AN EVALUATION OF THE CUMULATIVE SURFACE WATER POLLUTION WITHIN THE CONSOLIDATED MAIN REEF AREA, ROODEPOORT, SOUTH AFRICA

by

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ABSTRACT

Surface water pollution is prevalent in numerous areas of central Roodepoort mainly due to gold mining activities. The surface water quality for the Bosmontspruit, Russell's Stream and the New Canada Dam was assessed from October 2010 to March 2011. Physical, chemical and biological characteristics of the water were determined for 8 monitoring points and the results obtained were compared with the In-stream water quality guidelines for the Klip River catchment and the South African Water Quality Guidelines. A trend noticed throughout the sampling period was the non-compliance in the levels of total dissolved solids (TDS) and dissolved oxygen. The results indicated that concentrations of iron, aluminium, nickel, manganese and potassium were above the limit across the Bosmontspruit and Russell's stream. There was also significant evidence of excessive faecal coliform and ammonium pollution in the Bosmontspruit. During the monitoring period it was noted that water from these streams were utilised for crop irrigation, bathing, livestock and human consumption and may pose a health hazard due to poor water quality.

Key words:

1. Water quality,
2. Water pollution,
3. Klip River catchment
4. Acid mine drainage
5. Tailings
6. Cumulative pollution
7. Gold mining
8. Biological characteristics
9. Physicochemical parameters
10. Monitoring

DECLARATION

I declare that the thesis titled "An evaluation of the cumulative surface water pollution within the consolidated main reef area, Roodepoort, South Africa" is my own work and that all sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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Signed

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Date

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CHAPTER 1. INTRODUCTION

1.0 Introduction

The impact of mining on South Africa's water resources has in recent months received a great deal of publicity through the various media (Mining weekly, 2011 Earth magazine, 2011). In particular there is the challenge faced with dealing with the acid mine drainage in the Witwatersrand Basin. The Eureka Alert press release, 2011 stated that the volume of acid mine drainage from abandoned mines in the Witwatersrand goldfields alone could reach 350 million litres per day if action is not taken (Earth magazine, 2011). In dealing with the above problem a key area outlined in the Inter Ministerial Committee (IMC) 2010 report was the knowledge gap that needed to be addressed in terms of available water quality data (IMC, 2010).
The IMC 2010 report pointed out that very few specialist investigations appear to have been done to identify the status of the geohydrology, the level of contamination, preferential pathways and predictions regarding long-term dispersion (IMC, 2010).

The Witwatersrand Basin is made up of the Eastern (Springs-Nigel area), Central (Johannesburg area) and Western (Krugersdorp-Randfontein area) basins/ regions located in Gauteng, South Africa and is famous for its prolific gold, coal and uranium deposits with mining activities being conducted in the basin since the late eighteen hundreds (Handley, 2004). The Witwatersrand has always had a rich mining legacy which has generated vast economic benefit and to date mining remains a key sector in ensuring the country's position in the global market. Despite such benefit, large scale closure of mining operations since the 1970s within the Witwatersrand mining regions and the subsequent termination of the extraction of underground water from mines have become important national concerns (IMC,2010).Although mining has many economic benefits, the available case studies and evidence suggest that the activities of the mining sector have resulted in serious environmental consequences all over the world, in particular the poor environmental and water management.

Due to the major role that mining plays within the South African economy, water and specifically mine water management must be regarded with a high level of concern so that one of the country's most important natural resources is preserved.

The continuous extraction of underground mine water is often essential for the safe continuation of mining activities, should the extraction of underground mine water cease the existing mine voids flood resulting in significant water pollution. This situation was illustrated in September, 2002, when acidic mine water started flowing from an abandoned shaft in the Mogale City/Randfontein area of the Western Basin (IMC, 2010). The resultant flooding of the mine shaft allowed polluted water to decant onto the surface and enter the ground and surface water systems. This surface flow or decant of mine water is of concern to the environment as the water is of an acidic nature and contains sulphide contaminants. The (IMC, 2010) report further indicates that a similar situation is developing in the Central and Eastern Basins. The decanting mine water poses a potentially devastating environmental impact. The initial impact caused by the decanting water will result in further stresses on larger river systems subsequently resulting in a regional impact, and in general the entire receiving water environment would be affected.

Surface and groundwater pollution because of mining is prevalent all over the central Roodepoort area in Johannesburg, South Africa. Human activities have a major impact on the environmental factors influencing the composition of water results. The power of humans to alter the environment is great and is widely evident in the changes they can bring about in water composition (Hem, 1989). Gold mining activities such as gold extraction and beneficiation frequently affect water resources by introducing by-products of the mining process into the natural water system. Examples of such situations have been illustrated all over the world, e.g. in 1982, 2,953 litres of cyanide-contaminated solution leaked from a containment pond from the Zortman-Landusky mine in the United States and a section of piping used in the mine's cyanide sprinkling system ruptured and released 196,841 litres of cyanide solution onto lands and creeks (Klauk, 1996). The tap water revealed cyanide concentration levels above drinking water standards and the community's local water system was shutdown (Klauk, 1996).

The construction of tailings dams at the mines also poses a major environmental impact. Storage of waste materials or tailings disposal has become a serious matter for the mining industry the world over due to its enlargement especially for the last 30 years (IMC, 2010). During the beneficiation of valuable metals and industrial minerals from their ores, large volumes of waste materials or tailings are produced and these tailings can be harmful to the environment. This is largely due to the acid mine drainage and ground water contamination that results from these waste deposits (Ozkan *et al*, 2002).

In November, 2008 Central Rand Gold (Pty) Ltd, were awarded a new order mining right to commence mining in the Central basin on the basis of total resource extraction on three reef horizons, namely the Main, Bird and Kimberly Reefs. With the recent re-establishment of mining within the central Roodepoort region, located between the Crown Mines golf course and the redundant Durban Roodepoort Deep tank farm in the north of Johannesburg, there is a need to consider and examine the disruption of surface water systems attributed to surface and underground mining. The Central Rand Gold mine is situated approximately 10 km to the west of the Bosmontspruit[1]. The major hazard in terms of polluting the river is the tailings deposition facility as well as runoff from the redundant Crown Mines tailings facility belonging to Crown Gold Recoveries. The Bosmontspruit flows under the western bypass and across Main Reef road through the Stormill industrial complex and finally deposits into the New Canada Dam. The Russell's stream also flows into the New Canada Dam and is situated south of Crownwood Road and will also form part of the study. According to the Ferret mining environmental assessment report, 2008 the most adversely affected environmental components in the area include:

- The local surface water quality owing to seepage from the waste dumps, mine run off and industrial areas.
- Land capability and land use owing to poorly rehabilitated areas and other impacts associated with historical mining activities.
- The general decline in aesthetic quality of the area owing to visual impact of the tailings dumps (situated in close proximity to the suburb of Bosmont) as well as the noise and dust created by mining operations (Ferret mining environmental assessment report, 2008).

[1] Spruit- Afrikaans word for stream

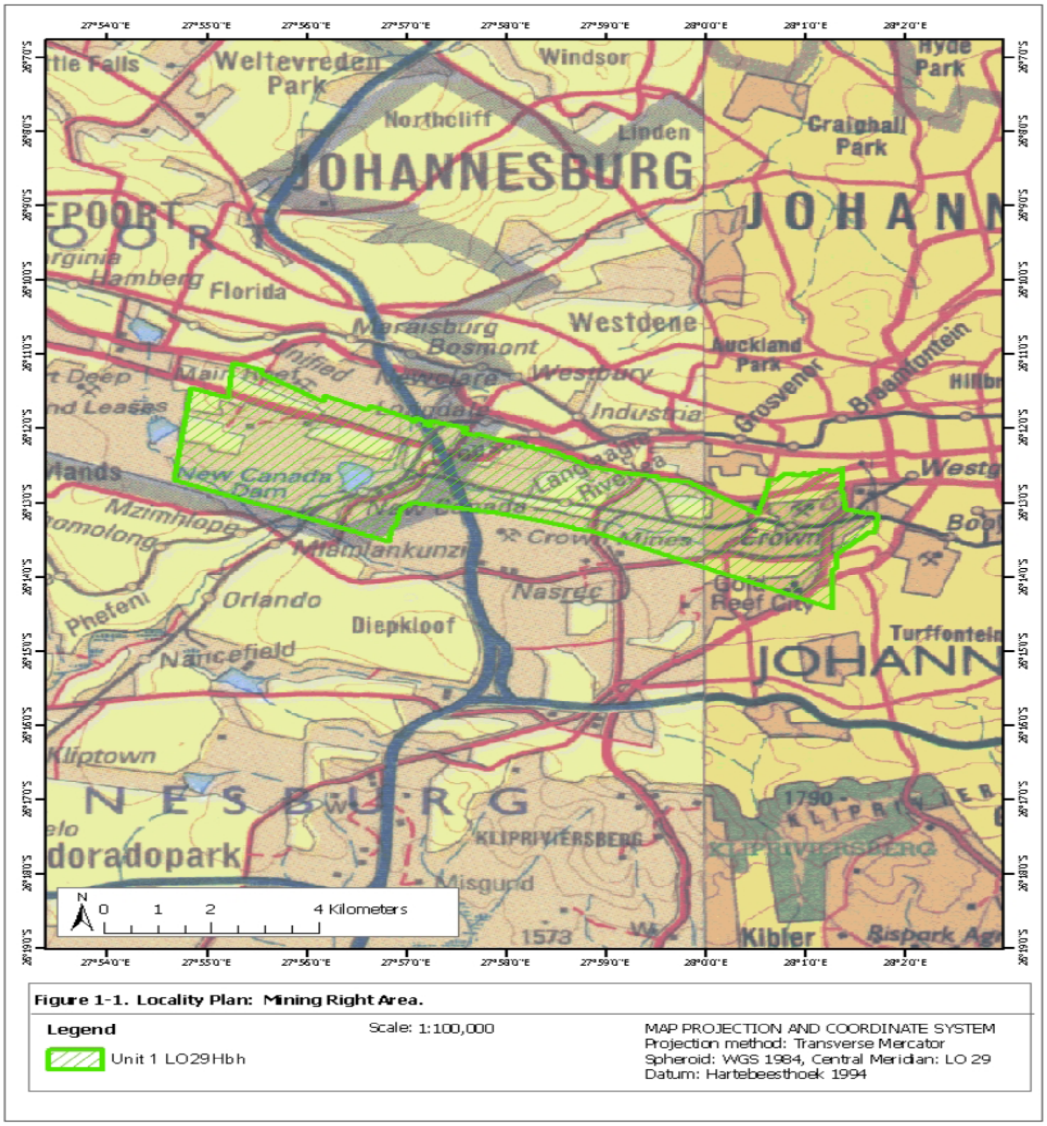

Figure 1-1Area under the Central Rand Gold Mining Right (Ferret, 2008)

Majority of the mine water discharges across South Africa are acidic due to the acid generating potential of pyrite bearing geology and contain dissolved metals and trace elements which may be detrimental to the environment. Naiker *et al*. (2003) undertook a study of the surface and ground water in the Central Rand area. The study revealed that the ground water within the mining area is heavily contaminated with metals such as calcium, magnesium and sulphates exceeding the limits stipulated by the Department of Water Affairs. The author also noted that significant acidification existed as a result of acid mine drainage emanating from the tailings dumps (Naiker *et al*, 2003). Where the water table is close to surface, the upper 20 cm of soil profiles are severely contaminated by heavy metals and the polluted ground water is discharging into the streams, lowering the pH level. The contaminated water persists for more than 10 km beyond the source (Naiker *et al*, 2003).

However, although the tailings dumps are attributed for most of the water pollution in the region there is sufficient evidence of industrial and informal settlement impacts within the area, these activities coupled with agricultural activities and waste water treatment works are identified as the major causes for the further deterioration of the water quality within the region, (Johannesburg Water, 2009).

This study focussed on assessing the surface water quality in Bosmontspruit, New Canada Dam and Russell's stream. This included chemical analyses of specific chemical and physical water quality parameters at the stipulated sampling points. The specific chemical parameters which include calcium, sodium, chloride, dissolved iron, dissolved manganese, total hardness, total alkalinity, magnesium, nitrites, potassium, sulphate, gold, cobalt, nickel, sulphur, uranium, total cyanide, ammonium and calcium hardness were analysed. The values obtained were compared to the specified Target Water Quality Range (TWQR) as set in the Water Quality Guidelines produced by the Department of Water Affairs (DWA, 1998). In addition, a regression analysis was performed to determine the relationship between the analysed water quality parameter concentration and associated river flow (m^3s^{-1}), so as to determine if there was any direct link between water flow and concentration or if an external influence was disturbing the concentration levels. The study also aimed to determine whether or not the surface water has been degraded by the mine's past and present activities or other industrial sources.

This research was important since it is vital to determine the water quality of rivers and streams so as to be able to prudently manage this resource. The impacts are usually not only restricted to the immediate vicinity of the mine, but the effects of degraded water quality are often felt downstream of the mines further away from the source of pollution. The effects of degraded water quality impact aquatic life and all biota found in the river. Certain aquatic life is extremely sensitive to the chemical balance of a river and changes in the chemical balance can have adverse effects on the natural ecosystem. It may also impact the agricultural sector if the degraded water is used for irrigation of crops or for livestock and this could be disastrous for farmers. The efficient management of water resources requires careful monitoring, prior, during and post mining operations, in addition prudent water management should occur during land reclamation activities. However, in the past many mining sites were abandoned with inadequate rehabilitation and closure procedures leaving a legacy of contaminated drainage and water pollution.

1.1 Problem Statement

Gold mining is seen to be extremely problematic to water quality across the world. The Witwatersrand region in Gauteng, South Africa has seen extensive mining activities and subsequently has experienced severe changes to the chemical and physical balance of the river systems within it. This study aimed at analysing and comparing the sampled chemical and physical water quality parameters in accordance with the water quality guidelines as stipulated by the DWA. River flow plays a vital role. Changes in river flow may increase or reduce the nature and characteristic of the results. River flow may differ as a result of a number of factors such as rainfall, temperature, evaporation rates, gradient and riverbed roughness among others (Taylor, 1977, Cheong 2012). Thus this study also focused on determining the influence of gold mining and other industrial sources on the local surface water quality.

In recent years (2009-2011) the situation on the decant of acid water in Johannesburg has received extensive media coverage due to the detrimental impact this could have on the receiving water environment. One of the key areas identified in IMC 2010 report was the knowledge gap that existed with regards to surface water quality assessments and the availability of baseline information on smaller river systems. Thus it is a key objective of the research to add to the existing knowledge base and provide surface water quality assessments for the area of concern.

The river systems within the Roodepoort area form part of the Klip River catchment, the streams within this system were viewed as historically polluted due to the redundant tailings facilities as well as the legacy left by the historical mining activities within the region. Limited information is available on the surface water quality of the Bosmontspruit, Russell’s Stream and New Canada Dam.

It was also noted that water from these streams was used for bathing, irrigation of crops as well as drinking water for livestock, making it also essential that an updated surface water quality assessment be conducted to ensure that water users are not making use of polluted water systems.

1.2 Research Hypothesis

Due to the historic gold mining activities in the Central Rand and the current active mining operations it is expected that the dominant source of pollutants in the Bosomontspruit, Russell's stream and New Canada Dam will be predominantly as a result of gold mining and its associated activities and acid mine drainage generated from the oxidation of pyrite bearing material.

1.3 Motivation and Objectives of Study

Gold mining activities and tailings dams regularly impact on water resources. According to WRC (1995[b]), rivers are the main source of water in South Africa. South Africa's water resources are under threat of water pollution and abstraction. As a result the water quality of the river systems are constantly deteriorating. Clarke (1995) points out that the major reason for this is that many industries exploit the water resources by utilising it in their processing operations. In South Africa freshwater systems are recognised as a crucial element in the battle against poverty, the cornerstone of prosperity, and a limiting growth factor (Basson *et al*. 1997). Most of the water pollution originating from mining is from a non-point nature which makes it difficult to measure and manage.

In the past such pollution received little attention from the regulatory bodies e.g. Department of Mineral Resources resulting in abandoned tailings facilities with no closure plans. WRC (1995[b]), states that as a result of the increased awareness of the importance of non-point source pollution, mining pollution is receiving more attention from regulatory authorities therefore resulting in plans to be put in place to better manage pollution. The establishment of the Inter-ministerial committee in 2010, to address the situation of acid mine drainage in Gauteng has shown the commitment by the South African government in recognising the importance of the conservation of water.

After the reserves have been extracted it was often the practice of gold mining companies to allow the landscape to rehabilitate itself. Due to the severe impacts associated with mining, the surface water is often left to degrade owing to the discard dumps from historical mining. It is thus imperative to monitor the local water quality to ensure continuous improvements and implement corrective action if necessary.

The objectives of this study were to:

1. Assess the overall water quality of the Bosmontspruit, New Canada Dam and Russell's stream thus generating suitable surface water quality reports for the identified sampling points and subsequent comparison of the results with the TWQR as set out by Department of Water Affairs.

2. Determine the relationship between river flow and observed water quality parameters at selected surface water sample points.

CHAPTER 2. LITERATURE REVIEW

2.0 Assessment and collation of work done by various institutions

Several studies pertaining to water ingress have been conducted in the main gold-mining basins (Buttrick *et al* 1993, Duane *et al* 1997, Roychoudhury and Starke 2006 and Tutu *et al* 2008). Most of these studies dealt with the associated environmental impacts of acid mine drainage. Conclusions indicate that serious environmental challenges exist. The work includes specialist studies performed on behalf of the various government departments, science councils (Council for Geoscience, Council for Scientific and Industrial Research (CSIR) and Mintek), and other organisations such as the Water Research Commission (WRC), universities, the National Nuclear Regulator (NNR), town councils and other organisations (IMC, 2010).

Thirty eight WRC-funded projects have been completed, with the major focus being on mine water management; a further 16 are continuing at present, most of these projects are focused on specific research questions, ranging from the development of treatment technologies to the characteristics of mine dumps (IMC, 2010). Due to no active mining in the Central Basin few studies have addressed the water quality within the area.

The IMC report 2010 points out that very few specialist investigations appear to have been done to identify the status of the geohydrology, the level of contamination, preferential pathways and predictions regarding long-term dispersion.

The Department of Water Affairs (DWA) recently updated the management strategies pertaining to the integrated Vaal River and Crocodile-Marico Systems (IMC,2010). These updated plans focus on the following key areas:

- reconciliation strategies
- water quality management strategies that, amongst others, specify measures to curb and manage the pollution effects on the river system
- salinisation on these river systems, noting the contribution of acid mine drainage of these salt loadings.

The collective aim of these strategies is to secure continued water security on the medium to long term (DWAF, 2010).

WRC (1998) focused on the surface water pollution associated with mine tailings with less attention given to cumulative water pollution impacts and the effects it has on the environment. WRC projects concentrated mainly on the development of solutions to contamination derived from the generation of acid mine drainage from surface waste disposal facilities.

Recent WRC projects focused on the treatment of acid mine drainage as well as the disposal or use of the associated treatment technologies. Eleven WRC projects concerned with the quantification of acid mine drainage production have been completed (IMC, 2010). Most of these projects have been conducted in active mining areas hence a knowledge gap exists in specific areas of the country, more specifically the historically mined areas which currently have no active mine operations. These areas are of critical importance, as they are often left abandoned or neglected and create a significant environmental hazard.

Several regulatory guidelines have been developed by government departments and these include the Best Practice Guidelines for Water Resource Protection in the SA Mining Industry, developed by DWAF 2010.

The sustainable development of the environment through Mining Projects of the Department of Mineral Resources has produced the following documents in an attempt to address the environmental management issues associated with mining:

- The Regional Mine Closure Strategies (RMCS), developed by the Council for Geoscience (CGS), (2009) aimed at addressing the problems, particularly in Witwatersrand Basin, associated with interconnected underground mines.

- The National Strategy for the Management of Derelict and Ownerless Mines, developed by CGS (2009), aimed at addressing the liability of government for the thousands of derelict and ownerless mines.

- Mine and Environmental Management (MEM) guidelines, developed by MINTEK (2006), aimed at addressing the management and closure of mines in an environmentally friendly and sustainable manner.

A significant amount of research has been done on understanding and predicting the impact of mining on the environment. Thirty one reports dating back to 1989, of which most are of an applied nature, have been prepared utilising mainly government funding (IMC, 2010).

2.1 Research knowledge gaps

Many risks in the Central Basin have been identified (e.g. the decant of acid water onto the streets of Johannesburg, the impact on the river systems and receiving water bodies, the absence of funding to conduct the suggested mitigation measures) because of its proximity to central Johannesburg. The IMC report (2010) recommended the following:

- That the identified risks be investigated

- That monitoring programmes be put in place to refine assumptions and to improve future management situation

- That the precautionary principle be adopted in areas where significant uncertainty exists in order that prudent action can be taken to minimize latent hazards.

Other proposed investigations through continuous improvement of the knowledge base include (IMC, 2010):

- Identifying mines, surface and underground infrastructure and mine interconnection
- Quantification of water use and wastewater/acid mine drainage production in mining
- Predicting and quantifying the effects of mining activity on the environment.
- Source identification, quantification and characterisation of mine related pollutants

- Recipient identification and characterisation
- Assessment of environmental risks
- Regulatory mechanisms
- Regulations to address the problem
- Development of management tools
- Design ingress prevention and decant management schemes
- Suggest improved mine waste and water management

Based on the above the major aim of the study was to add to the existing knowledge base by providing a surface water quality assessment of the study area.

The Witwatersrand Basin is made up of the East, Central and West Rand basins in South Africa and is famous for its prolific gold, coal and uranium deposits and mining has been going on in the basin since the late eighteen hundreds (Handley, 2004).
Records of water ingress into the underground mines in the East Rand date back to 1909 (Scott,1995). In order for the safe continuation of mining operations, mine water was pumped out from the shafts and disposed off in the surrounding environment. As the mining developed and the underground operations became interlinked, so the task of dewatering was carried by fewer mines (Roychoudhury and Starke, 2006).

As is the case in the Central Rand most of the mines on the East Rand are currently inactive, closed or abandoned and mining areas are inaccessible as water was allowed to flood the lower workings.
Grootvlei Gold Mine is one of the mines in the East Rand area that regularly dewaters their underground workings and disposes of the effluent in the Blesbokspruit to keep their operations going. Due to recent labour issues, the Grootvlei operation has ceased pumping activities; (Aurora Grootvlei Mine issues: Department of Labour report, 2010) this puts the Blesbokspruit under potential threat of metal pollution from dewatering actions of the mines in the area (Roychoudhury and Starke, 2006).
Mining activities are associated with the production of rock piles, sand and tailings dumps on the surface, and back fill rock piles underground in voids or worked out

areas. The Witwatersrand rocks contain varying proportions of sulphides minerals, the predominant type being pyrite (Forstner and Wittmann, 1979). The pumping of mining effluent in surface water systems there results in sulphate and trace metal contamination in the system.

Förstner and Wittmann (1976) and Wade *et al*. (2000) found metal enrichment in aquatic sediment caused by effluent from Witwatersrand gold mines which they ascribed to the presence of ore minerals. Tailings dams and mineral beneficiation plants also provide a pathway for trace metals entering the surface water system. Seepage from tailings dams as well as atmospheric fall-out of fine particulates are two contributing pathways to surface water contamination.

The New Canada Dam, Bosmontspruit and Russell's Stream mimic the situation in the Blesbokspruit where metals are also introduced by sources other than mining, as the stream flows through settlements and industrial areas before it passes through the wetland (Ferret mining report, 2008).

Numerous studies have looked at the trace metal dynamics, partitioning and subsequent impact on the receiving environment around active and abandoned mines (Ahn *et al*., 2005; Bruce *et al*., 2003; Coates, 2005; Dushenko *et al*., 1995; Kim and Jung, 2004; Lee and Correa, 2005; Leybourne *et al*., 2000; Lupankwa *et al*., 2006, Reddy and Behera, 2006; Roussel *et al*., 2000; Roychoudhury and Starke 2006, Younger, 2001). However despite South Africa having a rich mining legacy with extensive mining activities occurring in most parts of the country, little information is available from South Africa on pollution and fate of trace metals in surface waters or sediments. This is largely due to the lack of stringent regulatory guidelines in the past and instrumental limitations.

Mining also poses indirect impacts on water quality. Mining at, or close to, the soil surface is coupled with the disturbance of surface soils and shattering of bedrock. This in turn affects the water balance of the affected area in that infiltration is mostly increased while surface run-off is decreased (WRC, 1999). It is the combined effect of increased through flow of water and percolate quality degradation, that result in deterioration of ground and surface water quality on previously mined areas (WRC, 1999).

The Central Roodepoort area has experienced over 100 years of associated mining impacts. Surface mining has resulted in a great deal of damage to the landscape. Many mining operations have removed acres of vegetation and altered topographic features due to the intrusive nature of the activity (Ferret environmental assessment report, 2008). This leaves soil exposed to erosion and allows for runoff into the surrounding rivers and dams. The mining waste deposits also pose a significant problem in terms of producing acid mine drainage as well as ground water contamination through seepage. Funke (1985) investigated the impact of mining wastes on the water quality of the Vaal catchment area and of the Vaal Barrage. The author found that the contribution of acid mine drainage from sand dumps and slimes dams towards a high salinity of the Vaal Barrage water is approximately 2% per annum compared to the pollution load originating from underground mine effluents which are pumped to the surface and discharged into the rivers. Pulles *et al*. (1996) wrote a manual for the environmental assessment and management of gold mining operations in South Africa on the water quality impact of three different mines in the Witwatersrand, the Carletonville and Klerksdorp area respectively. The authors concluded that seepage released from various waste deposits such as mine dumps has been identified as the most significant pollution source with regard to the deterioration of water quality.

With gold being a major contributor towards the South African economy and with new mining activities commencing in the Central Rand, it is of utmost importance that with continued mining of gold in the future, the effects of gold mining on our rivers and aquifers is monitored and mitigated. Harrison (1990) recognised that any chemical in the aquatic environment can become a pollutant if it is present at a high enough concentration. The introduction of pollutants into a water source creates a situation where the concentration of the pollutant is initially high. Due to river's having the ability to disperse a pollutant as a result of the river's flow, the concentration of the pollutant becomes less and less as the pollutant moves further away from its point of introduction.

2.2 Mining and its effects on the aquatic environment

The environmental pollution caused by mining is a significant and costly problem worldwide. The environmental impacts associated with mining continue to affect surface and groundwater resources even after the cessation of mining operations. The major hazard is acid mine drainage which is a recurring problem at abandoned mine sites around the world. The IMC (2010) report states that the oxidation of sulphur rich mine wastes and the resultant release of acid mine drainage is one of the main environmental challenges facing the South African mining industry. Pyrite is often the primary constituent of many metallic ores, mining and the production of waste rock dumps and tailings facilities on surface often exposes pyrite bearing material to oxidation. The sulphide bearing material now has the capability of releasing acidic metal runoff into ground and surface water environments. The excavation process also exposes sulphides in the walls of opencast and underground operations, and disturbs the host rock and hydrological regime around mined out areas, allowing ingress of water and oxygen (IMC, 2010).

The treatment costs for managing mine related environmental impacts can have major effects on the economy especially in developing countries. In Australia, a first world country, it has been estimated that the cost of managing such impact at operating mines amounts to US $60 million per year (Harries, 1997).The Australian government further estimates that when mine water pollution is discovered after mine closure the cost of remediation can be as much as US $100 000 per hectare (Harries, 1997). This situation illustrates the severe economic impacts of mine related environmental impacts.

The Canadian Mine Environment Neutral Drainage (MEND) programme was established by mines and stakeholders in 1989 in response to the recognition of mine water impacts being the major environmental problem facing the Canadian mining industry (IMC, 2010). Due to the efforts of the MEND programme Canadian mining companies have reduced the liability due to acidic drainage by at least $400 million. This has gone a long way into reducing the environmental liability associated with Canada’s tailings disposal facilities.

Mine related environmental impacts particularly those impacts that impinge on water resources are treated with a high level of severity all around the world. It is thus imperative that South Africa as a developing nation learn from the above situations so as to avoid both economic and environmental disasters.

According to Hilson (2002), some of the most noticeable environmental effects caused by mining activities are scarring and disruption of the land surface. Land above ground mines subsides or collapses, which often causes disruptions to the groundwater systems. Miller (1999), writes that rainwater seeping through a mine or mine wastes can carry sulphuric acid to streams and groundwater. The acidity produced by iron sulphides pollute water systems and can contaminate water supplies.

A significant amount of literature indicates that one of the major problems associated with mining is the surface and groundwater contamination associated with tailings disposal facilities (Bindler *et al*., 2009: Huang *et al*., 2010; Sanchez *et al*., 2010)

Sulphuric acid and heavy metals such as aluminium are detrimental to aquatic life found in surface water. These heavy metal contaminants have the potential to bio-accumulate in the liver and the gills and thus impact on an organism's oxygen exchange ability in the aquatic environment.

In addition the pH is lower in the mined areas in comparison to un-mined areas. Further Borchers *et al*. (1991) found that iron concentrations were the same in mined and un-mined areas, whereas the concentration of manganese increased dramatically in the mined basin thus suggesting significant pollution.

2.3 Mine tailings contribution to water pollution

Gold mine tailings are the primary source of ground and surface water pollution on the Central Rand. Due to original inadequate design of tailings dams, subsequent poor management, neglect or present activity (reprocessing status) of mine tailings deposits, they are subjected to varying degrees of water and wind erosion. Water pollution relates directly to the mineralogical and geochemical composition of the auriferous reefs and hence also mine tailings derived from these (Jamieson *et al*., 1995).

Pyrite is the major source for the generation of acid mine drainage (AMD) which leads to the pollution of various streams and dams. Pyrite together with other sulphide minerals in the conglomerate ore or reef are liberated during the mining and metallurgical processes of extracting gold and are deposited with other waste materials onto the tailing dams. On the tailings dams sulphide minerals oxidize when exposed to oxygen and water. This process results in the formation of secondary minerals or efflorescence. Efflorescence is composed of water soluble salts, and, in addition to dominant iron hydroxides and sulphates, has enriched concentrations of several metals including Co, Ni, Cu and Zn. Efflorescence is the start of the contamination of the hydrological system and surrounding soil.

Water pollution studies undertaken over the past decade have established good baseline data on the state of the water environment of the Central Rand. Water quality information from Rand Water Board, Water Research Commission and Crown Gold Recovery show that the drainage systems on the Central Rand have been affected by AMD and high salt loads (Buttrick *et al* 1993, Duane *et al* 1997, Tutu *et al* 2008, Roychoudhury and Starke 2006 , Rosner *et al*., 2001; Rosner and Van Schalkwyk, 2000; Scott, 1995; Davidson, 2003; Forstner and Wittmann, 1976; Lloyd, 1997; Marsden, 1986; Uddin *et al* 2011;Gibert *et al* 2011; Mishra *et al* 2012; Wei *et al* 2011; Mackie and Walsh 2012; Gomes *et al* 2010).

The impact on streams also includes siltation where stream sediments frequently comprise a large component of tailings materials (Mphephu, 2001).

There is a relationship between current status or activity on mine tailings dams and footprints, and the degree of contamination. Thus there is high contamination of water in areas where reprocessing is currently taking place, in the vicinity of active slimes dams (depositional sites) and around poorly cleaned or unrehabilitated tailings dams footprints.

A large volume of literature concerning the mineralogy of the Witwatersrand reefs exists. The matrix of the conglomerates is composed of quartz, pyrite and phyllosilicates (muscovite, sericite and pyrophyllite). Other minerals present but in lesser abundance include chlorite, chloritoid, rutile, zircon, chromite, gold, uranium and carbon. In some instances, chlorite and chloritoid may be the dominant phyllosilicate (Feather and Koen, 1975; Hallbauer, 1986; Viljoen, 1968; Wei *et al* 2011; Mackie and Walsh 2012; Gomes *et al* 2010). The variations in major and in particular trace element geochemistry are largely due to changing ore body mineralogy.

Pyrite is invariably the most important secondary component of the matrix of the conglomerate and hosts most of the gold in very fine state. On the surface of the tailings dams, the oxidizing pyrite and other sulphide minerals form secondary minerals such as melanterite ($FeSO_4$ –$7H_2O$), copiapite ($(Fe,Mg)Fe_4(SO_4)_6(OH)_2$-

$2OH_2O$), gypsum ($CaSO_4$ x $2H_2O$) and jarosite ($KFe_3(SO_4)(OH)_6$) (Naicker *et al*., 2003; Eglington *et al*., 2001; Gleisner, 2005). These secondary minerals are dominant on the outer walls of non-vegetated or exposed mine tailings dams and in areas close to tailings where seepage discharge takes place.

Oxidation of pyrite, accelerated by bacteria, causes the gradual conversion of the water insoluble pyrite into water soluble ferrous sulphate ($FeSO_4$) and ferric sulphate (Fe $(SO_4)_3$), with a concomitant increase of acidity in the surface layer. Oxidation occurs on the top and sides of slimes dams to a depth of about 2 m, with the zone of maximum acidity at about 0.3 m below the surface (Rosner *et al*., 2001). The pH value near the surface varies, depending on how much pyrite is present and the extent to which oxidation has occurred.

From the mineralogical and chemical composition of tailings material, tailings are reservoirs and potential sources of heavy metals such as Fe, Ni, Co, As, Cu, Zn and Cd, which are enriched with respect to the average crustal abundance. During rainfall, the water run-off erodes the tailings dams together with the efflorescence and this often escapes into nearby streams and dams (Rosner *et al*., 2001; Caboi, 1996). The acid mine tailings condition results in trace elements such as Cu, Co, Ni, and Zn becoming mobilized with the highest mobility taking place in stream sediments and topsoil (Cukrowska *et al.,* 2004; Cogho *et al*., 1992; Concas *et al*., 2005).

Seepage water is typically acidic (pH ~ 4.0) and displays high salinity (TDS > 6 000 mg/l), attributable to high concentrations of sulphate and iron (Mphephu, 2001; Scott, 1995). Evans *et al* (1990) also found enhanced concentrations of Co, Ni and Zn. Naicker *et al*., (2003) found that groundwater is contaminated and acidified as a result of oxidation of pyrite (FeS_2) contained within mine tailings and has elevated concentrations of heavy metals. Where the water table is close to surface, the upper 20 cm of the soil profile is severely contaminated by heavy metals due to capillary rise and evaporation of the groundwater. The polluted groundwater discharges into streams in the area and contributes up to 20% of stream discharge causing a lowering of pH of the stream water (Naicker *et al*., 2003).

This water flows down the Klipriver drainage and into the Vaal River, a major water source for Gauteng. The contribution of mine tailings to pollution of the Vaal barrage system and hence Vaal dam have been well documented (Davidson, 2003; SRK, 1988). Davidson (2003) shows that there are unacceptable levels of heavy metals such as iron and sulphate around mine tailings which improves downstream.

2.4 Purpose of water quality monitoring

Water quality management may be defined as a mechanism to obtain the physical, chemical and biological characteristics of water (Ongley, 2000; Wei *et al* 2011). Water quality monitoring allows the researcher to obtain quantitative information on the physical, chemical and biological characteristics of a water body by utilising statistical sampling. Historically, the main purpose for water quality monitoring was the assessment of aquatic life and the suitability of the water body for end users, this evolved to focusing on the quality of the receiving water environment as well as the release of pollutants and the cumulative effects of human impact. In the past legislation on water quality was not stringent creating a situation where deterioration of a water system was deemed as acceptable. Since the publication of target water quality levels and more stringent controls applied by legislative authorities, water monitoring is core to all activities having direct or indirect impacts on aquatic environments. It is also used simply to check whether any unexpected change is occurring in otherwise pristine conditions.

Kilian (1997) states that, the definition for monitoring is that the water quality assessment procedure is viewed as a long term operation with standardised measurement, observation, evaluation and reporting of the aquatic environment in order to define status and trends.

Water monitoring data is never taken in isolation, data are principally collected at given geographical locations (often described by an acceptable coordinate system) coupled with recorded ambient temperature conditions. Monitoring data can also be further characterised by the depth at which the sample is taken as well as the prevailing flow of the water body. Monitoring data must also be characterised and recorded with regard to the time at which the sample is taken or the in situ measurement is made.

2.5 The concept of water quality and associated parameters

According to (DWAF 1998[b]), the term water quality is used to describe the biological, physical and chemical properties of water that determine its fitness for use. The Department of Water Affairs under the National Water Act of 1998 stipulates that certain minimum water quality standards are required for domestic, industrial, agricultural and recreational purposes. The water quality standards are based on the physical, chemical and biological properties within a water body. Many of these properties are controlled or influenced by substances that are either dissolved or suspended in water (WRC,1998).

Physical quality refers to water quality properties that may be determined by physical methods such as conductivity, pH and turbidity (DWAF 1998[b]). Chemical quality refers to the nature and concentration of dissolved substances such as salts, metals and organic chemicals. Microbiological quality refers to the presence of organisms that cannot be seen by the naked eye, such as protozoa, bacteria and viruses (DWAF 1998[b]).

The major overall water quality management goal for the DWA is the maintenance of the fitness for use of South Africa's water resources. This must be done on a sustainable basis. The fitness for use concept is based the evaluation of water quality in terms of the requirements of a particular user or categories of users. It is usually measured against water quality criteria and guidelines that have been established as representative of the ideal water quality for a particular use.

The South African Water Quality Guidelines serve as the primary source of information for the determination of water quality requirements of different water uses. The Guideline is crucial in assisting with the protection and maintenance of the health of South Africa's aquatic environments. The guidelines form an integral part of South Africa's water quality management system. The table below shows a list of physical, biological and chemical parameters[2].

[2] * Denotes parameter used in this study

Table 2-1: Physical, chemical and biological parameters

		Possible source
Biological	**Faecal coliforms***	Informal settlements/Waste water treatment works
	Total coliforms	
	Free available chlorine	
Physical	**pH***	Mining/ Industrial
	Conductivity*	Urban runoff/Mining/Industrial/Waste water treatment works/Agricultural impacts
	Turbidity	
	Temperature*	
	Dissolved Oxygen*	
	Total dissolved solids*	
	Flow ($m^{3/}s$)*	
Chemical	Arsenic	
	Cadmium	
	Calcium*	Urban runoff/Mining/Industrial/Informal settlement
	Sodium*	Urban runoff/Mining/Industrial
	Chloride*	Urban runoff/Mining/Industrial/Waste water treatment
	Copper	
	Fluoride	
	Dissolved Iron*	Urban runoff/Mining/Industrial/Waste water treatment
	Dissolved manganese*	Urban runoff/Mining/Industrial
	Total hardness*	Urban runoff/Mining/Industrial
	Total alkalinity*	Urban runoff/Mining/Industrial
	Magnesium*	Urban runoff/Mining/Industrial
	Nitrate and nitrite*	Urban runoff/Mining/Industrial/Waste water treatment/Agricultural impacts
	Potassium*	Urban runoff/Mining/Industrial
	Sulphate*	Urban runoff/Mining/Industrial
	Gold*	Mining
	Cobalt*	Mining
	Nickel*	Mining
	Sulphur*	Mining/Industrial
	Uranium*	Mining
	Total cyanide*	Mining

	Ammonium*	Urban runoff/Mining/Industrial
	Calcium hardness*	Urban runoff/Mining/Industrial

For the purpose of this study more focus will be given to the physical and chemical parameters as these were considered the most relevant to the evaluation of effects by mining activities. The chemical parameters will be evaluated in terms of DWA's TWQR as stipulated in the Water Quality Guidelines according to a determined use (DWAF 1998[b]).

2.6 River flow and water quality parameter concentration

River flow is an extremely important parameter when determining water quality. Changes in river flow are often related to changes of the concentration of constituents in the water. In order to develop a clear understanding of the correlation that exists between river flow and surface water quality it is necessary to conceptualise the associated parameters such as flow paths, biotic processes and deposition estimates. Prathumratana *et al.* (2008), suggests that the prediction of surface water quality is made simpler by obtaining a complete knowledge of the above mentioned variables.

Many authors point to the fact that river flow is directly related to a number of corresponding factors that impact on water quality concentration. Prathumratana *et al*. (2008) illustrated the impacts that climatic factors such as precipitation, temperature, sunshine, humidity and wind have on river flow to some extent but only precipitation and temperature account for major differences among river flow. It is thus imperative to obtain as much information as possible on the ambient conditions when conducting river flow assessments.

Sherrell and Ross (1999) noted the apparent inverse relationship between stream discharge (river flow) and constituents. This is most noticeable during seasonal variations in ambient conditions and the corresponding flow reductions and/or increases. Vesley (1994), builds on the concept of the seasonal variations in flow, and illustrated that more trace metals were liberated thus increasing their concentration in acidified water during high flow seasons. Massoud *et al.* (2006) showed that dissolved oxygen levels were consistently higher at the end of the wet season. The concentrations of biochemical oxygen demand, ammonia nitrogen and ortho-phosphates did not exhibit a clear seasonal variation. Chakrapani and Saini (2009) showed how seasonal variations accounted for high sediment loads in the Alakananda and Bhagirathi rivers in India. During monsoon season >75% of annual sediment loads are transported.

The determination of river flow and the relationship that exists between river flow and contaminant concentration is of the objectives of the research study.

2.7 Location of sampling points

Eight water quality monitoring sites in the study area/catchment were chosen for monitoring the cumulative surface water impacts. Three of the eight water quality monitoring sites served as controls (SW01, SW04 and SW07) for various activities that could affect water quality. These sites were chosen upstream of any sources of pollution, however due to the monitored river systems being historically polluted the controls sites displayed poor water quality. Samples were taken monthly over a six month period. The criteria used for the selection of the sites were based on the following as stated by McMillan and Moore, (1993):

- Accessibility by road to enable water quality samples to be taken
- Perennial flow of the streams, since the presence of flow is an important factor in determining water quality
- Proximity to active mine sites, tailings depositions sites and industrial areas since the aim of the study is to assess the cumulative water pollution impacts.

Table 2-2: Sample locations

Sample code	Sample coordinates	Sample description	Notes
SW01	26°11'30.12"S, 27°57'19.44"E	Upper Bosmontspruit	The site is situated in the suburb of Bosmont and served as a control sampling point. There are no mining or industrial activities but human settlement. Water velocity features include slow running water, fast riffles and pools. The water is discoloured.
SW02	26°11'44.52"S, 27°57'0.72"E	Portion of Bosmontspruit	This site is situated closest to the Central Rand Gold Mine. It is south

		directly below Central Rand Gold Mine	east of the mine's tailings disposal facility. Water velocity features include slow riffles. The water had a slight discolouration and the river bed is a mix between rocks and sand.
SW03	26°12'9.00"S, 27°56'58.92"E	Lower Bosmontspruit	The site is situated where the Bosmontspruit crosses under Main Reef Road and is situated east of an inactive mine tailings disposal facility. The velocity features include shallow water with slow riffles. No water discolouration.
SW04	26°13'38.94"S 28° 0'11.34"E	Upper Russell's Stream	This sampling point will be serving as a second control point as it is upstream of the major point source of pollution, the Crown Gold recovery plant. The velocity features are characterised by medium flow, no water discolouration evident.
SW05	26°13'28.80"S, 27°59'44.76"E	Russell's Stream	This sampling point is directly downstream of a gold processing plant. The velocity features are defined by medium to high flow. No water discolouration was evident however; there was evidence of "foam" as a result of the acid mine drainage.
SW06	26°13'10.14"S, 27°59'12.42"E	Russell's stream tributary	This sampling point is downstream of the industrial complex west of Crownwood Road. Velocity features are slow flowing waters, slight water discolouration evident.
SW07	26°13'1.86"S 27°59'20.40"E	Upper Russell's stream tributary	This sampling point served as the control for the tributary. It is situated in the Riverlea township; the flow is generally slow with a grey water discolouration.
SW08	26°12'51.12"S, 27°56'18.24"E	New Canada Dam	Final Decant point for Bosmontspruit and Russell's Stream (Mixing Point). The velocity features were characterised by fast flowing water with no water discolouration.

*Note: Arrows in below figure indicate sample positions.

Figure 2-1:SW01

Figure 2-2:SW02

Figure 2-3:SW03

Figure 2-4:SW04

Figure 2-5: SW05

Figure 2-6: SW06

Figure 2-7: SW07

Figure 2-8: SW08

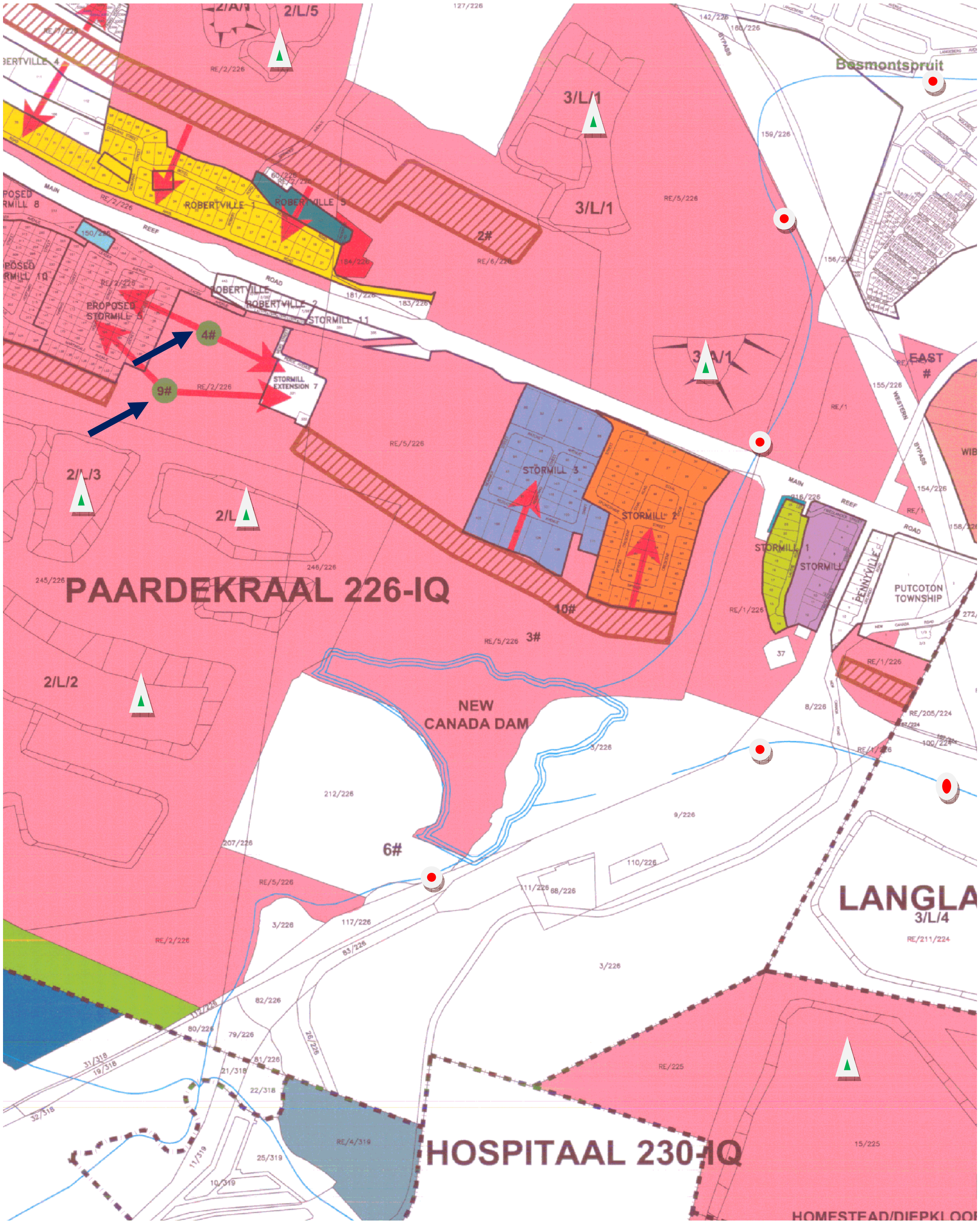

Figure 2-9: Sampling points in relations to mine dumps

Key	
	Sample positions
	Mine dumps
	Old Mine shafts

Figure 2-10: Sample locations

2.8 Regional Climate

2.8.1 Mean rainfall

The mean annual rainfall recorded at Johannesburg International weather station was 710 mm during 2010. The rainy season extends from October to April, and the average rainfall peaks occur during the months of December and January.

2.8.2 Evaporation

Mean annual rainfall ranges between 600 mm and 800 mm per year over most of the water management area, with potential evaporation between 1,300 and 1,700 mm per year.

Average potential mean annual gross evaporation (as measured by Class A-pan) ranges from 1 600 mm in the east to a high of 2 200 mm in the dry western parts. The highest Class A-pan evaporation is in January (range 180 to 260 mm) and the lowest evaporation is in June (80 to 110 mm).

2.8.3 Maximum Rainfall

The summer (October to April) climate is mild neither too hot nor humid. The study area is located in the summer rainfall region of South Africa and therefore receives most of its rainfall during this period. While gentle soaking rains do occur, the rainfall in the area is often characterised by intense thunderstorms, which occur mainly in the late afternoon. These thunderstorms, although brief, are often ferocious, and are accompanied by thunder, lightning and occasional hail, and are generally followed by clear skies.

The highest monthly rainfall occurs in November and January with maximum daily recorded rainfall ranging from 112.0 mm on 8 February 2000 to 210.0 mm on 20 January 1915 (Ferret, 2008).

2.8.4 Temperatures

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise), and determining the development of the mixing and inversion layers. Data was obtained from the Johannesburg Airport in 2006 as it was believed to be the most reliable source of meteorological data (Ferret, 2008).

Annual mean temperatures for Johannesburg Airport are given as 15.9℃. The average daily maximum temperatures range from 25.3℃ in January to 16.0℃ in June, with daily minima ranging from 14.3℃ in January to 4℃ in June and July. The seasonal and diurnal variations in temperatures recorded at Johannesburg are depicted below.

Table 2-3: Long-term minimum, maximum and mean temperature (°C) for O.R. Tambo International Airport for the period 1951-1984 (Schulze, 1986)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Maximum	25.3	24.9	23.9	21.2	18.6	16.0	16.5	19.2	22.7	23.9	24.1	25.0
Minimum	14.3	14.1	12.9	10.2	7.0	4.0	4.2	6.0	9.2	11.3	12.7	13.8
Mean	19.8	19.5	18.4	15.7	12.8	10.0	10.4	12.6	15.9	17.6	18.4	19.4

2.8.5 Meteorological climate

Climate over the water management area is temperate and fairly uniform. Rainfall is strongly seasonal, with most rain occurring as thunderstorms during the summer period. Mean annual rainfall ranges between 600 mm and 800 mm per year over most of the water management area, with potential evaporation between 1,300 and 1,700 mm per year. Frost occurs in winter, and occasional light snow on high lying areas.

The area is characterised by northerly and north-westerly winds during winter and spring, and north-north-easterly and north-easterly winds during summer. Although calm conditions occur for less than 2.5% of the time, gentle to light winds (1-5 $m.s^{-1}$) prevail for more than 80% of the time, with stronger and slightly unstable winds being experienced for approximately 15% of the time. The highest monthly rainfall occurs in November and January while the months of May to August experience little rainfall. December and January are the hottest times of the year. There is not a large variation in MAP (mean annual precipitation) over the area, although MAP does increase with height.

In accordance with the rainfall pattern, the relative humidity is higher in summer than in winter. Humidity is generally highest in February (the daily mean ranges from 65% in the west to 70% in the east) and lowest in August (the daily mean ranges from of 55% in the west to 62% in the east). The gross irrigation requirement (based on rainfall and A-pan evaporation) ranges from 1 600 mm/a in the dry western parts to 900 mm/a in the eastern escarpment areas. The minimum monthly requirement is in June (ranges from 70 to 110 mm) and the maximum monthly requirement is in September (ranges from 130 to 200 mm).

Table 2-4: Ambient Conditions during sampling

	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
Mean Temp (℃)	18.3	18.1	17.7	20.7	19	13.7
High Temp (℃)	26.7	22.3	21.9	27.3	25.8	18.7
Low Temp(℃)	9.3	15.2	14.1	15.4	13.8	9.8
Rain (mm)	0	0.3	0.5	0	3.8	0
Average Wind Speed (m/s)	0.4	2.7	0.8	0.6	0.6	0.6
High Wind (m/s)	5.4	10.3	9.4	5.4	8.5	6.7
Wind Direction	ESE	NW	W	NNW	S	W
Humidity (%)	56.52	75.89	78.4	63.41	73.27	86.18
Barometric pressure (mb)	1015.82	1015	1015.5	1014.14	1014.8	1020.95

2.9 Air Quality

The atmospheric conditions in Johannesburg area are not conducive to the rapid dispersion of pollutants particularly in winter. Surface temperature inversions occur often in winter and elevated inversions are common. Moist unstable conditions and rainfall, which promote dispersion and deposition of pollutants, are confined almost exclusively to the summer period.

Current and past mining activities are a major source of dust and particulates which are blown from the tailings dams, ash heaps and mine dumps.

There are 159 mines in the Gauteng Province (Johannesburg: State of the Environment Report, 2003) several of which still operate on the outskirts of Johannesburg. A more problematic area of concern are the mine dumps of discontinued operations which occur south of Johannesburg and which were abandoned prior to legislated rehabilitation requirements being established in 1991.

2.10 Regional Geology

In a regional sense the area is underlain by sedimentary and igneous rocks belonging to:

- The Witwatersrand Supergroup more specifically the Central Rand Group compromising the quartzite, conglomerate and shale at the base of the succession and outcropping in the north (Ferret Mining 2008)
- Overlain by rocks belonging to the Ventersdorp Supergroup (Klipriviersberg group compromising tuff, lava, feldspar porphyry, basaltic lava and agglomerate) in a west east band across the central part of the area (Ferret Mining 2008).
- Overlain to the south by rocks belonging to the Transvaal Supergroup (Chuniespoort Group compromising Black Reef quartzite, conglomerate and shale, overlain with dolomite and chert of the Malmani Subgroup) (Ferret Mining 2008).

The Central Rand geology is separated from the West Rand and East Rand goldfields by the regional structural features. In the west the Central Rand is separated from the West Rand by the Roodepoort and Saxon faults causing a 2 kilometer non-mineable gap between the two goldfields. In the east the separation is known as the Boksburg gap which comproses a region of poor gold sediments.

Structural geological features include a high incidence smaller faults, fissures and dykes of various compositions and ages. The dominant trend is NNW by SSE, with a secondary trend of NE/SW.

The more localized structural features will play a significant role with respect to the occasional movement of ground water (Ferret Mining 2008).

The Central Rand Goldfield compromises a 7km wide sequence of quartz pebble reefs where heavy minerals including gold, pyrite and uranium have been concentrated to a greater or lesser extent.

2.11 Soil Characteristics

Soils found in the study area are dominated by shallow to moderately deep, yellow brown loamy sand soils of the Clovelly form. These soils have grazing land capability due to restricted effective depth. Subdominant is the deep red, sandy loam soils of the Hutton form which have arable land capability. The distribution of soils is linked to topography and parent materials from which they derived. Free draining soils (e.g. Clovelly) are generally derived from the sediments (i.e. sandstone and shales) from the Central Rand formation while the more structured and clayey soils are associated with the intrusive dolerite dykes and lavas of the Ventersdorp Super Group.

Large portions of the study area are severely disturbed and all topsoil was removed, according to Ferret Mining 2008, these areas have no land capability and can be classified as wilderness according to the Chamber of Mines definition. The remaining areas are covered by tons of building rubble and domestic which currently pose a major a health and safety hazard.

2.12 Regional Water Management

The Klip River catchment is situated in the Gauteng province of South Africa, and drains the southern Witwatersrand region. It flows primarily southwards until it joins the Vaal River at Vereeniging (Figure 2-11: Regional drainage map – Upper Vaal Water Management Area. The Vaal-Orange system then flows westward terminating in the Atlantic Ocean near Alexander Bay. The Klip River catchment incorporates the southern part of Johannesburg, one of the most developed urban complexes in Africa. This river is seen as one of the most heavily impacted river systems in South Africa and is subjected to almost every conceivable type of pollution (DWAF, 1999). Two of its major tributaries, the Klipspruit and Rietspruit, are also considered to be highly impacted rivers. The Klip River must, however, still serve all recognised user groups as identified by the Department of Water Affairs and Forestry (*i.e.* domestic, agricultural, industrial and recreation).

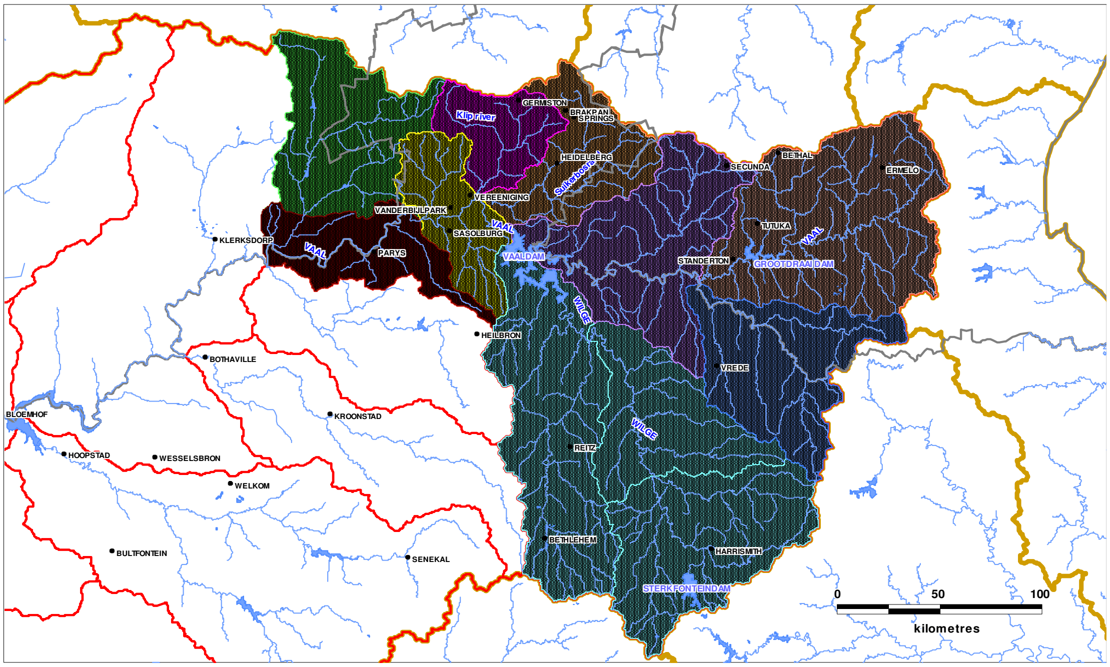

Figure 2-11: Regional drainage map – Upper Vaal Water Management Area.

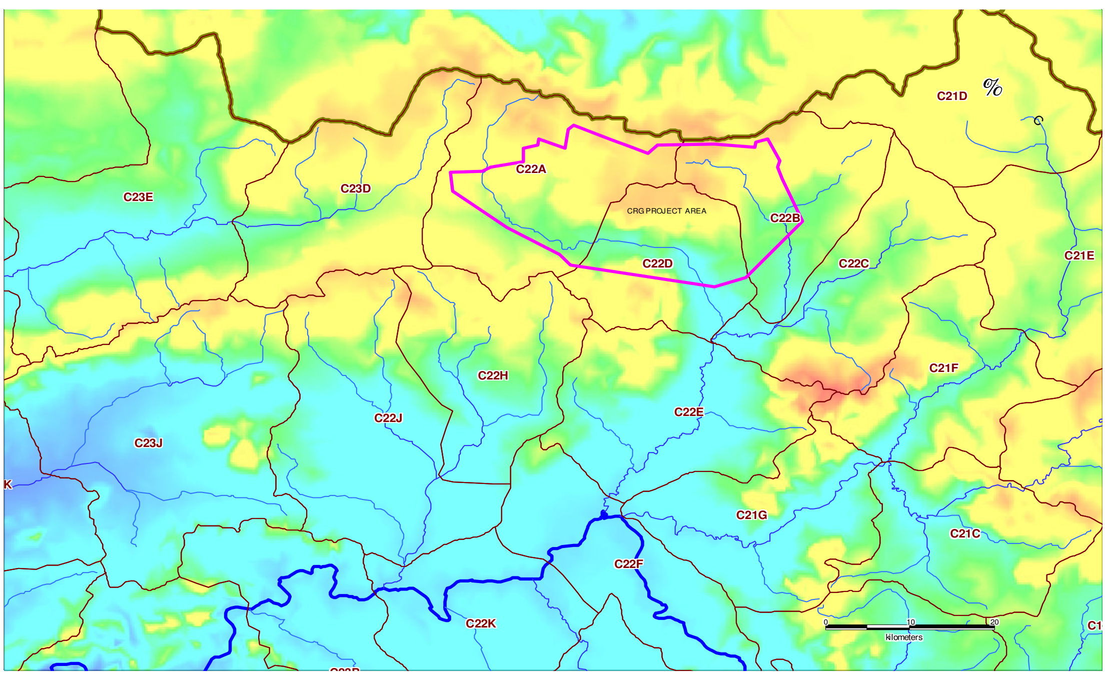

Figure 2-12: Regional drainage map for the Central Rand.

The Klip River (Figure 2-14) originates in the Witwatersrand range of hills, which runs across the Witwatersrand urban complex in an east-west alignment (Krugersdorp to Springs). This ridge also forms the drainage border between the larger Vaal River Catchment (to the south) and the Crocodile River catchment (to the north). The altitude of the study area ranged from approximately 1,780 mamsl, to 1,420 mamsl at the confluence with the Vaal River.

The natural topography of the upper catchment is largely modified by mine dumps. Steep rocky ridges are found in the upper Klip River catchment. The Klipriviersberg, the Gatsrand and a range of hills to the north of Ennerdale and Walkerville are prominent topographic features in this upper segment. The Suikerbosrand range of hills (highest in Gauteng) form the watershed divide between the Rietspruit (major tributary of the Klip River) and the Suikerbosrand River catchment in the south east of the area. Topographically, the lower Klip River area is fairly featureless as the flood plain widens and as the catchment area narrows towards the confluence with the Vaal River.

The uppermost reach of the Klip River (first 10 kilometres running southwards) has a steep gradient of more than 9 m/km. Thereafter, the gradient flattens continuously after the river's eastward turn (4.5 m/km), and the gradient is especially low (<2 m/km) in the lower section of the river (from Rietspruit confluence). The natural mean annual runoff (MAR) of the Klip River catchment is estimated to be in the vicinity of 111 x 106 m^3/annum (Scott, 1995). The average returns are in excess of 200 x 106 m^3/annum, showing how dominant effluent return flows are in the catchment. Although more water is generally seen as a good thing, there are various negative connections to this increased amount of water being transported to the Klip River. The most important being reduced water quality, and reduction in natural habitats for biota, increased bank erosion and lack of naturally occurring floods as stimuli for fish migration. On the positive side, the return flow ensures the river to be perennial, permitting year round recreational activities, irrigation and also provides a permanent source of water for wildlife (DWAF, 1999).

The urban areas cover approximately 20% of the surface area in the catchment. The paved surfaces of urban areas cause an increase in surface run-off during the wet summer months and a decrease in sub-surface flow during the winter months (Scott 1995). Dams and impoundments occurring in the catchment are primarily structures associated with mining (especially in the upper catchment). Only two impoundments occur in the mainstream, namely at Olifantsvlei Waste-water Treatment works (WWTW) and a weir at Henley-on-Klip. The present use of impoundments is predominantly for recreational activities, although the quality of the water is not always within limits for this use.

2.12.1 Surface Water Hydrology

A catchment is defined as all the land from mountain to sea, drained by one river system. The physical, chemical and biological characteristics of any river are determined almost entirely by the nature of the catchment, and activities – anthropogenic and natural- that take place in it (Davies and Day, 1998). Rivers reflect the health or ill-health of the catchment, and it is therefore of cardinal importance to monitor.

Catchment description

Three quaternary catchments are of importance in Johannesburg (C22A, C22B and C22D) falling in the primary catchment, the Upper Vaal Catchment.

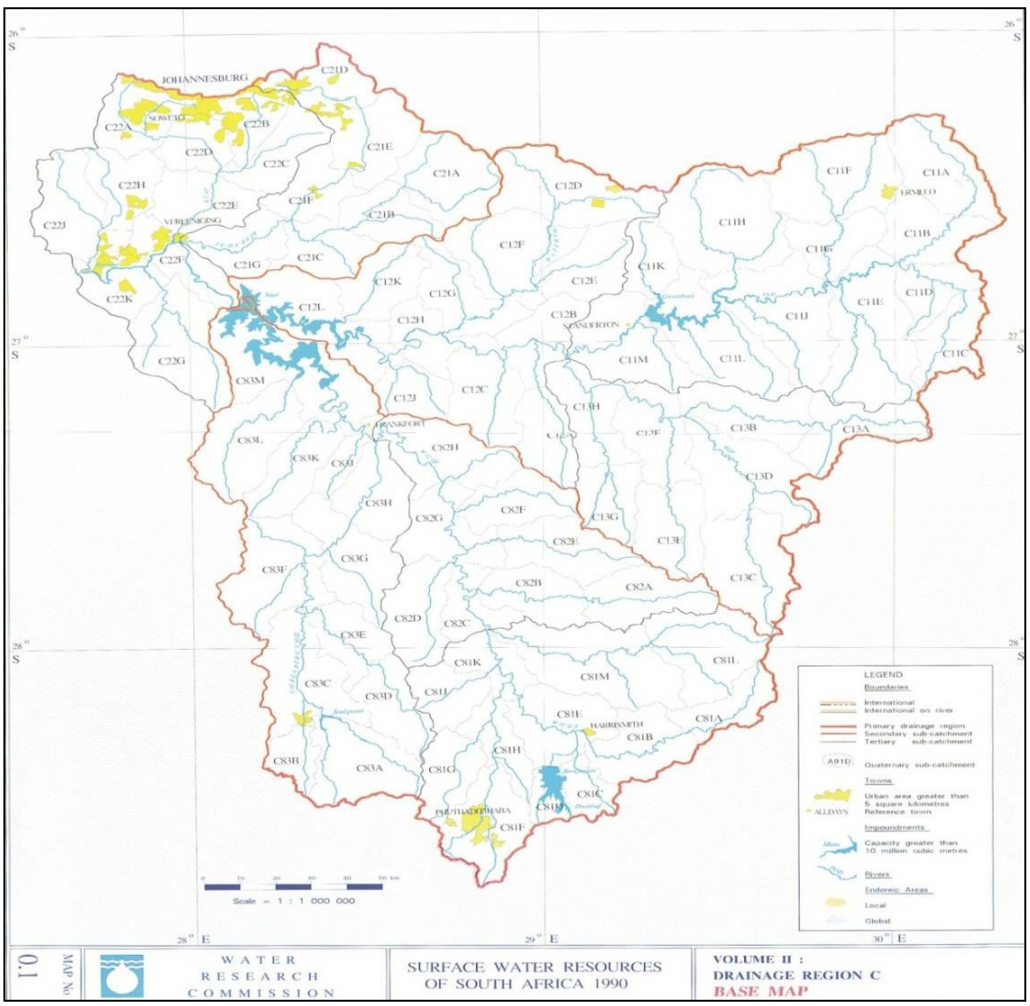

Figure 2-13: Central Rand catchments and receiving water bodies – (Surface Water Resources of South Africa – 1990).

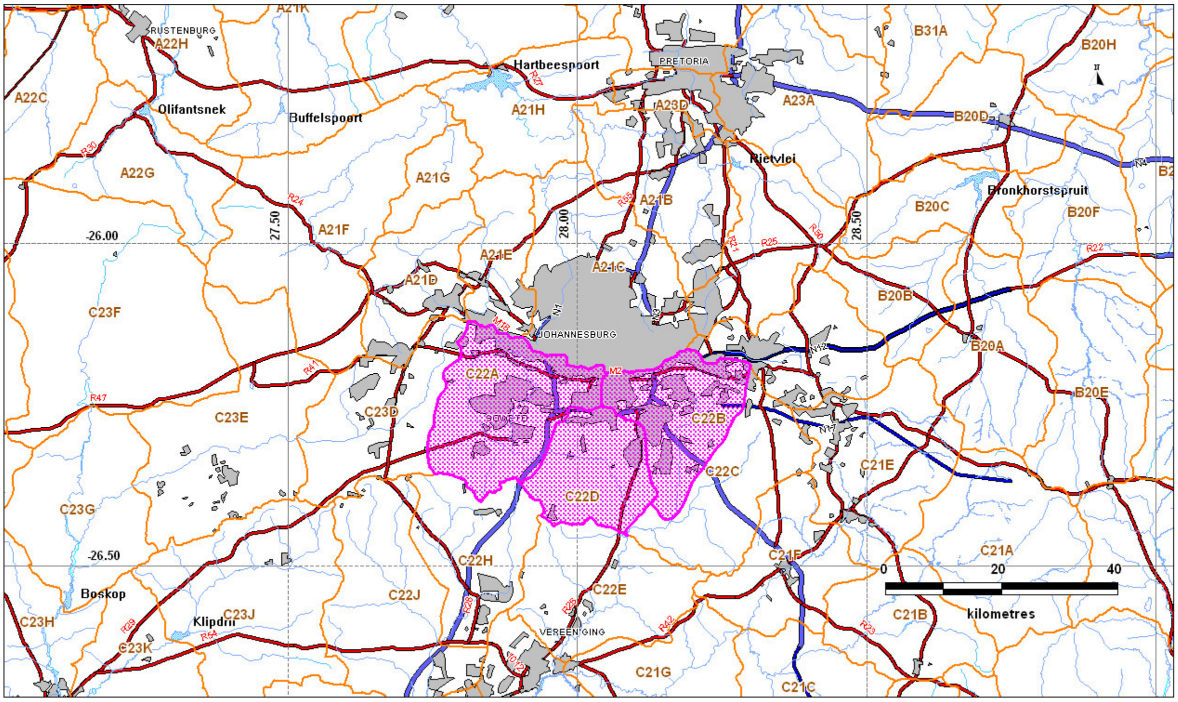

Figure 2-14: Catchment description for the Central Rand

Quaternary Catchment description:

Three quaternary catchments (C22A, C22B and C22D) falling in the primary catchment are considered areas of interest, the Upper Vaal Catchment.

- C22A incorporates the western section of the study area. Covering a total surface area of 455 km^2 of which the CRG-SA site forms approximately 20%. The catchment has a MAP of 694.96 mm/a. The site is located on a south draining side slope, and drains into the Klip River. The Klip River in turn drains into the Vaal River, which flows to the Vaal River near Vereeniging.

- C22B incorporates the eastern section of the study area. Covering a total surface area of 345.8 km^2 of which the Rand Quest site forms approximately 50%. The catchment has a MAP of 700.52 mm/a. The Elsburgspruit lies in the north east section of the catchment and drains into the Natalspruit after approximately 11.2 km. The site is located on a northern draining side slope, and drains into an unnamed tributary of the Natalspruit approximately 1.9 km before its confluence with the Elsburgspruit. The Natalspruit in turn flows into the Rietspruit which joins the Klip River approximately 9km downstream.

- C22D incorporates the central section of the study area. Covering a total surface area of 455 km^2 of which the Rand Quest site forms approximately 20%. The catchment has a MAP of 694.96 mm/a. The site is located on a south draining side slope, and drains into the easterly flowing Klip River. The Klip River in turn drains into the Vaal River. The study area includes the Kliprivierberg Nature Reserve.

2.13 General Description of catchment

There are six quaternary catchments in the Vaal catchment which drain south towards the Vaal Dam. These include the Upper, Middle and Lower Blesbokspruit, Rietspruit, Natalspruit and Klip River catchments. Brief descriptions of the relevant sub-catchments of the watercourses and their primary contributions are provided in Table 2-5 below. Urbanisation has altered the flow regime of all rivers and streams in the area and as such, the current flow patterns bear little resemblance to the pre-developed flow regime.

Table 2-5: Description of watercourses in the within the Study Area Catchments

RIVER	SOURCE AND DESCRIPTION	PRIMARY CONTRIBUTIONS
Klip River	City of Johannesburg; flows south-easterly across the south west corner to be joined by the Rietspruit and flows towards the Vaal River.	Runoff from urban and industrial areas, sewage effluent and some localised agricultural inflows during rainfall events.
Rietspruit	A tributary of the Klip river, source in the upper areas just south of Benoni; flows south-westerly to join the Rietspruit	Runoff from urban and industrial areas, sewage effluent and some localised agricultural inflows during rainfall events.
Natalspruit	Upper areas of Alberton; flows south easterly to join Elsburgspruit which has its source in Germiston and Boksburg.	Runoff from urban and industrial areas, sewage effluent and some localised agricultural inflows during rainfall events.

2.14 Surface Water User Survey

2.14.1 Domestic users

Rand Water supplies most domestic water users in the Klip River catchment with potable water. They are responsible for providing drinking water to more than ten million people in Gauteng and its surrounding areas. In the lower Klip River catchment, a few individuals and small communities are reliant on the extraction of ground water via boreholes. In the west of the upper Klip River catchment, Rand Water also extracts ground water from the Zuurbekom underground water compartment for domestic use. Otherwise, the urban use of borehole water is mainly limited to watering of gardens. Generally, Rand Water supplies potable water to a local authority which then distributes that water to end users. Rand Water is, however, increasingly supplying water to previously unserved end users, especially those living in informal settlements. Their area of supply stretches much further than just the Klip River catchment, and goes as far as Rustenburg, Pretoria, Bethal and Heilbron. Present and future growth in the large area covered will cause increased water demands and therefore also increase the pressure on Rand Water to meet these demands (DWAF, 1999).

In especially the informal settlements of the Klip River catchment, water is used directly from the river for domestic purposes (drinking, washing clothes, *etc.*). One can expect this user group to be increasing as the number and extent of informal settlements in the catchment increases. These informal areas are generally supplied with potable water in tankers or stand pipes. Experience and community knowledge of the potential health risk associated with drinking water from the Klip River seems to be relatively good and has prevented widespread use of the water for drinking purpose. If their needs are, however, not met and their education not satisfactory, one can expect the direct use of water from the river to increase. Poor water quality in the river can therefore severely impact domestic users if not monitored and kept within limits.

2.14.2 Industrial users

Similar to the case with domestic water users, industrial water users in the Klip River catchment are supplied with water by Rand Water, either directly or via local authorities. A few industrial users abstract water directly from the river system (Hippo Quarries in upper Klip River), make use of ground water (Glen Douglas Dolomite

Mine in lower Klip River), or use purified sewage effluent. A number of industries (*e.g.* Nampak and Everite in the upper Klip River) used to abstract river water in the past for their industrial processes, but now also rely on Rand Water for water supplies. In general, the direct use of river water for industrial use has declined over the past few years due to declining water quality and the increased accessibility to potable water (DWAF, 1999).

2.14.3 Agricultural users

Crop irrigation and livestock watering are the main agricultural users of water in the Klip River catchment. It is confined to the rural and peri-urban areas between Johannesburg and Vereeniging. Surveys conducted by the Department of Water Affairs and Forestry (DWAF) revealed that approximately 4 400 *ha* of land could potentially be irrigated in the catchment (DWAF, 1999). It is furthermore estimated that the actively irrigated land is presently consuming just over 11 000 000 m^3/annum. The main irrigated crops grown in the Klip River catchment are maize, fodder crops, vegetables (especially carrots, spinach, cabbage, onions, potatoes and salad greens), instant lawn, nursery plants and private gardens. Livestock watering for dairy and beef cattle, sheep and pigs is also undertaken using river water. The irrigation of crops in the catchment plays an important role in the economy of the area and constitutes part of the market gardening belt surrounding and supplying Johannesburg. Treated sewage effluent from Johannesburg's southern wastewater treatment works is used to irrigate crops and also for livestock watering in the upper Klip River, while East Rand Water Care Company (ERWAT) irrigates land in the area of the Klip River-Rietspruit confluence with sewage sludge.

2.14.4 Recreational users

Various recreational activities commonly take place in the Klip River catchment. These include non-contact, intermediate contact and full contact recreation such as riparian home ownership, picnicking, fishing, bird watching, nature walks, boating/canoeing, swimming, windsurfing and water-skiing. Most of these activities occur mainly in impoundments in the urban areas, but is also often observed in the Klip River itself.

The Vaal Barrage into which the Klip River flows is also a key recreational area both for permanent residents and weekend visitors, with full contact activities being common. The number of people regularly using the Vaal Barrage as a recreational facility heightens any risk associated with poor water quality. These activities are of significant economic value to the area, generating income that could be jeopardised by significant changes in water quality.

A number of small holiday resorts are situated on the banks of the middle Klip River. Additionally, existing and proposed hotels, riparian homes and commercial centres throughout the Klip River catchment, view the proximity to a water resource as being of economic and aesthetic importance. In particular, the Henley-on-Klip community in the lower Klip River is very active in promoting and protecting the Klip River as a recreational resource. Although not strictly identified as recreational activities, certain cultural practices of town ownership dwellers also rely on the Klip River system. These include church baptisms and the use of river water in traditional medicine.

2.15 Indicators of pollution and Ecological status of water sources

The River Health Programme (RHP) monitors the ecological status of rivers in Gauteng. Information obtained from biological indices (habitat integrity, aquatic invertebrates, fish population and riparian vegetation) is used to assess the health of river systems. Table 2-6 summarizes the ecological status of rivers in the south of Gauteng. No rivers remain in their natural state, although the habitat and riparian vegetation remain largely intact in the Upper Klip River (near Soweto) and Middle Blesbokspruit respectively (Ferret, 2008). Aquatic biota and water quality are generally in poor to fair condition. In comparison to status of other provincial rivers, for example the Crocodile, Sabie-Sand, Olifants and the Free State River Systems (River Health Programme 2003, 2001A and 2001B) the ecological status of the rivers in Gauteng is generally fair to poor.

It is thought that rivers in the north of Gauteng are of a similar ecological state to those in the south, with the exception of Skeerpoort River. This river has its source in dolomitic cave systems and is still relatively pristine except for the exotic riverine vegetation that occurs downstream.

Table 2-6: The ecological status of southern Gauteng rivers (River Health Programme, 2003)

River Health Indicator	Upper Klip	Natal-Spruit	Lower Klip	Suiker-Bosrand	Rietspruit	Upper Blesbokspruit	Mid Blesbokspruit	Lower Blesbokspruit
Habitat	Good	Fair	Fair	Fair	Poor	Poor	Fair	Fair

Aquatic Invertebrates	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Fair
Fish Populations	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Riperian Vegetation	Fair	Fair	Poor	Poor	Not determined	Poor	Good	Poor

River Health Indicators	
Habitat:	In stream availability and habitat diversity
Aquatic Invertebrates	A variety of organisms (snails, insect larvae, crabs & worms) requires specific habitat types and water quality for part of their life cycle
Fish Populations	Fish are good indicators of the longer term influences on a river reach and general habitat conditions
Riperian Vegetation	Healthy riverbanks maintain the form of the river channel, provide habitat for species (aquatic and terrestrial) and filter sediment minerals and light
River Health Category	
Natural	No negligible modification of habitat and biota
Good	Some human-related impact; biodiversity largely intact
Fair	Significant pressure from development and land use; sensitive species may be lost
Poor	Natural functioning disrupted; extensive use of river ecosystem
Source: River Health Programme, 2003	

Surface water quality in Gauteng is generally marginal to poor with the exception of microbiological contamination. No obvious temporal change can be seen. There is no clear indication, based on the available data, of any significant impact on the groundwater quality. The temporal trend in the groundwater quality is unknown.

CHAPTER 3. METHODOLOGY

Eight water quality monitoring sites in the study area/catchment were chosen for monitoring the cumulative surface water impacts. Three of the eight water quality monitoring sites served as controls (SW01, SW04 and SW07) for various activities that could affect water quality. These sites were chosen upstream of any sources of pollution, however due to the monitored river systems being historically polluted the controls sites displayed poor water quality. Samples were taken monthly over a 6 month period. The sampling dates were at the end of each month. No more than one grouping of samples and one replicate was sent for analysis each month; due to the budget constraints.

3.0 Sampling materials and procedures

The following equipment was utilized for sample collection:

- Field sheets and sample labels
- Flow meter
- Cooler box with ice packs
- Powder less sterile gloves
- At each sampling point the following sample bottles were utilized:

  a) 1 X 500 ml sterile glass bottles cooled at 4 ℃ for faecal coliforms.

  b) 2 X 100 ml plastic bottles preserved to pH < 2 with nitric acid (1ml at 40%) for metals.

  c) 2 X 500 ml plastic bottles preserved pH >12 with sodium hydroxide cooled at 4 ℃ for pH, electrical conductivity, total dissolved solids, alkalinity, chlorine, fluorine, nitrite, nitrate, sulphate, ammonia and total cyanide

At each sampling point a field sheet was completed. The field sheets contained the following information:

- Name and location of sampling point
- Date and time of sample location

- Any relevant descriptive information, e.g. water level/flow, ambient conditions
- Sample appearance at time of collection, e.g. colour, clarity and odour
- Results of any on site analysis (dissolved oxygen, conductivity, temperature, pH)
- Sample treatment post collection

Samples were taken from the shore or by wading using the sample bottles described above. The researcher and/or assistant stood perpendicular to the flow facing upstream and completely submerged the sampling bottle into the stream. In order to prevent any unnecessary contamination during sampling gloves were worn at all times and sample bottle caps were kept closed to ensure that samples are not further contaminated.

Immediately after the water sample was taken a flow measurement was taken at the same point and immediately recorded. Samples were submitted for the analysis of feacal coliforms, pH, electrical conductivity, total dissolved solids, alkalinity, chlorine, fluorine, nitrite, nitrate, sulphate, ammonia and total cyanide and stored in a cooler box with ice packs immediately once collected. The cooler boxers were securely strapped into the back of the field vehicle to ensure no breakages or spillages occur during transportation to the laboratory. All samples were taken to the laboratory for analysis on the same day of sampling to ensure the integrity of the sample.

Kilian (1997), stated that water samples must be analysed immediately or stored in a container with a preservative (where applicable) e.g. to maintain integrity of the sample. Complete preservation is a practical impossibility. Regardless of the nature of the sample, complete stability for every constituent can never be achieved.

3.1 Sample analysis

The laboratory analysis for the chemical and biological parameters was conducted by an accredited South African laboratory (SGS Pty (Ltd) Johannesburg). Due to financial constraint and the high number of samples to be analysed, one composite sample of each analysis was analyzed by the laboratory. The physical parameters (dissolved oxygen, TDS, pH, EC, temperature) were measured in situ utilizing probes that are attached to monitor units. Below is the summary of the method of analysis utilized;

3.1.1 Physical Parameter analyses

a) Dissolved oxygen

Dissolved Oxygen was measured in situ using a field oxygen meter (InsiteIG Model 3100, Insite instrumentation group, USA).

b) pH

pH of the water samples was measured in situ using a pH meter (AZ8601 Portable pH meter, A.W.R. Smith Process instrumentation, South Africa)

c) Electrical Conductivity & TDS determination

There is a close relationship between TDS and Electrical Conductivity. Total Dissolved Solids (TDS) and Electrical Conductivity (EC) are two separate parameters. TDS, is defined as the combined total solids dissolved in water. EC is the ability of something to conduct electricity (in this case, water's ability to conduct electricity). TDS levels can be estimated based on the conductivity of the water since the hydrogen and oxygen molecules of the H_2O carry almost no electrical charge. The EC of most other metals, minerals and salts will carry a charge.TDS and EC were measured in situ using a field electrical conductivity meter (AZ8306 conductivity meter, A.W.R. Smith Process instrumentation, South Africa) which measures the EC level and then converts it to a TDS measurement.

d) Water velocity and depth

The Global Water Flow probe (FP111, AMS Haden, South Africa) was used to determine the water velocity. The water velocity probe consists of water turbo prop positive displacement sensor coupled with an expendable probe ending in a digital readout display. The Flow probe uses true velocity averaging. One reading is taken per second and a continuous average is displayed, once the average reading becomes steady, the true average velocity in m/s of the stream is obtained.

The Flow Probe is coupled with a depth measure. The depth will be taken to determine the cross sectional area of the river or stream so that flow can be determined.

e) Cross-sectional area and Flow

The cross-sectional area is determined as follows:

1) The width of the water body was determined using a tape measure.
2) The depth was taken at 1 meter intervals from the shore until the opposite shore is reached.
3) The depth vs the width intervals was plotted on a graph and the area under the curve obtained is the cross-sectional area in square meters (m^2).

River Flow:

The average velocity (V) multiplied by the cross-sectional area (A) provides the river flow (Q) in m^3/s.

$Q = V \times A$

3.1.2 Faecal coliforms

Faecal coliform are bacteria whose normal habitat is the intestinal tract of warm blooded animals and are able to grow at 44.5℃. The membrane filtration method was used to assess the amount of faecal coliforms per sample.
The membrane filtration method enumerates viable faecal coliform capable of growth on designated media, m-FC agar, at high temperatures.
The m-Fc agar contains peptone and yeast extracts as a nutritious source and bile salts to inhibit gram positive flora. Faecal coliform ferments lactose at high temperatures to form blue colonies on medium whereas non-faecal coliforms flora appears in grey colonies.

A specific amount (20 and 50 ml) of sample was filtered through a sterile membrane filter paper. The filter paper was placed onto medium under sterile conditions. Aerobically incubated onto m-FC media plates at 44.5℃ ± 1℃ for 24 ± 3 hours.

Calculations of the number of faecal coliform per 100 ml of sample from the number of characteristic colonies obtained in the plates chosen.

3.1.3 Metals determination by ICP-OES

Dissolved metals were determined on aqueous samples, by passing the sample through a 0.45µm pore size filter. The samples were then immediately acidified using concentrated HNO_3.

Total recoverable elements were determined on aqueous samples, which have been preserved with HNO_3, by digesting the sample with HNO_3. This sample was not filtered. The digestion process reduces interferences by organic matter and converts metals associated with particulates to the free metal form.

Samples prepared by these methods were analyzed by ICP-OES.

The samples were analyzed as prepared and/or diluted to fall within the linear range of the instrument calibration. The samples were analyzed against 2% HNO_3 standardization materials. The samples and quality control materials were aspirated into the plasma via nebulization, where they are desolvated, atomized and excited. The excited particles revert to a lower energy state, whereby the absorbed energy is released by the emission of photons. The wavelengths of the emitted light are characteristic for a particular element. Each element has several excited states, so an element will emit light at various wavelengths and different intensities, creating a line spectrum. The intensity of light at a given wavelength is measured by a detector. The measurement of the intensity signal is converted to concentration units via a host computer. Table 3-1shows the methods and limits for the analysis.[3]

Table 3-1: Test details

Parameter	Method	Limit (mg/L)	Parameter	Method	Limit (mg/L)
pH	Electrometric	-	Aluminium	ICP-OES	0.08
EC	Electrometric	1 mS/m	Gold	ICP-OES	0.02
TDS	Electrometric	20	Calcium	ICP-OES	0.05
Alkalinity	Titrimetric	10	Cobalt	ICP-OES	0.12
Chlorine	Chromatographic	5	Iron	ICP-OES	0.02
Nitrite	Chromatographic	0.5	Potassium	ICP-OES	0.11
Ammonium	Colorimetric	0.1	Magnesium	ICP-OES	0.02
Total Cyanide	Distillation, colorimetric	0.25	Manganese	ICP-OES	0.01
WAD Cyanide	Distillation, colorimetric	0.25	Sodium	ICP-OES	0.1
			Nickel	ICP-OES	0.05

[3] Table 3-1 provided by SGS South Africa (Pty) Ltd

			Sulphur	ICP-OES	0.6
			Uranium	ICP-OES	0.1
			Total hardness	Calculation	0.25
			Calcium hardness	Calculation	0.2

3.2 Regression analysis

The regression analysis was used to assess the relationship between the flow and pollution of the river system. The dependant variable (*y*) selected for the purpose of the study was the determined water parameter concentration and was compared with the independent variable (*x*) which was river flow.

The objective of the regression analysis was to attain the relationships between two sets of data and to explain the variation of the water quality parameter concentration in the water quality analysis in relationship to river flow. More specifically, regression analysis enables the researcher to understand how the typical value of the dependant variable changes when any one of the independent variables is varied, while the other independent variables are fixed. Taylor (1977), states that there are three aspects generated by a regression analysis that are determinant of relationships between two sets of data. They are as follows:

1. Correlation coefficient
2. Coefficient of determination
3. Regression coefficient

All three parameters were used in the regression analysis and subsequently assisted in determining if any correlations exist.

3.2.1 Correlation coefficient

The correlation coefficient (*r*) is an important indicator of strength of a linear relationship. The value of *r* can vary between -1 and +1, where *r* = 1 indicates that an increase in *x* is associated with an increase in *y*, *r* = -1 indicates that an increase in *x* is associated with a corresponding decrease in *y,* and *r* = 0 indicates the absence of a predictive relationship (that is knowledge of the *x* value gives no predictive information about *y*).

3.2.2 Regression coefficient

The regression coefficient measures the amount of change in *y* per unit *x*. The regression coefficient is the gradient of the regression line.

3.2.3 Coefficient of determination

This is the square of the correlation coefficient and is known as r^2. It measures the proportion of variability in one variable that can be accounted for, determined from predicted or explained by variability in the second variable.

CHAPTER 4. RESULTS

The water quality analysis for each sample point was tabulated. All parameters that exhibited non-compliance with the Instream Water Quality Guidelines for the Klip River catchment as well as the TWQR outlined by DWA and the RAW water quality guidelines outlined by Steynberg *et al* (1996), were plotted in graphs in order to interpret and assess major areas of non-compliance. Table 4- 1 shows the compliance indices utilised in the study, all parameters not demarcated by a footnote in table were obtained from the Instream Water Quality Guidelines for the Klip River catchment.

Table 4-1: Compliance indices utilized in the study*

Variables	Unit	Ideal Catchment Background	Acceptable Management Target	Tolerable Interim Target	Unacceptable
Physical					
Conductivity	mS/m	<80	80-100	100-150	>150
Dissolved Oxygen (O_2)	mg/l O_2		>6.0	5.0 - 6.0	<5.0
pH	pH units	6.0 - 9.0			<6.0; >9.0
Suspended Solids	mg/l	<20	20 – 30	30 - 55	>55
Organic					
Chemical Oxygen Demand (COD)	mg/l	<15	15 – 30	30 - 40	>40
Macro Elements					
Aluminium (Al)	mg/l		<0.3	0.3 – 0.5	>0.5
Ammonia (NH_4)	mg/l	<0.5	0.5 – 1.5	1.5 – 4.0	>4.0
Chloride (Cl)	mg/l	<50	50 – 75	75 - 100	>100
Fluoride (F)	mg/l	<0.19	0.19 – 0.7	0.7 – 1.0	>1.0
Iron (Fe)	mg/l	<0.5	0.5 – 1.0	1.0 – 1.5	>1.5
Magnesium (Mg)	mg/l	<8.0	8.0 – 30.0	30.0 – 70.0	>70.0
Manganese (Mn)	mg/l	<1.0	1.0 – 2.0	2.0 – 4.0	>4.0
Nitrate (NO_3)	mg/l	<2.0	2.0 – 4.0	4.0 – 7.0	>7.0
Phosphate (PO_4)	mg/l	<0.2	0.2 – 0.5	0.5 – 1.0	>1.0
Sodium (Na)	mg/l	<50	50 – 80	80 - 100	>100
Sulphate (SO_4) [4]	mg/l	<200	200 – 350	350 - 500	>500
Calcium (Ca) [2]	mg/l	<150			>150
Cobalt (Co) [2]	mg/l	<0.25			>0.25
Nickel (Ni) [2]	mg/l	<0.1			>0.1
Total alkalinity[2]	mg/l	20			<20
Dissolved Oxygen (DO)[5]	mg/l	80-120			<80
Potassium (K) [6]	mg/l	2-5			>5
Uranium (U) [4]	mg/l	0.07-0.2			>0.2
Bacteriological					
Faecal coliforms	Counts/100ml	<1,000	1,000 – 5,000	5,000 – 10,000	>10,000
Biological					
Daphnia	% Survival	>95.0	95.0 – 90.0	90.0 – 80.0	<80.0

*No footnote indicates Kilp River Instream Guideline

[4] Steynberg *et al.* (1996)
[5] South African Water Quality Guidelines Volume 8: Field Guide, DWAF (1996)
[6] South African Water Quality Guidelines Volume 1: Domestic Use, DWAF (1996)

4.0 Results overview

A typical trend noticed throughout the sampling period was the non-compliance with the levels of total dissolved solids (TDS) and dissolved oxygen, the TDS values can be attributed to erosion of material into the water course. The control point on the Bosmontspruit (SW01) exceeded the set guideline in terms of faecal coliforms. Levels ranged from $7.0X10^4$ CFU/100ml to $1.0x10^6$ CFU /100ml during the monitoring period, potassium levels also exceeded the guideline of 5 mg/l. The faecal coliform levels noted in the Bosmontspruit are characteristic of a raw sewerage discharge and this will require further investigation. Monitoring points on the Bosmontspruit (SW02 and SW03) in the vicinity of mine sites and tailings facilities were above the permissible levels with respect to aluminium and iron which are mineral constituents of silicate and pyrite bearing ore. The Russell's Stream control (SW04) and the in stream monitoring point (SW05) indicated pH levels below 6 and exceeded the guidelines in terms of nickel and iron levels, both these metals are typical constituents of mine tailings. The low pH readings indicated low alkalinity levels and increased acidity in the stream. The final mixing point of the above streams is the New Canada Dam (SW08), which consistently exceeded the guidelines with regards to ammonia and iron levels, with the exception of iron levels. The results indicate that metal levels of iron, aluminium, nickel, manganese and potassium were elevated across the Bosmontspruit and Russell's stream. During sampling visual observations indicated that there was significant evidence of raw sewerage being discharged in the Bosmontspruit resulting in excessive faecal coliform levels as well as ammonia and nitrate level. During the monitoring period it was noted that water from these streams were utilised for crop irrigation, bathing, livestock and human consumption and may thus pose a health hazard due to poor quality. Table 4-1 details the compliance indices utilised in the study. Parameters highlighted in red as shown in table 4-1 indicate non-compliance with the TWQR[7]. The uses of the term N/A in the tables of results (appendix 1 to 8) indicate months where no samples for that parameter were taken due to the unavailability of the measuring instruments. Appendix 1 shows all the raw data and statistical analysis conducted during the course of the study.

[7] Units in compliance tables are milligram/litre unless otherwise stated.

4.1 SW01-Upstream Control Bosmontspruit

This sampling point was located in the suburb of Bosmont and served as an upstream control reading for the Bosmontspruit as described in table 2-2. A typical trend noticed throughout the sample analysis was the high levels of total dissolved solids ranging above 157 to 500 mg/l and the low levels of dissolved oxygen (ranging from 16.9 to 59.20%) throughout the sampling period. None of the samples complied with the TWQR guidelines with regards to TDS and DO. SW01 displayed high levels of faecal coliforms in October (1.0×10^6 CFU/100ml), January (7.0×10^4 CFU/100ml) and February (4.5×10^4 CFU/100ml). Non-compliance in the levels of nitrates was noted in January with concentrations at15 mg/l and 17mg/l in March. The potassium levels were above the recommended level of 5mg/l. The water flow during the period showed little variance and the high levels of pollution in the stream resulted in restrictions to the water flow. These restrictions occurred as a result of debris that was dumped or washed into the water course. It should be noted that all metal concentrations are obtained from average values of the results obtained over the monitoring period.

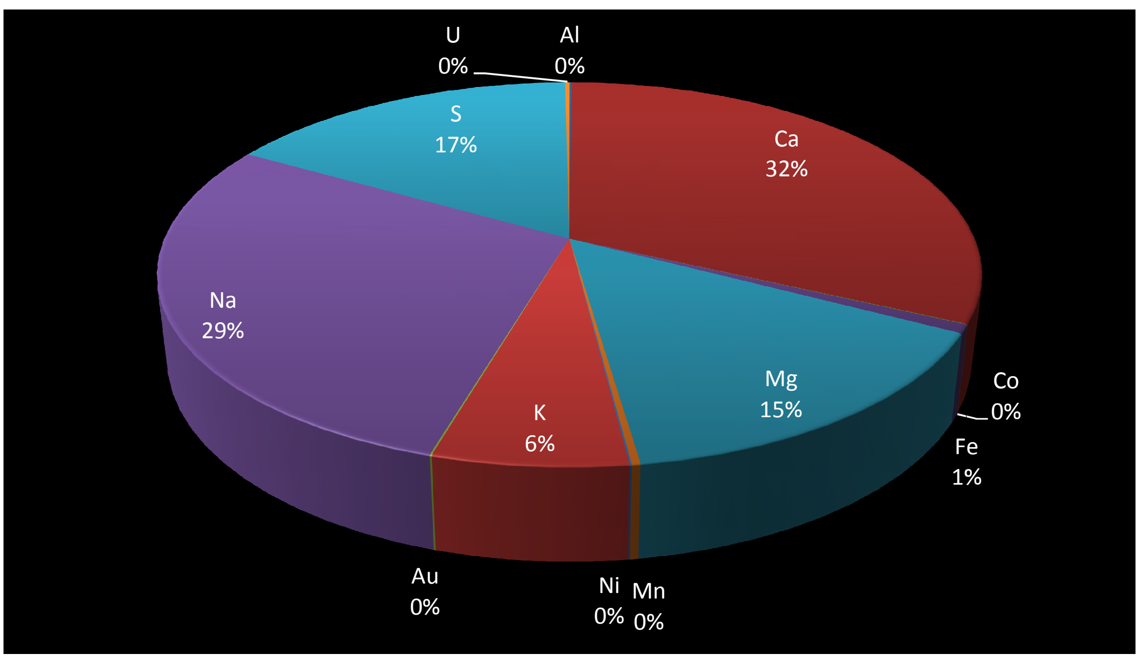

Figure 4-1: Metal concentrations in the water at SW01 from October 2010 to March 2011

A regression analysis was performed against the river flow on all variables that exhibited non-compliance with the TWQR[8]. The correlation coefficient (CC) values were all negative with nitrate exhibiting a low CC value (0.1). This indicates that there is almost no relationship between flow and the selected parameter concentration. The coefficient of determination (COD) values indicates that river flow accounts for only 29% of the variability for TDS concentrations, 1% of the variability in nitrate concentration, 17% of the variability in faecal coliforms, no variability for dissolved oxygen concentration and 9% variability in potassium concentration. The regression coefficient (RC) for TDS was -170.93, indicating that a 170.93 change in TDS per unit river flow occurs. The RC shows that with every unit of river flow the TDS value decreases by 170.93 which is significant as the relationship is inversely proportional. The RC for nitrate at SW01 is calculated at 1.72, indicating a directly proportional relationship between nitrate levels and river flow. There is an increase of 1.72 in nitrate levels per unit river flow. The levels of faecal coliforms, dissolved oxygen and potassium all exhibit inversely proportional relationships to river flow. The most noticeable change in RC is that of faecal coliforms, for every unit of river flow the faecal coliform levels decrease by $4.1x10^4$. Apart from the levels of dissolved oxygen, the RC values indicate that increased river flow will result in a reduction faecal coliform, TDS and potassium levels, the RC value for nitrate indicates that the increased river flow at SW01 may result in increased nitrate levels which indicates high levels of nitrate from an upstream source. However it must be noted that correlation coefficients do not support the above and in order for the regression analysis to be accurate the correlation coefficient values must correspond to the RC values.

4.2 SW02-In the vicinity of active mining on the Bosmontspruit

This sampling point was situated on the Bosmontspruit directly below the Central Rand Gold mine. The levels of metal contaminants determined were significantly increased when compared to SW01. SW02 showed elevated levels of aluminium (ranging from 1.05 mg/l to 5.30 mg/l), the TWQR stipulates that levels greater than 0.5 mg/l are unacceptable for aluminium. Iron levels ranged from 6.85 mg/l to 7.30

[8] Statistical parameter are unit less in all tables

mg/l during the first quarter of the year and this is significantly elevated as the TWQR dictates that levels greater than 1.5mg/l for iron are unacceptable. There was also a marked increase in the nickel (0.17 mg/l) and potassium (8.15mg/l) levels in the March 2011 as compared to the previous months. SW02 and SW01 followed a similar trend in terms of non-compliance with regards to total dissolved solids, nitrate and faecal coliforms, where both samples showed elevated levels of the above parameters. The impacts of mining in the surrounding area and runoff from tailings facilities can be attributed for these results as the metal contaminants increased at SW02 as compared to SW01 and are consistent with pollution from gold mine tailings run off.

The most significant relationship at SW02 is that of dissolved oxygen and river flow. The correlation coefficient (CC) is calculated as 0.8 which tends to 1, this indicates that there is an increase in river flow associated with corresponding increase in dissolved oxygen at SW02. The coefficient of determination values indicate that river flow accounts for 63% of the variability in dissolved oxygen levels which is significant as the faster flowing water increases the mixing of atmospheric oxygen thus resulting in an increase in dissolved oxygen levels. The RC value of 8.96 indicates the directly proportional relationship between river flow and dissolved oxygen and that there is an 8.96 increase in dissolved oxygen levels per unit river flow. No other significant conclusions can be drawn from the regression analysis performed on the data for SW02.

4.3 SW03-Bosmontspruit under Main Reef Road

SW03 was situated where the Bosmontspruit crosses under the Main Reef Road. The sampling point is in close vicinity to a redundant tailings facility and the storm water control dams belonging to Crown Gold Recoveries. As was the case with SW01 and SW02, non-compliance is noted with the levels of TDS (219 to 1398 mg/l through the sample period), nitrate (11.5 mg/l in February and 7.85 mg/l in January when compared with the TWQR of greater than 7mg/l), faecal coliforms (8.3E+04 CFU/100ml in October and $4.4X10^4$ CFU/100ml in February) and dissolved oxygen (ranged from 5.6% to 52% throughout the sample period). During January, there was a significant drop in pH (3.16); this could have been due to an illegal discharge from the storm water pond. At the actual time of sampling SW03 it was noted that a pipe was discharging the storm water into the water course, the discharge is assumed to be illegal as typically all active mine's in the Central Rand are required to operate closed water circuits so as to minimise overall water consumption. From working knowledge obtained from the mining operations in the area, Crown Gold Recoveries returns all the water to their plant on Crownwood Road, hence the discharge was assumed to be illegal. Aluminium (55mg/l), electrical conductivity (173.97 mS/m), cobalt (1.7 mg/l), iron (36 mg/l), manganese (6.75 mg/l), nickel (3.75mg/l) and uranium (0.96mg/l) were all above the TWQR during this month, there was no river flow from November 2010 through to February 2011. The levels of metal contaminants stabilised in February, however aluminium (0.70mg/l) and iron levels still remained elevated (5.65mg/l).

The correlation coefficient values indicate that the most significant relationships existed between faecal coliforms and potassium, and river flow respectively. The faecal coliform correlation coefficient is calculated at 0.87 which indicates that an increase in x is associated with the corresponding increase in y which is the same situation with potassium and river flow, with a CC value of 0.78. The coefficient of determination value indicates that river flow accounts for a 75% of the variability for faecal coliform levels and 61% of the variability for potassium levels. Both RC values for potassium and faecal coliforms indicate directly proportional relationships to river flow. This indicates that an external source introducing the pollutants at SW03 is evident, which was noticed during January when a discharge from a storm water pond was noted. The vicinity of the mining operations and tailings facilities provides pathways for metal pollutants to enter the water course at SW03. The CC values for pH, conductivity and alkalinity tended to 0 which indicates the absence of a predictive relationship between these parameters and river flow.

4.4 Comparative analysis of the water quality for the Bosmontspruit

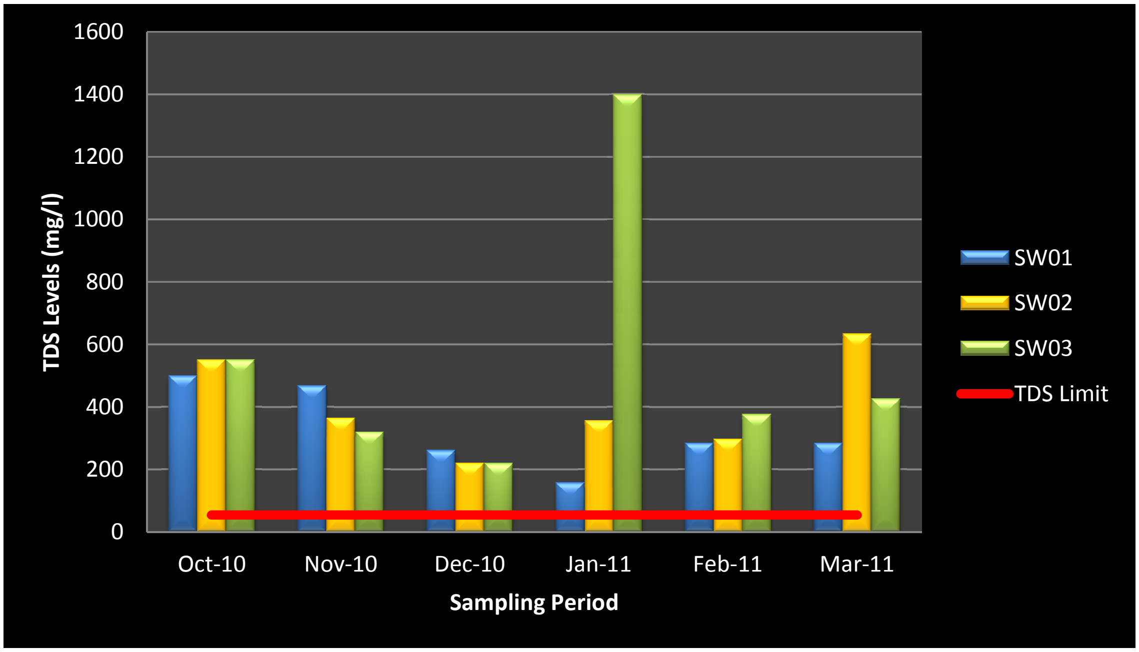

Figure 4-2: TDS levels determined for the different sampling points and time on Bosmontspruit

Figure 4-2 indicates that TDS was always above the TWQR throughout the monitoring period. The elevated levels at SW03 in January coincided with the discharge from the storm water dam belonging to Crown Gold Recoveries. The elevated levels of TDS at SW02 and SW03 are expected due to expected runoff from the mining facilities in the area.

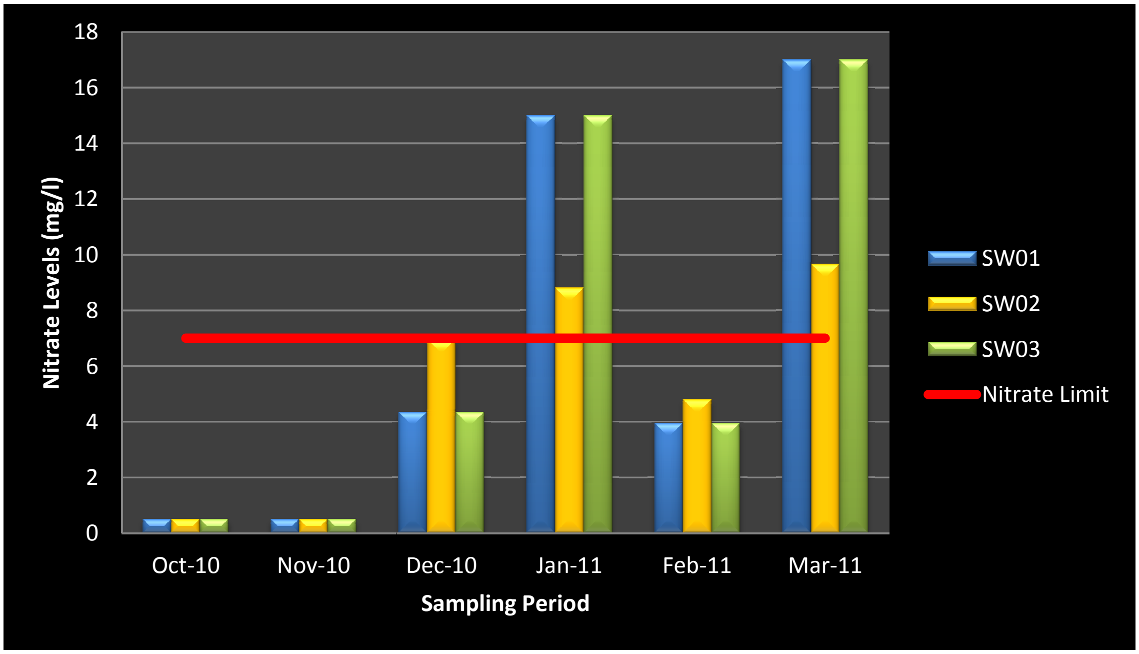

Figure 4-3: Nitrate levels determined for the different sampling points and time on Bosmontspruit

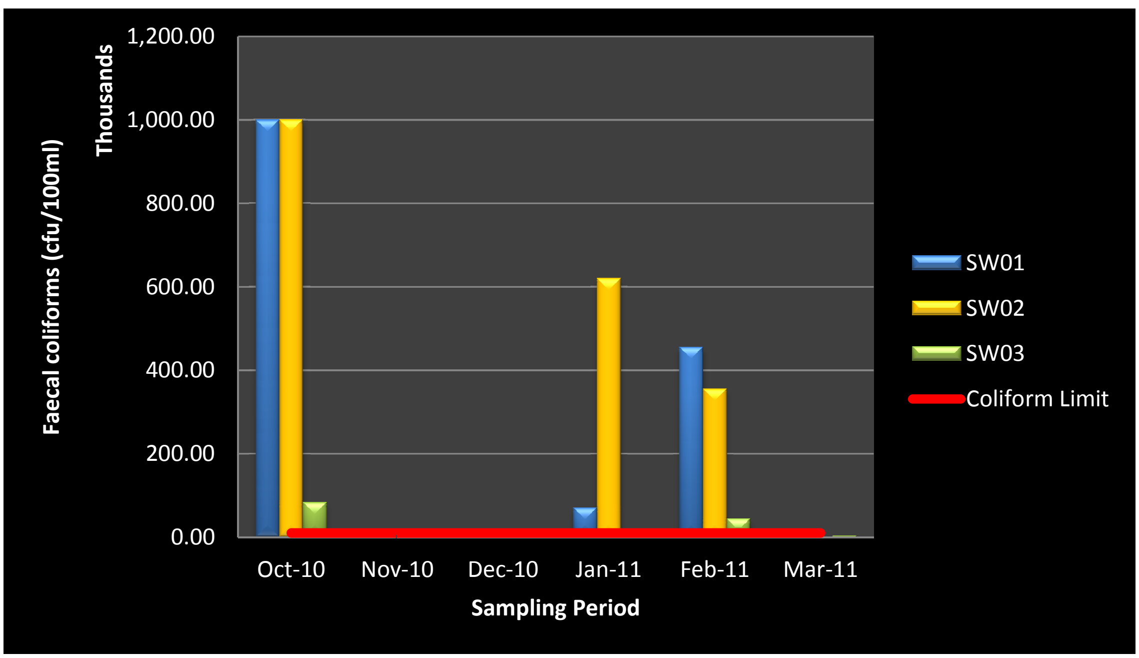

Figure 4-4: Faecal coliform levels determined for the different sampling points and time on Bosmontspruit

Figure 4-3 illustrates the trend in nitrate values obtained on the Bostmontspruit. Levels of nitrate exhibited non-compliance throughout the monitoring period. The levels of faecal coliforms at SW01 and SW02 in October 2010 were very high typical of high faecal input such as from a sewerage discharge. The levels stabilised during November and December but a marked increase was noted during January and February, this could be due to failures in the sewerage system pipes during these months.

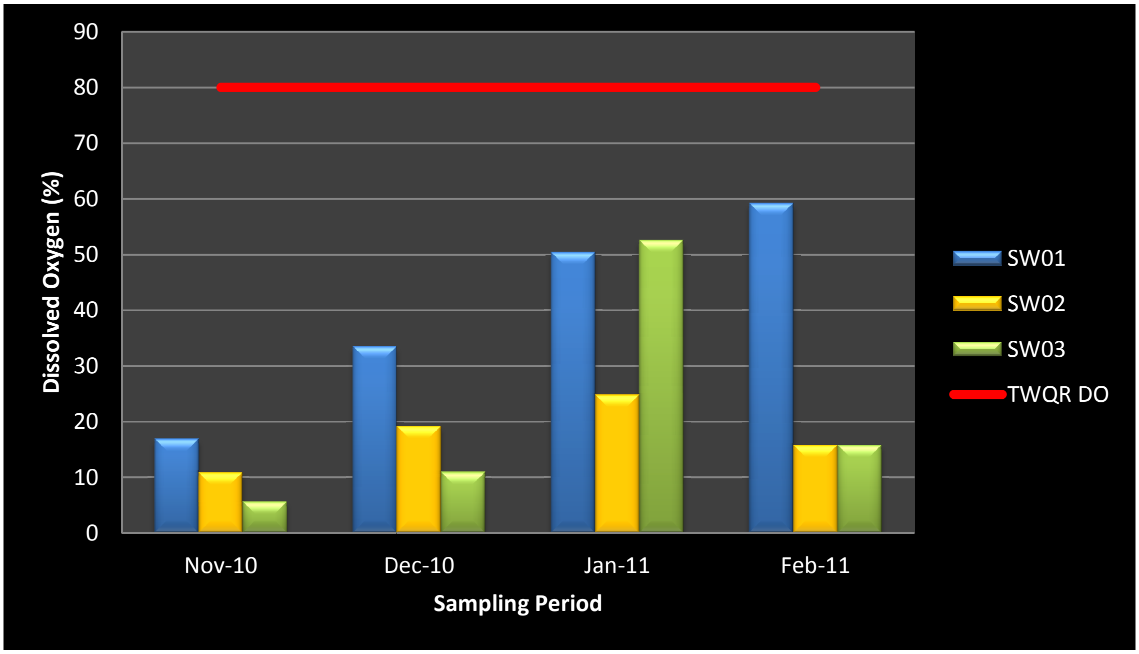

Figure 4-5: Dissolved oxygen levels determined for the different sampling points and time on Bosmontspruit

Figure 4-5 shows the dissolved oxygen levels on the Bosmontspruit, there was a gradual increase in dissolved oxygen levels at SW01and as the control point; SW01 was always higher than SW02 and SW03. SW01 was characterised by slow moving water, however it was noted that the elevated levels of faecal coliforms can be attributed to a suspected raw sewerage at SW01 most likely due to a possible failure in the sewerage system from the Bosmont residential area. During the monitoring period where sewerage entered the water course from the suburb of Bosmont there would likely be increases in flow which will result in an increase in DO. No such instances were noted on the sample collection days but the consistent elevated faecal coliform levels do suggest that this could be likely and from an undetected source.

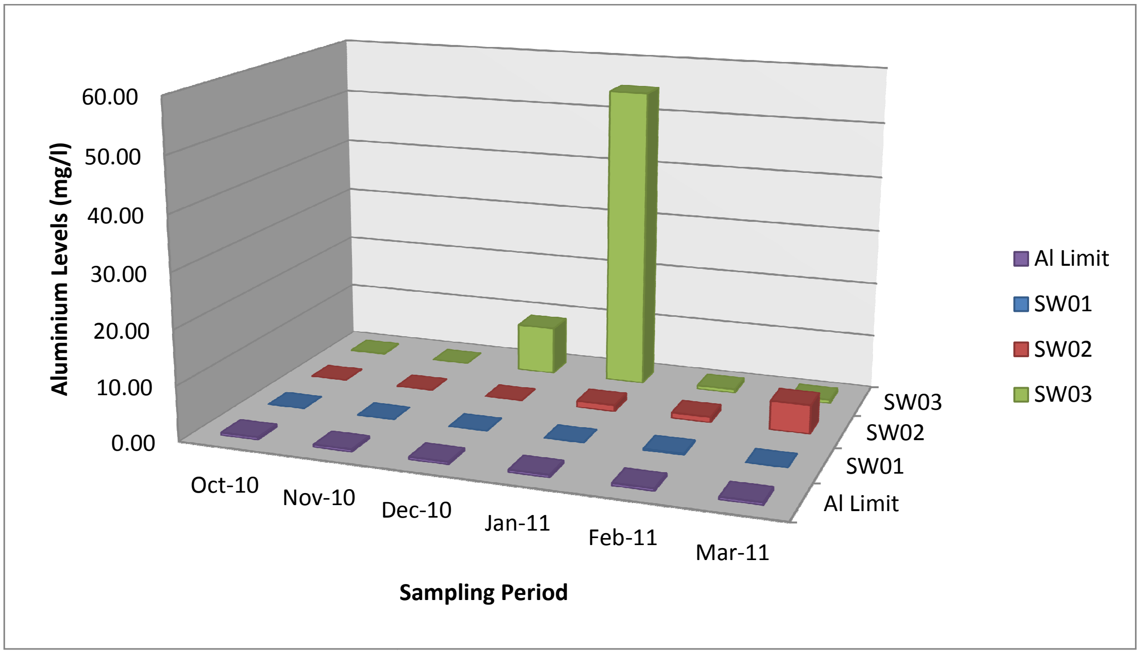

Figure 4-6: Aluminium levels determined for the different sampling points and time on Bosmontspruit

Figure 4-6 shows the trend for aluminium on the Bosmontspruit. A 3-D representation was chosen so as to best depict the results. SW02 exhibited non-compliance with the TWQR from January through to March. This is most likely due to the trace elements of aluminium that can be found in silicates which is characteristic of the material stored at the mine waste rock dumps. During January there was a significant increase in aluminium levels at SW03 and this could have resulted from a discharge from the mine storm water pond. No sample was analysed from the mine pond however it was clear that there was discharge from the pond and probably contained high aluminium levels.

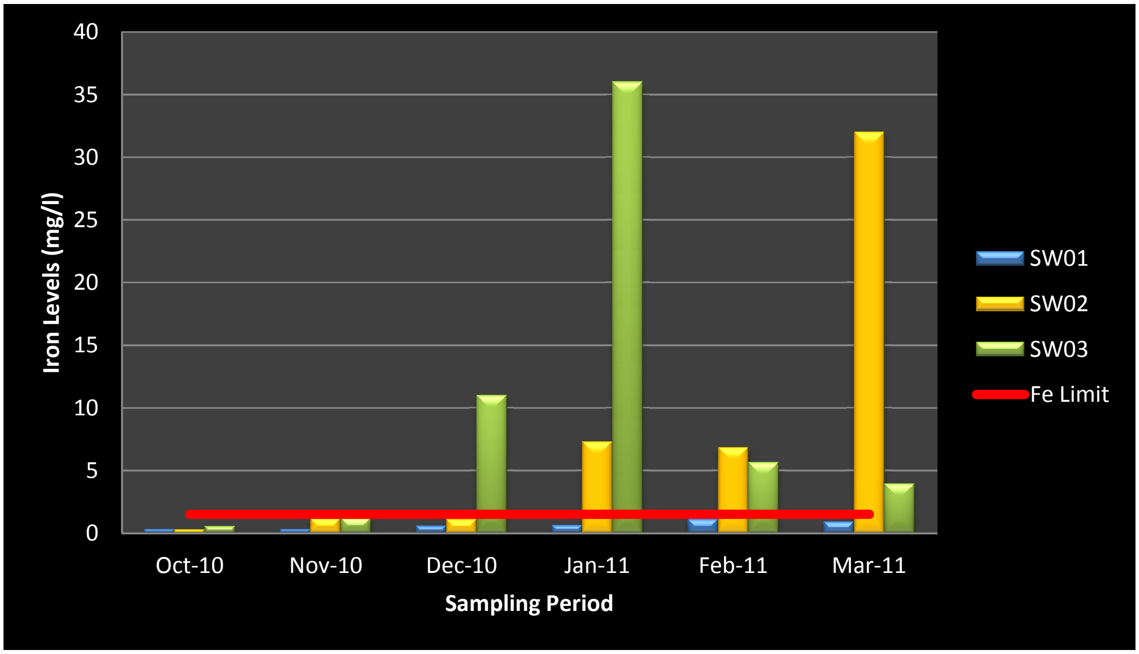

Figure 4-7: Iron levels determined for the different sampling points and time on Bosmontspruit

Figure 4-7 illustrates the iron levels on the Bosmontspruit. SW01 illustrated that the iron levels were well within the TWQR. SW02 and SW03 showed non compliance with iron levels from December through to March. As is the case with aluminium, iron pollution can be attributed to the pyritic rocks utilised in waste rock facilities. As is the case with aluminium the elevated levels in January are can be attributed to a possible mine pond discharge. SW02 showed a significant increase in iron levels in March, this could be as a result of increased watering down practices at the mine or a failure of a pollution/tailings dam. None of these were reported during this period, and no discharges were noted on the day of sample collection, the only available source of iron pollution remains the pyrite bearing waste rock material.

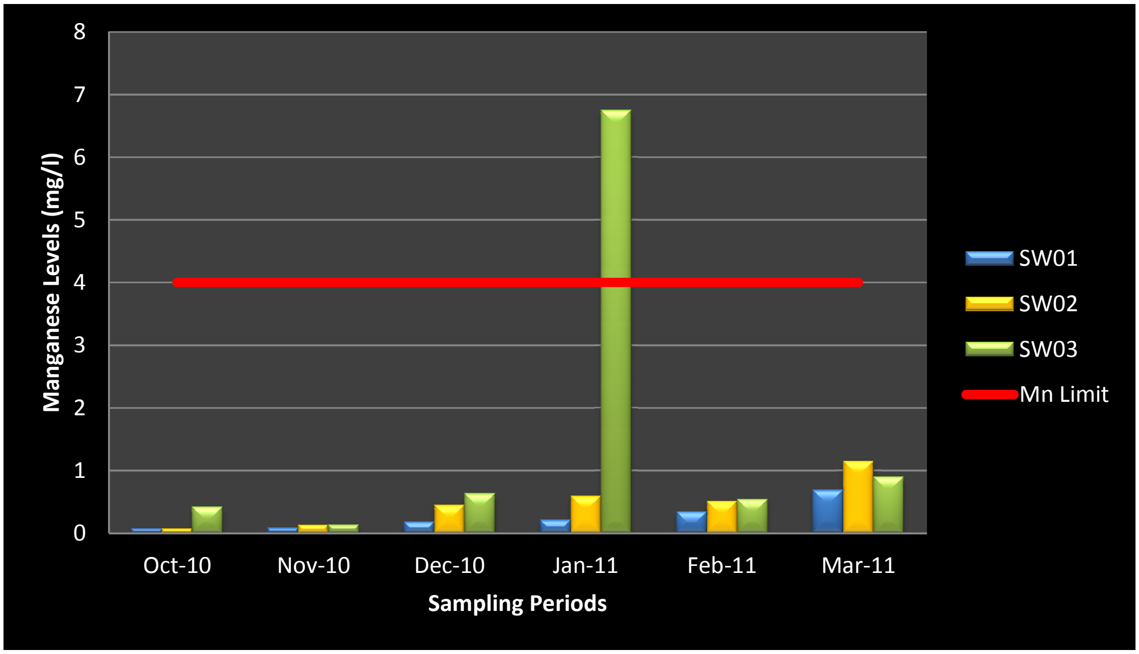

Figure 4-8: Manganese levels determined for the different sampling points and time on Bosmontspruit

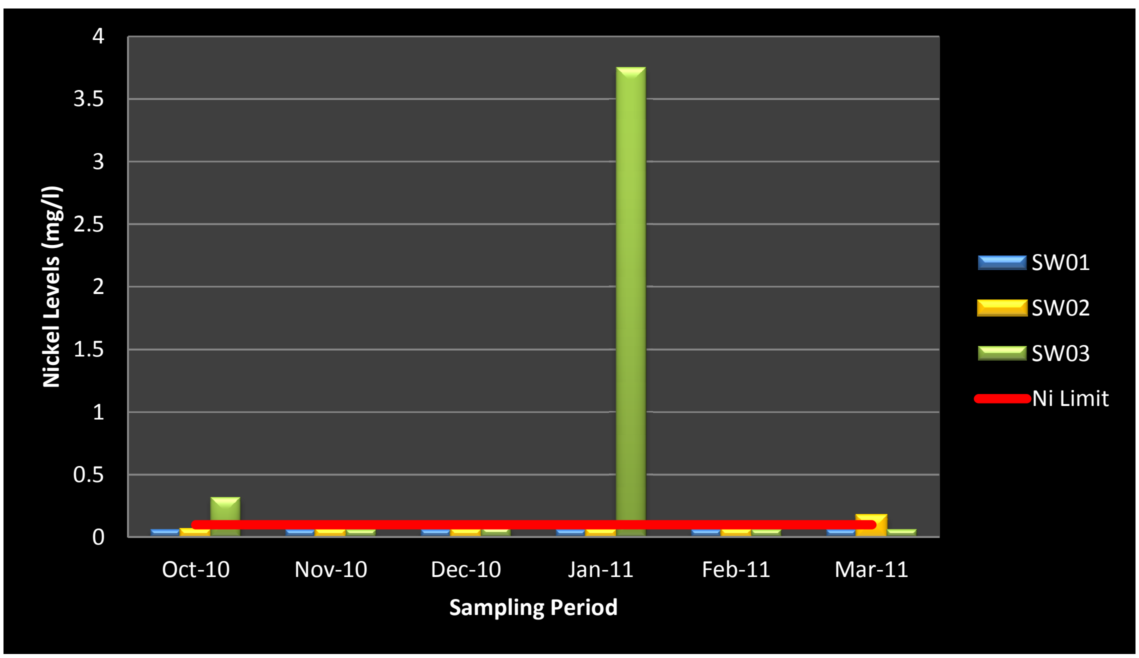

Figure 4-9: Nickel levels determined for the different sampling points and time on Bosmontspruit

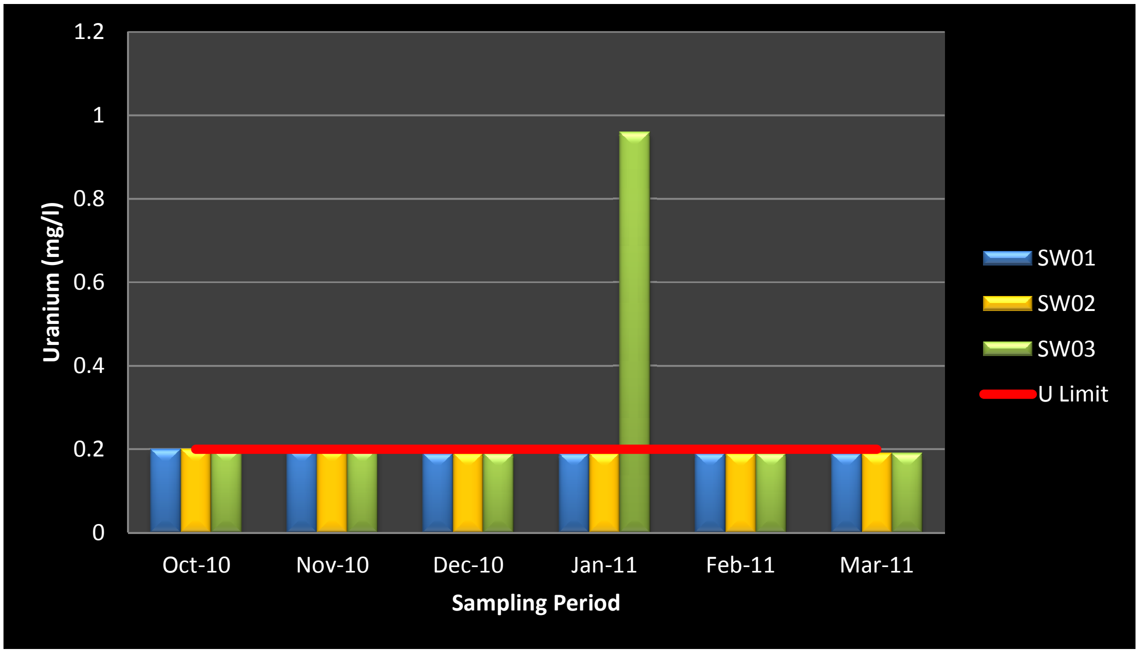

Figure 4-10: Uranium levels determined for the different sampling points and time on Bosmontspruit

Figure 4-8 through to 4-10 represents the levels of manganese, nickel and uranium on the Bosmontspruit. All of the above metal constituents complied with the TWQR throughout the monitoring period except SW03 in January. These parameters increased in order of magnitude of approximately 10 times during this month.

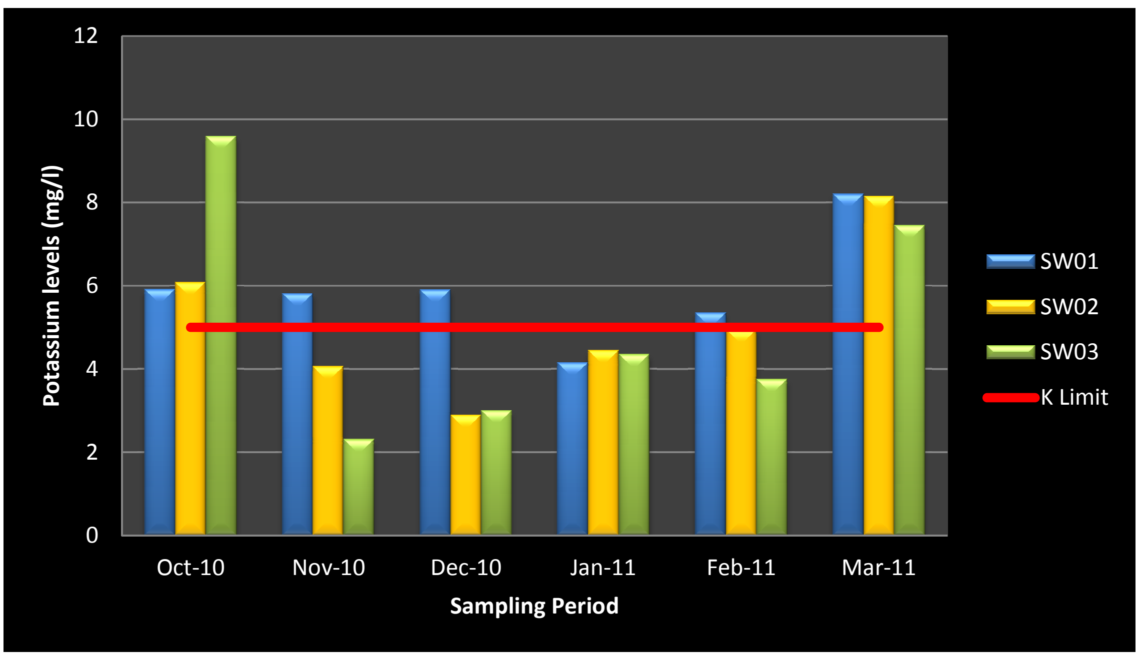

Figure 4-11: Potassium levels determined for the different sampling points and time on Bosmontspruit

Figure 4-11 depicts the potassium levels on the Bosmontspruit. With respect to potassium, SW03 showed a similar trend to SW01 and SW02 in terms of non-compliance. The most probable cause of the elevated potassium levels on the Bosmontspruit could be as a result of a possible sewerage system failure in the suburb of Bosmont, as figure 4-3 and 4-4 also show elevated nitrate and faecal coliform levels, characteristic of a sewerage discharge. This could not be confirmed during sampling and further investigation is required to substantiate this.

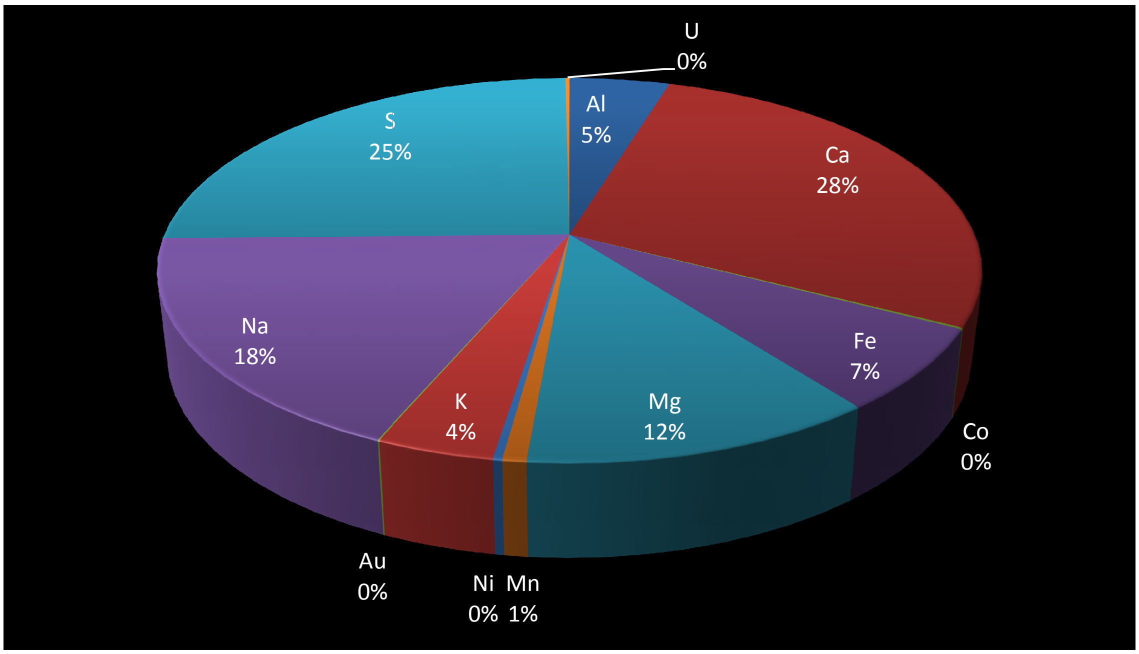

Figure 4-12: Metal concentrations by proportion at sample points downstream of mining activities on the Bosmontspruit from October 2010 to March 2011

Figure 4-12- provides an interesting comparison when compared with figure 4-1. Previous literature showed that water courses in the central basin show an elevated calcium, sodium, magnesium and sulphur tendency (Ferret, 2008) which is what is also depicted at SW01(figure 4-1), however the situation is different at SW02 and SW03 where the levels of aluminium and iron were much more increased. The downstream SW02 and SW03 had 6% more iron, 5% more aluminium and 1% more manganese than the upstream control, this is significant enough to highlight as SW01 contained 0 to 1% of the above elements. The impact of mining and exposure to silicates and pyrite bearing material can be attributed for these high levels of metal concentrations downstream, the exposed silicate material accounts for the aluminium and manganese increases and the pyrite is responsible for the elevated iron levels.

4.5 SW04- Upstream control Russell's stream

SW04 was the upstream control sampling point for Russell's stream. There were no noticeable industrial operational facilities that could contribute to the pollution however the surrounding landscape is that of a redundant tailings dam which has a high erosion potential as a result SW04 shows consistently high nickel and iron levels which is characteristic of gold tailings. During the first quarter of 2011 there was a significant increase in manganese levels ranging from 4.15 to 6.10 mg/l compared to the unacceptable range of greater than 4 mg/l. A spike in uranium levels was noted during March 2011 (0.73mg/l). The pH levels at SW04 were lower than the acceptable range in the TWQR of less than 6. The readings obtained were 5.60 for October, 4.83 for November and in March it was 4.30.There does not appear to be any immediate link between flow and contamination as the increased flow levels do not correspond to an increase or decrease in contaminants.

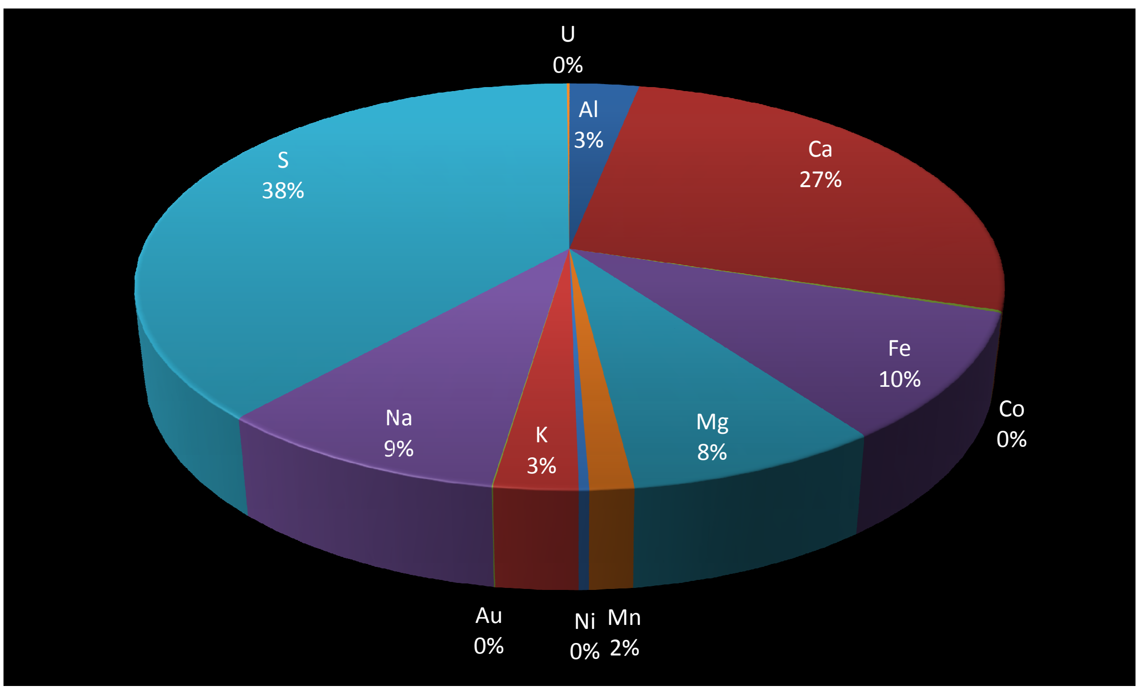

Figure 4-13: Metal concentrations by proportion in water at SW04 from October 2010 to March 2011

Figure 4-13 depicts the levels of metal concentration at SW04, as stated earlier the water in the central basin has a dominant elevated calcium, magnesium, sodium and sulphur characteristic. The most noticeable high concentration of metal at SW04 was for iron; with a concentration of 10% of the total metal constituents indicating that there is a potential of iron leaching from the pyrite bearing material contained in the redundant gold waste material.

Coefficient of determination value of 0.75 indicates that river flow accounts for 75% variability in dissolved oxygen levels. The negative RC value indicates an inversely proportional relationship and further indicates that for every unit increase in river flow there is a 21.83 decrease in dissolved oxygen. This may indicate that the water entering SW04 limits the levels of dissolved oxygen and this could mean that the incoming water was highly polluted by organic matter which results in a high biological oxygen demand which increases degradation resulting in oxygen being used up. The value of the CC for nitrate, iron, nickel, cobalt and manganese were close 0, which indicates the absence of a predictive relationship therefore knowledge of river flow values gives no predictive information about water parameter concentration.

4.6 SW05-Instream water quality point for Russell's Stream

SW05 is the in-stream water quality sampling point for the Russell's stream. The characteristics were very similar to that of SW04. The Russell's stream had a significant amount of metal pollution and the water pH conditions tended to border in the acidic range. It is also worth noting that there is an informal settlement alongside the stream that utilise the water for domestic purposes.

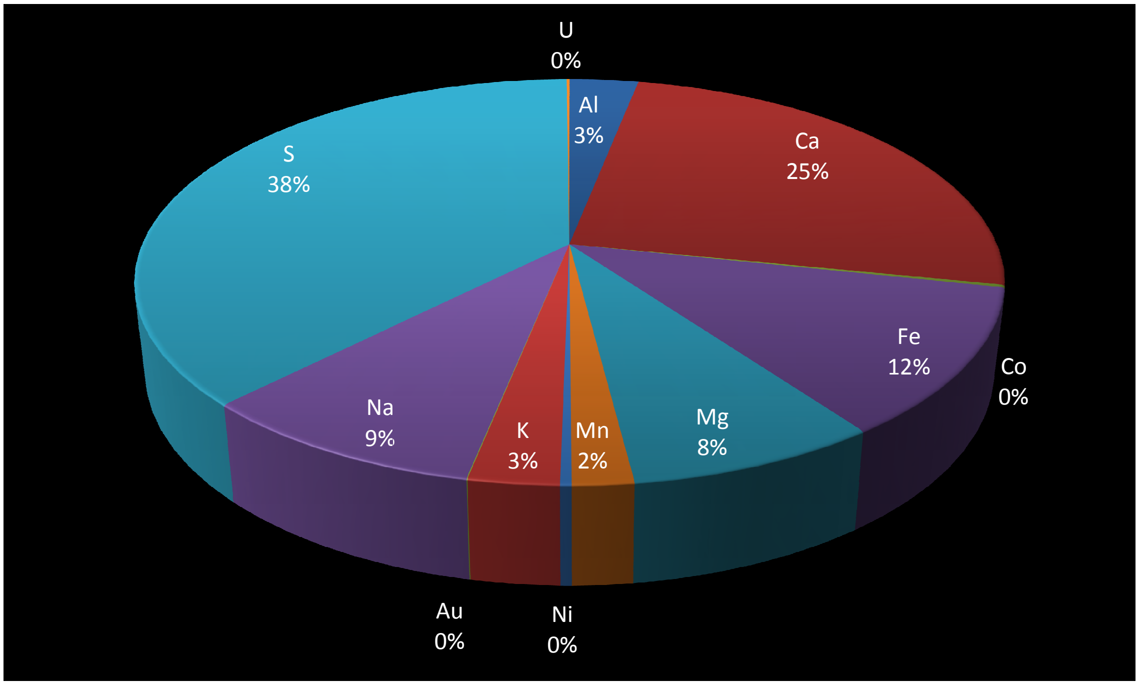

Figure 4-14: Metal concentrations in water at SW05 from October 2010 to March 2011

The metal concentrations at SW05 followed a similar trend to SW04 in that both showed increased levels of iron (12%). The dominant elements at SW04 were sulphur (38%), calcium (25%) and iron which are a characteristic of water in the central basin.

The most significant relationship that existed at SW05 was between manganese and river flow. The CC value 0.84 indicates that an increase in river flow corresponds to an increase in the levels of manganese thus indicating a directly proportional relationship. The coefficient of determination value of 0.7 shows that river flow accounts for 70% of the variability in manganese levels. The RC value of 1.17 indicates that for every unit of increase of river flow there is a 1.17 unit increase of manganese levels. The above situation does not exist upstream at SW04 and therefore the elevated manganese levels may be attributed to the washing down and subsequent runoff that is generated and the illegal processing of the redundant tailings facilities in the vicinity of SW05.

4.7 SW06- Instream water quality point for Russell's stream tributary

SW06 serves as the in stream sample point for the Russell's stream tributary. The levels of TDS and dissolved oxygen were found to be above the TWQR. In general the water quality was particularly good in this area meeting most of the set water quality standards.

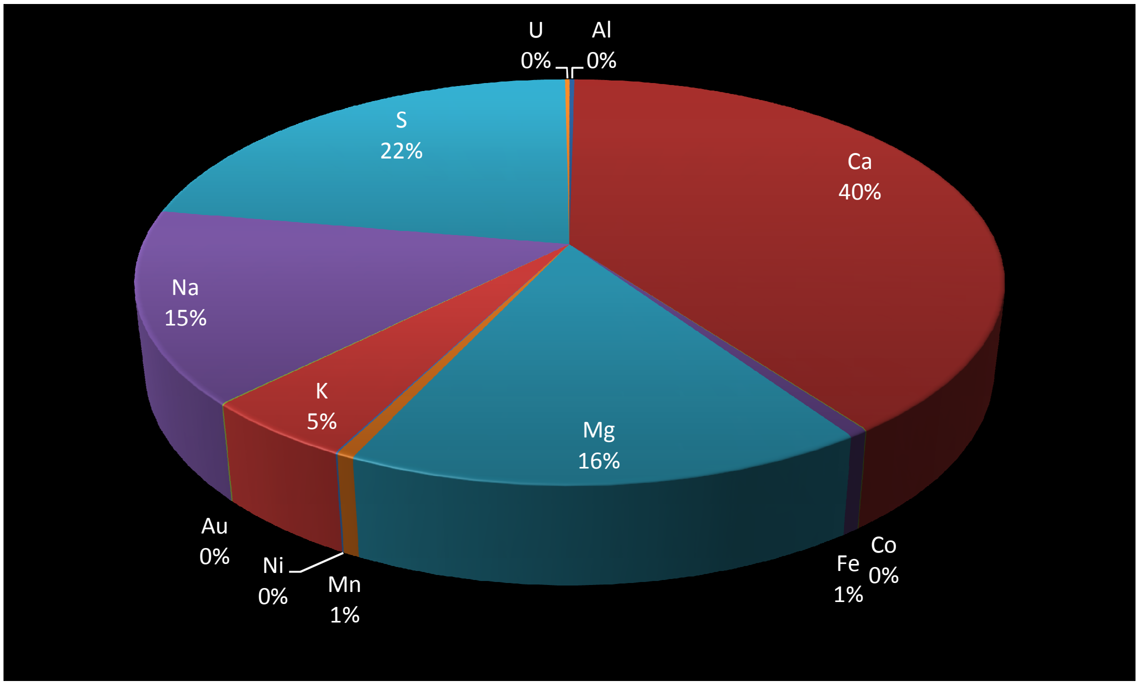

Figure 4-15: Metal concentrations in water at SW06 from October 2010 to March 2011

Figure 4-15 shows the proportions of the metal concentrations at SW05. The dominant metals are calcium (40%), sulphur (22%), magnesium (16%) and sodium (15%). This trend is similar to those observed along the Bosmontspruit and SW05.

The regression analysis at SW06 shows that no significant relationship existed between river flow and water parameter concentration.

4.8 SW07- Control point for Russell's stream tributary

The levels of TDS and DO at SW07 did not comply, elevated levels of nitrate was noted during October (10.2 mg/l) and November (8.80 mg/l). There could also be a significant amount of pollution from organic matter and this could account for the reduced DO levels and it would be expected to find an increased biological oxygen demand. The elevated levels of faecal coliforms in October corresponds with increases in nitrate. March showed a spike in potassium levels (9.05 mg/l) and ammonium levels (39.08 mg/l). It should be noted that there is a significant amount of illegal dumping in the vicinity of SW07 and the material dumped into the water course range from domestic, mining and construction waste. This material could very well explain the increases for the levels of TDS.

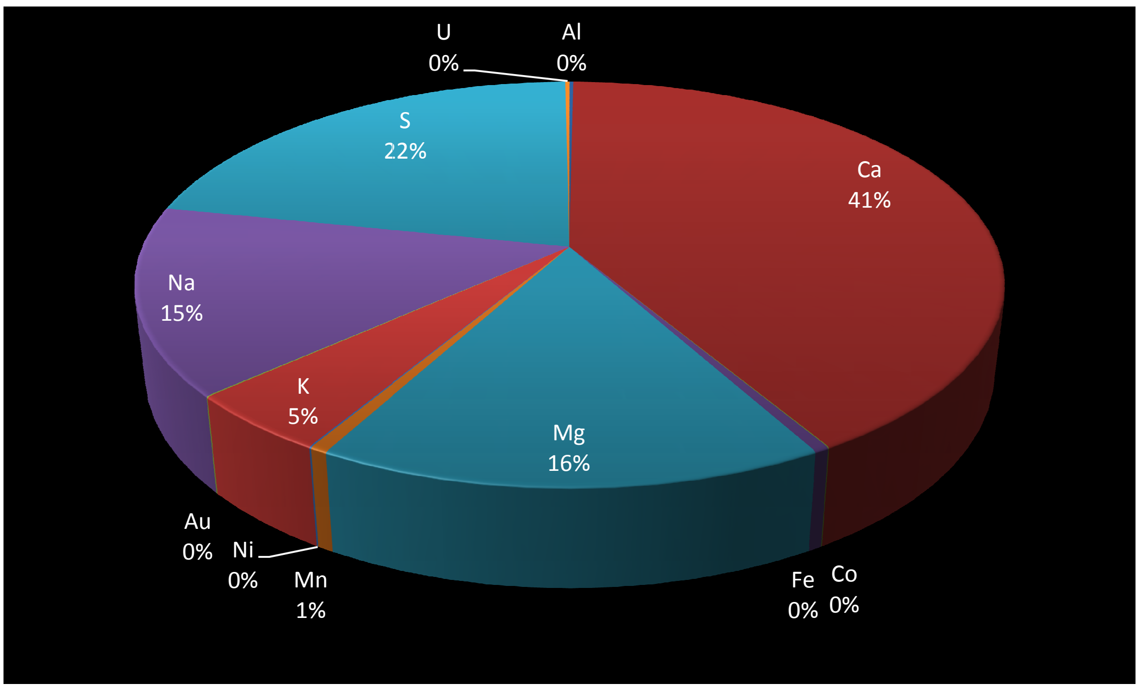

Figure 4-16: Metal concentrations in water at SW07 from October 2010 to March2011

The trend at SW07 mimics that of SW06 and contains no acid mine generating potential since the levels or iron are at 0%.

As with the case at SW06, the regression analysis indicates that no significant relationship exists between river flow and water parameters concentration. This is largely due to the values obtained for the CC which are all negative. Only nitrate exhibited a positive value but it is still not significant. The flow at SW07 remains restricted due to a large amount of debris that obstructs the flow and therefore there was significant fluctuation in flow, thus the absence of a predicted relationship was expected. The CC for nitrate tends to incline towards 0 indicating that no predictive relationship exists.

4.9 Comparative analysis of the water quality at different sampling points of the Russell's stream

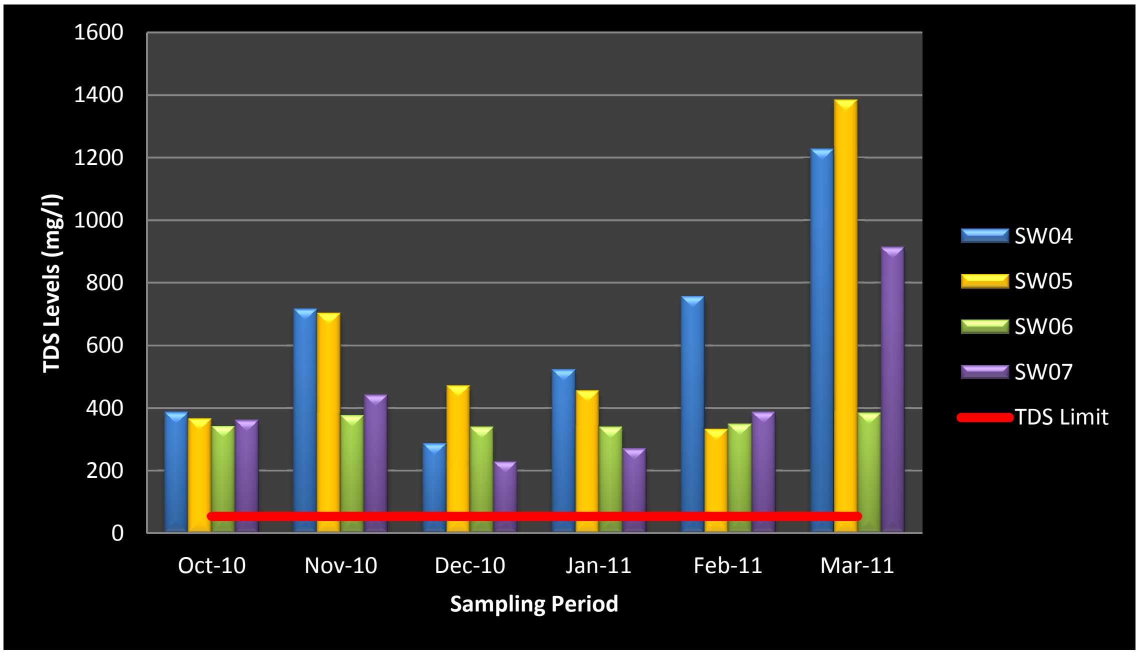

Figure 4-17: TDS levels determined for the different sampling points and time on Russell's Stream

The TDS trend for all of the sampling points showed that the TDS remained consistently above the TWQR guideline (figure 4-17).

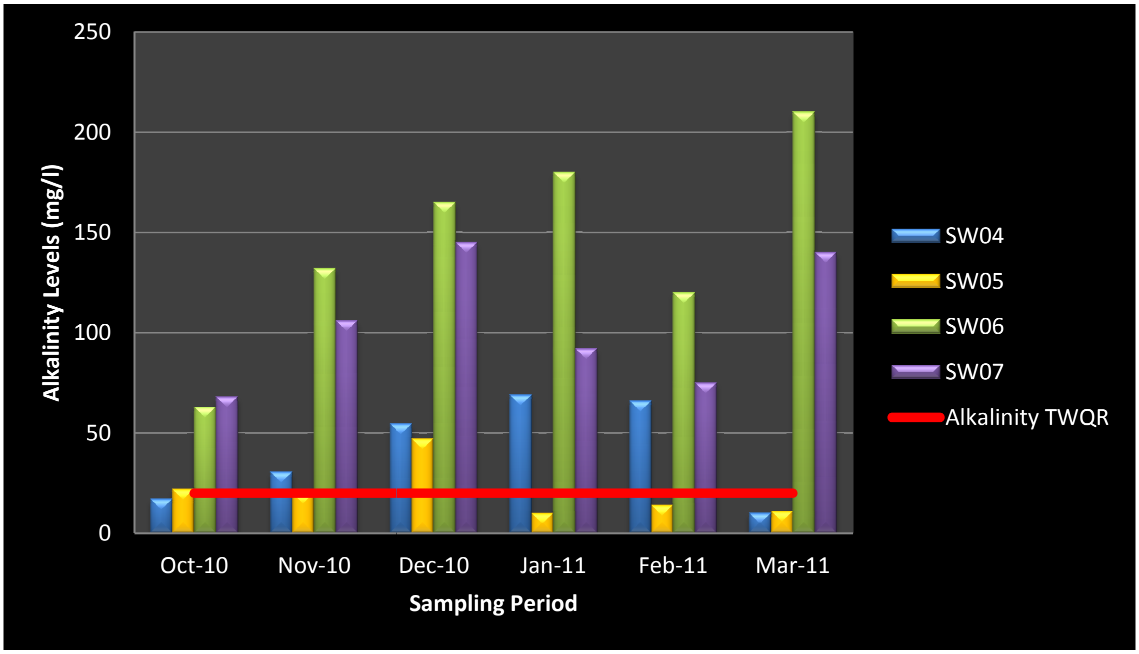

Figure 4-18: Alkalinity levels determined for the different sampling points and time on Russell's Stream

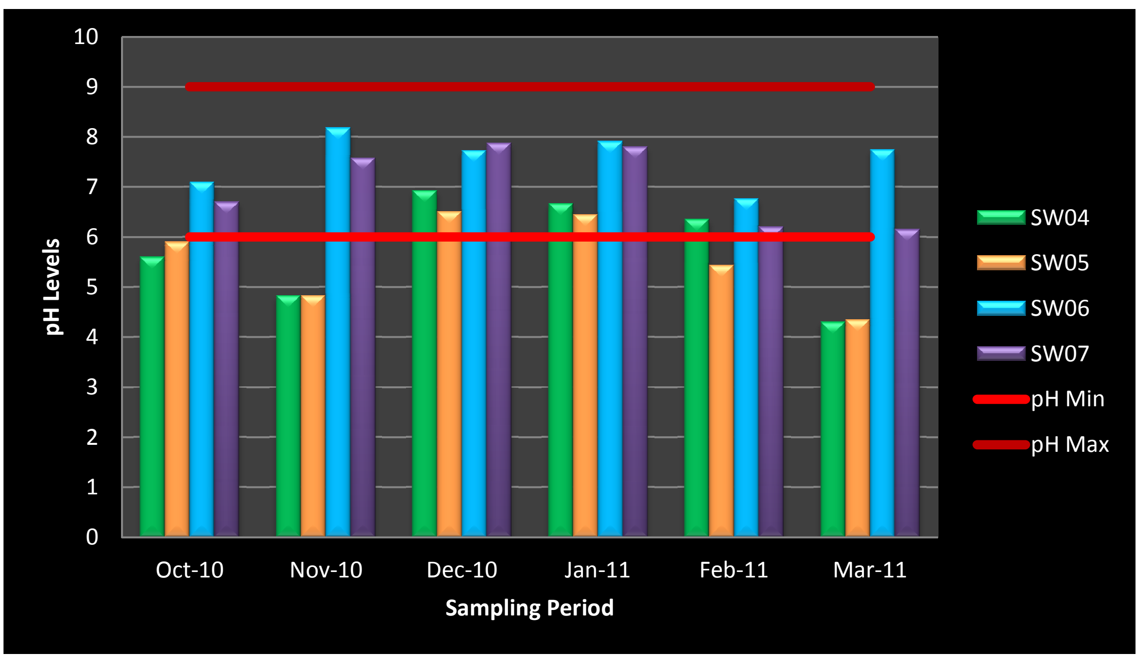

Figure 4-19: pH levels determined for the different sampling points and time on Russell's Stream

Figure 4-18 and 4-19 shows the alkalinity and pH levels on the Russell's Stream respectively. Both these parameters are closely related in that pH will increase as the water becomes more alkaline or basic. SW04 and SW05 had low pH levels in October, November, February and March. The low pH levels coincided with reduced alkalinity levels which are to be expected as there is a greater affinity for hydrogen ions and subsequent reduction in alkalinity and pH. The possible cause for this could be the oxidation potential of the iron available in the water which could result in acidic conditions being produced.. As described earlier both these sample points had between 10 and 12% of iron in them which occurs from the pyrite waste entering the water course. Further to this the processing plant of Crown Gold Recoveries is along the Russell's Stream, thus potential failures at the plant could result in discharges into the water course, although none were noted during the study the possibility does exist for the processing plant to be a source of pollution.

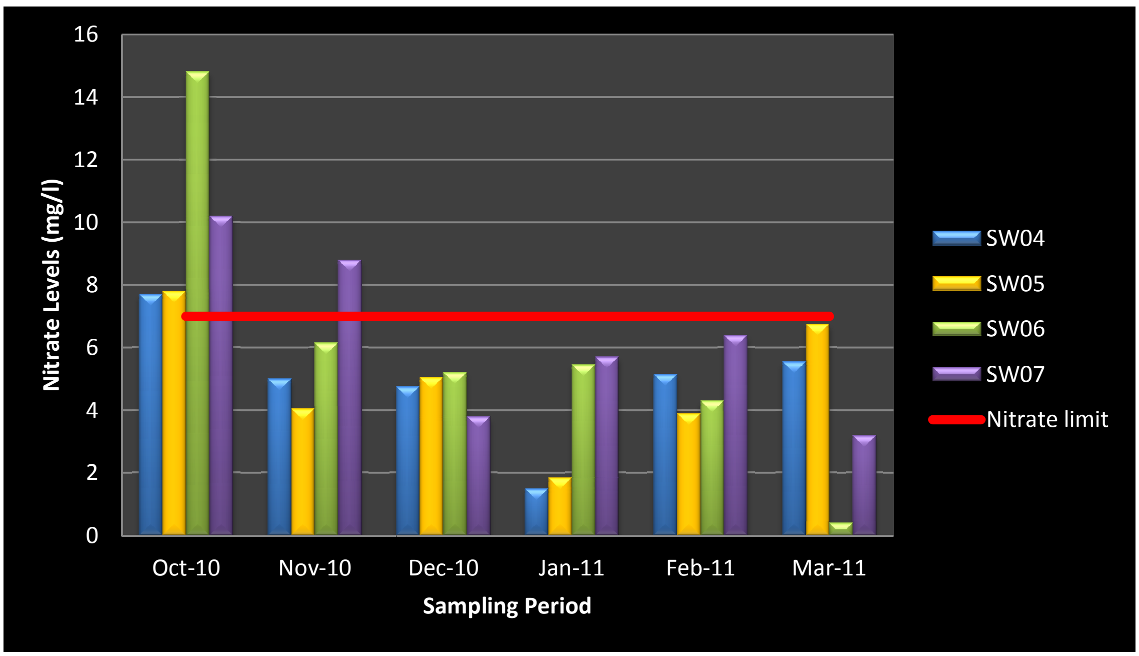

Figure 4-20: Nitrate levels determined for the different sampling points and time on Russell's Stream

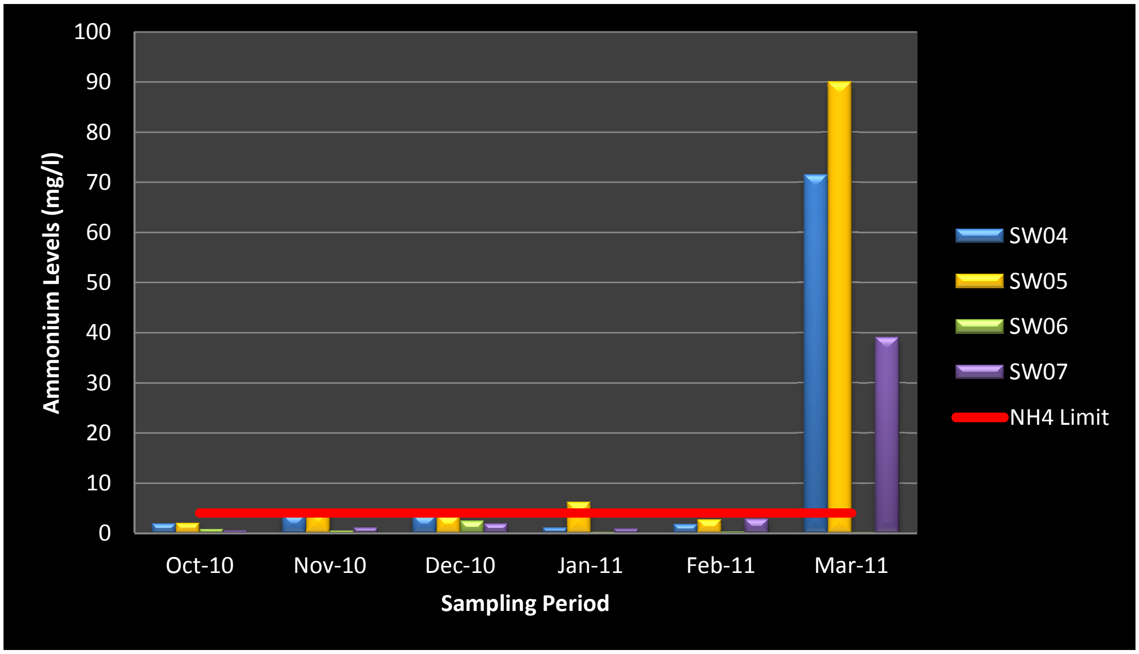

Figure 4-21: Ammonium levels determined for the different sampling points and time on Russell's Stream

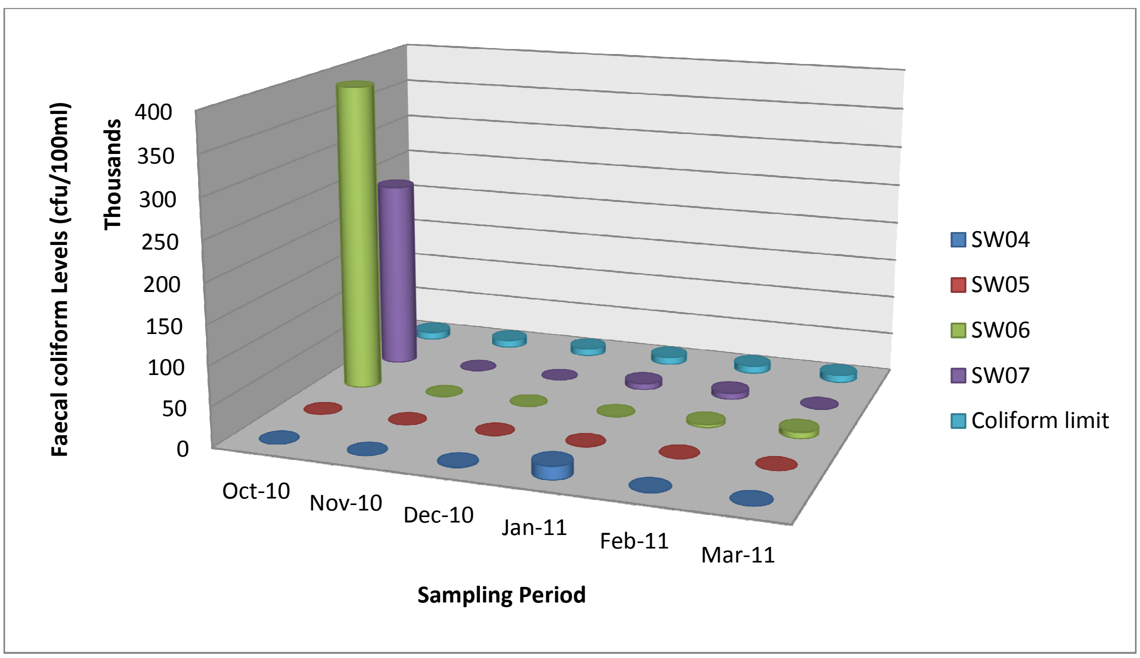

Figure 4-22: Faecal coliform levels determined for the different sampling points and time on Russell's Stream

Figure 4-20, 4-21 and 4-22 illustrate the nitrate, ammonium and faecal coliform levels on the Russell's Stream. These three parameters are very closely linked. SW04 and SW05 showed elevated nitrate levels in October and November, this coincided with elevated faecal coliform levels for these months. A spike was noted in the ammonium levels in March in SW04 and SW05. It would be expected that the levels of nitrate, potassium and faecal coliforms fluctuates as the human activities and number of individuals that reside in the area continuously fluctuates. This water is used for domestic purposes by these individuals as well.

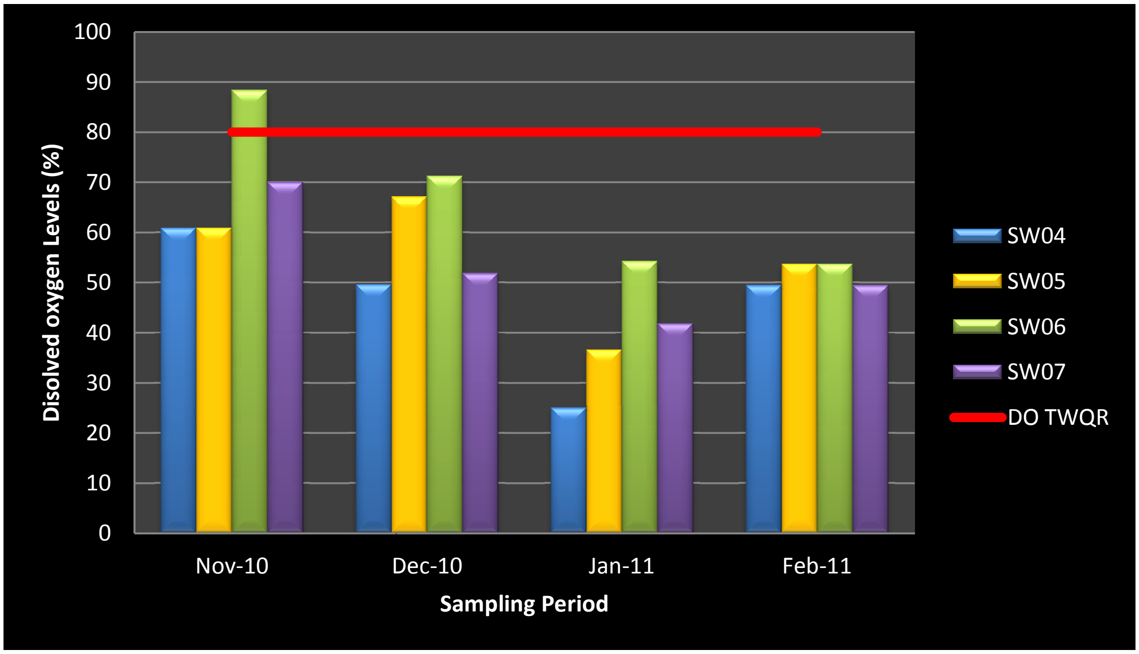

Figure 4-23: Dissolved oxygen levels determined for the different sampling points and time on Russell's Stream

As with the majority of the sample points figure 4-23 shows that dissolved oxygen levels did not comply to the set standard since levels were below 80% throughout the sample period except for SW05 in November. There was a significant amount of obstruction to the flow from illegal dumping which was evident along the stream during sampling and this had impacts on the rate at which oxygen mixes. Also this particular river system could be under stress due to pollution by organic matter resulting in an increase in biological oxygen demand and therefore a reduction in dissolved oxygen.

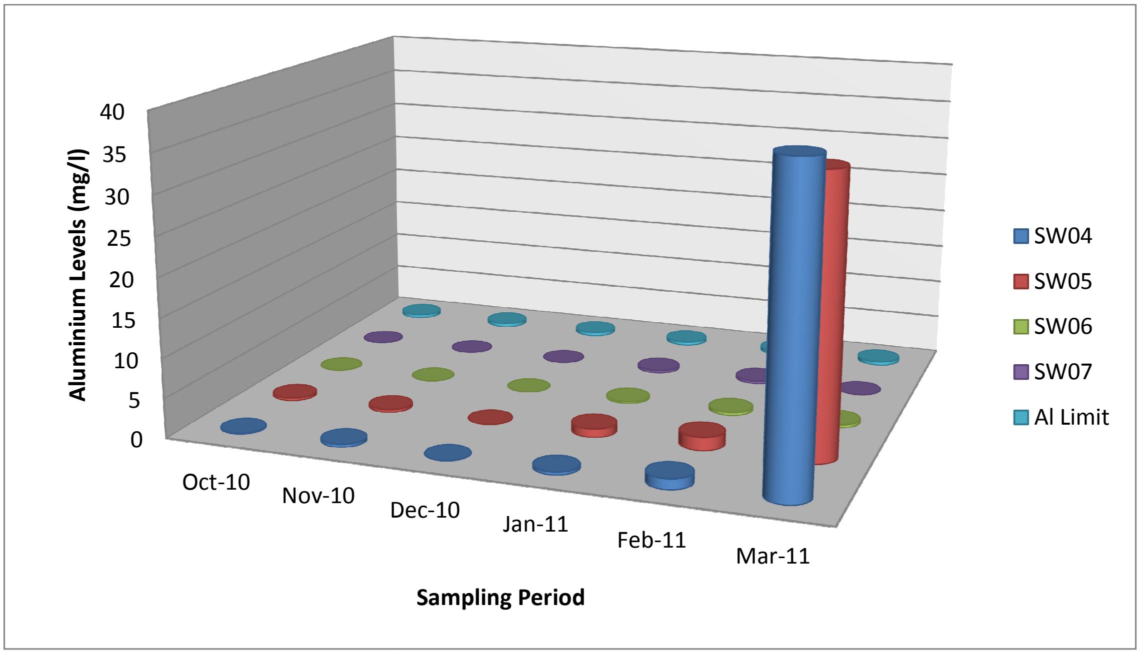

Figure 4-24: Aluminium levels determined for the different sampling points and time on Russell's Stream

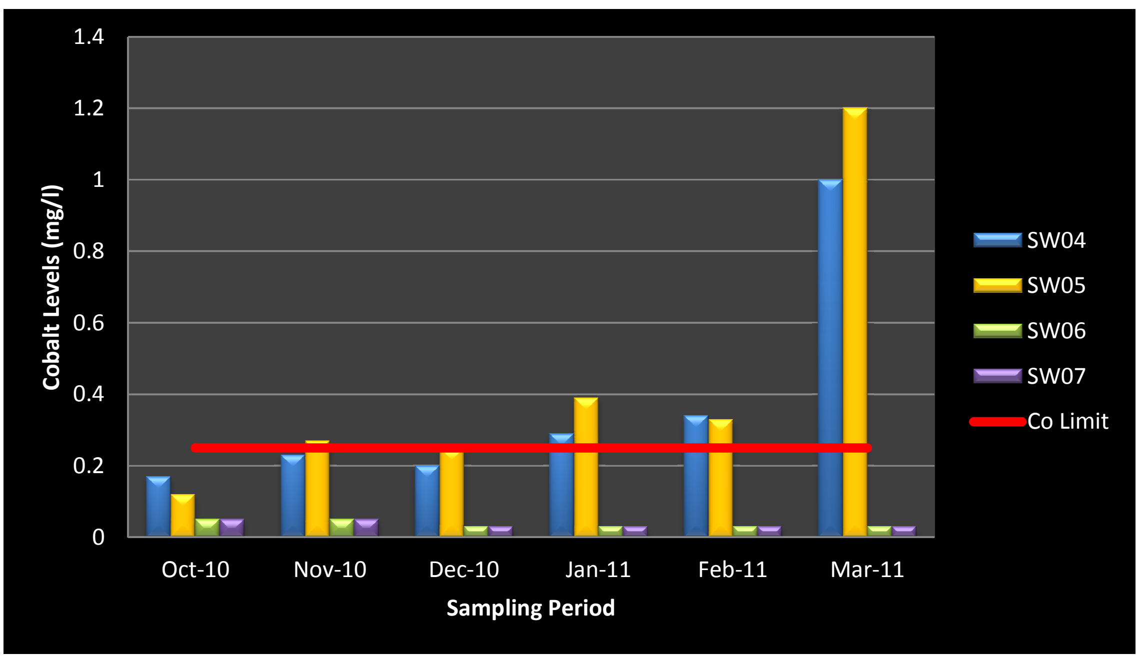

Figure 4-25: Cobalt levels determined for the different sampling points and time on Russell's Stream

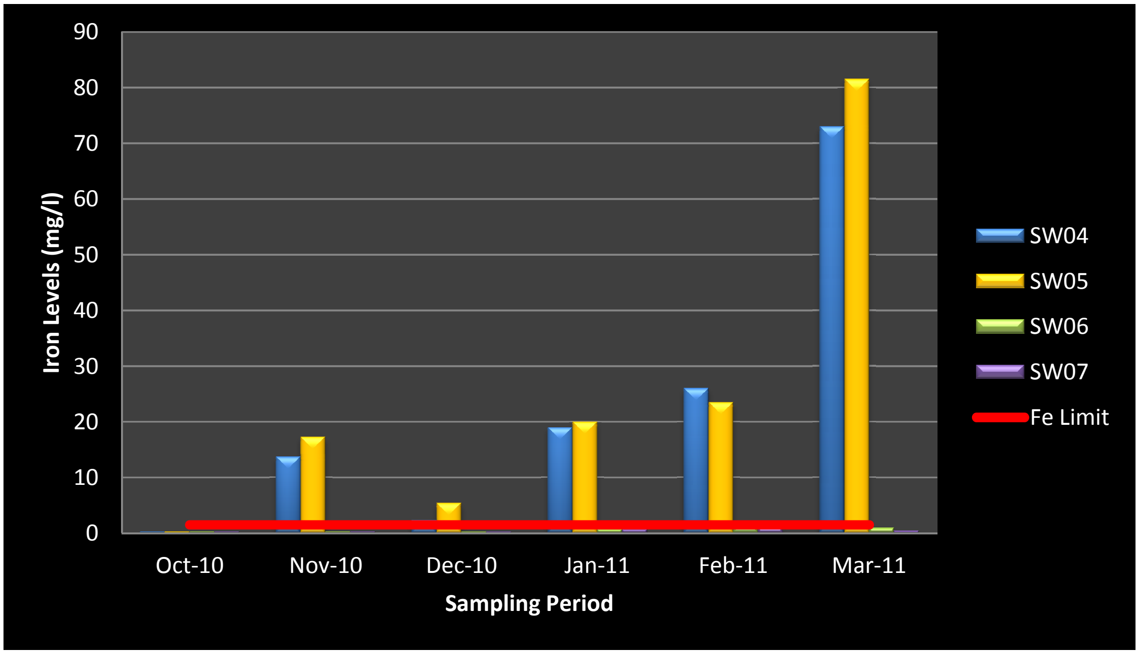

Figure 4-26: Iron levels determined for the different sampling points and time on Russell's Stream

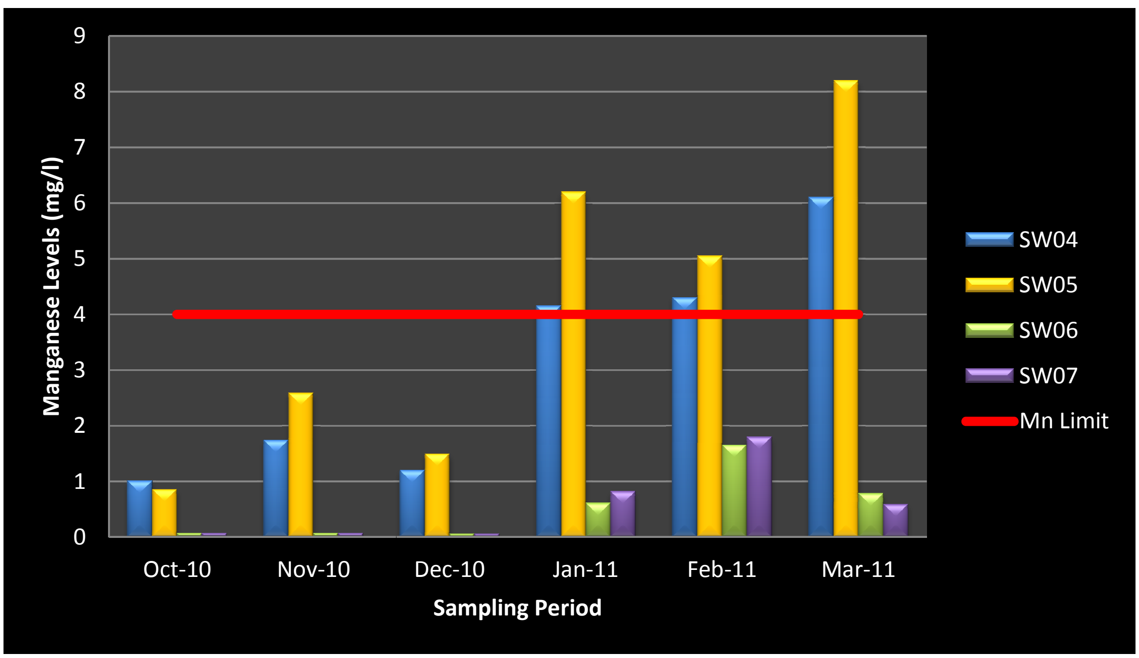

Figure 4-27: Manganese levels determined for the different sampling points and time on Russell's Stream

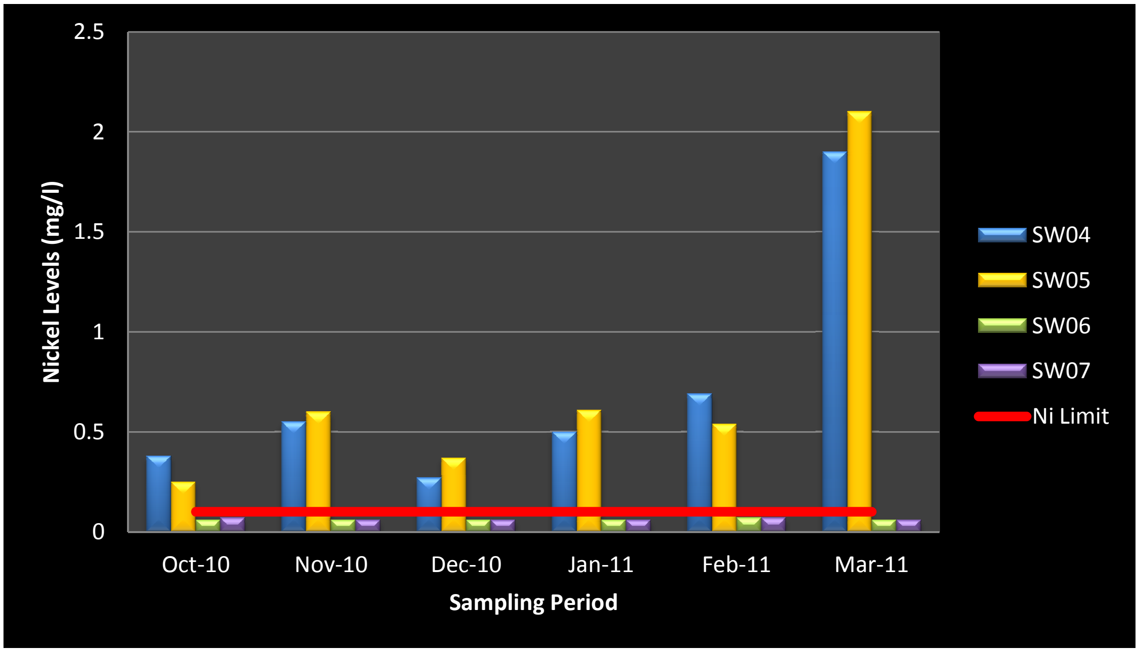

Figure 4-28: Nickel levels determined for the different sampling points and time on Russell's Stream

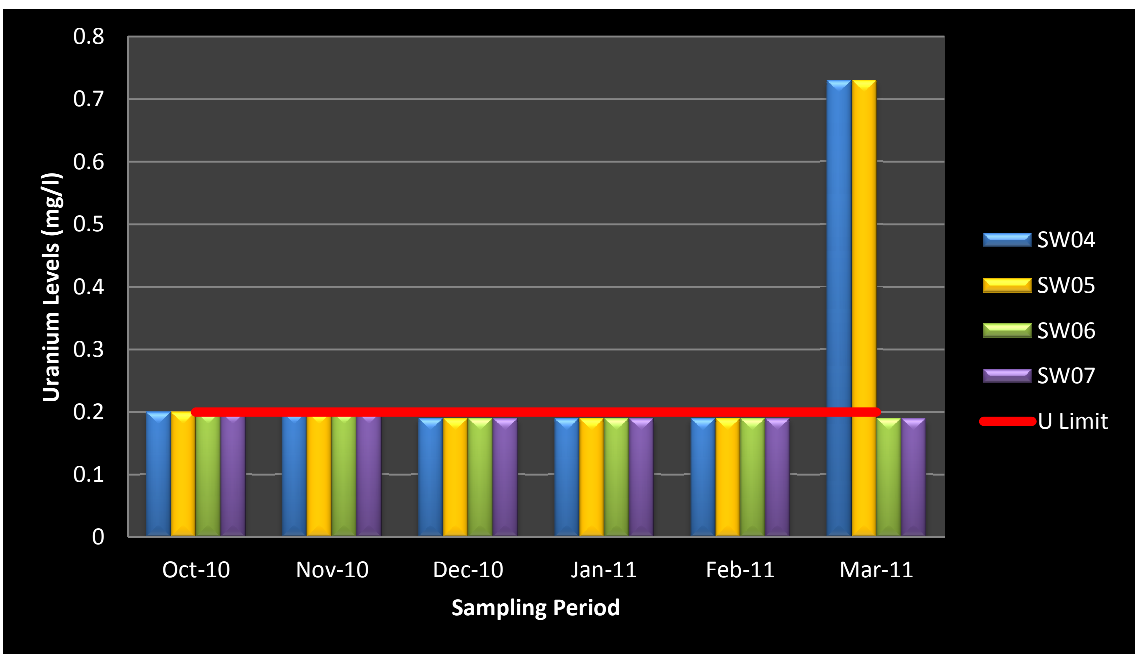

Figure 4-29: Uranium levels determined for the different sampling points and time on Russell's Stream

Figure 4-24 to 4-29 illustrates the levels of aluminium, cobalt, iron, manganese, nickel and uranium respectively on the Russell's Stream. These parameters are discussed together as their possible sources of pollution are all related. February 2011 brought the first significant rains as shown in table 2-4. This exposed both the silicate and pyrite material of the waste rocks dumps and subsequently transport the aluminium and iron respectively into the water course. The rainfall also coincided with elevated aluminium levels at SW04 and SW05 in February and March Cobalt and iron levels were above the TWQR at SW04 and SW05 from November through to March (refer to appendix 5). Iron, cobalt, nickel and manganese are typical constituents of gold waste generated from processing activities. Nickel did not comply with the TWQR guideline throughout the sample period and uranium showed elevated levels in March.

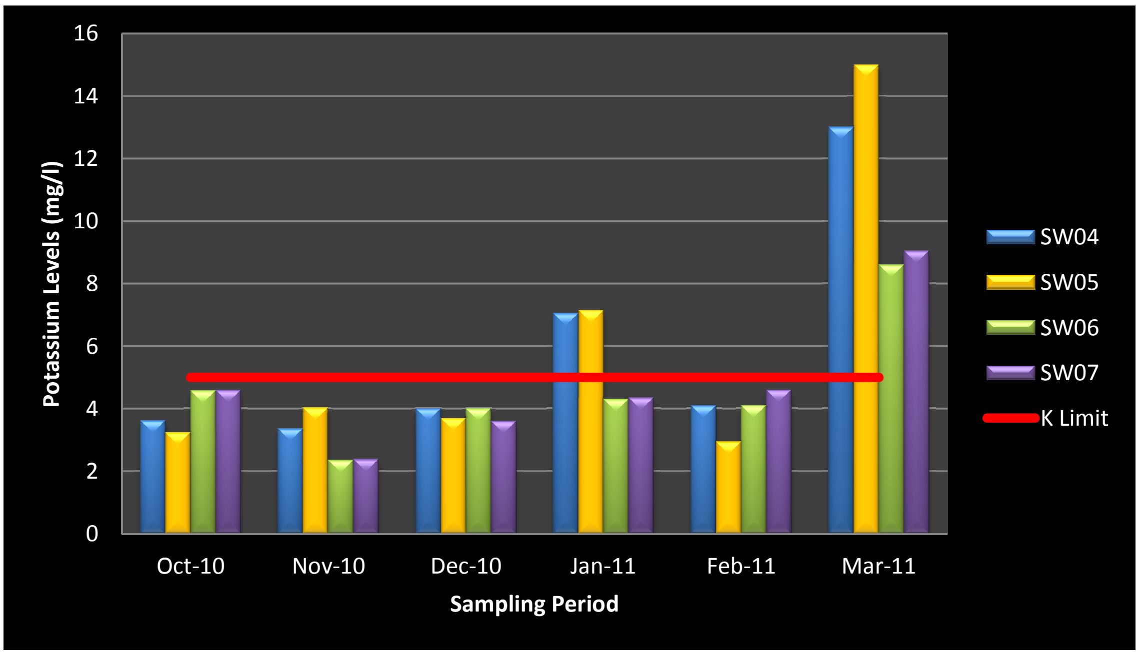

Figure 4-30: Potassium levels determined for the different sampling points and time on Russell's Stream

Figure 4-30 shows the potassium levels determined on the Russell's Stream SW04 and SW05 showed non-compliance with the TWQR guideline (greater than 5mg/l) in January and during March. Elevated levels of potassium are usually associated with human and animal excrement that is discarded into the water course possibly from the informal settlements.

4.10 SW08- New Canada dam sampling point

SW08 was the New Canada dam sampling point and was the final decant point for the Bosmontspruit and Russell's stream. As with all the other sample points the

levels of TDS and dissolved oxygen levels showed non-compliance with the guidelines with respect to these parameters. During October the highest levels of pollutants were detected. The pH levels were elevated (10.10), cobalt (0.3mg/l), manganese (5.3mg/l), nickel (0.57mg/l) and potassium (9.07mg/l) levels were all outside the allowable levels. The levels of iron in the New Canada Dam were consistently high. SW08 also did not comply with alkalinity or ammonia guidelines with levels being much higher than the standard.
Water from the New Canada Dam is utilised for human and livestock consumption as well as watering of crops despite the levels of metal pollution.

The most significant relationship existed between dissolved oxygen and river flow. The coefficient of determination value 0.80 indicates that river flow accounts for 80% of the variability in dissolved oxygen levels, which is significant. The RC value of -0.47 indicates that for every unit increase of river flow there is a 0.47 unit decrease in dissolved oxygen levels. This may indicate that water entering New Canada Dam reduces the amount of dissolved oxygen present and as a result one can assume that there is a significant amount of pollution from the organic matter which causes oxygen reduction. The CC values for TDS, nitrate, cobalt and manganese tend to 0 which indicates no predictive relationship.

CHAPTER 5. DISCUSSION

Dallas and Day, (1998) point out that, rivers draining highly populated areas, industrial and mining complexes are known to bear the consequences of human activities. The results from the water quality analysis show that anthropogenic impacts are clearly visible. The results for each of the streams are discussed below.

5.0 Bosmontspruit water quality

The sampling points on the Bosmontspruit SW01 (upstream control), SW02 (below the Central Rand Gold mine) and SW03 (where the Bosmontspruit crosses Main Reef Road), showed major non compliance with the levels of faecal coliforms in the months of October, January and February. The levels of faecal coliforms in the upstream control sample as measured at 1 000 000 CFU/100ml is indicative of faecal matter pollution and possibly raw sewerage being disposed of upstream. Johannesburg Water manages the sewerage infrastructure within the area and remains responsible for the management of the infrastructure, these levels of faecal coliform are an unacceptable risk to human and the overall river health. Greater concern needs to be given to the smaller river systems to ensure that such situations do not arise, this was a key point highlighted in the IMC 2010 report.

Joint efforts between the municipalities and local government should be looked at in order to address the issue of informal settlements alongside river banks which are a significant contributor to elevated levels of faecal coliforms in the Bosmontspruit. Faecal coliforms have been shown to represent 93%-99% of coliform bacteria in faeces from humans, poultry, cats, dogs and rodents (DWA, 1998). The levels of faecal coliforms compared to the norm of human health indicate that counts greater 20 CFU/100ml can result in significant and increasing risk of infectious disease transmission. The levels of faecal coliform obtained in the Bosmontspruit poses a significant health risk as the stream runs directly through the residential suburb of Bosmont. A similar situation was highlighted by Schaffner *et al* 2009 on the pollution of the Thachin river in Thailand.

The levels of total dissolved solids on the Bosmontspruit did not comply with the set guidelines; this was a trend that was noticed throughout the sampling area. DWAF

1998 suggests that TDS are likely to accumulate in water moving downstream because salts are continuously being added by anthropogenic and natural processes while very little of it is removed by precipitation or natural processes. On the lower portion of the Bosmontspruit (SW02 and SW03) the levels of TDS can be attributed to the runoff from the active and redundant mine tailings facilities.

The water quality in the Bosmontspruit exhibited non-compliance with respect to nitrate levels between January and March and is most likely due to the onset of the rainy season and the subsequent urban runoff from the densely populated area of Bosmont. The elevated levels of nitrate on the Bosmontspruit can be attributed to the oxidation of vegetative and animal debris and of human excreta which could be as a result of sewerage system failure in the suburb of Bosmont. Sewerage generally contains nitrate and elevated faecal coliforms, hence there was an obvious link between the levels of faecal coliforms and nitrate levels on the Bosmontspruit.

A typical trend seen throughout the sampling area was the low levels of dissolved oxygen which indicates that the stream is under stress. During the study there were no noticeable signs of fish or frogs on the Bosmontspruit. The low levels of dissolved oxygen indicated poor water quality which is not favourable for survival of some aquatic organisms. A study of both the invertebrates and vertebrates present in the river system is necessary in the future to obtain a clearer picture on the river health.

SW01 and SW02 displayed elevated levels of potassium for a large part of the sampling period. The most likely introductory path for the potassium is the introduction of domestic waste discharged upstream of the Bosmontspruit. The levels of potassium tended to settle out in sediments before SW03.

SW02 and SW03 displayed non-compliance with the TWQR from December through to March in terms of the levels of iron and aluminium. Aluminium is the most common metal in the earth's crust, having an abundance of 81g/kg (DWAF, 1998). Due to the active mining operations in the vicinity of SW02 and SW03 and the large waste rock facilities there is a sufficient pathway for the introduction of aluminium into the water course. In terms of the levels of iron, one of the most important iron minerals is pyrite which is abundant in the reefs mined in the central basin (Buttrick *et al.,* 1993, Ferret 2008). The suggested pathway for iron to enter the water course is through the waste rock dump. SW02 exhibited occasional spikes in nickel and uranium levels this could be due to the sulphide and uranium bearing ore being mined at Central Rand Gold and the subsequent runoff (Ferret, 2008)

The most noticeable change in water parameter concentration was in January at SW03, this could be due to an illegal discharge from the storm water control dam belonging to Crown Gold Recoveries (personal communication from mine employees). This resulted in a significant reduction in pH (3.16) and subsequent acidic conditions were noted. The discharge resulted in elevated metal levels with aluminium (55mg/l), cobalt (1.70mg/l), iron (36mg/l), manganese (6.75mg/l), nickel (3.75mg/l) and uranium (0.96mg/l) all not complying with the TWQR during this month. All the metal levels except for aluminium and iron stabilised in February.

In general the water quality on the Bosmontspruit did not comply with the guidelines for the catchment for a number of water quality parameters (Klipriver Instream Water Quality Guidelines, 1998). The regression analysis performed on the data yielded limited relationships in terms of linking river flow to water parameter concentration, this was largely due to the fact that the most of the water courses sampled displayed limited flow due to the debris that obstructed the flow.

5.1 Russell's stream water quality

The sampling points on the Russell's stream were SW04 (upstream control) and SW05 (instream water quality point). Typically the levels for TDS at both SW04 and SW05 exhibited non-compliance with guidelines for water quality but not human health. This could be due to runoff from the redundant tailings facilities and the discard of the waste material from the illegal processing of these facilities. During the monitoring period there were numerous operations on these tailings facilities without the necessary permits to process the tailings. This information was obtained by personal communication with the individuals on site. There are numerous informal settlements along the banks of the Russell's stream and this water is used for human consumption and bathing. The levels of TDS are not significant enough to cause any physiological impacts as all measured levels are below the maximum level of 2000 mg/l (DWAF, 1998), however the levels should be carefully monitored as a significant increase was noted in March. DWAF, 1998 makes reference that bathing or washing in water with excessively high concentrations of TDS may give rise to excessive skin dryness and discomfort.

Alkalinity in natural waters are due mainly to the presence of calcium and magnesium salts and bicarbonate formed in reactions in the soil and rock through which the water percolates. Water with low alkalinity or hardness may be susceptible to pH reduction by 'acid rain'. SW04 showed low levels of alkalinity in October and March and this corresponded with low levels of pH in the acid range (4.30 to 5.60). The low pH levels could be as a result of the iron concentrations at SW04 and SW05 which create acid generating conditions. The high iron levels can be attributed to the pyrite material in the mine tailings. pH values less than 4 can cause severe danger of health effects due to increased dissolved toxic metal ions. The low alkaline levels exhibited at SW05 from January through to March, and acidic conditions noted in all the months except December and January can be attributed to acid generating potential of the water from the 10 to 12% iron concentration. Several informal settlements exist along SW04 section and this may contribute to elevated levels of nitrate from human excrement and urine. January displayed a marked increase in the level of faecal coliforms (16800 CFU/100ml) and this could be attributed to runoff input from the anthropogenic sources.

SW04 and SW05 displayed low levels of dissolved oxygen which was a trend noticed across the sample area, the low levels of dissolved oxygen are indicative of poor river health. The low levels of dissolved oxygen could be as a result of pollution by organic matter, which would then increase the biological oxygen demand and subsequently reduce the levels of dissolved oxygen in the water course. No noticeable traces of fauna and aquatic life were noted on the Russell’s stream. In the month of March the elevated ammonia levels at SW04 (71.50 mg/l) and SW05 (90.0 mg/l) were elevated and did not comply with the guideline; these levels could have been associated with raw sewerage discharges from poor management of sewerage systems. SW04 is in immediate vicinity of the Crown Gold Recovery treatment facility and SW05 is downstream from a redundant tailings disposal facility where runoff from the pyrite and silicate bearing material at these facilities could have contributing to the non-compliance for a number of metal constituents. The silicate bearing ore also could have resulted in aluminium levels exceeding the guidelines in both SW04 and SW05 from January through to March. Previous studies showed that the dominant pyrite and sulphate bearing ores associated with reefs of the central rand (Ferret, 2008) have contributed to elevated cobalt, iron, nickel and manganese levels on the Russell's stream.

A great deal of consideration must be given to the water quality on the Russell's stream as this water is used for human consumption, prolonged exposure to the metal contaminants above may result in neurological damage and overall damage to the renal system (DWAF, 1998).

5.2 Russell's stream tributary water quality

SW06 (instream sample) and SW07 (control) were the sampling points for the Russell's stream tributary. This tributary exhibited the best overall water quality compliance of the study. Typically the levels of TDS were all above the limit outlined in the guideline document and the dissolved oxygen was well below the stipulated 80% as recommended in the guideline. This was a trend that was seen throughout the monitoring period and is indicative of pollution by organic matter in the case of low levels of dissolved oxygen and runoff in the case of elevated TDS. This was most likely due to the runoff from the Riverlea township development. Faecal coliform levels were elevated during the month of October at both SW06 and SW07, possibly due to the introduction of human excrement; this corresponded with increased nitrate levels. It is assumed that the most significant contributor to the faecal matter into the water course is the numerous informal settlements in the area. Other than the spike of uranium and ammonia noted in March there were no significant pollution impacts from the measured parameters at this point. The uranium could be due to tailings discard entering the water course as gold tailings does contain traces of uranium (Ferret, 2008).

5.3 New Canada Dam water quality

SW08 is the final mixing point for the Russell's stream and the Bosmontspruit. The water from the New Canada Dam is utilised for bathing, irrigation and livestock and human consumption. The New Canada Dam had high levels of TDS and low dissolved oxygen levels. The elevated TDS can be attributed to runoff from the surrounding environment which is that of a number of disused mine tailings facilities. There was a significant increase in pH towards more basic conditions in October (10.10) and at these levels DWAF, (1998), states that the probability for toxic effects associated with deprotonated species increases sharply. The elevated levels of pH coincided with increases in cobalt, manganese, nickel and potassium. The cobalt, manganese and nickel elements are principal constituents of pyrite bearing ore which enters the dam as runoff. Anthropogenic activities such as farming, livestock rearing and bathing were noted on New Canada Dam and this is evident in the high levels of ammonia and potassium, this could be from livestock or the scattered informal settlements in the area. The iron levels exhibited in the water was consistently high from December through to March and could have largely come from the pyrite bearing waste in the area. Although outside the scope of this study the suitability of the water for livestock consumption must be assessed, as the levels of iron can be toxic or detrimental to livestock (>1mg/l) (DWAF,1998).

In general the water quality at New Canada Dam must be looked at from a perspective of livestock and human consumption suitability.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

It was evident from this study that water in the catchment is highly degraded from its natural state due to the extensive anthropogenic activities in the catchment. Urban runoff, gold mining and industrial activities, as well as formal and informal settlement runoff affected the water quality. There was significant evidence of raw sewerage being discharged upstream in the Bosmontspruit and the impacts of current and past mining activities was evident across the catchment area. The Klip River Instream Water Quality guidelines were found to be of great value to classify the general water quality of the site.

It is apparent that metal concentrations (iron, aluminium and nickel) and certain physical characteristics (total dissolved solids and dissolved oxygen) were always out of the permissible levels as per the water quality standards. These metals and compounds mostly seem to have originated from the historic mining activities. Thus it remains the responsibility of the mine owner to implement mitigatory measures according to regulatory requirements, in cases where the mine owners cannot be found the responsibility lies with the state.

The IMC 2010, report outlines the importance of environmental management strategies as a key tool for water management, reference is made to the major advancements that have been made in the treatment technologies available in Australia and Canada to prevent the generation of acid mine drainage.

DWAF and WRC (1995), make reference to the rehabilitation of open areas by re-vegetation. The catchment has a number of open areas, the introduction of vegetation will serve to retard runoff and increase filtration, thereby decreasing the concentration time, attenuating flood peaks and increasing the period flow. This in turn will have a direct impact on water quality as soil erosion and sediment loads will be reduced. Once vegetation cover has been removed, far greater quantities of salts and sediment are delivered to nearby rivers via surface runoff.

When gold is mined, pyrite existing in the gold reefs is exposed to air and water resulting in pyrite oxidation (Kelly,1988). Acid mine drainage, the product of pyrite

oxidation, is a wastewater high in iron and sulphate and is common in gold mines. IMC 2010, suggests methods such as reverse osmosis or chemical methods such as limestone to treat the problem. According to Pulles, *et al.* (1996), anoxic limestone drains are increasingly being used for treatment of small and large flows from defunct mines where operational and maintenance staff is not available.
Methods such as those described above should be considered in order to address the situation and remediate the problem. The contributing polluters need to accept liability for their actions and if latent impacts exist as a result of their activities then they should provide the financial capability to rehabilitate these water courses. From the above it can be seen that there are solutions to addressing the water quality in Central Rand and these need to be driven by the responsible authorities.

As stated earlier in the problem statement, gold mining and its associated activities are problematic to surface water systems all over South Africa. A significant amount of the pollution is from acid mine drainage and originates from a non-point source. Non-point pollution in the past received little attention from regulatory authorities as it is difficult to measure and control. One of the critical areas highlighted in the IMC 2010, report is the increased awareness of non point pollution in particular the water quality of the smaller river systems which was the focus of the study. Continuous monitoring of water quality and inputting sources is vital in the management of water quality for water sources that are very vulnerable to water pollution.

The impacts of historical mining in the central basin is evident and from the results obtained in this study significant pollution from silicates and pyrites was noted. With very limited active mining, historical and redundant tailings and waste rock facilities are significant contributors of water pollution. According to Davies and Day (1998), the present and future of South Africa's fresh water resources is fundamentally important if the continued existence of both the resource, and the populations reliant on the resource, are to be ensured.

A regression analysis performed to determine if any significant relationship existed between flow and water quality parameter concentration showed that the little to no relationship could be established. The use of river flow was not always possible due to the river flow in the catchment being often restricted and some zero readings obtained for flow thus casting a doubt over the statistical analysis. It would have been ideal to obtain 12 months worth of data but this was not possible due to budget constraints.

The results indicated that metal levels of iron, aluminium, nickel, manganese, potassium were elevated across the Bosmontspruit and Russell's stream. There was significant evidence of raw sewerage being discharged in the Bosmontspruit resulting in excessive faecal coliform levels as well as ammonia and nitrate levels. The impacts from the surrounding mining environment were clearly evident when the results were viewed in detail which supported the research hypothesis. The results were compared with various guidelines to assess compliance. Although the regression analysis did not yield the desired results, review of the correlation coefficient and regression coefficient provided a perspective to determine theoretical proportionality of the data set.

The purpose of the research was to assess the water quality of the Bosmontspruit, Russell's stream and New Canada Dam and encourage the need to develop further studies on the overall river system. In this regard the study has generated a number of questions which can be looked at for future research and which will assist in improving the overall knowledge base which is a fundamental of any research.

During the study it was unearthed that water from the Russell's stream and New Canada Dam are utilised for human and livestock consumption as well as irrigation respectively. A key area of research would be the assessment of these systems for livestock and human consumption and the impacts on the surrounding communities, further to this the bioaccumulation of the contaminants in vegetables and livestock can be looked in more detail as well as the pathways of the pollutants through the food chain.

Gold mining is associated with uranium and subsequent radioactive decay, the radioactive contaminants were excluded from this study and this will be a critical area to look at in the future as well as the levels of alpha, beta and gamma pollutants in water, the study could build on the uptake by plants and livestock of radioactive elements and exposure of the public to the radioactive contaminants that may enter the water course from the redundant tailings facilities.

There is significant evidence going forward to look at the area in more detail from a number of different key environmental perspectives and expand onto a doctoral level of study.

CHAPTER 7. REFERENCES

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Appendix 1: Statistical and raw data for the sampling points

SW01	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	-170.93	368.05	-0.54	0.29
Nitrate	1.72	6.46	0.10	0.01
Faecal coliforms	-401111.41	354384.15	-0.41	0.17
Dissolved oxygen	-1.99	40.74	-0.05	0.00
Potassium	-0.98	6.13	-0.31	0.09

SW01	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**500.00**	**468.00**	**261.67**	**157.33**	**284.33**	**284.00**
Total alkalinity	150.00	203.00	165.00	160.00	130.00	125.00
Chloride	23.20	49.05	31.50	47.50	49.50	32.00
NO3	0.50	0.50	4.35	**15.00**	3.95	**17.00**
Ph	6.90	7.80	7.49	7.73	7.38	7.35
EC (mS/m)	45.00	67.00	17.57	47.73	51.10	44.50
NH4	3.61	1.40	0.69	0.05	0.50	0.93
Total CN	0.25	0.25	0.01	0.01	0.01	0.01
Total hardness	126.00	81.00	120.10	145.00	153.88	145.00
Calcium hardness	73.10	37.00	75.00	76.00	86.14	89.00
Faecal coliforms (CFU/100ml)	**$1.0x10^6$**	$3.0x10^2$	$7.6x10^2$	**$7.0x10^4$**	**$4.6x10^5$**	6.6E+03
Flow (m^3/s)	0.00	0.00	0.99	0.49	0.00	0.00
DO (%)	N/A	**16.90**	**33.50**	**50.40**	**59.20**	N/A
Temperature (℃)	N/A	26.80	19.00	28.40	27.20	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.05	0.05	0.04	0.06	0.27	0.04
Ca	29.30	14.90	30.00	30.50	34.50	35.50
Co	0.05	0.05	0.03	0.03	0.03	0.03
Fe	0.30	0.30	0.58	0.64	1.12	0.91
Mg	12.90	10.66	11.00	17.00	16.50	14.00
Mn	0.07	0.08	0.18	0.21	0.34	0.69
Ni	0.06	0.06	0.06	0.06	0.06	0.06
K	**5.91**	**5.81**	**5.90**	4.15	**5.35**	**8.20**
Au	0.06	0.06	0.06	0.06	0.06	0.06
Na	30.20	16.00	20.00	29.00	35.00	27.00
S	15.00	33.10	13.00	5.80	19.00	4.55
U	0.20	0.20	0.19	0.19	0.19	0.19

SW02	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	-122.23	496.05	-0.37	0.14
Nitrate	3.21	2.79	0.38	0.15
Faecal coliforms	159557.65	209387.67	0.18	0.03
Dissolved oxygen	8.96	9.45	0.80	0.63
Aluminium	-0.75	1.85	-0.18	0.03
Iron	-4.62	11.60	-0.18	0.03
Nickel	-0.03	0.10	-0.34	0.12
Potassium	-1.56	6.27	-0.41	0.17

SW02	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**551.00**	**365.00**	**220.67**	**357.00**	**297.33**	**634.00**
Total alkalinity	135.00	167.00	110.00	140.00	145.00	59.00
Chloride	25.60	51.75	25.50	58.50	39.50	33.50
NO3	0.50	0.50	6.95	**8.80**	4.80	**9.65**
pH	6.90	7.93	7.30	7.14	7.45	6.35
EC (mS/m)	51.00	52.83	15.60	55.70	52.50	59.50
NH4	2.09	1.80	0.08	3.05	0.46	1.10
Total CN	0.25	0.25	0.01	0.01	0.01	0.01
Total hardness	150.00	60.50	117.31	175.00	170.81	200.00
Calcium hardness	87.90	31.50	80.00	90.50	95.36	120.00
Faecal coliforms (CFU/100ml)	**$1.0x10^6$**	$3.0x10^2$	$6.0x10^2$	**$6.0x10^5$**	**$4.0x10^5$**	5.E+01
Flow (m^3/s)	0.42	0.71	0.71	1.69	0.56	0.42
DO (%)	N/A	**10.90**	**19.20**	**24.80**	**15.80**	N/A
Temperature (℃)	N/A	24.50	17.90	25.00	23.10	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.06	0.05	0.04	**1.20**	**1.05**	**5.30**
Ca	35.20	12.60	32.00	36.00	38.00	46.00
Co	0.05	0.05	0.03	0.03	0.03	0.09
Fe	0.30	1.19	1.10	**7.30**	**6.85**	**32.00**
Mg	15.20	7.05	9.10	21.00	18.00	21.00
Mn	0.07	0.13	0.45	0.59	0.51	1.15
Ni	0.06	0.06	0.06	0.06	0.06	**0.17**
K	**6.08**	4.06	2.90	4.45	4.95	**8.15**
Au	0.06	0.06	0.06	0.06	0.06	0.06
Na	25.30	14.40	12.00	33.00	29.00	26.00
S	30.10	19.95	18.00	11.50	30.50	21.00
U	0.20	0.20	0.19	0.19	0.19	0.19

SW03	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	2.77	547.87	0.00	0.00
Nitrate	-5.23	6.31	-0.56	0.31
Faecal coliforms	65051.68	9491.60	0.87	0.75
Dissolved oxygen	-15.03	16.98	-0.35	0.12
Aluminium	-11.42	13.07	-0.24	0.06
Iron	-9.75	11.56	-0.34	0.11
Nickel	-0.43	0.80	-0.13	0.02
Potassium	4.79	4.17	0.78	0.61
pH	0.15	6.54	0.04	0.00
Conductivity	-7.14	65.07	-0.06	0.00
Ammonia	1.02	1.90	0.20	0.04
Cobalt	-0.27	0.37	-0.19	0.03
Manganese	-1.21	1.79	-0.22	0.05
Uranium	-0.13	0.35	-0.19	0.04

SW03	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**551.00**	**319.67**	**219.33**	**1,398.67**	**375.67**	**426.00**
Total alkalinity	48.00	147.00	125.00	10.00	125.00	76.50
Chloride	20.60	42.30	25.00	10.75	41.50	32.50
NO3	0.40	0.50	5.05	6.65	**11.50**	**7.85**
pH	6.70	7.67	7.46	**3.16**	7.54	6.85
EC (mS/m)	57.00	45.50	14.17	**173.97**	43.70	48.00
NH4	3.06	2.15	**6.20**	0.09	0.41	0.67
Total CN	0.25	0.25	0.01	0.19	0.01	0.01
Total hardness	174.00	50.00	114.85	270.00	168.36	180.00
Calcium hardness	127.00	28.50	80.00	145.00	97.15	110.00
Faecal coliforms (CFU/100ml)	**$8.3x10^4$**	$4.8x10^1$	$1.1x10^3$	0.0	**$4.4x10^4$**	2,450.00
Flow (m^3/s)	1.13	0.00	0.00	0.00	0.00	0.00
DO (%)	N/A	**5.60**	**10.90**	**52.60**	**15.80**	N/A
Temperature (℃)	N/A	22.80	17.60	28.10	23.20	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.16	0.05	**8.90**	**55.00**	**0.70**	**0.69**
Ca	50.90	12.05	32.00	58.00	39.00	44.00
Co	0.06	0.05	0.04	**1.70**	0.03	0.03
Fe	0.54	1.21	**11.00**	**36.00**	**5.65**	**3.95**
Mg	11.50	5.16	8.50	33.50	17.00	17.00
Mn	0.42	0.13	0.63	**6.75**	0.54	0.90
Ni	0.32	0.06	0.08	**3.75**	0.06	0.06
K	9.59	2.31	3.00	4.35	3.75	**7.45**
Au	0.06	0.06	0.06	0.27	0.06	0.06
Na	18.30	13.20	11.00	52.00	26.50	24.00
S	73.80	13.45	19.00	115.00	29.50	10.50
U	0.20	0.20	0.19	**0.96**	0.19	0.19

SW04	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	-182.31	918.60	-0.29	0.09
Nitrate	-0.29	5.37	-0.08	0.01
Faecal coliforms	5675.89	-5319.56	0.45	0.21
Dissolved oxygen	-21.83	74.87	-0.86	0.75
Aluminium	3.89	1.15	0.13	0.02
Iron	-1.60	24.75	-0.03	0.00
Nickel	0.00	0.72	0.00	0.00
Potassium	2.24	2.54	0.32	0.10
pH	0.54	4.99	0.28	0.08
Alkalinity	-3.25	45.97	-0.07	0.00
Ammonia	6.73	3.95	0.13	0.02
Cobalt	0.05	0.30	0.08	0.01
Manganese	0.12	2.90	0.03	0.00
Uranium	0.06	0.20	0.14	0.02

SW04	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**386.00**	**716.33**	**286.33**	**523.00**	**756.67**	**1,228.00**
Total alkalinity	**17.00**	30.50	54.50	69.00	66.00	**10.00**
Chloride	8.90	26.00	25.00	36.00	20.00	27.50
NO3	**7.70**	5.00	4.75	**1.50**	5.15	**5.55**
pH	**5.60**	**4.83**	6.93	6.67	6.36	**4.30**
EC (mS/m)	43.00	76.80	23.30	74.60	63.20	130.00
NH4	1.87	3.70	3.50	1.01	1.75	**71.50**
Total CN	0.25	0.25	0.01	0.02	0.01	0.01
Total hardness	124.00	130.00	194.77	205.00	255.61	430.00
Calcium hardness	91.70	91.50	155.00	110.00	169.75	280.00
Faecal coliforms (CFU/100ml)	1.1×10^1	0.0	1.1×10^3	**1.7×10^4**	4.5×10^2	0.0
Flow (m^3/s)	1.97	0.66	1.64	1.97	0.98	1.64
DO (%)	N/A	**60.90**	**49.60**	**25.00**	**49.40**	N/A
Temperature (℃)	N/A	21.80	18.60	21.20	20.90	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.14	0.40	0.04	0.41	**1.35**	**39.00**
Ca	36.70	36.70	62.00	44.00	68.00	110.00
Co	0.17	0.23	0.20	**0.29**	**0.34**	1.00
Fe	0.30	**13.75**	**2.30**	**19.00**	**26.00**	**73.00**
Mg	7.89	9.39	9.70	23.00	21.00	36.00
Mn	1.01	1.74	1.20	**4.15**	**4.30**	**6.10**
Ni	**0.38**	**0.55**	**0.27**	**0.50**	**0.69**	**1.90**
K	3.62	3.36	4.00	**7.05**	4.10	**13.00**
Au	0.06	0.06	0.06	0.23	0.06	0.06
Na	9.05	13.35	15.00	33.50	18.50	34.50
S	63.00	138.00	65.00	35.00	120.00	90.50
U	0.20	0.20	0.19	0.19	0.19	**0.73**

SW05	**Regression Coefficient**	**Intercept**	**Correlation coefficient**	**Coefficient of determination**
Total dissolved solids	64.12	398.88	0.34	0.11
Nitrate	-0.14	5.40	-0.14	0.02
Faecal coliforms	934.98	-148.58	0.29	0.08
Dissolved oxygen	-3.76	66.75	-0.60	0.36
Aluminium	3.94	-7.11	0.58	0.34
Iron	9.28	-7.19	0.66	0.43
Nickel	0.19	0.08	0.59	0.35
Potassium	1.36	1.34	0.61	0.37
pH	-0.05	5.74	-0.11	0.01
Alkalinity	-2.97	30.88	-0.45	0.20
Ammonia	9.55	-14.64	0.56	0.32
Cobalt	0.12	0.00	0.66	0.44
Manganese	1.17	0.06	0.84	0.70
Uranium	0.06	0.09	0.54	0.29

SW05	**Oct-10**	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
TDS	**366**	**703.67**	**471.67**	**456.00**	**333.00**	**1384.00**
Total alkalinity	22	20.00	47.00	**10.00**	**14.00**	**11.00**
Chloride	7.1	37.40	25.00	37.50	12.00	29.00
NO3	**7.8**	4.05	5.05	1.85	3.90	6.75
pH	**5.9**	**4.83**	6.51	6.45	**5.44**	**4.35**
EC (mS/m)	30	84.13	21.63	76.33	52.63	130.00
NH4	2.02	**4.45**	3.50	**6.25**	2.70	**90.00**
Total CN	0.25	0.25	0.01	0.01	0.01	0.01
Total hardness	87.1	146.00	162.60	210.00	183.48	410.00
Calcium hardness	63	101.50	117.50	110.00	126.61	265.00
Feacal coliforms (CFU/100ml)	0	0.00	1.00	515.00	0.50	0.00
Flow (m^3/s)	1.852	0.46	2.78	4.63	5.09	5.79
DO (%)	N/A	**60.90**	**67.10**	**36.60**	**53.70**	N/A
Temperature (℃)	N/A	21.80	18.40	22.00	20.40	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.38	0.40	0.04	**1.10**	**1.70**	**35.00**
Ca	25.20	40.55	47.00	45.00	51.00	110.00
Co	0.12	**0.27**	0.25	**0.39**	**0.33**	**1.20**
Fe	0.30	**17.30**	**5.40**	**20.00**	**23.50**	**81.50**
Mg	5.86	10.80	11.00	23.00	14.00	36.00
Mn	0.86	2.59	1.50	**6.20**	**5.05**	**8.20**
Ni	**0.25**	**0.60**	**0.37**	**0.61**	**0.54**	**2.10**
K	3.24	4.03	3.70	**7.15**	2.95	**15.00**
Au	0.06	0.06	0.06	0.10	0.06	0.06
Na	6.26	15.70	13.00	35.50	10.50	36.00
S	40.10	158.00	59.00	38.50	87.00	92.50
U	0.20	0.20	0.19	0.19	0.19	**0.73**

SW06	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	-6.78	360.28	-0.21	0.05
Faecal coliforms	-110785.81	149791.93	-0.44	0.19
Dissolved oxygen	-15.38	82.35	-0.58	0.34

SW06	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**342.00**	**377.00**	**339.67**	**339.67**	**349.00**	**384.00**
Total alkalinity	63.00	132.00	165.00	180.00	120.00	210.00
Chloride	14.30	36.25	25.00	24.50	9.88	33.00
NO3	14.80	6.15	5.20	5.45	4.30	0.40
Ph	7.10	8.18	7.73	7.91	6.77	7.75
EC (mS/m)	30.00	50.70	17.60	48.30	49.63	58.50
NH4	0.75	0.45	2.40	0.22	0.31	0.11
Total CN	0.25	0.25	0.01	0.01	0.01	0.01
Total hardness	105.00	78.50	146.70	170.00	196.30	260.00
Calcium hardness	60.90	44.00	97.50	85.50	110.75	170.00
Feacal coliforms (CFU/100ml)	**$3.9x10^5$**	$4.9x10^1$	$3.3x10^2$	$7.0x10^2$	$4.2x10^3$	$8.3x10^3$
Flow (m^3/s)	0.18	0.70	0.61	0.79	1.93	0.26
DO (%)	N/A	88.30	**71.20**	**54.20**	**53.70**	N/A
Temperature (℃)	N/A	20.90	17.70	20.30	20.40	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.05	0.05	0.04	0.26	0.42	0.42
Ca	24.40	17.65	39.00	34.00	44.00	69.00
Co	0.05	0.05	0.03	0.03	0.03	0.03
Fe	0.30	0.30	0.25	0.66	1.10	0.89
Mg	10.80	8.28	12.00	21.00	21.00	21.00
Mn	0.07	0.07	0.06	0.61	1.65	0.78
Ni	0.06	0.06	0.06	0.06	0.07	0.06
K	4.57	2.35	4.00	4.30	4.10	8.60
Au	0.06	0.06	0.06	0.06	0.06	0.06
Na	9.61	7.61	13.00	17.00	16.50	24.00
S	19.10	31.40	17.00	11.00	37.00	11.00
U	0.20	0.20	0.19	0.19	0.19	0.19

SW07	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	-103.45	669.93	-0.57	0.32
Nitrate	0.06	6.22	0.03	0.00
Dissolved oxygen	-4.40	63.96	-0.59	0.35
Potassium	-0.44	5.77	-0.26	0.07

SW07	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**361.00**	**441.67**	**229.00**	**270.33**	**387.33**	**914.00**
Total alkalinity	68.00	106.00	145.00	92.00	75.00	140.00
Chloride	14.20	34.40	26.00	24.00	20.50	30.50
NO3	**10.20**	**8.80**	3.80	5.70	6.40	3.20
pH	6.70	7.58	7.88	7.80	6.20	6.15
EC (mS/m)	32.00	62.13	17.03	49.00	62.53	96.00
NH4	0.47	1.05	1.90	0.80	2.85	**39.08**
Total CN	0.25	0.25	0.01	0.01	0.01	0.01
Total hardness	115.00	78.50	144.20	175.00	228.88	280.00
Calcium hardness	66.00	44.00	95.00	86.00	142.80	190.00
Feacal coliforms (CFU/100ml)	**$2.4x10^5$**	$3.0x10^2$	$2.1x10^2$	$8.2x10^3$	$8.3x10^3$	$3.5x10^2$
Flow (m^3/s)	2.74	1.52	2.74	4.56	0.91	1.22
DO (%)	N/A	**70.00**	**51.80**	**41.80**	**49.40**	N/A
Temperature (℃)	N/A	22.50	17.80	20.50	20.90	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.06	0.05	0.04	0.37	0.38	0.04
Ca	26.40	17.70	38.00	34.50	57.00	75.50
Co	0.05	0.05	0.03	0.03	0.03	0.03
Fe	0.30	0.30	0.25	0.69	0.95	0.42
Mg	11.90	8.40	12.00	21.00	21.00	22.00
Mn	0.07	0.07	0.06	0.82	1.80	0.59
Ni	0.07	0.06	0.06	0.06	0.07	0.06
K	4.59	2.38	3.60	4.35	4.60	**9.05**
Au	0.06	0.06	0.06	0.06	0.06	0.06
Na	10.20	7.63	12.00	17.50	17.00	25.50
S	22.00	31.45	18.00	11.00	36.50	11.00
U	0.20	0.20	0.19	0.19	0.19	0.19

SW08	Regression Coefficient	Intercept	Correlation coefficient	Coefficient of determination
Total dissolved solids	-1.03	512.38	-0.05	0.00
Alkalinity	-0.25	25.76	-0.21	0.04
Nitrate	0.00	1.38	0.00	0.00
pH	-0.08	8.73	-0.39	0.15
Dissolved oxygen	-0.47	75.32	-0.90	0.80
Iron	0.16	0.64	0.48	0.23
Nickel	0.00	0.28	-0.16	0.03
Potassium	0.11	3.94	0.38	0.14
Cobalt	0.00	0.15	-0.13	0.02
Manganese	0.00	3.31	0.00	0.00

SW08	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
TDS	**397.00**	**744.33**	**377.33**	**489.67**	**424.67**	**526.00**
Total alkalinity	**19.00**	35.50	23.50	23.00	**14.00**	**12.00**
Chloride	23.40	38.30	22.00	25.50	24.50	14.50
NO3	**2.90**	0.50	**2.95**	0.40	0.40	1.20
pH	**10.10**	6.85	7.14	6.40	6.88	6.25
EC (mS/m)	0.60	99.87	24.67	70.67	68.20	63.00
NH4	**4.73**	**5.60**	2.85	**9.40**	**4.15**	2.05
Total CN	0.25	0.25	0.01	0.01	0.01	0.01
Total hardness	309.00	124.50	206.70	200.00	263.08	265.00
Calcium hardness	190.00	91.00	157.50	120.00	181.96	200.00
Faecal coliforms (CFU/100ml)	5.00	2.00	0.00	0.00	77.50	0.00
Flow (m^3/s)	15.27	13.47	19.76	26.94	9.88	26.94
DO (%)	N/A	**71.40**	**65.10**	**62.60**	**69.10**	N/A
Temperature (℃)	N/A	19.30	17.40	21.50	20.60	N/A
	Oct-10	**Nov-10**	**Dec-10**	**Jan-11**	**Feb-11**	**Mar-11**
Al	0.09	0.05	0.10	0.07	0.04	0.04
Ca	76.10	36.40	63.00	48.00	73.00	81.00
Co	**0.30**	0.05	0.10	0.09	0.08	0.09
Fe	0.30	1.42	**4.40**	**4.05**	**5.05**	**6.85**
Mg	28.90	8.24	12.00	19.00	20.00	15.50
Mn	**5.30**	1.56	2.00	3.30	3.90	3.85
Ni	**0.57**	0.06	0.13	0.17	0.15	0.12
K	**9.07**	3.84	4.40	6.10	4.80	**8.25**
Au	0.06	0.06	0.06	0.06	0.06	0.06
Na	38.70	17.55	15.00	29.00	22.00	20.00
S	182.00	140.00	74.00	39.00	120.00	35.50
U	0.20	0.20	0.19	0.19	0.19	0.19

Appendix 2: Ethics clearance letter and consent forms

UNISA university of south africa

2011-06-06

Ref. Nr.: 2011/CAES/018

To the student: **Student nr: 40761487**
Mr D Muruven
Department of Environmental Sciences
College of Agriculture and Environmental Sciences

Dear Mr D Muruven

Request for Ethical approval for the following research project:

An evaluation of the impacts of cumulative surface water pollution within the consolidation Main Reef Area, Roodepoort, SA

The application for ethical clearance in respect of the above mentioned research has been reviewed by the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa.

The committee is pleased to inform you that ethical clearance has been granted for the research set out in the Ethics application (Ref. Nr.: 2011/CAES/018) submitted and additional documents attached to the application.

Please be advised that the committee needs to be informed should any part of the research methodology as outlined in the Ethics application (Ref. Nr.: 2011/CAES/018), change in any way. Should that be the case, a new application, for the amendments, needs to be submitted to the Ethics Review Committee for review.

We trust that sampling, data gathering and processing of the relevant data will be undertaken in a manner that is respectful of the rights and integrity of all participants, as stipulated in the UNISA Research Ethics Policy.

The Ethics Committee wishes you all the best with this research undertaking.

Kind regards,

Prof E Kempen
CAES Ethics Review Committee Chair

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsmile: +27 429 12 429 4150
www.unisa.ac.za

Information & Consent Form

Date: 03/06/2010

Title of Project: An evaluation of the impacts of cumulative surface water pollution within the consolidated main reef area, Roodepoort South Africa

Faculty Supervisors: Dr. Tekere, Dept of Environmental Sciences, Tel +27 11 471 2270
email: tekerm@unisa.ac.za or memotek2000@yahoo.com

Student Investigators: Dean Muruven, Dept of Environmental Sciences, email: dean.muruven@centralrandgold.com

Study Overview

I am a Master's student in the Department of Environmental Science at the University of South Africa conducting research under the supervision of Dr. Tekere.

I will be conducting monthly water sampling at the points illustrated below. The sample points fall within the tenement boundary of your mine. Samples will be analysed by a SANAS accredited laboratory and the results will be used to determine to current water quality of the current catchment.

Sample code	Sample coordinates
SW01	26°11'30.12"S, 27°57'19.44"E
SW02	26°11'44.52"S, 27°57'0.72"E
SW03	26°12'9.00"S, 27°56'58.92"E
SW04	26°13'28.80"S, 27°59'44.76"E
SW05	26°13'10.14"S, 27°59'12.42"E
SW06	26°12'51.12"S, 27°56'18.24"E

What You Will Be Asked to Do

You will be asked to provide access to the above mentioned sampling points on a monthly basis for the period of a year, commencing June 2010.

Personal Benefits of the Study

As a key stakeholder within the region it is important that your impacts or lack thereof on the water courses be defined, thus the study will provide you with such information.

Risks to Participation in the Study

There are no risks in participating in this study as all information obtained will be used for academic purposes.

Confidentiality

All information obtained from the study will be viewed by the researcher and the supervisor for academic purposes only.

Questions and Research Ethics Clearance

If after receiving this letter, you have any questions about this study, or would like additional information please feel free to ask the student investigator or a faculty supervisor listed at the top of this sheet.

I would like to assure you that this study has been reviewed and received ethics clearance.

Thank you for your interest in our research and for your assistance with this project.

Consent of Participant

I have read the information presented in the information letter about a study being conducted by Dean Muruven under the supervision of Dr. Tekere of the Department of Environmental Science at the University of South Africa. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

This project has been reviewed by, and received ethics clearance.

With full knowledge of all foregoing, I agree that Central Rand Gold SA (PTY) Ltd is aware of the research and agree to participate in this study.

Jenny Johnson
____
Print Name

____
Signature of Management Representative on behalf of CRG SA

03/06/2010
____
Dated at Roodepoort

____
Witnessed