Determination of coal mine impacts on surface water bodies (Olifants River)

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ABSTRACT

The purpose of the study was to determine the impact of a coal mine on the water quality quaternary catchment B11J. The study area is situated in quaternary catchment B11J of the Olifants Water Management Area. The objectives of the study were to (i) to compare the surface water quality upstream and downstream of the mine in the Olifants River; (ii) to examine the pathways and factors that can contribute to the contamination of the water from the mine flowing into Olifants River.

In order to achieve objective (i), surface water was sampled upstream and downstream of the mine, during the summer and winter season in 2015. The pH and electrical conductivity of surface water samples were within SANS 241 specifications. A Piper diagram and durov diagram were also used to analyse the character of the surface water samples.

Objective (ii) was achieved by conducting field investigations, specifically of the coal washing plant, stockpile area, mining area (opencast pit) and pollution control dam. The investigation found that contaminated water from the stockpile area, washing plant and open pit is disposed into a lined pollution control dam and re-used for dust suppression on haul roads. Berms and trenches were constructed upstream and downstream of the mine to divert clean storm-water away from the mine. A simplified surface water model was constructed to determine the possible migration of pollution. A groundwater study was conducted to determine the groundwater level and contour lines on site as well as any possible seepage of polluted groundwater into the Olifants River.

The results of the particle tracking exercise indicate that the surface flow will drain towards the Elandspruit tributary from the mining area. The flood lines also show that the mine infrastructure is outside of 100 years flood lines. Groundwater levels were found vary from 1.6 mgbl to 51.1 mbgl. The contour lines were indicating that the groundwater flow is heading in a westerly direction from the watershed towards Elandspruit tributary of the Olifants River. It is important for the mine to monitor both ground and surface water upstream and downstream of the mine in order to monitor the contamination trends.

Key Words: Contaminated surface water, pH, Sulphates, Olifants River, Heavy Metals, Coal mine and Groundwater levels.

ABBREVIATION

AMD: Acid Mine Drainage
CER: Centre for Environmental Rights
CSIR: Council for Scientific Industrial Research
DEAT: Department of Environmental Affairs and Tourism
DWA: Department of Water Affairs
DWAF: Department of Water and Forestry
DWS: Department of Water and Sanitation
EC: Electrical Conductivity
GIS: Geographic Information System
Mamsl: Meters above mean sea level
Mbgl: Metres Below Ground Level
PCD: Pollution control dam
pH: Potential Hydrogen
SANS: South African National Standard for Drinking Water
SANRAL: South African National Road Agency Limited
TDS: Total Dissolved Solids
WMA: Water Management Area
WWTWs: Waste Water Treatment Works

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Introduction

Surface water pollution can be defined as the pollution of aquatic systems such as rivers, lakes and streams. The contamination of surface water can be the result of both non-point source and point source pollution. Point source contamination may be discharged deliberately and illegally, or even accidentally and are relatively easy to measure and control (Davies & Day 1998). Non-point source contamination occurs when toxic substances enter surface and underground water through for example runoff from urban and industrial areas, leaching from domestic and solid waste disposal sites and seepage from mines. These are very difficult to quantify and control and there is little or no data available in South Africa due to the irregular discharges of non-point source contamination (Roux, 1994; Heath & Claassen 1999; Dallas & Day 2004). In South Africa, pollution has been found as one of the main pressures affecting freshwater systems (Young, 2001).

Water is essential for life. Water is a prerequisite for development in the world, especially mining industries. Coal mining is one of biggest industries polluting water resources in the world. Water resources can be either ground or surface water. Living organisms are depending on both surface and groundwater for living. Coal mines affect water resources when it releases large volume of contaminated water. These discharges can be either via through pipeline or channel. Seepage from for example, tailings and waste rock facilities can also result in pollution. Increasingly, mining threatens the water resources on which people depend.

There are various types of water contamination from mining for example: heavy metal contamination, processing chemicals; erosion and sedimentation. Another concern is Acid Mine Drainage (AMD) from historic and present mines. Acid Mine Drainage is a process which is formed when sulphide bearing minerals are exposed to air and water (Eutech, 1997).

1.2 Motivation

There are extensive opencast and underground coal mines within the Olifants River Water Management Area (WMA). The Olifants River has been affected since 2004 after mining industries started discharging more than 50 000 m^3/d of contaminated water (Centre for Environmental Rights (CER), 2016). Coal Mine X is situated close to the Olifants River. It is a concern that waste water from the mine can affected the surface water and groundwater quality. Other water users in the area can then be negatively impacted as the water is that is used for domestic use, watering livestock and irrigation is now contaminated (Wamsley & Mazury, 1999).

Apart from mining impact, other land uses such as agricultural practices and treatment of waste water also affects the surface water quality on the catchment. Salinity and eutrophication are also problems in the study area. These problems affect surface water when agricultural farmers and sewage treatment plants release high volumes of water contaminated with fertilizers and raw sewer (DWA, 2011). However, it is important to note that these impacts are not taken into consideration in this study.

The study of coal mine impacts on the natural environment is essential, especially in the Mpumalanga Province where surface water is highly contaminated due to mining activities taking place in the province (DWA, 2011). This study focussed on the impact that Coal Mine X has on the water quality of Olifants River.

1.3 Aim and objectives

1.3.1 Aim of the research

The aim of this study is to determine the impacts of a coal mine activities on water quality of the Olifants River.

1.3.2 Objectives of the research

The objectives of the study include:

- Comparing water quality of upstream and downstream of mine and upstream of the Olifants River.
- To examine pathways and factors which contribute to the contaminated water from the mine flowing into the Olifants River.

1.3.3 Research questions

- What is the difference in water quality upstream and downstream of mining area?
- How does the water from the mining area reach the Olifants River?
- What are the factors that contribute to contaminated water flowing into the River?

These questions are addressed for the operational phase of the mine.

1.4 Layout of mini-dissertation

The layout of this mini-dissertation is as follows:

- Chapter 1 includes a background, motivation as to why the study is important. The aims and objectives are also discussed.
- Chapter 2 focuses on a literature review of all information/methods that can be used in the study and relevant case studies.
- Chapter 3 discusses the study area, including the location, climate, surface water drainage, geology and land use.
- Chapter 4 introduces the proposed methodology based on the literature survey.
- Chapter 5 includes the results of the followed methodology and a discussion of these results.
- Chapter 6 includes conclusions made based on the results. Recommendations are then provided, including further research.

CHAPTER 2: LITERATURE REVIEW

2.1 Potential contamination sources

As mentioned in the previous chapter, there are two types of contamination sources, namely (i) non-point source contamination. This type of water contamination is generally results from land runoff, precipitation, drainage, seepage or hydrologic modification; (ii) Point source water contamination is defined as discharges which enter water bodies from an easy identified single source such as a pipe or canal (Hanley *et al*., 2001). More details of non- point source and point source water contamination are described in the following sections.

2.1.1 Settlements

The population growth of quaternary catchment of B11J is affecting the water resource in a negative way. Both formal and informal settlements are using contaminated water due to poor design of sanitation and low standard of water supply. In the study area, urban developments are taking place within the watercourse of the River. These developments are putting the water resource under pressure. Informal settlements are still using pit toilets which affect the groundwater. The typical types of environmental impact arising from dense settlement pollution are sedimentation, faecal pollution and Eutrophication. The impacts of sedimentation, faecal pollution and Eutrophication on the economic activities of downstream users can be dramatic (Department of Water Affairs (DWA), 2011).

2.1.2 Waste disposal and Waste Water Treatment Works (WWTW)

The study area contains landfill sites and waste water treatment works which are poorly managed. Both activities do not have a monitoring system to determine the level of both ground and surface pollution. Most of the polluting materials are washed to the river during rain seasons (Department of Environmental Affairs and Tourism (DEAT), 2007).

Waste water treatment works are facing the challenge of heavy loads of waste as the result of population growth. The plants are failing to treat polluted waste in a sustainable manner. Some of the industries are discharging untreated waste to the municipal system which ends up in the river. The discharge of untreated raw sewer can lead to eutrophication (DEAT, 2007).

2.1.3 Industry and mining

The water quality of quaternary catchment B11J is dominated by the intensive coal mining activities. Mining and industrial sectors are discharging contaminated or polluted water to river system in order to balance the load of contaminated water disposed into containing facilities. Both sectors are failing to treat affected water due to poor design ad failure of treating facilities. The discharged affected water is dominated by anions and cations. Middleburg Dam is receiving affected water which contains high volume of sulphates and magnesium. The water quality of Wilge River is still safe to use unlike the water from Witbank Dam and Middelburg Dam (DWA, 2011).

2.1.4 Agriculture

The impact of agricultural drainage as a result of agricultural activities has a significant impact on water quality. Agricultural farmers in quaternary catchment B11J are using fertilizers which can have negative impacts to the environment. These fertilizers find their way to the river during rainfall season. Effluents from animal husbandry locations such as feedlots, piggeries, dairies and chicken farms, also contribute to contamination (DEAT, 2007).

2.2 Case studies

A study was conducted by George *et al.,* (2010) to review the effects of mining on water resources in South Africa. In this study, AMD was found to be the biggest environmental problem in the mining industry. The water quality samples collected from Blesbok spruit, Klip spruit and Wonderfontein spruit were found to be above the South African National Standard for Drinking Water 241 due to the presence of AMD.

Kgari *et al.*, 2016, conducted a study in Witbank using the tracer test technique on abandoned coal mines. The data were collected at discharge points. The objective of the study was to classify the different water types as pre- assessment for using tracer techniques. The results show that the water samples collected at the discharge point have high concentrations of major elements such as sulphate, chloride, sodium, aluminium, potassium and calcium.

McCarthy (2011) conducted research about the impact of AMD in South Africa. The methodology used was to collect water samples from different mines across Mpumalanga and other mining operations in South Africa and observe how contaminated water is polluting clean water. He observed that some of the polluted mine waters entering the tributaries of the Olifants River, where pollution load was reduced by dilution and various chemical and biological reactions.

Tutu *et al*., (2008) analysed the chemical characteristics of AMD on water resources. The aim of the study was to identify the sources and distribution and effects of AMD on surface water quality. The researcher found that oxidation of pyrite is the main cause of acid mine drainage. Pyrite is defined as small brass yellow mineral with a bright metallic luster. It has chemical contents of iron disulphide. The researcher results indicate that pollution loads were significant at the end of rainy season due to the rise of water table (Tutu *et al*. 2008).

Hoehn and Sizeremore (1999) conducted research relating pollution of a small Virginia stream in United State of America. The aim was to know the characteristics of AMD and its impact on the stream, with the objective to examine water pH, and aluminium concentrations and the total hardness to see how this will affect water quality. The methodology used was to collect water samples and analyze the samples to find chemical characteristics/chemicals present in the water. It was found that even after complete neutralisation of acidity in mine waters, residual pollution still exists in the form of dissolved sulphate.

Acantiaco (2004) conducted hydro-chemical study to determine the impact of contaminated water from the coal mines to the quality of surface water. The results of the study indicate that sulphate and metal concentration can have potential impacts to the quality of surface water. The parameters were analysed to determine the influence of coal mines to deteriorate the quality of surface water. The data was collected from abandoned mines in Serbia (Acantiaco, 2004).

Titrus (2004) conducted research at the Callahan mine in Dartmouth. The study concentrated on the metal ore mine's impact on the marine estuary, finding high levels of copper, zinc, cadmium and lead in the sediment, water and small fish. The methodology used was to collect water samples for testing. Fish and other aquatic animals in the water were observed and researched to see if water contains high levels of heavy metals that affect normal living conditions of the fish. It was discovered that the levels of toxic metals in killing fish were high enough to have an impact on larger fish like striped bass and tautog that feed on them, increasing the potential for harm to humans.

Tiwary and Dhar (1994) investigated how the Damodar River Basin in India was polluted from coal mining activities. Water samples were taken upstream and downstream of the mining area and analysed to see if there was a change in water characteristics. It was found that when coal surfaces are exposed, pyrite comes in contact with water and air and forms sulphuric acid.

Dahrazma and Kharghani (2012) have conducted research to assess the impacts of alkaline mine drainage on barium, chromium, nickel and zinc in the water resources of the Takht Coal Mine, Iran. Samples were collected from surface water resources upstream and downstream of the mine and analysed. The results indicated that an alkaline environment was responsible for producing alkaline mine drainage due to the presence of limestone. Increased barium concentrations in water resources was due to high barium concentrations in the coal, coal tailing and in quarry tailings. Electrical conductivity has increased downstream of the mine due to the high concentration of heavy metals and ions (Dahrazma & Kharghani, 2012).

Atanackovic *et al.*, 2013, investigated the effects of grey water from mines in Serbia. The purpose of the study is to determine effects of contamination water on surface water quality. Discharge points, upstream of river and downstream of the mine were used to collect surface water quality data. Sulphate was identified to be higher and is decreasing quality of surface water of the area.

A multivariate statistical method was used in China to identify the trace elements of surface water quality of Huaihe River (Wang *et.al*, 2017). The water quality data was analysed into three groups of water contamination. The purpose of the study was to identify the source, and health effects of the trace elements. The results were compared with the national and international drinking water guidelines. The methodology reveals that the surface water of the study is highly affected by trace elements (Wang *et.al*, 2017).

Sener *et al.*, 2017, conducted a study in Turkey to evaluate the water quality of the Aksu River. Geographic Information Systems (GIS) and a water quality index were used in the analyses. Physical and chemical analyses of water samples were collected along the path of the River. The results were compared with permissible limits recommended by the World Health Organization and Turkish drinking water standards. The water quality index method was also used to evaluate water quality for drinking purposes. The results indicated that the water quality was very poor.

2.3 Surface water model methods

It is common knowledge that in South Africa, rainfall does not occur in average amounts throughout the year but occurs on a seasonal basis. In general, the South African rainfall can be very erratic and unpredictable on a year-to-year basis, but also between thunderstorms. One thunderstorm may be relatively small or average and the next one could cause a severe flood (Dennis & Dennis, 2012). As a result, contaminated areas can be flooded.

Then, once in a while a storm will occur which will exceed the average rainfall by a massive amount. For this reason and as far as mining is concerned, in terms of Government Notice GN704 of the National Water Act of 1998 (Act 36 of 1998), both the 50- and 100-year return period rainfall events must be modelled and indicated on maps.

However, in cases where the catchment of a stream is relatively small (such as the Elandspruit in the vicinity of the study area) there is almost no difference between the 50- and 100-year flood lines, often only a few centimetres vertically. Subsequently, only the 100-year flood lines will be modelled.

Perlman, 2008, defines a 100- year flood event which has a 1 percentage possibility of taking place in 12 months. Frequency analysis is a method used to calculate the possible occurrence on a given time. Flood water level can be calculated as an area covered by water. The resulting floodplain map is referenced as the 100-year floodplain, which may be very important in how close to the stream buildings or watercourse (Perlman, 2008).

The first part of the process comprises the modelling of a series of “design storms” with a statistical return period of 100-years and durations. If a catchment is smaller than approximately 50 km², design storms are derived using a deterministic approach, as opposed to the purely statistical methods used for larger catchment areas (i.e. catchments over 50 km²). The conventional procedure is to employ the Rational Method from which the discharge is calculated (SANRAL, 2013). The calculated discharge produced by the design storm is then routed through cross sections across the stream, from which resulting flood lines are produced.

2.4 Groundwater model methods

2.4.1 Conceptual model

A conceptual model is necessary to identify the factors that influence groundwater flow and contamination. A conceptual model incorporates simplified conditions for the problem at hand. These simplifications must be realistic taking into account the modelling objectives and probable predictive scenarios. Once the conceptual model has been completed, the data is included in a numerical model, which in general which can then be solved using existing computer software. It is however important that one understands that a model is only representation of the real system.

It is therefore at most an approximation and the level of accuracy depends on the quality of the data that is available. This implies that there are always errors associated with models due to uncertainty in the data and the capability of numerical methods to describe natural physical processes. Normally models are the best tool available to quantify water flow and associated water quality, which can be used to make decisions. The models in this investigation should therefore be seen as a prospective evaluation tools to determine the potential behaviour of the system with time and space, given a set of changing parameters.

2.4.2 Numerical modelling

A groundwater numerical model is a conceptual description of the physical system, described by mathematical equations. Numerical modelling is an accepted practice used to predict and assess an aquifer’s response to changing environmental conditions, usually as a result of anthropogenic activities (Fetter, 2001).

There are a number of numerical modelling packages available, the complexity of which differs. According to Spitz & Moreno (1996) main components of any numerical model are:

- Compiling and interpreting field data
- Understanding the natural system
- Conceptualising the groundwater system
- Selecting the numerical model
- Calibrating the model
- Applying the model
- Presenting the results

It is however important to note that there are always assumptions that have to be made when creating a numerical flow and/or mass transport model.

One of the first steps in groundwater modelling (flow and mass transport) is to identify an area to be modelled and its associated boundaries. This boundary forms the interface between the model area and the surrounding environment. Typical boundaries include fixed hydraulic head, groundwater flux and head dependent flux boundaries. Initial conditions are important for modelling transient flow problems. Generally, measured head distribution serves as the initial conditions. Normally these values have to be interpolated for the area. Additional information that needs to be included in the model:

- Aquifer layers
- Type of aquifer (e.g. confined/unconfined)
- Groundwater recharge
- Hydraulic conductivity/transmissivity
- Specific storage/storativity and or specific yield
- Porosity
- Source terms
- Dispersivity values
- Chemical reactions

CHAPTER 3: STUDY AREA

3.1 Location of the study area

The Olifants River originates at Trichardt to the east of Johannesburg. It flows northwards before gently curving in an eastwards direction through Kruger National Park and into Mozambique. The Olifants River joins the Limpopo River before discharging into the Indian Ocean. It falls within three provinces (Mpumalanga, Gauteng and Limpopo). The main tributaries to the Olifants River are Wilge River, Elands River, Ga-Selati River, Klein Olifants, Steelpoort, Blyde, Klaserie and Timbavati Rivers. Coal mines are located in the upper reaches of the catchment around Witbank, Middelburg and the Delmas area. The Olifants River is shared between South Africa and Mozambique (DWA, 2011).

The study area is situated in the Mpumalanga Province. The nearest road to the study area is Middelburg road (R555). The study area falls within the Olifants WMA (see Figure 1) and specifically quaternary catchment B11J. Coal mining is a major contributor to Gross Domestic Product in the Olifants WMA (DWA, 2011).

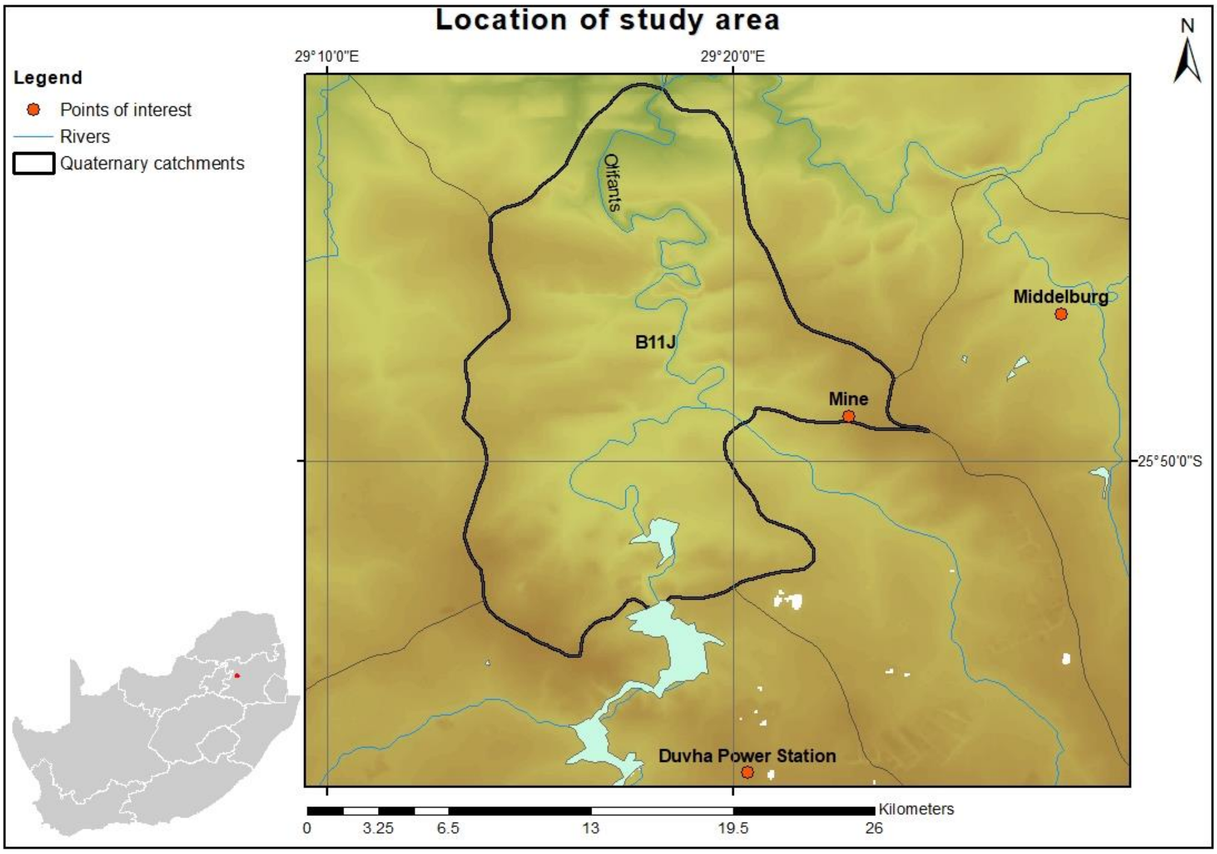

Figure 1: Location of study area

3.2 Climate

3.2.1 Temperature

The summer months are moderate and wet, while the winter months are harsh, cold and dry. Average daily temperatures are in the middle 20°C range in summer (October to March) and are lower than 15 °C in winter (April to September). During winter months temperatures can fall below 0°C in June, July and August. The hot season temperatures range from 9 ˚C to 32 ˚C and cold season temperatures from -6 ˚C to 22 ˚C. Frost occurs frequently between May and September (Middleton & Bailey, 2005).

3.2.2 Rainfall

The area where the mine is located falls within the hot season rainfall region, which is characterised by thunderstorm activity and relatively low average rainfall. Rainfall is strongly seasonal with most rain occurring in the summer period (October to March). The maximum rainfall occurs during the November to January period. Whereas summer months receive about 80% of the rainfall, winter months are normally dry. The area experiences an average rainfall of 735 mm per annum as indicated in Figure 2. The driest months fall in mid-winter, June to August, when less than 10 mm of rain falls on average (Middleton & Bailey, 2005).

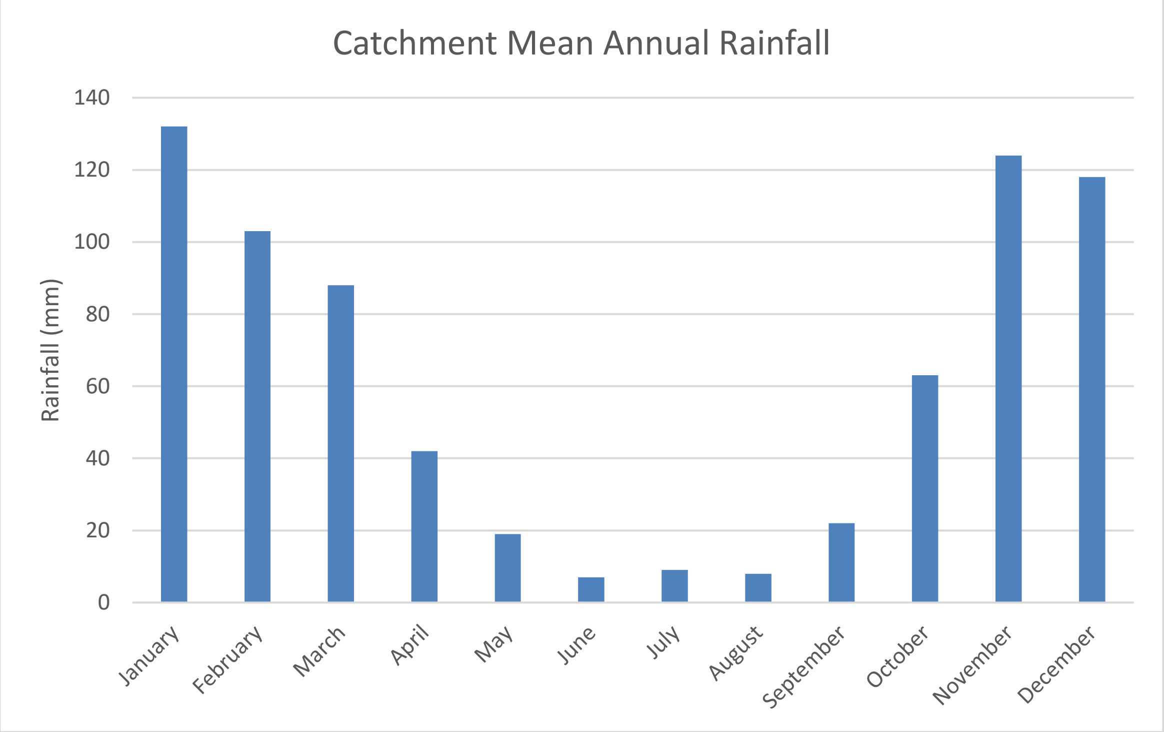

Figure 2: Catchment Mean Annual Rainfall

3.2.3 Evaporation

The evaporation in the general vicinity surrounding the study area is shown in Figure 3 (Middleton & Bailey, 2005). The evaporation is lowest in June, while December and January are the months when the evaporation is the highest.

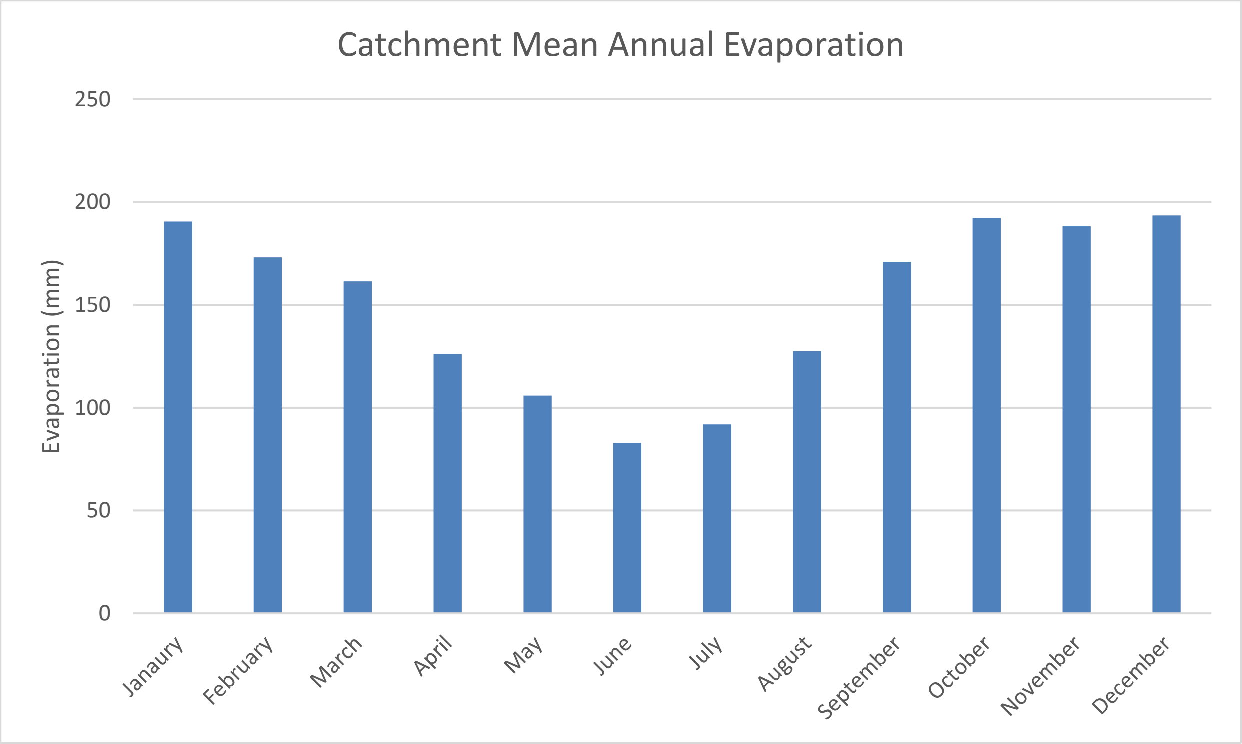

Figure 3: Catchment Mean Annual Evaporation

3.2.4 Geology

The study area is situated within the Springs-Witbank Coalfield. The sediments of the coalfield were deposited on an undulating pre-Karoo floor and consequently the distribution and thickness of the Karoo Sequence sediments vary significantly. Dolerite dyke intrusions are ubiquitous throughout the area and in the southern sections of the coalfield the dykes are typically up to 5m thick with an east-west orientation. The sediments of the Karoo Basin were deposited in fluvial floodplains and shallow shelves over a period of more than one hundred million years extending from the late Carboniferous (290 million years ago) to the early Jurassic (190 million years ago). Locally, siltstones and sandstones of the Vryheid Formation, Ecca Group are encountered. These rock types weather to fine grained sands, silts and clays. In the lower terrain units transported, wet, clayey sand with occasional gravel overlies the residual profile. The underlying geology of the area forms part of the Vryheid Formation which consists of a sequence of sandstone and shale, with carbonaceous shale overlying the coal seams (CSIR, 2003).

The Witbank Coalfield in the Mpumalanga Province of South Africa is situated on the northern sector of the main Karoo Basin. The main Karoo Basin is described as an asymmetric depository with a stable, passive cratonic platform (Kaapvaal Craton) in the northwest and a fore deep to the south with the Cape Fold Belt on its southern margin. Coal seams developed in the Witbank Coalfield are contained within the Vryheid Formation, which ranges in thickness between 80m and 200m (Mucina & Ruthford, 2006). Dolerite dykes and sills outcrop over two thirds of south. The structural complexity of these intrusions is phenomenal and has not received much attention in the past published literature. These intrusions form a complex network within the coal bearing Vryheid Formation of the Ecca Group, leaving these sedimentary rocks of sequences of succession structurally and metamorphically disturbed. The structural disruptions of the coal seams in the Witbank Coalfield are mainly due to the intrusion of dolerite dykes and sills. However, small-scale graben type faulting and fracturing within the coal seams to also occur. Exposure of the dolerites is limited to where it intersects the coal seams in underground and opencast mines (CSIR, 2003). The geology of the study area is shown in Figure 4.

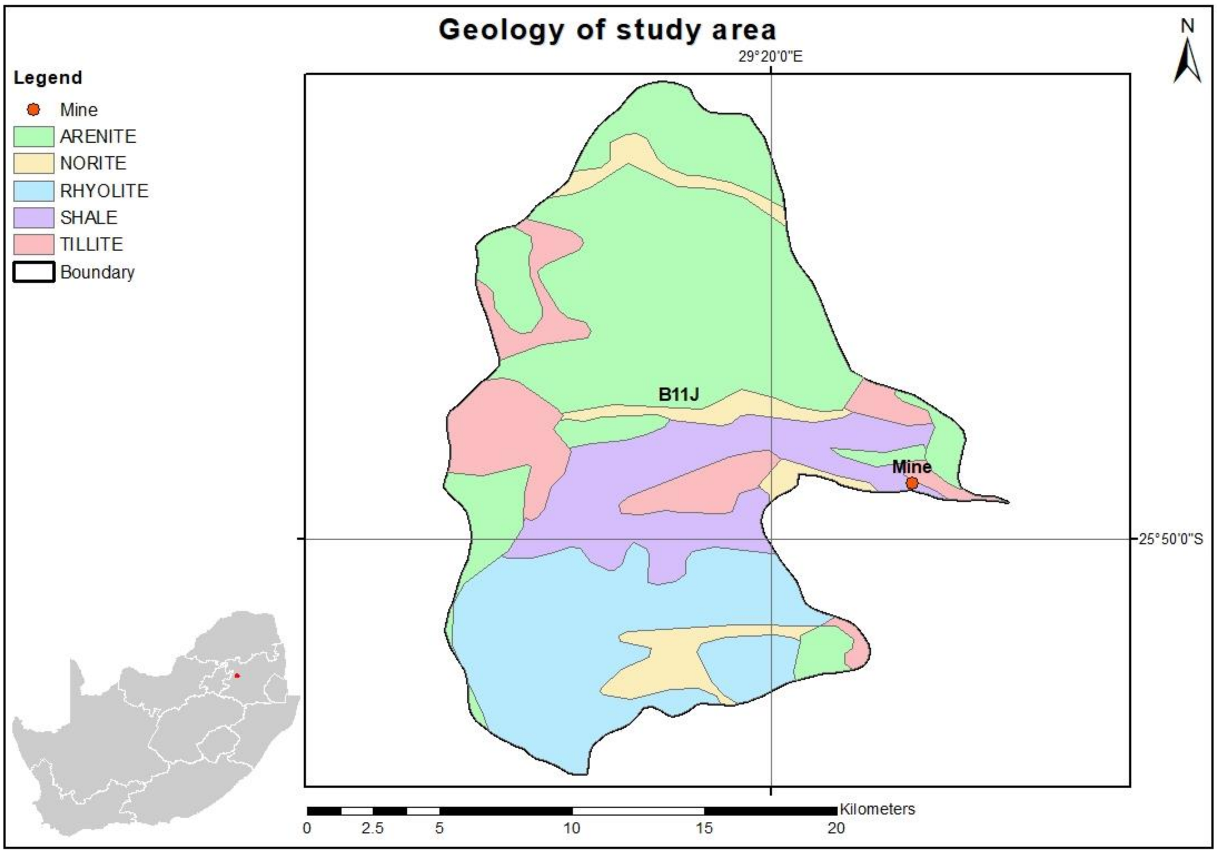

Figure 4: Geology

3.2.5 Land cover

Land use in study area is characterised by rain-fed cultivation in the southern and north-western parts, with grain and cotton as main products. Maize is the most common crop planted in the area (CSIR, 2003). There are also a number of mines as seen in Figure 5.

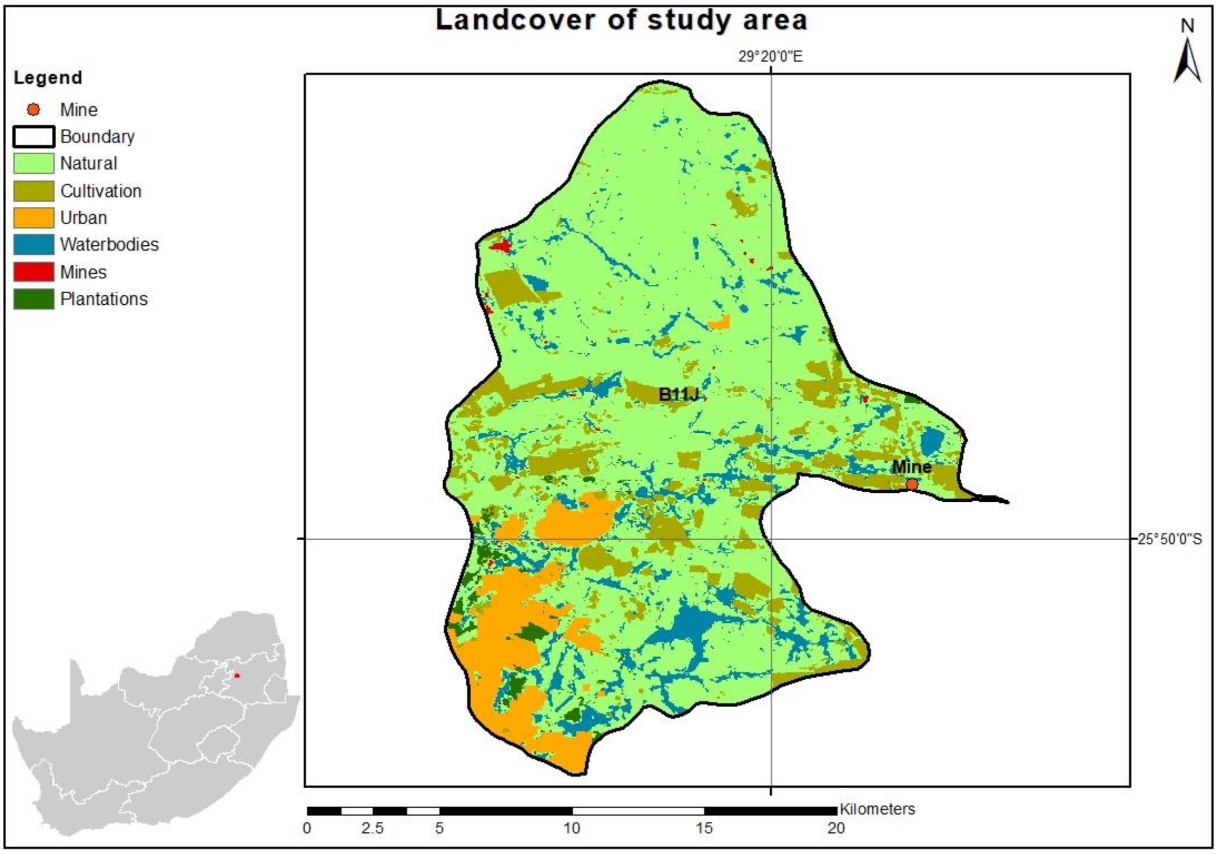

Figure 5: Land cover

3.2.6 Hydrology

The study area falls within B11J quaternary catchment of the Olifants WMA. The Olifants WMA falls within the Limpopo River Basin, which is shared by South Africa, Botswana, Zimbabwe and Mozambique. The Olifants River flows directly from South Africa into Mozambique, where it joins the Limpopo River (DWA, 2011). The river and its tributary are indicated in Figure 6.

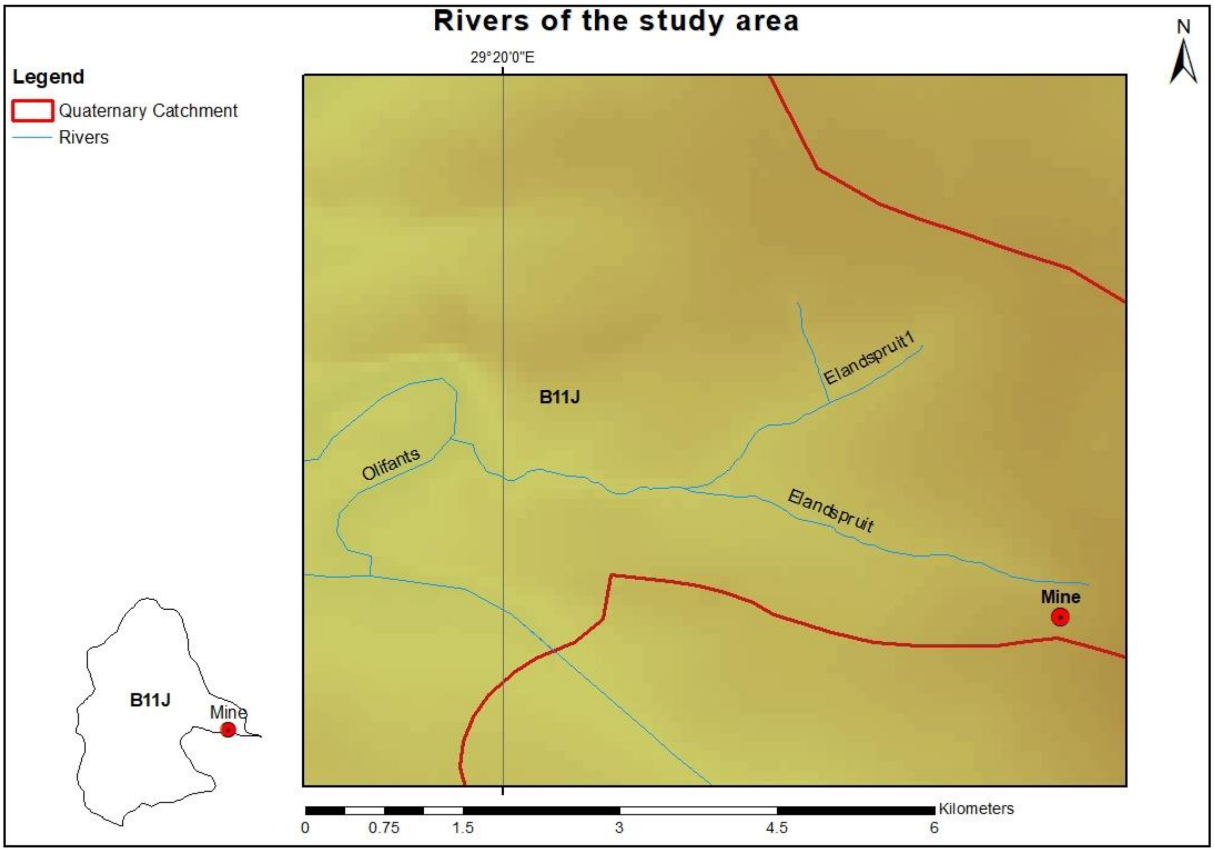

Figure 6: Rivers of the study area

CHAPTER 4: RESEARCH DESIGN AND METHODOLOGY

4.1 Compare surface water quality water upstream and downstream of Mine X in the Olifants River.

4.1.1 Description of the sampling points definitely

A quantitative research methodology was used. There are two water sources of importance at the study area, namely the Olifants River, the receiving body of the water and Elandspruit tributary spring, the link between the mine and the Olifants River. The Elandspruit tributary is roughly 6.4 km in length, from its origin to its confluence with the Olifants River. Nine water samples were collected from three sampling points. Three water samples were collected upstream of the mine, three downstream of the mine and three from upstream of the Olifants River. The sampling points are shown in Figure 7.

Figure 7: Locations surface water sampling points

4.1.1.1 Sampling point 3: Olifants River upstream of the mine

A single sampling site is located in the Olifants River upstream of the mine, at the railway bridge where the railway line passes over the River. This bridge is about 300 metres downstream from the DWS gauge station B1H001. Surface water samples were collected from this sampling point during 2015 (summer and winter seasons). As can be seen from Photo 1 much of the water surface of the Olifants River is covered by water hyacinths.

Photo 1: The Olifants River covered by hyacinths

4.1.1.2 Sampling Point 1: upstream of the Mine

Surface water samples were collected to determine the impacts from the mine on the water quality in the Elandspruit tributary. The Elandspruit Spring is shown in Photo 2.

Photo 2: Upstream of the mine sampling point

4.1.1.3 Sampling point 2: downstream of the mine

Surface water samples were collected at this point (Photo 3). This water represents the water quality in the stream downstream from the mine. This sample determines the impacts from the mine on the water quality in the Elandspruit and also on the Olifants River.

Photo 3: Downstream of the mine sampling point

4.1.1.4 Instruments and data analysis

The potential hydrogen (pH) and electrical conductivity (EC) of the surface water were determined in situ by means of a hand held multi parameter instrument at all sampling sites. Clean, labelled one litre polypropylene bottles were used to collect sample for chemical analysis. The sampling bottles were first rinsed with sample water and where possible, then submerged 10 to 15 cm below the surface water. The sampling bottles were filled and sealed to prevent contamination and transported to the laboratory in a cooler box filled with icepacks. The following surface water parameters were analysed by a SANS accredited laboratory: sulphate, nitrates, chloride, bicarbonates, potassium, calcium, magnesium and total alkalinity.

The analysed parameters are firstly compared to water quality standards and also plotted on Piper and Expanded Durov diagrams to characterise the water types.

4.2 Examine pathways and factors which contribute to the contaminated water from the mine flowing into Olifants River

A field investigation at the mine was conducted during the summer season (2015). In order to achieve the study objective, the field investigation was conducted as indicated below.

4.2.1 Potential source of contamination

The coal stockpiles, pollution control dam, softs and overburden dumps and an opencast pit were identified as potential sources of contamination as indicated in Figure 8. Surface water could be impacted by means of two pathways being a point source discharge or diffuse contamination as a result of mining activities.

Runoff water and seepage from stockpile areas are highly contaminated causing degradation of water quality of the receiving water environment (both surface water and groundwater). Opencast mining activities will increase the surface water contamination threat. This can be further increased by post mining flooding and possible decant. The contaminated water from opencast pit to be used for recycling and for coal washing purposes is characterised by elevated levels of nitrate, sodium, sulphate, hardness and conductivity. The source of contaminated water from the pit it can either runoff from the contaminated area or underground water.

Figure 8: Potential source of contamination

4.2.2 Surface flow at the mine

A digital elevation model was developed for the catchment using global mapper as shown in Figure 9. The determination of flood lines was done in two steps namely (i) modelling of a series of “design storms” which give a discharge in m³/s and (ii) modelling this discharge through cross sections across representative sections of the river at the study area and then determining the elevation that the floodwaters would reach at that particular cross section. The flood lines are then drawn using the elevations at the cross sections as guides. The flood lines indicate the area that will be inundated during the occurrence of a 100-year flood event in the stream.

The contour lines produced by the point data supplied by the client were used to plot the final flood lines at the study area. The accuracy of the flood lines is subsequently directly related to the accuracy of these elevation points. As the point data was on a 10m x 10m grid, the actual stream channel of the Elandspruit upstream from the spring was missed altogether when the contour lines were interpolated and subsequently, the 100-year flood lines were exceptionally far apart in this area. These flood lines upstream from the spring must subsequently only be used as guides and not as absolute.

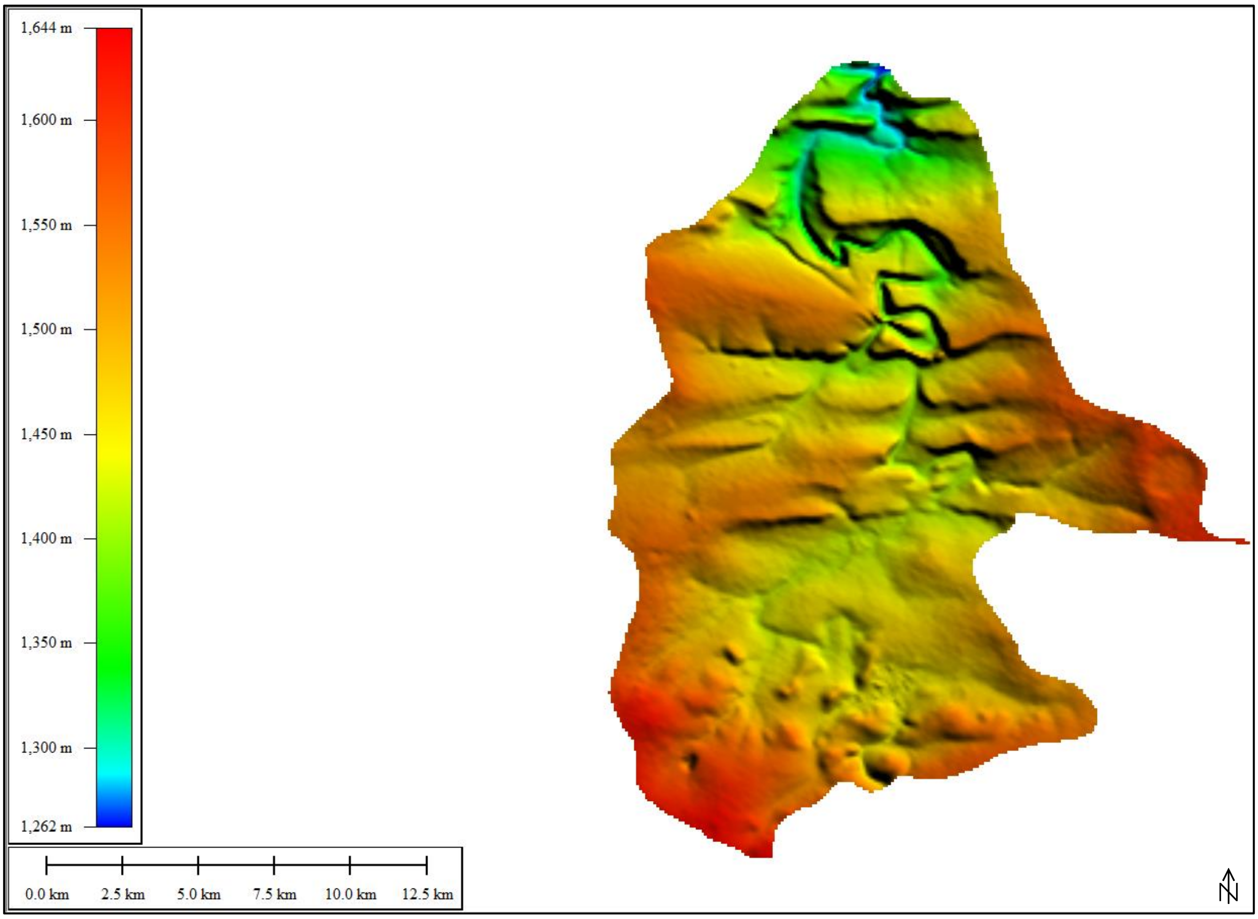

Figure 9: Digital elevation model

A particle tracking of the movement of surface water was simulated, from the mine location. It shows that water from the mine can flow into the Olifants River (Figure 10).

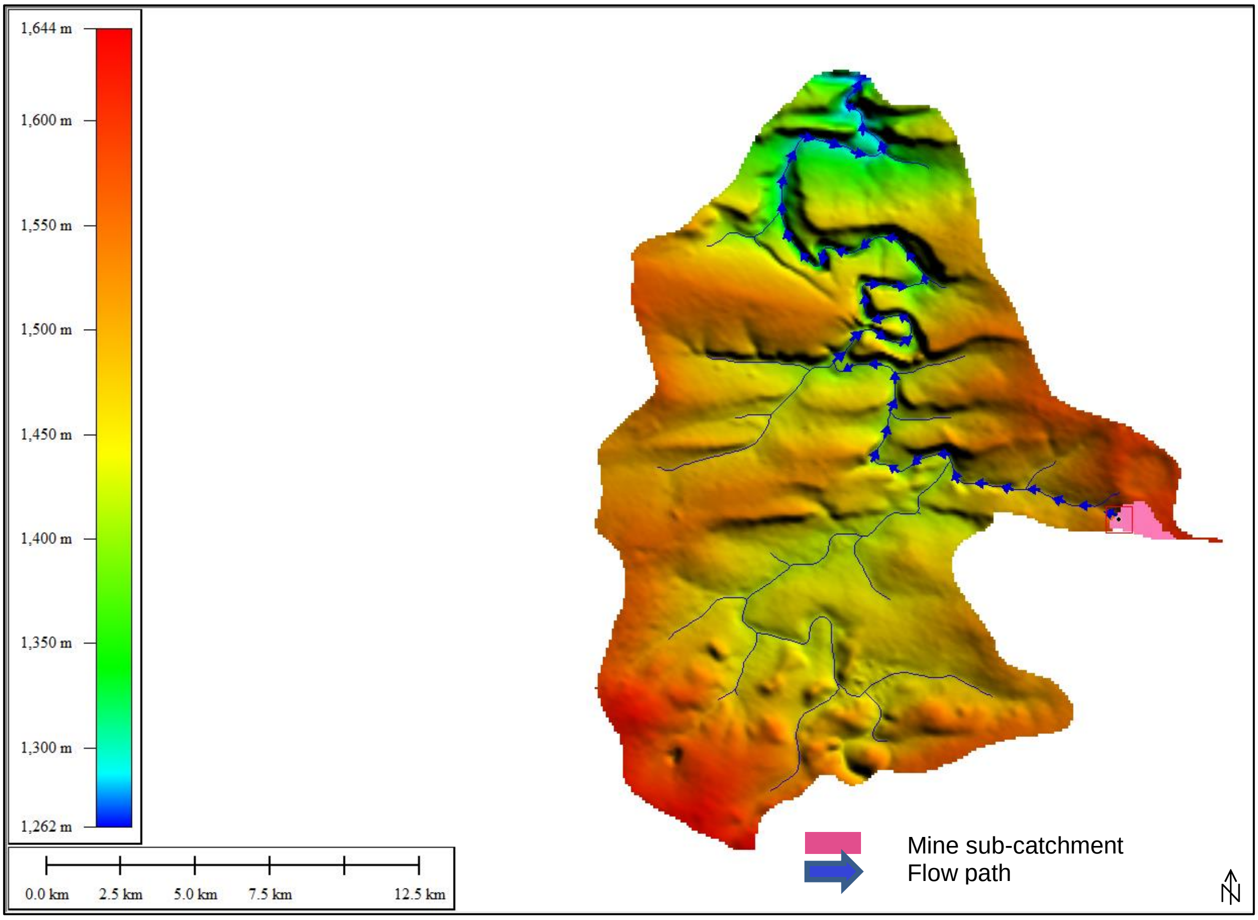

Figure 10: The direction of surface water flow across the study area

4.2.3 Groundwater levels and contours

A hydrocensus study was conducted in 2015. Three aquifers were identified in the study area namely: high weathered Karoo aquifer; fractured Karoo aquifer; and fractured pre -aquifer. Lineaments for example fractures and fault lines can be potential pathways for pollutants. The lineaments in the vicinity of the mine are shown in Figure 11. There are no lineaments that intercept any pollution sources on site. Figure 12 indicates the groundwater flow direction and contour lines.

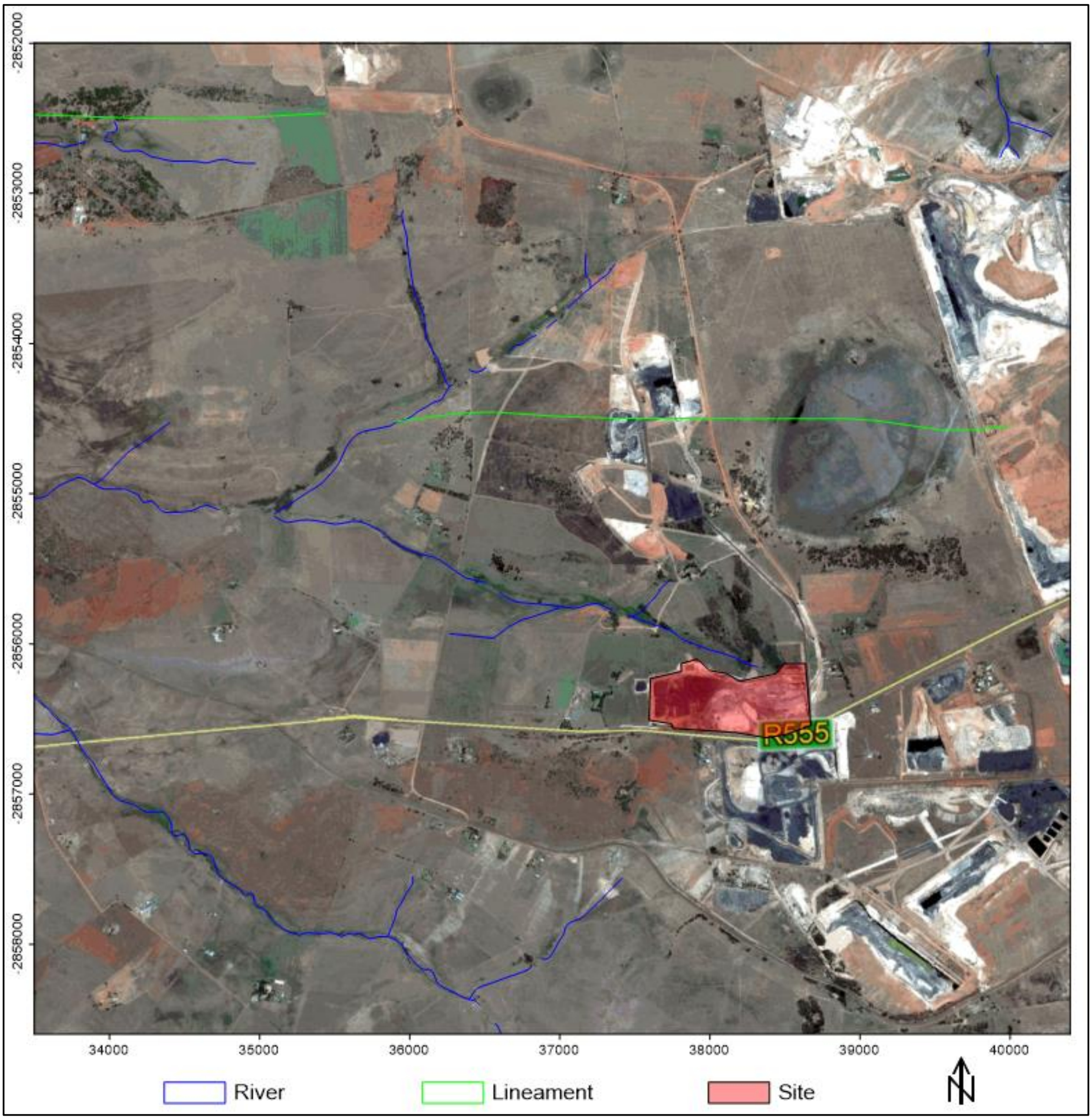

Figure 11: Lineaments

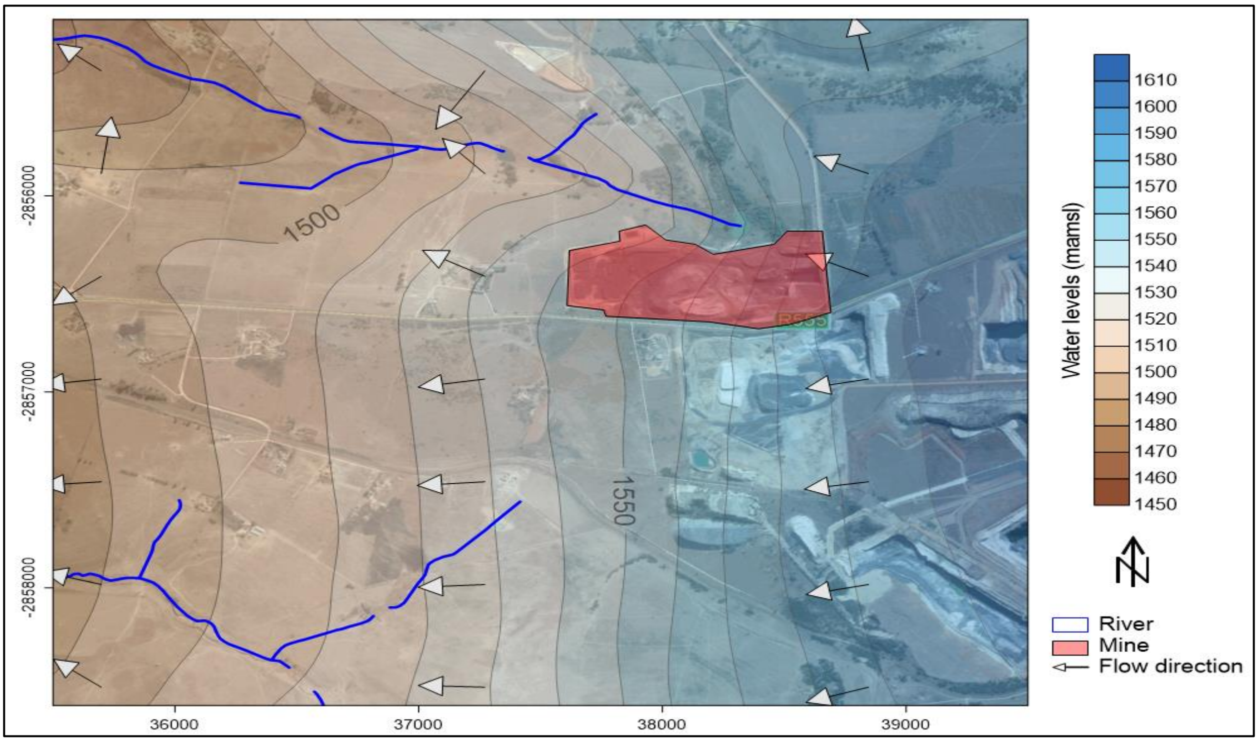

Figure 12: Groundwater levels and flow directions

A groundwater model and associated mass transport model is then built to simulate potential pollution plumes. A groundwater model and associated mass transport model is then built to simulate potential pollution plumes. There are a number of numerical modelling packages available for groundwater (Spitz & Moreno, 1996). However, for this study there is limited data and therefore simplified model that does not need to much detailed information is to be considered. The software package Modflow was used to develop a 2-dimensional flow and mass transport model.

The information included in the model is as follows:

- Rivers were set as constant head boundary conditions
- Pre-mining groundwater levels were set as initial conditions
- The transmissivity was set as 10 m^2/d. This value was determined for a mine in the vicinity of the study area. The transmissivity of the lineament is set as 50 m^2/d.
- Recharge was set at 4.5% of mean annual rainfall. This value was determined for a mine in the vicinity of the study area.
- A porosity of 6% (Volume of voids/ total volume x 100)
- All potential pollution sources were assigned a source term of 100%.
- A longitudinal dispersivity of 75 m. (A longitudinal dispersivity value of 75 m was selected for the simulations)

CHAPTER 5: DISCUSSION AND RESULTS

5.1 Water quality results

Nine surface water samples were collected from three sampling point sites during 2015 (summer and winter seasons). Three sampling points site are indicated in Figure 7. The first sampling point site was labelled as sampling point 1: upstream of the mine; second point was labelled as sampling point 2: downstream of the mine; and third point was labelled as sampling point 3: upstream of the Olifants River. The sample results were compared with South African National Standard (SANS 241:2011). SANS is the official South African drinking water standard. SANS provided 4 levels of quality recommended (class 0) ideal, (class I) acceptable, (class II) maximum allowable, (class III) exceeding. Piper diagrams were used to characterise the water.

5.2 Water quality results of the upstream mine: sampling point 1

Table 1 lists the parameters analysed for and compares then to the guidelines.

The pH values of most raw water sources are within the range of 6.5 to 8.5 (DWAF, 1996). A decrease in the pH values of the surface water in mining area can be the indication of AMD.

The result in Table 1 indicates that the pH values of surface water samples collected upstream of the mine are within the acceptable limits of SANS: 241. The highest value of pH recorded was 8.4 and the lowest value was 7.3.

Electrical conductivity is a measure of the ability of the water to conduct an electrical current which is the results of the presence charged ions such as chloride, sulphates, magnesium and calcium (DWAF, 1996). The results in Table 1, indicates that the electrical conductivity of surface water samples of the upstream of the mine are within the acceptable limits of SANS: 241.

The concentration of sulphates in surface water is typical low (5 mg/l). The concentrations of several hundred may occur where dissolution of sulphate mineral or discharge of sulphates rich effluent takes place (DWAF, 1996). AMD decanting or seeping from the mining areas can increase the sulphate in surface water significantly. Sulphate is a key indicator of water affected by coal mining.

The sulphate recording varies from 11 mg/l during August 2015 to 368 mg/l during October 2015 as indicated in Table 1. Sample 1 and sample 2 are falling under class 0 of the SANS 241 which is ideal whereas sample 3 is falling under class I of SANS 241 which is acceptable.

Table 1: Surface water quality of upstream of the mine

SANS 241		**pH**	**Electrical Conductivity (mS/m)**	**Bicarbonates (mg/l)**	**Chloride (mg/l)**	**Sulphates (mg/l)**	**Nitrates (mg/l)**	**Sodium (mg/l)**	**Potassium (mg/l)**	**Calcium (mg/l)**	**Magnesium (mg/l)**	**Total Alkalinity (mg/l)**
Class 0	Ideal	6.0-9.0	70	N/S	100	200	6	100	25	80	0.05	N/S
Class I	Acceptable	5-6	70-150	N/S	100 - 200	200-400	6.0 - 20	100-200	25-50	80-150	0.05-0.1	N/S
Class II	Max. allowable	4-5 or 9.5	>150 - 370	N/S	>200 - 600	>200-400	>10-20	200-400	50-100	>150-300	>0.1-1	N/S
Class III	Exceeding		>370	N/S	>600	>600	>20	>400	>100	>300	>1	
Sample 1 (August 2015)		8.3	1.8	5.6	38.7	11	1.2	2	1.5	1.3	0.8	6.1
Sample 2 (September 2015)		8.4	1.8	5.7	18	36	1.3	3	1.2	1.6	3	3.4
Sample 3 (October 2015)		7.3	2.9	10	35	368	1.6	13	1.7	6	3.1	2.4

Figure 13 is a Piper diagram with the surface water quality samples collected upstream of the mine. The Piper diagram is a graphical representation of the chemistry of water samples. The cations and anions are indicated by separate ternary plots (Piper, 1953). The plot indicates, calcium, sulphate rich waters which can be an indication of pollution. It means sample 2 is having high amount of sulphate which is key indicator of mine impact on surface water.

The expanded Durov diagram (Figure 14) indicates the following:

- Sample 1: Mix of different types or contaminated by nitrates and/or chlorides
- Sample 2: water that is usually mixed with different types and has undergone sulphate and sodium chloride mixing or old stagnant sodium chloride dominated water that has been mixed with clean water.
- Sample 3: water that is usually mixed with different types and has undergone sulphate and sodium chloride mixing and has been in contact with a source rich in sodium or old stagnant sodium chloride dominated water.

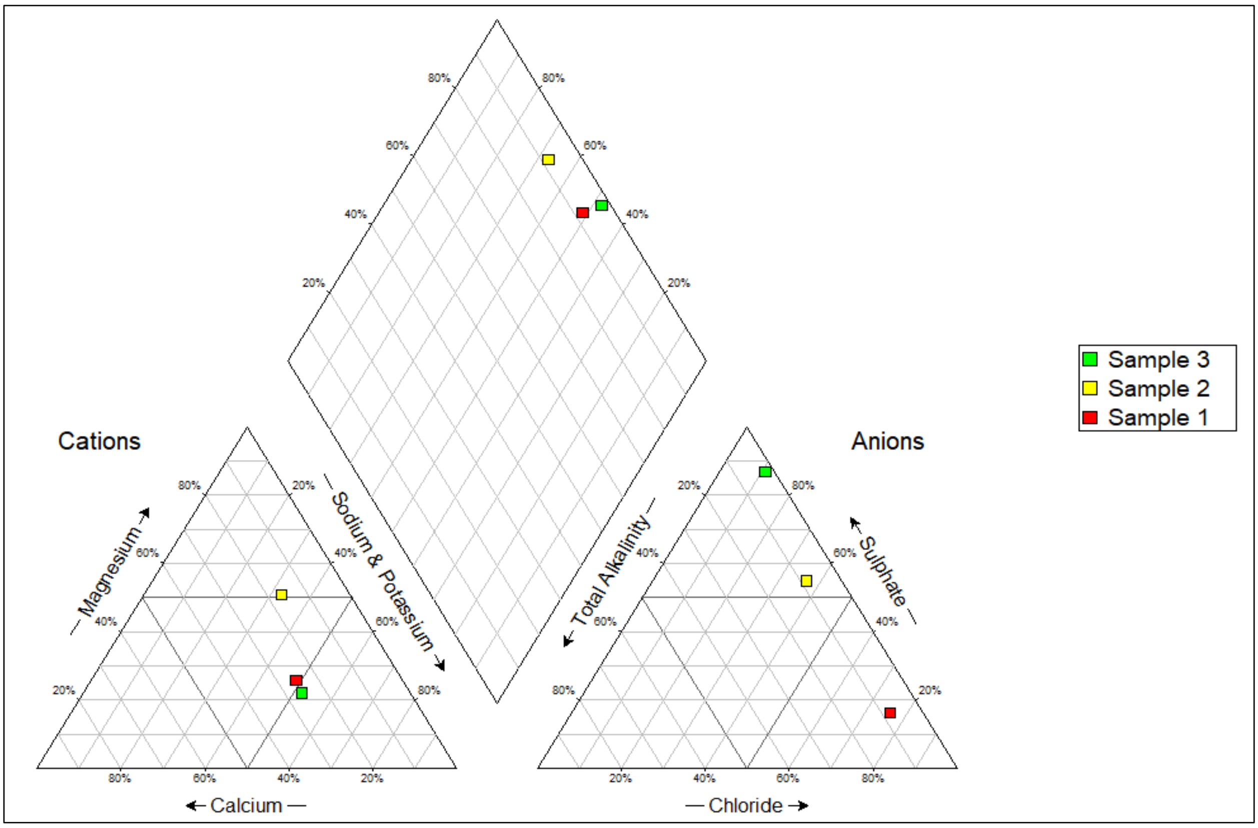

Figure 13: Piper diagram water quality of samples of the station no. 3 of upstream of the mine

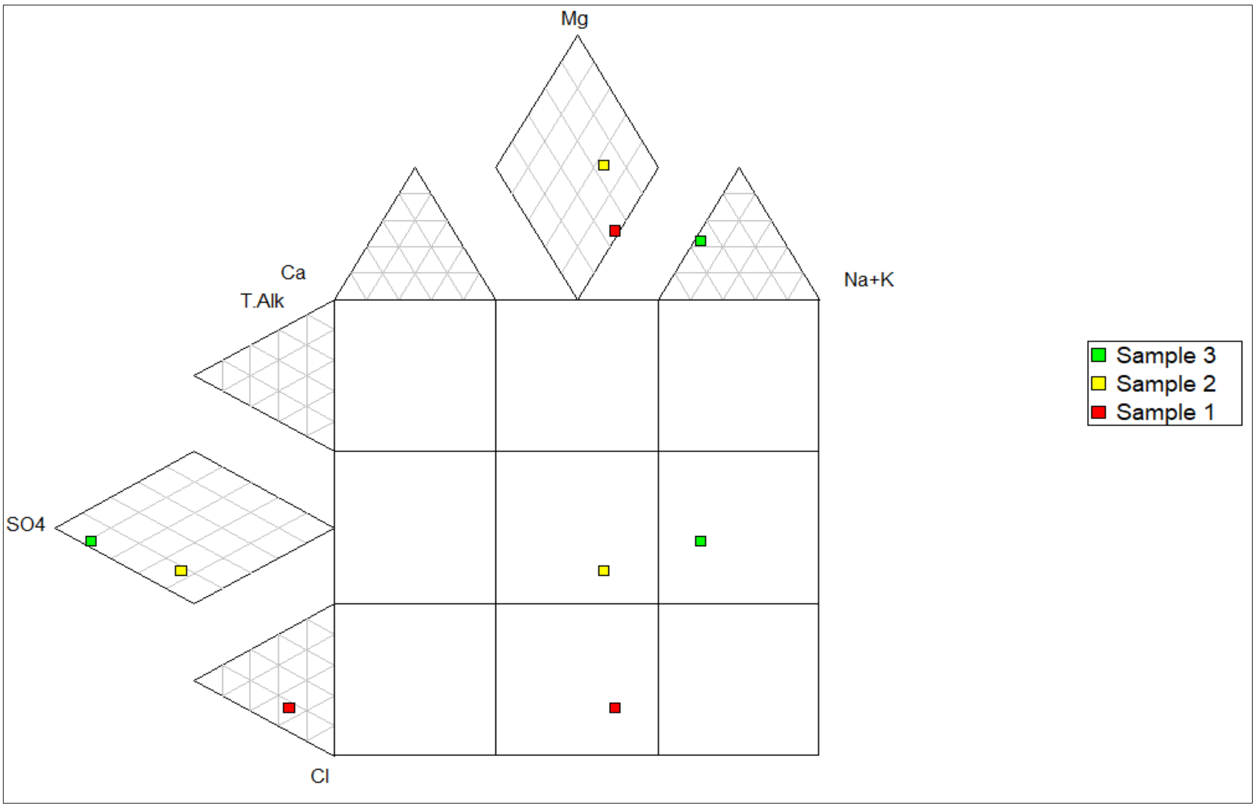

Figure 14: Expanded Durov diagram water quality of samples of the station no. 3 of upstream of the mine

5.3 Water quality results of downstream of the mine: Sampling Point 2

Table 2 represents the parameters and surface water samples collected in sample point 2. The results surface water samples, indicates that the pH values of all three samples collected in August, September and October are falling under acceptable limits of SANS 241. The pH values of surface water sample 2 collected in September 2015 is the highest as compared to the sample 1 and 3.

The Electrical Conductivity of sample 3 collected in October 2015 is higher as compared to sample 1 and 2 collected in August and September 2015.

All sulphate values are within the acceptable limits of SANS 241. The sample collected in October is has a higher sulphate value when compared to samples collected in August and September 2015.

Table 2: Surface water quality of downstream of the mine

Sample ID		**pH**	**Electrical Conductivity (mS/m)**	**Bicarbonates (mg/l)**	**Chloride (mg/l)**	**Sulphates (mg/l)**	**Nitrates (mg/l)**	**Sodium (mg/l)**	**Potassium (mg/l)**	**Calcium (mg/l)**	**Magnesium (mg/l)**	**Total Alkalinity (mg/l)**
Class 0	Ideal	6.0-9.0	70	N/S	100	200	6	100	25	80	0.05	N/S
Class I	Acceptable	5-6	70-150	N/S	100-200	200-400	6.0 - 20	100-200	25-50	80-150	0.05-0.1	N/S
Class II	Max. allowable	4-5 or 9.5	>150 - 370	N/S	>200 - 600	>200-400	>10-20	200-400	50-100	>150-300	>0.1-1	N/S
Class III	Exceeding		>370	N/S	>600	>600	>20	>400	>100	>300	>1	
Sample 1 (August 2015)		8.1	6.2	15	18	5	0.7	5	3.8	3	2	12
Sample 2 (September 2015)		8.2	9.3	34	16	11	01	9	1.9	3	3	28
Sample 3 (October 2015)		7.1	12.1	15	05	37	0.2	8	4.9	8	1	15

The Piper diagram in Figure 15 indicates sodium chloride nature of the water for all 3 samples. The expanded Durov diagram (Figure 16) indicates the following:

- Sample 1: old stagnant water of water with a sodium chloride source

- Sample 2: water that is usually mixed with different types and has undergone sulphate and sodium chloride mixing and has been in contact with a source rich in sodium or old stagnant sodium chloride dominated water.
- Sample 3: water that is usually mixed with different types and has undergone sulphate and sodium chloride mixing and has been in contact with a source rich in sodium or old stagnant sodium chloride dominated water.

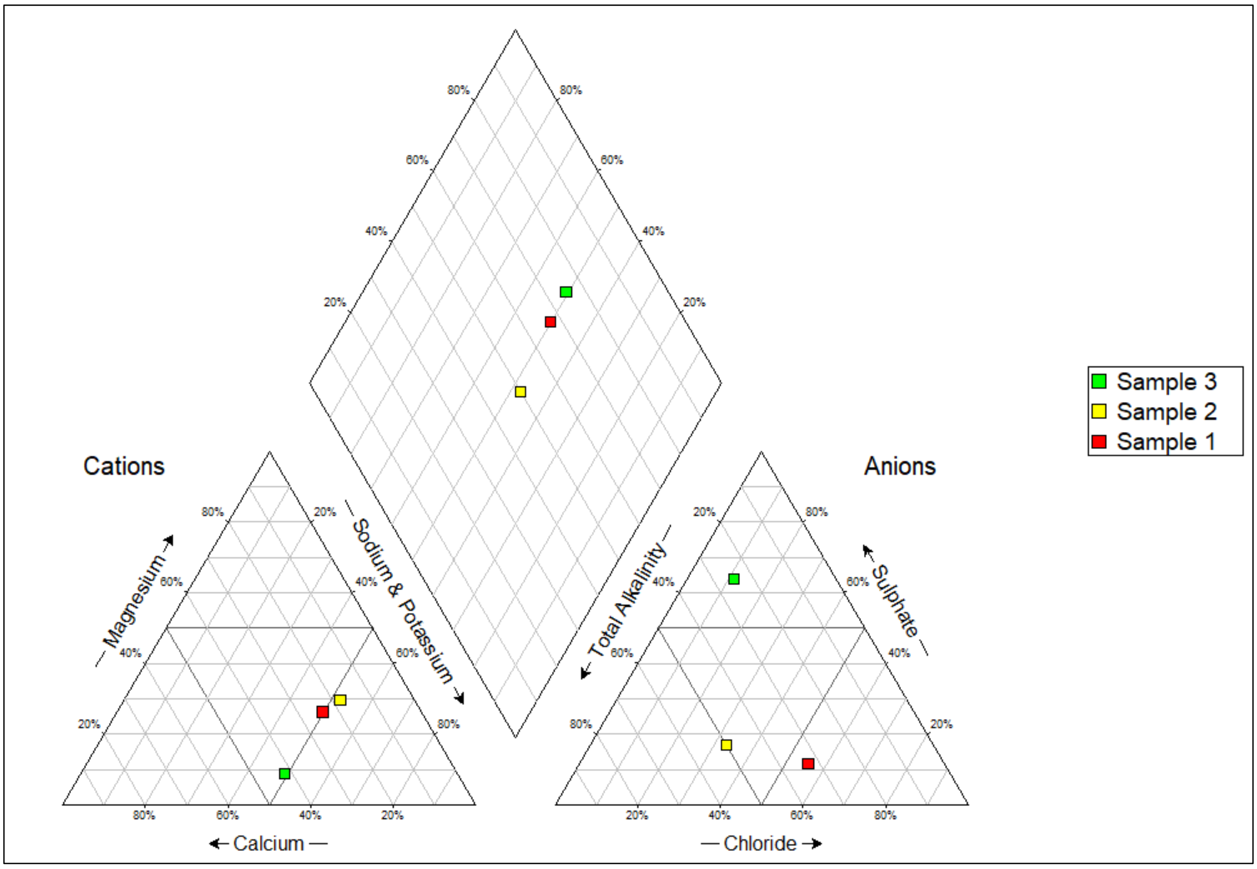

Figure 15: Piper diagram surface water quality of samples of downstream of the mine

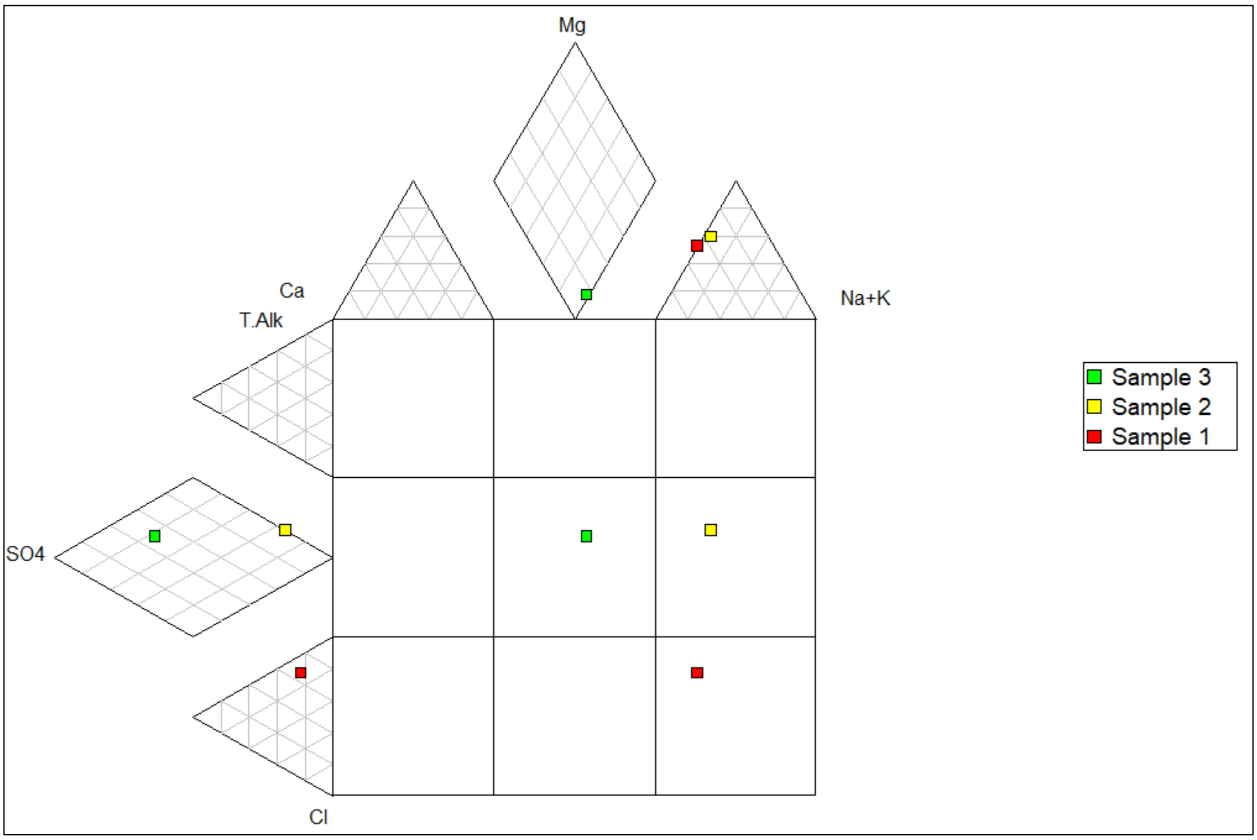

Figure 16: Expanded Durov diagram surface water quality of samples of downstream of the mine

5.4 Surface water quality of upstream of Olifants River: sampling point 3

Table 3 documents the parameters and surface water samples collected at sample point 3.

The pH values’ reading varies between 7.7 and 8.0. The pH values of all samples collected upstream of the Olifants River is falling under ideal limits of SANS 241.

The EC reading varies between 82.6 mS/m and 89.6 mS/m during the sampling periods. The EC of all recorded samples is within the acceptable limits of SANS 241.

The sulphate reading varies between 241 mg/l and 307 mg/l. The surface water samples (1 and 2) recorded between July and August 2015 are higher than sample 3 collected during September 2015. The sulphate variables indicated in Table 5 are falling under class II of SANS 241 which is maximum limits. The highest sulphate value is 307 recorded during winter season and lowest value is 241 recorded during summer season (2015).

Table 3: Surface water quality of upstream of Olifants River: sampling points no 3

Sample ID		**pH**		**Bicarbonates (mg/l)**	**Chloride (mg/l)**	**Sulphates (mg/l)**	**Nitrates (mg/l)**	**Sodium (mg/l)**	**Potassium (mg/l)**	**Calcium (mg/l)**	**Magnesium (mg/l)**	**Total Alkalinity (mg/l)**
Class 0	Ideal	6.0 - 9.0	70	N/S	100	200	6	100	25	80	0.05	N/S
Class I	Acceptable	5-6	70-150	N/S	100-200	200-400	6.0 - 20	100-200	25-50	80-150	0.05-0.1	N/S
Class II	Max. allowable	4-5 or 9.5	>150 -370	N/S	>200 -600	>200-400	>10-20	200-400	50-100	>150-300	>0.1-1	N/S
Class III	Exceeding		>370	N/S	>600	>600	>20	>400	>100	>300	>1	
Sample 1 (July 2015)		7.7	89.6	15	137	307	3.5	49	16.7	64	48	112
Sample 2 (August 2015)		7.8	82.6	34	137	234	1.8	52	12.1	55	43	80
Sample 3 (September 2015)		8.0	85.8	15	98	241	0.8	42	11	49	80	88

The Piper diagram in Figure 17 shows the water has a calcium sulphate character. The Expanded Durov diagram (Figure 18) indicates that the water is a mix of different types, either clean water that has undergone sulphate and sodium chloride mixing or old stagnant water sodium chloride dominated water that has been mixed with clean water.

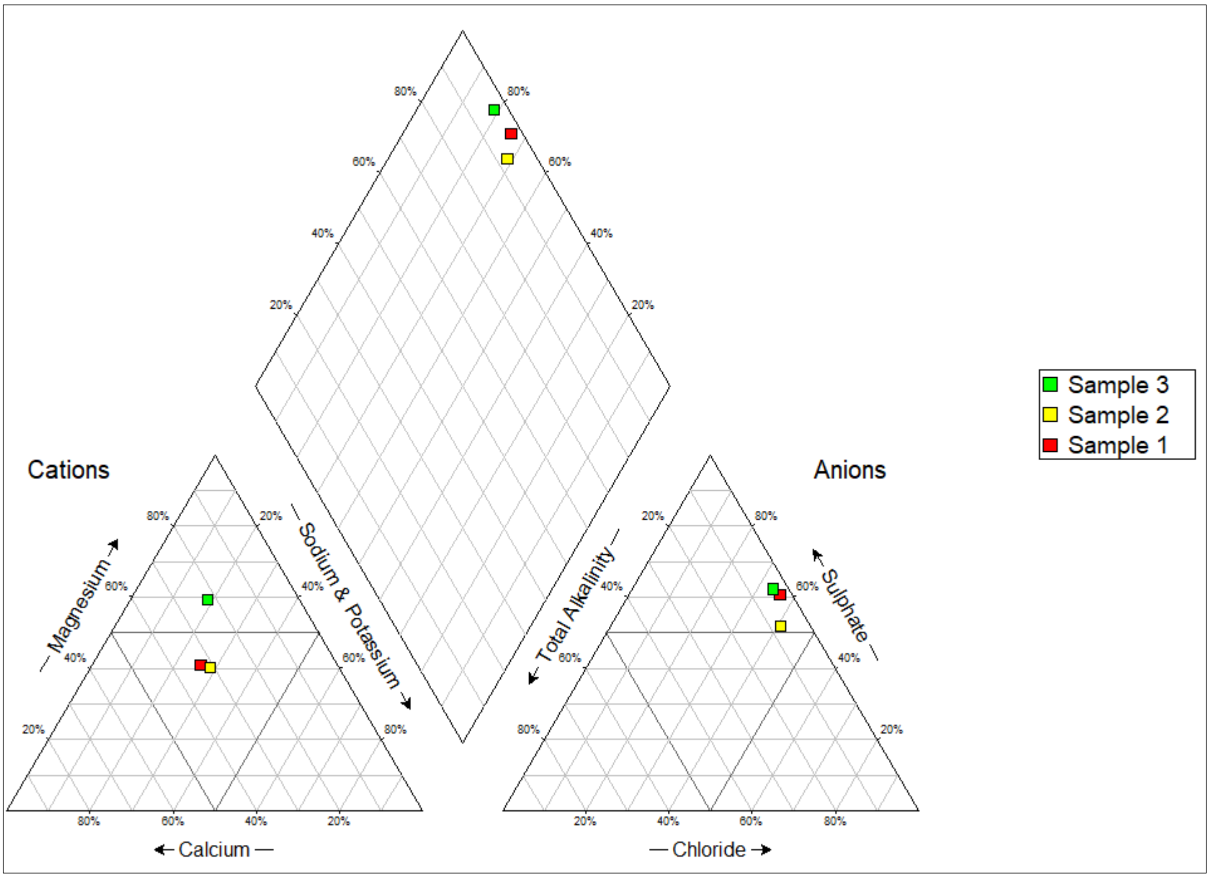

Figure 17: Piper diagram water quality of upstream of the Olifants River

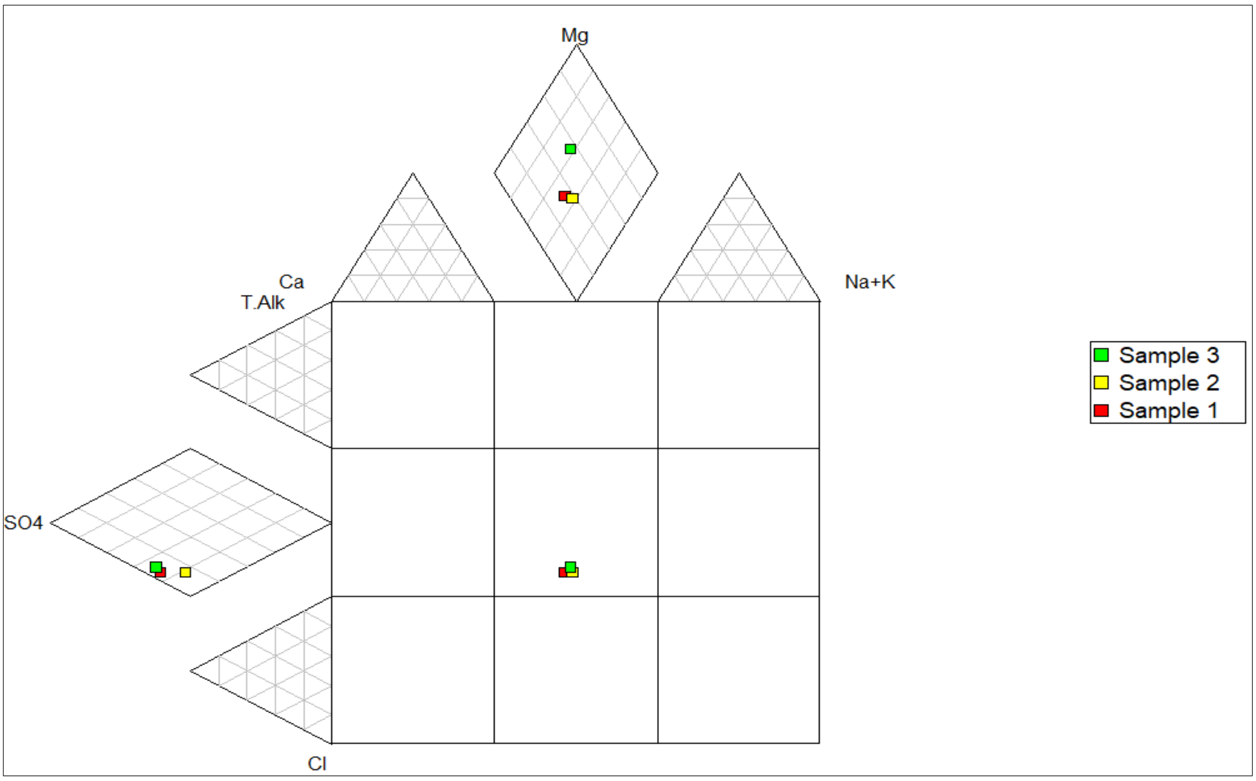

Figure 18: Expanded Durov diagram water quality of upstream of the Olifants River

5.5 To examine pathways and factors which contribute to the contaminated water from the mine flowing into Olifants River.

5.5.1 Potential source of contamination

Contaminated surface water coal stockpiling, coal washing plant, slurry ponds softs and overburden dumps and opencast pit is to be contained in lined PCD that would minimise the risk of surface water degradation. Storm-water management is taking the form of perimeter berms and trenches around the overburden stockpiles, which drain into PCD. Storm water falling in the opencast pits is pumped into PCD. The perimeter berms and trenches are sized such that they convey water from the 1:50 year storm event to the PCD. Storm-water management along the access road is in the form of ramps that allow silt to settle before allowing water to enter the veld. All contaminated water within the mine is channelled via drains, pipes and trenches to the Pollution Control Dam.

5.5.2 Ground and surface water flow at the mine

Figure 10 and 12 demonstrates the actual directions of both ground water and surface flow in the vicinity of the mine. As can be seen in Figure 12 and 13 both Surface and ground water flow around the area where mining is occurring will generally drain towards the Elandspruit, which will confluence with the Olifants River downstream.

5.5.3 Surface infrastructure and 100-Year Flood lines for the Elandspruit at the mine

The flood lines of the Elandspruit show that the mine’s surface infrastructure is well outside both the 100-year flood lines and a distance of 100 m from the centreline of the stream. All surfaces that could become contaminated are grouped together with berms and trenches around the area leading to the mine's PCD, where all contaminated water will be intercepted.

A storm with a duration of <1 hour produced the highest discharge at the study area. The discharge will be 74.12m^3/s for the 100-year flood. The elevations containing the maximum discharge, at each cross section along the stream at the study area, were plotted on either side the stream’s centre-line and transferred, in plan, to the drawing, to demarcate the 100-year flood lines for this stream section. The resulting flood lines were supplied as a separate CAD file. The flood lines resulting from this model are indicated in Figure 20.

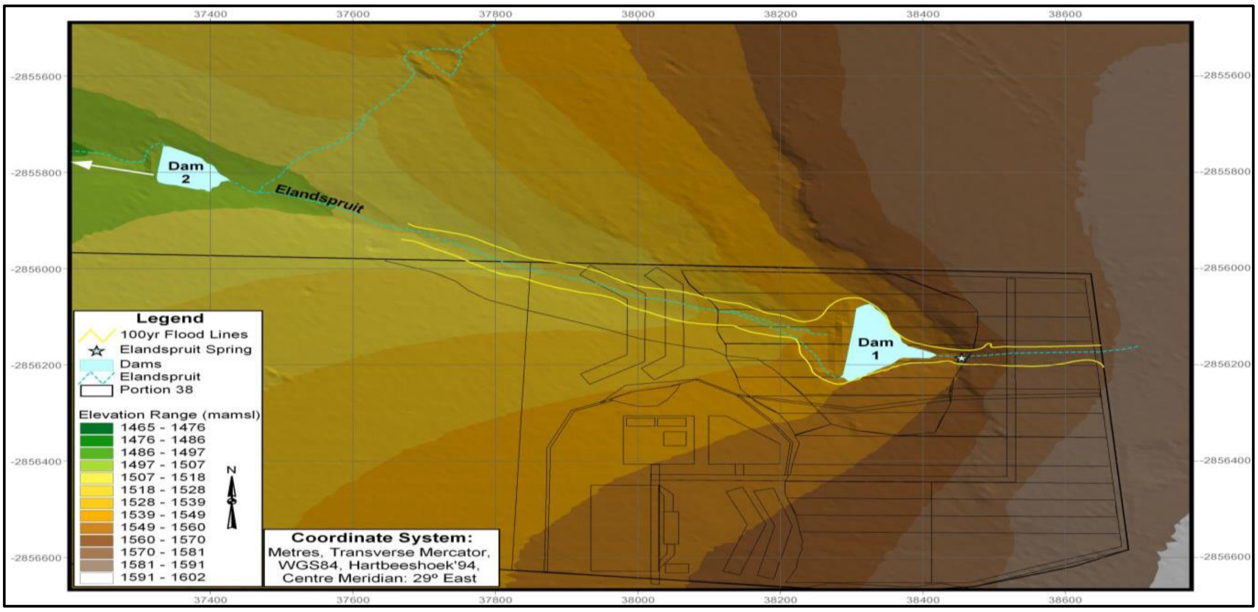

Figure 19: 100-year flood lines (yellow lines) for the Elandspruit at the study area

5.5.4 Groundwater model

A model network with a cell size of 25 m x 25 m was generated as seen in Figure 21.The groundwater flow and mass transport model are run for a period of 10 and 20 years. The resultant pollution plumes are shown in Figure 22 and Figure 23. Figure 12 shows the Calibrated flow and flow direction. The numerical model for the project was constructed using Visual Mod flow (Version 2011.1 Pro, Schlumberger 2014), a pre- and post- processing package for the modelling code MODFLOW. MODFLOW is a modular three dimensional groundwater flow model developed by the United States Geological Survey (Harbaugh et al., 2000). MODFLOW uses 3D finite difference discretisation and flow codes to solve the governing equations of groundwater flow. MODFLOW 2000 and the Preconditioned Conjugate-Gradient Package (PCG2) were applied to solve the flow model. The PCG2 Package is described in Water-Resources Investigations Report 90-4048 of the USGS (Mary Hill, 1997). Both are widely used simulation codes and are well documented. The numerical model was based on the conceptual model developed from the data obtained during the desktop investigations.

The model was first calibrated for groundwater levels and flow using the trial-and-error method whereby the aquifer parameters are varied within realistic ranges as determined during the baseline study. Aquifer parameters determined during previous investigations were also considered. The groundwater levels calculated by the model were compared to those recorded during the historical and current investigations. Following the calibration of the flow model, a preliminary contaminant transport model was constructed for the mining area. In order to determine the long term effect of mining on the groundwater quality, the post-operational migration of contamination was simulated. Sulphate was chosen as the parameter to be modelled.

Sulphate would be one of the end-products of acid rock drainage and is therefore a chemical of concern and makes up about 50% of the TDS.

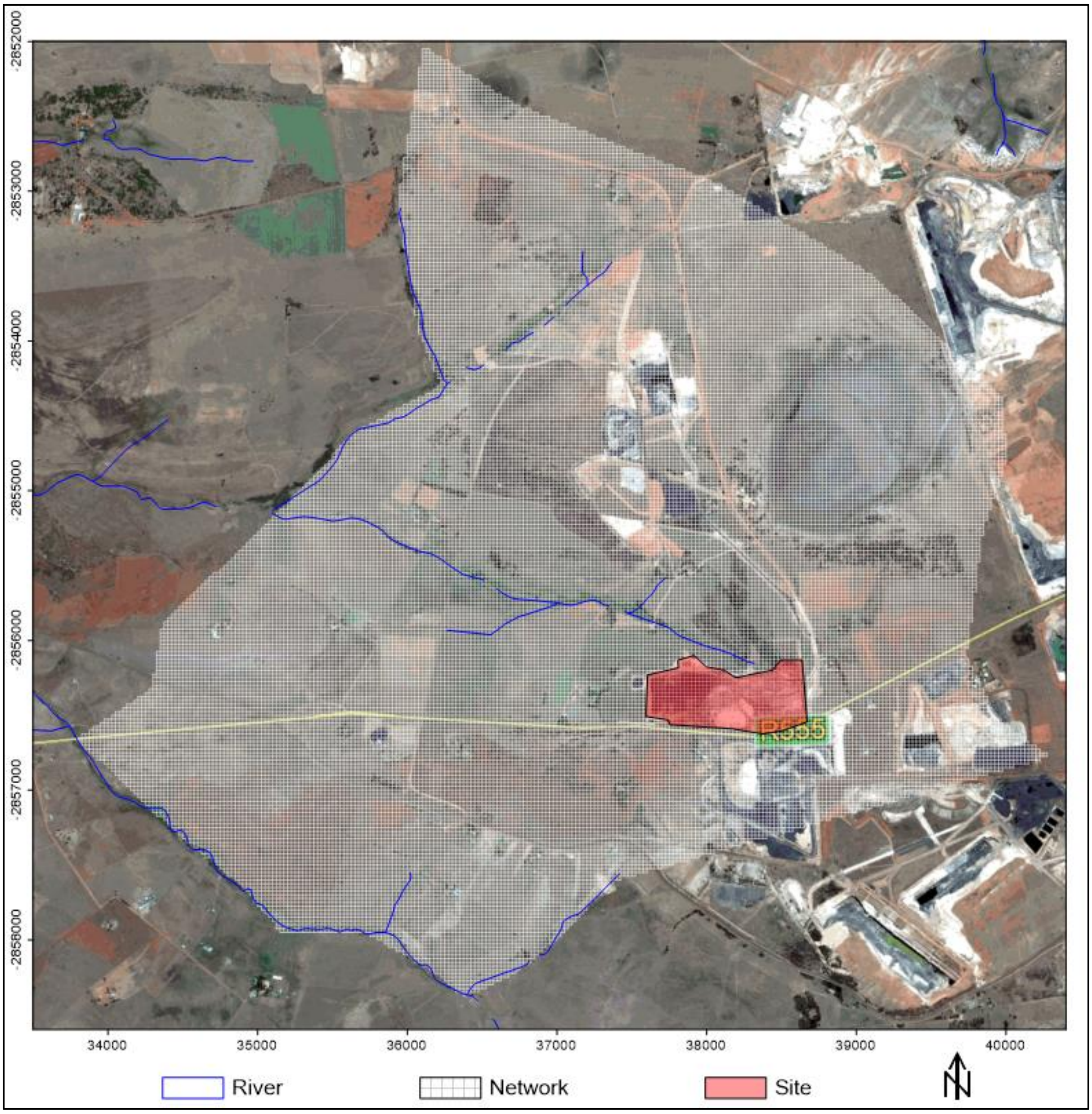

Figure 20: Model network

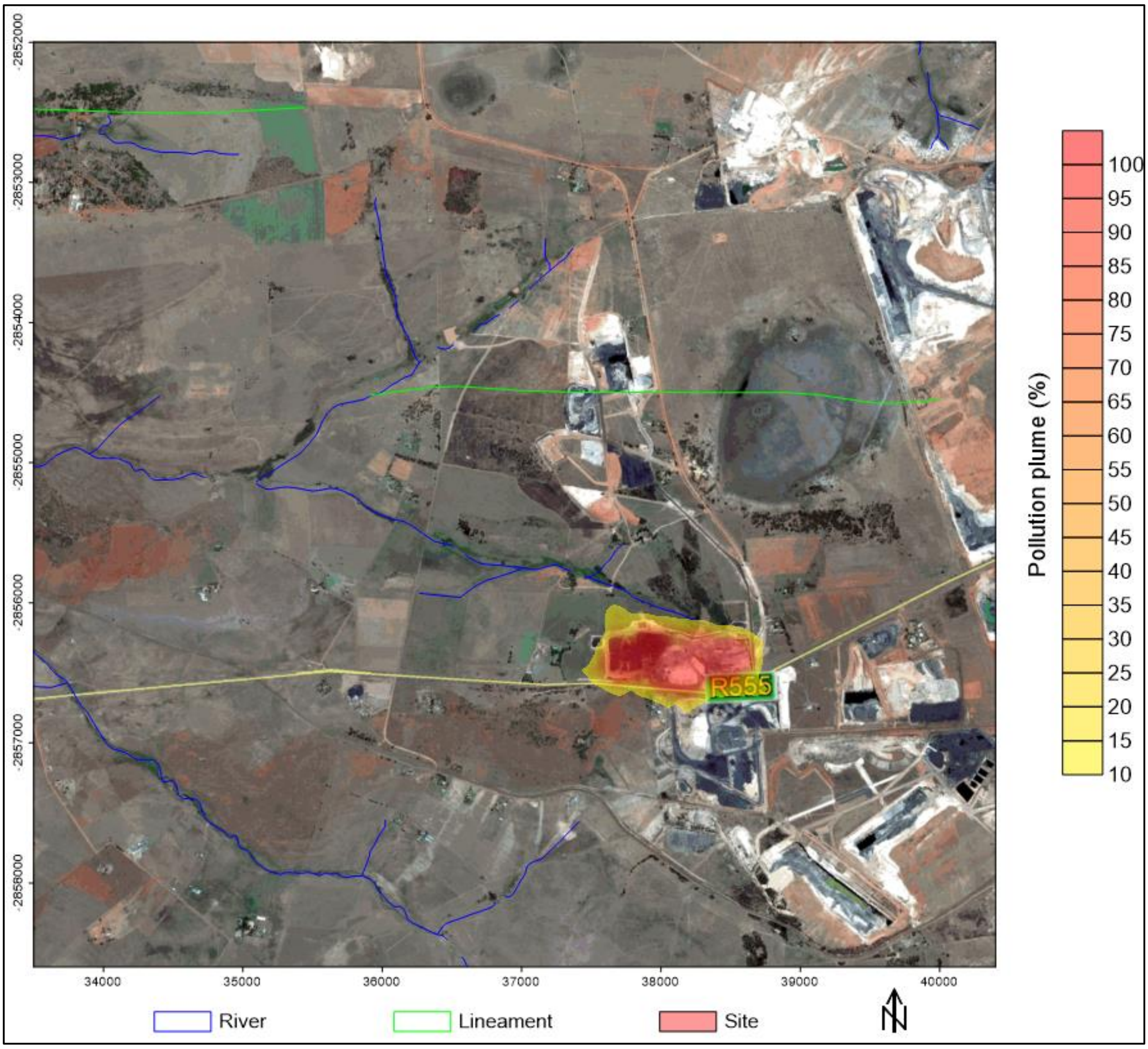

Figure 21: Pollution plume (10 years)

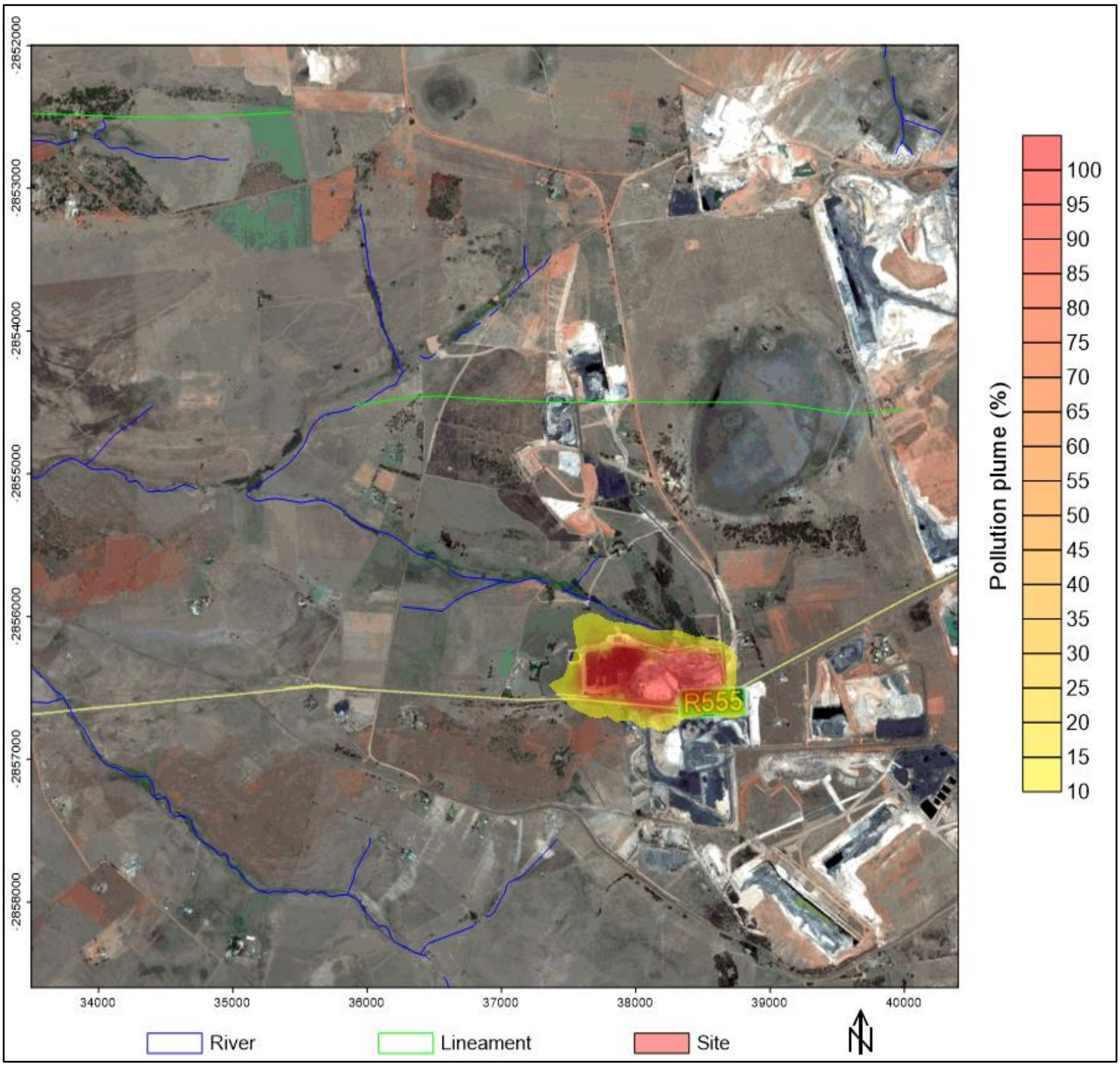

Figure 22: Pollution plume (20 years)

In both cases the pollution plume reaches the stream to the north of the site.

CHAPTER 6: SUMMARY AND CONCLUSIONS

The surface water of Olifants River is contaminated by point source and non- point source due to the poor management of waste water from the mines, industries municipalities and agricultural sector. It was found that the water quality issues within the Olifants WMA include decants from coal mines, agricultural runoff and nutrients from the Waste Water Treatment Works.

In this study, surface water samples were collected from upstream and downstream of the mine and upstream of the Olifants River to determine if mine is contributing to the contamination of Olifants River. The surface water samples were collected during the summer and winter season (2015). The collected samples were compared with South African National Standards (SANS) 241. The Piper diagram was also used to analyse the surface water quality of upstream of the Olifants River, upstream and downstream of the mine. The pH values of all collected samples were falling under ideal limits of SANS 241. The highest pH value recorded was 8.4 and the lowest value was 7.1. The sulphate value of surface water of upstream of the mine was found to be higher as compared to the samples of downstream of the mine and upstream of Olifants River. The highest value of sulphate was recorded was 368 mg/l and the lowest value of sulphate was 5 mg/l. The sampling results indicate that the mine is not contributing is contamination to an already contaminated system.

Field investigation was conducted to determine if the facilities around the mine are the contributing factor to the contamination of both ground and surface water within the study area. It was found that the all dirty runoff from the washing plant area, stockpile area and mining are disposed into lined PCD. The mines also install leakage detector to monitor if the pollution control dam is leaking to prevent both ground and surface water contamination. All waste from the PCD is re-used for dust suppression on haul roads. The mine has constructed berms and trenches to separate clean water and dirty water around the mine. All dirty runoff is channelled to pollution control dam and clean water is diverted away to the mining area.

The results of the particle tracking exercise indicate that the surface flow will drain towards the Elandspruit tributary from the mining area. The flood lines also show that the mine infrastructure is outside of 100 years flood lines. Groundwater levels were found vary from 1.6 mgbl to 51.1 mbgl. The contour lines were indicating that the groundwater flow is heading in a westerly direction from the watershed towards Elandspruit tributary of the Olifants River. It is important for the mine to monitor both ground and surface water upstream and downstream of the mine in order to monitor the contamination trends.

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