirmation that there is a continuous input of these pollutants into the river by surface runoff or by waste water discharge from Scottsdene.

The ANOVA's trend in suspended solids did not show any variance throughout the sections, except an abrupt increase followed by a decrease observed in sections 2 and 3 during November 2007 and December 2007 that could be due an input from the surface runoff, subsurface flow generated by neighbouring farms that used animals manures and the discharge from the WWTP.

Chapter 8: Conclusion and Recommendations

8.1 Conclusion

A spatial distribution of pollutants between the sections of the river and within the land-use of the Bottelary River catchment has shown some interesting results. In fact the concentration level of some variables is above while other is below the Target Water Quality Range (TWQR) set by DWAF (1996a, 1996b). The high concentration of variables indicate pollution wash off into the river. It is also important to mention that in some cases the results obtained from the NPS (GIS model) vary from those measured in the field.

The following suspended solids maximum concentration of 149 mg/l obtained from NPS model (Figure 5.5), 126 mg/l measured on the field (Figure 5.9) and electrical conductivity concentrations of 126 μS/cm (Figure 5.8) recorded at the BR3 obtained from the field are higher than the TWQR set by DWAF (1996a, 1996b, 1996c). The increases in concentration could be linked to the discharge from the Scottsdene Waste Water Treatment Plant and the effects of surface runoff and subsurface flow from the land-uses within the catchment.

The NPS model concentration of chloride that ranged between 0.91 – 50 mg/l (Figure 5.4) is below the TWQR (DWAF, 1996a). There is also an increase in chloride concentration at the BR2 during December 2007 (Figure 5.6). The increases in chloride concentration could be due to the location of the sampling point BR2 downstream of the Bottelary River. Thus, the pollutant discharged for example from the Scottsdene WWTP which is situated upstream of the De Novo flows downstream to the Bottelary River.

Chloride concentration along the river varied from one section to another. The concentration changes in chloride observed with ANOVA is significant along the sections. The sections 2 and 4 are most of the time above zero (positive) while, sections 1, 3, 5 are below zero (Figure 5.16). The reason for those changes in chloride along in section 2 and 4 could be due to the input from the WWTP.

However, phosphorus concentrations obtained both from NPS model (Figure 5.3) and in the field (Figure 5.14) are below the TWQR set by DWAF (1996c). ANOVA analysis in phosphorus distribution has shown variances (Figure 5.18).

8.2 Recommendations

Based on the findings of this research, the following measures and practices can be done in order to decrease and monitor the level of water pollution in the Bottelary River:

- The Scottsdene Waste Water Treatment Plant needs to improve its Waste Water Treatment Techniques and methods in order to minimize the pollutants level discharged into the De Novo River and the Bottelary River.

- The housing development and Golf course within the Bottelary catchment need to re-assess their practices in order to decrease the level of pollutants produced by their activities that enter into the Bottelary River.

- An artificial wetland should be created upstream of De Novo River. The wetland will receive and recycle waste water from the Scottsdene Waste Water Treatment Plant and polluted runoff water from the farms before reaching the Bottelary River.

- A Bottelary River catchment forum should be created to ensure sustainable management of the catchment. The forum should include all stake holders along the river and the municipality.

- An awareness campaign on the degradation of the ecosystem within the Bottelary River catchment should be organized.

- Farmers should be encouraged to adopt less water pollution practices by introducing a sustainability practice award. A certificate of sustainable practice will be given to a farmer who has shown consistency during a certain period of time in environmental (fresh water) friendly practices.

- Pollution remedial plans should be implemented by all farmers and entrepreneurs within the Bottelary River catchment.

Chapter 9: References

9.1 References

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Appendices

Appendix 1: Bricks Factory next to the Bottelary River

Appendix 2: Botteraly River (under the bridge next to the Rainbow Chicken Farm)

Appendix 3: Bottelary River surface cover by riparian vegetation

Glossary

Abbreviations and explanations

BR:	Bottelary River.
COD:	Chemical Oxygen Demand.
DEM:	Digital Elevation Model.
DO:	Dissolved Oxygen.
DWAF:	Department of Water Affairs and Forestry.
EC:	Electrical Conductivity.
EMC:	Event Mean Concentration.
GPS:	Global Positioning System.
HACCP:	Hazard analysis and critical control points
HDR:	High Density Residential.
KR:	Kuils River.
MDR:	Moderate Density Residential.
NPS:	Non-point Source Pollution.
TSS:	Total Suspended Solids.
UKWIR:	United Kingdom Water Industry Research.
WWTP:	Waste Water Treatment Plant.