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Assessing how an adaptive management approach was incorporated in the mitigation strategies for acid mine drainage discharge in the Witwatersrand basin

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July 2018

Declaration

I declare that this Research Report is my own, unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



31th of July 2018 at the University of the Witwatersrand.

Acknowledgements

This research is dedicated to my parents, *Matshediso* and *Molise Rantsieng,* for their unapparelled support, unwavering love and profound belief in my abilities.

My deepest gratitude to my supervisor Ingrid Watson, for her guidance and patience throughout this journey.

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Abbreviations

AM .....Adaptive management

AMD .....Acid Mine Drainage

CSIR..... Council for Scientific and Industrial Research

DWA ..... Department of Water Affairs

DWS.....Department of Water and Sanitation

EIA .....Environmental Impact Assessment

HDS..... High Density Sludge

IMC .....Inter-Ministerial Committee

ECL .....Environmental Critical Level

SDM ..... Structured Decision Making

SWV..... East Rand Mines at the South West Vertical

TOL..... Target Operating Level

TCTA .....Trans-Caledon Tunnel Authority

Abstract

The predicaments faced by humanity today differ from the past due to the increasing scale of human influence, complexities and uncertainties (Allen *et al.,* 2010), which limit management options. Adaptive management is based on the philosophy that knowledge is incomplete i.e. there will always be uncertainty and unpredictability in the behaviour and dynamics of complex social-ecological systems. Given the complexity of the South African mining industry, this research aimed to explore the link between management and science by assessing the extent to which an adaptive management approach had been incorporated into short-term and long-term mitigation strategies for the discharge of acid mine water in the Witwatersrand Basin.

The methodology included a review of the adopted mitigation strategy document, a literature review of adaptive management literature and an in-depth analysis of a case study using nine interviews, conducted with key informants and contributors from the government, an educational institution, industry (mines currently dealing with the issue), and civil society. An inductive and descriptive approach was followed to gather and analyse data to formulate answers to the research questions.

The findings of the study indicated that the efforts that went into designing the short-term solutions were limited due to the lack of communicating amongst stakeholders and the failure to incorporate a value-based approach. Results also showed that complexities and uncertainties were not addressed to allow for adaptation to constant change. It was found that the short-term interventions had no managerial flexibility which limited learning. Insufficient monitoring and a lack of transparency regarding the dissemination of monitoring results were highlighted. Moreover, experimental efforts were limited due to lack of capacity and funding. In conclusion, although the long-term strategy incorporated some aspects of adaptive management, the short-term mitigation measures were reactive rather than proactive.

It is recommended that on-going training and good communication are maintained amongst stakeholders. Recommendations for economic constraints include the sharing of costs through partnerships, evaluating trade-offs between costs and effectiveness and investigating cheaper measuring methods for monitoring. Risk-averse initiatives such as conducting risk assessments during pilot studies and accommodating for different project scales can be employed to mitigate against resources that are sensitive to change.

1. Introduction

1.1 Introduction

Netwon's laws of motion established a supposedly clear relationship between cause and effect in the nineteenth century (Chapman, 2016). For decades, scientists were confident that even the most complex behaviours of natural systems could be reduced to calculations based on a few laws and formulae which could in turn be extrapolated to determine the exact behaviour of that system far into the future (Chapman, 2016 and Stirzaker *et al.*, 2011). Discoveries that were made in the past few decades have however shown that this and many other historical scientific assumptions are in fact fundamentally wrong and that the behaviour of some natural systems are far from being predictable (Owens, 2009). Complex systems usually have different components which interact both directly and indirectly and are also socially complex with numerous stakeholders who often have conflicting goals (Owens, 2009)

The traditional 'normal' scientific paradigm can make effective use of scientific methodology designed for controlled experiments however they are ill suited for the complex science-related problem we face today. The traditional scientific paradigm fosters expectations of regularity, simplicity and certainty in managing phenomena rather than addressing complexities and uncertainties by continuous learning (Halbert, 1993). This is however not to say one should do away with conventional science and mathematics in order to embrace complexity theories

In recent years, significant attention has been given to challenges relating to science and policy integration in the sense that scientific predictions are growing faster than our understanding of ecological systems which results in a gap between the scientists generating the predictions and the environmental managers using them (Mouquet *et al*., 2015). There has been a need to improve the link and communication between science, management and policy in order to enable improved environmental decision-making (Leenhardt *et al.,* 2015).

Many agencies are now adopting a more ecosystem-based management approach (Leenhardt *et al.,* 2015) instead of the traditional scientific method. This shift can be attributed to the necessity of improving the link and communication between science, management and

policy, where uncertainty and complexities place a limitation on effective decision-making (Leenhardt *et al.*, 2015) and the contribution of science to management.

This comprehensive approach involves multiple disciplinary perspectives, multiple objectives, and a growing concern with cause and effect over large spatial scales and long timeframes. A management approach that incorporates all of these aspects is called adaptive management, often referred to as "Learning by doing" (Holling, 1990).

The application of adaptive management has evolved over the years and can be traced back to ancient civilization. According to Falanruw (1984), the Yap people of Micronesia have been using adaptive management for many generations in order to sustain high population densities amidst the scarcity of resources (Stankey *et al*., 2005). Falanruw describes how the Yap people adapted to their environment by undertaking actions, observing and reporting the result through songs and story-telling and thereafter modifying their practices through rituals. Although Falanruw (1984) noted that the Yap people embraced the experimental nature of adaptive management, it is this very essential element that caused some reluctance to the application of adaptive management (Stankey *et al*., 2005). Nevertheless, by 1993, Lee (1993) had already reviewed case studies from the United States, Australia, Canada and the Mediterranean. Lee also noted the application of adaptive management from non-resource industries such as health care and criminal justice (Lee, 1993).

1.2 Defining adaptive management as a management tool

Holling (1978) and Walters (1986) defined adaptive management as an integrated and multidisciplinary method of managing natural resources. Gunderson and Holling (2002) go on to describe it as a process that allows management actions to be changed in relation to how well the systems respond in a specified desired state. Adaptive management is therefore adaptive because it acknowledges that due to constant change, humans will have to respond by adjusting and conforming. It also integrates the views and knowledge of the parties involved in order to achieve a common goal. An adaptive management approach requires that management not only be used as a method to achieve the objectives but also as a tool to enquire and learn more about the resources and system being managed.

Adaptive management is a form of structured decision making (SDM) for recurrent decisions made under uncertainty (Runge, 2011). Structured decision making is the use of decision-analytical tools to help natural resource management. It is the umbrella concept that covers a

broad set of decision problems (Gregory and Keeney, 2002). Along with adaptive management, other decision-analytical tools that fall under SDM include info-gap decision theory, multi-attribute utility theory, expected value of information and expert elicitation (Runge, 2011). The common thread that forms the basis of all these tools is a focused view of how decisions are constructed and the emphasis on value focused thinking (Runge, 2011).

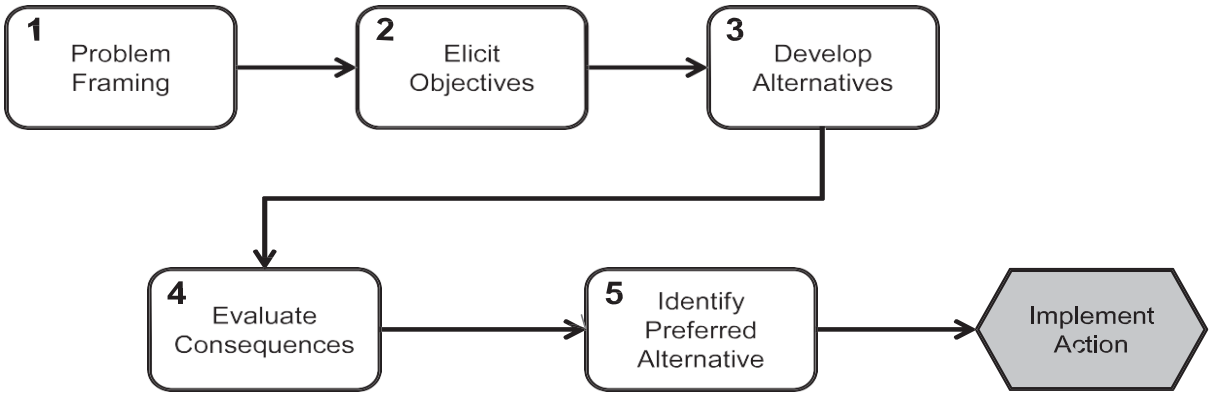

Figure 1: The core steps in decision analysis (Runge, 2011)

The core steps in a decision analysis (Figure 1) are 1) framing the context in which a decision is made, 2) drawing the objectives, 3) developing a set of alternative actions, 4) evaluating the consequences of the actions relative to the objectives, and 5) identifying the action that is expected to best achieve the objectives (Runge, 2011).

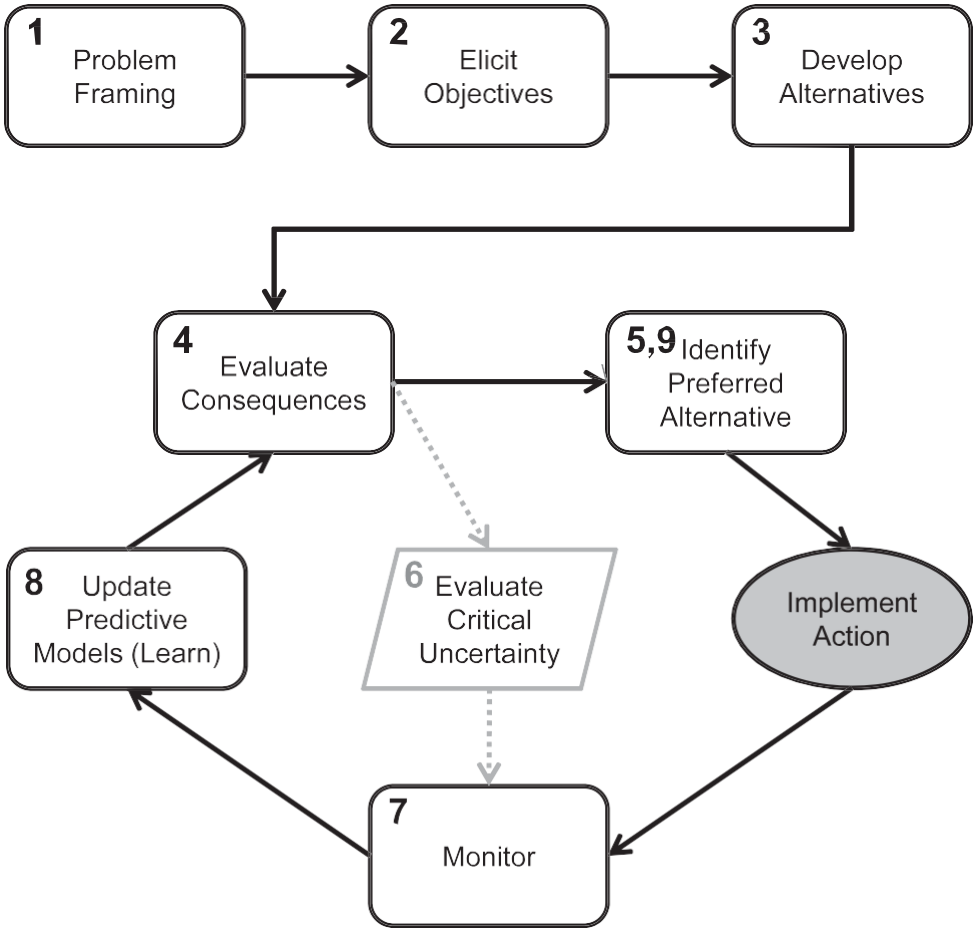

Figure 2: The core steps of adaptive management (Runge, 2011)

Ever since the introduction of adaptive management in natural resources systems, an essential feature has been the feedback loop between learning and decision-making (Williams and Brown, 2014). To the five core steps of SDM shown in Figure 1, adaptive management adds an additional four steps (Figure 2) which are: 6) evaluating critical uncertainty, 7) monitoring, 8) updating the predictive models based on ongoing monitoring information, and 9) adapting subsequent decisions based on the new understanding of how the system responds to management (Runge, 2011). In the absence of the additional four steps, a decision analysis framework does not distinguish between technical learning and social or institutional learning in a double-loop arrangement (step 4 to 8). By including an additional feedback loop as in Figure 2, both kinds of learning can be represented.

The core of adaptive management is that there are uncertainties relating to systems and that they will respond differently to various management actions, and this uncertainty hinders decision making. An adaptive management framework extends the generic SDM method by adding steps whereby those uncertainties are addressed (step 6, Figure 2) which includes the

description of alternative hypotheses, in the form of multiple predictive models (Runge, 2011).

In order to represent uncertainty, the multiple models must lead to different recommended actions. There is high value of information that manifests from resolving the uncertainty (Runge, 2011). Therefore, adaptive management is not restricted to the fact that future management will change as a result of information that accrues but rather, demonstrates and identifies what information is required and exactly how it will change future decisions (Runge, 2011). The different types of adaptive management; namely, incrementalism, passive adaptive management and active management are detailed in the literature review section

1.3 The complexities and uncertainties within the mining industry

The uncertainties within complex industries such as mining and agriculture are a product of the growing emphasis on long-term and multiscale issues, the increasing human population, an increasing concern for the environment (especially water), and a desire for more direct public involvement in management (Johnson, 1999). In the past three decades, there has been an increasing public awareness of the potential environmental dangers caused by mining activities, in particular acid mine drainage (AMD).

The impacts of AMD are challenging to predict due to the variability of discharge from adits, variation in adit strength and composition which varies seasonally. There are variations in how the effects of surface water runoff changes from exposed areas of the mines during heavy rainfall. In addition, the effect of the catchment discharge on the characteristics affecting dilution and the concentration of organic matter in the water chelating soluble metals constantly vary. Assessments are also difficult due to the complexity of the impacts (Gray, 1997).

The nature, uncertainties and complexity of the impacts of mining make it very challenging to rehabilitate or return the environment to its pre-mining state (Gray, 1997). Due to South Africa's geography and unstable politics, the effects that the discharge of acid mine water have could threaten future development and human security substantially. South Africa is a water scarce country therefore any potential threats to water security (industrial, potable and agricultural) should not be taken lightly. It is of the utmost importance that the aspects relating to AMD be well understood.

1.4 Background to the problem

The origin of acid mine drainage discharge in the Witwatersrand Basin

In 1886, gold was first discovered in the Witwatersrand basin (Werdmuller, 1986), a ridge consisting of gold deposits located mostly in the Gauteng province, South Africa (Figure 3). The ridge consists of a highland, which forms the watershed between the Vaal and Limpopo rivers and is approximately 100 km long and 37 km wide; its average elevation above sea level is approximately 1,700 metres (Whitefield, 2006). The Witwatersrand basin is divided into three distinct basins, namely the Eastern, Central and Western Basins.

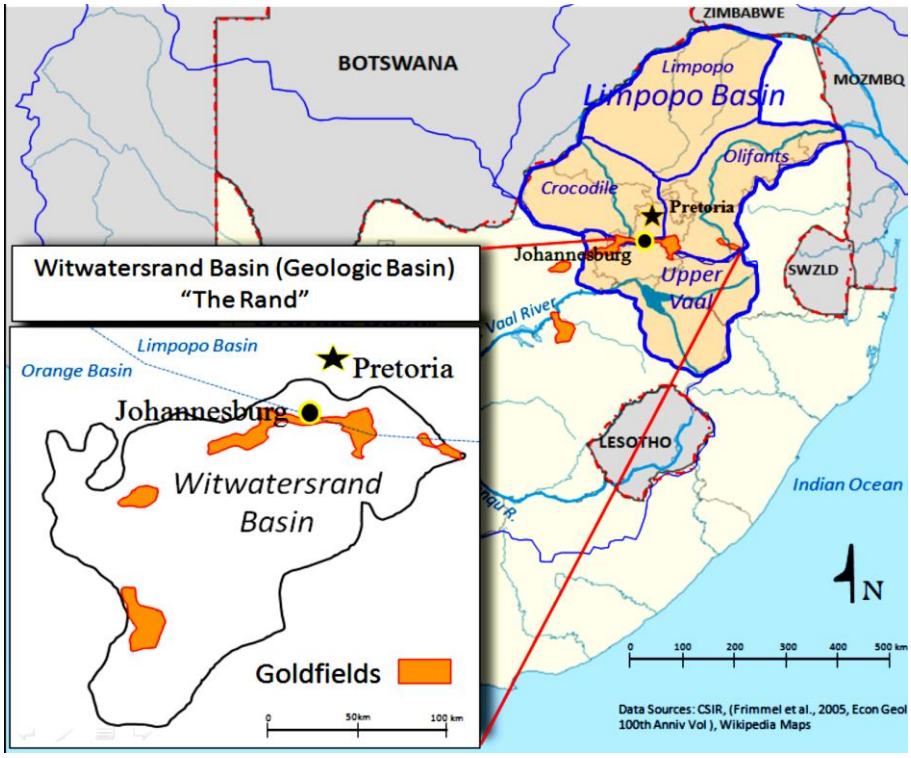

Figure 3: Location of the Witwatersrand Goldfields (Hanlon, 2012)

Soon after its discovery, gold was mined at an increasingly fast pace in order to drive the national economy in the Witwatersrand basin Gold mining soon became the cornerstone of South Africa's flourishing economy (Mathibe, 2011) until the 1960's when mining operations in the Witwatersrand reached maximum depths of 2500m below surface, thereby rendering the operations uneconomic (Naiker *et al.*, 2003) as they could not mine any deeper. This in turn led to the large-scale closures in the 1970's (Naiker *et al.*, 2003) which translated into the slow decline of the gold mining's economic power.

While the mines were still in full operation, water would be pumped out of the mine workings so that it would not block the access to the underground gold deposits. The economic decline caused by decreased profits in the 1950s led to the closure of many mining operations in the 1970's, which meant the pumping of underground water came to a halt due to the extremely high costs associated with it (Tapio *et al.*, 2012). This inevitably triggered a situation whereby the water (contaminated by the geochemical reactions between ore minerals, water and oxygen) flooded the mine voids to the point where the AMD could be visible on the surface (DWA, 2012 a).

As the mine voids containing pyrite refilled with oxygenated water, it triggered a process known as the acidification process of AMD (Tutu *et al*., 2005). The acidification process is when the mineral ore (i.e. pyrite) becomes exposed to atmospheric oxygen and water, and then forms sulphuric acid (pH of 2.5 to 4.0) which decants into the surrounding environment as AMD. Due to its toxicity and corrosiveness AMD causes ecological degradation to downstream areas (Figure 2) (Tutu *et al.*, 2005). The acidification process is illustrated by the reaction below: (Tutu *et al.*,2005)

$$FeS_2(s) + 7/2O_2 + H_2O \rightarrow 2SO_4^{2-} + Fe^{2+} + 2H^+$$

1.5 The decant of acid mine drainage in the Witwatersrand basin

Some environmental texts report that the decant of AMD had been occurring from as early as 1996 (Khumalo, 2011), but it was not until 2002 that government first recognised that this was a pressing issue. In 2002, the water contained in the Western basin began to decant, causing an uproar (Department of Water Affairs, 2012 b). This was partly due to the fact that acid mine water would flow into the Tweelopiespruit (van Eeden and Liefferink, 2009) and in turn affect the Crocodile River; the well-known Cradle of Humankind World Heritage Site (Hanlon, 2010) and the Wonderfonteinspruit, which ultimately feeds into the Vaal River catchment. In 2002, the pH of the water decanting from a borehole and mine shafts into the Tweelopiespruit was found to be 2.6 due to AMD contamination (Fourie, 2005).



Figure 4A: Water pumps at the Grootvlei Mine in the Eastern Basin prior to the cessation of pumping (du Toit, 2011)



Figure 4B: Hippos swimming in polluted water in the Krugersdorp Game Reserve (du Toit, 2011)

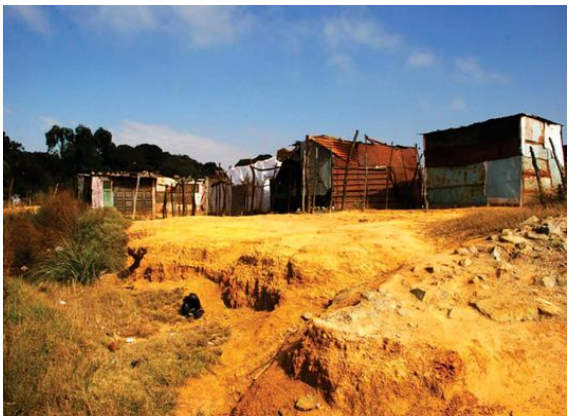

Figure 4C: Households within close proximity to tailing slopes in the Witwatersrand goldfields (du Toit, 2011)



Figure 4D: Acid mine water discharging into the Tweelopiespruit (du Toit, 2011)

Figure 4: The impacts of AMD in the Witwatersrand Basin

1.6 The impacts of the AMD decant

The discharge of acid mine drainage from abandoned mines has had detrimental impacts on aquatic and terrestrial ecosystems (Figure 4A and 4B) as well as many farming communities and informal settlements (figure 4C and 4D) (McCarthy, 2011; van Eeden *et al.*, 2009). Some surrounding communities (in western Gauteng and North West) that do not receive adequate provision of municipal water depend on groundwater resources for drinking and cooking purposes as well as watering livestock and irrigating crops (McCarthy, 2010).

Acid mine drainage pollutes water resources with toxic contaminants such as arsenic, iron, mercury, manganese, aluminium, nickel and uranium (Tutu *et al.,* 2005). Depending on the concentration and period and level of exposure, any of the metals can be toxic (Tutu *et al.,* 2005). The main toxin of concern released by the gold mining industry is uranium which is a carcinogen (Tutu *et al.,* 2005). Uranium has a very long radioactive life-span (Tutu *et al.,* 2005).

In cases where the water used for irrigation is contaminated by acid mine drainage, there is a potential for the bio-accumulation of the metals and naturally occurring radioactive materials (NORM's) to occur in edible plants which could lead to detrimental health impacts if consumed (Tutu *et al.,* 2005).

1.7 Solutions to manage the problem

The importance of finding a solution to the rising AMD and the need for inter-departmental cooperation led to the establishment of an Inter-Ministerial Committee (IMC) on AMD, comprising the Ministers of Mineral Resources, Water and Environmental Affairs, and Science and Technology, and the Minister in the Presidency: National Planning Commission (Inter-Ministerial Committee, 2010). A task team, chaired by the Directors General of Mineral Resources and Water Affairs, was appointed to advise the IMC on an intervention to mitigate the discharge of acid mine water in the Witwatersrand basin (Inter-Ministerial Committee, 2010).

The IMC (2010) proposed two sets of mitigation strategies, namely:

1. The short-term mitigation strategies for AMD
2. The long-term mitigation strategies for AMD

According to the report that was subsequently produced by the IMC, the short-term solution proposed was to neutralise acid water already decanting from the Western Basin. In addition, interventions included pumping water from the Central, Eastern and Western Basins in order to prevent surface discharge and to neutralise this water before its release into the environment (Inter-Ministerial Committee, 2010).

Following the approval of the IMC report on the findings of the Team of Experts, in 2011, the Minister of Water Affairs issued a directive to Trans-Caledon Tunnel Authority (TCTA), a parastatal organisation appointed to implement the short-term solutions for the treatment of

AMD in the Western, Central and Eastern Basins (TCTA annual report, 2013). Funds were then allocated to the Department of Water Affairs (DWA) (also known as Department of Water and Sanitation (DWS)) by National Treasury with the purpose of implementing some of the IMC recommendations, namely to (Inter-Ministerial Committee, 2010):

- Implement a strategy to pump the underground mine water to stay below the Environmental Critical Levels (ECLs)
- Investigate and implement measures to neutralise AMD
- Initiate a Feasibility Study to address the medium- to long-term solution

1.8 The short-term mitigation strategies for AMD

Due to water ingress in the form of rain, the water in the mine voids rose and reached the target operating level (TOL) and subsequently the environmental critical level (ECL) which triggered action from the DWA. According to the Technical Prefeasibility report it was at this point that the water quantity and quality of mine voids were determined as well as the technical management of underground AMD (Inter-Ministerial Committee, 2010).

The TCTA would then have to pump the water from the abstraction points closest to ingress points (as they would be less contaminated) to the treatment plants for neutralisation and desalination (Inter-Ministerial Committee, 2010).

Western basin:

It was proposed that AMD be abstracted from the Rand Uranium No. 8 Shaft in the Western Basin. The AMD would then have to be treated at a High Density Sludge (HDS) plant at Randfontein Estates and ultimately discharged into the Tweelopies Spruit, which leads to the Crocodile River (Inter-Ministerial Committee, 2010). At this point the pH and electrical conductivity (EC) of the water being discharged must not at any point exceed the parameters set by the DWA.

Presently, the treatment capacity of the upgraded Rand Uranium treatment plant has been used to discontinue the uncontrollable decant and the water quality of the Tweelopies River has improved. The construction of a new pump station to increase the pumping capacity has also been completed (Creamer, 2016).

Central Basin:

For the short-term mitigation strategy, AMD would have to be abstracted from the East Rand Proprietary Mines (ERPM) at South West Vertical (SWV) Shaft in Germiston. It would then have to be treated in an HDS plant and ultimately the neutralised water would be discharged at the Elsburgspruit which forms part of the Vaal River System (Inter-Ministerial Committee, 2010). As with the Western Basin, the pH and EC of the water being discharged must not at any point exceed the parameters set by the DWS (Inter-Ministerial Committee, 2010).

Presently, the HDS plant has ensured that the water level does not exceed the ECL. Additional funding is required to maintain a consistent underground water level at the Central Rand Gold Mine (Creamer, 2016).

Eastern Basin:

For the short-term mitigation strategy, pumps at the Grootvlei No. 3 Shaft would be used to abstract water so it can be treated at the HDS treatment plant near Grootvlei No.3.The neutralised water would then be discharged into the Blesbokspruit (Inter-Ministerial Committee, 2010).

The HDS Plant for the Eastern Basin was constructed in February 2017 and is said to one of the best in the world (TCTA, 2017)

Despite the completion of the short-term mitigation strategies, one of the biggest criticisms was that the water cleaned with gypsum crystallisation reduced the salts but did not remove them even though the pH was corrected, and metals removed. Hence the need for an additional strategy for the removal of salts from the water (Creamer, 2016). Following the assessment of all the options, the preferred method was modelled into a feasibility study to inform the long-term mitigation strategy.

1.9 The Long-term mitigation strategy

Subsequent to the implementation of the short-term mitigation strategy to prevent the breaching of the ECL at all three basins by the TCTA, on the 18th of May 2016, the Minister of the DWS signed off on the launch of the long-term mitigation project to convert AMD into safe water (Creamer, 2016). The long-term mitigation project will involve the removal of salts by either reverse osmosis or desalination technology in order to extract the salts that the

short-term mitigation strategy left in the water (Creamer, 2016). Thereafter the water is intended to be used commercially as either industrial or potable water.

The recovered water is planned to increase the water supply capacity of the Vaal River system and therefore set to be on par with the going potable water tariff, which it however presently exceeds (Creamer, 2016). Seeing that the long-term mitigation strategy will cost approximately 10 billion rands to implement, it would also allow the recovery of gypsum which can be sold to create a revenue stream from the sale of clean water (Creamer, 2016).

An Environmental Impact Assessment for the long-term mitigation strategy was scheduled for June 2017 in order for construction to commence in January 2018, reach commissioning in November 2019 and become operational in February 2020. As of 218, the EIA has not commenced. With the desperate need to increase the water supply to the Vaal River System, the TCTA will have to accelerate the implementation of the project.

1.10 Problem statement

The South African mining sector has, apart from exceptions (such as technology development), embraced few efforts to adopt diversity in terms of encouraging multidisciplinary sets of ideas for management. Instead there has been a strong drive toward standardization and consistency, which has been very effective in achieving goals to some degree, however some factors that make this approach futile include environmental accountability, complexity and an increase in humanity awareness.

Acid mine drainage is a significantly costly environmental impact of the mining industry worldwide. In the Witwatersrand basin, the distribution of abandoned mines and widespread contamination of water and ecosystems caused by AMD presents a complex multi-dimensional and social-ecological issue which is also multi-scalar (Gray, 1997). The impacts of mining have a temporal issue with past, present, and more and future impacts which may together lead to challenges with regards to legislative and governance interventions. AMD has the potential to occur in perpetuity, and the long-term socio-economic and environmental impacts will continue long after those mining activities that led to its creation have ceased (Gray, 1997).

Following the announcement of the short-term mitigation intervention, many believed that they were reactive and ‘a little too late to solve a problem that manifested over a decade ago’

(Turton, 2009; Bobbins, 2015). The question that stands is whether the mitigation strategies have been adequately informed to enable the government to manage the problem.

1.11 Rationale

Despite the legacy of gold mining in South Africa, the emphasis on more sustainable management solutions has been inadequate. While many studies have focussed on the impacts of AMD decant, few have dealt with the management strategies (Hanlon, 2010; Inter-Ministerial Committee, 2010).

No empirical research exists, which measures and assesses the adaptive capacity of the systems that has been put in place to address the decant of acid mine drainage in the Witwatersrand based on the work of C. S. Holling (1973). In addition, no study has aimed to address the complexities and uncertainties of adopted management strategies for AMD.

Most literature that has been published for the purpose of introducing management strategies is either too technical or fails to address the economic and social aspects of management. Considering the nature of impacts caused by the discharge of AMD decant, the outcomes of current and future actions need to be well understood and well-managed to avoid history repeating itself and to close the gap between science and management through learning.

Despite the prediction of the impacts from mining over the last 120 years, the abundance of international and local literature on all aspects of acid mine drainage indicates the great extent to which it is has been researched (Inter-Ministerial Committee, 2010), however it is clear that the linkages between the social-ecological complexities remain weak. Interestingly enough, in other countries, mine flooding was planned to minimise impacts, while in South Africa this has not been done and, in many cases, this would not have been possible owing to closure of older mines within a basin long before flooding was contemplated (Inter-Ministerial Committee, 2010).

According to the Inter-Ministerial Report (2010), the key factors which differentiate the AMD problem in South Africa from the international examples cited in the section above, are how the voids are interconnected, the sheer scale of the Witwatersrand operations and the fact that many of the problem areas are located close to urban centres, posing both environmental and socio-economic impacts. All of these factors necessitate the implementation of comprehensive and long-term programmes to address the problem of acid mine drainage

International experience has revealed that a number of factors that lead to the successful implementation of programmes dealing with mining legacies, such as AMD include:

- The acknowledgement that there is a problem that it needs to be addressed in a multi-disciplinary fashion;
- Decisive action will need to be taken by the government to secure and provide funding
- Ongoing research and learning to develop appropriate and sustainable solutions (Inter-Ministerial Committee, 2010);

Furthermore, the IMC recommended that the management of the decant of AMD takes a more adaptive approach, in other words, a more structured way of 'learning by doing' (Inter-Ministerial Committee, 2010).

The sound understanding of how systems work; why they could collapse and the need for high quality information are important factors when deciding which management approach should be adopted. "*Ecosystems and the people whose fates are intertwined with them form inherently complex systems that display periods of stability and instability, as well as unexpected behaviour due to a variety of factors. The periods of predictable and unpredictable behaviour suggest that humans are likely to be always searching for understanding in these complex resource systems" (*Gunderson, 1999 a p. 32)?

Re-evaluating the management of the discharge of acid mine drainage in a framework of sustainable development and adaptation (as recommended by the task team in the Inter-Ministerial report) can in part, resolve these dilemmas. There is also a critical need to improve how research is incorporated into management decisions where uncertainty places limitations on contributions of science (Reynolds *et al.*, 1996).

This study recognizes that sufficient understanding within and among complex biophysical, social-economic-political systems require an emphasis on new knowledge by adopting adaptive management strategies.

1.12 Purpose of the study

1.12.1 Aim

Given the growing rates of change in social-ecological systems as well as the uncertainty and complexity of the causes and impacts of acid mine drainage, this study aims to explore the link between management and science by assessing the extent to which an adaptive management approach (or if any) has been incorporated into the short-term and long-term strategies for the discharge of acid mine water in the Witwatersrand Basin.

1.12.2 Research objectives:

1. To identify and describe the elements that constitute an adaptive management strategy
    - Research question 1: From literature, what are the most common and important elements that constitute an adaptive management strategy?
2. To investigate whether there has been any traction, for an adaptive management approach in the short term and long-term mitigation strategies for AMD decant in the Witwatersrand Basin
    - Research question 2: To what extent have the elements of adaptive management been incorporated into the mitigation strategies for AMD, according to:
        - The DWS policy documents detailing the short-term to long-term mitigation strategies?
        - The perception of experts in the field of managing acid mine drainage as well as key informants who advised the IMC on the mitigation of AMD decant on the Witwatersrand basin?
3. To determine whether adaptive management would be a better approach for the mitigation of AMD discharge in the Witwatersrand basin in comparison to the current management approach (short-term and long-term mitigation strategy)?
    - Research question 3: How will adaptive management improve the mitigation of AMD decant in the Witwatersrand Basin?

2. Literature Review for the overall study

This chapter is aimed at exploring the different literatures and views on the management of acid mine drainage and adaptive management. It enlightens on past and current research in both these fields and further affirms the motivation of this study

2.1 Paradigms of management

In the natural world, two paradigms of management are dominant, namely the traditional and ecosystem management approaches. These two forms of management are distinguished by the law, principles and instrumentation that they are fundamentally based on. As noted in the introduction, the traditional management approach has increasingly become subject to criticism due to falling short in its capacity to deal with complex systems (Halbert, 1993). The underlying operational assumptions, organizational structure, and methods of operation of an ecosystem approach stand in stark contrast to the traditional approach (Table 1).

The traditional paradigm for environmental management is characterized by clarity and simplicity and relies on the ability to resolve problems through rational, quantitative and ordered means (Halbert, 1993). Traditional management rarely acknowledges uncertainty as it is often assumed that the policy is correct therefore it is not tested (Halbert, 1993). The ecosystem approach however acknowledges that the knowledge of ecological systems is not only incomplete but elusive (Walters and Holling 1990) because the information obtained through traditional scientific inquiry will always be limited by resources and time (Halbert, 1993). This however should not discount the value and contribution that the traditional approach has had in developing natural resource management.

The ecosystem-based approach explicitly recognizes uncertainty and emphasizes the role of ongoing monitoring and evaluation as the foundation for learning. This learning can be fostered by adaptive management (Halbert, 1993).

Table 1: Comparison of the two paradigms for management (Cortner and Moote, 1999)

Comparison of traditional resource management and ecosystem management		
	Traditional management	**Ecosystem management**
Nature	The process must be dominated and mastered	Ever-changing, interrelated and complex
Ethics	Compartmentalised, interrelations are kept marginal	Holistic, interrelations are deemed important
Science and models	Consistent and determined to manage status quo, linear and deterministic	Non- linear, sudden shifts occur, stochastic, non-linear, variable rate dynamics, learning from failure is acceptable
	Robust, well- defined theory, discrete and highly predictable data	Always developing, theory and practise is intertwined, interrelated data and unpredictable results
	Maps, linear optimisation, monetised cost-benefits analysis, quantitative	Geographic information systems (GIS) relation database, qualitative evaluation for social, economic and political aspects
Management and organisation	Rigid, little focus on incentives and innovation	Interrelated teams, adaptive, flexible, focus on incentives, innovation and shared learning
	Hierarchical, top- down bureaucracy approach	Adaptive, bottom-up, co-operative and open
Planning	Comprehensive, rational and neat	Interrelated, chaotic, experimental
Decision- making	Rigid, command and control, expert driven, science provides the answer	Deliberated, inclusive, science provides information however alone it does not provide the answer

2.2 Linking science to management

According to Jacobs *et al.,* (2005) scientific information to be used in a decision-making process should be:

- Relevant to the management question(s) at hand in order to answer them
- Understood and accessible to policy makers
- Reliable and accurate
- Usable
- Provided well in time in order to be incorporated into the management strategy (see also Jacobs *et al.,* 2005).

Despite the above, in normal science, research is usually separated from actual management (Halbert, 1993) and there is rarely any explicit procedure illustrating how emerging science is used to influence management or decision making.

2.3 How adaptive management incorporates science into management

The two distinguishing characteristics of adaptive management that set it aside from other types of management such as trial and error or traditional science are:

1. A direct loop that is established between management and science which allows for management policies to be modified and improved upon generating new scientific information (Holling, 1978; Walters, 1986; Lee and Lawrence, 1986).

2. Management strategies are regarded as experiments. Managers have to explicitly test the management regime that thy have decided to implement. This allows for newly learnt information (Holling, 1978; Walters, 1986; Lee and Lawrence, 1986).

3. Evaluation and monitoring that established a link between science and management by formalising the learning process and is often referred to as experience (Oliver *et al.,* 1992). The feedback part of monitoring is what changes it from mere data collection to becoming a vital link within the adaptive management cycle (Williams and Brown, 2014; Salwasser *et al.,* 1983). Feedback can be categorised as either single-or double loop learning. In single loop learning, the goals are evaluated whereas with the double-loop learning, the results are used to change the policy and objectives (Halbert, 1993).

2.4 Types of adaptive management

There is a notion that adaptive management is simply the use of information as it becomes available in order to modify management. According to Williams (2001), adaptive management has proved to be a difficult concept to define and understand. The term 'adaptive management' is used often in South Africa but the implementation thereof seldom tests assumptions systematically. It is generally "trial and error management" and is not really adaptive at all (South African National Parks, 2005). The two different types of adaptive management are described below:

2.4.1 Passive adaptive management

Incrementalism is analogous to the concept of passive adaptive management. Bormann *et al*. (1999) described it as learning which relies on the use of historical data to develop a single approach along a linear path that is assumed to be correct. This means there is a belief that the historical assumptions and conditions that were applicable in the past still prevail. Passive adaptive management can be informative (Walters and Holling, 1990; Williams, 2011).

Two problems limit passive adaptive management approaches: Firstly, the approaches can cause confusion in term of management and environmental effects because it can be indistinguishable whether observed changes are due land management practices or to changes in environmental factors (such as global warming) (Walters and Holling, 1990). Second, the analyses can fail to detect opportunities that should be utilised to improve the performance of a management strategy (Walters and Holling, 1990).

2.4.2 Active adaptive management

Active adaptive management is the second model. It differs from passive adaptive management in its purpose to incorporate experimentation into policy and management (Lee, 1993; Williams, 2011). In other words, policies and management activities are treated as experiments and opportunities for learning (Lee, 1993; Williams, 2011). Active adaptive management is designed to provide feedback on the relative effectiveness of alternative models and policies, rather than focusing on the search for only one model (Lee, 1993; Williams, 2011).

2.5 The core components of adaptive management

Overall, there are two dominant schools of thought in adaptive management (Table 1):

- The resilience-Experimentalist Adaptive Management School originating from the work of Gunderson *et al*. (1995);
- The Decision-Theoretic Adaptive Management School illustrated by (Williams *et al.*, 2007).

The main constituents of adaptive management have been emphasised differently in literature. A comparison of nine adaptive management related variables sourced from adaptive management literature as well as the order in which they are sequenced in each decision making method is summarised in the Table 2 below and then discussed.

Table 2: Characteristics of adaptive management and a comparison of the manner in which they are prioritised in literature

Adaptive management methods (McFadden, 2011).					
Element	**Gunderson's *et al.*, (1995)**	**Possingham (2000)**	**Collaborative Adaptive Management Network (2004)**	**Williams *et al.*, (2007)**	**Sustainable Ecosystems Institute (SEI) (2007)**
1. Emphasises stakeholder involvement	Yes, entire process	Yes	Yes, entire process	Yes, for objectives	Yes. Entire process
2. Well defined objectives	Yes	Yes	Yes, key decision points	Yes	Yes
3. Stipulated multiple alternatives	Yes	Yes	Yes	Yes	Yes
4. Predicts consequences	Yes, competing hypotheses and models	Yes, part of the decision making protocol	Yes, rarely predictive	Yes	No
5. Specifies constraints	Yes, specifically policy	Yes	Yes	Yes	Yes
6. Acknowledges uncertainty	Yes	Yes	Yes	Yes	No
7. Emphasis explicit experimentation	Yes	No	Yes	Yes	Yes
8. Monitoring	Yes	Yes	Yes	Yes	Yes
9. Emphasises active learning	Yes	No	Yes	Yes	No
10. Order of elements when planning and implementing the strategy	1,4,5,2,3,4,6,7, 8,9	2,3,5,6,4	1,2,4,6,7,8	2,3,4,5,6,7,8	1,2,3,5,7,8

2.5.1 Stakeholder involvement

A very important step in applying any adaptive management strategy is to involve the appropriate stakeholders. Involving stakeholders in discussions at an early stage highlights different stakeholder values, priorities, and perspectives. Stakeholders are able to directly influence both decision making and learning (McFadden, 2011).

The involvement of stakeholders differs in the adaptive management field because adaptive decision making does not prescribe the number of stakeholders that should be involved, who

they should be and how they should be prioritised or arranged. It is the researcher's opinion that this is what leads to disagreements about whether the stakeholder is sufficient or not. In some cases, a few managers and decision makers may work directly with each other and the resource. In other cases, a large number of stakeholders such as scientists, managers, regulatory organisations and civil society may engage in a highly structured and organised way.

Common stumbling blocks of adaptive management include the failure to have meaningful stakeholder engagement and disagreement about the resource problem, its objectives and management alternatives. According to Williams *et al.* (2009), in order to be successful, an adaptive strategy must ensure that stakeholders have both the capacity and sufficient incentives to participate. A research project that analysed and evaluated 105 'ecosystem management' efforts found that the involvement of participants is the single most important factor behind success (Yaffee, 2002).

Table 3: Armstein's ladder of participation (Armstein, 1969)

Armstein's ladder of public participation		
Level 1	Manipulation	Deceitfully give partial or construed information to persuade an assumed passive audience
Level 2	Education	Provide information arbitrarily
Level 3	Information	Inform audience of the past, status quo and what is going to happen
Level 4	Consultation	People are given a voice nut no guarantee that their views will be considered
Level 5	Involvement	People are given a voice but no guarantee that their views will be considered
Level 6	Partnership	People negotiate with decision makers over role and shared responsibilities
Level 7	Delegated power	Power is partially delegated
Level 8	Citizen control	Fully delegating actions and decision making

Armstein (1969) prescribed levels in which stakeholder engagement could be assessed (Table 3) whereby the degree of stakeholder empowerment obtained from participation can shift from no engagement (being dictated to) through to increasing levels of participation (delegation of all decision making), which emerges from a shared understanding of a complex problem.

2.5.2 Setting clear goals and objectives

An objective is a desired outcome that can be applied to processes (e.g., peak stream flow) and states (e.g., population size). To be useful, objectives need to be clear, specific, compatible, agreed upon and measureable within a recognizable timeframe (Williams *et al.*, 2007).

Objectives for management strategies are often stated in such a generalised manner that it becomes very challenging, if not impossible to measure whether the management actions are meeting the objectives (Walters, 1986). It is imperative to have specific performance measurement so that management is not to be reduced to a trivial academic discussion (Baskerville, 1985).

Setting and agreeing on clear goals is required from the outset in order guide decision making and measure progress, hence the importance of stakeholders' participation right in the beginning of the process. Stakeholder involved in the planning process should have his or her own ideas of how to develop strategies to achieve the objectives, based on their knowledge and values derived from past experience and education. Separating and distinguishing knowledge from values is a crucial step in adaptive management, because it allows knowledge to be examined and improved.

2.5.3 Predicting the future through modelling

Models play a role in illustrating uncertainties in a system and how they would likely respond to management actions (Table 2). According to Meffe *et al.,* (2002) there are three sources of uncertainty and complexity in ecosystems that greatly affect management decisions and a manager's ability to achieve a set of desired conditions (Meffe *et al.,* 2002):

- Environmental uncertainty
- Biological uncertainty
- Non-independence of events and interactions (Meffe *et al.,* 2002).

In adaptive management uncertainty can represented by multiple hypotheses about system structure and functions (Stankey *et al.,* 2005). The hypotheses can then be illustrated different models that forecast resource changes in response to the different management actions. The evidence will show the differences in the competency of each model in characterizing resource dynamics (Stankey *et al.,* 2005).

2.5.4 Management alternatives

Adaptive decision making involves selecting a management action at each decision point of a process, based on the status of the resource at the time (Stankey *et al.,* 2005). The managers and relevant stakeholders, usually working with scientists, must identify the set of potential actions which should be considered (Stankey *et al.,* 2005).

Alternative management actions are important elements of an adaptive management because they produce distinguishing patterns of system responses. If that does not take place, then adaptive management will be less useful in producing effective and informative strategies (Stankey *et al.,* 2005).

2.5.5 Monitoring of progress

Monitoring is another core element of adaptive management (Table 2). Monitoring provides data for four key purposes (Williams *et al.,* 2007):

1. To evaluate the progress toward achieving project objectives

2. Determining and identifying the status of the resource

3. Learning about resource dynamics

4. Developing and updating models of resource dynamics in order to adapt accordingly

Monitoring can however be constrained by a lack of budget, capacity or when the frequency of monitoring cannot keep up with the changes in the natural system. This eventually leads to an insufficient understanding of the resource system and then learning is retarded (Williams and Brown, 2016).

As mentioned in the introduction, monitoring is the most important factor for incorporating learning in adaptive system as it enables a feedback loop (Williams *et al.,* 2007).

2.5.6 Acknowledges uncertainty and complexity of systems

As previously mentioned, uncertainty forms part of the need for adaptive management because surprises are in inevitable in processes that characterise ecological and socio-economic systems. By definition, uncertainty involves situations in which the probability distribution is not known.

Holling points out that we may be led astray by some ideas about ecosystems and how they are characterised because they have not been based on a sound understanding (Holling, 1978). He stresses that this has led to unnecessary efforts being put into the wrong kind of analysis. He also adds that contrary to popular belief, bigger data systems that are based on uncritical information do not imply better data if the aim is to contribute to decision making

2.5.7 The treatment of management actions as experiments

As mentioned earlier, active adaptive management treats all management actions as experiments. This is especially important, as it provides better information for the long term, more especially where nature does not provide natural disturbances (Halbert, 1993). Unfortunately, as with most countries, more especially developing ones such as South Africa, there is a trade-off in trying to balance the cost of managing future uncertainties vs. the cost of maintaining the status quo without incorporating experimentation.

Although monitoring and evaluation are useful for describing the status quo and determining whether certain management objectives are met, they do not describe why a particular policy worked or did not work. In other words, they do not determine causality; therefore, it becomes imperative to incorporate experimentation. Policy makers require more than just descriptive information; they need to know how well one policy will work as compared to the other (Halbert, 1993).

2.6 Recent thinking on the challenges of adaptive management

Adaptive management has evolved tremendously over the years into being a legitimate and useful paradigm to be implemented for natural resource decision making (Owens, 2009; Williams and Brown, 2016). Advances in decision analytic theory since the work of Holling's (1978) early studies of adaptive management of natural resources have led to a proliferation of applications (Williams and Brown, 2016; Williams and Johnson, 2017).

The recent developments of the adaptive management framework and processes (based on prior literature) allow it to better characterise and reduce uncertainties. However, with the ever-changing attribute of landscapes, the climate, culture values and accelerating biodiversity loss creates new challenges for the implementation of adaptive management. Most of these challenges are generic to the 21st century; however, adaptive management provides a suitable model and context for addressing many of these problems, in fact, in most cases it may be the only solution (Williams and Brown, 2016). A critical challenge for an adaptive framework is to be able to address a large number of decision problems and yet be flexible enough to be applicable to the details of any particular problem. To stray true to its name, the adaptive management paradigm will require adjustments in order to accommodate these new issues (Williams and Brown, 2016).

As with any other management strategy, adaptive management is not exempt from challenges or barriers which may cause delays in its implementation or even cause it to fail. In this respect, identifying probable barriers and establishing solutions to deal with such barriers, often in the form of alternatives, helps to ensure that the implementation process runs relatively well.

A review of some technical challenges (Williams and Brown, 2016), barriers and possible solutions (British Columbia Ministry of Forests and Range, 2008) for the application of adaptive management have been identified in Table 4:

Table 4: Constraints, challenges and respective solutions for the implementation of adaptive management (British Columbia Ministry of Forests and Range, 2008; Williams and Brown, 2016)

Barrier or technical challenge	**Solutions or alternatives**
Funding and costs required for adaptive management	Identify designs and monitoring schemes that offer good trade-offs between cost and effectiveness
	Use volunteers or students for smaller tasks or tasks such as data capturing
	Use cheaper monitoring and measuring techniques
	Identify and formulate partnerships where the sharing of costs is likely
Problems associated with designing and conducting large experiments	Consider alternative methods and designs that may seem less ideal but can still be applicable as solutions Use other sources of knowledge to help interpret results (e.g., local knowledge)

Barrier or technical challenge	**Solutions or alternatives**
Reluctance stemming from the risk of experimenting with critical ecosystems:	Consider that passive approaches may be less risky than active approaches in some circumstances
	Conduct risk assessment for test plots first
	Monitor indicators that respond quickly to change due to their sensitivity
	Realise that the consequences of managing in continued ignorance is also high
Maintaining transparency, good staff and funding	Establish and maintain good documentation, ensure the accessibility of information and communicate the results and knowledge gains
	Generate local support
	Maintain continuous staff training
	Design plans to make provision for shortage of funding
Regulatory and institutional inactivity	Establish responsibilities and commitments right in the beginning
	Ensure good on-going communication between the decision makers, managers, scientists, all those who are involved in the implementation of the strategy; those who evaluate the strategy and other relevant stakeholders
	Delegate decision-making authority to those as close to the ground as possible
Fear of altering plans or poor understanding of how to implement plans	Involve the operational staff and/or contractors who are meant to be implementing the strategy in the assessment and design phases
	Prepare for potential pressures that may arise to alter plans and agree on response
Fear of making mistakes	Emphasise that we learn from our mistakes and reward learning and innovations in performance evaluations
The frequency of monitoring may not be able keep up with changes in the natural system.	Integrate monitoring into the management framework (from the initial panning phase) in such a way that it is regarded as critical and not optional.
There may not be a firm commitment to funding and institutional support for monitoring for the duration of the learning effort	
Dealing and managing uncertainties caused fluctuating environmental conditions and management conditions	Identify the uncertainty about resource status explicitly with probabilities for possible resource states, and incorporate them directly into planning and the decision-making process

Barrier or technical challenge	Solutions or alternatives
Establishing an appropriate scale for decision making. An adaptive management plan often has institutional and ecological linkages across large landscapes with high degrees of heterogeneity.	To plan and develop decision making that can accommodates for larger and smaller scales to address scale specific issues

Striking a balance between short-term costs and long-term benefits can also be a challenge since any benefits that come about the manipulation biophysical systems will most likely not appear immediately, their costs, however are paid for by today's individuals and organisations (Stankey *et al*., 2005).

2.7 Adaptive management in the mining industry

In the 1990's, the South African National Parks (SANParks) formally adopted an adaptive management paradigm in the form of strategic adaptive management (SAM) in the Kruger National Park (Biggs *et al*., 2011). Sustainability at the Kruger National Park has employed an adaptive management approach that links monitoring to management, incorporates the amalgamation of scientific and local knowledge, and allows for flexibility for the governing of resource use.

SanParks uses an adaptive management approach to change indicators to monitor trends in resource use. But instead of using fixed targets, SANParks measures sustainable resource use against thresholds of potential concern (TPCs) which allows for a certain amount of ecosystem change brought about by resource use. As a result, the TPCs create a feedback loop between monitoring and management whereby undesirable changes to ecosystems are detected early and informed management interventions are prompted to promote cyclical learning (Scheepers *et al.*, 2011). The adaptive management plan also incorporates active involvement and support of all stakeholders to maintain the effective monitoring of sustainable resource use (Scheepers *et al*., 2011). As a result, the application of adaptive management has spread to other protected areas and other natural resource management (Biggs *et al*., 2011).

Unlike the Kruger National Park, the mining industry is not as widely known for implementing adaptive management. The cycle of adaptive management described by the pioneers of adaptive management, as shown below Figure 5 is different to what is depicted as an adaptive management framework in the mining industry (Figure 6 and Figure 7)

Adaptive management within the two mining related cases seem to be more of a "checking and correction action plan" and less of a value-based approach with little influence on learning and adapting.

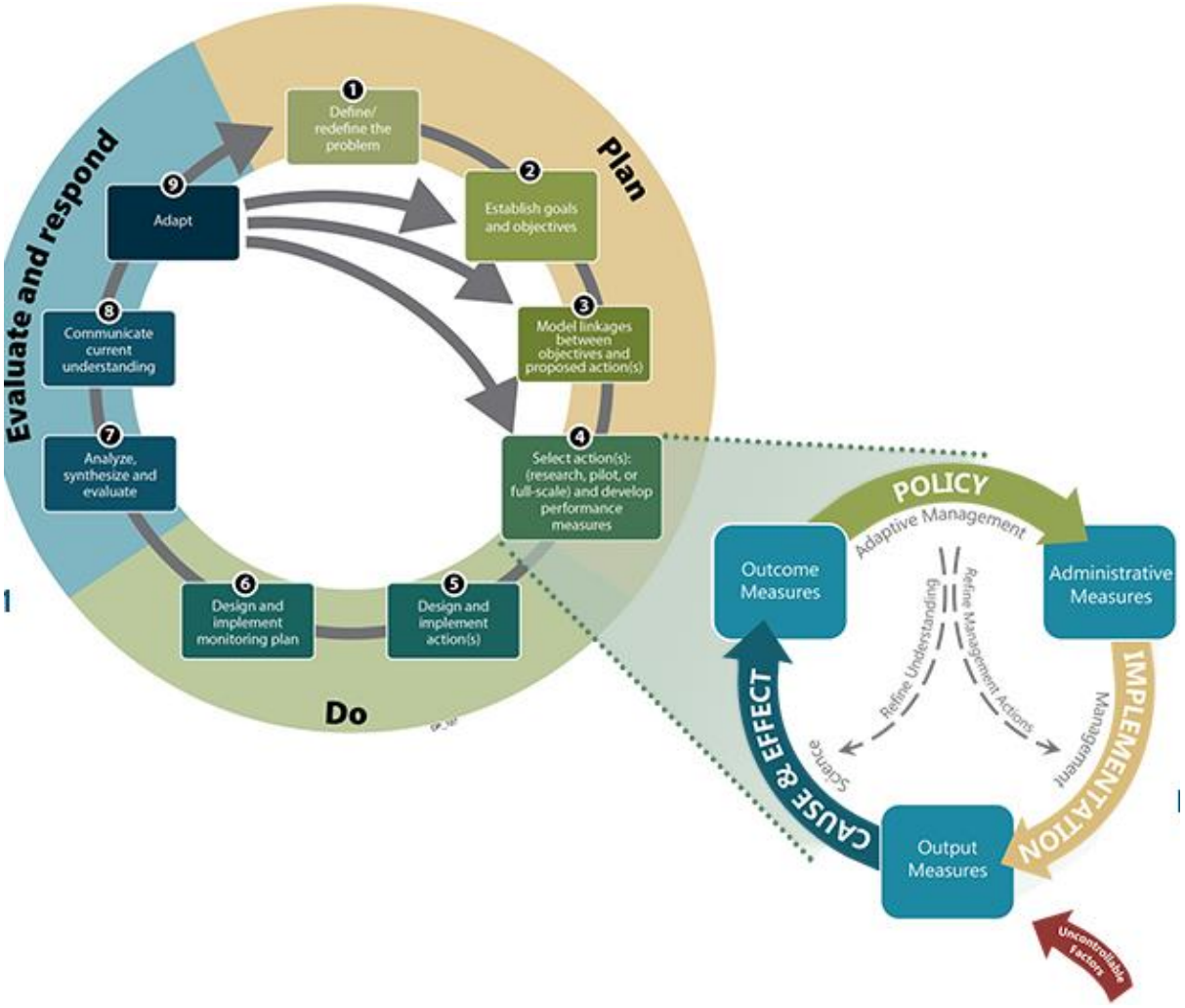

Figure 5: The adaptive management framework derived from the work of Gunderson and Holling (2002).

In Figure 5, the shading represents the three broad phases of adaptive management (Plan, Do, and Evaluate and Respond), and the boxes represent the nine steps within the adaptive management framework. The circular arrow represents the general sequence of steps. The additional arrows indicate possible next steps for adapting (e.g., revising the selected action based on what has been learned). This framework and the description of each step are largely derived from Stanford and Poole (1996).

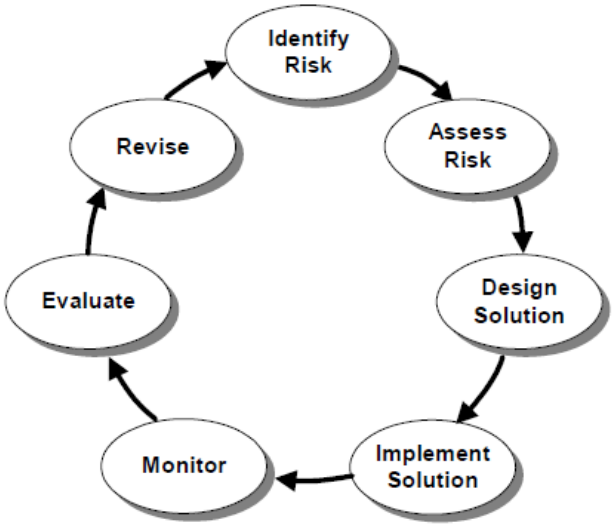

Figure 6: The adaptive management framework used for the De Beers Snape Lake Diamond Project (De Beers, 2004).

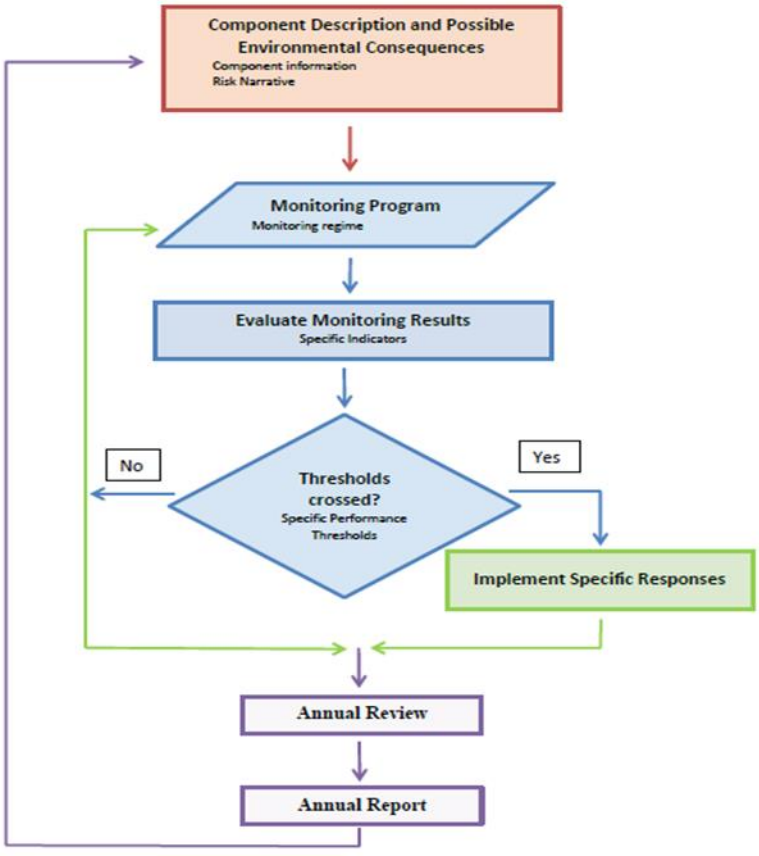

Figure 7: The steps and components of the adaptive management plan used for the Minto Mining Operation in Yokon, Canada (Minto Explorations Ltd, 2016).

The adaptive management framework and management used for the latter management plans (Figure 6 and Figure 7) differ from the typical (and more comprehensive) practice of adaptive management because it views adaptive management as a risk assessment tool as opposed to experimental learning. Moreover, the adaptive management frameworks only use a one-solution approach, which translates into the incorporation of passive adaptive management rather than an active form of adaptive management.

As mentioned earlier, passive adaptive management is the implementation of one management treatment that is believed to be best, whereas active adaptive management considers the implementation and comparison of several treatments or management action actions as experiments (Bormann *et al.,* 1999, Stankey *et al.,* 2005, Gregory *et al.,* 2006). Thus, the steps outlined in the above planning documents (frameworks for the De Beers Diamond Snap lake project and the Minto Mining Operation) do not reflect those of a typical adaptive management process.

The other characteristic of the two adaptive management frameworks at the mines is that they both depict a "monitor, note and respond to unexpected and monitor again" approach. As noted by Walters (1997) adaptive management is about more than just responding to unexpected events and monitoring. The elements of experimentation and alternative actions and explicit predictions of outcomes are also lacking from the adaptive management frameworks.

2.8 AMD decant in the Witwatersrand Basin: Policy review

2.8.1 The work undertaken by various institutions to inform the mitigation strategies for the decant of AMD in the Witwatersrand

Prior studies were conducted in the Witwatersrand basin to determine the cause of the resulting AMD issues. All studies revealed that there were serious environmental challenges that led to the decant of AMD in the Western basin in 2002 as well as possible decant from the surrounding area. According to the Inter-Ministerial committee (2010), management solutions are two-fold, namely, the management of flooding from the mine void and secondly, management of the treatment of AMD.

The work conducted included specialist studies conducted by/on behalf of science councils such as the CSIR and Mintek, government departments such as the Department of Water and

Sanitation, universities and other organisations such as the Water Research Commission (WRC) (Inter-Ministerial Committee, 2010).

The nature of work contained in the Inter- Ministerial Report is sourced from research projects and post-graduate studies from various universities, report for projects that may or may not have been funded by the government and may or may not be available in the public domain, private work done for commercial projects as well as reports produced by consulting companies.

From the 54 WRC-funded projects that had been conducted on acid mine drainage, the topic of the flooding of the Witwatersrand basins had only been mentioned in few instances (Inter-Ministerial Committee, 2010). Information regarding the flooding of the Witwatersrand Gold Mines was collected by the Council of Geoscience (2004). The work was obtained to inform solutions to managing the water ingress and decant of AMD as well as to propose remedial actions.

According to the IMC (2010), the only available guiding document regarding the regulatory and institutional arrangements for the management of AMD are limited to the Global Acid Rock Drainage Guide however, several guiding documents have been developed such as the Best Practice Guidelines for Water Resource Protection in the South African Mining Industry.

2.8.2 Uncertainties and knowledge gaps

There are uncertainties relating to the risk that rising water could have on the reactivation of solution features in dolomite which may result on sinkholes (Inter-Ministerial Committee, 2010). Although a study was conducted for the Management Authority of the Cradle of Humankind World Heritage Site, it has been recommended that further studies be conducted (Inter-Ministerial Committee, 2010).

Furthermore, available information regarding volumes and quality of waste water is very limited; however, it suffices to point out that mining house own much more (accurate) information which may not be open to the public (Inter-Ministerial Committee, 2010).

Although focussed studies have been done on the impacts of AMD, the IMC encouraged the need for a birds-eye-view on the issues relating to the management of AMD in the

Witwatersrand Gold Fields in order to reduce areas of uncertainty (Inter-Ministerial Committee, 2010).

2.8.3 Immediate term mitigation strategy

In April 2011, a directive was issued by the Minister of Water Affairs to the TCTA to undertake the "Emergency Water Works Management" which comprise of the work implemented in the Western Basin (referred to as the Immediate Works) and the work implemented in the Central and Eastern Basin (referred to as the Short-term Interventions (STI) (Inter-Ministerial Committee, 2010).

The immediate works implemented in Western Basin comprise of the following:

- The installation of an additional pump in Rand Uranium No. 8 Shaft to increase the pumping capacity
- Expanding and upgrading the existing Rand Uranium treatment works

2.8.4 The short-term intervention

In order to address the rising AMD in the Witwatersrand basin, the IMC implemented the following mitigation measures for each basin:

The Western basin: The TCTA utilised pumps to abstract water from the abstraction points that were closest to ingress points (because they would be less contaminated). Abstraction from Rand Uranium No. 8 Shaft in the Western Bain is conducted to maintain a pumping rate of 36Ml in order to maintain the water level to the TOL and to stay under the ECL. An HDS neutralisation water treatment plant is used to treat water (Inter-Ministerial Committee, 2010). Treated water is discharged into the Tweelopies Spruit which flows into the Crocodile River.

Central Basin: The Abstraction and treatment works for the Central Basin are located on the East Rand Mines at the South West Vertical (SWV) Shaft near Germiston. The estimated ingress at the Central basin is 46 Ml/day. Two pumps are used at joint capacity of 56Ml/day to treat water (Inter-Ministerial Committee, 2010).

An HDS sludge plant was constructed to treat water at a capacity of 72 Ml/19 hours. The neutralised water is transferred to the Elsburgspruit, which is within the Vaal River System (Inter-Ministerial Committee, 2010).

The Eastern Basin: With an estimated average ingress volume rate of 80 Ml/d, three pumps were proposed at Grootvlei No. 3 near Springs and treatment works of 84Ml/day.

2.8.5 The long-term solution

The final recommendation from the IMC report was the commissioning of a Feasibility Study for the long-term solution. The focus areas of the Feasibility Study comprise technical, legal, institutional, financial/economic and environmental assessments, as well as public communication and key stakeholder engagement (DWA, 2012 a). The Feasibility Study comprises three phases; the Initiation, Prefeasibility and Feasibility Phases. Once the proposed pumping and neutralisation would commence in the Central and Eastern basin, it was discovered that the dewatering of the mine voids and partial treatment of water would still prevail as it did when the mines in the area were still active. This meant that the saline AMD would flow into the Vaal River System. There was an urgency in reducing the salt loading on the Vaal and Crocodile Rivers (DWA, 2012 a). In 2012, DWA commissioned the Feasibility Study for the long-term solution which would have to support the Water Resource Strategies for the Vaal and Crocodile River Systems (DWA, 2012 b).

3. Methodology

Answering the research questions of this study required determining how the management approach to AMD had been conceptualised; what constitutes the management approach and how scientific knowledge and the on-going generation of scientific knowledge was integrated in that approach. This was achieved by conducting a review of the strategy documents and a an in-depth analysis of a case study using nine interviews, conducted with key informants and contributors from the government, an educational institution, industry (mines currently dealing with the issue), and society. An inductive and descriptive approach was followed to gather and analyse data to formulate answers to the research questions (Hennink *et al.,* 2011). A descriptive study is one whereby information is collected without changing the environment. The descriptive approach was used to obtain information pertaining to the status of the phenomena to describe what was in existence at that present moment in time with respect to the variables or conditions of managing AMD (Thomas, 2005). The reasons behind using an inductive approach were to:

- condense extensive raw text data into a more concise summary;
- establish clear links between the research objectives and the findings derived from the raw data and;
- develop themes or theories about the underlying structure of observations or experiences which are evident in the raw data (Thomas, 2005).

The research methodologies used for the study are outline below (Figure 5)

Table 5: Outline of the research methods used to address the research objectives

Method	Purpose	Research question
Literature review	To identify and describe the elements that constitute an adaptive management strategy	Research question 1
Review of strategy/policy documents (document analysis)	To investigate whether the DWS Policy documents address adaptive management in the approach to implementing the short and long-term mitigation strategies for AMD decant in the Witwatersrand Basin	Research question 2
Case study: interviews	To obtain perspectives from key informants that were involved or had some input in developing the mitigation strategy in order to understand whether there was any traction in adopting an adaptive strategy for managing the decant of AMD. To also gain an	Research question 2

	understanding of what the shortcomings of the adopted mitigation strategies were.	
Literature review	To determine whether adaptive management would be a better approach for the mitigation of AMD discharge in the Witwatersrand basin in comparison to the current management approach.	Research question 3

Since the management of acid mine drainage is multidisciplinary, the above methodologies have been chosen in order to maximise the diversity relevant to the research questions, as well as to explore how the management of acid mine drainage is understood among different people from different sectors.

3.1 Document analysis

In a study of this nature policy documents, key legislation, government strategies and other information relating to the management of AMD that was available in the public domain assisted in understanding the pertinent issues especially due to time and resource constraints.

For the study the following documents were reviewed:

- Short term mitigation strategy: "Report to the Inter-Ministerial Committee (IMC) on acid mine drainage: Mine water management in the Witwatersrand Gold Fields with special emphasis on acid mine drainage". The report was prepared by the team of experts under the Inter-Ministerial Committee (December 2010)
- "The Draft Scoping Report for short term interventions for the treatment of acid mine drainage (AMD) in the Western, Central and Eastern Basins of the Witwatersrand Gold Field" prepared by Digby Well Environmental Pty Ltd (November 2012)
- "Feasibility Study for a Long-Term Solution to address the Acid Mine Drainage associated with the East, Central and West Rand Underground Mining Basins, Gauteng Province", prepared by the Department of Water and Sanitation (July, 2013)

The following set of questions were used to assess the policy documents:

Probing questions:

1. While developing the mitigation strategy, was there a clear statement of project objectives which could be used to evaluate the effectiveness of the management strategies

2. How effective was the stakeholder engagement process? Did you work collaboratively across different disciplines and how much public participation was incorporated?

3. How does the adopted management strategy address uncertainties and complexities?

4. How does the adopted strategy improve learning?

5. What is monitored under the mitigation strategy and how (frequency, extent, intensity etc.)?

3.2 Interviews

Case study research is a way in which to address the research questions of "why" and/or "how" (Noor, 2008). The strategy reports referred to above do not contain the context of discussions that took place before and after the mitigation measures were proposed. It was therefore decided to supplement the researcher's document analysis on the case study with interviews with people that were involved in different roles in the cases.

3.2.1 Interview strategy

The interviews were conducted in person (face-to-face), telephonically or via email, depending on the availability of the interviewees. A list of guiding questions (Appendix A) (including the checklist questions) was used to guide the interviews to ensure that all respondents addressed the same themes of the study. I therefore only asked "semi-structured" questions. This meant that the questions were not standardised to avoid limiting the participants' responses, but rather provided a framework to guide the experts' narratives.

The study was accomplished by using an in-depth, qualitative approach. Delattre *et al*. (2009) stated that the main objective of qualitative research is to create a method for approaching, analysing, understanding and explaining management phenomena at a social or organisation level. Unlike purely quantitative research, qualitative methods therefore centre their attention on exploring the type and the origin of opinions or positions (Delattre *et al.,* 2009).

Conducting semi-structured anonymous interviews was the method of inquiry. This choice was based on the fact that semi structured interviews allow the participants to express diverse views of which may be based on personal experience and allows the researcher to react or follow up on those views (Creswell 2005). The semi structured interviews also questions

minimised the influence of the researcher's attitudes and previous findings (Creswell 2005) onto the participant therefore allowing the participants to freely express themselves.

3.2.2 Targeted selection

In this study, the interviewees included experts in the field of managing acid mine drainage as well as key informants who advised the IMC on the mitigation of AMD decant in the Witwatersrand basin. The experts have been active in the acid mine drainage environment in varying capacities and within different sectors such as academic, private sector, government and non-government organisations. The experts have also made direct contributions to the mitigation strategies of AMD in the Witwatersrand basin.

Participants were chosen based on specific criteria rather than randomly, thus the experts were chosen according to the contribution that they could make towards the objectives of the study. Experts and panel members were also identified through the judgment based on the snowball method (Creswell, 2005) and the maximal variation sampling strategy. I had initially identified potential experts and the contacted them to establish their willingness to participate in the research study and also enquired about other experts in the field to maximise the sample size and relevance of the participants.

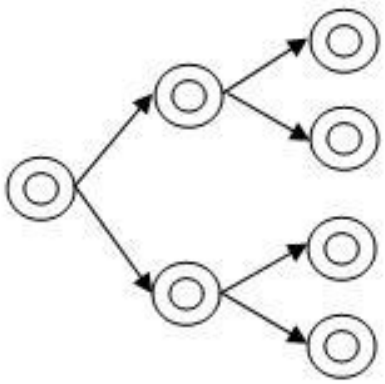

Figure 8: Illustration of the snowball effect (Creswell, 2005)

I utilised the snowball sampling process (Figure 8) which entailed finding research subjects whereby one subject gives the researcher the name of another subject, who in turn provides the name of a third, and so on. In this way a set of potential contacts were expanded. The maximal variation approach was used in order to incorporate the diversity of expert perspectives (Creswell, 2005).

My interviewees were sent an email detailing the purpose of the study, wherein they were requested to sign the following documents:

- Participation Information Letter: Letter detailing the background, rational and purpose of the study
- Interview Consent Form: Letter requiring consent to conduct the interview, provided that confidentiality and anonymity is provided for the interviewee
- Interview Recording Consent Form: Letter requiring consent to record the interview, provided that confidentiality and anonymity is provided for the interviewee

Interviews were carried out under ethics clearance certificate (protocol number H14/06/36) (Appendix B) that was granted by the University of the Witwatersrand.

Anonymity was guaranteed to the interviewees not only to protect their identities but to allow them the opportunity to express their views freely.

The interviews were planned according the schedule below:

Table 6: Schedule of interviews conducted

Coding title	Interview date	Sector
Expert 1	6 October 2014	Industry
Expert 2	10 November 2014	Education
Expert 3	27 October 2014	Education
Expert 4	3 October 2014	Civil Society
Expert 5	20 October 2014	Industry
Expert 6	30 September 2014	Government
Expert 7	20 October 2014	Education
Expert 8	16 October 2015	Industry
Expert 9	1 December 2015	Civil Society

The content and observations of the interviews were transcribed. This was followed by a thematic analysis in which themes were identified (Creswell, 2005).

3.3 Data analysis

The unit of analysis was the views, opinions and perception of certain individuals that were relevant to the study, based on their knowledge and interactions within the AMD

management arena. The answers from the interviews were captured and grouped according to the research questions asked in this study.

3.4 Limitation of the methodology

Some of the individuals that were chosen for the interviews displayed reluctance at the beginning of this research. It was therefore decided to revert to anonymity, because the purpose of this research is to get personal and honest opinions, particularly related to the challenges related to managing acid mine drainage. It is normal to expect that interviewees will not want to be completely open and honest about the challenges experienced in their work, as the South African mining industry is openly criticised and openly criticising one's organisation or other people in the same industry is not conducive for keeping good professional relations. Obtaining honest reflections were considered more important here than mentioning interviewees by name hence the anonymous interview approach was taken.

4. Results and discussion

The results Chapter is divided into three sections, namely the findings from:

- The review of the DWS Policy documentation for the mitigation strategies of AMD
- Interviews conducted with key informants that were involved or had some input in developing the mitigation strategy
- Advantages and disadvantages of adopting adaptive management strategy

4.1 Review of the DWS policy documentation for the mitigation of AMD

As already identified in the literature review (Table 2), the most common and important elements that constitute an adaptive management strategy have been identified and are listed in the first column of Table 7.

A summary of the findings of the policy document review, indicating the extent to which each elements of adaptive management were incorporated into the mitigation strategies for AMD, are also listed in Table 7 .

Table 7: The incorporation of adaptive management elements in the mitigation strategies for the Witwatersrand Basin

Element that constitute an adaptive management strategy	Short term mitigation strategy	Long-term strategy
Category 1: Deliberative phase		
1. Emphasises stakeholder involvement	Yes, but to a very limited extent.	Yes
2. Well defined objectives	Yes, however not comprehensive and not value based	Yes, however not comprehensive and not value based
3. Stipulated multiple alternatives	Yes	Yes
4. Predicts consequences	Yes, risk assessment conducted, however not predictive	Yes, risk assessment conducted
5. Specifies constraints	Yes, specifically from lack of knowledge implementation	Yes, specifically from lack of knowledge implementation
6. Acknowledges uncertainty	Yes	Yes
7. Emphasis explicit experimentation	No	No. Recommends pilot studies to be conducted.
Category 2: Iterative phase		
8. Monitoring	Yes, but limited	Yes, but limited

9. Emphasises active learning	No	No

The results in the above table were further categorised into the following:

Deliberative phase:

The deliberative phase is the planning phase in which key elements were developed and refined to inform decision making. It included the first seven elements identified in Table 7, including stakeholder engagement, determination of objectives, identification of multiple management alternatives, prediction of consequences and the design of monitoring protocols.

Iterative phase:

In the iterative phase, the elements in the deliberative phase are aligned into a sequential process of decision-making and learning. Follow-up monitoring provides information to estimate the status of whether the management actions are working and understanding the changes better. Learning is then subsequently promoted by the understanding gained from monitoring and evaluation.

The manner in which each of the elements are incorporated into the adopted mitigation strategies for AMD are discussed below:

4.1.1 The efficacy of the stakeholder engagement process adopted

Stakeholder engagement during the study for the short-term intervention was limited (Inter-Ministerial Committee, 2010). The urgency and the relatively short study period for such a complex study meant that it was solely based on the information at hand and technical analyses that had been completed by the time the decisions had been made (Inter-Ministerial Committee, 2010). Although the stakeholder engagements and public participation for developing the short-term intervention study was minimal, Digby Wells Environmental (Digby Wells) was appointed by the Trans-Caledon Tunnel Authority (TCTA) to conduct the Scoping Assessment for the immediate and short term interventions for the treatment of AMD in the Witwatersrand (Inter-Ministerial Committee, 2010). According to Digby Well's scoping report, interested and affected parties (IAPs) were informed of the project as well as provided the opportunity to provide their input in terms of issues and concerns they may have had. Although this may have been the case, the comments and suggestions were not fully addressed and there has since been no EIA conducted for both the short term and long-term

mitigation strategies. Which also raises an issue of whether stakeholders and the public's inputs were considered in the decision making process for the strategies.

Since the feasibility study for the long-term mitigation was a planning tool to investigate different options and recommendations for the long-term solution for the AMD challenges, it did not include a public participation process in terms of the National Environment Management Act (NEMA, Act 107 of 1998).

The key stakeholders for the feasibility study were defined as directly affected parties, those who had a high level of negative or positive influence (in government and civil society domains, and on the direction and success of AMD long-term initiatives) and those whose input was critical to the study (for example, representatives of various National, Provincial, and Local and District Government, NGOs, organised business, mining, industry, labour, agriculture, affected mines, affected water utilities, community leaders, academics.

According to the Department of Water Affairs, the current stakeholder engagement and communication context involving AMD management related issues and projects, is fragmented and not coordinated well, leading to *"stakeholder confusion, mistrust, fear, media speculation and lack of confidence in Government's efforts regarding AMD management in the bigger context"* (DWA, 2013 b p. 1). The adaptive management concept stresses the importance of social interaction and consensus building in reaching management decisions.

4.1.2 The clarity of the mitigation strategy objectives

According to the Inter-Ministerial report, the objectives of the mitigation strategy were based on the principles and the hierarchy of actions that are stipulated in the DWA Best Practise Guidelines for Mine Water Management (Department of Water Affairs and Forestry, 2008),

The approach for the short-term intervention was split into two main components

1. Management of decant and/or flooding
2. Management of water quality

The objective of the long-term study was to investigate and recommend a technically sound, economically viable and feasible long-term solution to the AMD situation in the study area. Unlike the short term-mitigation strategy, stakeholder engagement as well as a stakeholder

communication plan were proposed and initiated early in the feasibility study, before the objectives of the strategy were established (Inter-Ministerial Committee, 2010). Therefore, the long-term strategy (and an adaptive strategy) differs from the short-term study in that it incorporates a value system right from the beginning whereby the value systems are understood and are incorporated into planning and designing the solution.

4.1.3 Stipulated multiple actions and alternatives

Technological and site layout alternatives for the immediate and short-term interventions were identified as part of the Scoping Phase. The "no-go" option (no intervention) was also investigated. The following the alternatives were investigated using specific selection criteria:

- Treatment technology alternatives
- Abstraction alternatives
- Sludge disposal alternatives
- Treated water discharge alternatives

The Final Treatment Technology Options Report (DWS, 2013) states that due to the rising AMD water in the basins, there was time left for experimentation to search for the optimal solutions for implementation in the near future. It also states that DWS accepts that if any proven technologies were used, the solution that was implemented could later be shown to have contained some element of 'non-optimal' expenditure.

The feasibility study for the Long-term mitigation strategy also revealed that the DWS had received proposals by service providers that claimed that they could treat AMD water to the required standards. Those service providers were subsequently invited to present their solutions to the study team. In 2012, DWS then advertised for requests for information on various technologies that could treat AMD. Due to the late advertising in the press, the study team only invited technology stakeholders that had contacted DWA with respect to the AMD challenge at the time.

The following criteria were selected as a guideline for the evaluation of the technology presented by the prospective service providers:

- Quality of the water that could treated with the technology and quality of the treated AMD

- Chemicals used, and waste products produced used in the technology
- Requirements for the disposal of the waste products
- The developmental stage of the technology (laboratory scale, pilot scale or proven technology)
- Complexity of the process
- Risks associated with the technology:
    - Variations in the volume to be treated
    - Variations in the quality of the AMD to be treated
    - Health risks
    - Environmental risks
    - Potential failure.

4.1.4 Predicts consequences

The Inter-Ministerial Report contains a detailed risk analysis for each Basin, whereby the risk owing to the flooding of the mine voids and the decant of water to the surface are assessed. The risk management measures were also detailed within the risk matrix

During the scoping phase of the short terms mitigation strategy, a risk assessment was conducted to identify the potential risks to the project.

The objectives of the Risk Assessment were the following:

- To review and rank the environmental and social risks related to the treatment of polluted water from the West, Central and Eastern Witwatersrand Basins;
- To develop mitigation measures, with action plans, for the critical risks;
- To determine the detail and the scope of specialist studies and investigations required for the permitting process of the project

Unfavorable events were identified during the Risk Assessment. The risk associated with each event was then assessed, and a ranked list of risks has been developed. One of the

critiques of the short-term mitigation strategy however was the lack of an EIA to assess the impacts of each activity. The risks of the long-term mitigation strategy were also assessed. In addition, an EIA will be conducted whereby specialists' inputs will inform the impact study.

4.1.5 Specifying constraints and acknowledgment of uncertainty

Limitations and uncertainties in the body of knowledge concerning the management of acid mine drainage decant have been detailed in the Inter-Ministerial Report and the Water Research Commission Report for the long-term study. The long-term study is based on the premise that AMD from all three basins will need to be managed and that the management plans will have to continuously change accordingly.

The DWA (Report No.8 – Implementation Strategy and Action Plan, 2012) states that the quality of the water to be abstracted is expected to change and that economic future is uncertain, and the value of gold fluctuates.

The uncertainties can be summarised as issues involving the reactivation of dolomitic solutions causing the formation of sink holes; uncertainties about the volume of water used in the mining operation and quality of waste water released; the beneficiation of AMD through regulations and adopting best practice; implementing the polluter pays principle; the larger scale of the AMD decant and the potential risks owing to the seismic activity (Inter-Ministerial Committee, 2010).

The above has however been contradicted in a statement made by the Inter-Ministerial Committee: In the opinion of the Team of Experts, *"sufficient information exists to be able to make informed decisions regarding the origins of the mine water, potential impacts, management strategies, treatment technologies, etc.*" (Inter-Ministerial Committee, 2010 p. 13)

"… there is a good understanding in the scientific and consulting communities of the requirements for technologically feasible measures that may be taken to reduce the effects of AMD and other mining-related wastes on the environment." (Inter-Ministerial Committee, 2010 p. 10).

4.1.6 Addressing the complexity of the system

The task team responsible for managing the impacts of acid mine water decant was confronted with the complexity of the following components:

- Human component: Society is affected by the discharge of acid mine drainage and is also a significant agent of change within the system.
- Physical components: The effect on the quality and quantity of water that is being discharged from the mines has a direct impact on the country's water supply. Factors such as runoff, geomorphology, and sediment processes are complex and not easily foreseeable. The physical processes that are associated with acid mine drainage such as metal toxicity, acidification, and salinization are also complex and difficult to predict
- Biological component: The short to long-term ecological processes, unpredictable natural disturbances and phenomena such as climate change are not easy to predict. The effects of AMD are also complex and the management approach for each requires a systems management approach.

4.1.7 The treatment of management actions as experiments

The majority of experimental work undertaken for understanding the generation of AMD in tailings facilities was funded by the WRC (Inter-Ministerial Committee, 2010). This work was however done before the short-term mitigation strategies were proposed and does not treat management actions as experiments.

Although no experimentation was conducted to compare the various treatment technology options, it was recommended that the implementation of the long-term solution in the Western Basin should comprise installation of one or more pilot scale technologies to allow them to be tested.

As detailed in the literature review, adaptive management regards management strategies as experiments. Managers are required to explicitly test the management regime that thy have decided to implement.

4.1.8 Monitoring the mitigation strategies

The success of the proposed mitigation strategy can only be verified by detailed monitoring of the water in the mine voids and the affected environments. According to the Inter-Ministerial report, the investigations undertaken in the identification of treatment options have identified critical shortcomings in the current monitoring of water quality and, in particular, flow in the areas downstream of mining activities (Inter-Ministerial Committee, 2010). These shortcomings need to be remedied so that the long-term strategies can be optimised for AMD management, particularly where this impacts on the Vaal River System.

Currently, the Wits AMD Hydrological Monitoring Committee (HMC) is responsible for the hydrological monitoring in the three basins (DWA, 2013). The three major aspects of the basins which are monitored are the mine void water, near surface aquifers and surface water. The implementation strategy and action plan for the long-term mitigation measures recommended that water samples taken should be tested for the following parameters: pH; EC; TDS; Total Alkalinity; Magnesium (Mg); Calcium (Ca); Potassium (K); Sodium (Na); Sulphate (SO4); Nitrate (NO3) and Chloride (CI). In addition, Inductively Coupled Plasma Mass Spectrometry (ICP) should be conducted to trace dissolved metals, including Uranium (U) and Thorium (Th). The monitoring of the radioactivity of the sample and Radon gas emission were also recommended (DWA, 2013).

The monitoring of other aspects of the mitigation strategy are not mentioned in the DWS implementation strategy- which should include the monitoring aspects of the social and socio-economic impacts caused by the chosen strategy. Only hydrogeological and water resource monitoring is detailed.

It is recommended that a multi-institution monitoring committee be established to facilitate the implementation of the required monitoring and assessment programmes. Monitoring results may also identify additional remedial measures required in the future.

4.2 Interview results

All the parties that were interviewed during this study acknowledged that the management strategies were steered by efforts from the government; however, that the government was slow to act and then hurriedly established the short-term study with very limited planning.

Results from the interviews also revealed that the aggressive approach to hold companies liable without the understanding of legal procedures, went back to lack of government leadership and that it was recent that there had been a coherent and technical document to address AMD.

It was also felt that the mines would only improve their environment management with the aim of generating profits. Historically, the mine companies wanted to mine as cheaply as possible at cheap labour and make as much money, so environment would not come first. Government focus would be to consider those measures, so the mines would not voluntarily implement any measures for the environment unless they had something to gain.

It was also mostly felt that there may be some responsible mining companies but only to a certain level and that most will implement measures only if it will benefit them in the long term.

4.2.1 The quality of management objectives which could be used to evaluate the effectiveness of the management strategies

When the interviewees were asked how clear and well defined the objectives of the mitigation strategy was, the following was found:

The policy review of the recommendations made by the IMC indicated that the objectives of the mitigation strategies were clear and relevant due to the fact that prior studies had been conducted. In contrast to the policy review results, the majority of respondents felt that the objectives were not clear and sufficient due to the following limitations:

- The exclusion of a value-based approach from the very beginning
- The lack of capacity
- The lack of a clear communication plan being set and implemented prior to adopting the objectives

- The lack of a more stakeholder participatory approach
- The lack of an environmental impact assessment supporting the objectives of the mitigation strategy

4.2.2 The efficacy of the stakeholder engagement process

When the interviewees were asked how effective they thought the stakeholder engagement process was and the extent of public participation for the mitigation strategy, the responses were found to be concurrent with the results of the policy review.

The general consensus amongst the majority of the respondents was that the level of stakeholder engagement was very poor due to the absence of an EIA and therefore did not include a public participation process in terms of the National Environment Management Act.

On the other hand, two respondents emphasised that the process of establishing the short-term mitigation strategy was a multi-disciplinary process not a public participation process. It was highly technical, and it has been agreed that the longer term interventions would incorporate an EIA which would involve the public at large. For the long-term strategies, different specialists were involved and focus group meetings with different stakeholders such as conservationists and government officials.

The responses were not very conclusive because an equal number of respondents argued that there was wide engagement; further stating that the stakeholder engagement process for the short-term strategies was limited by the exemption of an EIA mainly because it would have been rejected anyway. In other words, due to the nature of the problem and considering how urgent the solution was required; the EIA process would have caused a delay in trying to mitigate the problem. One respondent then argued that concerns were raised 10 years prior to the establishment of the IMC and that the problem was allowed to continue for 10 years unmitigated despite the warnings. She added that due to the reactive approach taken by the government, the public was not involved in any decision making so the interventions were decided on without any public participation which makes the strategy flawed by default.

The other shortcoming that was brought to light by a respondent was that most of the municipalities were ill informed and hardly submitted any comments due to the fact that most of them were not sufficiently capacitated to meaningfully and intelligently participate in

decision making nor were the rest of the stakeholders. The following was also stated: *"The stakeholder engagement process was not adequate at all especially since the approach was highly technical and not stakeholder focussed."*

4.2.3 How does the adopted management strategy address uncertainties and complexities

Only one respondent mentioned that the adopted strategy for dealing with the risks was based on the probability and of the size of the risk in making decisions.

The general consensus was that the complexities and uncertainties were not addressed sufficiently in the short-term mitigation strategies, despite the in-depth risk assessment that were documented in the mitigation strategy documents. The general consensus was however that a lot of efforts were put into the feasibility study for the long-term strategy.

The reoccurring issue of the strategies being a reactive process rather than a proactive one was highlighted similarly to the findings of the policy review.

4.2.4 How does the adopted strategy improve the understanding of ecosystem responses, thresholds and dynamics, in order to adapt practices to fit the changing social values and ecological conditions?

Despite the fact the policy review did not provide any indication to how flexibility was incorporated into the mitigation strategies, the majority of the respondents mentioned that the short-term interventions had no managerial flexibility.

On the contrary, it was stated that although there was a lack of flexibility in the past, lessons had been learnt and that there was flexibility in the design and operation of treatments for the short-term mitigation strategy: "*The treatments plants were designed conservatively in order to have flexibility and to accommodate environmental and societal uncertainties"*.

Furthermore, it was revealed that in the Central Basin, the treatment plants were 'overdesigned' in order to allow for flexibility in the case that if something had gone wrong, that there would be capacity. The main uncertainties that were catered for were water quantity, flow rate and quality, mostly as a result of fluctuating levels of rainfall.

It was claimed that as a result, the treatments plants were therefore designed to accommodate rainfall fluctuations by treating very poor quality water, in the case that rainfall is low and water quality dropped. Similarly, the plants were designed to treat very large quantities of water to accommodate the change in flow and quantity of water needing treatment in the case that rainfall levels rose, and the capacity required increased. One of the responds stated the following:

> *"There is also flexibility in operation by controlling retention time, ie. The time in which the suspended solids from the AMD is kept in the clarifier of the plant in order for it to settle down, the longer the retention time, the better the treatment because the flow through will not be too large and the solids will not be carried over into the discharge"*

The overall response was that the longer-term solutions incorporated flexibility to overcome the shortfalls of the short-term interventions particularly with regards to the lack of an ecologically sound approach.

4.2.5 Transfer of information and learning

The overall response was that that the strategies were designed in such a way that the information and knowledge gained from experience would be passed on through different channels such as research portals and houses, government departments, universities and forums, however some concerns were raised as the issue of transparency was highlighted.

One respondent from the education sector stated that *"the information will be passed on but whether it will be passed on well in time is a whole new issue. The mitigation interventions were initiated by the government not the mines, however to be fair to the mines, the government had received numerous proposal from the mine companies 10 years prior but at the stage the government did not take it seriously and did not consider implementing anything so there is a question on whether the newly found information will be passed on well in time, transparently and effectively".*

The need to disperse accurate information was also stressed. One respondent claimed that *"the technical knowledge was fragmented and very often inappropriate*". He then said that "*the only way to ensure the dispersion of accurate information would be to incentivise the involvement of mining companies in rehabilitation. And that it could only be achieved by "depoliticising the initiatives and making companies part of the solution".*

4.2.6 Monitoring under the mitigation strategy

More than half of the respondent claimed that not everything was being conducted as per the short mitigation recommendations and as obligated by the water use license, and that some results were not made the publicly available.

Apart from the issue of transparency, there was an overwhelming response that monitoring was insufficient and conducted inefficiently and ineffectively, thus the following limitations were brought to light:

- A limitation in the different factors and variables that should be monitored.
- The failure to collect data from multiple data points
- Insufficient/missing data
- Scarcity of data sources from government websites
- Lack of regular monitoring
- Slow monitoring due to lack of funds and capacity

One expert claimed the following: "*Monitoring was done once a month. Some results were not available because they had not monitored during certain month and results are only shown at one point in time each month. No night and day fluctuations are being monitored. It's a very crude way of monitoring not made known to affected land owners that won't know whether there are elevated concentrations of uranium or cobalt in their water, etc."*

On the other hand, another expert claimed it may have also been possible that monitoring was not a priority, *"currently the focus is on getting the treatment plants operational before the water decants naturally, so everything else is taking a back seat".*

Few experts gave responses as to whether they thought the government and mining companies were responsive to the monitoring results: "*Sulphate exceeded the permissible levels—that was all they had said and that it was better than raw AMD"*

The debate of the legacy of mining and holding companies liable for pollution also come up.

Similarly to the findings of the policy review, the monitoring in all basins is weak and the DWA has lost the ability to collect data from multiple data points. Monitoring is conducted on a monthly basis without night and day fluctuations. Some monitoring results are not available because monitoring may not have been done for that particular month. This limits the ability of the strategies to become adaptive.

The observation was in line with that of Williams and Brown (2016) in that monitoring can be constrained by a lack of budget, capacity or when the frequency of monitoring cannot keep up with the changes in the natural system. (Williams and Brown, 2016). Furthermore, the lack capacity exacerbates the lag. The lack of transparency and discloser of monitoring results also further creates institutional problems whereby trust is compromised amongst relent stakeholders. This eventually leads to an insufficient understanding of the resource system and then learning is retarded.

4.3 The advantages versus the challenges of adopting adaptive management

Adaptive management also does not represent an end in itself but emphasizes the importance of a feedback loop to continuously adapt to change (Panel on Adaptive Management for Resource Stewardship, 2004). Adaptive management would also help to foster collaboration between various agencies such as academic institutions, government, private companies and other stakeholders (Lee, 1993).

Despite the above-mentioned benefits of adaptive management, the design, implementation and monitoring thereof has its own share of challenges. In fact, relatively few cases exist in which adaptive management has been implemented effectively and successfully (Taylor *et al.*, 1997). The complexities of the systems that are to be addressed by adaptive management also translate into the complexity in implementing adaptive management.

Each system presents itself with its own challenges which can be overwhelming if the challenges all manifest at the same times or become intertwined.

However, given the potential benefits of the above mentioned, the following challenges and barriers associated with designing and implementing an adaptive management strategy should not discourage attempts to implement it but rather to become aware and invest much thought into designing a strategy based on adaptive management.

4.4 The technical challenges of implementation

Similarly to the challenges listed by Williams and Brown (2016) and discussed in the literature review, the objective of the long-term study was to investigate and recommend a technically sound, economically viable and feasible long-term solution to the AMD situation in the study area. Therefore, technical challenges resulting from the pressure and difficulty in designing robust experiments as well as the time needed to produce significantly correct results (Williams and Brown, 2016) were evident from the findings.

4.4 Economic challenges

One of the most prevalent challenges in South Africa is the limitation of funding (Inter-Ministerial Committee, 2010). Conducting experiments within an adaptive management framework can be very expensive due to the spatial and temporal scale associated with it. From the findings, it is clear that the economic challenges of managing acid mine drainage may not only come from implementation but may also arise from designing and monitoring.

In addition, expenses may also arise from assessing alternatives and implementing risk assessments or even outcomes of failed strategies. The potential impact of the limitation of funds may manifest itself as pressure to use cheap and maybe not-reliable techniques which may produce false results that may not be statistically robust.

However, even though a large amount of money may be required for implementing an adaptive approach to management, it cost less to do it right the first time around in order to avoid spending money on futile management strategies in future.

4.4 Ecological challenges

Ecological concerns involve risk pertaining to the irreversible damage of the environment as well as the reluctance to experiment with endangered species and ecosystems, however it can be argued that not implementing experiments may prove to become riskier than managing in ignorance or not managing at all.

If the outcome of conducting experiments results in ecological damage, then it would be limited to replication areas which may be better than the extensive damage that has already resulted from implementing conventional management strategies to manage acid mine drainage on the Witwatersrand basin.

As mentioned in the literature review section, the effects of AMD occur over large spatial and temporal scales therefore, therefore, similarly to the challenges listed by the British Columbia Ministry of Forests and Range (2008), the ability and capacity to apply and maintain the mitigation strategy on a short-term, medium term and long- term basis present a critical challenge. Addressing the different timescales will also require managing uncertainties caused by fluctuating environmental conditions and management conditions (Williams and Brown, 2016).

4.4 Institutional challenges

The findings of this research have emphasized challenges relating to managing time and meeting prescribed project deadlines. Gregory and Failing, (2002) and Lee (1993) have linked the unsuccessful implementation of adaptive management to some of the strong responses that arise from participants during planning and implementation. For instance, managers may lack the patience to obtain statistically valid data from scientists and in turn, scientists may become frustrated from the level of pressure they may put under (Gregory and Failing, 2002 and Lee, 1993).

Civil society may become annoyed by scientists who may seem insensitive to the risks posed by experimentation due to being in the school of thought that upholds the pursuit of scientific knowledge as a justified end in itself. The affected community may be dismayed by the concepts of experimentation and uncertainty and may require an assurance of success especially if previously failed experiments have affected them directly. Therefore, Lee (1999) emphasizes that implementation of adaptive management can be improved if stakeholders can agree on a collaborative structure and a set of questions prior to undertaking any experiments.

If there is an unwillingness to admit to uncertainty then it is almost impossible to believe in the value of adaptive management (Taylor *et al.*, 1997). As mentioned above in the previous sections of this report, the conventional and historic nature in seeking scientific knowledge has not given much attention to embracing uncertainty. Undesirable outcomes are still perceived at failures (Taylor *et al.*, 1997)

4.4 Lack of expertise and capacity

Already the status quo in South Africa is that we lack the relevant skills and expertise to undertake small to medium sized projects so the question at hand is how then will large projects, based on adaptive management be implemented effectively and efficiently? The lack of skills may also lead to the mismanagement and insufficiency of data. The added fear of altering plans or poor understanding of how to implement plans as identified by the British Columbia Ministry of Forests and Range (2008) also presents a challenge

4.4 Lack of collaboration and leadership

Adaptive management requires the interaction of a team of people with different expertise, knowledge and backgrounds, therefore communication barriers will have to be addressed and overcome (Stankey *et al*. 2005).

Co-operation and effective communication between different participants and stakeholders will be a challenge.

South Africa is famous for issues that manifest from political power struggles. Despite the fact that the various government departments involved in mitigating AMD are all mandated differently and may therefore have different motives for wanting and/or not wanting to implement adaptive management, the desire for political power may become a stumbling block in implementing adaptive management effectively and efficiently. As highlighted in the literature review finding, communication involving AMD management related issues and projects, is fragmented and not coordinated well, leading to “stakeholder confusion, mistrust, fear, media speculation and lack of confidence in Government’s efforts regarding AMD management in the bigger context” (DWA, 2013) leads to lack of communication and leadership.

5. Conclusions

The rationale for this research was the observation that although AMD has been discharged from gold mines in South Africa from as early as 1996, the emphasis on more sustainable management solutions has been inadequate. While many studies have focussed on the impacts of AMD decant, few have dealt with the management strategies

Research question 1: From literature, what are the most common and important elements that constitute an adaptive management strategy?

From literature review, the most common elements constituting an adaptive management strategy were identified and grouped into two categories, namely deliberative and iterative. The deliberative phase is the planning phase and the iterative mostly concerns the monitoring and evaluation of the strategy.

Research question 2: To what extent have the elements of adaptive management been incorporated into the mitigation strategies for AMD?

The review of policy documents and interviews that were conducted with key informants revealed that the AMD mitigation strategies adhered to each element of adaptive management differently; however most of the elements were embraced for the long-term mitigation strategy.

The lack of financial resources and capacity from the government was one of the topics that seemed most pressing throughout the interviews as it had a direct and/or indirect limitation on every aspect of the mitigation strategy.

The lack of integration between scientists, managers and engineers could be due to their respective approaches to problem solving. Scientists tend to like exploring the unknown, whereas managers like to rely on what they already know; and engineers tend to restructure or reconstruct certain situations or scenarios.

The researcher’s observation was that the information needs for the mitigation strategy were predominantly defined by the technical experts, leaving out other stakeholders. This observation could be explained by the work of Pahl-Wostl whereby he states that scientists are often segregated from social and economic drivers or shy away from them due to the fact

that scientists that desire to blend these factors often find themselves excluded from the decision-making arena (Pahl-Wostl,2007). He states that it is largely due to "a pre-conceived bias by policy makers who shy away from overly technical assessments and scenarios requiring complex trade-off considerations" (Pahl-Wostl,2007).

The researcher's finding from the literature review, document analysis and interview was that communication with stakeholder and interest groups was and is mainly by passive channels, through focussed group meetings, with limited information sharing.

It was also apparent that apart from the limited stakeholder engagement, the ability of the interested groups to meaningfully participate was limited due to lack of understanding. The lack of broad and effective communication is a limiting factor for the success of the mitigation strategy.

It is clear from the result of this study that the mitigation measures for the decant of AMD on the Witwatersrand basin have been reactive rather than proactive, seeing that the alarms had been raised 10 years prior to the actual decant. Furthermore, flexibility and experimentation are limited and the approach is more risk based.

The underlying explanation for the reluctance to generate and distribute more knowledge through experimentation could be that mine managers may be reluctant to allow publications in peer-reviewed journals that cite studies at specific mines, regardless of findings (Pahl-Wostl, 2007). This is reinforced by the findings of how poorly monitoring is conducted and managed for the mitigation strategy.

It was made clear that certain monitoring results were not made public. In this case, unfortunately the absence of transparency will inhibit learning and will end up creating more suspicions about the economic motives between mining companies and the government. The monitoring process also limits the amount of information learnt from implementing the strategy, therefore limiting the possibility of knowing whether the strategy is meeting the objectives or not.

From the findings of this study, it is apparent that although elements of adaptive management are employed by the mitigation strategies of AMD (more especially in the long-term mitigation strategy) it is rather passive and does not promote vigorous active learning through experimentation.

Research question 3: Would adaptive management be a better approach for the mitigation of AMD discharge in the Witwatersrand basin in comparison to the current management approach (short-term and long-term mitigation strategy)?

Although the design, implementation and monitoring of adaptive management has its own share of challenges and has relatively few cases which have been implemented effectively and successfully, from the findings of this research, it is clear that adaptive management seeks to tackle the very same issues that scientists and managers have to tackle from managing AMD in the traditional sense. Adaptive management offers a more proactive, comprehensive and sustainable approach.

Seeing that South Africa is famous for issues that manifest from political power struggles, the greatest advantage to adopting adaptive management for the management of AMD is that it would help foster collaboration between various agencies such as academic institutions, government, private companies and other stakeholders. It would also allow the relevant people to manage the social-ecological systems in the face of uncertainty and 'learn by doing'.

6. Recommendations

Based on the findings and drawing from the literature, the following recommendations are made:

6.1 The technical challenges of implementation

Although the technical challenges relating to the management of AMD are substantial, solutions to minimise them can be sought such as planning and developing a decision-making plan that can accommodate for larger and smaller scales to address scale specific issues (Williams and Brown, 2016). Identifying the uncertainty about resource status explicitly with probabilities for possible resource states and incorporate them directly into planning and the decision-making process is critical in this respect. Assistance can be provided by experts that have extensive experience and knowledge in statistics and experimental design. It is also recommended that on-going staff training is maintained and evaluated.

One of the most important points is to acknowledge is that communication is a two-way stream. It is important to have a sound understanding of how the mitigation strategies should be conducted and how the results may or may not affect the needs and wants of others. It would therefore be advisable to capacitate stakeholder groups with enough knowledge prior to any stakeholder engagement meetings. Local authorities who are more involved with the affected communities at grassroots level also need to be provided with enough knowledge and training to understand what the values and needs of the people are

6.2 Economic challenges

Decreasing costs and seeking opportunities for funding can involve using schemes that offer good trade-offs between cost and effectiveness, using cheaper monitoring and measuring techniques as well as identify and formulating partnerships where the sharing of costs is possible. Monitoring should be integrated into the management framework (from the initial panning phase) in such a way that it is regarded as critical and not optional (British Columbia Ministry of Forests and Range, 2008; Stankey *et al.*,2005).

6.3 Ecological challenges

Establishing an appropriate scale for decision making is critical. Decision makers should consider that passive approaches may be less risky than active approaches in some

circumstances. It would also be beneficial to conduct risk assessment for test plots first in order to identify the risks from the very beginning (British Columbia Ministry of Forests and Range, 2008). Also dealing with the consequences of managing in continued ignorance will prove to be a bigger challenge in the end.

If the outcome of conducting experiments results in ecological damage, then it would be limited to replication areas which may be better than the extensive damage that may result from implementing conventional management strategies that do not work.

It is however important to realise that scientifically, the current management strategy in place (or lack of) is also an experiment.

6.4 Lack of collaboration:

Good on-going communication between the decision makers, managers, scientists, all those who are involved in the implementation of the strategy; those who evaluate the strategy and other relevant stakeholders should be maintained.

Collaboration within different domain is one of the ways in which more funding can be generated- from different investors as well as the government. Working in different domains also provides some flexibility as would it allow for alternative funding sources to be made available in the case that a given current system fails.

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Appendix A: List of interview questions

Interview schedule

A. The development of the adopted management approach.

1. What led to the development of the mitigation strategy for the discharge of acid mine water on the Witwatersrand goldfields developed?

2. While developing the mitigation strategy, was there a clear statement of project objectives which could be used to evaluate the effectiveness of the management strategies?

3. Does the adopted management approach find better ways of meeting these goals?

B. Other management alternatives

4. What other management alternatives were considered and what propelled the decisions made against them?

C. Stakeholder engagement and governance

5. An interdisciplinary approach was taken into planning the mitigation strategies but how effective do you think it was in this case?

6. Do you think the mitigation strategy was value-based?

7. Which challenges came forth in terms of decision-making?

8. Does the adopted management approach improve understanding of ecosystem responses, thresholds and dynamics, in order to adapt practices to fit changing social values and ecological conditions?

Addressing uncertainties and complexities

9. Were the management actions designed in an experimental framework (versus experimentation being carried out independently from management)?

10. Do the management actions pass on information and knowledge gained through experience, and if so how?

11. Does the management approach foster an organizational culture that emphasizes learning coupled with responsiveness?

12. Are there any predictive models which will characterise change over time in response to fluctuating environmental conditions and management actions?

Monitoring

13. How will the monitoring help to detect cumulative, long-term, large-scale, and emergent effects of actions? And do you think the government and mines are responsive to this?

14. In your opinion how well does the management approach address uncertainties and complexity, if so, what some of the points that would stand out most?

Appendix B: Ethic Clearance certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Rantsieng

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER H14/06/36**
PROJECT TITLE	The extent to which an adaptive management approach has been incorporated in the mitigation strategies for acid mine drainage discharge in the Witwatersrand basin
INVESTIGATOR(S)	Ms M Rantsieng
SCHOOL/DEPARTMENT	Animal, Plant and Environmental Sciences & Law
DATE CONSIDERED	20 June 2014
DECISION OF THE COMMITTEE	Approved Unconditionally
EXPIRY DATE	03/07/2016

DATE 04/07/2014 **CHAIRPERSON** E.M. Take
pp (Professor T Milani)

cc: Supervisor : Prof T-L Humby

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10000, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

_____ _____/_____/_____
Signature **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES