

The impact of acid mine drainage in the Witwatersrand Western basin

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ABSTRACT

The mining and industrial sector grew rapidly in South Africa during an era of less stringent environmental regulations resulting in a substantial amount of waste material released to the environment. The industrial wastes contain heavy metals, which, when in contact with water, re-dissolve and seep through the unlined tailing dumps draining directly into the environment (this contaminated water is generally called acid mine drainage (AMD)). In 2002, AMD water containing heavy metals such as uranium had started decanting from the Western basin, located below the Krugersdorp-Randfontein area. Communities in informal settlements, as they do not have access to clean and potable water use the untreated uranium contaminated water.

Research to evaluate the AMD impact on mining companies' strategy, how to mitigate the cost of AMD and to review the environmental policies pertaining to the mining activities was conducted. The study focussed on the challenges experienced due to AMD particularly on companies within the Witwatersrand, Western basin and the surroundings. A qualitative methodology was used to collect appropriate data (interviews conducted eye to eye with the respondents) on how to mitigate the cost of AMD and its impact on mining and associated activities on the water regime in and around the Witwatersrand mining areas.

The research has indicated that South Africa's future water balance paints a bleak picture characterised by severe water shortages. If AMD water is allowed to decant from the mines into the environment, an enormous amount of fresh water will be needed for dilution which presents a threat to water security, and ultimately inversely impacting the South African economy. This also has adverse impact on mining companies' profitability; hence it is important that the mining companies have strategies to prevent risks associated with AMD. It is believed that treating the water to solve the problem of water security and at the same time having other by-products via the recovery of metals and reagents from AMD could be a viable solution to water pollution.

The regulatory standards and policies in combating the challenges caused by AMD have been proven adequate in the opinion of the experts in the literature. Although standards have been established to set maximum acceptable levels of contaminants that can be released into the environment; mining companies find it difficult to achieve the set standards due to the legacy left by the mining activities that happened more than a century ago and mines that go into liquidation and abandoned their environment liability once closed down. These old abandoned mines significantly contribute to AMD; hence, it is in this regard that the treatment of AMD has to be done by existing mines in collaboration with the government.

Given that South Africa is a water scarce country, AMD water is seen to present an opportunity as a source of water for South Africa. Treating the AMD water to drinkable standards is the ultimate goal for the mining sector, which could in addition improve the water supply in South Africa. Hence most of the mining industries are including plans to build treatment plants into their strategy, which would deal with the environment problems, while creating jobs at the same time.

DECLARATION

I, Thembi Ruth Thulare, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Thembi Ruth Thulare

Signed at

On the day of 2016

DEDICATION

This thesis is dedicated to my two wonderful kids Vivianne Kgothatso Thulare and Phidiso Thulare, who have been my source of inspiration.

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TABLE OF CONTENTS

ABSTRACT	i
DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
LIST OF TABLES	ix
LIST OF FIGURES	x
1 INTRODUCTION.....	1
1.1 PURPOSE OF THE STUDY	1
1.2 CONTEXT OF THE STUDY.....	1
1.3 PROBLEM STATEMENT	4
1.3.1 MAIN PROBLEM	4
1.3.2 SUB-PROBLEMS	4
1.4 SIGNIFICANCE OF THE STUDY	4
1.5 DELIMITATIONS OF THE STUDY	4
1.6 DEFINITION OF TERMS	5
1.7 ASSUMPTIONS	6
2 LITERATURE REVIEW	7
2.1 INTRODUCTION	7
2.2 BACKGROUND DISCUSSION	7
2.2.1 ACCOUNT OF URANIUM POLLUTION IN SA	9
2.2.2 POLLUTION POINT SOURCES	12
2.2.3 MINING EFFLUENTS	13
2.2.4 SURFACE RUNOFF FROM STORM-WATER DRAINAGE SYSTEMS	15
2.2.5 SINKHOLES FILLED WITH TAILING MATERIAL.....	16
2.2.6 DOMESTIC WASTE WATER FROM MINING RELATED SEWAGE WORKS.....	17
2.3 URANIUM METAL AND ITS EFFECT	17
2.3.1 RELEVANT ENVIRONMENTAL LEGISLATION	18
2.3.2 URANIUM REGULATORY LIMITS IN DRINKING WATER	21
2.3.3 THE IMPACT OF AMD	22
2.3.4 URANIUM POLLUTED AREAS	23
2.4 SOUTH AFRICA'S CHALLENGES PERTAINING TO MINE CLOSURE	33

2.5	COMPANIES OPERATING AROUND THE WITWATERSRAND WESTERN BASIN	34
2.5.1	GOLD FIELDS LIMITED	34
2.5.2	SIBANYE GOLD	36
2.5.3	HARMONY GOLD	37
2.5.4	ANGLO GOLD ASHANTI	38
2.6	CONCLUSION OF LITERATURE REVIEW	40
2.7	RESEARCH QUESTION 1	41
2.8	RESEARCH QUESTION 2	41
3	RESEARCH METHODOLOGY	43
3.1	RESEARCH METHODOLOGY / PARADIGM	43
3.2	RESEARCH DESIGN	43
3.3	POPULATION AND SAMPLING	44
3.3.1	POPULATION	44
3.4	THE RESEARCH INSTRUMENT	44
3.5	PROCEDURE FOR DATA COLLECTION	45
3.6	DATA ANALYSES AND INTERPRETATION	45
3.7	LIMITATIONS OF THE STUDY	45
3.8	VALIDITY AND RELIABILITY	46
3.8.1	EXTERNAL VALIDITY	46
3.8.2	INTERNAL VALIDITY	46
3.8.3	RELIABILITY	47
4	PRESENTATION and DISCUSSION OF THE RESULTS	48
4.1	INTRODUCTION	48
4.2	DEMOGRAPHIC PROFILE OF RESPONDENTS	48
4.3	RESULTS PERTAINING TO RESEARCH QUESTION 1	49
4.3.1	STRATEGIC CHOICES A MINING COMPANY TAKES TO MITIGATE PROBLEMS ASSOCIATED WITH AMD	49
4.4	RESULTS PERTAINING TO RESEARCH QUESTION 2	56
4.4.1	THE IMPACT OF AMD IF NOTHING IS DONE	56
4.5	ADDITIONAL COMMENTARIES	63
4.6	CONCLUSION	66
5	CONCLUSIONS & RECOMMENDATIONS	68
5.1	INTRODUCTION	68
5.2	CONCLUSIONS OF THE STUDY	68
5.3	RECOMMENDATIONS	70
5.4	SUGGESTIONS FOR FURTHER RESEARCH	72

REFERENCES.....73

6 APPENDICES.....78

6.1 APPENDIX A: INTERVIEW MATRIX 78

LIST OF TABLES

Table 1: Minimum limits for the concentration of dissolved uranium in drinking water by various sources	21
Table 2: Lancaster Dam water analyses	27
Table 3: Lancaster Dam water analyses	27
Table 4: Wonderfonteinspruit catchment water analyses.....	30
Table 5: Wonderfonteinspruit catchment solids analyses	30
Table 6: Robinson lake water analyses	32
Table 7: Robinson Lake sediments analyses.....	33
Table 8: Sample demographics	48

LIST OF FIGURES

Figure 1: Geographic location of gold mining areas and streams affected by mining pollution in the Witwatersrand basin (Winde, 2013)	10
Figure 2: Goldfields and polluted water streams in the West Rand gold fields (Winde, 2009)	11
Figure 3: Estimated dissolved uranium loads in the WFS based on uranium concentrations measured in 1997 (Winde, 2009).....	24
Figure 4: Uranium loads for selected sampling sites in the WFS catchment area post 1998 (Winde, 2009).....	25
Figure 5: Lancaster Dam (Busby, 2014)	28
Figure 6: Total-count radiometric image of a portion of the Wonderfonteinspruit catchment (Busby, 2014)	29
Figure 7: Informal settlements built on uraniferous tailings at the Tudor Shaft (Busby, 2014).....	31
Figure 8: An aerial view of the Cooke tailings dam (MiningNews, 2013)	37
Figure 9: Discharge of untreated acid mine water, West Rand (Photo: John Wesson).....	38

1 INTRODUCTION

1.1 Purpose of the study

The purpose of this research is to evaluate acid mine drainage (AMD) impact on mining companies' strategy and how to mitigate the cost of AMD, and to review the environmental policies pertaining to the mining activities. The study focuses on the challenges experienced due to AMD particularly by companies within the Witwatersrand, Western basin and the surroundings. Interviews were conducted to gain an understanding of the extent to which AMD impacts on the strategy of each company.

1.2 Context of the study

South Africa (SA) is a country that is highly dependent on mineral resources. Since the late 19th century, South Africa's economy has been based on the production and export of minerals and agricultural products, which in turn have contributed extensively to the country's skills development that is biased towards these industries.

Government involvement in SA's mining industry is largely restricted to ownership of the national electric power supply and the national oil and gas exploration companies. The bulk of mineral land investments and production has historically been controlled by private organisations. SA covers the world's largest reserves of a number of minerals, such as gold and platinum group metals. The mining industry has played a crucial role in the country's economic development by employing a large force of employees and contributing to the country's exports (Hamann, 2004). However, "The contribution of the mines to the economy of South Africa over the past century has been overvalued, while the social injustices and negative environmental impacts that accompanied mining have (Van Eeden, Liefferink, & Durand, 2009)

Mining and associated activities have impacts on the water regime and water quality in and around the mining areas. "Water-pollution problems, caused by mining, include acid mine drainage, metal contamination and increased sediment levels in streams. Sources

can include active or abandoned surface and underground mines, processing plants, waste-disposal areas, haulage roads or tailing ponds. Mine drainage is a potentially severe pollution hazard, which can affect surrounding soil, groundwater, and surface water” (Schwarz, Gerth, Morgenstern, & Hebner, 2009).

Since 1886, when gold mining commenced in the Witwatersrand, mining activity has left a legacy of approximately 400 km² of slimes dams which constitute about six billion tonnes of pyrite tailings with an average uranium concentration of 100 ppm (Winde, 2013). “The pollution reality of gold mining waste is illustrated by a case study in the West Rand area, where water decant from gold mines started in 2002” (Oelofse, Hobbs, Rascher, & Cobbing, 2007). It is estimated that gold mining has brought approximately 800,000 tonnes of uranium to surface of which only about a quarter was extracted and sold while the vast majority is left in the tailings (Winde, 2013). “This waste from gold mines constitutes the largest single source of waste and pollution in South Africa and there is wide acceptance that Acid Mine Drainage (AMD) is responsible for the most costly environmental and socio-economic impacts” (Lieverink, 2014).

It is estimated that more than 100 000 tonnes of undissolved uranium is still present within the tailings deposit in the West Rand and Far West Rand areas (Coetzee, Winde, & Wade, 2006). Exposure of the tailing deposits to chemically aggressive environments of the atmosphere with free oxygen and water often leads to an accelerated release of dissolved heavy metals from the tailings particles. The pyrite present in slimes/tailings dams can therefore become a source of AMD. “Based on conservative estimates of the total surface area covered by tailings dams in the Western basin, the volumes of received rainfall and the rate at which uranium is re-dissolved from the tailings particles, it is estimated that a total of 24 tonnes of dissolved uranium could be released into the environment from unlined tailings deposits” (Coetzee et al., 2006)

Dust blown by wind from active and decommissioned slimes dams into adjacent storm-water drainage systems also constitutes a potential source of water pollution (Coetzee et al., 2006). Based on (conservative) assumptions regarding the affected surface area and average deposition rates of dust from adjacent slimes dams, it is estimated that

approximately 10 tonnes of particle-bound uranium per year are flushed by storm-water into receiving water courses (Coetzee et al., 2006). The sinkholes that occurred in the catchment area since dewatering commenced have been filled with uraniferous slimes material and this also constitutes as a major potential source of uranium water pollution (Coetzee et al., 2006). In addition to uraniferous tailings particles, many inactive slimes dams develop another major uranium source by forming extensive salt crusts that are readily dissolved by rainwater. Owing to the evaporation of contaminated water leaving dissolved salts behind, these crusts tend to enrich uranium to levels up to 10 times the concentration in underlying tailings (Coetzee et al., 2006). Hence, there is an urgent need to treat the slimes dams of many active and abandoned mines in the Western basin to combat the prevalent environmental problems, and this will have an impact on companies operating around the Western basin area.

Seepage of dissolved uranium and other heavy metals through the unlined pits has been associated with water contamination along the Wonderfontein spruit and Tweelopies Spruit in the Western basin where uranium loads of up 300 mg/L have been reported (Winde, 2014). Water has a natural uranium concentration of 0.0004 mg/L, however, the Department of Water and Sanitation considers a concentration of 0.07 mg/L safe to drink (Department of Water Affairs, 2013). The World Health Organisation (WHO) has recommended uranium maximum limit of 0.015 mg/L as safe for potable water. The uranium concentration in the Western, Central and Eastern basin ranges between 100-0.05 mg/L and does not meet the WHO specifications (Coetzee et al., 2006). Uranium concentration in excess of the maximum permissible limits (MPL) in potable water can be detrimental on human health. The absorption of uranium through ingestion leads to the destruction of the kidneys, affects the neurological system causing blindness, chromosome aberrations in sperm, blood and other connective tissue diseases, changes in the immune and endocrine systems and prevalence in malignant diseases, including cancer (Vermeulen, 2013b).

Evaluating the extent to which the AMD has on companies' strategy and profitability may bring more insight to the understanding of the future implications of the state of SA's mining industry, health system, and to the SA's economy.

1.3 Problem statement

1.3.1 *Main problem*

How to mitigate the cost of AMD and its impact on mining and associated activities on the water regime and water quality in and around the Witwatersrand mining areas.

1.3.2 *Sub-problems*

The first sub-problem is to assess the strategic choices a mining company takes to mitigate problems associated with AMD.

The second sub-problem is to evaluate the impact of AMD on the mining companies if nothing is done.

1.4 Significance of the study

The study will give more insight into companies' strategy in dealing with AMD problems. The study will also provide guidance to the stakeholders in understanding the implication of lack of funding, if any, or for investment in rehabilitation of mines and the consequences thereof on the companies' strategy and profitability.

In addition, the study will provide guidance and give more insight in the development of the strategy that may be adopted by the government in regulating any environmental impact made by the mining industry. The stakeholders include the government, the mining industry, workers, and the people of SA.

1.5 Delimitations of the study

The study will focus on evaluating the companies' strategy with regard to the impact of AMD, the government policies, and the environmental impact associated with AMD. This study will not address the impact of mining in the whole of SA, but will focus on the Witwatersrand western area of SA where the impact is high due to high radioactivity that

was caused by the AMD. Only three companies that are dominating the Witwatersrand Western basin area will be used in the study, i.e. Gold Fields Limited, Anglo Gold Ashanti, and Sibanye Gold.

1.6 Definition of terms

- **AMD:** Acid mine drainage
- **Bq:** Becquerel measures the strength of a radioactive source. 1 Bq is equivalent to 1 event of radiation emission per second
- **DEA:** Department of Environmental Affairs
- **DMR:** Department of Mineral Resources
- **DWAF:** The Department of Water Affairs and Forestry
- **DWS:** The Department of Water and Sanitation
- **EIA:** Environmental Impact assessment
- **Measurements:**
 - **mg/L/ppm** – milligrams per litre/parts per million, measures concentration of the metals in solution.
 - **ML/Day** – Mega litres per day, measures the water volume
 - **pH** – measure the acidity or alkalinity of a solution or liquid
- **NGO:** Non-Governmental Organisation
- **NEA:** Nation Environmental Act
- **NEMA:** National Environmental Management Act
- **NNR:** National Nuclear Regulator
- **NWA:** National Water Act
- **Radiation:** A process in which electromagnetic waves travel through a substance
- **Remediation:** “An action to be taken to remove radioactive contaminated material from a site and rehabilitate the site” (Van Veelen et al., 2009)
- **SABS:** South African Bureau of Standards
- **TCTA:** Trans-Caledon Tunnel Authority

- **TDS:** Total dissolved salt or Total dissolved solids
- **Triangulation:** Triangulation refers to the use of more than one approach to the investigation of a research question in order to enhance confidence in the ensuing findings
- **Uranium:** Uranium (chemical symbol U) is a naturally occurring radioactive element, with atomic number 92. It is commonly found in small amounts in rocks, soil, water, plants, animals and humans. All uranium isotopes are radioactive.
- **Uraniferous tailings:** “Since the discovery of gold in the Witwatersrand Goldfields in 1886, gold mining resulted in the establishment of more than 270 tailings dams, containing more than 6 billion tonnes of tailings and some 600 000 tonnes of uranium, and covering 400 km² (Lieverink & Liefferink, 2015). These tailings are called uraniferous tailings”
- **WCA:** Wonderfonteinspruit Catchment Area
- **WFS:** Wonderfonteinspruit is a tributary of the Vaal River, a national water resource
- **WHO:** The World Health Organisation
- **Witwatersrand Western basin:** “Underground geological formation which surfaces in the Witwatersrand, South Africa. It holds the world's largest known gold reserves and has produced over 40,000 metric tonnes, which represents about 50% of all the gold ever mined on earth” (Norman & Whitfield, 2006)

1.7 Assumptions

The following assumptions were made regarding the study:

- Interviews were conducted and the respondents were able to give information on the strategy development and implementation.
- The sample was enough to get adequate data.

2 LITERATURE REVIEW

2.1 Introduction

This section contains a literature review on the economic and environmental impact that is brought about by the mining companies. The report includes the key concepts and issues relating to the challenges experienced due to acid mine drainage in SA and the financial burdens it may impose on the companies operating in such areas. The section concludes with the key outcomes of the literature review.

2.2 Background discussion

The mining and industrial sector grew rapidly in South Africa during the era of less stringent environmental regulations resulting in a substantial amount of waste material released to the environment. Radioactive materials such as uranium are a natural part of our environment. Mining activities accelerate the natural geological processes such as the reprocessing of the earth's crust, by transferring ore from underground to tailings dams on surface (Wendel, 1998). "Water plays an important role in moving naturally occurring radionuclides through the environment, both as a transport medium for bulk ore, and as a medium for chemical reactions. In some cases, radionuclides are separated from the bulk ore and may pass into the environment via water streams, for example, uranium in underground water pumped to surface, and uranium leakage from tailings dams resulting from oxidation of pyrite" (Wendel, 1998).

The extent to which uranium has been exposed to the biosphere as a result of gold mining in the Witwatersrand is illustrated by the monetary value placed on many tailings deposits earmarked for re-processing, reaching tens of millions of rand per slimes dam (Winde, 2009).

Since 1886, when gold mining commenced in the Witwatersrand, mining activity has left a legacy of approximately 400 km² of slimes dams which constitutes approximately six billion tonnes of pyrite tailings containing an average uranium concentration of 100 ppm (Winde, 2009). It is estimated that gold mining has brought approximately 800 000 tonnes of

uranium to surface of which only about a quarter was extracted and sold while the vast majority is left in the tailings (Winde, 2013). The enormous amount of uraniferous tailings spread over large areas constitutes an environmental problem of extraordinary spatial dimensions, causing uranium water pollution in many rivers and aquifers in mining regions (Winde, 2013).

The industrial wastes contain heavy metals, which, when in contact with water and under appropriate oxidising conditions, will re-dissolve and seep through the unlined tailings dumps draining directly into underlying aquifers. This leads to contamination of already limited clean/potable water resources in the surrounding areas as observed in the Wonderfontein spruit catchment area (WCA) in the Western basin.

In 2002, acid mine drainage had started decanting from the Western basin, located below the Krugersdorp-Randfontein area. It is estimated that between 2002 and 2012, uranium contaminated AMD water continued to flow into the Vaal and Limpopo river system (Vermeulen, 2013b). The water monitoring program of Potchefstroom has released data which indicates a significant rise in uranium levels in raw and tap water (Coetzee et al., 2006). Communities in informal settlements, as they do not have access to clean and potable water use the untreated uranium contaminated water.

A short-term intervention strategy of neutralising the contaminated water is currently employed as a result of a lack of treatment capacity (Winde, 2014). Tonnes of lime is poured into the Tweelopies Spruit in an effort to neutralise the acid mine water resulting in sludge formation in the water course. Uranium and other metals accumulate in the river sediment and soil in this region, with a serious negative impact on the vegetation surrounding the water bodies, and poses serious threats to the farming industry adjacent to mining areas. The current AMD treatment plant at Grootvlei Shaft 3, in Germiston pumps water at an average of 57 ML/day, resulting in 4.3 ML of sludge produced per day (Winde, 2014).

The volume of the sludge produced by the neutralisation treatment requires enormous storage capacity. The sludge also retains a lot of moisture, which promotes seepage and limits the quantity of water available for recycle. Furthermore, lime treatment produces

water with concentrations of heavy metals, radionuclides and dissolved salts, which do not meet all regulatory requirements (Ring et al., 2004). Additional treatment to reduce residual concentrations of uranium in the treated water may be necessary. Thus, there is a need for improved and sustainable technologies for the long-term treatment of AMD to meet these standards, particularly cost-effective methods for reduction of sulphate, which is present at the saturation level of gypsum after lime treatment.

Though there is an increased interest in treating the waste dumps, most stakeholders are still conducting desktop studies, evaluating alternative treatment technologies. A limited literature review has been conducted to assess the impact of uranium acid mine drainage pollution in the Western basin and feasible technologies that may be employed to recover the radionuclides without causing any further environmental burdens.

2.2.1 *Account of uranium pollution in SA*

The Witwatersrand basin is known as the world's largest gold deposit. Auriferous sediments of the Witwatersrand do not only contain gold, but also contains elevated concentration of uranium. The gold-to-uranium concentration ratio in most of the Witwatersrand basin deposits is in the range of 1:10-1:100 (Winde, 2009). Gold mining produced exceptionally high volumes of tailings owing to the typically low concentration of gold necessitating the mining of large volumes of rock (Winde, 2006a). This has resulted in large amounts of uranium being brought to the biosphere by deep-level gold mining.

Uranium was produced as a by-product of gold in South Africa to subsidise the mining costs. In the 1980s the uranium price dropped, resulting in a significant drop in uranium production. This resulted in radioactive heavy metal being dumped along with tailings on the slimes dams. Since the discovery of gold in the Witwatersrand basin in 1886, gold mines produced over 6 billion tonnes of gold tailings with an average concentration of 100g/t uranium (Winde, 2013). This has resulted in increased uranium environmental mobility and exposure to local residents. In the areas surrounding the Witwatersrand Goldfields, tailings dumps are the main source of pollution since they are generally composed of elevated proportions of pyrite and other minor metallic sulphides.

The Witwatersrand basin is characterised by various gold fields as shown in Figure 1. The tailings and the abandoned mine workings in this area are potential sources for water stream pollution. (Winde, 2013) The upper part of the Wonderfonteinspruit (WFS) is characterized by several auriferous reefs which are defunct and abandoned, and have produced large amount of radioactive tailings (Winde, 2009). Geographic location of the gold fields in the upper part of WFS in the far West Rand are shown in Figure 2.

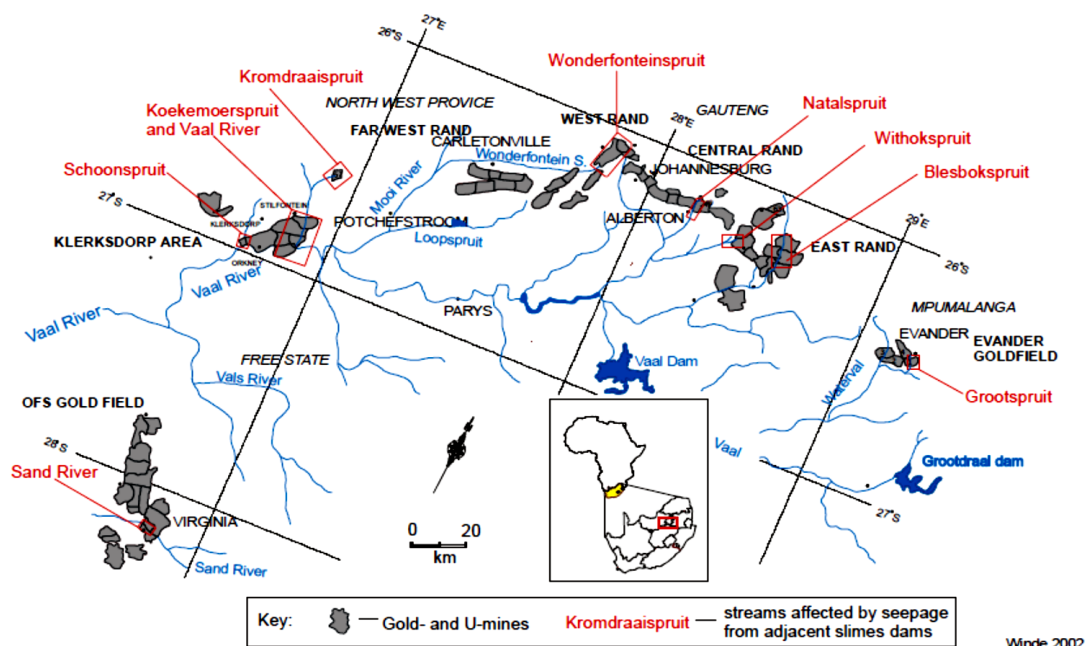


Figure 1: Geographic location of gold mining areas and streams affected by mining pollution in the Witwatersrand basin (Winde, 2013)

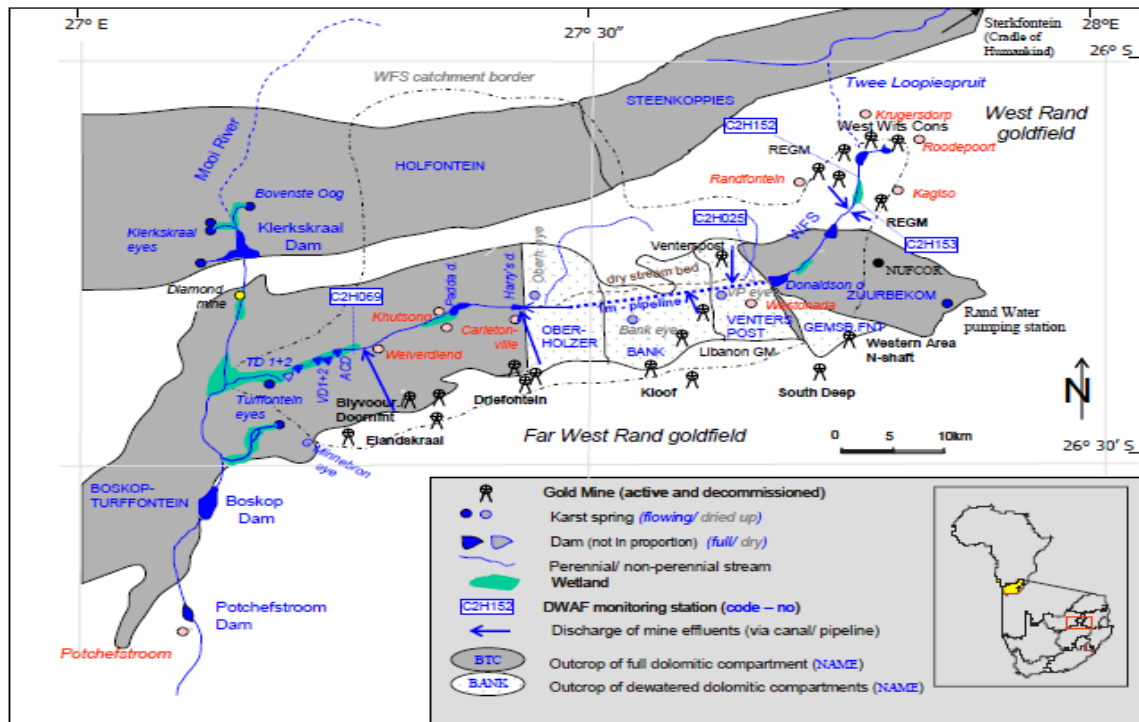


Figure 2: Goldfields and polluted water streams in the West Rand gold fields (Winde, 2009)

Even though uranium was produced as a by-product of deep-level gold mining in South Africa, environmental hazards associated with mining of uraniferous ore deposits in the Witwatersrand basin exceeds those of genuine uranium mines e.g. Canada and Germany (Winde, 2013). There is a range of potential point sources contributing to the uncontrollable release of uranium into the environment and thus resulting in above average exposure to the vulnerable population. The major potential point sources for uranium pollution, especially in the WFS catchment area were studied by Winde [(Winde, 2013), (Winde, 2006a)], of which the major ones are:

- Uranium seepage from slimes;
- Mining effluents (comprising of process water from metallurgical plants, outflow from settling ponds, fissures and service water from underground);
- Polluted run-off from storm-water drainage systems of mines and municipalities;
- Sinkholes filled with tailings material;
- Domestic water from mining sewage treatment systems.

2.2.2 *Pollution point sources*

2.2.2.1 *Seepage from slimes/tailing dams*

The slimes dams of the West Rand and the far West Rand contain more than 100 000 tonnes of uranium (1998) with an average concentration in some mines being above 300 mg/L (Winde, 2006a). The termination of uranium production in the mid-1980s resulted in an increase of uranium levels in tailings of many gold mines. The slimes dams (or tailings dams) contain uranium in two orders of magnitude above the natural background concentration in soils and surface rock in the area. Radioactive slimes dams and unmined uraniferous ore in mine voids constitute a source from which uranium migrates uncontrollably into the environment (Winde, 2013). The oxidised ore bodies in the underground mine workings also constitutes a potential source for uranium water contamination.

The tailings contain a significant amount of pyrite, which upon exposure to oxygen and water forms sulphuric acid. Sulphuric acid is used in uranium leaching circuits to extract up to 90% uranium. Thus, exposure of the milled uraniferous tailings to oxygen and water constitutes a chemically aggressive environment, whereby the produced acidic water re-dissolves the heavy metals and uranium (Winde, 2013) (van der Walt & Winde, 2002). Mining activity drastically increases the extent and rate at which uranium water pollution occurs by expanding the reactive surface area of the mined rock through milling and exposing large volumes of sulphides to atmospheric conditions.

During the early stages of mining it was believed that the negative climatic water balance will result in more water evaporating than infiltrating, hence the slimes dams in SA were generally not lined (Winde, 2013). Many slimes dams were deliberately placed on top of permeable dolomite in order to enhance natural drainage of tailings pore water and reduce the risk of dam failure. This promoted the outflow of highly contaminated seepage into nearby water sources (Winde, 2013). Owing to the limited porosity of the fine grained tailings, the vertical percolation through the slimes dams is slow, resulting in a continuous outflow even during dry winter months.

Seepage from slimes dams frequently displays significantly elevated concentrations of uranium, exceeding the discharge global background concentration of uranium in fresh water by factor of between 1000 - 1 000 000 (Winde, 2013). Based on conservative estimates of the total surface area covered by tailings dams in the WFS catchment area, 24 t/annum of dissolved uranium is released into the environment from unlined tailings deposits (Coetzee et al., 2006). Draining directly into underlying aquifers or dewatered dolomite, this constitutes a source of uranium water pollution that is costly to control.

Uraniferous tailings particles of many inactive slimes dams form extensive salt crusts that are readily dissolved by rainwater. Evaporation of contaminated water leaves dissolved salts behind and the crusts tend to be enriched with uranium. The crust is instantly dissolved by rainfall and thus acts as a major source of rapid stream pollution via storm-water runoff. In some instances, the waste rock dumps consisting of un-milled overburden, also act as uranium-source as examples from the Klerksdorp goldfields [(Winde, 2013), (Winde, 2014)].

In mined out areas such as the West Rand and Central Rand of the Witwatersrand basin water flowing out of flooded mine voids may act as another major source of uranium pollution affecting surface- and groundwater (Winde, 2013).

2.2.3 Mining effluents

The mining industry in South Africa commenced during an era of less stringent environmental regulations. Uranium was leached from the ore and thus present in elevated concentrations in water circuits of most metallurgical plants. During the early stages of uranium leach commissioning, poor leach efficiencies and process failures allowed uranium exiting metallurgical plants along with waste-water streams (Winde, 2006b). Uranium production between the 1950s and mid 1980s significantly contributed to the water pollution (Winde, 2013). An average uranium concentration of 0.74 mg/L was reported in mining effluents across the Witwatersrand basin in the 1990's (Winde, 2006b).

Uncontrolled point sources such as spillages and pipeline leakage contribute to uranium pollution. Many mine slimes dams are located near water courses, dams, wetlands and canals. As a consequence, the distance between potential pollution sources and receiving water courses was often considerably shortened promoting water pollution (Winde, 2013). In some instances, return water for recycling slurry water from tailings dams were placed directly into water courses such as the Tudor and Lancaster dams in the upper WFS.

Exposure to oxygen of the un-mined reefs with low grades gold led to uranium dissolving into ingressing (fissure) water and causing contamination of underground mine water [(Winde, 2006a),(Winde & Van der Walt, 2004)]. The ingressing water posed a danger of flooding the mine workings. In the 1960's a dewatering process was implemented to dewater the mine workings. Water was pumped outside the catchment boundaries into nearby catchment streams (Winde, 2006c). The acidic water decanting from the flooded mine-void system of the Western basin initially contained approximately 16 mg/L uranium (Winde, 2013). Based on the water discharge volumes, a conservative approximation of 12 tonnes of uranium per annum is estimated to have been released into the WFS catchment (Winde, 2006a).

After the underground mine water decanting into Tweelopies Spruit, water was pumped into Robinson Lake as an emergency precautionary measure. This lake has been reported to have an uranium concentration of 16 mg/L, which is more than 40 000 times the background uranium concentration for water, according to data from the National Nuclear Regulator (Vermeulen, 2013b). The Robinson Lake has been declared a radioactive area and it is closed off to the public, while the Hippo Dam has become a reactor dam containing radioactive sludge.

The gold fields of South Africa are located in water-scarce areas. Polluted rivers and streams have a relatively low dilution capacity compared to water-rich mining areas resulting in relatively high uranium levels in receiving streams compared to humid areas (Winde, 2013).

2.2.4 *Surface runoff from storm-water drainage systems*

South Africa is characterised by semi-arid climate. The climatic conditions in the Witwatersrand region allowed for low-cost tailings disposal in the form of uncovered slimes dams. This is in contrast to mines in humid climates where tailings are commonly contained in water-covered storage facilities (Winde, 2013). The uncovered tailings contribute significantly to uranium pollution because of wind and water erosion.

Dust blown by wind from active and decommissioned slimes dams into adjacent storm-water drainage systems constitutes a potential source of water pollution, especially during dry winter months. Based on (conservative) assumptions regarding the affected surface area and average deposition rates of dust from adjacent slimes dams, it is estimated that approximately 10 tonnes of particle-bound uranium per year are flushed by storm-water into receiving water courses (Coetzee et al., 2006). The particle bound uranium not only affects nearby residents but also contributes indirectly to pollution of urban water courses as much of the blown-off dust settles on impervious surface where it is flushed into storm-water drainage systems (Winde, 2013).

The tailings are also eroded by rainfall affecting especially un-vegetated slimes dams, which often form deep channels that accelerate the access of oxygen and the associated acidification of pore water. The eroded tailings act as source of AMD [(Winde, 2013), (Winde, 2014)]. The eroded tailings, when in contact with unpolluted fluvial sediments and natural soil, results in uranium levels decreasing with increasing distance from the source of pollution. The dissolved uranium can be re-concentrated outside access-controlled mine properties to levels exceeding the concentration in the original pollution source (Winde, 2014).

In addition to wind and water erosion of slimes dams transporting uraniferous tailings particles into adjacent areas, the chemical leaching of uranium from tailings particles and subsequent, waterborne transport as a dissolved phase into subjacent aquifers and nearby streams often constitutes the single largest source of mining-related water pollution [(Winde, 2013),(Winde, 2006a)].

2.2.5 *Sinkholes filled with tailing material*

Winde highlighted that deliberate spreading of uraniferous tailings particles was practiced in dolomitic areas of the WFS for a limited period. The tailings were pumped into natural caves on mine property in order to save disposal costs [(Winde, 2013), (Winde, 2006b)]. “Environmental awareness and conservation in the WFS catchment area since the 1950s appear to have had a slow beginning, with users of the area being genuinely ‘aware’, but still not necessarily driven by ‘responsibility’. Although it is accepted that physical landscape manipulations are inevitable in the process of meeting human needs, these alterations will produce (and have done so in the past) biological consequences, of which some are unavoidable” (Van Eeden, 2008).

When dewatering of the abandoned mines commenced, more than a 1000 sinkholes formed along the 30 km of the WFS (Winde, 2013). Large amounts of tailings from nearby metallurgical plants were pumped into the many subsequently forming sinkholes to reduce infiltration of surface water into the underlying mine void. This was also practiced to reduce the pumping costs. The sinkholes have been filled with uraniferous slimes material with an average concentration of 100 ppm uranium [(Winde, 2013),(Winde, 2006b)].

The filled sinkholes were reactivated by rainfall erosion resulting with the fill material washed into underground karst receptacles (Winde, 2006b). An example is the Venterpost compartment where 77 000 m³ of tailings material was dumped in a sinkhole and 35000 m³ disappeared overnight (Winde, 2006b). The Oberholzer compartment sinkhole was also filled with more than 250 000 m³ and disappeared underground without filling the hole. The presence of oxidised slimes material in sinkholes and dewater aquifer is of concern, since the leaching rates of oxidised slimes material in sinkholes are significantly higher, hence, there is a threat of uranium dissolving into the underground karst receptacles (Winde, 2006b). This constitutes a major potential source of uranium water pollution. It is estimated that seepage from fill material may contain uranium concentrations of between 60 to 310 mg/L (Winde, 2013). Seepage from tailings-filled sinkholes is a significant potential source of uranium pollution with modelled uranium concentrations of up to 300 mg/L (Winde, 2013).

2.2.6 *Domestic waste water from mining related sewage works*

High uranium concentration in sewage system can be associated with miners drinking uranium contaminated water in underground mine workings. Water samples from toilet drains of changing rooms at shafts of several gold mines have uranium concentration of 0.4-13 mg/L (Winde, 2006b).

2.3 Uranium metal and its effect

Uranium is a radiotoxic naturally occurring element, which has chemo-toxic properties like cadmium (Cd) and mercury (Hg). Uranium is radioactive in nature, hence, it spontaneously gives off energy and particles that can break chemical bonds and damage living cells (Winde, 2013). Uranium is 1000 times more abundant than gold (Au), 40 times more than silver (Ag) (Aguilar, 2002) and 10 times more common than the notoriously toxic metals such as Cd (Guion, 2011) and Hg (Winde, 2013).

Heavy metals such as Cd, lead (Pb) and nickel (Ni) are mobile and soluble in acidic conditions. At higher pH values, the dissolved heavy metals precipitate out of solution, which is seldom the case with uranium. Uranium displays a very complex geochemical behaviour; it is soluble over a wide pH-range and often forms soluble complexes that stay in solution (Winde, 2013). Hence, the chemical mobility of uranium is higher than those of the other heavy metals. Instead of forming insoluble precipitating sulphides like many other heavy metals, uranium, under reducing conditions, changes from a hexavalent to a tetravalent ion and forms insoluble oxides (Winde, 2013). When this occurs, for example, in organic-rich dam sediments, uranium may be immobilised. Exposing such sediments to atmospheric oxygen may release parts of the accumulated uranium back into the water (Winde, 2013). Thus, with the conventional method of treating acid mine drainage water with lime, the precipitated uranium has the potential to re-dissolve and enter the water system. Uranium isotopes emit relatively large alpha particles which are considered to be 20 times more biologically damaging than the two other types of ionising radiation (beta and gamma radiation) (Hebden & Smit, 1984). Hence, mainly uranium is problematic as a heavy metal.

2.3.1 *Relevant environmental legislation*

In South Africa, the Regulatory Authorities responsible for the regulation of radiological contamination in the water resources are the Department of Water Affairs and Forestry and the National Nuclear Regulator reporting to the Department of Minerals and Energy (Van Veelen et al., 2009).

“Development of clean-up goals is based primarily on the regulatory authority applied and the risk assessment used. Legislation governing radioactively contaminated sites are rather complex and somewhat confusing due to overlapping mandates of the different authorities” (Van Veelen et al., 2009).

A summary of the main legislative issues as outlined from the “Wonderfonteinspruit catchment area remediation plan” report (Van Veelen et al., 2009) is as follows:

- Pollution, as defined in the NWA (Republic of South Africa, 1999b), includes the indirect or direct alteration of the physical, chemical or biological properties of a water resource. This can be linked to Section 24 of the Constitution of the Republic of South Africa.
- Definition of a water resource and a water course, which includes wetlands and dams are important in the extent of the mitigating actions. The NWA’s definitions of a water resource and water course are very broad. The only ambiguity is the flood lines, which is clearly defined in the NWA (Republic of South Africa, 1999b).
- Polluters pay principle (Section 2 of the NWA) (Republic of South Africa, 1999b), which requires that the persons responsible for the pollution must cover the costs of prevention, remediation and impacts of the pollution or impact from the activity. Section 5 and 8 of the NWA discuss the establishment of National Water Resource Strategy (NWRS) and Catchment Management Strategy (CMS). The WCA remediation plan must be included in the strategies as they will be an integral part of the strategy to be developed in the catchment area.
- Section 19 of the NWA is an important regulatory tool specifically for the Department of Water and Sanitation to give the responsible parties options to implement the remediation in the WCA and to take legal and constructive intervention if so required.

This is closely coupled with Section 28 and 30 of the NEA (Republic of South Africa, 1998).

- Government Notice No. 704, 4 June 1999, can also be used as a legal tool and one of the fundamental pillars of the establishment of clean up and prevention strategy in the WCA.
- Section 53 of the NWA (Republic of South Africa, 1999b) is used where there is contravention of licence conditions and in this exercise Section 19 can be used more effectively in a remediation strategy.
- Section 151 of the NWA, taking a party to court for non-compliance, should be seen as a last resort. Legal action in court is a long and arduous process and does not leave scope for remediation in a short period. If this action is followed, it should be done in conjunction with an action where the authorities take responsibility of the remediation and in parallel seeks criminal and legal compensation.
- Section 2 of the NEMA sets the principles for sustainability, and the need to avoid any activities that degrade or pollute the environment. The remediation plan must view this section from two angles; (1) the actions taken must take the impact on the environment into consideration and (2) whether the remediation action taken will benefit the environment. This view or consideration is in light that one of the objectives of the remediation plan only considers the impact on human health and not the environment.
- Section 24 of the NEMA requires that the EIA process be followed. However, there are processes, which can be followed that will allow for exemption. There are stricter EIA requirements for Wetlands that could influence the priority of remediation or even the mitigating actions to be implemented to effect the remediation.
- Section 28 of the NEMA is similar to Section 19 of the NWA; however, Section 28 of NEMA may not be allowed to be enforced in retrospect. In other words, Section 28 only deals with current companies currently polluting.
- Legal action can be taken in terms of Section 32 of NEMA. However, this should be seen as a last resort or in parallel with other forms of mitigating actions.
- Government Notice R388, promulgated in terms of Section 36 of the NNR Act (Republic of South Africa, 1999a). In terms of the provisions of Section 2 (2) (b) of the NNR Act, the Act does not apply to solid materials where the level of radioactivity concentration

of each radionuclide in materials is below 0.5 Bq per gram for naturally occurring radioactive nuclides of uranium and thorium and their progeny except for radon.

- NNR guideline: a guideline document for the release of contaminated sites from regulatory control. Section 6 of the above-mentioned guidelines refers to release criteria. Contaminated sites may either be released conditionally (restricted use) or unconditionally (unrestricted use):
 - Unrestricted release of land and water

It is required that sites used in the conduct of authorised activities may be released for unrestricted use provided that it is demonstrated that radioactive contamination, which can reasonably be attributed to the regulated activity, have been removed from the site. Compliance with this requirement can be achieved by demonstrating that the activity concentration levels are below those on the background reference site.
 - Restricted release of contaminated land and water

In the event that removal of radioactive contamination and radioactive materials, which can reasonably be attributed to the regulated activity, is not feasible, then release for use is allowed subject to any restrictions specified by the Regulator if the following can be demonstrated:

 - (i) Compliance with an annual effective dose limit, applicable to the average member of the critical group from residual contamination for all feasible future situations. The limit must be approved by the Regulator on a case-by-case basis and must provide sufficient assurance that the site-specific limit that was applicable during operations will not be exceeded.
 - (ii) Remedial measures have been taken to achieve an optimal level of safety, which is, cleaning to levels equivalent to that of exclusion. Under these circumstances, the regulator may choose not to put any restrictions.

2.3.2 Uranium regulatory limits in drinking water

The WHO has set the guideline limit for uranium concentration in drinking water as 2 µg/L (World Health Organization, 1998). Major uranium producing countries such as Canada, the USA and Australia have higher guideline limits ranging from 20-30 µg/L, while South Africa has the highest guideline limit of 70 µg/L. The SABS has adopted a value of 15 µg/L uranium in water suitable for consumption. Various sources have set regulatory limits for the minimum permissible levels of uranium in drinking water. The recommended concentration limits of dissolved uranium in drinking water set by various sources are given in Table1.

Table 1: Minimum limits for the concentration of dissolved uranium in drinking water by various sources

Organization/Country	Year	U concentration limit, µg/L
World Health Organization (WHO): drinking water	1998	2
	2003	9
	2004	15
	2011	30
Environmental Protection Agency of the USA (USEPA): drinking water	2012	30
Health Canada: drinking water	2008	20
South Africa (Department for Water Affairs)	1993	
Class A (no risk): domestic water		1000
Class B (insignificant risk): domestic water		4000
Target Water Quality Ranges (TWQR): - domestic water	1996	70
South African Bureau of Standards	2011	15

Uranium concentration in excess of the minimum permissible limits (MPL) in potable water can be detrimental on human health. Uranium attacks the brain, acts as endocrine disruptive compound by mimicking oestrogen, compromises the immune system and damages the DNA (Botha, Bester, & Hardwick, 2009). The provisional guideline for uranium in drinking water as specified by the WHO is 0.015 mg/L (Botha et al., 2009; World Health Organization, 1998). The uranium concentration in the Western, Central and Eastern Basin does not satisfy this specification (Department of Water Affairs, 2013). Recent scouting water samples collected at the Western basin contained 5-30 mg/L uranium, which is 2000 times more than the 0.015 mg/L ppb regulatory limit.

In assessing health risks associated with uranium pollution especially at the Western basin, it is rather clear from the literature that there is an urgent need to implement preventive measures that will combat uranium pollution. Assessing health risks entails quantifying the existing hazard (i.e. the health damage potential and extent of uranium pollution) and the probability that humans will be adversely affected.

2.3.3 *The impact of AMD*

Given the huge amount of uraniferous tailings spread over large areas it is no surprise that many rivers and aquifers in mining regions are affected by uranium pollution. Specifically addressing pollution associated with gold mining activities, two regional surveys of radioactive pollution of rivers in and around the Witwatersrand goldfields were conducted by the DWS confirming that a number of rivers and streams were indeed significantly contaminated (Department of Water Affairs, 2013). Due to the interconnectivity of ground and surface water systems in South Africa, high volumes of polluted water have the potential to severely impact upon the quality of South Africa's water supply. This impact has the potential to affect all major industries, across the value chain.

In 2002, AMD had started decanting from the Western basin, located below the Krugersdorp-Randfontein area. Between year 2002 and 2012, uranium contaminated AMD water continued to flow into the Vaal and Limpopo river system (Vermeulen, 2013b).

The outflow has grown worse over the years after heavy rains, prompting the Department of Water and Sanitation to intervene. Since August 2012, the water has been neutralised to remove the heavy metals but damage has already been done.

The potential of AMD water pollution to affect river systems has been identified in Mpumalanga, Free State, Gauteng, Limpopo, North West and the Northern Cape (Deloitte, 2013). The contamination of streams by adjacent slimes dams poses a severe risk to the health of people in informal settlements where polluted stream water is often consumed without appropriate treatment due to the lack of municipal services (Deloitte, 2013). Most people residing in proximity to rivers in Gauteng and the West Rand use water, from either streams or boreholes contaminated by uranium and other heavy metals. Long-term effects on cattle and crop farming and established drinking water supply schemes are also of concern. The following are the major risks associated with uranium AMD water pollution:

- Contamination of shallow groundwater resources required for agricultural use and human consumption;
- The decant of AMD to the environment (currently the major focus of this project) may result with the following (Deloitte, 2013):
 - Negative ecological impacts;
 - Localised flooding in low-lying areas;
 - Impacts on major river systems.

All the identified risks of AMD could have adverse impact on company profitability; hence, it is important that companies have strategies to prevent such risks, such as closure due to the impact of mining in human health.

2.3.4 *Uranium polluted areas*

Winde conducted studies on uranium pollution of sediments and estimated that fluvial sediments in the WCA contain over 2200 tonnes of uranium of which a third consists of

non-tailings material, i.e. secondary uranium accumulation in fluvial sediments (Winde, 2013). Over the past 122 years of mining, an average rate of uranium accumulation is approximately six tonnes per year. The average uranium load of dissolved uranium in the WFS is 3.5 t/a, thus, this will suggest that approximately 10 tonnes particulate and dissolved uranium, of which approximately two thirds is retained in sediments, are released into the WFS per annum (Winde, 2006b, 2009). On a global scale, such uranium loads are significant. Figure 3 and Figure 4 shows the estimated uranium loads at selected sampling sites along the WFS catchment area.

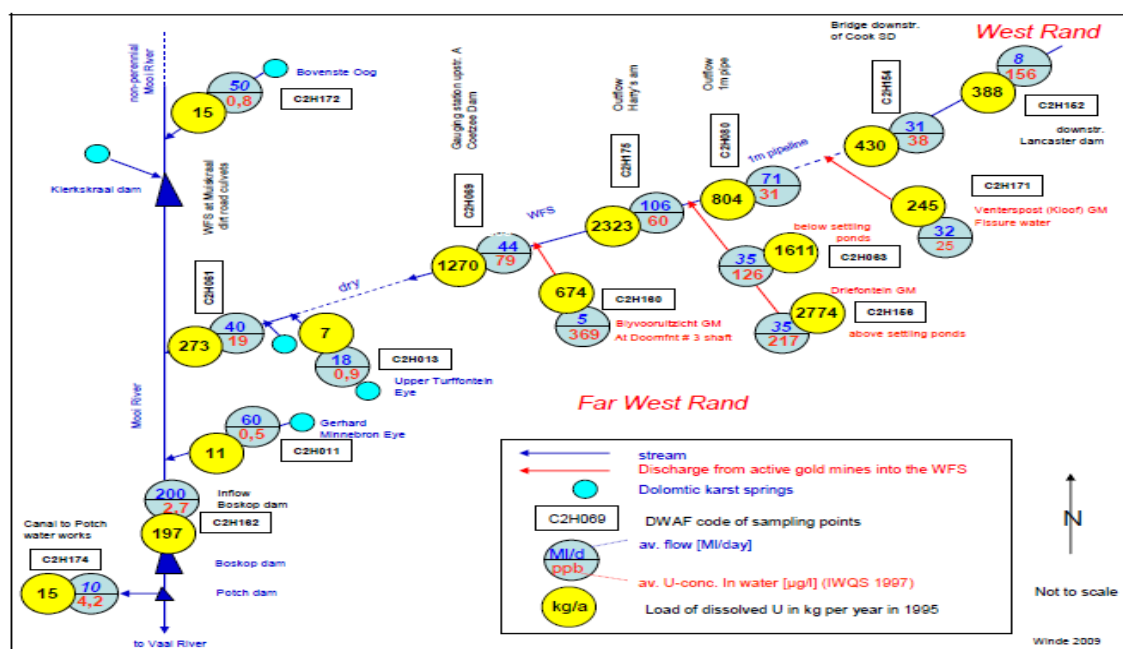
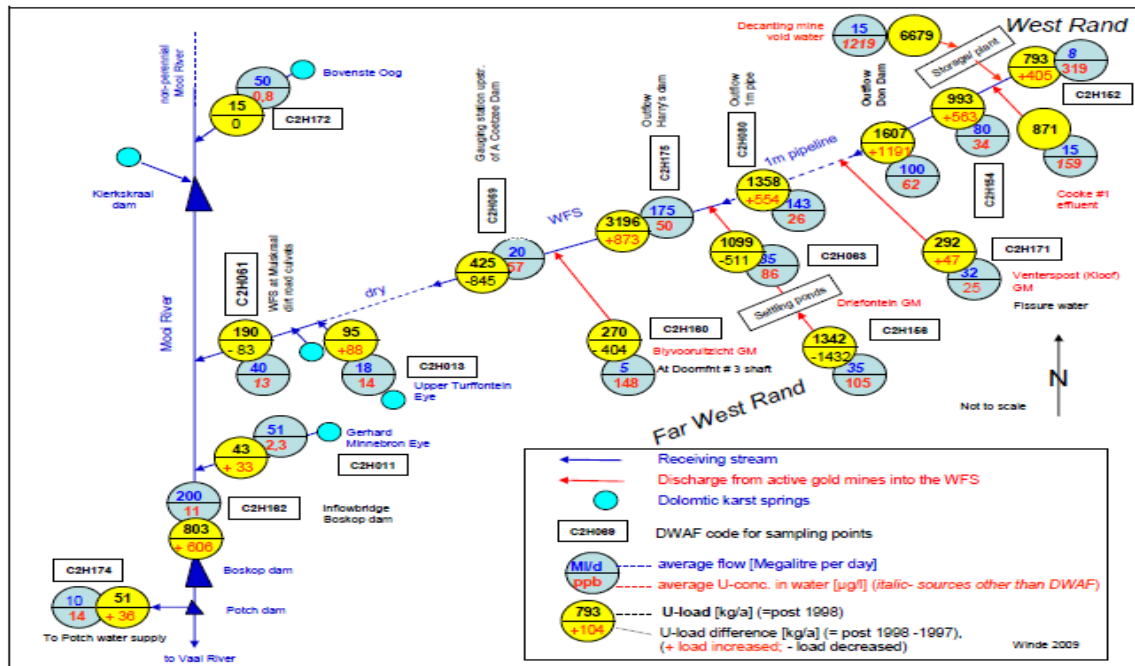


Figure 3: Estimated dissolved uranium loads in the WFS based on uranium concentrations measured in 1997 (Winde, 2009)



- In 2009, the WFS, heavily affected by AMD decant originating in the Western basin of the Witwatersrand, was reported to have 3.6 tonnes of dissolved uranium dumped from 1997 to 2008, resulting in a 60% increase in the Donaldson Dam (Winde, 2009) (Kardas-Nelson, 2010).
- Tweelopies Spruit, which flows into the Crocodile river, is a highly toxic river system, owing to the amount of AMD that has seeped into the system over the years (Vermeulen, 2013b).
- In Klerksdorp, there are constant radioactive and toxic spillages caused by the remaining operations on private farmland, which have resulted in cattle dying (Vermeulen, 2013b).

The major primary pathways by which contamination can enter the environment from a mine site are:

- Airborne pathway, where radon gas and windblown dust disperse outwards from mine sites.
- Waterborne pathway, either via ground or surface water or due to direct access, where people are contaminated.
- Living in settlements directly adjacent to mines or in some cases, living in settlements on the contaminated footprints of abandoned mine.

2.3.4.1 **Lancaster Dam**

The re-mining of historic uraniferous tailings dams in the West Rand is currently affecting the Lancaster dam and the surrounding wetlands. The Lancaster Dam is an acutely toxic dam with water pH of 2. Acidic water and fine slimes drain into the wetland immediately below the dam. There is an orange pool of settled slimes on the downstream site of the dam, which is filled with AMD water. Dry slimes blow throughout the Lancaster dam site during windy seasons. Grab water samples were taken by Mintek from the Lancaster dam

on the 13th June 2014. The analyses are given in Table 2 and sediments analyses are given in Table 3.

Table 2: Lancaster Dam water analyses

Elements	Units		Elements	Units	
pH	mg/L	3	Mn	mg/L	22
Eh	mg/L	519	Fe	mg/L	261
U₃O₈	mg/L	2.3	Co	mg/L	6.3
Mg	mg/L	105	Ni	mg/L	14
Al	mg/L	284	Cu	mg/L	<2
Si	mg/L	5.8	Zn	mg/L	4.7
Ca	mg/L	505	Mo	mg/L	<2
Ti	mg/L	<2	Pb	mg/L	<2
V	mg/L	<2	S	mg/L	1285
Cr	mg/L	<2	As	mg/L	<2

The uranium concentration in the Lancaster dam is approximately 153 times above the regulatory limit set by WHO (i.e. 0.015 mg/L). The dam has been classified by the National Nuclear Regulator as a radiological hotspot and immediate remediation is required to rehabilitate the dam (Vermeulen, 2013b). The dam is not enclosed and easily accessible and thus poses as a serious threat to the public.

Table 3: Lancaster Dam water analyses

Elements	Units	
U₃O₈	mg/L	13
Mg	mg/L	820
Al	mg/L	31200
Si	mg/L	343000
Ca	mg/L	<500
Ti	mg/L	1700
Mn	mg/L	<500
Fe	mg/L	43100

The Lancaster Dam is filled with AMD and seeps into the WFS. The Lancaster dam is shown in Figure 5.



Figure 5: Lancaster Dam (Busby, 2014)

2.3.4.2 *Wonderfonteinspruit catchment*

The Wonderfonteinspruit catchment covers two parts of the goldfields of the Witwatersrand basin, namely the western part of the West Rand goldfields and the far West Rand's goldfields including the 'Carletonville mining area (Busby, 2014). Total-count radiometric image of a portion of the WFS catchment is given in Figure 6 with the red areas indicating elevated radioactivity. There is elevated radioactivity in the wetlands downstream of mining areas (Busby, 2014).

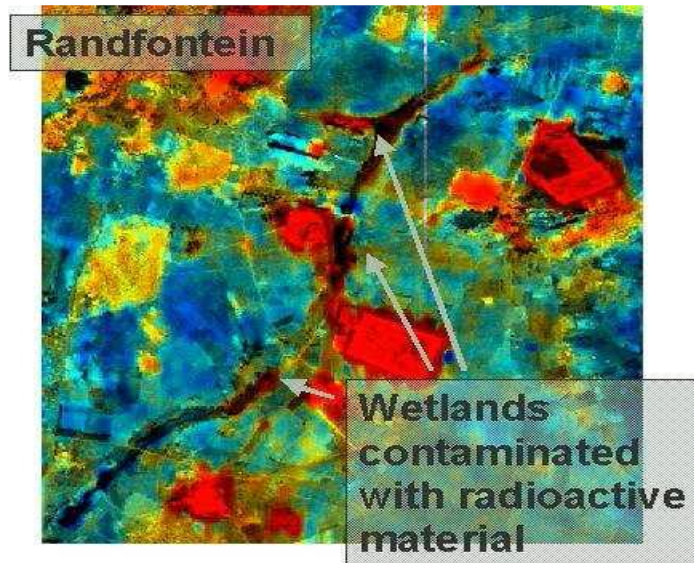


Figure 6: Total-count radiometric image of a portion of the Wonderfonteinspruit catchment (Busby, 2014)

Winde conducted an intensive sampling programme in the WCA. It was found that mining activities in the area are a major contributor to the radionuclide content of the water, specifically with respect to uranium and uranium-series nuclides (Winde, Coetzee, Winde, & Wade, 2006). The activities of dissolved radionuclides were found to decrease downstream of mining activities. The mean values for the WFS samples were found to exceed not only natural background concentrations, but also levels of regulatory concern for cobalt, zinc, arsenic, cadmium and uranium, with uranium and cadmium exhibiting the highest risk coefficients (Winde et al., 2006).

The water supply of the City of Potchefstroom was identified as a potential for downstream contamination. A study conducted by the City of Potchefstroom council confirmed the findings, with uranium concentrations of several hundred mg/kg being found in the sediment (the expected natural background concentration for a dolomitic area such as this would be less than 1 mg/kg) (Winde et al., 2006). The uranium-series radionuclides are adsorbed into a number of sediment phases, all of which can be re-released by plausible geochemical processes.

Water and sediments analyses of grab samples taken by Mintek collected along the WCA is given in Table 4 and Table 5.

Table 4: Wonderfonteinspruit catchment water analyses

Elements	Units	Hippo Dam	BRI Dam	18 Wize	Untreated AMD feed to Hippo	Sands Dump
pH		7.14		4.97	7.22	2.08
U₃O₈	mg/L	2.66	0.1	0.1	1.9	30
Mg	mg/L	119	165.5	157	155	368
Ca	mg/L	633	670	657	683	336
Mn	mg/L	13.08	42	39	50	46
Fe	mg/L	0.84	375.5	375	8	5013
Cu	mg/L	0.04	<2	<2	<2	5
Al	mg/L	0.56	<2	<2	<2	515
Cr	mg/L	<2	<2	<2	<2	3
Co	mg/L	<2	<2	<2	<2	9
Cu	mg/L	<2	<2	<2	<2	5
Zn	mg/L	0.29	<2	<2	<2	52
Ni	mg/L	0.08	<2	<2	<2	48
S	mg/L	768	1065	891	687	5283
SO₄²⁻	mg/L	2304		2673	2062	15849

Table 5: Wonderfonteinspruit catchment solids analyses

Elements	Units	Hippo Dam	Untreated AMD feed to Hippo Dam	BRI Dam
U₃O₈	mg/L	50	22	262
Mg	%	<0.05	0.25	0.054
Al	%	<0.05	3.75	1.91
Si	%	<0.05	25.2	10.3
Ca	%	<0.05	3.94	<0.05
Ti	%	<0.05	0.36	0.18
Mn	%	<0.05	0.16	0.072
Fe	%	6.7	7.31	40

2.3.4.3 *Tudor Dam*

The Tudor Dam is a desiccated dam with radioactivity levels between 10 000 and 100 000 Bq/kg. The regulatory limit is 500 Bq/kg. The Tudor Shaft informal settlement has been erected in close proximity to the Tudor dam and was built on uraniferous tailings and amongst open shafts as shown in Figure 7. The inhabitants are exposed to toxic and radioactive metals (Busby, 2014). Pollution related to Witwatersrand mines poses a number of hazards to surrounding communities.



Figure 7: Informal settlements built on uraniferous tailings at the Tudor Shaft (Busby, 2014)

2.3.4.4 *Robinson Lake*

The Robinson Lake has been declared a radioactive hot spot by the NNR with uranium concentration of more than 1000 times above the regulatory reported (Vermeulen, 2013b). The elevated uranium concentration in the northern watershed of the headwater region of the WFS (i.e. Robinson Lake) is the outcome of underground mine water decanting into the Tweelopies Spruit being pumped into the lake. The extreme concentration is believed to be the result of remobilisation of uranium from contaminated sediment by acidic water. Grab water samples were taken by Mintek from the Robinson lake on the 13th June 2014 and analyses are given in Table 6.

Table 6: Robinson lake water analyses

Elements	Units		Elements	Units	
pH		3	Mn	mg/L	320
Eh		438	Fe	mg/L	7.6
U₃O₈	mg/L	23.1	Co	mg/L	57
Mg	mg/L	584	Ni	mg/L	210
Al	mg/L	389	Cu	mg/L	13
Si	mg/L	32	Zn	mg/L	138
Ca	mg/L	459	Mo	mg/L	<2
Ti	mg/L	<2	Pb	mg/L	<2
V	mg/L	<2	S	mg/L	2606
Cr	mg/L	<2	As	mg/L	<2

The solids analyses of the sediments at Robinson Lake is given in Table 7.

Table 7: Robinson Lake sediments analyses

Elements	Units	
U₃O₈	mg/kg	300
Mg	mg/kg	880
Al	mg/kg	13800
Si	mg/kg	83500
Ca	mg/kg	54800
Ti	mg/kg	640
Mn	mg/kg	<500
Fe	mg/kg	267000

Analyses given in Table 6 and Table 7 show that there is an urgent need to rehabilitate the lake since the uranium concentration and that of the other metals are high and could result into remobilisation of uranium to the rivers.

2.4 South Africa's challenges pertaining to mine closure

“Mine closure in areas of cumulative and integrated environmental impacts, without regional closure strategy planning, not only results in negative social and national economic impacts, but may also be severely detrimental to the immediate and surrounding physical environment. One such an example is the Grootvlei mine in the East Rand mining basin; where pumping without a regional closure and management strategy could result in the local alteration of the Blesbokspruit and Marievale wetland system (in terms of the quantity and quality of water entering the system) and possible pollution of the dolomitic aquifer supplying water to the area. This could in turn impact negatively on a regional scale on all downstream users in the Vaal river (supplying part of Gauteng, Mpumalanga and the Free State) and sensitive ecosystems in the Vaal Barrage Catchment (e.g. the Suikerbosrand nature conservancy)” (Van Tonder et al., 2008).

2.5 Companies operating around the Witwatersrand Western basin

“The Witwatersrand contains the eastern, western and central basins. The Western basin covers the Krugersdorp, Witpoortjie and Randfontein areas; the central basin extends from Roodepoort in the West Rand to the east rand mines; and the eastern basin covers the east rand area, including Boksburg, Brakpan, Springs and Nigel” (Mahlaka, 2014). The Western basin has been considered to be an environmental disaster, as its acid mine water levels are rising (Mahlaka, 2014). Most of the AMD problems was caused by mining companies that no longer exist (Orange-Senqu, 2014). “Over many decades these corporations were allowed to use South Africa’s natural resources to enrich themselves, without having to worry about the consequences in the future. When a gold deposit was exhausted, they simply closed and the company executives left” (Orange-Senqu, 2014).

Mining companies such as Anglo Gold Ashanti, Goldfields, Sibanye Gold and Harmony Gold that are operating within the Western basin sites, are taking responsibility for AMD (Vermeulen, 2013a). Therefore, the legacy of AMD left by the old mining operators could have some impact on these mines with regards to business strategy and financial planning.

2.5.1 *Gold Fields Limited*

“Gold Fields Limited is an unhedged, globally diversified producer of gold with eight operating mines in Australia, Ghana, Peru and South Africa” (Goldfields Limited, 2015).

Gold Fields has been operating in South Africa since 1887, when Cecil John Rhodes and Charles Rudd formed Gold Fields of South Africa (Goldfields Limited, 2015). In 1932, the company began mining the mineral-rich Western basin, where it discovered high-yielding gold deposits. A merger between Gold Fields of South Africa and Glencore in 1998 led to the formation of Gold Fields Limited (Goldfields Limited, 2015).

Gold Fields Limited recognises water management as a key potential risk in all of the regions in which they operate (Goldfields Limited, 2015). In 2012, Gold Fields Limited

started scoping activities for the development of a group-wide water strategy, to establishing consistent, best-practice water management standards, procedures and systems across their operations (Goldfields Limited, 2015).

Gold Fields Limited has indicated that the company is acutely aware of the AMD issues; and that there is need to deal with the AMD problems effectively to prevent the adverse impact on their goal of being the global leader in sustainable gold mining (Goldfields Limited, 2015). Hence, the company has recently focused on the dewatering of the AMD from the underground mines. The company considers AMD as a short-term and long-term risk, hence a number of controls have been successfully employed at the operation to ensure that AMD is well managed throughout the mining life cycle (Goldfields Limited, 2015). “These include (Goldfields Limited, 2015):

- Implementation of a full life cycle risk mitigation strategy;
- Full integration of AMD issues into the Environmental Management System;
- Continuous and extensive leach testing, using methods that exceed industry’s best practices;
- Integration of AMD mitigation measures into the design of all the components of the operation;
- Continuous monitoring of the performance of these mitigation measures”.

Gold Fields Limited has reported in their 2011 annual report that the key environmental issues they are facing include (Goldfields Limited, 2015):

- The dewatering of underground mines;
- The prevention of post-closure AMD;
- Leaching from tailings dams;
- Carbon emissions.

2.5.2 *Sibanye Gold*

“On February 18, 2013, the board of directors of Gold Fields Limited, completed the separation of its wholly-owned subsidiary, Sibanye Gold Limited (formerly known as GFI Mining South Africa, or GFIMSA), into an independent, publicly traded company” (SibanyeGold, 2014).

Sibanye Gold Limited is a South African company and all of their operations are located in South Africa (SibanyeGold, 2014). The company currently owns and operates four underground and surface gold operations, namely the Driefontein, Kloof and Cooke operation in the west Witwatersrand region and the Beatrix operation in the southern Free State (SibanyeGold.co.za, 2015). “Sibanye Gold is listed on the Johannesburg stock exchange Limited in South Africa (primary listing) and the New York stock exchange” (SibanyeGold.co.za, 2015).

Sibanye Gold also holds a 33% interest in Rand Refinery, one of the largest global refiners of gold, and the largest in Africa. Rand Refinery markets gold to customers around the world (SibanyeGold.co.za, 2015).

Gold Fields Limited, together with Sibanye Gold, are jointly investigating the feasibility of establishing a joint venture company into which both parties will contribute surface assets for retreatment (MiningNews, 2013). “These assets are expected to comprise in excess of 700 Mt from 16 historical tailings deposits and represent over 60% of the total tailings material in the region” (MiningNews, 2013). Figure 8 shows an aerial view of the Cooke tailings dam currently owned by Sibanye Gold.



Figure 8: An aerial view of the Cooke tailings dam (MiningNews, 2013)

2.5.3 *Harmony Gold*

Harmony Gold is a gold-mining and exploration company, with more than six decades of experience. “Harmony was incorporated and registered as a public company in South Africa on 25 August 1950 and later became a Randgold-managed company, exploiting the single Harmony mine lease. In 1995, Harmony was recreated as a separate entity following the winding up of Randgold” (Harmony, 2014).

The company has operations in South Africa and in Papua New Guinea (Harmony, 2014). In South Africa, the company has nine underground operations located on the Witwatersrand basin (Harmony, 2014).

“In line with Harmony’s strategy of ensuring compliance with legislation and regulation, the company is implementing environmental management systems that ensure compliance with legislation and regulation at all operations, and that environmental management is addressed through a formalised, systematic approach” (Harmony, 2014).

It has been reported by Cobbing that “the AMD first appeared on the Randfontein operations property (formerly Randfontein Estates Ltd.) of Harmony Gold Mining

company” (Cobbing, 2008). Harmony also reported in 2010 that there were no specific risks to Harmony with regard to AMD and that all operations managed their water and there is minimal risk of AMD water reaching the environment (Harmony, 2014). “In the case of closed operations, the risk of AMD has been assessed and no threat has been established and in the event of a risk of rising water levels and potential impact to the ore reserves of other operations or to the environment, the water is pumped to the surface” (Harmony, 2014). Figure 9 shows the discharge of untreated water in the West Rand area.



Figure 9: Discharge of untreated acid mine water, West Rand (Photo: John Wesson)

2.5.4 *Anglo Gold Ashanti*

“The AngloGold journey began in South Africa in May of 1998, when the gold and uranium mining interests of Anglo American Corporation of South Africa were consolidated” and the company, AngloGold Ashanti, was formed in April 2004 following the business combination of AngloGold Limited with Ashanti Goldfields Company Limited” (Ashanti, 2014).

AngloGold Ashanti, headquartered in Johannesburg, South Africa, is a global gold company with 20 operations located in 10 countries (Argentina, Australia, Brazil, Ghana,

Guinea, Mali, the Democratic Republic of Congo, South Africa, Tanzania and the United States of America) (Ashanti, 2014). Today, AngloGold Ashanti is the third largest gold producing mining company in the world (Ashanti, 2014).

The mining industry's approach to reducing erosion and dust from tailings dams largely involves the planting and irrigation of pasture grasses. Pasture grassing costs on average R90,000 per hectare for slopes and R30,000 per hectare for tops, utilises up to three times annual rainfall for irrigation, and prevents surface erosion (i.e. dust control) for less than 10 years. Although grassing prevents dust emissions for some years, it is rarely effective in containing erosion in the longer term, and does not prevent seepage and water pollution, or achieve ecological sustainability. Since the pasture-grassing approach has proven unsustainable for mine closure purposes, there is a need to determine what type of vegetation would prevent pollution emissions from tailings dams, and so lead to rehabilitation.

With regard to AMD and other environmental issues, Anglo Gold Ashanti saw a need to provide a sustainable solution to the problem of tailings dam waste through the use of vegetation (Ashanti, 2004). Hence, a survey of tailings dams and polluted soils has been conducted between 1996 and 2002, to characterise biological and chemical status in relation to region, climate, geochemistry and vegetation practices (Ashanti, 2004). "Constraints to current vegetation practices on tailings dams were identified, as well as the practices and flora that have a higher probability of contributing to sustainable rehabilitation" (Ashanti, 2004). The studies have indicated that "reducing the slopes of tailings dams from about 30 degrees to less than 16 degrees reduces the cost of grassing, significantly improves the longevity of grassing and erosion control, and significantly reduces irrigation requirements. The effects of AMD and polluted groundwater on plant growth and reproduction extend well beyond tailings dams, resulting in strong selection pressures and the development of tolerant plant 'land races' and micro-organisms" (Ashanti, 2004).

2.6 Conclusion of Literature Review

The mining industry forms the backbone of the South African economy and has a vast mining capacity dating back as early as the nineteenth century. The mining and industrial sector, which grew rapidly during the era of less stringent environmental regulations, resulted in a substantial amount of waste material being released into the environment.

The Witwatersrand area has large amount of mining waste generated from gold ore deposits, which contained small amounts of uranium. The gold ore deposits in the area are also associated with sulphide minerals (which are a big source of AMD when exposed to atmospheric oxygen and moisture), radionuclides (uranium, radium and thorium) as well as non-radioactive elements (manganese, zinc, fluoride and zinc). Radioactive and non-radioactive elements, if not properly contained, can contaminate drinking water resources or enter the food chain, potentially harming the environment and endangering the health and well-being of human populations.

Although regulatory standards have been established to set maximum acceptable levels of contaminants, especially uranium that can be released to the environment; in 2002, AMD had started decanting from the Western basin, located below the Krugersdorp-Randfontein area. The outflow had grown worse over the years prompting the Department of Water and Sanitation to intervene. In an attempt to dewater the mining voids and keep the water at critical levels, an average pumping capacity of 23 ML/day was proposed for the Western basin (Department of Water Affairs, 2013). Thus, decanting water at the proposed rate will result in over 100 kg of uranium being released in the neighbouring rivers. A lack of treatment capacity for the AMD within the area compelled in-stream treatment as a short-term intervention where tonnes of lime was poured into the Tweelopies Spruit in an effort to neutralise the acid mine water. This had led to problems with the resulting sludge that had formed in the water course.

Mine closure in areas of cumulative and integrated environmental impacts, without a proper closure strategy planning, not only results in negative social and national economic impacts, but may also be severely detrimental to the immediate and surrounding physical environment (Van Tonder et al., 2008). "Poorly planned closure strategies or lack of

closure strategies have the potential to cause long lasting negative economic impacts on the community” (Van Tonder et al., 2008).

Literature suggest that the AMD problem does exist and it is currently at an adverse situation, which can highly impact the mining companies with regard to strategy, profitability, and the environment as a whole.

Conducting research in order to get an understanding of the extent at which the AMD has on companies’ strategy is important to bring more insight to the future implications of the state of SA’s mining industry, health system, and to SA’s economy. Companies such as Harmony Gold Limited, Anglo Gold Ashanti, and Sibanye Gold have also acknowledged that the AMD problem does exist, and that there is a need within each company to deal with the complications that emanates from AMD. The study will focus on evaluating the companies’ strategy and the impact of the AMD.

2.7 Research Question 1

Literature indicated that the mining structure around the Witwatersrand area are divided into subsidiary companies, with each subsidiary company being responsible for its own production and maximizing its own profit (Lieverink, 2014). The companies are structured in such a manner that the profits of company cannot offset the liabilities and impacts of another company. Therefore, the highest burden of the pollution costs are currently being borne by either neighbouring mines, communities and the environment (Lieverink, 2014). Research question 1 is “to assess the strategic choices a mining company takes to mitigate problems associated with AMD”.

2.8 Research Question 2

Literature has shown that the plans from various companies on ensuring that the current and future mining activities do not continue to burden the SA government with the environmental liabilities such as AMD proved to be inadequate. Though a number of mining companies has put some activities in place, evaluation of the adequacy of these

activities to eradicate the impact of AMD to the environment is essential. Research question 2 looks into “evaluating the impact of AMD if nothing is done”.

3 RESEARCH METHODOLOGY

The research methodology section summarises the procedure that has been used to address the research questions that have been presented following the literature review. The qualitative research has been chosen as the research methodology to be used for this research. The literature review on qualitative research, a review of the research design and research instruments are discussed. Information on data collection and analyses in relation to this study are also discussed; subsequently a summary of the validity and reliability of this study is given.

3.1 Research methodology / paradigm

A qualitative methodology was used in order to collect appropriate data to address the research questions. Qualitative research has been described as the method that seeks to understand social phenomena within the context of the participants perspectives and experiences (Merriam, 2002). The researcher can make use of participatory knowledge claims and open ended interviews (Creswell, 2003) as a way of collecting data. This research topic is more of a nonfigurative nature, more flexible, responsive, and open to contextual interpretation than in quantitative research (Merriam, 2002) and therefore the method is best suited for collating data for this kind of a research. The data was collected using in-depth interviews. The interviews were conducted in person with each respondent. Participants were the ones who can legitimately determine the credibility of the results.

3.2 Research Design

Interviews were conducted as a form of a qualitative research method. "Qualitative research methods are designed to help researchers understand people and what they say and do" (Myers, 2013). "Qualitative research is an approach of exploring and understanding the meaning individual or groups ascribe to a social or human problem"

(Creswell, 2013) . The research is intended to assist researchers to understand the social and cultural contexts within which people live or organisation operate. “One of the key benefits of a qualitative research method is that it allows a researcher to see and understand the context within which decisions and actions take place. It is often the case that human decision and actions can only be understood in context – it is the context that helps to explain why someone acted as they did. And this context (or multiple context) is best understood by talking to people” (Myers, 2013).

Triangulation is said to be a good idea if one needs to look at the same topic from different angles (Myers, 2013). It allows a researcher to triangulate data from interviews with data from documents, or data from two different research methods. The idea is to triangulate data and findings on the same topic, but to use different methods (Myers, 2013). In this research, interviews and literature will be used to triangulate data. This will assist in gaining a complete picture of what is happening within each organisation.

3.3 Population and sampling

3.3.1 *Population*

The population is made up of the governmental organisations and the mining companies operating within the Witwatersrand Western basin.

The respondents for the research were selected from the strategic leaders from the three mining companies that are dominating in the Witwatersrand Western basin, i.e. Sibanye Gold, Gold Fields Limited, Anglo Gold Ashanti, and the Government regulators, i.e. DMR, DWS, and TCTA. The respondents are appropriate for use in qualitative research.

3.4 The research instrument

Qualitative research is necessary if one needs to understand companies’ motivations, their reasons, their actions, and the context for their beliefs and actions in an indepth way

(Myers, 2013). Meyers believes that qualitative research is only by talking to people or reading what they have written that we can find out what they are thinking, and understanding their thoughts goes a long way towards explaining their actions (Myers, 2013).

The disadvantage of qualitative research is that it is difficult to generalise to a bigger population, however one can generalise from qualitative research to theory and you can generalise in this way just from one case (Myers, 2013). Formal interviews were setup with relevant respondents and open-ended questions were asked. Follow-up questions differed depending on the response given by the respondent.

3.5 Procedure for data collection

Data was collected from the formal interviews with relevant respondents and specific questions were asked, which were followed by open-ended questions. Minutes were taken during the interviews and used to formulate the outcomes of the research.

3.6 Data analyses and interpretation

Content analyses was used to evaluate the narratives. Content analyses is described by Cole, “as a method of analysing written, verbal or visual communication messages” (Cole, 1988). An advantage of the content analyses method is that large volumes of textual data from different sources can be analysed and used in validating data (Elo & Kyngäs, 2008).

3.7 Limitations of the study

A qualitative research technique can be subjective as it uses small, purposeful samples of articulate respondents because they can provide important information, not because they

are representative of a larger group (Reid, 1996). Furthermore, since the study relies on the effectiveness and accuracy of the research outcome, it is important to identify respondents according to their in-depth knowledge of the subject matter; therefore, all respondents for this research were carefully selected based on their knowledge and experience in mining environmental activities.

3.8 Validity and reliability

3.8.1 *External validity*

“The extent to which a study's results (regardless of whether the study is descriptive or experimental) can be generalised/applied to other people or settings reflects its external validity” (Huitt, Hummel, & Kaeck, 1999). All situational specifics (e.g. treatment conditions, time, location, etc.) of a study potentially limit generalisability (Huitt et al., 1999). The objective of this research was not just to generalise the findings but to a greater extent give more definitive findings that could give meaning to all the stakeholders. However, by interviewing a diverse sample of respondents such as strategic managers, technical managers, and the government representatives, will aid in ensuring the external validity of this study.

3.8.2 *Internal validity*

Internal validity refers to studies to which a causal conclusion based on a study is reasonable. One of the keys to understanding internal validity is the recognition that, when it is associated with investigational research, it refers both to how well the study was run (research design, operational definitions used, how variables were measured, what was/wasn't measured, etc.), and how confidently one can conclude that the change in the dependent variable was produced solely by the independent variable and not extraneous ones (Huitt et al., 1999). In this research, it was possible to quantify the observed changes

in the dependent variable to the independent variable, hence internal validity was done and assured by identifying the casual links involved using the content analyses method.

3.8.3 ***Reliability***

Reliability is when using the same measures over and over again, and getting the same results (Peter, 1977). A measure that produces similar results under consistent conditions is said to have a high reliability. For this research, the interviews were formalised, conducted by one individual researcher, and the use of the same question structure ensured reliability of the research. Using open-ended questions could bring some degree of biasness when interpreting the responses; therefore, this was addressed by not using leading questions to limit any biasness.

4 PRESENTATION and DISCUSSION OF THE RESULTS

4.1 Introduction

The study focuses on evaluating the impact of AMD on chosen mining company's strategy and how to mitigate the cost of AMD and to review the environmental policies pertaining to the mining activities. The research was conducted on companies within the Witwatersrand Western basin. Findings from the literature review were used to formulate the interview questions in an aim to obtain information and assessing the impact of AMD within the Witwatersrand area. Content analysis was used as a method of analysing information obtained from the interviews. Subsequently, the views obtained from the interviews were used to support the findings of the research. The interview discussions are presented in Appendix A.

4.2 Demographic profile of respondents

The respondents were from government environmental regulators and the three mining companies that are dominating the Witwatersrand Western basin, i.e. Sibanye Gold, Gold Fields Limited, and Anglo Gold Ashanti. The interviews were conducted with members in senior positions from each organisation. The government institutions, i.e. DMR, DWS, and TCTA reiterated the views obtained from the literature review on the environmental policies.

Other institutions were added to the sample since they were found to play a role in the outcome of the research. These institutions were selected due to their involvement in assisting both government and the mining companies in developing processes and strategies for the treatment of acid mine drainage. Table 8 gives the demographics of the interview respondents for the research.

Table 8: Sample demographics

# Respondents	Type of Institution	Position/Institution
3	Mining Companies	Vice-President Group Sustainable Development
		Group Water Consultants
		Senior Environmental Manager
4	Government organisations	Department of Water and Sanitation (Water affairs)
		Trans-Caledon Tunnel Authority (TCTA)
		Department of Mineral Resources
2	Academic	Tshwane University of Technology
3	Parastatals	CSIR
		SA Water Research Commission
1	NGO	Federation for a Sustainable Environment
1	Private Company	Management: Strategy

4.3 Results pertaining to Research Question 1

4.3.1 *Strategic choices a mining company takes to mitigate problems associated with AMD*

Literature indicated that the mining structure around the Witwatersrand area are divided into sub-companies, with each sub-company being responsible for its own production and maximizing its own profit. The companies are structured in such a manner that the profits of the company cannot offset the liabilities and impacts of another company. The three major discussions pertaining to the question of strategic choices a mining company takes to mitigate problems associated with AMD, i.e. leakages of AMD in the mining industry; economic feasibility with regards to water treatment and recovery; and organisation strategy on AMD, are explained below.

4.3.1.1 *Leakages of AMD in the mining industry*

As indicated from the literature, the mining and industrial sector grew rapidly in South Africa during the era of less stringent environmental regulations resulting in a substantial amount of waste material being released to the environment. Mining activities in the Witwatersrand area has left a legacy of approximately 400 km² of tailing dams. The industrial wastes contain heavy metals, which, when in contact with water, re-dissolve and seep through the unlined tailings dumps draining directly into underlying aquifers or dewatered dolomite. This leads to contamination of already limited clean/potable water resources in the surrounding areas as observed in the Western basin.

Literature and interview sessions have indicated that the mining industry is aware of the environmental impact mining has brought about, and the problem of AMD is currently at an adverse situation which can highly impact the mining companies with regard to strategy, profitability, and the environment as a whole. The mining industry has alleged that there are no current AMD leakages to the environment, and that everything is currently contained for the mines that are in operation. This is said to be due to the pumping and treating of the water before releasing to the environment. However, one of the respondents from the mining industry said, “there are incidents where the pipelines burst which could release mine water to the environment”.

The government institutions have indicated that the leakages of the AMD to the environment are more problematic with old abandoned mines, and the mining companies operating within the Western basin have indicated this. AMD mostly decant from such mines. Nevertheless, given the interlinkage of the mines in the Western basin, all the mines do somehow contribute to the AMD that is released to the environment. It has been indicated by the NGO that “a water monitoring program has not been done consistently by the mines and the surrounding municipalities; however, there are mines that consistently monitor their water quality”. The NGO has also mentioned that “the problem is mainly for the abandoned mines”.

The research has pointed out that the current running mines within the Witwatersrand do have strategies and plans in place to make sure that there are no AMD seepages to the

environment and the water regime. One of the mine respondents mentioned that “we are currently developing a post closure management plan in collaboration with our peers which also involves the AMD issue”. However, there are problematic areas where water from the neighboring mines, especially the closed mines, seeps through the current running mines; hence, they have to treat this water before it gets released to the environment. Section 28 of the NEMA and Section 19 of the NWA states that any person who pollutes must pay. However, Section 28 of NEMA may not be allowed to be enforced on the old mines that are now abandoned and which operated during the era of less stringent environmental regulations, even though it has been proven that these mines are currently responsible for a substantial amount of waste material being released to the environment. The respondent from one of the Government regulators said that “we are currently in discussions to finalise the cost structure for treating of mine waste”. Therefore, this give an indication that the liability for the treatment of AMD has not yet been finalised by the government.

4.3.1.2 *Economic feasibility with regard to water treatment and recovery*

Literature has revealed that since gold mining commenced in the Witwatersrand, mining activities have left a legacy of waste, which constitutes the largest single source of waste and pollution in South Africa. There is wide acceptance that AMD is responsible for the most costly environmental and socio-economic impacts. Mining companies such as Anglo Gold Ashanti, Goldfields Limited, and Sibanye Gold that are operating within the Western basin sites are taking responsibility for AMD generated by their operations as indicated from the literature.

It has been indicated by one of the government respondents that “AMD is a small portion of water but the impact to the water security is big, such as environment pollution, and threat to water security”. It is therefore of utmost importance to treat AMD water before it decants into the environment. Nevertheless, it has been indicated by all the respondents that before treating the water, pumping of the water from the underground needs to be done, which has also proven to be a costly process mainly due to high-energy cost associated with pumps. One of the mine respondents said that “The high cost currently is

the cost of pumping the water from the underground”, and another respondent said that “having to pump the water from underground is a challenge due to high cost of pumping. Though the cost of pumping is part of our operating cost, 95% of the water we pump is as a result of legacy”. Other means of getting water from the underground needs to be looked at, such as letting the water rise to a point of decant or stop pumping at excessive depth, which will then reduce the cost of pumping, but then again this could also be a problem in areas where mining still needs to happen, and hence the water still has to be pumped to clear such areas.

It has to be understood that the water system in mining areas is a complex system that has lots of water interlinks, hence managing this water is a challenge. Nonetheless, it has been indicated by one of the respondents that “in terms of treatment of the water, there are processes developed to treat the water but the challenge could be the ultimate cost of treating the water, who will do it and who will pay for it”. It has been indicated by another of the mining industry respondents that “mine activities happen where there is AMD formation, hence lime is dosed underground to neutralise the water, and this is where the first cost of AMD goes to”. One of the mine respondents also stated that “we do not have a problem with surface water and maintain a high pH at the tailing facilities”.

The government regulators mentioned that the DMR issues licences to mines, but when the mine goes into liquidation the mining stops and the mine ceases to exist. Ultimately, the licence also ceases to exist; hence, there are difficulties in regulating such mines. It has been said by one of the regulators that “the challenge is to regulate the mines with regards to any impact that may arise and it is difficult to impose compliance when a mine is liquidated”. It has been mentioned that mining companies do make financial provision for environmental impact that may arise after mine closure that can be used to rehabilitate the mine. However, one of the respondents said that “when a mine goes into liquidation such money cannot be used until the liquidation process is completed and all creditors are paid”. Most often, such funds are found to be inadequate to rehabilitate such a mine. The parastatals have furthermore indicated that the mining industry has not shown much appetite to solve the AMD problems, since they do as much as they can to externalise the

cost and the risk, hence, they declare a mine or a particular site to be liquidated rather than accepting responsibility.

The legacy of AMD left by the old mining operators have shown to have some impact on the current running mines with regards to business strategy and financial planning. One respondent from the mining companies said that “getting other surrounding mines to come on board because of the interconnection of the underground mines is a challenge. The treatment needs to be done in collaboration with our peers because if they close down, and the environmental problem will be left with the mines that are still running”. The other mine respondents have also mentioned that “it is important to collaborate with our peers and we are currently developing a post closure management plan in collaboration with our peers, which also involves AMD issues given that we might be the only mine standing in future; hence, it may affect the business”. It has also been said by some respondents of the mining industry that the government regulators are not mature enough to deal with the issues of AMD, especially for those companies that go into liquidation, which also affects their mines due to the interlinks between the mines. One of the mining respondents stated that about 95% of the water they pump is as a result of companies that go into liquidation.

A short-term intervention strategy of pumping and neutralising the contaminated water is currently employed as indicated by the literature. Tonnes of lime is poured into the Tweelopies Spruit dam in the Western basin in an effort to neutralise the acid mine water, resulting in sludge that forms in the water course. This process treats the water to low TDS, and hence the water can be decanted to the rivers thereafter. However, literature has indicated that the sludge produced by the neutralisation treatment requires proper storage capacity. The sludge retains a lot of moisture, which can promote seepage and limit the quantity of water available for recycle. Additional treatment to reduce residual concentrations in the treated water is necessary to prevent salts from re-dissolving and seeping into the environment. Thus, there is a need for improved and sustainable technologies for the long-term treatment of AMD to meet these standards.

4.3.1.3 *Organisation strategy on AMD*

Literature has indicated that the mining industry forms the backbone of the South African economy and has a vast mining capacity dating back as early as the nineteenth century. However, the waste generated by the mining sector is found to not only affect the environment but also have an impact on the operation of the mines, hence, there is a need for the mines to have a strategy in mitigating the risks that may arise due to mining operations.

Interviews were conducted to get an understanding of the mines strategies in handling and eradicating the environmental impact that comes with AMD. The interview discussions are being presented in Appendix A. The most important subject matter with regards to managing AMD is to have a better understanding of the water balance around the mines, which is something all mining respondents are in consensus with. Owing to the inter-linkage of the mines in the Witwatersrand and the problems associated with the abandoned mines that significantly contribute to AMD that is released to the environment, it has been indicated by the respondents that collaborating with neighbouring mines, peers and the government is important to manage the problems associated with AMD. With the exception of one of the mining companies that were interviewed, a post closure management plan is currently being developed by the other mining companies interviewed in collaboration with neighbouring mines with regards to the environmental impact, especially for the mines that might be the only ones standing in future as it may affect their business.

As part of the strategy, terms of reference has been developed for the DMR, forums such as “The Far Westrand basin Technical Working Group” has been established. The main focus is working towards mine closure with regards to what will happen to the water once a mine is closed, where will the treatment plants be if water needs to be treated and how could that be executed. With regards closed operations, Harmony mine has mentioned in their company reports that, “the risk of AMD has been assessed and no threat has been established and in the event of a risk of rising water levels and potential impact to the ore reserves of other operations or to the environment, the water is pumped to the surface”.

Acquiring mines (mineshfts) that threatens the operational boundaries of a specific mine site is a strategy that is used by one of the mining companies. Acquiring of these mineshfts could be a better way of understanding the water mass balances within the operational boundaries of each mine. Establishing of subsidiaries to deal with the pumping of the water and understanding of water mass balances is also an approach the mining industry are keen to follow.

One mine house has mentioned during the interview discussions that “as part of their strategy they are currently treating and reprocessing tailing and waste dumps which could reduce the formation of the AMD to a certain extent and that the treatment of the AMD that comes from the underground is done through a treatment plant”. Gold Fields Limited indicated from their annual reports that they have already started scoping activities for the development of a group-wide water strategy, to establishing consistent, best-practice water management standards, procedures and systems across their operations. They have recently focused on the dewatering of underground mines. Anglo Gold Ashanti saw a need to provide a sustainable solution to the problem of tailings dam waste through the use of vegetation (Ashanti, 2004). Hence, a survey of tailings dams and polluted soils has been conducted between 1996 and 2002, to characterise biological and chemical status in relation to region, climate, geochemistry and vegetation practices.

Given that South Africa is a water scarce country, treating the AMD water to drinkable standards is the ultimate goal for the mining sector, and engaging with the municipalities on how to supply them with treated drinkable water is something that is been looked into. “As part of our strategy about +R600 million per year is currently being spent to pump water, this includes other mines' water, and also spending capital and changed infrastructure to be able to deal with the AMD”, said one of the respondents of the mining sector. One other mine respondent said that “their plan is to build a plant that will treat about 15 ML/day of AMD which could then be given to farmers or municipalities”.

It is understood that the cost of treating the water is less than that of the municipal water. At least one of the mine respondent said “it is cheaper for us to treat mine/AMD water to drinkable water standards than to release the water to the river streams/environment due

to the fact that the water that goes to the stream is licenced and have to conform to certain treatment standards that are stricter than the drinkable water standards at the current moment”. Hence, most of the mining industries are including plans to build treatment plant into their strategy, which would deal with the environment problems, while creating jobs at the same time. The treated water can then be put back to the system for the treatment of the tailings, and other users could benefit from the water.

4.4 Results pertaining to Research Question 2

4.4.1 *The impact of AMD if nothing is done*

Literature has shown that the plans from various companies on ensuring that the current and future mining activities do not continue to burden the South African government with the environmental liabilities such as AMD proved to be inadequate. There is a concern as to what will be an adequate process to follow to reduce the AMD impact, hence this sections explores what would be the consequences of the AMD if nothing were done. The three major discussions pertaining to this question i.e. economic impact if nothing is done; economic benefits and opportunities of AMD; and who must bear the cost, are described below.

4.4.1.1 *Economic impact if nothing is done*

It has been iterated by the government that, due to the legacy of mining, and having two legislations (the Mineral and Petroleum Resources Development Regulation Act (NPRDA) and the Mineral Act), some of the mines’ documentation, which initially operated under the Mineral Act and then under the NPRDA, in terms of the environment management did not change and is not aligned to suit the current legislation. Therefore, when AMD cases arise it becomes a challenge to regulate such mines. Hence, task teams were formed to look into this. The government has allocated funds to deal with AMD aiming at finding tangible

solutions, and a number of case studies are currently underway. The task teams initiated a number of scenarios and strategies which have been described in a report published by the DWS (Department of Water Affairs, 2013). This report was issued to the interviewer and formed the basis of the discussion during the interview with DWS. The scenarios and the cost benefits of each scenario that were explored during the interviews with the DWS are as follows:

- **Scenario 1: Do nothing**

Scenario 1 looks at not releasing water from the Vaal dam to neutralise the TDS level from AMD and the AMD water decants to the river system. The study has found that this scenario would lead to high salinity levels downstream of the Vaal Barrage and would affect other water streams.

Scenario 1 (Do nothing) has been indicated by all the respondents as a no option scenario, because the water has high TDS levels. One of the respondents said that “if the water decants to the rivers the dilution effect could be adequate but the problem is that the water contains heavy metals such as uranium and base metals, hence, there will be a need to remove these minerals and acidity before the water flows to the river system”. One of the respondents added and said that “it is not an option not to do anything, if nothing is done we will be out of business because we will not be able to mine since the water will fill up the mines, the water system will be adversely affected which will affect the socio-economics and the lives of the ordinary South Africans”. Some of the respondents said that more than 25000 people in the mining sector could lose their jobs if the AMD water is not treated.

The AMD problem is primarily a water security issue. The major problem is, if the AMD is left to decant, an enormous amount of water will be needed to dilute this water. The government respondent indicated that the water needed for dilution is not a cheap option, stating that “it will involve water from the Thukela river which will have to be pumped 400 m over the Drakensberg mountain range, which makes it even more expensive, due to energy costs of pumping, and also water from the Orange River and the Lesotho dam,

which is water that is on paid tariffs”. It is said that South Africans are already paying via taxes for getting water from the Lesotho dam. Hence, it will not make sense that the water that was already paid for could be used to dilute the high TDS coming from the AMD. This means that the public will not only pay for the water needed for dilution but they will not be in a position of using the water since the water will not be available for use due to contamination, hence, the problem with water security.

The respondents iterated that if the mine water is not treated, the dirty water will be taken down to the public for use and the cost would now be externalised to everyone downstream. Restrictions in water supply will be enforced, which may lead to economic slowdown. One of the respondents explained it as follows; “if nothing is done, the water will start decanting to the rivers and some of the mines will have to stop mining, then there will be a socio-economic challenge. Given the problem with water drought in South Africa, there will also be an increase in water treatment cost and eventually the public will feel the effect and people will then struggle to get water because water will be expensive and they might not be able to pay for that water. The cost of business will be high; hence, there is no way that nothing could just not be done”. Another respondent said that “if nothing is done it would have an effect on water supply which will affect about 60% of the economy and 45% of the population. The mining in other provinces will be affected and economic growth will be stagnant as well as job creation. Water needs to be treated to be made fit for use”.

It has been proven during this research that it will not be viable not to do anything because it will not only create pollution but the long-term cost of not cleaning up the water is high. If nothing is done there will also be a threat of health and loss of income. It is therefore important to treat the AMD water to reduce the impact. Rather than a “do nothing scenario”, DWS proposed the following scenarios:

- **Scenario 2A: Dilution without early implementation of the Thukela Water Project**

This is the scenario that is currently being used to some extent, whereby AMD water is pumped from the underground, neutralised to reduce the amount of the TDS from the water, and released into the river system. Continuous release of water for dilution from the

Vaal Dam will be made in order to maintain the water quality to the required TDS levels. The Thukela Water Project (TWP) will not be commissioned until it will be required for normal expansion, which will be after 2050. More information on the TWP project could be found in the Thukela water Project Feasibility study report (Department of Water Affairs, 2001). DWS mentioned that “the release of water for dilution will result in water deficits from 2016 until the full annual volume of water is transferred from the Polihali Dam in year 2022”.

- **Scenario 2B: Dilution with Thukela Water Project implemented**

This scenario was analysed with the Thukela dam to be commissioned by the year 2025 to augment the Vaal River System and continuous dilution releases will be made from the Vaal Dam to maintain the TDS levels to the required standards in the Vaal Barrage. It is said that the water deficits will occur from 2016 until 2025 when the TWP is commissioned.

- **Scenario 3: Desalination**

The AMD water generated in the Central and Eastern Basins will be neutralised and desalinated. This scenario was used as the reference for all the other scenarios in estimation of the cost benefits. The TDS of the water released into the Vaal river system will not be greater than that of potable water. Desalination will also be implemented in the Western basin, but the AMD discharges would flow into the Crocodile (West) river system rather than the Vaal river system; the costs for the Western basin were therefore not included (Department of Water Affairs, 2013). Until such time when the desalination plant is in place, dilution releases from the Vaal dam will be made in order to maintain the TDS level to the required levels in the Vaal Barrage, and some deficits will occur until the dilution is no longer required. It has been mentioned that “the TWP can therefore be delayed until after the end of the planning horizon in year 2050” (Department of Water Affairs, 2013).

The analyses of these scenarios indicated that Scenario 2A costs were lower than all the other scenarios. This is the current scenario implemented and paid for by the government and the mining industry, whereby pumping of AMD water from the underground is done

before neutralising to the required TDS levels. Nevertheless, the respondents from the mining industry have indicated their dissatisfaction with the cost of pumping AMD from the underground.

4.4.1.2 *Economic benefit and opportunities of AMD*

Mine water such as AMD creates a number of operational and mine stability problems. The ingress water poses a danger of flooding the mine workings; hence, dewatering needs to be done. Given that the South African gold fields are located in water-scarce areas, the mining industry acknowledges that there is a need for something to be done with the mine drainage waters. As indicated from the literature, there are a number of water sources from the mines; this includes water from the processing plants, active and abandoned underground and surface mines, tailings dams, etc. One of the respondents said that there is over 23 ML/day (Western basin), 46ML/day (Central basin), and 80ML/day (Eastern basin) of AMD water that needs to be treated and most of this water is present in the mines. This water could be used for food security and rural development. Therefore, there is massive opportunity of using the water usefully compared to as treating the water as a liability.

All the respondents contemplate the mine drainage water as a source of water and that value can be recovered from dissolved metals in the water. Water could be treated to industrial standards that can be reused by mines and other industries, which could reduce the cost of treating the water, and supply these water-to-water restricted areas such as Rustenburg and Limpopo. “What needs to be done is to identify other users of such water in industry, identify agricultural uses in terms of salt tolerance of the soil and crops. This could alleviate the water shortage SA is experiencing while creating jobs” as mentioned by one of the respondents. Treating of the AMD water could also assist in creating jobs, which is an added advantage. Another mine respondent said that “by harnessing the potential of AMD as a resource you might not need the Lesotho dam, thus implementing the treatment of AMD could push the Lesotho dam project by a number of years”.

One of the respondents said that “treating water to drinkable water standard will be creating value. There are metals that can be recovered from AMD such as uranium, base metals, and rare earths”. Another respondent agrees and said, “There is lot of volumes of water underground, hence, this is a resource that needs to be explored, as the water can be used as a source of water by treating to potable standards for water supply in South Africa. We have a growing economy and population; hence there is an increase in water demand”. Nonetheless, all the respondents agree that what needs to be done is to characterise the water and its minerals, optimise the water quality and the quantity, put it through proper recovery methods, and recover metals as saleable products where feasible. Then this could add to the benefit of using AMD as a water resource.

The mining industry is not only in a business of the recovery of the minerals from underground, but also financial value has to be realised in doing so. Thus, the mining companies will only have appetite to treat AMD if there is something to it for them. The mining respondents indicated that when mining, licences are given only to mine a specific mineral; hence, the problem is getting a licence for the recovery of other metals that might be in the water. One respondent said that “they are only required to recover gold, and they throw away all other metals”.

It has also been said by one of the mining respondent that “as a mine, by law, in terms of the municipal system Act only municipalities can sell water at a profit because the mines are not licenced to sell water, but by giving the water to someone else at cost, the mines can at least recover cost of treatment”. Therefore, a need for government policy intervention is necessary, which could not only assist in mitigating the problem of AMD and waste but also have value addition by recovering valuable metals dissolved in the water. This will be an incentive for value recovery for the mines. One of the mining respondents said that “what works for us currently is changing water circuits and putting up a treatment plant to stop using municipal water which has a big positive impact because we treat at R6/kL to make drinkable water compared to the cost of R13/kL for getting water from the municipalities. There are benefits to be self-sufficient; hence, we have big savings in terms of water treatment”.

The AMD water certainly presents an opportunity as a source of water for South Africa. All the respondents concur to the opportunities the mine drainage water presents. This is something the government and the mining industry should start building on to mitigate the cost of treatment while managing the environmental impact.

4.4.1.3 *Who must bear the cost of AMD*

As indicated in section Economic feasibility with regard to water treatment and recovery^{4.3.1.2}, a short-term intervention strategy of pumping and neutralising the mine-contaminated water is currently employed in the Western basin and paid for by the South African government. This process treats the water to low TDS, and hence the water can be decanted to the rivers thereafter. As previously discussed, before treating the water, pumping of the water from the underground needs to be done, which has been indicated by all the respondents as a costly process mainly due to high-energy cost associated with pump energy requirements. It has also been indicated by all the respondents that mining will cease if nothing is done; more information on this has been discussed in section Economic impact if nothing is done^{4.4.1.1}.

The other challenge concerning management of the AMD water is the legacy that has been left by the mining companies that operated since 1886, when gold mining commenced in the Witwatersrand. Literature has indicated that, the legacy waste from the gold mines is said to constitute the largest single source of waste and pollution in South Africa and there is a wide acceptance that AMD is responsible for the most costly environmental and socio-economic impacts. Nevertheless, holding the mining companies that were operating during the era of less stringent environmental regulations liable is something that has been said by the Government respondents to be a challenge. Hence, the liability for the treatment of AMD has not yet been finalised by the government.

The mining respondents have indicated that collaboration between the government and the mining industry could be a reasonable solution, but more responsibility should be placed with the government because of the legacy of mining. While the government agrees

that collaboration could be a better solution, the apportionment of the cost of treatment has not yet been agreed to. DWS has indicated that they are currently in discussions with all the relevant stakeholders to finalise the cost structure.

Currently the mines are paying for the ingress and the DWS is paying for the treatment, said one of the mine respondents. The other respondent from the mines said that they currently have an agreement with the government to treat the water under the short-term intervention strategy of pumping and neutralising the mine contaminated water. For this project, that specific mine company covers a third of the treatment cost while the government covers two thirds. The cost amount to treat about 10 ML/day at R6/kL while the government covers the cost of treating 20 ML/day.

The National Environmental Act makes provision for mining companies to contribute funds for post closure and rehabilitation of mines. The respondents indicated that the management of these funds are not managed to address fully the actual post closure effects of mining, especially if the mine goes into liquidation. It has been said that the rehabilitation funds need to be strategized to take into consideration all the aspects of the post closure and ongoing treatment that may arise from the closure of each mine. The funds have to specify the environmental management processes that needs to be followed and how to manage the risks, and sufficiency of the funds to cover such risks, more so for the mines that go into liquidation. Currently there are no strategies to look into a better way of managing the post closure of mines; hence, all the respondents agree that there is a need for such intervention from the government.

4.5 Additional commentaries

During the course of the interviews, several other topics were explored that were not part of the original discussion based on the research questions. One such important theme was the collaboration with peers as discussed above. Further issues discussed are described below.

4.5.1.1 *Regulatory Systems in SA*

In South Africa, the Regulatory Authority responsible for the regulation of water resources is the DWS. Development of clean-up goals is based primarily on the regulatory authority applied and the risk assessment used. Legislation governing contaminated sites proved to be complex, predominantly due to overlapping mandates of the different authorities especially in the mining industry, with overlapping responsibilities between the DWS, DMR and the DEA (Dean, Bosqui, & Lanouette, 1972).

The legislations pertaining to the environment and water resources are explained in Section 2.3.1. The mining industry concurs that South Africa has good legislation but cannot effectually regulate it. More regulations might not assist with the problem of the enforcement of the applicable Acts. What is needed is to have alignment between the departments and have one regulator for the mining industry to regulate all issues pertaining to mining. It has been indicated by the mining respondents that the regulatory process is cumbersome and presents challenges for the mining industry. For example, it is said that it can take more than 7 years to get legal rights for water usage. Moreover, one application within the same regulator, have different directives (regulatory framework), hence, it is even more complex to deal with a number of departments.

The mining industry displayed appreciation to the government and their drive to resolve the AMD challenges, yet, they showed no confidence with respect to the regulators having proper resources and human capital that can deal with the enforcement of the legislation. Furthermore, the NGO has pointed out that DWS and DMR policies are in conflict, e.g. the DMR mandate is to promote mining, however is in conflict with the water Act that states that all water resources must be protected. If mining is promoted in water scarce areas, the conflict is obvious.

The government respondents have also indicated that there are challenges in the implementation of the different Acts and the due deliverable of each department. The process for project approval in government departments is tedious which prevents progress in mitigating the problems sooner than later. Concerning the AMD challenges in SA, DWS has been taking the lead while DMR gives support to the processes of the DWS,

while other departments are hoping that DWS could do something to resolve the AMD problems.

The newly introduced Act (NEMA) is set out to deal with the water and environmental problems. Section 2 of the NEMA sets the principles for sustainability, and the need to avoid any activities that degrade or pollute the environment. Section 24 of the NEMA requires that an EIA process must be followed. Legal action can be taken against the polluter in terms of Section 32 of NEMA. The efficiency of the newly NEMA will only be realised when the Act is implemented on one or two mines.

4.5.1.2 *Water security*

Mining and associated activities have an adverse impact on the water regime and water quality in and around the mining areas. Literature has pointed to the fact that the mining operations has caused water pollution, which includes acid mine, drainage, metal contamination and increased sediment levels in streams. Mine drainage has been indicated as a severe pollution hazard, which can affect surrounding soil, groundwater, and surface water. These waste streams, especially from the gold mines, constitutes the largest single source of waste and pollution that threatens the South African water security. Exposure of the tailing deposits to chemically aggressive environments such as the atmosphere with free oxygen and water often leads to an accelerated release of dissolved heavy metals from the tailings particles.

In a case where there are no mines, there will be no water flowing down to the earth voids, and the water will flow naturally through the streams and fountains. Some of the respondents highlighted the fact that rainwater is mainly the source of water that goes naturally to the ground, and this is something that cannot be controlled, leaving no option but to treat the water. Therefore, if there is uncontrolled seepage of the AMD water it adversely affects the quality of the entire water system and impacts the national water security. This can limit the availability of potable water to the public due to poor quality

such that no one could use it, including the fact that the cost of treating the water will be too high.

4.5.1.3 *Backfilling of mines*

All respondents from the mining industry have indicated to support the backfill of mines and promoting it for the shafts where the minerals have been exhausted. This has been shown by one of the projects that is currently being carried out in the Western basin, whereby retreating of the waste dumps are being done followed by backfilling of the old open pits. The project is aiming to backfill the old western mines completely, which will then prevent the formation of acidic water, and enhance slowing down of water seepages to the surface. The respondents have indicated that backfilling the mines has a potential of reducing the AMD by 50%, hence, the impact could be reduced significantly. Nevertheless, backfilling of mines will depend on the amount of the unrecovered minerals after mining. Since mining could be done later to, recover valuable minerals that may be left after initial mining, backfilling might not be an appropriate option.

4.6 Conclusion

Literature has shown that mining and associated activities have an adverse impact on the water regime and water quality in and around the mining areas. All the identified risks of AMD could also have an adverse impact on mining company's profitability; hence, it is important that the mining companies have strategies to prevent risks associated with AMD. Though there is an increase interest in treating the AMD, most stakeholders are still conducting desktop studies, evaluating alternative treatment technologies. It is a general believe that treating the water to solve the problem of water security and at the same time having other by-products such as recovered metals and reagents from the AMD could be a viable solution to water pollution. However, the challenge would be to identify niche markets for these by-products, which can then be sold to generate revenue.

The study has also indicated that it will be a big risk If no action is taken, allowing the water to decant to the environment, which will not only create unwanted pollution, but also introduce high costs for cleaning up the water. The mining industries have shown to have appetite to resolve the issues of AMD, however, there are challenges of historically abandoned mines and mines that go into liquidation leaving their environment liability once they close down, that have to be addressed. Therefore, it is generally viewed that the treatment of the AMD has to be done by the mines in collaboration with the government.

Given that, South Africa is a water scarce country; all the respondents believe that AMD water presents an opportunity as a source of water for South Africans. Treating the AMD water to drinkable standards is the ultimate goal as indicated by the mining sector.

5 CONCLUSIONS & RECOMMENDATIONS

5.1 Introduction

Chapter 5 discusses the research conclusions to assist the mining stakeholders on ways of mitigating the challenges pertaining to acid mine drainage. The outlined recommendations are aimed at providing both the government and the relevant mining industry to bring some level of sustainability in the gold mining sector.

5.2 Conclusions of the study

Research from the literature review has indicated that the mining structure around the Witwatersrand area is divided into subsidiary companies, with each subsidiary company being responsible for its own production and maximizing of its own profit. The companies are structured in such a manner that the profits of the company cannot offset the liabilities and impacts of another company in the group. In assessing the impact of AMD, two main research questions were looked into. i.e. “To assess the strategic choices a mining company takes to mitigate problems associated with AMD” and “To evaluate the likely outcome of the AMD impact if nothing is done”.

The problem of AMD at the gold fields of South Africa in the Witwatersrand area is currently impacting the mining companies with regard to strategy, profitability, and the environment as a whole. The literature has shown that in 2002, acid mine drainage had started decanting from the Western basin, located below the Krugersdorp-Randfontein area. The water-monitoring program of the City of Potchefstroom has released data, which indicates a significant rise in uranium levels in raw and tap water. Communities in informal settlements, as they do not have access to clean and potable water currently use the untreated uranium contaminated water

The major problem is, if the AMD decants, an enormous amount of water will be needed to dilute the water to acceptable levels, which presents a threat to water security in South

Africa. Nevertheless, the mining industry together with the government agree that doing nothing will not be a sustainable solution, because it will not only create further pollution, but the long-term cost of not cleaning up the water will be high. Research has pointed out that the current running mines within the Witwatersrand area do have strategies and plans in place to make sure that there are no AMD seepages to the environment, however there are challenges of the abandoned mines that significantly contribute to AMD and mines that go into liquidation and leave the environment liability once closed down. It is therefore essential that the mines in collaboration with the government should do the treatment of the AMD.

The AMD water certainly presents an opportunity as a source of water for South Africa. All the respondents have indicated that there are opportunities the mine drainage water presents. Given that South Africa is a water scarce country, treating the AMD water to drinkable standards is the ultimate goal for the mining sector, and engaging with the municipalities on how to supply them with treated drinkable water is something that is looked into. It is a general understanding that the cost of treating the water is less than that of the municipal water. Hence, most of the mining industries are including plans to build treatment plants into their strategy, which would deal with the environment problems, while creating jobs at the same time.

Though there is an increased interest in treating the waste dumps, most stakeholders are still conducting desktop studies, evaluating alternative treatment technologies. A limited literature review has been conducted to assess the impact of uranium acid mine drainage pollution in the Western basin and feasible technologies that may be employed to recover the radionuclides without causing any further environmental burdens.

In reviewing the adequacy of the South African's environmental policies in addressing challenges associated with AMD, the policies have been proven adequate by the literature. Development of clean-up goals is based primarily on the regulatory authority applied and the risk assessment used. Although regulatory standards have been established to set maximum acceptable levels of contaminants, especially for uranium that can be released to the environment, mining companies find it difficult to achieve the set standard due to the

legacy left by mining activities that happened more than a century ago, and the interconnectivity of ground and surface water systems, which also affects all major industries across the value chain.

In a case where there are no mines, there will be no water flowing down to the earth voids, and rain water will flow naturally through the streams and fountains, and hence the mines will not contribute to water pollution. Nevertheless, urban people will pollute the water after which the water still needs to be treated before filtering through the ground with possible mineralisation to some extent. In terms of water security for South Africa, the same water needs to be treated when mining or not mining, with the difference that the water will be delayed to surface from the underground compared to accelerate surfacing in the case of mining.

A critical assessment of South Africa's future water balance generally paints a bleak picture characterised by severe water shortages. The country's economic hubs and households in general will be the most severely affected, if the problems of AMD are not managed effectively.

5.3 Recommendations

The South African gold mine industry will remain under pressure if nothing is done about the AMD. In understanding and mitigating the problems of AMD, a need for cooperation at all levels of the government and the mining sector is critical.

Decision making processes need to be expedited to resolve the urgency of dealing with AMD, hence, one of the keys to manage successfully the AMD problems is to have full support from both the mining and the government institutions. The CEO and the board of directors of the mining companies are encouraged to consider all business capitals in their strategy for addressing the problems associated with AMD, i.e. to provide financial capital for the treatment and management of AMD water; to provide a safe living environment for the communities surrounding the mines; to provide a healthy environment for employees;

and to also have suitable and optimised strategies to extract the minerals from the underground while managing the natural resources by not exceeding the environmental capacity to handle and dispense the ore that is extracted from the underground.

Technically, each company should be responsible to treat its own water; however, this research has indicated that it will be difficult to determine the proportions in responsibilities with regard to the companies and government. Therefore, a viable partnership between the government and the mining industry is highly recommended to be able to move forward with the treatment of water aiming at not only improving the life of all South Africans but also improving the profitability of the mines.

For the mines, the cost benefit of treating the water is to be able to sell the water and recover the metals that are present in water as a saleable product. Currently, by law, the mines are not licenced to sell the water, but only licenced to mine specific minerals. It is advisable for the government to develop terms of reference in this regard in order to provide the mines a reassurance of being able just not to treat the water, but to recover value by selling the water either at cost or at profit, and also to trade the metals recovered from the water.

The impact of not having a proper mine closure strategy planning will not only result in negative social and national economic impacts, but it is also severely damaging to the immediate and surrounding physical environment. It is therefore recommended that terms of reference should be developed, especially for the mines that go into liquidation. The main focus should be working towards mine closure with regards to the financial resources that will be required for better management of the environmental impact that mining brings about.

The government should find better ways of regulating the mining industry holistically. Addressing the application systems within each regulator is required. It will be ideal to have one regulator that will include the licencing, management of water resources and the environment management. This will assist in building better relationships between the government and the mining industry. Furthermore, the regulators will be able to have a common understanding of the mining sector and what would be required before a licence

to mine is issued. Currently DMR promotes mining opportunities and issues licences to mine without a water licence, hence, this presents problems in managing the environmental risk and water security.

5.4 Suggestions for further research

- It has been proven from the research, that AMD presents a threat not only to the environmental but also to water security and to the economy as a whole. The mining industry together with the government have indicated that doing nothing will not be a sustainable solution. Further research could be done to investigate how the government institutions could form workable structures with the mining industry to mitigate the AMD problems. The research could be benchmarked with other countries to evaluate best practices available to assist in this regard.
- There are challenges with mining companies that undergo liquidation, avoiding in some cases the environmental liabilities during normal mine closure, which demands proper rehabilitation of the mine. A research review is suggested to probe the reasons for liquidation of the mines, which is important at this stage. “What are the underlying factors that determine a mine to go into liquidation?” is a research question that could be explored.
- “The licencing of mining rights procedures” is a topic that could be of interest in understanding the decisions made by the state in issuing mining rights. “Can the state give a licence to mine without environmental liability aiming at job creation?” could be a research question to get more clarity on the irregularities of issuing mining rights, which impact on the long term sustainability of the environment and the economy as a whole.

REFERENCES

- Aguilar, J. (2002). Adaptive random fuzzy cognitive maps *Advances in Artificial Intelligence—IBERAMIA 2002* (pp. 402-410): Springer.
- Ashanti, A. G. (2004). Report to Society 2004. Johannesburg PricewaterhouseCoopers and AngloGold.
- Ashanti, A. G. (2014). Anglo Gold Ashanti company information. 2015
- Botha, M., Bester, L., & Hardwick, E. (2009). *Removal of uranium from mine water using ion exchange at driefontein mine*. Paper presented at the International Mine Water Conference, Pretoria, South Africa.
- Busby, D. C. (2014). Tour of the West Rand Goldfields. Johannesburg.
- Cobbing, J. (2008). Institutional Linkages and Acid Mine Drainage: The Case of the Western Basin in South Africa. *Water Resources Development*, 24(3), 451-462.
- Coetzee, H., Winde, F., & Wade, P. (2006). *An Assessment of Sources, Pathways, Mechanisms and Risks of Current and Potential Future Pollution of Water and Sediments in Gold-mining Areas of the Wonderfonteinspruit Catchment: Report to the Water Research Commission*. Johannesburg: Water Research Commission.
- Cole, F. L. (1988). Content analysis: process and application. *Clinical Nurse Specialist*, 2(1), 53-57.
- Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches*. United Kingdom: Sage Publications, Inc.
- Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. United Kingdom: Sage publications.
- Dean, J. G., Bosqui, F. L., & Lanouette, K. H. (1972). Removing heavy metals from waste water. *Environmental Science & Technology*, 6(6), 518-522.
- Deloitte. (2013). Acid Mine Water Drainage. Debating a sustainable solution to a serious issue. Johannesburg: Deloitte.
- Department of Water Affairs. (2001). Thukela water project feasibility study water resource evaluation and systems analysis task. Pretoria: Government printer.
- Department of Water Affairs. (2013). Feasibility Study for a Long-Term Solution to address the Acid Mine Drainage associated with the East, Central and West Rand underground mining basins. Assessment of the Water Quantity and Quality of the Witwatersrand Mine Voids. Pretoria: Government printer.

- Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing*, 62(1), 107-115.
- Goldfields Limited. (2015). Annual reports. Retrieved 03-01-2015, 2015
- Guion, L. A. (2011). Triangulation: Establishing the validity of qualitative studies. Florida: Florida Cooperative Extension Service.
- Hamann, R. (2004). *Corporate social responsibility, partnerships, and institutional change: The case of mining companies in South Africa*. Paper presented at the Natural Resources Forum.
- Harmony. (2014). Harmony company information. Retrieved 03 January 2015, 2015
- Hebden, D., & Smit, J. (1984). *The use of supported liquid membranes in the treatment of mining effluents*. United Kingdom: Ellis Horwood Ltd.
- Huitt, W., Hummel, J., & Kaeck, D. (1999). Internal and external validity: General issues. Retrieved May, 10, 2007.
- Kardas-Nelson, M. (Producer). (2010, 06 January 2015). The battle over Uranium: Just how bad is it?
- Liefferink, M. (2014). Criminal Investigation by the Department of Environmental Affairs of Blyvooruitzicht Mine's Alleged Failure of Duty of Care pursuant to Criminal Charges laid by Civil Society.
- Liefferink, M., & Liefferink, S. (2015). Current reclamation of historical uraniferous tailings dams and sand dumps—exacerbating the mess or minimizing the mining footprint? Case studies within the Witwatersrand goldfields *Uranium-Past and Future Challenges* (pp. 387-400): Springer.
- Mahlaka, R. (Producer). (2014, 26 December 2014). Johannesburg's underground Hazard.
- Merriam, S. B. (2002). *Qualitative research in practice: Examples for discussion and analysis*: Jossey-Bass San Francisco.
- MiningNews (Producer). (2013, 2015). The end of gold tailings dumps is near.
- Myers, M. D. (2013). *Qualitative research in business and management*. Los Angeles: Sage.
- Norman, N., & Whitfield, G. (2006). *Geological journeys: A traveller's guide to South Africa's rocks and landforms*. Cape Town: Struik.
- Oelofse, S., Hobbs, P., Rascher, J., & Cobbing, J. (2007). *The Pollution and Destruction Threat of Gold Mining Waste on the Witwatersrand: A West Rand Case Study*.

Paper presented at the 10th International Symposium on Environmental Issues and Waste management in Energy and Mineral Production Bangkok.

- Orange-Senqu, T. O.-S. R. A. K. (Producer). (2014, 26 December 2014). The legacy of gold mining.
- Peter, J. P. (1977). Reliability, generalizability, and consumer behavior. *Advances in consumer research*, 4(1), 394-400.
- Reid, A. J. (1996). What we want: qualitative research. Promising frontier for family medicine. *Canadian Family Physician*, 42, 387.
- Republic of South Africa. (1998). NEMA. Cape Town: Government printer.
- Republic of South Africa. (1999a). National Nuclear Regulator ACT. Vape Town: Government printer.
- Republic of South Africa. (1999b). National Water ACT No. 704. In W. A. a. Forestry (Ed.), (Vol. 408). Cape Town: Government printer.
- Ring, R., Holden, P., McCulloch, J., Tapsell, G., Collier, D., Russell, R., . . . Stimson, D. (2004). Treatment of liquid effluent from uranium mines and mills during and after operation. *Treatment of liquid effluent from uranium mines and mills*, 7.
- Schwarz, R., Gerth, A., Morgenstern, S., & Hebner, A. (2009). *Strategies for managing environmental problems and water treatment in mining*. Paper presented at the International Mine Water Conference” Pretoria, South Africa.
- SibanyeGold. (2014). *Annual report pursuant to Section 13 or 15(d) of the securities exchange ACT of 1934*.
- SibanyeGold.co.za. (2015). Sibanye Gold Company information, Annual reports. Retrieved 03 January 2015, 2015
- van der Walt, J., & Winde, F. (2002). Uranium contamination of fluvial systems. Mechanisms and processes. Part II: dynamics of groundwater, stream interaction. A case study from Koekemoerspruit (South Africa). *Cuadernos de investigación geográfica*(28), 59-74.
- Van Eeden, E. (2008). Weaknesses in environmental action in South Africa: A historical glance on the West Rand (Gauteng Province). *Water Resources Development*, 24(3), 463-475.
- Van Eeden, E., Liefferink, M., & Durand, J. (2009). Legal issues concerning mine closure and social responsibility on the West Rand. *TD: The Journal for Transdisciplinary Research in Southern Africa*, 5(1), 51-71.

- Van Tonder, D., Coetzee, H., Esterhuyse, S., Msezane, N., Strachan, L., Wade, P., . . . Mudau, S. (2008). South Africa's challenges pertaining to mine closure—the concept of regional mining and closure strategies. *A. B Fourie et al.*
- Van Veelen, M., de Beer, G., Winde, F., Lush, D., Cohen, R., Khoathane, M., & Mlangeni, G. (2009). Wonderfonteinspruit Catchment area remediation plan. *Radioactive contamination specialist task team report on site visits and recommended actions. Final Draft Report (2009-04-03). Prepared for the Department of Water Affairs and Forestry and the National Nuclear Regulator.*
- Vermeulen, A. (Producer). (2013a, 26 December 2014). Tackling the Witwatersrand AMD problems.
- Vermeulen, A. (Producer). (2013b, 06 January 2015). Uranium contamination a health risk of AMD. *Mining weekly.*
- Wendel, G. (1998). Radioactivity in mines and mine water-sources and mechanisms. *JOURNAL-SOUTH AFRICAN INSTITUTE OF MINING AND METALLURGY*, 98, 87-92.
- Winde, F. (2006a). Challenges for Sustainable Water Use in Dolomitic Mining Regions of South Africa—A Case Study of Uranium Pollution Part I: Sources and Pathways. *Physical Geography*, 27(4), 333-347.
- Winde, F. (2006b). Challenges For Sustainable Water use in Dolomitic Mining Regions of South Africa—A Case Study of Uranium Pollution Part II: Spatial Patterns, Mechanisms, and Dynamics. *Physical Geography*, 27(5), 379-395.
- Winde, F. (2006c). Long-term Impacts of Gold and Uranium Mining on Water Quality in Dolomitic Regions—examples from the Wonderfonteinspruit catchment in South Africa *Uranium in the Environment* (pp. 807-816): Springer.
- Winde, F. (2009). *Uranium pollution of water resources in mined-out and active goldfields of South Africa-a case study in the Wonderfonteinspruit catchment on extent and sources of U-contamination and associated health risks.* Paper presented at the Proc. 2009 International Mine Water Conference.
- Winde, F. (2013). Uranium pollution on water—a global perspective on the situation in South Africa. *Vaal Triangle Occasional Papers: Inaugural Lecture*, 10, 2013.
- Winde, F. (2014). *AMD in the central basin- An alternative view on risk and coping strategies.* Rand Water.
- Winde, F., Coetzee, H., Winde, F., & Wade, P. (2006). Inventory of uranium sources and transport pathways in the Wonderfonteinspruit catchment. *An Assessment of Sources, Pathways, Mechanisms and Risks of Current and Potential Future Pollution of Water and Sediments in Gold Mining Areas of the Wonderfonteinspruit Catchment (Gauteng/North West Province, South Africa).* WRC Report(1214/1), 06.

- Winde, F., & Van der Walt, I. (2004). The significance of groundwater–stream interactions and fluctuating stream chemistry on waterborne uranium contamination of streams—a case study from a gold mining site in South Africa. *Journal of Hydrology*, 287(1), 178-196.
- World Health Organization. (1998). The World Health Report 1998: Life in the 21st century a vision for all *The world health report 1998: life in the 21st century A vision for all; The world health report 1998: life in the 21st century A vision for all*. Geneva: World Health Organization.

6 APPENDICES

6.1 APPENDIX A: Interview Matrix

	Discussion Raised	Mining Industry		
Strategic choices a mining company takes to mitigate problems associated with AMD.	Economic feasibility wrt water treatment and recovery	We have Operating mines, dumps, tailings and rock dumps which gerates AMD. Mines are situated in dolamites. Mine activities happen where there is AMD formation, hence lime is dosed underground to nuetralise the water (this is where the 1st cost of AMD), this makes sure not to discharge metals and AMD water to the surface. On surface they dont have a big problem wrt AMD, and also at the tailing facilities a pH high is maintained. The cost of lime and its logistic and doing it underground is high. To pump water from under ground is also costly, hence this is a big challenge which needs to be looked at.	Getting other surrounding mines to be on board because of the interconnection of the underground mines is a challenge. the treatment needs to be done in collaboration with the peers because if the peers close down, the enviromental problem will be left with the mines that are still running. High cost of pumping is currently a challenge.	Having to pump the water from underground is a challenge due to high cost of pumping. Though the cost of pumping is part of our operating cost, however 95% of the water we pump is as a results of legacy. If stop pumping at excessive depth it will then make sense. Regulators not mature enough to deal with the issues of AMD especially for those companies that goes into liquidation which also affects our mines due to the interlinks between the mines.
		The treatment of AMD is very small interms of the economic impact but the potential opportunities is to optimise and separate at source not taking fissure water and polute it with mine water. But in a perfect world this could be a sollution to sepearate the fissure water from the mine water and sort out the mine water balance. The treatment could be economically viable when pumping at a point of decant and treat the water and sell to the municipal to recover the cost.	Whether or not is economically viable the treatment of the water still has to be done. Hence we have strategies in place and made provision to treat the water.	The water treatment could be viable if the cost could be recovered by selling the treated water and reusing into the system.
	Organisation strategy on AMD	Have a contract with the Government to Pump and treat AMD from the old mines on behalf of the government. Strategy is to make drinkable water from the AMD, and engage with the municipal on how to supply them with this treated drinkable water. Which will deal with the environment problem, and creating jobs at the same time. Also use the mine water to put on the system for the treatment of the tailings, and also treat the water from the treatment plant (the plan is to build a plant that will treat 15ML/day which could be then be given to farmers or municipalities). The cost of treating the water is less than the that of the municipal water which has some financial benefits to it. The water that goes to the environment is lisenced and have to conform to certain treatement before releasing to the environment. Its cheaper for us to take mine/AMD water and make drinkable water than to put it in the stream because the stream water are stricter than the drinkable water standards at the current moment. We have developed a terms of reference for the DMR. Have a forum called the far westrand basin technical working group. The main focus is working towards mine closure, what will happen to the water and where will the treatment plants be and how we could that be done. Working together with mines in our surroundings.	It is important to collaborate with our peers and we are currently developing a post closure management plan in collaboration with our peers, which also involves AMD issues given that we might be the only mine standing in future hence it may affect the business. We are also currently treating and reproccessessing tailing and waste dumps. Not much problem with AMD currently because there are plans in place to mitigate that and we have a treatment plant that treats the water. The CEO and the board of directors fully supports (Financially, socially, and health matters) the projects for handling AMD,hence we are able to contain the water and treat it to the required standard. if not done it will have an effect on the company reputation. In generating any once of gold all the 5 capitals are being considered into the strategy.	The strategy is to acquire the mines that threatens our boundary. Established subsidiaries to deal with the pumping of the water and understanding of water mass balances. Water that is released is currently not of bad quality and also used for tailing reclamation. Currently spending +R600 million per year to pump water (this includes other mines' water. Also spending capital and changed infracture to be able to deal with the AMD. Specialist were brought in to look into the AMD, mine water situation, mine operations and to develop a strategy to offset the water as much as possible and utilise the water back into the mine processes. No any structures in place for mining companies to collaborate and solve the problem. The failure is being unable to collaborate with other mining companies. The make or brake of dealing with AMD is to collaborate with other mines.
	Leakages of AMD in your company	No AMD leakages into the system. Everything is contained. Sometimes there could be incidents where the pipelines burst, but other than that we contain all the water and treat before releasing it to the environment or recycle back to operations.	No AMD leakages into the system. Everything is contained.	No AMD leakages, water is contained and treated before release.

	Discussion Raised	Mining Industry		
The likely outcome of the AMD impact if nothing is done	Who must bear the cost of AMD	The high cost currently is the cost of pumping the water from the underground. The cost of lime and its logistic and doing neutralising underground adds up to the costs. We cover a third of the treatment cost while the Gov covers the two thirds. 30ML/day which is R6/kl. of the treatment which we cover a third of that.	We are responsible for our mine site, and government should be responsible for the legacy, basically it should be a collaboration between the government and the mining industry.	Collaboration between the state and the mining industry, but more the government because of the legacy. Waste discharge charge system, pay levy to Government like a super fund, the fiscas then support the mines, regulates and create a structure and build treatment plant. backfill of mines, manage liquidation and the zamazamas, how to manage that if you backfill.
	Economic Impact if nothing is done	It will not be economical viable if nothing is done, because the water has high TDS and if the water goes to the rivers the dilution effect is fine but the problem which is associated with the heavy metals and uranium, hence you need to remove this minerals and acidity before the water flows to the river system. if not we will be creating pollution.	Its not an option not to do anything. if nothing is done we will be out of the business because we will not be able to mine since the water will fill up the mines. The water system will be affected which inturn will also affect the socioeconomics and the lives of the ordinary South Africans.	If nothing is done we will not be able to mine because the water could flood the mines hence we will be out of the business. +25K people will loose their jobs. The mines will flood and wont be able to mine. It will also not be economical viable if nothing is done, because the water has high TDS which can affect the river system and threaten the water security.
	Economic benefit and opportunities of AMD	AMD can be a source of water and value recovery for dissolved metals in the water. ECL (Economic critical level) at the water level for the basin to survice must be below a certain level, hence there is a need for pumping which will mean to pump and treat forever because if there is any void under ground, then you have oxygen, then the water goes into the mines which then creates AMD. But if you flood the mine to the highest possible level, there will be no farmation of AMD. Currently conducting a study, if we backfill and let the water to rise as high as possible and do treatment where the water flows out, which eliminates the high cost of pumping and treat the water to drinkable standards which will be much cheaper than the current method of pumping and treatment. looking at treating the water to drinkable water will mean you create value. there are metals that can be recovered from AMD as well, such as uranium, BM, and rare earths. what needs to be done is to characterise the water and its minerals and put it through proper recovery methods for such metals. This will create additional jobs. The problem is the lisenace for the recovery of these metals, we are only required to recover gold, and we throw away all other metals. Needs a policy intervention, which will mitigate the problem of AMD and waste and have value addition and recover anything that can dissolve. this should be called "value recovery".	AMD can be a source of water and value can be recovered from the dissolved metals in the water. Treat to portable standards for water supply in SA. There is lot of volumes of water underground hence this is a resource that needs to be explored. We have a growing economy and population hence there is an increase in water demand	the water can be a potential resource. We need to optimise the water quality and the quantity, then this could add to the benefit of using AMD as a water resource. This could also assist in creating jobs. by harnessing the potential of AMD as a resource you might not need the Lesotho dam
		As a mine, by law, in terms of the municipal system ACT only people who can sell water at a profit are the municipalities because the mines are not licenced to sell water. But can give it to someone else at COST, at least they can recover cost. what works for us currently, we are changing water circuit and putting up treatment plant to stop using municipal water which has a big positive impact because we treat at R6/kl. to make drinkable water compared to a cost of R13/kl. for municipalities. there is a benefits to be self-sufficient, hence we have big savings interms of water treatment. Treat and recycle back to the mines	Treat the water and recover the metals and nitrates for fertilisers. Currently treating the water and reusing it back into the processes	The cost benefit of treating the water is to be able to sell the water as potable water which is expensive but gives the maximum price. The legislation doesn't allow us to sell the water because we are not registered as a water company. the strategy is to have partnership and joint ventures for the treatment of water. Cant build infrastructure to treat the water and transfer it to the municipality because the liability will still remain with the company. Financial institution could look into financing this, this is also an opportunity for them. Pump and reuse the water in the mine.
Additional Comments	Regulatory Systems in SA		SA has good legislation but can't regulate it. Putting more on legislation wont help anything the problem is the enforcement of the ACTS. have one regulator (DWS,DMR,Environment) regulatory process is combersome and not good for the business, hence companies just break the law. it can take 7 years to get the right for water usage. one application within the same regulator takes longer, they have different directives (regulatory framework), hence difficult to deal with a number of departments. DWS must stick to regulation not treating the water. But no plan can be built in isolation. Industry must run the project and treat the water while the regulators must regulates. The polluter must pay principle is good in a perfect world, but given the legacy then that could be a problem.	
	Water security	if there are no mines, there will be no water flowing down to the earth voids, and the water will flow through the streams and fountains. Urban people will pollute it and have to be treated and the same water goes to another step, goes through the ground and comes out and it mineralises and now have to be treated, but interms of water security its same water that needs to be treated but the difference is that the water will be delayed to surface from the underground compared to when you have mines. but the problem is the cost of pumping the water from the mines which currently the government pays for it through taxes. There is AMD in the coalfields which is different to the GOLD mines, and have the dumps, stop thinking of the pumping and get permanent solution.		
	Backfilling of mines where AMD is formed, is that an option of preventing AMD.	Depends on the amount of the minerals left after mining, because you might need to come back later to recover those minerals, backfill might not be a good adea. But we fully support that and promoting it, on the western basin we are retreating the sanddumbs and we are currently busy backfilling the old open pits, the aim is to backfill the old western mines fully which will then prevent the water from turning acid.	backfilling of mines has been considered into the strategy but one needs to be carefull, since you might need to mine again at the same area	backfill can also be a problem because you might need to mine again at the same place. allowing the mine to flood will be cheaper to treat the water and not pump from the shafts. as long as mining is carrying on, the pumping needs to be done.

	Discussion Raised	Government institutions		
Strategic choices a mining company takes to mitigate problems associated with AMD.	Economic feasibility wrt water treatment and recovery	The AMD is a small portion of water but the impact to the water security is big, such as environment pollution, and threat to water security. Before treating the water, pumping needs to be done. The cost of pumping and the energy cost that comes with is a challenge. Challenges are found when a company goes under liquidation and leave the environment liability once is closed down.	The challenge is to regulate the mines with regards to any impact that may arise when a mine is liquidated. DMR gives licence, when the mine goes to liquidation this means that the mining stops and cease to exist and the licence cease to exist hence the are difficulties in regulating. Mining companies do make provision for environmental impact that may arise after mine closure that can be used to rehabilitate the mine. However when a mine under liquidation such money can be used until the liquidation process is completed and when the mines pays all it's creditors. Challenges is to impose compliance because when the mine goes under liquidation. The legislation is not clear about the specifics such as AMD, it just says the impact association with mining environment	The water system is a complex system. Has lots of water interlinks underground, hence managing this water is a challenge.
		We are currently pumping the water and neutralising it which is costly. The water treatment could be viable by selling the water after treatment.	The DWS and environmental affairs champions the programmes of AMD.	Pumping the water from the under ground before treating the water has proven to be expensive. The water treatment could be viable if the cost could be recovered by selling the treated water and reusing into the system.
	Organisation strategy on AMD	We are currently pumping the AMD water and do desalination to reduce the TDS to acceptable levels and pump the water to the dams. Currently working with mines in treating the water and setting up strategies on handling the AMD issues	Because of the legacy of mining, (having two legislations, the NPRA and the Mineral ACT), some of the mines operated under Mineral act and moving to NPRA as a results the documentation part of it interms of the environment impact did not change and did not aligned to suit the current legislation, therefore when AMD cases comes it becomes difficult to manage. Hence task teams had to be formed to look into this. The government has put funds to deal with AMD and research to check what could be a tangible solutions. Most of the mines that have AMD problems they go into liquidation. From December 2014, the implement the NEMA act started, if a mine gets liquidated or not the NEMA allows to enforce compliance to the directors of the mine, hence in future we can bring everyone to book to solve any environmental impact that may arise from mining. Currently challenges is the implementation of the ACT, and the effective of the NEMA will only be seen when this is tested on one or two liquidated mines. Alignment between the departments is needed. DMR regulates the activities that are within the mining rights. The departments, DWS, Environmental Affairs and DMR are developing one environmental system between the three spheres of the government. This will ensure proper regulation.	3 scenarios has been looked at: 1. DO NOTHING , do not move Thukela project forward (not to Build the Dam), release water to the vaal, hence cannot maintain this scenario. This can not be afforded and too expensive for the users 2. long term solution, "DESALLINATION" , supply to industry the treated water, this is the scenario managed for. Not including recovery of metals, but disposing of sludge, and backfilling of mines using the sludge, proposed to use the eastern basin as a test. Also not to sterilise any mine reefs that could be mined in future 3. "DESALLINATION AND TREATMENT OF SLUDGE AND RECOVER THE METALS" . Need to work on a funding model to calculate the real costs. proposed the following: capital contribution may come from the Lesotho highlands water project, but this is still to be decided.
The likely outcome of the AMD impact if nothing is done	Who must bear the cost of AMD	Currently the mines are paying for the ingress and the DWS is paying for the treatment.	DMR had its own legislation and when it came to environmental issues it was not strict, eventually when the new legislation came through one could not enforce the legislation right through. With the legacy of mining which came with lots of environmental problems, cannot enforce new legislation on the old mines, and only can enforce it going forward with the current mines. The legacy of mining the state has to deal with it and its cost of it. Collaboration between the state and the mining industry could be a reasonable solution, but more responsibility to the government because of the legacy.	The cost recovery mechanism could be a combination of a polluter pays method, TAX, levy for the mines, waste discharge system (All polluters, e.g mines, sewerage etc. Implement the levy that will assist the funding of the treatment. The tax payer will only pay only the portion that accounts for their benefit, the rest could be covered by government. But this has not yet been apportioned. Currently in discussions to finalise the cost structure.
	Economic Impact if nothing is done	The AMD problem its primarily a water security issue. The major problems is, if the AMD get to the water supply, and then we will have a problem of the salt load in the water. 600ppm TDS is allowed to the vaal system, if more TDS you have to release water from the vaal dam for dilution. This water is not cheap water, its the water from the Thukela river (Pumped over +400m over the drakensburg mountain, which makes it even more expensive, due to energy costs of that) and the orange river (Grootdal dam), also water coming from Lesotho on a paid tariff. We take water that we paid for and use it to dilute the high TDS coming from the AMD, and not only paying for it but also the water is not available for use, hence the problem with water security. If water is not treated, then the dirty water will be crapped down to the lower users. Restrictions in water supply will be enforced, which may lead to economic slowdown. The AMD water will threaten the water security	The AMD does bring a long term economic benefit. Treating the water to solve the problem of water security at the same time having other by-product such as recovery of metals and reagents from the AMD. But the challenge will be to get a niche market for the by-products which then can be sold to generate income. Treat the water to industrial standards that can be reused by mines and other industries, which could reduce the cost of treating the water. Also supply this water to water restricted areas such as Rustenburg and Limpopo. This also presents an opportunity for job creation.	If nothing is done, the water will start decanting and some of the mines will have to stop minning, then there will be socio economic challenges. We will also have a water security problem, given the problem with draught, hence this will also increase the treatment cost and eventually the triple down effect will be felt by the public and people will then struggle to get water because water will be expensive and people might not be able to pay for that water. The cost of business will be high, hence there is no way that nothing could just not be done
	Economic benefit and opportunities of AMD	AMD as a water resources, to be used in other industries such as power stations. Treat the water and sell to recover the costs	Alignment between the departments is needed,	Treat water and sell back to industry or to the people. Implementing AMD will push the lesotho dam project by a number of years. recover metals as saleable product, job creation could add as a possible move. the mining industry will only have appetite to treat AMD if there is something to it. if they dont, by the time they stop mining, then the problem still remain.
Additional Comments	Regulatory Systems in SA	Companies buy mines without the liabilities. The liabilities are much high and if they had to buy the land with liabilities then they will go in liquidation		

	Discussion Raised	Parastatals	
Strategic choices a mining company takes to mitigate problems associated with AMD.	Economic feasibility wrt water treatment and recovery	The cost of treating can be high, especially when the pumping system is used. Pumping of water from the underground is expensive which could be a challenge. But in terms of treatment of the water, there are processes developed to treat the water but the challenge could be the ultimate cost of treating the water. Treating and not treating presents its own cost. the best option will be to treat for the benefit of the environment. Depending on the use, the treatment cost will depend on the quality of water needed for such a need, hence this needs to be quantified. The pumping system that is currently used is not economically viable because of its high cost of electricity needed, hence this is something that needs to be strategized properly. Treat and resell to the municipality, this could be a viable solution. Anglo indicated the recovery of sulphur as the product, and water irrigation for agriculture use.	No challenge when it comes to the treatment of the water but the challenge is more on who will do it and who will pay for it. The mining industry has no appetite to solve the AMD problems, because they do as much as they can to externalise the cost and the risk and that's why they do things like declare a mine or a particular site to be liquidated rather than accepting responsibility. There is value in treating the water. The water contains metals that are also valuable. You can recover the metals as additional products. Treat and sell the water for municipal or other uses such as agriculture and industrial use.
The likely outcome of the AMD impact if nothing is done	Who must bear the cost of AMD	The mining industry and the government are both financially liable. This should be a shared responsibility but the proportion of it should be looked into. The legislation should give guidelines to that. The national environmental ACT talk about the funds for the post closure and rehabilitation of mines. what is saved for rehabilitation and environmental management would it be enough to manage the risk? hence this is something that needs to be looked at.	The current running companies if they have to pump and treat the water it cost a lot of money. If this cost is too much for the mines to absorb, therefore they should not mine, and if they don't mine there will not be void spaces which could contribute to the formation of AMD, hence we don't have to deal with AMD problems later. In a case of active mines, mining companies should pay for it. For the historical sites, before we had waste ACTS, natural environment management ACT, for the ownerless mines, the water becomes water of the states, then the government should pay for it. There is an ongoing argument about the apportionment of the responsibility, and the best combination will be the public private partnership. technically each company should be responsible to treat its own water and not responsible to treat other mines water, however technically is very complex and difficult to decide how much water is their responsibility and how much should be the government portion.
	Economic impact if nothing is done	there is no way that one could just release the AMD to the environment because of the impact it comes with. This will mean that the problem could also be transferable to other basins. Most of the increased future cost associated with both electricity and water supply will be passed on to the consumer. Not only domestic electricity, but also water accounts will have to increase several-folds to fund the expenditure required. The country's economic hubs and three main urban areas, Johannesburg, Cape Town and Durban, will be the most severely affected, with predicted water demand exceeding availability by a factor of about two by 2025	It is not viable not to do anything because it will create pollution. The long term cost of cleaning up the impact is higher than the cost of doing nothing. The water has high level of metals and once it is released it runs into the water system and affects the water quality, therefore it is important that the water is treated before releasing to the environment.
	Economic benefit and opportunities of AMD	AMD presents itself as a water resource that needs to be explored. To identify other uses of such water in industry. Identify agricultural uses in terms of salt tolerance of the soil and crops. This could alleviate the water shortage SA is experiencing while creating jobs.	AMD is a massive resource of water. SA has drought. 300-400 million litres only in Gauteng, and is seeping in the mines. This water could be used for food security and rural development, there is massive opportunity of using the water usefully compared to as treating the water as a liability.
Additional Comments	Regulatory Systems in SA		The implementation of the legislation and policies is a problem. The government has the will to resolve the problem but the problem is having proper resources and human capital that can deal with the enforcement of the legislation. Liquidation of the mines is a serious problem to be looked at because these mines once they are liquidated it is currently a challenge to enforce legislation on them, hence the government is left with a mine that has environmental problems such as AMD.
	Water security		Rain water infiltration is mainly the water that goes to the ground, and we can not control that, and have no choice but to treat the water. If you have uncontrolled seepage of the AMD it damages the quality of the entire water system. This can take the water away from anyone who wants to use it because the quality will be such that you can't use it at the same time the cost of treating the water will be too high. it is massive impact on water and national security

	Discussion Raised	University	NGO	Private Company
Strategic choices a mining company takes to mitigate problems associated with AMD.	Economic feasibility wrt water treatment and recovery	AMD is a protected problem. Mine water is only 4% of the total volume, hence do not put it on the river because it destroys the value. The cost of pumping is high hence there is a need to look into these challenges and come up with a strategies that could be more economical viable	Once the mine is no longer profitable or goes into liquidation, it gets issued with a closure certificates with no social liability for closure interms of environmental impact. The environment carries the cost and the cost are externalised to the communities. Mines during the operation must make adequate financial provision not for the life time of the mine but the lifetime of the impact. since the impact may continue for centuries. The government notice 904 (DMS) states that the financial provision must be made for the lifetime of pumping and treatment of the water.	Pumping the water from underground at high cost is not economically viable because of the high cost associated with pumping.
		It will be viable to treat the water if you look into the aproach of treating the water. Recovering the metals as saleble product could be a solution.	There is cost associated with treating and also cost associated with not treating. Hence it will not make sense not to treat the water because of the effect it comes with it. The best option is to treat and sell the water. There are many open pits which contributes to AMD and the these pits has to be backfilled and sealed. Pumping also may creates voids underground which contributes to AMD due to oxygen formation.	There are processed that can be used to treat the water which presents a cheaper way of treatment. The water could be treated and sold to end users
The likely outcome of the AMD impact if nothing is done	Who must bear the cost of AMD	Make the liability to be of the industry, but the government should also be liable for the legacy. Monitor water and charge penalties to the polluter. The costs of treating the water lies in the value of selling the water and recovering the metals as saleble products	The national water act section 19 says that the polluter must pay and sect 28 of the national enviromental act states that any person who pollutes must pay. This includes directors and mine managers and operators. The government and the mining sector are liable for the treatment of the water	The mining industry and the government are both financially responsible for the treatment of the water. The propotion of it is something that needs to be regulated
	Economic Impact if nothing is done	It is not viable not to do anything, but don't pump because the cost of pumping is too high but leave the water to decant and treat water at the point where it decants. if nothing is done there will be a threat of health and loss of income. It's a must to neatralise the water to reduce the impact	it is not viable not to treat the water. Currently the AMD is treated to about 2500ppm sulphides by pumping and neutralising the water and the WHO limit is currently at 200ppm. hence the government is using the water from the lesotho highland to dilute the water for usage which is the expensive water. But if there is a draught then this will cause the vaal to go to defeasit, because of high salinity and this would impact about 60% of the economy and 45% of the population will be affected. no water will segment to the limpopo river and olifants river. the mining in other provinces will be affected and economic growth will be stagnant as well as job creation. water needs to be treated to be made fit for use.	It is not economical viable if do nothing because of the high sallinity in the water. if the water is discharged to the environment it will effect the water from the river, and this will increase the cost of treatment.
	Economic benefit and opportunities of AMD	The water is a valuable resource in SA, since SA is as a water scares country. It presents opportunity (600ML/day). It will be cheaper to treat the water than building a pipeline of longer distances such as the one fromm the Lesotho dam.	AMD can benefit the economy as a source of water, and if the water is treated it will also creat jobs. Some mining companies are proposing to allow the basin to flood and where it decants there will be less volumes to treat. Intent to treat to portable standards and make the water available to municipal usage.	AMD can be treated and used as a source of water for use in other industries such as agriculture. Treat and sell the water to recover the cost of treatment
Additional Comments	Regulatory Systems in SA	The process of project approval in government departments is long which prevents progress in mitigating the problems sooner than later before more damage could be evitable.	There are no ownerless mines except for one mine. Water affairs and DMR policies are in conflict, DMR mandate must promote mining, however is in conflict with the water act which states that the water sources must be protected. If mining is promoted in water scares areas, then there is a conflict. there are conflict between different legislation. Many municipalities are not educated about AMD. Cooperation in all levels of government, National, regional and municipal, department of health and all stake holders in understanding the problems of AMD is needed.	