# Acid mine drainage in the Gauteng province of South Africa – A phenomenological study on the degree of alignment between stakeholders concerning a sustainable solution to acid mine drainage

by

**Timothy Ian Ewart**

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Supervisor: Professor Alan Brent

School of Public Management and Planning

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# Declaration

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# Abstract

Ecosystems, and the very services and resources that they provide, are fundamental to our existence. Regardless, mankind shows scant regard for the biotic and abiotic components of the environment that serve as both sources and sinks for anthropocentric demands, practices and behaviours.

Of these vital resources, perhaps the one that is most under threat is water which while crucial for growth and development around the globe, is rapidly becoming a scarce commodity. In South Africa - already a water-scarce country - this situation is further compounded by mining practices that are not only unsustainable, but also largely unregulated from an environmental perspective. Mining activities have resulted in the mass exposure of iron pyrite and heavy metals, both underground and on the surface. Upon exposure to weathering, the iron pyrite gives rise to sulphuric acid, which, in turn results in the mobilisation and concentration of toxic metals. Although this is a geological phenomenon, the increasing concentrations of toxic metals as a result of mining have exposed the Gauteng province to enormous environmental, social and economic risks.

Concerning the risks, the research highlighted the following:

- Although comprehensive research has been found relating to the physical attributes of acid mine drainage (AMD), very little is known of the health aspects associated with AMD. Of immediate concern is, the subsequent environmental and health implications stemming from the association between living organisms and heavy metals.
- In the absence of such information, the credibility of current solutions is thus questionable. Of the solutions that have been proposed, most have been reductionist in approach and have only focused on dealing with the surface decant of contaminated water from predominately non-functioning mines. The health risks associated with radioactive and highly toxic waste have been down played or simply ignored (Albrecht, 2011).
- The absence of a comprehensive solution also raises questions as to the assessment and decision-making process utilised to date by the Department of Water Affairs (DWA).
- Both government and the private sector have allowed the AMD threat to amplify over the years. Their inaction has been facilitated by the poor enforcement of legislation and, clever manoeuvring by mining companies, in what can only be described as a mutually beneficial relationship between government and the mining industry.

In stark contrast to the inaction of government and the private sector, environmental activists have been very vocal in calling for a solution to a number of the risks associated with AMD. This, together with the recent decant of AMD in the Western Basin, has culminated in a public outcry and prompted calls for a solution to the AMD threat. Government's response to this was a narrow and incomprehensive solution, which only served to further frustrate the different stakeholder groups.

Where stakeholders have different themes as to the implications and thus solutions to the AMD threat on the Witwatersrand (as driven by the profiles of the different stakeholder groups), an appropriate solution will only be realised by adopting the following recommendations:

- Government must show the necessary political will, to fully engage the threat of AMD and address their poor track record as regulator - their credibility has been skewed through their vested interests in the mining industry.
- Having taken ownership of the AMD threat on the Witwatersrand, government must move to avert any immediate risks to human well-being.
- Under governments' leadership, the capacity of all stakeholders must be addressed to facilitate a participatory trans-disciplinary review of the assessment mechanisms and facts, in order to reach a mutually acceptable solution(s) to the social and environmental impacts associated with mining activities - a solution that will ensure future environmental integrity, social development and economic growth.

# Opsomming

Ekosisteme, en die dienste en hulpbronne wat dit voorsien, is grondliggend aan die mensdom se bestaan. Tog toon die mensdom weinig respek vir die biotiese en abiotiese komponente van die omgewing, hoewel ons met ons behoeftes, praktyke en gedrag daarop staatmaak én daaraan afbreuk doen.

Van hierdie lewensnoodsaaklike hulpbronne is die mees bedreigde waarskynlik water, wat – hoewel dit vir groei en ontwikkeling wêreldwyd van deurslaggewende belang is – spoedig besig is om 'n skaars kommoditeit te word. In Suid-Afrika, wat in elk geval 'n waterarm land is, word hierdie toedrag van sake vererger deur mynboupraktyke wat nie net onvolhoubaar is nie maar ook ongereguleerd. Mynboubedrywighede het gelei tot die massablootstelling van ysterpiriet en swaarmetale, sowel ondergronds as op die oppervlak. Wanneer ysterpiriet chemies verweer, vorm dit swawelsuurwater, wat op sy beurt toksiese metale mobiliseer en konsentreer. Hoewel dít 'n geologiese verskynsel is, het hierdie verhoogde konsentrasies as gevolg van mynbou die Gautengprovinsie aan enorme omgewings-, maatskaplike en ekonomiese risiko's blootgestel.

Wat die risiko's betref, beklemtoon hierdie studie die volgende:

- Hoewel omvattende navorsing oor die fisiese kenmerke van suur mynwater ("acid mine drainage" – AMD) onderneem is, is weinig bekend oor die gesondheidsaspekte wat daarmee gepaardgaan. Wat tot dusver van onmiddelliker belang was, was die omgewings- en gesondheidsimplikasies wat daaruit voortvloei wanneer lewende organismes aan swaarmetale blootgestel word.
- In die afwesigheid van sodanige inligting is die geloofwaardigheid van huidige oplossings dus twyfelagtig. Die meeste van die oplossings wat voorgestel is, is reduksionisties van aard en beklemtoon slegs die hantering van besoedelde water wat op die oppervlak uit hoofsaaklik onaktiewe myne sypel. Die gesondheidsgevare wat met radio-aktiewe en hoogs toksiese afval gepaardgaan, word geheel en al onderspeel of bloot misgekyk (Albrecht, 2011).
- Die gebrek aan 'n omvattende oplossing laat ontstaan ook vrae oor die beoordelings- en besluitnemingsprosesse wat die Departement van Waterwese oor die jare sowel as meer onlangs gevolg het.
- Sowel die regering as die privaat sektor het toegekyk hoe die bedreiging deur suur mynwater oor die jare vererger. Dié gebrek aan optrede is aangehelp deur swak wetstoepassing sowel as slimmer bewimpeling deur mynboumaatskappye in wat eenvoudig as 'n wedersyds voordelige verhouding tussen die regering en die mynboubedryf beskryf kan word.

In skrille kontras met die regering en privaat sektor se traagheid het omgewingsaktiviste nog nooit geskroom om hul stem te verhef en op oplossings vir baie van hierdie risiko's aan te dring nie. Dít, tesame met die onlangse uitvloei van suur mynwater in die Westelike Kom, het op openbare protes uitgeloop en aanleiding gegee tot oproepe om 'n oplossing vir die bedreiging van suur mynwater. Die regering se antwoord hierop was 'n eng, beperkte oplossing wat die verskillende belangegroepe slegs verder frustreer het.

Aangesien belangegroepe (in ooreenstemming met hul uiteenlopende profiele) verskillende aspekte van die implikasies van – en dus ook die oplossings vir – die bedreiging van suur mynwater aan die Witwatersrand beklemtoon, sal 'n toepaslike oplossing gevind word slegs deur die volgende aanbevelings te aanvaar:

- Die regering moet die nodige politieke wil toon om die bedreiging van suur mynwater ten volle die hoof te bied, en moet daadwerklik verbeter op sy swak prestasiegeskiedenis as reguleerder, waarin hy heelwat geloofwaardigheid ingeboet het vanweë regeringsbelang by die mynboubedryf.
- Nadat die regering sy verantwoordelikheid rakende die bedreiging van suur mynwater aan die Witwatersrand aanvaar het, moet hy dringend optree om enige onmiddellike gevare vir menslike welstand te voorkom.
- Onder leiding van die regering moet die vermoëns van alle belanghebbendes betrek word ten einde 'n deelnemende, kruisdissiplinêre beoordeling van die meganismes en feite te onderneem, om sodoende ('n) wedersyds aanvaarbare oplossing(s) vir die maatskaplike en omgewingsimpak van mynboubedrywighede te bedink – 'n oplossing wat die integriteit van die omgewing, maatskaplike ontwikkeling en ekonomiese groei sal verseker.

# Acknowledgements

Firstly, I count myself privileged to have been part of this programme and am therefore grateful to all the staff of the Sustainability Institute and especially the founding members who chose to pursue and share their beliefs and passions.

Not only did this research prove to be a great learning opportunity, but it also provided a significant turning point and journey, in the face of what is otherwise a very materialistic consumer driven world.

I would also like to express my sincere gratitude to my supervisor Alan Brent, for his professional and practical, support and guidance throughout this research process.

Finally, acknowledgement is also given to the environmental activists who have dedicated the lives to raising attention to the possible implications of acid mine drainage, for the sake of our well-being.

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# List of Acronyms and Abbreviations

| | |
|---|---|
| AMD | Acid mine drainage |
| CDE | Centre for Development and Enterprise |
| CERES | Coalition for Environmentally Responsible Economics |
| CGS | Council of Geosciences |
| CSIR | Council for Scientific and Industrial Research |
| DFI | Development Finance Institution |
| DEA | Department of Environmental Affairs |
| DME | Department of Minerals and Energy |
| DMR | Department of Mineral Resources |
| DST | Department of Science and Technology |
| DWA | Department of Water Affairs |
| DWAF | Department of water Affairs and Forestry |
| ECRR | European Committee of Radiation Risk |
| EIA | Environmental Impact Assessment |
| GGEDS | Growth Employment and Development Strategy |
| GPG | Gauteng Provincial Government's |
| GRI | Global Reporting Initiative |
| IDC | Industrial Development Corporation |
| IRP | Integrated Resource Plan |
| MAP | Mean annual precipitation |
| MCDA | Multi-criteria Decision Analysis |
| MDG | Millennium Development Goals |
| MEA | Millennium Ecosystem Assessment |
| MEND | Mine Environment Neutral Drainage |
| MPRDA | Mineral and Petroleum Resources Development Act |
| MRC | Medical Research Council |
| NEMA | National Environmental Management Act |
| NHLS | National Health Laboratory Service |
| NIOH | National Institute of Occupational Health |
| NRF | National Research Foundation |
| NWA | National Water Act |
| OMIGSA | Old Mutual investment group South Africa |
| PFA | Public Financial Act |
| TCAC | Trans Caledon Tunnel Authority |
| USHSS | US Department of Health and Human Services. |
| UNEP | United Nations Environment Programme |
| UNFPA | United Nations Population Fund |
| USGS | United States Geological Survey |
| WBEC | Western Basin Environmental Corporation |
| WHO | World Health Organisation |
| WRC | Water Research Commission |
| WUC | Western Utilities Corporation |

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# Chapter 1 – Introduction and Strategic Overview

## 1.1 Introduction

Acknowledgement of the critical relationship between a vibrant economy, human well-being and environmental integrity is an important concept. International bodies, like the United Nations, have tried to convey this for many years. Mankind has only recently begun to grasp this interdependency, where typically priority was given to issues of an economic nature as opposed to socio-political and environmental issues (Swilling, 2010). This phenomenon is evident around the globe.

Mankind's treatment, in particular with reference to the environment as both source and sink for anthropocentric demands, practices and behaviours, is changing as a result of his growing awareness to the collective importance of both the abiotic and biotic components of the earth's biosphere. The condition of which (see Figure 1.1) is crucial in ensuring the provision of the very ecosystem services and natural resources, which the existence of all living organisms are dependent on.

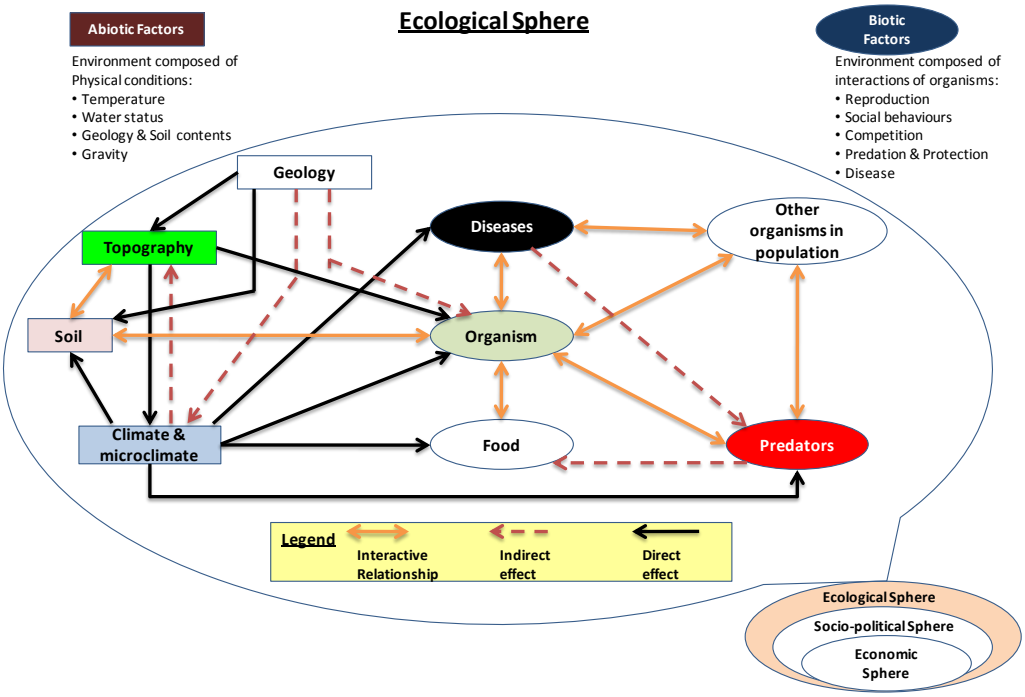


**Figure 1.1: Interactions between abiotic and biotic components of the environment. Adapted from work by Chapman *et al.*, (1999)**

Out of these ecosystem services and resources, perhaps the most important is light/energy, air and water. With regards to water, the earth holds more freshwater than the annual consumption of mankind, although much of this water is not easily accessible and is unevenly distributed around the globe (Webber, 2008:36). Approximately thirty percent of the world's freshwater reserves are stored in underground reservoirs, which constitute ninety seven percent of the available water for use by mankind (Borchert, 2009:36).

At a global level, water (like energy) is a fundamental commodity to development, industrialisation and growth, for which security of supply is rapidly becoming a strategic issue. A predicament that is being pressured by increased demand, driven by a global population explosion and climatic conditions. In the case of Africa, the collective threat to the scarcity of freshwater is of particularly concern, when one considers that Africa is second only to Australia, as the driest continent (Jackson, 2009:22).

The African continent has an abundance of natural resources, yet regarding water resources, many countries are classified as either water stressed or facing a situation of water scarcity (UNFPA, 2009). The scarcity of fresh water across Africa is being compounded by human activity, inefficiencies and contamination from waste (including human, domestic and industrial), all of which are poorly regulated and managed. As a result, access to vital sources of fresh water such as rivers, lakes and groundwater, which are already in short supply and are becoming more and more polluted, is restricted.

The majority of the current water-stressed countries in Africa are situated in the northern portion of the continent, which is the driest, with central and southern countries soon to be added to this list. Predictions by the United Nations Population Fund (UNFPA) (2009) suggest that if current trends continue, African countries will not be able to meet the minimum daily water requirement for its 4.2 billion residents, of fifty litres per person per day by 2050.

South Africa is an example of a country that is tinkering on the verge of becoming another water-scarce statistic (WWF, 2009). In particular, the Gauteng Province's (see Figure 1.2) fresh water supplies could be compromised by mankind's disregard for the environment (DWAF, 2009). Where allowances could possibly be made, for the country's early ignorance towards environmental integrity, poorly regulated and managed practices now need to be condemned. Reference here is given to the externalities associated with those activities that result in contamination of water supplies.

In particular, attention is drawn to the bed rock of Johannesburg's and ultimately South Africa's economy - mining. The very industry that breathed life into the economy now looms as an enormous threat. Mining operations (and to a lesser degree civil operations) and the activities associated with it, have led to the exposure to millions of tonnes of excavated waste rock, which has given rise to environmental and social threat in the form of acid water and toxic metal compositions. This in turn has lead to a phenomenon that is related to both

soft and hard-rock mining operations and is particularly prevalent in abandoned mines, where it goes on unattended.

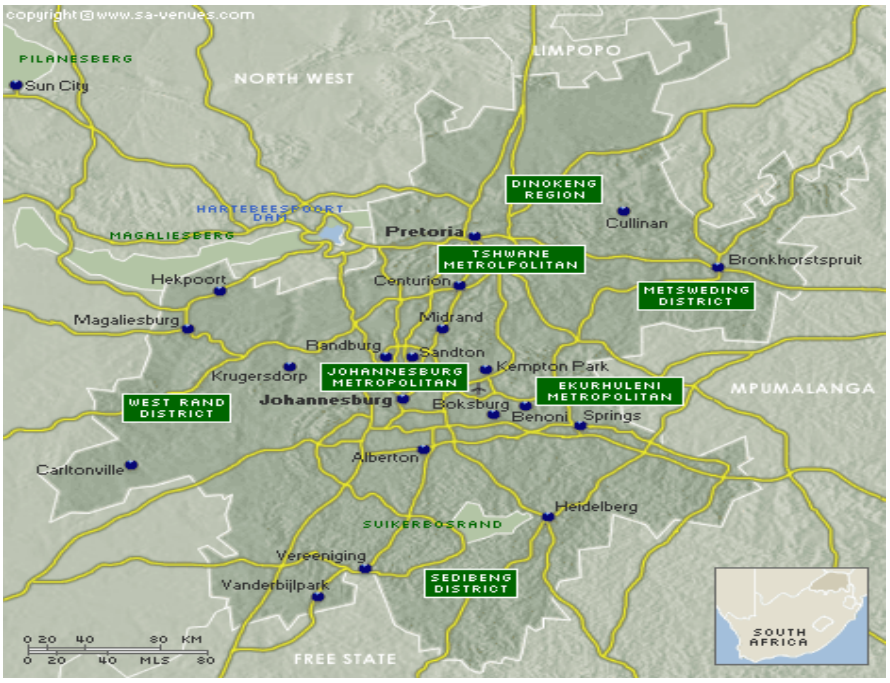


**Figure 1.2: Map of the Gauteng Region. Source: SA-Venues (2011).**

Historically, the Witwatersrand was renowned for the natural springs that occurred in the area, that were fed from the dolomitic groundwater. According to the Council of Geosciences (CGS) (2011b) in 1960, permission was granted that allowed mining companies to dewater their operations, which facilitated the pursuit of gold bearing reefs below the water table. The discharge of the water outside the dewatered boundaries meant the water table was artificial lowered, which resulted in a majority of the natural springs drying up. With many of the mining operations having now ceased, the water table has now returned to its natural level and water is now decanting as it typically would have done. Although this time the water is heavily contaminated, much of which is as a result of the abandoned mining operations in the area (Turton, 2011).

Although this is a geological phenomenon, the drainage and seepage from mining operations is resulting in elevated levels of toxic and radioactive waste which is contaminating surface waterways and underground water resources (McCarthy, 2010). Furthermore, it is leaching into surrounding soil, resulting in sterilisation and the degradation of ecosystems (CGS, 2011a). This associated ecological risk is another example of man's insatiable desire to consume and his total disregard for the very biosphere that gives life, for which a sustainable solution must now be found.

## 1.2 Rationale

The research topic is of particular interest to the author, in that as one of the 11 million residence of Johannesburg, there is a need to understand the possibility and, extent of the social and environmental implications that may arise as a result of acid mine drainage. Especially, in the context of a statement made by the United States Environmental Protection Agency (1987) which concluded that, "*problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk"* (as quoted in Oelofse report on Mine Water Pollution for DEAT, 2008) . In this regard, where different views have been communicated by different groups through numerous channels, it is important to try and establish one's own perception on the matter.

The research topic is also of relevance to the author, because nine years of his early career life was spent in this very industry, that is at the heart of this research project and with one of the major mining houses that perhaps even contributed to the present day acid mine drainage threat. Central to the engineering discipline (for which the author was a part of), was a support service to mining operations and, to which Pareto's 80:20 principle was most appropriate. By this, the author would argue that eighty percent of all mining and support service activities were focused on the volume and quality of mineral bearing ore.

Throughout the author's tenure in the mining industry, it is acknowledged that at no stage was concern or reference given to the possible threat of AMD. In fact within hind sight, there were numerous roles within the engineering discipline that were associated to the generation or concentration of AMD. These included:

- the treatment and management of underground water, as a result of the dewatering of underground workings;
- the transfer of underground water and residue to surface;
- the extraction and accumulation on surface, of waste rock; and
- the beneficiation process that resulted in millions of tonnes of residue.

Subsequent years were spent with various management consulting firms, whose service offering focused on driving profits and reducing costs in the mining industry. Admittedly seldom (if ever) was attention given to the ecological and social risk brewing in our midst. Once again as previously argued by the author, Pareto's 80:20 principle applied, as attention was only given to areas against which people were measured i.e. tonnage and grade. All other 'functions' (including engineering), were seen as secondary processes, which were not in any way allowed to distract attention from the 'real' goals of mining.

In this context and with specific relevance to Johannesburg, Younger (1997) argues that AMD poses a short and long-term pollution threat. The short-term component relates to the generation of AMD as a result of the rewatering of underground workings of abandoned mines, which he believes will decrease over a period of ten to forty years. The long-term threat, he associates with the seepage of acid water into the water table from current and future waste dumps - a scenario that he envisages will run as long as mankind continues to extract minerals.

However, the great concern in the case of South Africa is that AMD is by no means a new phenomenon. Numerous countries around the world have been confronted with this challenge, and many of which are proving successful in managing this scourge (DWA, 2010a). In 1982, the Canadian government established a group to address radiation from uranium tailings (McGinness, 1999:27). Their discovery of the much great threat of AMD led to the establishment of a program referred to as the Mine Environment Neutral Drainage (MEND) - a forerunner in the treatment of acid mine drainage. In fact, the South African predicament should be less burdensome with the knowledge that most resource enriched countries (including America, Australia, the United Kingdom and Germany) have encountered and are confronting the challenges posed by AMD.

Of the numerous passive and active solutions that have been proposed in South Africa in the past, the author would argue that such solutions are proving unsustainable, as many have given scant regard to the broader array of the socio-environmental issues. Although the author will acknowledge, that of the more recent solutions that have been proposed, certain of them do point to addressing AMD in a more proactive and integrated manner. Pump stations would manage the water levels of underground voids and thus eliminate the potential of AMD decant in sensitive areas. Together with this, mine water treatment plants would be established or refurbished, allowing the production of both industrial and potable grade water, while facilitating the recovery of sulphur and other metal complexes on a commercial scale (Manders *et al.,* 2009).

Such solutions must be considered because the problem is real and although opinions differ on the urgency of the problem and the pending social-economic and environmental implications, decisive action is required. Especially if one considers that in the context of Gauteng's water management philosophy, water which is vital for growth and development, is scarce and therefore the AMD problem must be solved. Where AMD from abandoned mines could "*result in catastrophic ground and surface water pollution"* (McCarthy T. , 2010), thus impacting the Gauteng provincial water delivery system - this threat needs to be stabilised, against which future strategic water projections must be made. Unless this scenario is addressed, it could well play out in other mining centres across South Africa, such as the Limpopo and Mpumalanga provinces.

## 1.3 Problem Statement

While the extent of the pending environmental threat is partially acknowledged, discussions rage as to an appropriate solution and to who should fit the bill of the significant funds, which are required to address the problem. Certain parties believe that the mining houses should address the problem, although many of the mines are now second or even third generation operations. Even more concerning, is that the majority of the initial mining companies are no longer functioning and the emergent mining companies are unable to fund the remediation of such liabilities (Turton, 2011). Unfortunately, this situation has been allowed to develop over time and has been exacerbated by clever manoeuvring on behalf of the mining houses and governments' delay in the promulgation of environmental legislation. On government's side, this has been further complicated by their subsequent non-enforcement of regulations and directives (Liefferink, 2010), issued to the mines to clean up the acid mine water problem.

Of the few mining houses that are still in operation, many are either second or third generation owners with limited tenure. One of which is DRD Gold (2010), who believe they are not the main offenders. Such companies have taken their cases to court, in defiance against directives issued. Others hold the view that, government has benefited greatly from mining activities over the last hundred years, and therefore should foot the bill (McCarthy, 2010:viii). Either way, the current inaction to date by the Gauteng provincial government and the private sector towards the resolution of acid mine drainage threat, would indicate the lack of an appropriate and sustainable solution.

Having said this, in the latter half of 2010 the government tasked a team of experts to compile a report on the AMD situation (with specific reference to the rising water levels and the water quality) and options to resolve the problem including the associated costs thereof. The panel of experts tasked with compiling the report was made up of representatives from: *"the Council for Scientific and Industrial Research (CSIR), the Water Research Council (WRC), the Council for Geoscience (CGS), the Chamber of Mines (CoM), the Department of Water (DWA[1]) and the Department of Mineral Resources (DMR)"* (van der Merwe, 2010b)The DWA AMD report (DWA, 2010a) (as it is referred to) was submitted to a Cabinet appointed Inter-Ministerial Committee (IMC) in October 2010 for review, and was subsequently passed to Cabinet. Civil activists hope that, following Cabinet's approval of the recommendations of the report, progress towards the resolution of the AMD threat will finally commence.

Acid Mine Drainage is a classic example of an inter-generational and intra-generational problem, where subsequent generations must seek resolution to an historical issue. In addressing this threat, numerous stakeholders have emerged with varying solutions and concerns. So while government has had AMD on its urgent agenda since 2009 (McCarthy,

[1] The abbreviation DWA is utilised (as opposed to full abbreviation DWAF) – as referenced in the DWA AMD report (2010).

2010:Viii) the compilation of the DWA AMD report can be seen as progress, although many parties question why; the AMD reappraisal process[2] and the content of the report were not made open to independent participation and review and why the continued delay in addressing the AMD threat.

## 1.4 Research Goals, Objectives and Questions

With reservations that an independent review of the findings of the DWA report would ever take place, the author intends to research **the degree of alignment to the perceptions and perspectives of the broader (but select) array of stakeholders, to the real problem and potential solution, to the AMD threat**. In doing so the author sought understanding of the following:

- Which stakeholders would be most relevant to this research?
- The perception and perspectives of stakeholders. A review of the level of questions that stakeholders ask and how they propose to resolve the AMD problem.
- What degree of overlap exists with regards to the questions that stakeholders ask?
- Where past solutions have been reactive, is the answer to see the threat as an opportunity? Why are we not thinking of more proactive solutions? Who is being pulled into the thinking of certain solutions and by whom?
- What do stakeholders say about the solution – is it sustainable and can they work together to resolve it? Do stakeholders see it this way and if so, what overlap exists?
- Who are the technical experts advising government and what was their brief?
- Who will fund the proposed solution and who will advise potential funders?
- Who are the activists and will they play a role as facilitators in the solution?

More specific to AMD, answers to the following were also sought:

- What is the scale of the AMD threat in the context of the total water balance of Gauteng?
- Is AMD damaging and in what way? If so, is this damage irreversible?
- What are the human related risks associated with AMD?
- Does current legislation point to a sustainable solution?

[2] Numerous research has already been conducted, some of which reference is given to in Section 2.3.

- What behaviours are typically encouraged in the mining industry by the current regulations?
- What contribution will the Water for Growth and Development Framework offer towards addressing the AMD threat?
- What is the extent of the damage since the promulgation of environmental legislation?
- Is the funding of research skewing the actual outcome of investigations into the true implications of AMD?
- Is institutional fragmentation a problem that complicates and blurs the responsibility in government's ability to effectively tackle acid mine drainage?
- What regulations currently exist with reference to the management of waste rock in active mining operations, with specific regards to its potential for acid water generation?
- What will future due diligence teams look like?
- To what extent has the responsibility for funding hampered the ability to resolve AMD?
- Is the environment conducive to tackle the problem head-on and to use AMD as a water source, perhaps even as a business venture? Due to the proximity, could this be a viable option? Could specialist water companies be established through a national co-ordinated framework and co-funded at a provincial level?
- Will continual flooding and dewatering of underground voids result in seismic events as predicted by Dr Anthony Turton of TouchStone Resources (Naidoo, 2009)?

## 1.5 Overview of research approach / strategy

In evaluating the views of the stakeholders, concerning a sustainable solution(s) for AMD, a flexible approach was required that would allow for the analysis and review of data across the four cornerstones of sustainable development: ecological, social, political and environmental. It was also important that the research process allowed for the analysis of the interrelationship and interconnectedness/interdependency between these components. Thus the research process could not afford to be too rigid, as it was expected that new developments may arise (from the understanding of such relationships) which may result in alterations to the initial methodology or part thereof. According to Hammersley & Atkinson (1995), this could require revisiting the; data collection, analysis processes and thus the research questions.

Furthermore, a traditional linear design would thus not be appropriate for such research and similarly, limited reasoning to a single paradigm on AMD would only serve to restrict the understanding and will not do justice to the threat at hand. For example, while a quantitative analysis will highlight the economical aspects of AMD, it will not do justice to the social and environmental threat that is looming. So while an array of research data already exists, there are numerous views (on this data) that need to be elicited and understood, and hence the belief is that the research will be exploratory in nature, which points to the requirement of a qualitative study.

The research process, as a important platform to the whole research strategy, commences with a review of related literature, which serves as an introduction to current causes, implications and possible solutions with regards to AMD and in the context of the four cornerstones of sustainable development. In this regard, specific mention is made with reference to crucial departure points that proved extremely useful in directing the author to valuable resources and which also served to clarify the research problem (Leedy *et al.*, 2010). These included:

- an understanding of the broader philosophy of sustainable development, as established through the Sustainability Institute. In particular, the awareness to the importance of our very biosphere, on which all life include human well-being, depends;
- the numerous environmental and mining journals and the timely release of the DWA AMD report. The participants of which contributed to the sampling design and the bibliography of which also provided a useful tool in sourcing both local and international literature; and
- the documentary 'The Cove' (Psimoyos, 2008) and especially the bonus features thereof. The totally unrelated viewing of this documentary initiated a crucial awareness to the impact of heavy metals to living organisms.

With the acknowledgement that new information (and sources) would be exposed in the engagement of participants, it was important that the qualitative research process (as a more holistic approach), would allow the author to interact with the research participants (elaborated in Chapter 3), in an phenomenological study (Leedy *et al.*, 2010), in interpreting the complexity of the AMD threat. The intention of the qualitative research process was to obtain an inside understanding of their perceptions and perspectives of the AMD threat. It is expected that the outcome will lead to a multitude of possible solutions from which themes would emerge, that will help with the solving of the research problem.

Although primarily a qualitative study (Bryman, 2001), the author will incorporate a mixed-method approach, to substantiate the interpretations of the phenomenological study. This will include the undertaking of field trips, which will allow the author to observe the impact of AMD firsthand.

## 1.6 Summary

Preliminary investigations show that where AMD poses numerous risks, the ramifications concerning social and environmental implications, specifically with reference to health, ecosystem and water scarcity, are particularly daunting in the Witwatersrand. It is in this context, that the proposed study will investigate 1) the severity of and 2) alignment to sustainable solutions to AMD in the Gauteng region. Such investigations will adopt a two-tier approach, encompassing; a review of related literature and a phenomenological study, which will be supported by field trip observations.

The intended benefit of the research is that, not only will it contribute to the extensive array of literature, but it will elicit the degree of common ground between the various stakeholders in the Gauteng region and expose the barriers posed by different parties, in the commencement of a comprehensive solution to the AMD threat. The divulgence of common ground could serve to bring stakeholders with opposing views and approaches, together.

Surely, it is inexcusable that an environment is allowed to develop, where iron (as a catalyst) can trigger the mobilisation heavy metals, in the formation of a deadly toxic threat. If one considers the social and environmental damage that has been document around the world, as a result of the exposure to heavy metals, then surely a solution must be determined, against which immediate action must be taken.

## 1.7 Structure of the report

The report commences with an introduction to the chosen research topic, the threat of AMD, and elaborates on the concerns relating to the lack of action towards this perceived crisis. Reference is made to a 'perceived crisis', in that besides the repeated voices of a few environmental activists, there appears to be very little awareness across the general public of the AMD threat and numerous other related questions that go unanswered. Through the approach discussed in Chapter one, the study then sets out to obtain clarity for these uncertainties, and particularly those pertaining to the implications of and appropriate solutions to AMD.

This understanding is the result of a literature review and the engagement with cross section relevant stakeholders and is communicated in Chapters two and three respectively. Chapters four and five address the purpose of this research study, through the analysis and interpretation of the accumulated research data, and culminates with conclusions and recommendations specific to the AMD threat in Gauteng (see Figure 1.3).

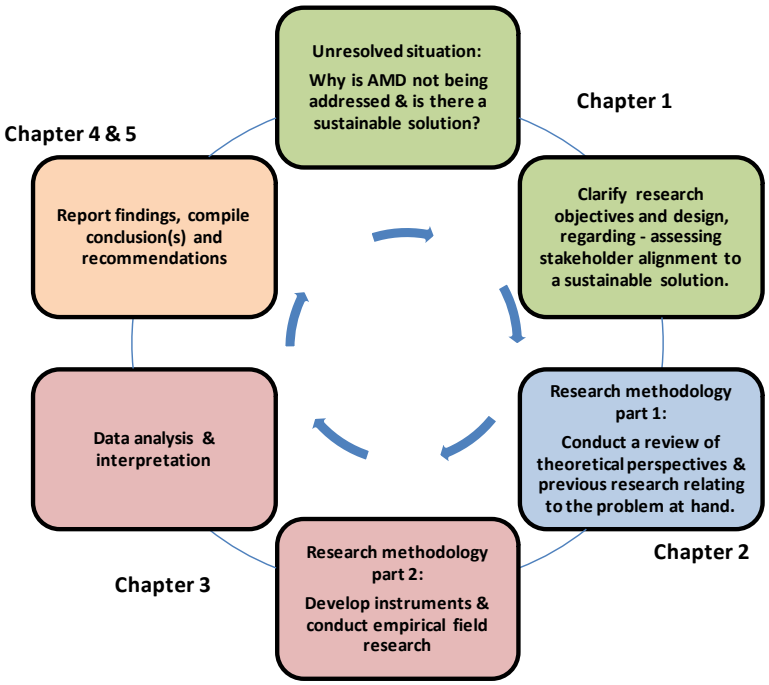


**Figure 1.3: Overview of research study. Adapted from work by Leedy *et al.,* (2010)**

# Chapter 2 – The acid mine drainage threat in Gauteng

## 2.1 Introduction

The origin of South Africa's economy has a strong association with mining, in particular gold mining, through the discovery of gold on the Witwatersrand in the now province of Gauteng, in the late 1800's. Recognised as the world's largest gold and uranium mining basins (MBendi Information Services, 2011), the Witwatersrand facilitated the extraction of 43 500 tonnes of gold and 73 000 tonnes of uranium (in one century and between 1953 and 1995 respectively) (Sutton *et al.*, 2006, Sutton *et al.,* 2006a & GDARD, 2011) and, in so doing, generated enormous wealth for the state, the province, companies and individuals alike.

Typically mining has been held in great regard as the backbone of the economy for many years, although now after some 120 years, its contribution to the greater economy (see Figure 2.1) has been in decline (from 1991 to 2000, mining's contribution declined from 8.4% to 6.5% - MBendi Information Services, 2011). However, as a result of increased public awareness of the social impacts associated with mining, its public image across the region and communities has shifted, specifically with regard to social and environmental perspectives (Liefferink, 2011a). In contrast to the early 'Gold Rush' opportunist days, and the middle of the previous century, when mining was seen as the great employer offering employment and security, members of the public are now tenaciously challenging the unsustainable practices that threaten this once prestigious industry.

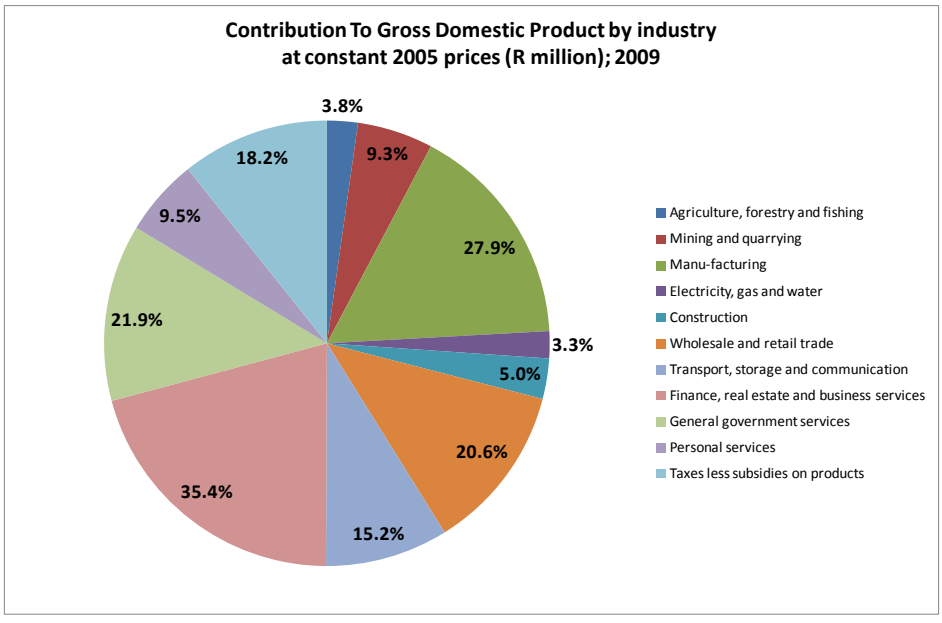


**Figure 2.1: Contribution to GDP by industry. Source: Statistics South Africa (2011)**

Perhaps the most vocal challenges have been the environmental activists, whose major concern has been the discharge of contaminated water from both functioning and predominately non-functioning mines. There has been particular emphasis on the *"serious environmental consequences, notably in respect of the poor environmental and water management"* practices (DWA, 2010a:1). These voices have grown stronger and have possibly resulted in individuals being ostracised for their stance towards the perceived lack of required action to address the real issues.

Following the outcome of an investigation by a specialised task team commissioned by cabinet in 2010, environmental activists continue to lobby for a sense of urgency and for more appropriate action towards AMD. Although AMD is a challenge that is being encountered across the globe, the Gauteng scenario is fairly unique due to the close proximity of the source of the contaminant to the community (DWA, 2010a:6).

Although it is the smallest of the South African provinces, Gauteng is the most densely populated, accommodating some 11 191 700 residents in an area approximately 16 548 square kilometres (SouthAfrica.Info, 2011). The province serves as the financial and administrative capital of the country, a position acquired from its historical association with *"the world's most important centres of gold production"* (McCarthy, 2010).

While there has been awareness, both nationally and internationally, of the threat of AMD since the mid-1900's (DWA, 2010a), the threat facing South Africa has only really been bought to attention recently as a result of its escalating nature, which prompted a public outcry and in reaction to which little, if any, action has yet been taken (Manders *et al.*, 2009). South Africa is essentially playing catch-up to an environmental predicament that has been increasing in scale since mining activities commenced in the Witwatersrand goldfields in the late 1800's (Boyd, 2008). The challenge now is to manage and contain the ecological and socio-economic risks posed by an industry that commenced well before legislation for environmental management was promulgated.

## 2.2 The nature and extent of the acid mine drainage threat

According to Ponapean *et al.,* (2005), acid water occurs as a result of the exposure of sulphate-bearing minerals to oxygen. They argue that:

- While sulphide minerals occur naturally in rock formations, it is through the oxidisation of these sulphides (namely pyrite) in the presence of oxygen and water, that sulphuric acid is formed.
- The oxidation process is accelerated by bacteria, which results in a further lowering of the pH of the solution.

- In this low-pH environment, heavy metals are mobilised by the sulphuric acid, thus adding a toxicity component to the water.

While the oxidation of sulphur is a natural occurrence, the concentration thereof, is typically minimal and thus of limited concern. However, mining activities (in particular) have led to an amplification of this natural phenomenon through exposure to the environment, of an increased surface area of sulphate-bearing minerals. The generation of acid water occurs above and below the ground, from the discharge of rainwater from surface workings and waste dumps, the seepage of rainwater into mine workings, and the exposure of fresh water to sulphate-bearing rock as a result of fissure drainage and water-assisted mining operations that occur below the water table (McCarthy, 2010:15).

Drilling operations (for the excavation of the vast network of underground tunnels and the subsequent extraction of gold-bearing ore) require a high water to rock ratio (3:1 tonne) (Chamber of Mines, 2008) – large volumes that the author would argue, would increase the exposure underground of sulphides (namely pyrite) to the presence of oxygen and water and thus resulting in the increased prevalence of AMD underground. Water build-up is pumped to the surface to prevent the flooding of the underground workings, and mining companies typically neutralise the acidic water using lime (or limestone) to reduce the damage to mine infrastructure and precipitate out the heavy metals. Although the author would argue, that the continual quarrying for lime and limestone supplies makes for an expensive and unsustainable solution to neutralising acidic mine water.

The resulting by-products of this process are effluent saline water, which typically is discharged into natural waterways (DWA, 2010a) resulting in the salinisation of vital ecosystems, and a residue rich in toxic metals that typically is disposed of into tailings dams, which require space and management to prevent the contamination of freshwater resources (Bosman, 1974:341).

Oblivious to the impact of AMD, early miners' pumped toxic water to surface in an attempt to prevent their workings from flooding, and without concern for the environment into which such water was discharged. While a large portion of the mining operations in the central Gauteng region have long since ceased to function, the practices of well over a century ago set mining-related environmental degradation in motion. This predicament has been exacerbated in the Witwatersrand region (see Figure 2.2) through the recent closure of the East Rand Propriety Mines Ltd (ERPM) (one of the few remaining mining operations) in 2008 and the liquidation of Pamodzi Gold in 2009 (McCarthy, 2010:vi).

So, while not necessarily visible, the threat has increased substantially as a result of the build up of AMD from mines that are flooding and from discharges from waste dumps, both of which go unattended (Turton, 2011). The surface decant, which is dependent on the topography and resulting water table level, is resulting in the destruction of waterways and ecosystems, while compromising the well-being of nearby communities (Turton, 2011). This

is a predicament that runs the width of the Witwatersrand, from east to west, and includes the Eastern, Central, Western and Far Western mining basins. It, poses an equally important risk to the structural integrity of central Gauteng, which sits upon a massive mining void that is overlain by dolomite and could be compromised by the ingress of acid water (McCarthy, 2010:20).

The reality and severity of the associated environmental and socio-economic risks began to set in after, the publication of media reports concerning the decant of AMD from abandoned mining operations into the western basin area of the Witwatersrand in 2002 (Manders *et al.*, 2009). In the subsequent years that it has taken for remedial actions to be instituted (despite the issuing of a directives[3] by the DWA for the treatment of the relevant mining water), AMD had succeeded in polluting the surrounding natural water courses, including the Randfonteinspruit and Wonderfonteinspruit, threatening the Cradle of Humankind heritage site (Oelofse *et al.*, 2007:2).


**Figure 2.2: Witwatersrand Gold Mining Belt. Source: International development research centre (2011)**

[3] According to Liefferink (2011b), three directives were issued with regards to the decant on the West Rand. She argues that the first two (issued in 2005 & 2009), were never complied with and the third which was issued in May 2010, has since expired, basically legalising pollution.

## 2.3 An overview of the more recent events pertaining to acid mine drainage

The inability to resolve the South African AMD threat has not been as a result of a lack of ideas or solutions; in fact, the subject has been well researched (see Annexure 1). Government departments, private institutions, mining houses, university professors and scholars have conducted research on AMD, the impact thereof and possible solutions. However, the evidence reveals that researchers have adopted a reductionist approach regarding AMD, with studies that have typical revolved around isolated solutions to individual elements of the process, such as; sulphate reduction (Poinapen *et al.*, 2005), the treatment of heavy metals (van Hille *et al.,* 1999) and cost savings through the use of alternative reagents (Somerset *et al.*, 2005). Regardless of the numerous solutions that have been researched and proposed, the immediate AMD threat posed by the abandoned mines (of which there are a reported 8000; Turton, 2010) still awaits urgent intervention.

Delays in conclusive actions may have been prompted by debates on who is to blame and thus who should foot the bill when addressing AMD - government or the mining companies? However, stemming from an DWA commissioned task team, the DWA announced in February 2010 that an agreement had been reached in a joint collaboration with the mining houses on a model to deal with AMD (McCarthy, 2010:viii). While the announcement made mention of the establishment of a public-private partnership that would assume technical and operational responsibility for the model, it made very little mention of the exact treatment approach that would be followed. Reference was only given to the refurbishment and development of infrastructure for the collection, conveyance and treatment of mine water at a central point.

Richard Doyle of Earth Metallurgical Solutions has suggested that there may be various reasons for the delay in implementing a solution, including; *"technical complexity, responsibility, cost, changes in government and the state's shortage of skills"* (Ensor, 2011). McCarthy (2010:ix) questioned whether the inaction was *"due to the nature of government or the proximity of government to mining companies and their revenue, or the impact of BEEllionnaires in the mining sector"*. However, in the latter half of 2010 (prompted by what some say was sensationalism by environmental activists and the media), it appeared that action would finally commence when the South Africa government announced a reappraisal of the threat of AMD by a special team of experts commissioned by the Minister of Water Affairs.

The assembled team of experts was tasked with reappraising the research and risks associated with AMD (see Annexure 2), assessing viable short-term solutions and exploring medium- to long-term sustainable options in partnership with the private sector (DWA, 2010b). The findings of the team were compiled into a report in December 2010 that, was submitted to the DWA for approval, and the recommendations of which (overview shown in

Figure 2.3) were subsequently adopted by cabinet early in 2011. The report was made public by the DWA in February 2011, following pressure from non-governmental organisations in terms of the Promotion of Access to Information Act. While government has had the issue of AMD on their urgent agenda since 2009, it seems that attention to the AMD threat will finally commence.

Payment towards a resolution for AMD was a contentious issue. In terms of apportioning responsibilities for the threat, the identification of the accountable mines and mining companies has proven to be difficult. Prof Terence McCarthy of Wits University's School of Geosciences argues that, as the state was historically the largest beneficiary through the receipt of taxes, which were subsequently utilised for infrastructure improvements, government should be tasked with funding the resolution of the AMD threat (Blaine, 2011a).

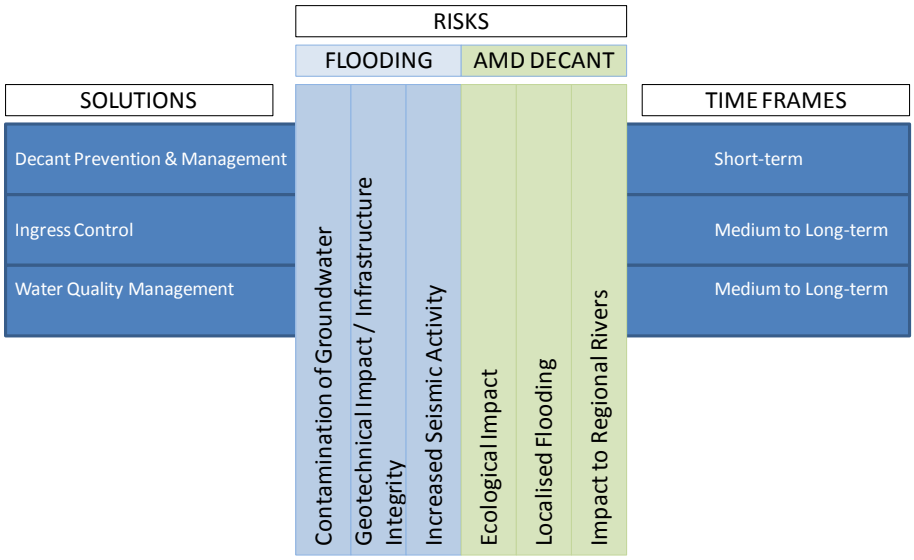


**Figure 2.3: Summary of AMD Report findings and proposed solutions. Source: DWA (2010a).**

Where government had previously made available, a R6,9 million subsidy to assist with pumping costs in February 2010 – this has been depleted (van de Merwe, 2010a). Moreover, as a further commitment, the Minister of Finance announced in February this year (2011) that R3,6 billion spend would be assigned to water infrastructure and services, including funds to address AMD in the medium-term (Minister of Finance, 2011). However, where the Minister of Planning Trevor Manuel did indicate that government would try to recoup the costs from existing mines that were profitable (Ensor, 2011), there is the fear that this in essence may mean that the tax-payers may have to foot the bill.

As welcoming as the news of government's awareness of the threat and the sense of urgency that may be required may sound, attention is drawn to the manner in which the

reappraisal was conducted and to the proposed recommendations. In this regard, the author raises the following concerns that for now remain un-answered:

- Considering the recent news reports of sensationalism and hysteria pertaining to AMD in Gauteng (McCarthy, 2010), it was unfortunate that the team of experts consisted, mainly of representatives from government institutions (see Figure 2.4) and that a public review of the AMD report and its recommendations was not undertaken.
- Where the DWAF (2009) considers that AMD as a threat to the *"Water for growth and development framework"*, why then where stakeholders not involved in the investigation into AMD despite cabinet's approval for the engagement of *"all stakeholders in the water sector"*?
- When the DWA report concluded that *"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"* (DWA, 2010a:10), why is it that very little has happened since the AMD decant at 18 winze on Rand Uranium mine, on the Western Basin in 2002?
- According to the recommendations of the DWA report, the intention in the short-term is to *"create a situation equivalent to the status quo during the period of active mining of the Witwatersrand Gold Fields"* (DWA, 2010a:96). Surely this is just advocating more of the same and falls short of addressing the environmental and socio-economic implications.
- While South Africa seems content to exploit certain resources for economic gain, other life-sustaining resources are poorly managed. The country must be reassured that the short-medium-and long-term recommendations form a comprehensive plan to ensure the protection of our resources and development systems.

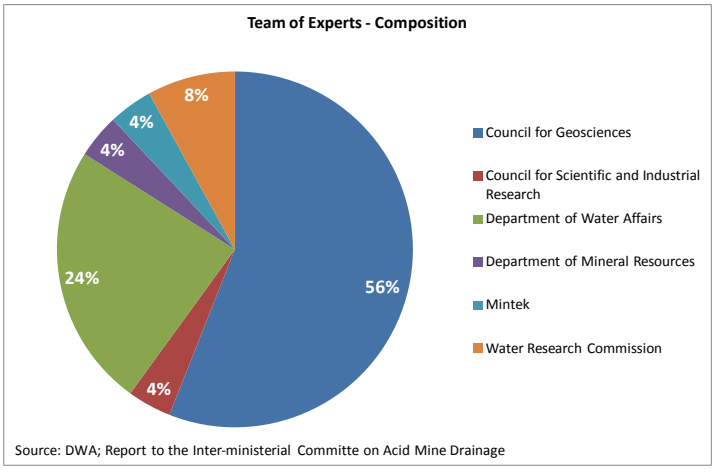


**Figure 2.4: Composition of the DWA commissioned task Team. Source: DWA (2010a).**

## 2.4 Continued environmental and socio-economic implications of acid mine drainage

**FROM A WATER PERSPECTIVE:**

While there may be numerous implications associated with mining, the author would argue that there are two significant issues, neither of which it is believed have received the appropriate level of attention when addressing AMD. The first is water conservation and security of supply, which are paramount for social development, economic growth and environmental sustainability (DWAF, 2009:1). While water fuels different activities across numerous industries and social arenas, the supply and quality of this scarce resource are heavily influenced by anthropocentric demand and behaviours, of which mankind's limited regard for the conservation of this vital resource is of concern.

With a semi-arid terrain, South Africa as a whole has been classified as the 28th (see Figure 2.5) most water-stressed country (University of Kassel, 2000), and therefore cannot afford to be negligent about water usage and conservation. With an average rainfall of approximately half that of the world's annual average rainfall of 860 mm (2009), the resulting rainfall figures equate to a per person water supply of between 500 $m^3$ and 1000 $m^3$, which means that the country is well below the *"water stressed"* classification of 1700$m^3$ per person per annum and is bordering on and below the *"water scarcity"* classification of 1000 $m^3$ per person per annum (WWF, 2009).

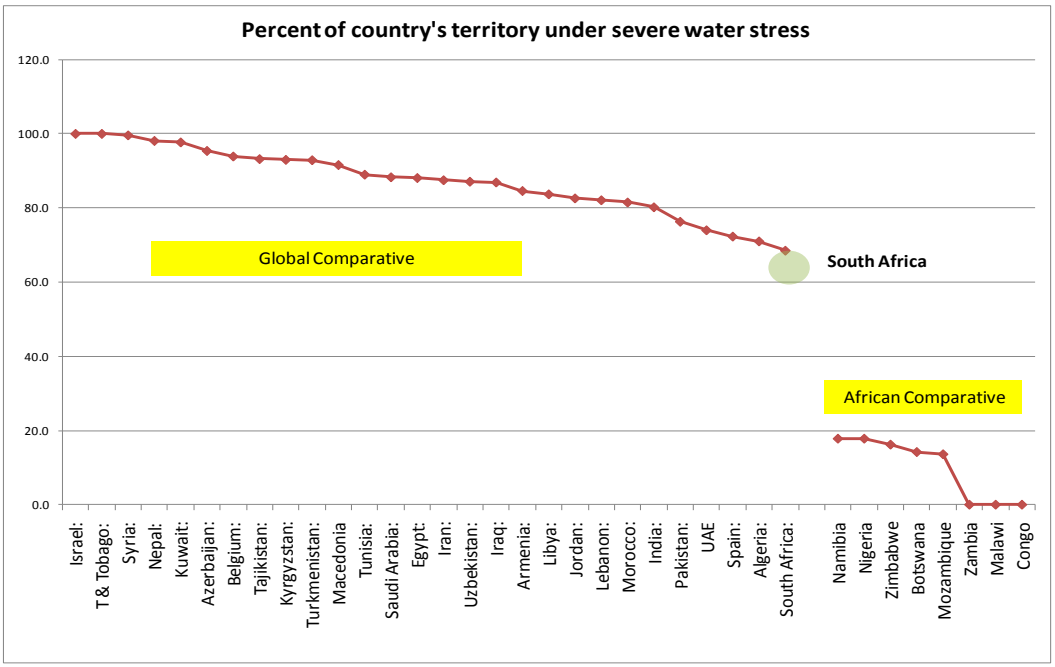


**Figure 2.5: A comparison of the most severe water stressed countries. Source: University of Kassel (2000).**

Central Gauteng, as the financial hub of South Africa and Africa, has the misfortune of not being situated near a river, lake or seashore (Turton, 2004:313). The topography of the land is such that Johannesburg sits atop a continental drainage divide, with the Orange River drainage basin to the south and the Limpopo River drainage basin to the north, both of which are internationally shared water courses (Turton, 2004:314). Over time, the supply of the economic and domestic demand for water in the province has changed from being met from local springs, before growing to include supply from the regional rivers, namely the Klip and Vaal Rivers. With a limited regional water cycle that is fed by a mean annual precipitation (MAP) of 600 mm (see Figure 2.6), demand soon outstripped supply and, to secure supply, the province became reliant on external sources of water. As strategic alternatives, the Thukela and Lesotho Highlands inter-basin water projects were commissioned in 1974 and 1998 respectively to supply water to the Vaal Dam (Turton, 2004:3).

As a result of continued growth and development, the province once again finds itself facing a demand dilemma, and despite an *"in balance"* rating by the DWAF (2009:10) for the province in 2000, South Africa as a whole no longer has any more surplus water (Turton, 2008:3). South Africa's current water availability is based on a mix of surface water (77%), return flows (14%) and groundwater (9%), but the Department of Water Affairs (DWAF, 2009:12) expects an increase in the usage of the latter two categories, specifically through the treatment of urban and mining effluent, to ensure that continued supply does not become a constraint. If this plan is to be carried out, then surely attention will now be drawn to the poor water management practices, relating to mining.

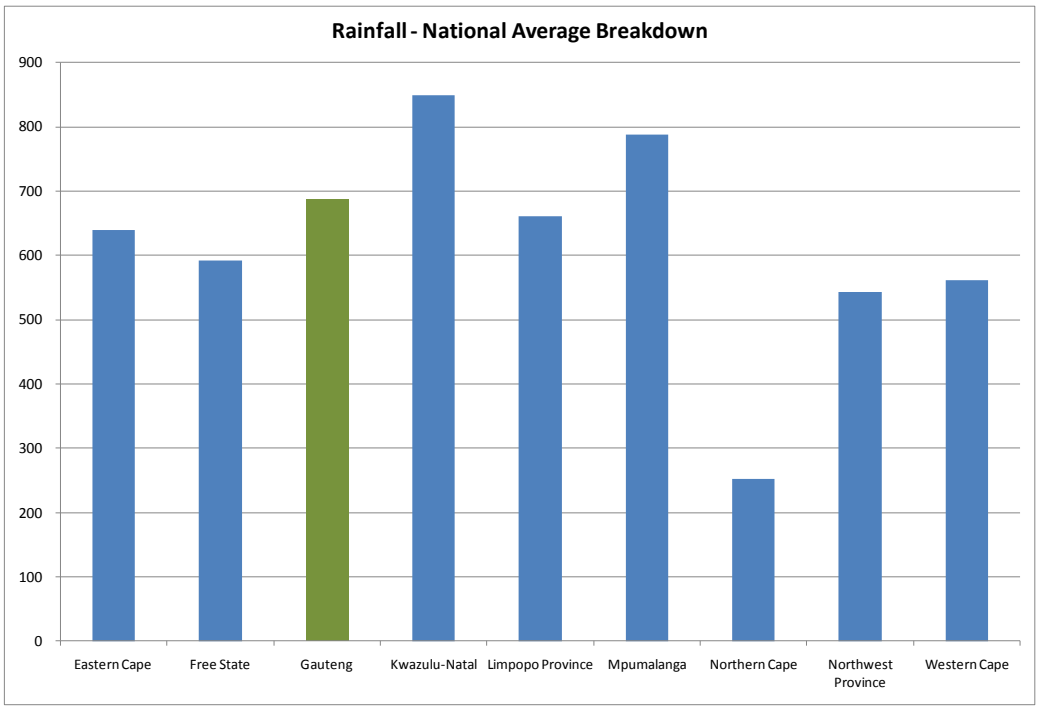


**Figure 2.6: National average rainfall. Source: South African Weather Bureau (2010)**

In relation to mining, different figures have been communicated in terms of the extent of effluent discharge. The CSIR (Manders *et al.*, 2009) equates the AMD threat to the Witwatersrand Goldfields alone at 10% (an estimated 350ML/day) of the total daily volume of *"potable water supplied daily by Rand Water to municipal authorities for urban distribution in Gauteng province and surrounding areas"*. Melissa Fourie of the Centre for Environmental Rights is of the view (Blaine, 2011b) that an estimated 2,5 billion litres of contaminated waste water has already been discharged into South Africa's streams and rivers, less than 900 million litres of which has been partially treated. She further believes that, on a daily basis, another further 40 million litres is discharged, of which only 12,5 million litres is partially treated.

While the water allocation associated with mining activities may be minimal (compared to other industries - see Figure 2.7) and the apportioned economic value in terms of a contribution to the gross domestic product (GDP) is substantial (R498.83/m³ versus agriculture's R0.98/m³) in relation to any other sector (DWAF, 2009:21), this should not justify practices and behaviours that are environmentally and socio- economically unsustainable.

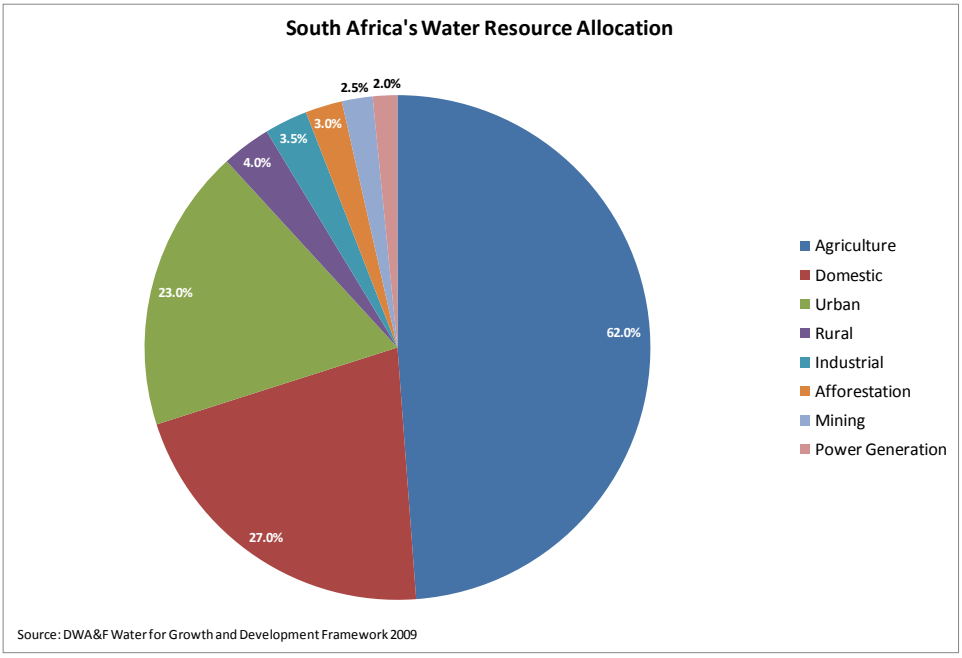


**Figure 2.7: South Africa's water resource allocation. Source: DWAF (2009).**

The uncontrolled discharge of contaminated mining effluent has resulted in the hydrological transport of acidic water and toxic metals into regional streams, rivers and drainage basins, polluting the primary element of South Africa's water availability mix (Turton, 2011). Such practices also serve to contribute to the pollution of the country's massive fresh groundwater reserves, which are recharged by surface water, and thus mining effluent must

be treated at source. However, while waste water can be treated to potable standards, mining residue dumps (tailings dams) will continue to be a threat in that they will always harbour the potential for AMD and heavy metal contamination. Even if retention ponds are used, it will be enormously difficult to prevent contamination from the direct wash-off and leaching of acid water and toxic metals from tailings dams into our eco-systems and water resources (Turton, 2011).

In this regard it would appear that, despite the recommendations approved in the DWA AMD report, government is content to ignore localised environmental damage and the risks to human health, and is more focused on managing such contamination reactively. Currently, the salinity of the AMD discharge from the Witwatersrand basin is only managed once it has entered the Vaal River system (DWA, 2010a). Where AMD constitutes only 5% of the volume and accounts for 20% of the salinity (and potentially toxic metals) of the water in the Vaal River system, the DWA (2010a) manages the quality of the Vaal River system through dilution with clean water from the Lesotho Highlands Water Project (DWA, 2010a), which surely amounts to the inefficient use and loss of a vital resource.

**FROM AN ENVIRONMENTAL AND HEALTH PERSPECTIVE:**

The second serious implication associated with mining, to which it appears minimal attention has been given, is the threat of the exposure of all living organisms to toxic metal and radionuclide contamination as a result of AMD. The author is of the opinion that the environmental and health risks associated with radioactive and highly toxic waste have been completed down-played or simply ignored. The threat arises, when metals present in the earth's crust and those residing in mining residue deposits, are mobilised by high concentrations of sulphuric acid generated from the mass oxidisation of sulphate-bearing minerals (pyrite). While most living organisms require metallic elements in varying amounts, excessive volumes can be detrimental.

According to Hogan (2010), heavy metals pose numerous challenges in that:

- they do not degrade and neither can they be destroyed;
- their degree of toxicity is dependent on the solubility of the metal;
- toxic metals will accumulate in biological organisms and will increase in levels of concentration up the food chain over time; and
- they are able to mimic other metals that are crucial for enzymatic processes, resulting in metabolic interference in the cells. A case in point is lead which often displaces zinc or calcium in the human body.

Living organisms typically require elements in the form of minerals, which can include zinc, iron, manganese, sulphate and potassium (Hogan, 2010). However, there are other metals, many of which are toxic in nature that are of limited or no benefit to living organisms. The excessive accumulation of these can be dangerous to the environment and health, prompting ecological destruction, serious illness and even death in animals and humans (see Annexure 3). Such metals are commonly referred to as 'heavy metals' and are typically elements with an atomic number of 21 or higher, although the term has more recently been utilised in conjunction with the treatment of plants and animals after exposure to high concentrations of metallic elements in the natural environment (Hogan, 2010). Such metals include lead, nickel, copper, cadmium, arsenic, cobalt, mercury, chromium and uranium.

While at present there is no known cause for autism, some speculate that it could stem from the severe impact of the build-up of heavy metals in humans (Parker *et al.*, 2005). According to Carin Smit (2009), a clinical metal toxicologist, *"when toxic metals enter the body, they attach themselves to the sulphur and hydrogen in proteins, which exist in the enzymes and hormones of the body, disabling these catalytic elements randomly or purposely leaving neuro-immuno-endocrinological devastation"*. She says further that, when children specifically are exposed, their neurological, metabolic and immune systems are devastated and they appear *"missing"* mentally and are diagnosed as having autistic spectrum disorder (ASD). Autism can have an impact children from birth (known as Kanners autism), or they are born normal and *"disappear"* at about nine, 18 or 24 months. Currently, there are limited statistics on children who are diagnosed with autistic spectrum disorder in South Africa, although international figures show that the number of incidents in the United States has increased from a ratio of 1 in 15 000 live births in 1985 to 1 in 99 in 2009 (USHSS , 2009).

Regarding the known behaviours of concentrated levels of metal complexes mobilised by acid mine water, there are numerous metals that are of immediate concern, namely iron, mercury and uranium. With regard to iron, it gradually oxidises in the presence of oxygen and water, forming ferric iron. In turn, actual ferric iron particles form, which give the acid water its distinct orange colour. These particles gradually precipitate out to the floor of waterways, essentially smothering all forms of life (Kilic, 2010). The reactions that occur (Bosman, 1974:340) include the oxidation of the sulphide to sulphate solubilises, forming ferrous iron,

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4$$

which is subsequently oxidised to ferric iron:

$$2FeS_2 + 7\,½\,O_2 + H_2O = Fe_2(SO_4)_3 + H_2SO_4$$

Uranium, on the other hand, is even more dangerous. It is a radioactive metal that decays into substances equally radioactive and deadly, namely thorium, radium, radon and palladium. Among its many symptoms are that uranium is neuro-toxic and that young

children who are exposed to it stand the chance that their *"fragile neurological wiring can become compromised early in life, leading to seizures, mental retardation and overt brain injury"* (Smit, 2009). Radon is a deadly, odourless gas which, when inhaled in excessive volumes, can cause numerous lung diseases, one of which is lung cancer. Thus while much emphasis has been placed on gold mining and the release of toxic metals, perhaps more attention should be paid to radioactive uranium waste, especially when it is taken into consideration that, although 43 500 tonnes of gold were extracted in one century, 73 000 tonnes of uranium were extracted from the Witwatersrand mining basin between 1953 and 1995 (Sutton *et al.*, 2006, Sutton *et al.,* 2006a & GDARD, 2011).

Locally, exposure to radioactive waste is a reality, as was determined in the Tudor Shaft informal settlement on the West Rand (see Photograph 2.1), between Roodepoort and Krugersdorp. Although radio-activity is directly related to mining activities, it is the disbursement of this material as a result of AMD, which is of concern to the author. Especially if one consider that in the adjacent fields to Tudor Shaft informal settlement, radiation levels of between 10 000 and 100 000[4] Becquerel's per cubic metre (Bq/$m^3$) above background radiation limits have been measured by Chris Busby (a member of the European Committee on Radiation Risk and the International Society for Environmental Epidemiology) (Smit, 2009). Upon discovery of these dangerous radiation levels, Busby recommended that not only should the community be relocated, but that an epidemiological study of cancer and genetic disease should be carried out to determine the impact of the community's level of exposure (Mammburu, 2010a).


**Photograph 2.1: Tudor shaft informal settlement. Source: Author (2011)**

[4] In the Saxonian, Thuringia, and Dresden regions of Germany, 7163 uranium miners who had been employed at Wismut, died from lung cancer between 1946 and 1990. For 73% of these miners, the cause of the disease was recognised as occupational exposure. Radon concentrations in Wismut's mines were approximately 100,000 Bq/$m^3$, with peaks of 1,5 million Bq/$m^3$ (Diehl, 2011).

International incidents of uranium poisoning, such as that at the Centre for Special Children in Punjab, India, should prove alarming and prompt South Africa into action. In 2008, while on a visit to India, Carin Smit (2009) was convinced that the physical symptoms exhibited by the children indicated that they had been poisoned (see Photograph 2.2). To verify this, tests were conducted on hair tissue samples in a German laboratory, the results of which showed that 87% of the children tested *"showed signs of elevated uranium in their systems"*. Although this predicament arose from the contamination of groundwater by fly ash generated by coal power stations, the potential for a similar disaster stemming from the mining industry could exists in South Africa.

**Photograph 2.2: The Broken Children of Punjab[5]. Courtesy: Gethin Chamberlain (Smit, 2009)**

The true extent of the threat of heavy metals and radioactive waste must surely be evident to the South African government, especially if one considers the wholesale ecological damage of the Robinson Lake on the West Rand (see Photograph 2.3). According to Liefferink (Mammburu, 2010b) what was previously a recreational dam is now a radioactive site totally devoid of life. This follows the pumping of mine acid water into the dam; by mines as an emergency measure to address the mine water drainage decant issue on the Western Basin in 2002. Although perhaps a precautionary step, the wholesale ecological damage should surely give rise to questioning of the findings of the DWA AMD report, which revealed that tests on the Witwatersrand river systems reflected no significant impact of AMD, and that the presence of heavy metals was hardly detectable (DWA, 2010a:45). The incident also provides support for the report's contradictory findings, which acknowledge that, if left untreated, acid mine drainage would have a serious effect on downstream environments (DWA, 2010a:58).

[5] The bitter legacy of governments' failure to act. The inclusion of these pictures is by no means intended to sensationalise the issue of heavy metals and neither is it intended to exploit the specific children. Rather they are intended to show the consequence of heavy metals to the fragile world of a child.

The third 'heavy metal' that the author believes warrants immediate attention is mercury. This should be understandable if one compares the mercury levels of AMD and the mercury levels recommendations in drinking water, by the EPA (2009). In the absence of South African surface-water samples, a sample taken from a Newmont Rain Gold Facility in Elko County, Nevada in July 1990, revealed mercury levels of 0.19 ppm (EPA, 1994), while the EPA's (2009) recommended maximum mercury levels in drinking water 0.002 ppm. In addition, the release of mercury as a result of AMD is cause for concern, in that according to the United States Geological Survey (USGS, 2011), inorganic mercury is converted by sulphur-reacting bacteria in soil sediment, to its most toxic form to humans, which is the most easily bio-accumulated in organisms - methyl mercury.

**Photograph 2.3: Robinson dam in Randfontein. Source: Author (2011)**

While South Africa's Mercury Assessment (SAMA) programme has been tasked with addressing the movement and implications of mercury, its focus has mainly been associated with mercury stemming from the country's coal-fired power stations (CSIR, 2006). This focus should be extended to include mining, especially when one considers the threat to human health from mercury poisoning, as highlighted by an incident in Minimata[6], Japan in 1950, where the blatant discharge of industrial waste into the sea resulted in many children being born with neurological damage and in the deaths of thousands of people (Psimoyos, 2008).

Whereas organic pollutants decay naturally, heavy metals lie dormant in the soil and thus require a different remediation approach. In addressing this requirement mining companies are making use of plants and micro-organisms with hyper-accumulation characteristics to remove heavy metals from the soil. The uptake of heavy metals is known to occur through plant root diffusion of metal solutes and the uptake of gaseous and ironic metals, via stomata and cuticle pathways respectively (Hogan, 2010). Such accumulation does not mean

[6] Minamata Japan was the scene of possibly the world's worst case of mercury poisoning in the late 1950's. The incident resulted in babies being born with; crippling cerebral palsy, blindness and serve mental retardation (Psimoyos, 2008).

elimination, and thus the plants are sometimes incinerated to recover the heavy metals (EPA, 2000).

While plants are able to release heavy metal ions through an efflux process via their stomata and cuticles, they are also susceptible to the impact of an *"elevated concentration of all heavy metals"*, which manifests itself in a *"decrease in germination, increase in seedling mortality, inhibition of growth rates and reduction in reproductive capability"* (Hogan, 2010). The bioaccumulation of heavy metals in plants also threatens the progressive food chain.

With the prevalence of environmental and health risks, there is cause for concern with regards to a few of the more toxic heavy metals (namely iron, uranium and mercury), in that there appears to be little evidence of research into the full effect of heavy metals and radioactive waste across the Witwatersrand mining basin. According to the CSIR (Turton, 2004), South Africa has yet to conduct a *"high confidence study of off-mine populations to determine what the impact has been from chronic exposure to heavy metals and radionuclide's".* Even though this lethal combination of radioactive and highly toxic waste-water is continually allowed to entering our freshwater reserves (aquifers, streams, lakes and rivers), affecting irrigated crops, destroying ecosystems, poisoning and killing wild-life, livestock and humans, no such recommendations for assessment programmes were made in the more recent DWA (2010a) AMD report.

Moreover, the proposed plans indicated in the DWA AMD report merely refers to treating the acid mine water as previously undertaken by the mining houses. While such practices neutralises the AMD, they would still result in the generation of water that is high in salinity levels and toxic and radioactive tailings that must be managed closely. This is only a short-term solution, and ecological damage will continue and health risks will increase. Allowing for natural or planned dilution by the release of clean water (as deemed appropriate by the DWA) is also not the solution. Believing that the threat will be minimised by being 'washed away' will not serve to change unsustainable practices and behaviours.

The issues surrounding AMD brings into question South Africa's philosophy on the relationship between ecosystems and human well-being, which should ensure that the needs of present and future generations are not compromised by current practices and behaviours. Under the umbrella of sustainable development, not only is South Africa failing to meet the environmental needs of the current population, but continued environmental degradation stemming from heavy metals and radioactive waste will have an impact on future generations and thus limit human progress. Even though South Africa has some of the most advanced environmental legislation in the world (GIBB, 2010), the country's focus and actions appear to be on social, political and economic growth that is supportive of consumer and materialist behaviours, while environmental integrity would appear to be on a different trajectory, especially as far as mining is concerned.

## 2.5 A policy framework review of acid mine drainage

Working ones way back up from acid mine drainage, there are numerous; governmental departments, environmental assessment tools, national policies, strategies and visions and international programmes that could have prevented the environmental and health threat that currently hangs over the Witwatersrand. In this context, the author tries to unravel South Africa's current predicament and explore a potential way forward.

In 1972, the United Nations Conference on Development and Environment gave rise to the philosophy of sustainable development as a result of the need to harmonise environmental and development goals. The subsequent establishment of the United Nations Environment Programme (UNEP) and the World Commission on Environment and Development (in 1983) led to the formulation of 'Agenda 21', a global programme as a framework for action towards sustainable development (Bartelmus, 1994). The commitments to this programme were reaffirmed at the World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa from 26 August to 4 September 2002. In support of this programme, South Africa instituted a national vision for sustainable development, which is enshrined in Section 24 of Constitution.

South Africa's National Vision for Sustainable Development reads as follows (DEAT, 2006);

> *"Everyone has the right to an environment that is not harmful to their health or well-being; and to have the environment protected for the benefit of present and future generations through reasonable legislation and other measures that prevent pollution and ecological degradation promotes conservation and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."*

In the context of this strategic framework, five priority areas were identified (DEAT, 2006):

- To enhance systems for integrated planning and implementation.
- To sustain ecosystems and use resources sustainably.
- To invest in sustainable economic development and infrastructure.
- To create sustainable human settlements.
- To respond appropriately to emerging human development, economic and environmental challenges.

An initial assessment within this broad framework would indicate that the government's response and approach to AMD was in contravention of its national vision and objectives for sustainable development, the intention of which was to realign all levels of government to

policies and decision making that would be consistent with the national goal of achieving sustainable development (DEAT, 2006).

In 2000 the United Nations facilitated consensus on the introduced of two programmes, in support of the Agenda 21 plan. These included the Millennium Development Goals (MDGs), in terms of which international communities would work *"to achieve eight critical economic and social development priorities by 2015"*, by investing in ecosystem services (UNEP, 2010:12), and the Millennium Ecosystem Assessment (MEA) programme, for the assessment of *"the linkages between ecosystems and human well-being and ecosystem services"* (UNEP, 2005:9).

Since South Africa is a member of the United Nations, the country is also a signatory to all three programmes (Agenda 21, the Millennium Development Goals and the Millennium Ecosystem Assessment). Although much has been communicated about the country's progress in this regard, one does wonder why the threat of AMD has gone unattended for so long, especially if one considers that, in accordance each of the three programmes, South Africa should have achieved the initiatives set out in Table 2.1.

**Table 2.1: Sustainable development programmes**

| PROGRAMMES | INITIATIVES | SOURCE |
|---|---|---|
| Agenda 21 | South Africa should, by 1996, have undertaken to create awareness of sustainable development, to engage communities in appropriate objectives, strategies and priorities for environmental integrity and human well-being (inclusive of public and private partnerships), had to build capacity that collectively would have led to the revision of policies, regulations, programmes and practices in support of the principles of sustainable development. | (UNCED, 1992) |
| MDG | • *"To eradicate extreme poverty and hunger and to achieve universal primary education"*<br>• *"To promote gender equality and empower women and to reduce child mortality"*<br>• *"To improve maternal health and to combat HIV/AIDS, malaria and other diseases"*<br>• *"To ensure environmental sustainability"*<br>• *"To develop a global partnership for development"* | (UNEP, 2010:13) |
| MEA | • A framework for the assessment, identification, benchmarking, management and review of priorities concerning ecosystems and human well-being.<br>• Building capacity for ecosystem assessments and *"to guide future research".* | (UNEP, 2005:11) |

A review of South Africa's roll out of the eight millennium development goals prioritised at the United Nations Millennium Summit in 2000 reveals that, of the ten supporting national development priorities included in the government's Medium term Strategic Framework (MTSF) for 2009–2014 (UNEP, 2010:13), one was related to health, and another to the sustainable management of resources, but no specific reference is made to environmental sustainability. However, environmental sustainability is one of the twelve outcomes against which the performance of the national priorities will be reviewed.

This lack of connection between the MDGs, the national development priorities and the performance outcomes is cause for concern if one considers that the purpose of the MTSF is to identify development challenges and to guide resource allocation and planning (UNEP, 2010:16). There is a further lack of connection between the goals and indicators utilised to assess development towards the eighth MDG - environmental sustainability (see Table 2.2). In relation to this goal (environmental sustainability) one would have thought it appropriate that the protection and management of environmental assets should have been a desired indicator. Where sustainability is mentioned, it is only in connection with MTSF strategic elements number 5 and 9, in which reference is only to sustainable livelihoods as a result of economic growth and transformation, and the use and management of resources (see Annexure 4).

**Table 2.2: Millennium Development Goals and Indicators for Environmental Sustainability. Source: UNEP (2010:85)**

| MDG Environmental Sustainability Goals and Indicators | 2015 target achievability (2010) | MDG or domestic goal |
|---|---|---|
| Proportion of land area covered by forest | Unknown | MDG & domestic |
| $CO_2$ emissions | Possible | MDG |
| Consumption of ozone depleting substances | Likely | MDG |
| Proportion of fish stocks within safe biological limits | Not applicable | MDG |
| Proportion of total water resources used | Unknown | MDG |
| Proportion of area protected | Likely | MDG |
| Number of species (vegetation) threatened with extinction | Unlikely | MDG |
| Proportion of population using an improved drinking water source | Achieved | MDG |
| Proportion of population using an improved sanitation facility | Likely | MDG |
| Proportion of urban population living in slums | Unlikely | MDG |
| Proportion of households with access to electricity | Possible | MDG |
| Proportion of population using solid fuels as primary source of energy | Achieved | MDG |
| Number of legally designated landfill sites | Not applicable | Domestic |

Moreover, where South Africa has acknowledged in its 2010 MDG country report (UNEP, 2010:84) that *"environmental preservation is an essential foundation for sustainable development and poverty alleviation",* it has failed to utilise the Agenda 21 programme, the Millennium Development Goals and the Millennium Ecosystem Assessment, all of which would offer a framework, desirable objectives and an assessment tool, for the achievement of environmental sustainability.

A review of the constitutional rights shows that government's stance on AMD, contravenes sections of South Africa's legislative framework (Algotsson *et al.*, 2009) pertaining to water, which include:

- Sections 24 and 27 of the Bill of Rights, which emphasises the right to a healthy environment that is protected from degradation.
- Section 3 of the National Water Act (NWA) (Act No 36 of 1998), which confirms that *"as the public trustee of the nation's water resources the National Government, acting through the Minister, must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate."*
- The provisions of the Municipal Systems Act, which calls for a municipal service that eliminates public health and environmental safety risks.
- The provisions of the National Environmental Management Act (NEMA) (Act no. 107 of 1998), which calls for the sustainable management of South Africa's natural resources and which also requires that government to implement environmental management plans as per section 11 of the Act.

Furthermore, the government as regulator has failed to ensure the compliance of mining companies to the Mineral and Petroleum Resources Development Act (MPRDA) (Act no. 28 of 2002), which calls for environmental management programmes (section 38) and a mine closure plan (section 43), both of which are official documents that are auditable. The MPRDA (Act no. 28 of 2002) adopts an upfront risk based approach concerning financial provisions (section 41) for rehabilitation and closure, which must be approved by government.

Finally dual environmental processes within governmental departments namely the DEA and DMR, has the potential for creating confusion. A position that has been supported by the CSIR, who has been quoted in saying; that between national, provincial and municipal levels, the delegation of power is unclear (Manders *et al.*, 2009). While May Hermanus (Naidoo, 2009) of the Centre for Sustainable Mining in Industry has also pointed out that the different facets of the mining industry rest with different government departments.

**ASSESSMENT MECHANISMS FOR ACID MINE DRAINAGE:**

The assurance of environmental integrity and human well-being in the long-term is dependent on interactions between the two and the ability of either to influence the other. This is a relationship that should not be left to chance, but rather evaluated in a structured manner, giving rise to a comprehensive understanding of the broader complexity of the system in which they co-exist. As the foundation for social development and economic growth, environmental integrity must be sustainable, and thus the assessment should hold no limitations when, determining the influence of drivers that would disrupt sensitive balances across geographical regions and time periods. Conceptual decision-making assessment frameworks are emerging as accepted mechanisms in the delivery of such outcomes.

Crucial for such decision-making mechanisms is the alignment with the broader intentions of sustainable development, although, in South Africa's bid to address AMD, obvious gaps exist between the country's environmental statements of intent and its action on the ground. Cascading down from the United Nations programmes on sustainable development, the national vision on sustainable development could be deemed appropriate, although environmental sustainability is evidently missing in government's development priorities. It is this gap, the disconnection between the MDGs and South Africa's MTSF strategic priorities (as previously mentioned), and governments' inaction towards addressing AMD, that has the author questioning governments' political will to take action.

Further to this, the author would argue that even more disconnections emerge, namely the disconnection between the government's development priorities and the specific performance outcomes concerning environmental asset and resource protection. This raises questions as to how such an specific performance outcomes will be achieved - a gap that is also glaringly evident in the recommendations proposed in the DWA's report on AMD. In fact, the report only proposes that, in the short term, there should be a return to a situation in which the conditions should *"be no worse than those which were experienced during periods of active mining"* (DWA, 2010:48).

It is doubtful that such a solution can be construed as environmental protection, especially if one considers that, in active mining operations, while waste water is neutralised, the social and environmental risks associated with the release of waste water and a toxic heavy metal residue, still remain. Neutralisation only serves to elevate the pH level of the water, and to allow the precipitation of the heavy metals, the resultant by products of which are, waste water high in salinity levels (as a result of the addition of lime) and heavy metals tailings (van Hille *et al.*, 2001), which are deposited onto tailings dams, and serve only as a toxic time bomb. All of this again raises questions about the extent of the recent research undertaken by the team of experts.

In view of the conclusions reached in the DWA AMD report, and with consideration for the wide range of implications associated with AMD, it is evident that the recommendations being proposed will fall far short of what should be deemed appropriate. Where the social and environmental implications will remain unresolved, one can only but question the overall goal(s) that were intended and the assessment process that the team of experts adopted in trying to get there.

Where there are numerous tools that could be utilised in the assessment of the environmental, social and economic implications associated with AMD and the appropriateness of a solution, many may prove reductionist in their approach and outcome. Solutions that would be deemed relevant to AMD are those that adopt a systems approach by ensuring environmental sustainability, social development and economic growth. Such tools are more commonly referred to as sustainability assessment framework mechanisms (see Annexure 5), which, while serving different purposes, will involve different trade-offs between socio-economic, environmental, technological and political factors. The relevance of an assessment mechanism is dependent on the overall vision/goal that one is trying to achieve, the appropriate temporal view and the desired outcome(s), as seen by the respective stakeholders, while serving the participant, who will live with the consequences of the environmental decision.

Moreover, assessment framework mechanisms must be driven by stakeholder participation, multi-criteria and perspective integration, capacity and consensus building (Kiker *et al.*, 2005). Although, in South Africa the author would argue that the current decision-making process is seen as having been adversarial and lacking in credibility in that little or no effort was made to engage various stakeholders regarding their perspectives and because of the conclusions reached, it would also appear that not all the criteria were considered. This further exacerbates the belief that historical approaches to the resolution of AMD have not been multidisciplinary, but rather reductionist in design.

According to Kiker *et al.* (2005), environmental decision makers are faced with dissimilar information that is of a quantitative and qualitative nature and difficult to integrate. Typically, such information includes four different types of technical inputs: *"the results of modelling and monitoring studies, risk assessment, cost or cost-benefit analysis, and stakeholder preferences"* (Kiker *et al.*, 2005). Kiker *et al.* (2005) also indicates that assessment tools that facilitate decision making must allow for the selection of management alternatives that *"minimises human health and ecological risks and cost, while maximising public acceptance".*

While there are a comprehensive number of assessment tools[7], they typically fall into three categories (Ness *et al.,* 2007), namely

- Indicator and indices-based tools, for performance assessment;
- product or service-related tools, which focus on material or energy flows from a life cycle perspective; and
- integrated tools, which focus on policy change or project implementation.

Of the different sustainability assessment framework mechanisms, the indicator-based models are more retrospective in their approach, while product and integrated models are inclined to be more prospective. In the case of AMD, while it obviously essential to focus on the three pillars of sustainability, specific attention must be given to the relationship between users and the environmental and health consequences that could prevail in the long-term. In this regard, until more sustainable mining practices can be adapted, an appropriate tool is one that would facilitate a longer term assessment.

The Multi-criteria Decision Analysis (MCDA) approach (see Figure 2.8), which is prospective in its nature, is best suited to the analysis of quantitative and qualitative problems and the evaluation of alternatives across multiple streams of dissimilar information. Stakeholders take full ownership, in that the process of selecting objectives, criteria, scores and weightings and the review of alternative options for, achieving the overall objectives form part of a participatory process (Kiker *et al.*, 2005). Although, where the use of scores and weights contributes to the openness and explicit nature of the process, the averaging of weightings can led to the interruption of the results and a loss of trade-off information (Argyrous, 2010).

According to Kiker *et al.* (2005), the three core ingredients for successful environmental decision making are people, process and tools. However, sustainability assessment tools will only hold power and serve the well-being of mankind if they are prompted by legislation, which is supportive of sustainable development.

[7] It is beyond the scope of this report to conduct an in-depth review of each of the assessment tools, and thus only a high-level comparison of a few of the tools is given: the Life cycle assessment process, the environmental impact assessment, and the driving force-state-response (see Annexure 5).

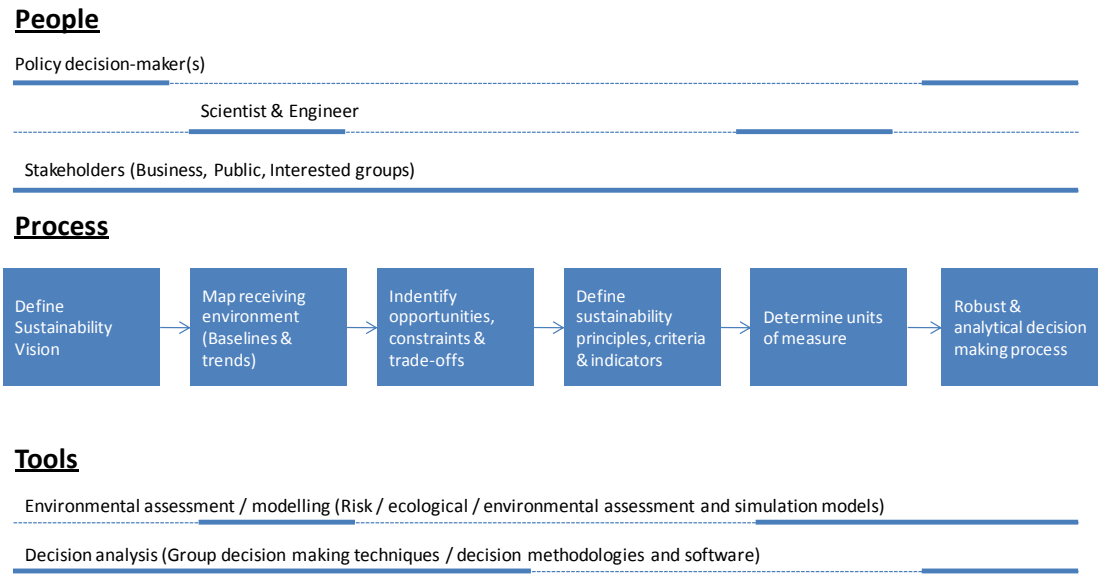


**Figure 2.8: Depiction of the MCDA assessment framework. Adapted from work by Kiker *et al.*, (2005)**

## 2.6 Summary

Where mining holds such economic potential for the country, one would assume that mining operations will no doubt continue and unless a conclusive solution is found, the threat to environmental and human well-being will persist. This is especially concerning when; while there is extensive literature and reports on physical aspects of this story such as geology, mining, hydrology, radioactivity, heavy metal distribution and so on, there is hardly any information in relation to the biological aspects and even less on the medical aspects of AMD and heavy metal pollution. According to Stoch *et al.,* (2008), the literature on the history of the Wonderfonteinspruit (on the West Rand) in particular, from the first study by Hunter and Duff in 1904, *"would exceed five metres if piled on top of each other".*

However, despite all of this research, stakeholders continue to question government concerning their inaction towards AMD, on the Witwatersrand. Perhaps as Turton (2009) argues, actors within civil society have grown tired of the *"endless stream of reports and worthless research"* and are now calling for action. A position, that one would be inclined to support, especially if it is perceived that the very well-being of the pollution (or portion thereof) could be jeopardised. This very imbalance concerning 'activism' and 'inaction' is what the next section of the report serves to understand, through the use of a phenomenological study.

# Chapter 3 – Research Process

## 3.1 Introduction

Where literature reviews may be restrictive either in the accessibility to data or as a result of time constraints, one is able to circumvent such limitations by structuring a reasonable comprehensive view on a specific topic. This can be accomplished by engaging with prominent stakeholders. Therefore, with a fairly well developed literature base on the causes and possible solutions to AMD (as confirmed from secondary data obtained from within the general public domain), the research process needs to understand the perspectives and perceptions of a selected group of stakeholders, in relation to the AMD threat and contrast this with observations in the field. The intended research approach, as mentioned in Chapter one, would be a phenomenological study, and was based primarily on one-on-one discussions conducted with a cross section of stakeholders – supported by field trips to the affected areas.

With an understanding of the broader context of the data that was required, a slightly ambiguous methodology was compiled that set out to unravel and explore possible common themes across a selected group of participants. In this regard, attention was given to the identification of preliminarily participants with direct experience in AMD and fortunately enough as a 'hot' issues, this did not prove difficult at all.

## 3.2 Data collection techniques and processes

Interviews served as the main data collection instruments, and where qualitative assessments are more prone to the utilisation of unstructured questionnaires, the decision was made to incorporate specific open-ended questions, in order to elicit stakeholder views on AMD related issues. This was done in order to improve the authors understanding and to assist in the data analysis process, with the evaluation of underlying themes. While set out as merely explorative in structure along certain subtopics of AMD, the interviews were based on an unstructured approach, where participants were encouraged to speak freely, about their experiences and understanding concerning the AMD threat. Where face-to-face interviews were not practical for geographical reasons, structured telephonic interviews were conducted.

To facilitate the interviews, loosely structured questionnaires were compiled on a broad range of topics that relate to AMD. The participants were engaged concerning their views on AMD, in order to gain a better comprehension of the threat at hand, in support of an

objective evaluation of potential solutions. Thus the questionnaires were structured in order to elicit data in the following general categories:

- AMD in general, including; awareness to and understanding of 'all' the potential risks, reasons for governments' inaction and possible solutions;
- understanding what 'corners' (if any) had been formed concerning AMD, and which stakeholders were standing in which corners;
- views on the DWA AMD report. Including the makeup of the team, the terms of reference and most importantly – the findings; and
- understanding of existing knowledge gaps.

Where it was expected that sensitivities pertaining to ethical and political views/issues may arise, during the interview process, (that would have been difficult to anticipate and which could have complicated interactions), the author adopted a position of neutrality. According to Maxwell (2008:234), it is necessary to maintain the desired relationship with participants, in unravelling the different perspectives, perceptions and relative positions on events, actions (or inactions) of primary role players. In order to understand and contextualise individual views and experiences, comprehensive notes were captured.

Thought was given to how questions would work in practice, especially with regards to time management, where experience has shown the time lost with selected participants is normally very difficult to recoup. As a typical constraint, careful attention was given to the maximising of the interview time, by consistently trying to gauge the relevance of data to the research questions. A typical fear in such situations is, the obvious concern that certain information could be filtered out. The author feels that while this was a difficult balancing act, it was well managed. However, it must be noted that ample value was gained by allowing participants to become slightly side-tracked.

Field trips that were undertaken in the accompaniment of different stakeholders, allowed the author to conduct informal observations of the affected area – specifically the Western Basin. Some of these field trips were fairly limited because permission to access mine property had not been sought, while others allowed for the extensive coverage of the affected areas.

## 3.3 Scope of research and sampling design

As for the boundaries of this research, it must be noted that rather than devising the next solution to a very technical subject (especially where numerous research has already been done regarding causes and potential solutions), the intention of the research was to

establish the degree of alignment (or misalignment) that existed between stakeholders, to an appropriate solution to AMD. It was also expected that where alignment did exist regarding such findings, clarity would also develop towards an explanation on the reasons behind the delayed implementation of a solution.

In the context of the above scope of research, and with the knowledge that a sustainable solution would require input concerning the environmental, social, economic and political aspects associated with AMD, the identification for the selected sample of participants was not as difficult as anticipated. Although while it was acknowledged that the final research sample group would ultimately be dependent on individual availability and a willingness to participate, the goal was to strive for a research sample that would be homogenous in nature and that focused on specific individuals knowledgeable on the concerns of AMD and its affected areas. The very reason for such a sampling approach revolved around concerns relating to the feasibility and accessibility of data, and hence a purposeful sample was selected. Confirmation of this sample was sought in the interaction with different stakeholders, throughout the data gathering process.

Preliminary research and contacts, gave rise to a specific mixture of stakeholders (as shown in Table 3.1), the characteristics of which are discussed in Chapter 4.

**Table 3.1: Acid mine drainage sample target**[8]

| ORGANISATION | AVAILABLE | POSITION |
|---|---|---|
| The Department of Environmental Affairs (DEA) | Yes | Deputy Director: Extension Services EIM |
| Chamber of Mines | No | Head of the Environmental Department |
| Western Utilities Corporation | No | CEO |
| TouchStone Resources | Yes | Environmental Advisor/Speaker/Author |
| The Federation for a Sustainable Environment | Yes | CEO |
| The Centre for Sustainable Mining in Industry (CSMI) | Yes | Programme manager – bio-physical environment |
| The Department of Water Affairs (DWA) | Yes | Acting Director. Gauteng regional office |
| Council of Geosciences | Yes | Specialist scientist. Environmental Geosciences |
| | Yes | Geologist |
| The Geosciences Department, University of the Witwatersrand | Yes | Professor of Geology |
| The CSIR | Yes | Senior researcher hydrogeologist |
| | Yes | Senior researcher |
| Old Mutual investment group South Africa (OMIGSA) | Yes | Head of sustainability index |
| Biomimicry South Africa | Yes | Head Biomimicry South Africa |
| The Cancer Association of South Africa | Yes | Member |
| University of the Witwatersrand Zoology department | Yes | Professor of Zoology |
| University of the Free State | Yes | Professors, Institute for Groundwater Studies |
| Synapse Africa Neuro-Nutritional Clinic | Yes | Clinical metal toxicology |
| Mine Health & Safety council | No | Chief research & operations officer |

[8] Without wanting to frustrate any of the different parties any further, some of the names of individuals interviewed as part of this research process have not been included and only reference to their respective departments or institutes has been made.

The risks of such a research sample were understood, taking into consideration that the theme of the research may develop (Fossey *et al.,* 2002) and that the contribution of the disenfranchised or disempowered individuals may have been excluded. In this regard particular reference is made to the poor, who are currently living with the consequences of governments' stance towards AMD. Although the intention was not to purposely side-line such groups, it was important to try to reach consensus regarding an 'appropriate solution', within the scope and time constraints of the research study. Although, it must be said that in an attempt to gauge the full extent of acid mine drainage threat and to gain firsthand experience, field trips were undertaken to the affected areas.

In terms of a geographical scope, where it is envisaged that the ultimate solution would be one that would be deemed appropriate for the entire Witwatersrand, encompassing the Eastern, Central, Western and Far Western basins, actual field studies focused more specifically on those areas warranting immediate attention, for example the Western Basin which is currently decanting.

## 3.4 Data analysis procedure and interpretation thereof

On completion of the main data gathering process, the data was analysed with the purpose to interpret and identify common themes. In the analysis of data, Coffey *et al.* (1996) stipulates that there are three main qualitative research analysis groups, which one can adopt. These methodologies include: a categorising strategy, a connecting strategy and a memos and display approach. In categorising strategies, data is fractured and rearranged into categories, from which themes can be established (Strauss, 1987). Categories in this approach could include: broad topics, concepts and beliefs of participants derived either before or after the analysis. However Maxwell (2008:237) cautions that such an approach may *"lead to the neglect of contextual relationships among the data"*. In a connecting strategy approach, an attempt is made to understand the relationships within the data, without first fracturing it. While the memo's and displays approach actually refers to the regular compilation of memos to *"stimulate and capture ideas"* (Maxwell, 2008:234), while displays are a method for the reduction and presentation of data in a holistic manner through concept maps.

Out of the above mentioned options, a combination of categorising and connecting strategies was utilised in the analysis and interpretation of the underlying themes, as determined by the various stakeholders. The analysis and interpretation of the data occurred concurrently with the data collection process, as recommended by Creswell (1997) as a basic principle of qualitative research.

No computer programs were utilised in the analysis of data.

## 3.5 Research complications and delimitations

In the context of the anticipated field work, there was the concern that where different or hidden agenda's may have existed, across the various stakeholders (including government), these would not surface in the research process. For example, where stakeholders are funded by the very organisations they are investigating. In order to address these concerns, attempts were made in the interview process to subtly test the waters. The concerns was also, that where such agenda's did exist, they would have resulted in restricted access to specific reports or sites, for example, where contaminated sites fell on mine property, visits may only have been permitted under the accompaniment of either mine or environmental personnel and it was feared that this could prove to be a barrier. Fortunately access to crucial sites was never a problem as discussed in Chapter 4.

With regards to the validity and creditability of the findings and conclusion(s), integrity was crucial in managing bias, particularly in the process of collecting and analysing data. In this regard, the author (and thus the interviewer) adopted a neutral stance towards any previous associations with or loyalties to the mining organisations which formed part of this study. According to Maxwell (2008), validity comes from, *"the sustained presence of the researcher in the setting studied"*, capturing *"verbatim transcripts of the interviews",* seeking confirmation of solicited information and evaluating conclusions against *"supporting and discrepant data".*

## 3.6 Summary

With reference to work by Mouton (2009), the above chapter *"documents the design and methodology followed"* in the fieldwork section of this study. Where, although allowances (as communicated earlier in Section 3.1) were made for on-going alterations to the data gathering process and instrument, and discussions were allowed to flow freely, the process overall was channelled in such a manner that enabled the author to listen for subtle and important cues (Leedy *et al.*, 2010), as divulged by the participants, in getting to the heart of the research study.

The validity and reliability of the outcome of the phenomenological study, while dependent on the bias of the author, was also dependent on; the data gathering instrument, contributions by participants and the analysis and interpretation of the data gathered. The author believes that this research process was more than appropriate in serving its intended purpose. A reflection of the intended purpose is covered in Chapter four.

# Chapter 4 – Research Findings

## 4.1 Introduction

As mentioned in Chapter one, the main goal and objectives of this report was to unravel the sense of alignment to the real problem and potential solutions associated with AMD, through a primarily two phased research approach that included a review of existing literature and a phenomenological study – supported by informal observations. The main driving issue behind this research was the lack of what would be deemed appropriate action on behalf of government and the private sector to this emerging crisis. It is in this context that the research process (Section 3.2) focused on: 'what actually is the problem', 'why is nothing being done about it' and 'what are the potential solutions' and it is in this very order that these findings are discussed[9].

While one can embark on an exhaustive review of existing literature, one may never get to the crux of an issue, as was established in the phenomenological study, undertaken as part of the overall research into AMD. The outcome of the study and the informal observations, highlighted the importance of trying to establish what is actually happening in reality, which is not always represented in the literature that is readily available in the public domain. Depending on who is yielding the power, relevant information can be withheld from respective recipients, in order to create the necessary level of awareness that would be deemed appropriate.

Unless one is able to deepen ones search, this false perception will continually be perceived as reality. In this regard, the phenomenological study and field trips proved to be enormously valuable sources of information, in unravelling crucial elements of this research, as reflected below.

## 4.2 Discussion on the sample and its characteristics

As the sample was targeted towards prominent stakeholders within the AMD arena, it must be noted that from the outset, the author was rather sceptical about obtaining access to individuals and their willingness to participate. Although for what is supposedly a

[9] While Mouton (2009) speaks of an exhaustive literature review, this is not always possible as was discovered in this study. In fact in the interview process, the author was directed to additional/new sources of literature, some of which was written by the respective participants. Where it was deemed necessary, such references have been included in the discussion on the findings, to substantiate the views of particular stakeholders.

contentious topic, it must be said that the level of participation of the stakeholders that did avail themselves, was unbelievable. What was very encouraging was the extent to which participants were willing to divulge information and direct the author to a cross section of important stakeholders. So much so, that across the final sample group the initial perceptions (held by the author) concerning the hidden agendas of individuals soon faded.

The make-up of the sample group (see Table 3.1) was important in ensuring the quality of the phenomenological study and thus it included a cross section of independent stakeholders (civil society activists), experts from government departments and research councils, experts from the health profession and professors from universities. Where the author did get access to certain representatives from government and the mining industry, wider access to such groups would have been preferable. For example, the Department of Environmental Affairs (DEA), the Chamber of Mines, the Mine Health and Safety Council and Western Utilities Corporation (WUC), whose recently proposed solution to AMD has been one of the more progressive solutions to date.

In summary, with regards to stakeholders' perceptions relating to the implications of AMD, there did not appear to be a massive variety of beliefs and positions concerning what needed to be done amongst the community of stakeholders – as will be explained in Section 4.3. However, it was evident to the author that a sense of frustration exists across the sample group. A sense of frustration that the author perceived is linked, to a concerned group of individuals and their inability to get something done. A clear divide, to which saw the majority of the government departments and institutions on the one side and civil society activists on the other. Although sadly, the continued inaction to a mutually acceptable solution, will only serve to fuel this unhealthy environment, prompting further scepticism and finger pointing, which will result in parties moving even further apart. This issue is expanded upon, in the recommendations in Chapter 5.

## 4.3 Discussion on findings

### A DISCUSSION ON WHAT ACTUALLY IS THE PROBLEM

Concerning interactions with participants on what actually was the problem, while there was consensus on the fact that mining operations were creating acid water, the general awareness seemed fairly confined to the need to prevent and manage the rise of AMD below the Witwatersrand. On the environmental front, where certain participants had conducted extensive research, others, while acknowledging that AMD was detrimental to the environment, were not in a position to explain to what extent this may be happening. More importantly, very few of the participants communicated any awareness to the potential health implications of AMD. In fact, the conclusion drawn by the author was that

across the broader sample group, very little was known about the potential environmental and health implications, although this could perhaps have been symptomatic of the arenas in which participants have been operating or as a result of the limited available data concerning research conducted in these two areas. Although, the need to address this knowledge gap has been supported by the DWA, in its call (in the recent DWA AMD report) for *"a birds-eye-view environmental risk assessment of the entire Witwatersrand gold-mining basin, focussing on the impacts of mining on the environment and the health and safety of communities"* (DWA, 2010a:12). However, this observation (to this limited awareness of the true scale of the environmental and health implications) did however raise immediate concerns as to the lens through which decisions were being made regarding potential solutions – an issue that is discussed later in this chapter.

Two main areas emerged influencing the scale of AMD - that relating to the surface (the mine waste and tailing dumps) and underground (the ground water and decant) impact. With regards to the underground impact, where it was widely acknowledged that AMD was polluting the groundwater, figures relating to the potential volume of groundwater in the dolomitic aquifer below the Witwatersrand differed substantially. While many speculate, the CGS (2011b) would argue that the volume is approximately equivalent to one third of the capacity of the Vaal Dam. However, while it was widely accepted that AMD was still a threat to the Witwatersrand region, clarity on the volume would help contextualise the scale of the threat.

The other area influencing the scale of AMD was that which related to the surface impact – the main driver of which is the tailings dams and the reef and waste rock dumps. The consensus reached by the participants was that depending on how well they are managed, such deposits will continue to impact both surface and underground water resources. Where discussions centred more on the immediate underground water problem, concerns were raised that the surface impact will prove to be the greatest contributor to AMD, for years to come. To substantiate this, the author was directed to the following data:

- The Department of Water Affairs and Forestry (2001) has acknowledged that waste from Gold mining is the largest single contributor to waste and pollution, in that it accounted for 47% of the total mineral waste in South Africa.
- Of the waste, the tailings dams alone account for some 6 billion tonnes that resides in 270 dams spanning a collective area of some 400 km² (Oelofse *et al.*, 2007) across the Witwatersrand.
- Added to which there are more than 1 000 sink holes (formed when AMD dissolves dolomitic ground) in the Western and Far Western Rand goldfields alone, many have been filled with uraniferous slimes material, for stability purposes (Coetzee *et al.*, 2004), further complicating the pollution of underground water.

Where the author has alluded to the fact that a general (as opposed to a specific) mention was made by the participants concerning details relating to environmental and social implications, field trips to the West Rand did revealed two obvious social risks. The first being that 'cakes' made of mine tailings are sold along the road side, to pregnant women in particular, who consume them with the belief that they were rich in essential minerals and therefore of great nutritional value. This is incredibly dangerous as according to Scott Baker (Psimoyos, 2008), a specialist in DNA species identification of Oregon State University, the most serious health risk of high levels of toxicity is to pregnant women, as the foetus is the most sensitive and therefore highly susceptible to toxic poisoning.

The second social risk relates to the use of mine tailings in the manufacture of building material (specifically bricks – see Annexure 7), that are being sold to unsuspecting buyers. While it has been acknowledged by the Department of Mineral Resources (DMR, 2009), that such practices aid the *"dispersal of radioactive material into the environment",* it continues to this day. Not only are occupants of houses built with such brick exposed to radon, they are also exposed to radon gas.

Both of these incidents are particularly worrisome if one considers the toxic elevation levels on the West Rand, as expressed in the Water Research Commission (WRC) 1214 report (Coetzee *et al.,* 2004), which shows that:

- in the Western and Far Western Rand goldfields alone there is approximately 100 000 tonnes of uranium (Coetzee *et al.*, 2004:iv), in the tailing deposits.
- *"a total of 24 tonnes of dissolved uranium was calculated to have be released into the environment from unlined tailings deposits alone",* into underlying aquifers or dewatered dolomite in the Western and Far Western Rand goldfields.
- an *"estimated that approximately 10 tonnes of (particle-bound) uranium per year are flushed by storm water into receiving watercourses."*
- in the Wonderfonteinspruit of the Western and Far Western Rand goldfields, the following uranium sediment readings[10] were recorded; 50-60 mg/kg in the Donaldson dam, 900 mg/kg in the Andries Coetzee farm dam and 1000 mg/kg in the slime and evaporate dams.

Moreover, what was even more deeply concerning was that in the interview process, stakeholders from the DWA (2011) down-played these figures, arguing that they could have accumulated over years. Although surely, regardless of their origin and the accumulation period, what is important is that they do not decay and their continued accumulation serve

[10] According to Coetzee (2004), readings were determined utilising semi-quantitative ICP-MS1 scans and quantitative XRF2 methods and *"were analysed using a Tier-I risk-assessment procedure based on the method described by the United States Environmental Protection Agency".*

as a current health risk, as is evident in the airborne radiometric map a shown in figure 4.1 (also see Annexure 7, to contextualise the location).

Also evident on the field trips, was the fact that settlements (both informal and developed) are being allowed to be established within close proximity of such tailing dams; informal settlements such as the Tudor shaft settlement (as mentioned in point 2.4) and the Amberfield retirement home (see Photograph 4.1). The latter of which is a new development and which was recently closed and auctioned off, as a result of health risks. All of which must have proved a big blow to one of the country's top financial institutions who financed the development, but failed to assess the risks upfront (Liefferink, 2011b). To think that elderly folk were being attracted to such a development, to live out their last years, is shocking to say the least.

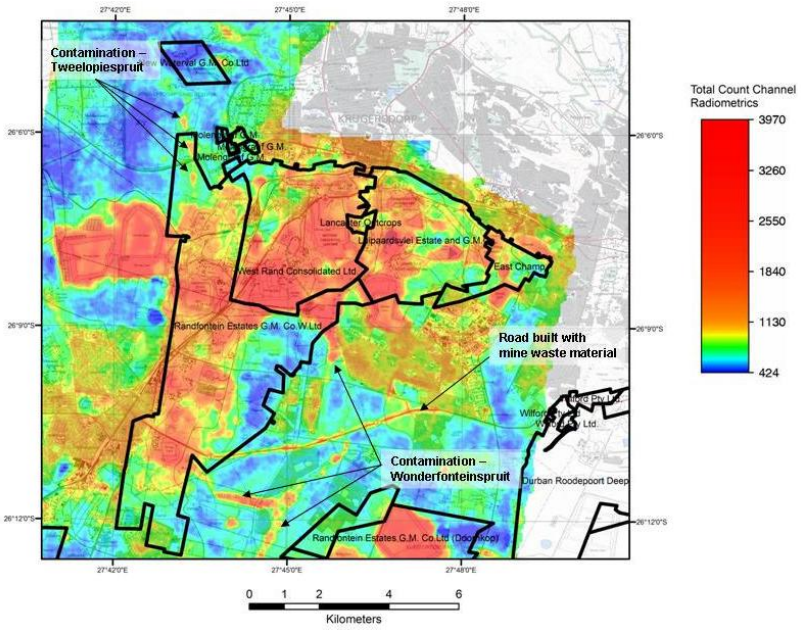


**Figure 4.1 : Airborne radiometric map of the West Rand Goldfields. Source DME**


**Photograph 4.1: The Amberfield retirement home. Source: Author (2011)**

Participants were in agreement that while there has been comprehensive research into the physical attributes of AMD, there is very limited information of the biological and health aspects of AMD. According to Albrecht (2011) (a member of CANSA), as far as the Cancer Association of South Africa is aware, when it comes to biological/health matters there are no reports from either; the Medical Research Council (MRC), the National Institute of Occupational Health (NIOH), the National Health Laboratory Service (NHLS), the Department of Science and Technology (DST), the National Research Foundation (NRF), and the Council for Scientific and Industrial Research (CSIR). He argues that if such research has been done, the reports are not being made public.

According to Turton (2009), it was reported in 2008, that the first national level epidemiological study (what has been referred to as the Tooth Fairy project) of the effect of radionuclide and heavy metals contamination would be carried out, by the CSIR (2008) and the Medical Research Council (MRC). To date very little progress has been made in this regard, in fact it is understood that the project never even materialised (CSIR, 2011).

The other challenge raised by participants, concerns the irreversible damage as a result of AMD. In this regard, the European Environmental Bureau (EEB, 2000) argues that the environmental damage to ecosystems is irreversible. According to Francois Durand (2011) (a professor of Zoology) examples of these irreversible damages are; the formation of sink holes and the destruction of complex food webs in groundwater. Complex food webs are shown to contain amphipod species, on which tests have shown that the exposure to a solution of water containing 10% of AMD, kills these organisms within less than 9 hours. He argues that once the amphipod species disappears, it is pretty much irreversible.

In this regard, specific attention has been drawn by participants, to the potential threat of AMD to the Cradle of Humankind World heritage Site. While obviously an important site, the author is of the opinion that this has been done with the sole purpose of creating awareness in an attempt to get government to respond to the crisis – although surely the immediate environmental and social concerns should be of greater importance.

**A DISCUSSION ON WHY VERY LITTLE HAS BEEN DONE TO ADDRESS THE AMD ISSUE**

The second important dimension of the field research revolved around assessing stakeholder alignment (or misalignment) to the reasons behind governments' and the private sectors' inaction towards AMD. In trying to comprehend why AMD (in the Witwatersrand) has been allowed to amount to the environmental and health risk that it is today, there was the general consensus that one needs to consider two main issues. One being the historical relationship between government and the mining industry that dates back to the late 1800's, and the other being governments' role as regulator of the mining industry, both of which are fundamental in understanding government's and the private sectors inaction towards AMD.

In the view of Turton (2009)- the evolution of South Africa's mining industry was one where *"powerful financial interests coincided with the interests of a racially defined elite, which saw government becoming a collaborator rather than a regulator of the mining industry",* which for the last century has manifested itself as a policy of extraction. A view that is supported by Van Eeden, Liefferink and Durand (2009), in their conclusion that; *"both parties benefited economically from this relationship, while government turned a blind eye to environmentally and socially harmful practices of mines".*

Turton (2009) argues that throughout this period, the focus was on the generation of profits, and reducing operating costs and thus all liabilities were avoided – basically these costs were externalised. This policy of extraction has continued through to our present day government, fulfilling different purposes along the way, which have included:

- the extraction of mineral wealth, by the British (1910 – 1948), following the Anglo-Boer War.
- a policy of mobilising the economy (in support of the new government), in the transition to an Afrikaans government (1948 – 1961).
- the collaboration of interests between the mining industry and the government in the preservation of an apartheid state (1961-1976).
- the mobilisation of national resources towards the survival of the state (1976 – 1994).
- *"the redistribution of wealth and privilege"* (1994 – present).

The other fundamental issue was that prior to the promulgation of NEMA (No. 107 of 1998) and NWA (No. 36 of 1998), mining companies were only really bound by the Water Act of 1956 (see Figure 4.2), which was insufficient (DWA, 2011) in dealing with mine closures. Thus, historically, mines that were no longer profitable were boarded up and abandoned and the land transferred to the government. Confirmation of this, was the Fanie Botha accord of 1975 (Chamber of Mines), where an agreement was reached between the Chamber of Mines and government, which stated that after 1976, government would take over the ownership of abandoned mines, if they existed before 1976 (DWA, 2011).

Moreover, even with such legislation, there was very limited regulation by government. Where both NEMA (Act no. 107 of 1998) and NWA (Act no. 36 of 1998) stipulated that *"a party has to take all reasonable measures to prevent pollution or degradation from occurring, continuing, or recurring as a result of mining operations for which it is responsible"* (van Eeden *et al.*, 2009), this was never enforced by government. In fact, according to current legislation, mining companies are only required to comply with the environmental legislation reflected under the DMR, as covered in the MPRDA (Act no. 28 of 2002), and are thus are able to avoid the more stringent DEA environmental legislation (DEA, 2011).

Basically this indicates that there are two parallel processes for basic and environmental impact assessments applications, one in the DEA and the other is the DMR. Although all prospecting or mining applications are dealt with by the DMR - mining is the only industry that has this privilege (Fourie, 2011).

According to the DEA (2011) this conflict of interest prompted an agreement in 2008 between the Ministers of Mineral Resources and Environmental Affairs, for the revision of legislation that would see all environment issues fall under one department, even though, in 2009 NEMA (Act no. 107 of 1998) had made provision for one authority and application process for environmental impact assessments. Despite the completion of amendments to NEMA (Act no. 107 of 1998) in August 2010, MPRDA (Act no. 28 of 2002) has yet to be amended. This has delayed the enactment of six of the one hundred and seven environmental impact assessment (EIA) listed activities that call for environmental authorisation prior to commencement – all six of the outstanding activities, relate to prospecting and mining (DEA, 2011).

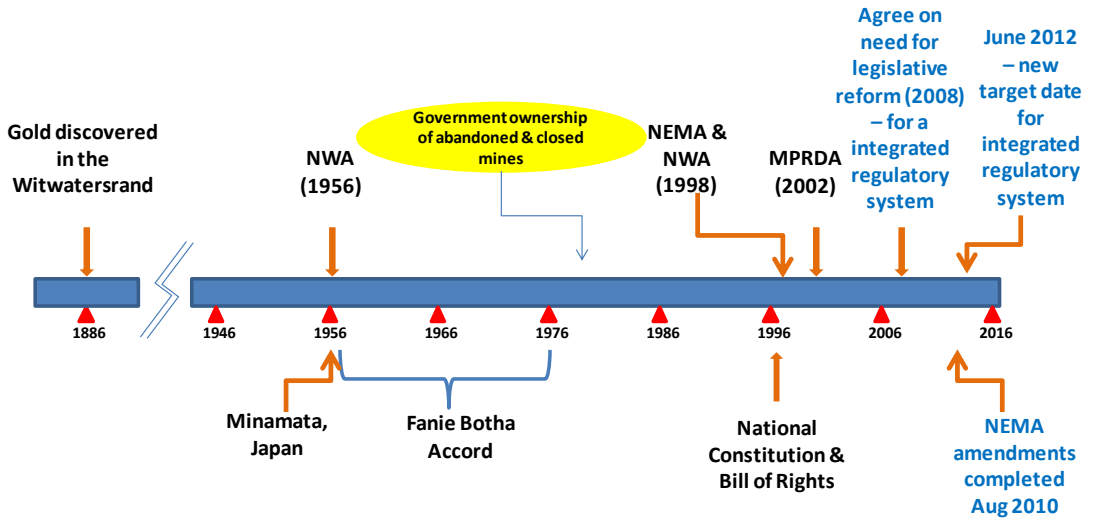


**Figure 4.2: Legislation timeline. Source: Adapted from work by the Centre for Environmental Rights & the Department of Environmental Affairs**

One of the big challenges with the mining legacy in the Witwatersrand is that very few of the perpetrators are still in existence and thus it has proved very difficult to enforce the 'polluter pays principle' as laid out in the NWA (Act No 36 of 1998) and NEMA (Act no. 107 of 1998). Although even with the introduction of the MPRDA (Act no. 28 of 2002) as mentioned in Section 2.5 (in which the principles of sustainable development are enshrined), government has failed to enforce compliance of those mines that are under new ownership, and to use environmental management programmes and mine closure plans, as stipulated in the MPRDA (Act no. 28 of 2002).

Today, current legislation is intended on preventing or minimising long-term environmental impacts through the up-front provision of remediation funds, in the form of trust funds that are held by the DMR. However, the guidelines (DME, 2005) for the calculation of such provisions, as set out by the Department of Minerals and Energy (DME), are not conclusive. Where both the mine water decant and the discharge from waste dumps and tailing dams will continue to flow for many years to come, aftercare is only planned for the 2-3 years after production stops. Further to this, no provision has been made for the long-term maintenance, operation and aftercare of the 'treatment plant', which might or might not be outsourced/transferred to a third party.

It has proved difficult to retrospectively impose such regulations (although limited) on mines that can no longer afford to make such provisions, as they near the end of the profitable life of the mine. In fact the DWA (2011) argues that where the idea of the trust funds was only introduced in 1992, many of the mining companies that operated in the Witwatersrand had already made their profits and have long since unbundled their operations. In this regard, the DWA is of the opinion that there are loop holes on the side of the DMR, that allow mining companies to play with 'ownership' – in doing so, unprofitable mines are hived off, with claims that they lack the necessary funds for remediation. The other complication is that where waste management falls under the auspice of the environmental authorities, mining waste has historically not been classified as waste, as it is seen as having a future potential value (Turton, 2009).

The DWA (2011) also believes that a lack of synergy between DWA and DMR contributed to governments' delayed response to the AMD threat. While the DWA has been mandated to manage AMD at an environmental critical level (which is believed to be around 150 m below ground level), this would result in the flooding of the country's mineral assets, and where the responsibility for the protection of such resources falls with the DMR, it was expected that the DMR, would have acted first – although to date, they have yet to take any action.

As for government's current position regarding AMD (specifically in the Witwatersrand), participants likened it to that of Thabo Mbeki's approach to HIV and Aids – one of avoidance in light of the financial implications. The feeling is that AMD is too big a problem and thus the government has not wanted to expose it, for fear of a disruption to the economy. Sadly though, this could have similar consequences to Minamata Japan (Psimoyos, 2008), where the Chisso factory and government had conspired to cover the dumping of toxic waste into the bay, for 12 years.

**A DISCUSSION ON POTENTIAL SOLUTIONS AS SEEN BY THE PARTICIPANTS**

The final dimension of the field research, sought to understand participants' alignment to a sustainable solution to the AMD threat. In this regard, participants were very much of the opinion that the current decant on the West Rand must be managed and the Witwatersrand

water resources must be protected from contamination, and while no specific mention was made concerning what technology should be utilised (although it was stated there were numerous processes that could be utilised), there was consensus that AMD should be viewed as potential source of water.

When questioned on the findings of the DWA AMD report, while participants spoke highly of the team of experts, many felt that the report highlighted nothing new and did not go far enough in addressing AMD. There were even suspicions as to whether the report was indeed the final report, as fears were expressed that perhaps it had been scrutinised by government and subsequently scaled down. However subsequent discussion with representatives from government departments regarding the report, clarified that the terms of reference had been limited to investigating solutions to the rising water and to the quality of the water and thus the report was not intended as a comprehensive solution to AMD (DWA, 2011). This would certainly seem plausible, especially if one considers that one of the leading compiler and contributors to the DWA AMD report, was also the compiler of the WRC report that highlighted the uranium threat in the Wonderfonteinspruit, which was dubbed the 'Infamous 1214' report by the mining community (Turton, 2009).

The DWA (2011) states, that, their AMD report focused primarily on finding a quick and easy solution in the short-term. In particular, the solution aimed at stopping the decant on the West Rand and to bring the level of AMD across the three basins to a level that was not critical to the environment. This would create a void/buffer for high levels of inflow, and would also mean the re-commissioning of old and the erection of new pump and neutralisation plants to maintain and treat at such levels. The DWA (2011) added that while the short-term solution would result in the release of effluent high in sulphates, it was deemed the only appropriate plan; if one considers that a water treatment plant could take up to one year to build.

While it was also acknowledged that the dilution of this water in the Vaal river system, with water from the Lesotho Highlands Water Project, was an inefficient use of 'tomorrows' assets, the DWA (2011) stated that this could not be sustained, as come 2014 Gauteng would be facing another water shortage. It is this deadline that is now prompting the debate, as to whether another augmentation scheme should be brought in sooner or whether the pollution should be stopped. The current thinking around which says, it would be cheaper to stop the pollution, which means that the water will need to be desalinated – this assumes that the effluent is being neutralised effectively in the first place. In effect this would mean that in averting a water shortage, water supplies would have to be supplemented with treated AMD, which in turn would mean a proactive approach to AMD.
Where no reference was made by participants to any particular scheme or technology in the treating of AMD, reference to the Emalahleni water reclamation plant in Witbank was made. The plant is co-owned by BHP and Anglo Coal and treats 25 Ml/day to a potable water standard (Günther *et al.*, 2006) by means of a reverse osmosis process and while the plant

costs some R300 million, it operates at a loss, which is in accordance with the 'pollutor-pays-principle' of the NWA (Act no. 36 of 1998) (Doyle, 2010).

With the acceptances that the Emalahleni approach may in fact serve as a solution to the AMD threat in the Witwatersrand, participants were questioned on why the Western Basin Environmental Corporation (WBEC) failed in their bid to erect a similar operation. WBEC was set up as an Agenda 21 company, by three mining houses (namely, MinTails, Harmony Gold Mine and Durban Roodepoort Deep) in response to a request from government (who threatened to hold back closure certificates), to find a sustainable solution to manage their liabilities (Liefferink, 2011b).

Liefferink (2011b) states that as a no profit organisation, WBEC set up WUC to attract investment in order to fund an environmental impact assessment (EIA) and the erection of a pilot plant. She goes on to say that where such investments were obtained, from the IDC, the DBSA, the respective mining companies, and Water Mark Global, WUC indicated that while they could treat the water, they would need a return on their investment in the form of a client for the takeoff and this is where the process began to break down. While apparently R73 million has been spent, the project has since been mothballed. There are various views as to why this happened. Without going into too much detail, the following views were expressed by participants:

- The bid was not submitted in accordance with the Public Financial Act (PFA) and was therefore seen as unsolicited and was thus rejected by government (Liefferink, 2011b).
- Negotiations failed as government was concerned that there was no black empowerment involvement and that WUC was wanting a 16% return on their investment (Turton, 2011), which is contrary to the 'polluter-pays-principle'. A difficult challenge if one considers that most of the mines are ownerless.
- WUC was seen as a commercial interest and taxpayers' money could not be utilised to subsidise an agreement from which a profit would be made (Keet, as quoted in the Mining Weekly – Prinsloo, 2010).

So where technology (the Emalahleni water reclamation plant in Witbank), has been tried and tested, how will this impasse be overcome? WUC argues (Prinsloo, 2010) that in the case of the Emalahleni plant, the polluters are known, which is not the case on the Witwatersrand, and thus a different mindset is required. Turton (2011) argues that to succeed, the economics must come in under R3 /$m^3$ (which is the current cost of water as supplied by the Rand Water Board), and which is not the case in WUC's proposal. Although he is of the opinion that water is currently under-priced and will have to be increased (a position that is supported by the Centre for Development and Enterprise) (CDE, 2010) - a barrier that he believes must be dealt with sooner or later.

While such an approach could go a long way in addressing the underground aspect of AMD in the Witwatersrand, participants seemed less aligned in terms of a solution to the other major source of AMD – the surface aspects which includes, the discharge and seepage from tailings dams and reef and waste dumps (see Figure 4.3). Of the solutions that were put forward, while some had merit, most would require further investigations. Listed below are the solutions that were proposed.

- Liefferink (2011b) voiced support to reclaiming and reworking existing dumps, with the view of recovering the gold and possibly the uranium resources, the tailings of which could be accumulated into a 'super dump', which may be easier to manage – as opposed to a number of smaller dumps.

  She argues that residual foot prints must be remediated especially where dumps were located on dolomite ground and that new dumps, if not lined, they should be located on non impervious ground.

- The CGS (2011b) proposed that disused dumps should be 'capped' to limit the ingress of water, thus limiting the possible subsequent generation of AMD. The council argues that 'capped' dumps would be more cost effective than creating 'lined' super dumps – as it would be far easier to control the ingress of water into the dumps as opposed to the seepage of AMD (generated by the ingress of water) out of the dumps.

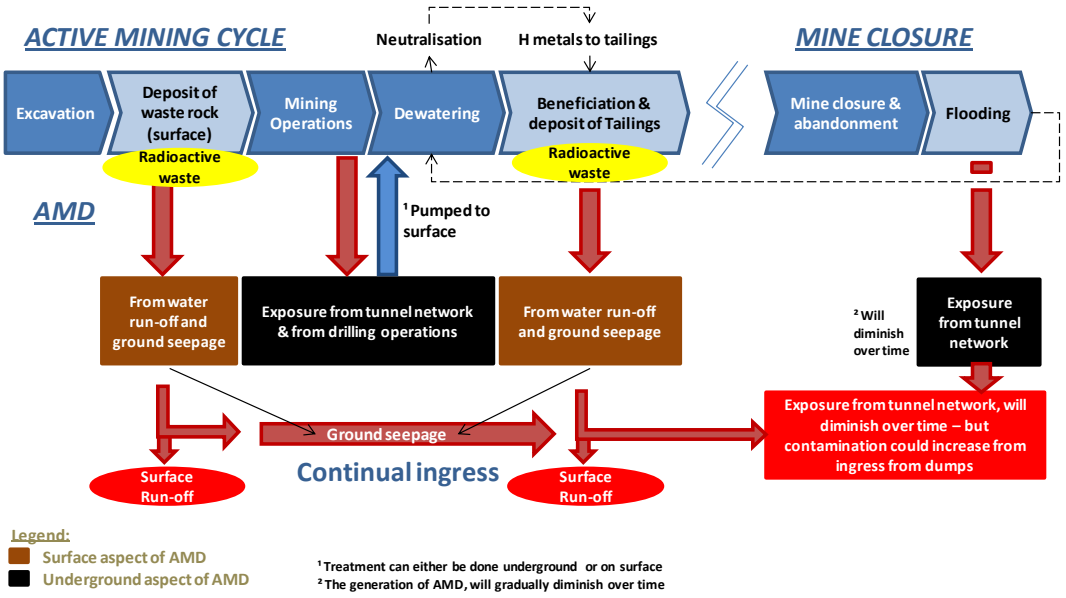


**Figure 4.3: Depiction of the role that tailings dams and waste dumps play in the formation of AMD**

## 4.4 Collation of themes in relation to research questions

Clearly evident from the research, was that a threat to the environmental integrity, human well-being and the economy of the Witwatersrand region has been allowed to develop, as a result of a mutually beneficial relationship between the mining industry and government, which has not only blurred the issue of 'ownership' (to the threat), but also saw the slow introduction and poor enforcement of legislation, which could otherwise have gone a long way to curtailing such a threat.

Also evident was a distinct lack of literature and awareness of the possible environmental and social risks associated with AMD, which brought into question the decision-making tool utilised in the identification of the solutions, as proposed in the DWA AMD report. The search for a sustainable solution is futile, unless consideration is given the three pillars of sustainability, through the use of a participatory trans-disciplinary assessment process. Although, even if a comprehensive solution had been decided upon, its chances of success would be questionable, as a result the inconsistency towards environmental protection across government departments and their poor record as regulator (see Figure 4.4).

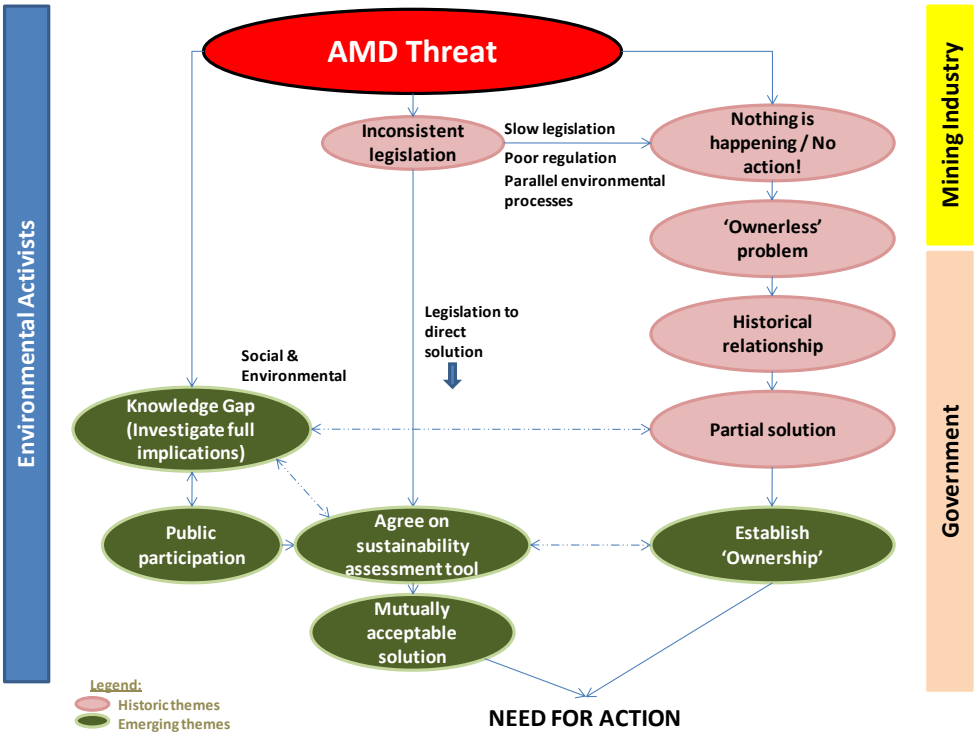


**Figure 4.4: Schematic collation of themes**

Where stakeholders were not in agreement on a particular solution, they do want to see some action, to what they perceive is a well researched issue – well at least with regards the physical aspects of AMD and a clear link to the source of the threat – the mining industry. While stakeholders are concerned about the limited available research of the true implications of AMD to the environment and human well-being (which they feel warrants urgent investigation), there is the belief that AMD (once treated), must be seen as a future resource.

The themes that have emerged from the research are very aligned to the profiles of the different stakeholder groups, which show that:

- The mining industry's paradigm has been one of extraction at least possible costs.
- As a collaborator in the mining industry, government policy has been to support the industry, through preferential treatment.
- Where the profile of the independent stakeholder group included medical professionals and environmental professional and activists, their motives have been towards environmental sustainability and social well-being. The group wants to see urgent attention to the AMD threat, through the enforcement of the 'polluter-pays-principle', where they believe the mining companies have profited from the very practices, which resulted in the development of the threat in the first place.

  Although where they acknowledge, that the establishment of ownership may prove difficult, their attention is turning to government (as a beneficiary and the ultimate authoritative body), to tackle the problem.

## 4.5 Summary

As highlighted through discussions with stakeholders, perceptions relating to the actual implications of AMD seemed to stack up into two distinct groups. Perceptions which related merely to controlling the decant of AMD and thus could be positioned more towards the starting point of a continuum, which concluded on the opposite end, with the dire concerns for environmental and health associated risks. A similar pattern emerged concerning; the inaction by both government and the private sector to potential solutions to the AMD threat on the Witwatersrand, which is consistent if one considers the respective departure points i.e. the perceptions towards the full implications of AMD.

Interesting enough, the perceptions were not split entirely along the lines of public stakeholders on the one side and government on the other. In fact certain government institutions held similar views and concerns with those of the civil society activists, especially concerning environmental issues. While not totally aligned, the mix of perceptions is not

surprising, considering the different profiles of the sample group – who essentially have been operating in isolation of one another. Although, such contrasting views are not conducive to a decision-making process, that should serve the interest of all stakeholders.

# Chapter 5 – Conclusions and Recommendations

## 5.1 Conclusion and an interpretation of results against the literature review

As highlighted in Chapter 1, (Section 1.4), the overriding objective of this study was not to arrive at the next great scientific solution, but rather to establish the degree of alignment between the perceptions and perspectives of stakeholders towards a sustainable solution for AMD on the Witwatersrand. However, as became evident from the research, such an evaluation would be fruitless, because the solutions that are being proposed are based on the different views (or positions) of stakeholders (see Figure 5.1) regarding the implications of AMD. Whereas civil society activists are calling for a solution that would lean more towards addressing the environmental and social implications, government and the mining sector are down-playing (or ignoring) these implications, and appear to be more concerned with the subsequent consequences of such a solution. While the activists are not disputing the role of mining, they are concerned about the well-being of South African citizens.

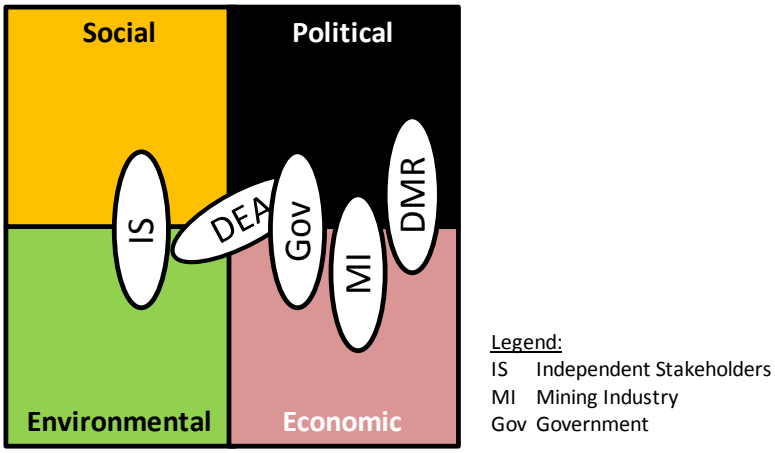


**Figure 5.1: Depiction of stakeholder positions regarding acid mine drainage. Source, Author (2011)**

Although there is some degree of alignment to a solution (as evident from the literature review and the phenomenological study), it is only with regards to one aspect of AMD – containment of the AMD decant (the underground aspect of AMD). There is very little agreement regarding solutions to the surface aspects, which include the following: the discharge of AMD from waste dumps and tailing dams, seepage of AMD from waste dumps and tailing dams into groundwater, and the radioactive sites that develop as a result of the

decant and subsequent flow of AMD - let alone the waste and tailing dumps that are themselves radioactive (CGS, 2011b).

Therefore, even if a comparison of the alignment of solutions as proposed by the sample group were to be conducted it would be of little value (as previously mentioned in Section 4.4), because crucial research and thus inputs regarding the full implications of AMD - specifically environmental and health related research - are missing. However it must be said that, while it is acknowledged that acquiring such information will take some time, government has had time. The South African government has been aware of the dolomite mine water problem since the 1960's and has had AMD on its agenda since the mid-1990's (Liefferink, 2011a & McCarthy, 2010).

If this logic that the picture of AMD is incomplete is applied to the solutions proposed in the DWA AMD report (which seemed to take on a single-criterion view), then surely all their solutions (short-, medium- and long-term solutions) can be seen as unsustainable, because of the mere fact that they do not consider the full implications of AMD, – which involves environmental, social/health and economic implications. The DWA findings and subsequent recommendations fail to address environmental and human well-being concerns, which raises questions firstly about the acceptance of responsibility or the liabilities associated to mining (including the potential implications thereof) and secondly about the governments' willingness to engage in a trans-disciplinary multi-stakeholder assessment process to find a comprehensive, sustainable solution that is mutually acceptable and rights based.

Two utterly fundamental issues that have been central to the problem:

- First, mining waste has typically been seen as 'spoils' (as an asset[11]) and not as waste. Therefore, mining houses have been allowed to skirt around the 'polluter pays principle', which otherwise would have forced them to address the AMD problem at source.
- Second, the historical and mutually beneficial relationship between government and the mining industry has, resulted in government (as regulator) ignoring the practices of the mining industry. This has been facilitated by an initial lack of appropriate legislation and, more recently, by less stringent environmental processes, as allowed under the DMR.

Even within the restricted terms of reference of the DWA investigation into the AMD threat (Section 4.3) the investigation failed, because it ignored the most essential elements of environmental decision-making – stakeholder participation. Kiker *et al.* (2005) would probably classify South Africa's approach as one of *"decide and defend"*, where stakeholders are seen as a constraint and where the process would do *"little to serve the interests of the*

[11] Where technology relating to the beneficiation process has improved over the last century, old tailing dumps are reworked to reclaim core minerals from previously inefficient processes.

*stakeholders who must live with the consequences of the environmental decision".* Confirmation of this is evident from the government's role in this whole debacle, and thus it is unsurprising that the DWA's AMD report did not go to an independent review. This, also despite South Africa's participation in the 'access initiative', which ensures; access to information, participation and justice in decisions pertaining to environmental integrity (WRI, 2002).

While South Africa now has probably the most advanced environmental legislation in the world (GIBB, 2010), government's slow introduction and poor enforcement of this legislation has caused immense damage and frustration. It is evident that nongovernmental stakeholders are frustrated with the continued environmental and social neglect by the mining sector and government, with government's failure as regulator, and with continued inaction regarding the AMD threat on the Witwatersrand. Perhaps equally frustrated are the representatives of government institutions, who do not want to accept full responsibility for the current AMD situation, as they believe this rests with the mining companies. However, as previously discussed (Section 1.3), because mines may belong to second-, third- and even fourth-generation 'owners', it has been extremely difficult to apportion responsibility.

This combined frustration is only serving to drive stakeholders apart, and is fuelling mistrust. While independent stakeholders are being seen as alarmist, this very group is asking questions as to government's (and unfortunately all associated government institutions are lumped together with government) political will to investigate the full implications of AMD, and to accept or assign accountability for the management of the associated risks. It seems obvious that the mistrust among stakeholders is the result of groups working in isolation. Stakeholders should work together to find a mutually acceptable solution. Perhaps they are being prevented from doing so by the very beneficiaries of the process.

While it is encouraging that the consideration of solutions appears to be moving in a more proactive direction, (which could include, for example, the erection of expensive plants for the conversion of contaminated water to potable water and the recovery of heavy metals to be sold for commercial gain), such solutions will only serve to address part of the problem. The focus of this report is on AMD, which is only one of the implications associated with mining. What is actually required is a comprehensive solution that addresses not only the underground aspects of AMD but also the surface aspects, such as the management of tailings dams and waste dumps, of limiting the threat of AMD and its associated environmental and health risks. This is an important factor that has been excluded from the current thinking regarding solutions; a fully integrated solution is what is required. Hence the proposal for a trans-disciplinary approach (as discussed in Chapter 2).

Funding acceptable solutions will be an enormous challenge. Certain funds have been allocated towards addressing the underground aspects of AMD (Section 1.4), but a considerably greater investment will be required for the remediation of the surface aspects. A review of the German Federal Government's estimated costs for the remediation of the

Wismut sites, which produced 220 000 tonnes of uranium between 1946 and 1990, shows that one is looking at a possible cost of US$ 43 per kg of uranium produced (Diehl, 2011). In the context of the Witwatersrand, where 73 000 tonnes of uranium where mined between 1953 and 1995 (Sutton *et al.*, 2006, Sutton *et al.,* 2006a & GDARD, 2011) one can thus expect these costs to be enormous. Nonetheless, the real question is: What cost is South Africa prepared to place on human well-being, when we have similar threats on our very own doorstep?

The recent incident that occurred at Robinson Lake on the Witwatersrand and the potential distribution of radioactive ground (from AMD discharge), should provide conclusive evidence of the detrimental implications of AMD, to motivate for a multi-stakeholder assessment of the four cornerstones of sustainable development - environment, social, economic and political - and their relationship to one another, in determining a sustainable approach to AMD. The solutions must meet our environmental and health standards if they are to be seen as even vaguely sustainable.

Although the South African government claims to support the global initiatives on sustainable development (as mentioned in Section 2.5), compliance on the ground shows differently, as is evident from the inconsistency within government concerning environmental regulations and the special treatment shown to the mining industry. In particular, government's inaction towards AMD only serves to expose its failure to deliver on the human rights of its citizens (as conveyed in the South African Constitution, as discussed in Section 2.5) and its misalignment to the global Agenda 21 plan and its supporting programmes, namely the Millennium Development Goals (MDGs) and the Millennium Ecosystem Assessment (MEA) programme.

Furthermore, while government has acknowledged that water is important for growth, one would question why its growing scarcity in the country should not have prompted actions that are supportive of provincial and national water management policies and strategies. Crucial to the Agenda 21 programme and to South Africa, was the call for the integrated management of water resources (CSD, 2001), with particular emphasis on the following: protecting water, the quality thereof, and the related ecosystem functions. In fact, whereas a national commitment was made to the Agenda 21 programme, one wonders why a complete disregard for associated behaviours has been allowed, as is the case with the whole AMD debacle.

Unfortunately, we have also chosen to ignore what other nations, such as Canada, have learnt before us (Section 1.2). Whereas the Canadian government established a Mine Environment Neutral Drainage (MEND) group in 1982 to address AMD, why then has the Gauteng provincial and South African governments ignored the environmental pollution created from mining – and for so long? It is difficult to comprehend that, with international experience to leverage on, that government in all this time has failed to address AMD, but has rather opted to protect mining companies - and thus the revenue that government

would stand to gain. The resulting legacy - an 'ownerless' environmental, social and economic threat to the province of Gauteng – will in the end, no doubt fall into the lap of the taxpayer.

## 5.2 Interpretation of results with reference to similarities, anomalies and deviations

The research showed that there is much more to the problem than initially perceived, as highlighted by the following rather surprising results:

- From the onset of this research the author was of the opinion that, although the mining companies were central to the source of the AMD threat, they were also central to the scale of the problem and behind the inaction that had been shown in addressing the AMD threat, which the Gauteng Province now faces. However, the author would argue that government were in fact the greatest of culprits, in that instead of adopting their assigned role as regulator they became a collaborator in a mutually beneficial situation.

  Whereas the DWA's AMD report mainly focused on the underground implications of AMD (the rewatering and ingress of surface water into underground voids), the research showed that this is only part of the problem. It is deplorable that the terms of reference of the report (as directed by government in response to a public outcry) chose to ignore investigations into the 'real' issues, namely the environmental and social implications of AMD. This knowledge is paramount in understanding the real implications of the threat as expressed in the concerns of environmental activists.

- Although it has been communicated in the public domain that heavy metals are mobilised as part of the AMD process, very little is known about the true implications of this. The following can be considered as crucial to this research: the documentary entitled 'The Cove', which highlights the health implications of heavy metals and which prompted an investigation into the broader topic of health implications in relation to mining. Whereas information on warnings of the severe implications of excessive exposure to heavy metals was found, very little literature was found that was directly related to mining (particularly in South Africa). However, the mere association between heavy metals and the possible environmental and health implications (evident in cases such as Minamata, Chernobyl and Wismut) should have been sufficient to prompt the inclusion of environmental integrity and human well-being into the DWA AMD report.

  The lack of information on the true environmental and health implications could stem from the fact that limited research has been conducted or, where such investigations have been undertaken, restrictions could have been placed on the release of such information into the public domain, for fear of exposure.

- Before the revelation concerning heavy metals and their potential environmental and health implications, it was thought that an appropriate solution to AMD would be fairly simple, and one to which the various stakeholders would be pretty much aligned. However, in light of the emergence of the possible implications (the full consequences of which are unknown), arguing in favour of a supposed 'comprehensive' solution would have been worthless. Instead, while elements of alignment are discussed, the author has mainly drawn attention to the crucial gaps in the decision-making process and argued that, if a truly sustainable solution was to be achieved; such information would need to be included in a trans-disciplinary, multi-stakeholder assessment process.
- The collective research processes showed that there is sufficient intellectual knowledge available to address the threat of AMD; the problem is the segregation that exists between individuals and groups. Nonetheless, the above points in this section provide substance to the different profiles that drive this segregation, as discussed in Section 4.4.

## 5.3 Relevance and value of the study

First and foremost, the study has been of great value to the author because it created an increased awareness to the true scale of the implications and reality of AMD on the Witwatersrand. This awareness has grown through all the aspects of this research, the foundation of which has been an enlightenment to the interrelationship and interdependency of the broader components and principles of sustainable development. Before this study, despite the author having worked in the mining industry both directly and indirectly for about nineteen years, such awareness would have done little to awaken the author to the real costs of mining and the associated costs to our environment, human well-being and economy.

Whereas the broader acknowledgement of the full implications of AMD as viewed from a sustainable development perspective appears limited as was established in the research process, the study is of particular relevance in creating awareness of the need for a more comprehensive solution - not just to AMD, but to broader mining activities across the country – an awareness that would signify that not all is well with mining. The study also informs the public of the great need for research into the real risks to the environment and human well-being, associated with such practices. Until all this has been achieved, these practices should be deemed unsustainable.

It is also intended that the study will highlight that, until the crucial research regarding the environmental and social aspects of AMD (and the broader mining industry) is conducted, all proposed solutions will be meaningless (as alluded to in Section 2.4). The study will also

highlight an awareness that will shed some light on the work that activists have been doing for years, in trying to bring this threat to the attention of the general public and, more importantly, to government's attention.

The study is also relevant in that it has given clarity to the role players behind this whole debacle, which in itself gives explanation to the reasons behind government's and the private sector's inaction towards the environmental, social and economic risks associated with mining. It has also highlighted the extent to which government has failed its citizens, which is especially disturbing when one considers that government (to whom the public looks for guidance) has been at the very centre of this issue, ever since the mining industry commenced.

Ultimately, whereas the study sought to unravel 'what actually is the problem concerning AMD on the Witwatersrand' and 'why is nothing being done about it', and 'the thinking concerning potential solutions as seen by prominent stakeholders', it has expanded to create a broader awareness of the knowledge and process gaps that need to be addressed in order to arrive at a comprehensive and sustainable solution.

## 5.4 Recommendations

The following recommendations are proposed. They are presented in what the author deems the most appropriate sequential order. The recommendations include immediate steps that should be taken and additional research that is required.

**OWNERSHIP AND LEADERSHIP OF THE AMD DEBACLE**

Resolution of Gauteng's AMD threat will prove to be a mammoth exercise, which will require the collective collaboration of government, private institutions, mining houses, university academics and industry professionals. However, most importantly, very little progress will be made unless government shows the necessary political will, to fully engage with the threat of AMD. Government will need to address its poor track record as regulator, as its credibility has been skewed through their vested interests in the mining industry. The following comment of the Minister of National Planning can be considered as evidence of this: *"there is no need for panic"* (Mammburu, 2011c). Very perturbing, especially as Johannesburg in the view of the author, is facing a social and environmental crisis with regards to AMD.

Government must leverage its power to address transgressions, because the promulgation of NEMA (Act No 107 of 1998) and the NWA (Act No 36 of 1998) have not stopped unsustainable practices from continuing unabated. Although it may be necessary to revisit certain legislation, the author does not consider it necessary to completely overhaul it, as the major pitfall to date has been the lack of law enforcement. Urgent attention must

however be given to the formation of an integrated regulatory system, within which all environmental issues shall be placed under a single system/department. This is evident from recent cases brought against three mining companies (Anglo Platinum, Australian Coal of Africa [CoAL] and Maccsand) for not being compliant with the environmental regulations stipulated in NEMA (Act no. 107 of 1998) (Fourie, 2010) - they argued that they need only comply with the MPRDA (Act no. 28 of 2002).

**IMMEDIATE RISK AVERSION**

Following government's ownership of the threat, it would be advisable that the general public be cautioned as to the potential risks of AMD, in order that immediate threats to the environment and human well-being may be averted. The dilemma will however be if the real environmental and social implications of AMD are unknown (as we are lead to believe) – what then gets communicated to the public and what precautionary actions should be taken? Careful thought is required in this regard, to prevent panic and potential uncontrolled economic disruption. Therefore, where research into the real implications of AMD will require time, it would be in government's best interest to align itself with a multitude of stakeholders, when devising an immediate communication and action plan. The author would caution against being drawn into lengthy debates at this stage – details and differences can be resolved later – what is needed now is a plan to advert any immediate health risks.

**ENGAGING STAKEHOLDERS**

In engaging stakeholders, government must give careful consideration to the involvement of all parties, particularly those (or representatives of those) that would have to live with the outcome of the decisions being made. Therefore it is proposed that government hosts a symposium on AMD, which is open to participation. It should perhaps be facilitated by a neutral party (as existing relationships between stakeholders may have become strained over time), under the leadership of government.

The use of a facilitator would be appropriate in managing what could be perceived as two adversarial parties and integrating political, environmental and socio-economic issues, which, as we know, are always contentious issues. Further to this, in breaking the current paradigm, as opposed to an omni-disciplinary team, what is required is a trans-disciplinary approach that operates proactively in protecting the assets of the country. This is a goal, towards which, research has shown, the various stakeholders are willing to work. However, for effective decision-making, there will definitely be a need for capacity building.

While copious amounts of research have been carried out and solutions proposed, the process has clearly been lacking in leadership. In this context, leadership can be considered as the sourcing (or the provision) of funding and the co-ordination of research activities to reach an appropriate solution – a role that the author believes can only be assigned to

government. To date, however, part of the problem has been government's failure to ensure continuity of leadership and the availability of technical skills in some relevant institutions – namely the water and environmental sectors. According to Bill Rowlston (formerly of the DWA), before 2008, the DWA had had four Director Generals in less than three years and, similarly the DWA had had a new Minister every year until 2006 (Hofstatter, 2008). Hopefully this problem is now something of the past.

**CAPACITY BUILDING**

The greatest concern is that ecosystems and ecosystem services are not seen as a resource and neither are they deemed sufficiently important. Resources are commonly referred to as minerals that can be exploited for financial gain – a standpoint that only serves to erect barriers in understanding the crucial linkages between human development and the environment. The understanding that the planet Earth is a biosphere of circulating and self-sustaining patterns and flows, that make up the ecosystems that provide the vital services, for which all life is dependent, is central to the solutions that need to be considered. If we fail to understand this, mankind will fail. Further to this, the capacity of all stakeholders will have to be developed concerning regulatory and market-based instruments, to address historic behaviours (DWAF, 2009:4).

In the above context, mining companies will need to be made aware of the real damage they are causing. Capacity will need to be built in relation to the management and protection of resources, including vital ecosystems. Capacity will also have to be developed in government institutions. According to the CGS (2011), however, even if mining companies were to compile mine closure plans it is doubtful whether the capacity within the DMR is adequate to determine the appropriateness of such plans. Another example of such a capacity gap is the DWA; it is understood that the Trans-Caledon Tunnel Authority[12] (TCTA) will be brought in to assist the DWA, as some believe they alone do not have the capacity to tackle AMD (DWA, 2011). The involvement of the TCTA does raise the concern that AMD will remain an internal issue of government, where stakeholders will not be invited to participate – hopefully this will not be the case.

**ASSESSMENT / DECISION-MAKING MECHANISMS**

The author is of the opinion that the capacity of all stakeholders will need to be directed numerous issues, including sustainable development and an environmental sustainability assessment framework mechanism. In order to arrive at an appropriate solution, a comprehensive assessment process must be adopted, where the various disciplines are

[12] In 2008, there was the concern that pending the release of the South African National water Resources Infrastructure Agency Bill, the TCTA (TCTA is South Africa's only bulk water parastatal) would be disbanded in favour of a new state-owned agency *"mandated to fund, build, manage and maintain our bulk water infrastructure and conclude service contracts with bulk users, including municipalities, irrigation schemes, mines and power stations"* (Hofstatter, 2008).

invited to participate, in order to fully understand the full consequences of actions and non-actions – the output of which will then facilitate awareness of the policy decisions that need to be made. It is strongly recommended that current proposals not be revisited as they do not consider vital social and environmental aspects. It is only through the exploration of all the issues that the correct solution can be designed. The assessment process however will not just happen, it will need to be designed, with guidelines, and with peer-review and policy formulation mechanisms built in to it. If more reliable and more mutually acceptable outcomes are to be obtained then training on the chosen environmental decision-making tool(s) should be offered.

The collective assessment/decision-making mechanism must allow for the integration and evaluation of 'all' environmental, social, political and economic aspects relating to AMD. In the process, indicators will need to be identified to facilitate the comprehension of management information – the consensus of the baselines and thresholds of which may prove difficult (CGS, 2011a). These indicators must be balanced across the four cornerstones of sustainable development, while allowing the assessment of performance on an inter-generational and intra-generational basis.

Indicators will facilitate the setting of targets pertaining to ecological limits and restoration, based on an understanding of the biotic and abiotic components of the environment. Boundaries should not be tested, but rather utilised in the evaluation of current positions and trends, and guiding appropriate behaviours and practices. There is a multitude of important criteria for such assessments, including the following:

- knowledge of the ecological regenerative capability across the Witwatersrand and other affected areas;
- knowledge of the levels of toxicity in wild life, livestock and humans systems;
- involvement of the Department of Health, in establishing the health risks associated with heavy metals; and
- an overall goal for sustainability, which must be retained in the evaluation of trade-offs.

**ADDITIONAL RESEARCH AND SOLUTIONS**

Where it is deemed that the information required for a comprehensive assessment is lacking; specifically, more research is required on the environmental and health fronts. For the benefit of all, there needs to be transparency as to who is funding research into these sensitive areas, as the output maybe skewed to benefit the very funders, who may otherwise be exposed by such investigations. It is hoped that government, in their historical relationship with the mining industry, has not conspired to hide crucial information that

could compromise environmental sustainability and human well-being. If Government has done so, it will have to go a very long way to regain credibility.

However, it is a foregone conclusion that the assessment process will expose both the government and the mining industry, which historically have refused to acknowledge their respective roles in this debacle. The mining industry has typically shifted the blame to other non-mining related issues. To date, laws have protected the mining industry and research still has to confirm the link between mining activities and environmental and social damage. Baseline tests must be conducted to establish the effects of exposure to background levels of toxicity of heavy metals (particularly uranium), against which individuals in contaminated areas would be checked. Checking in such areas should also include the investigation of birth, health and death records.

In terms of sources of water pollution, whereas it is possible to treat mine water effluent (AMD decant) the same cannot be said for the discharge and seepage that will occur from waste rock and tailings or residue dumps. Solutions must be found to manage waste dumps and tailing dams – which, after the decant of untreated mine water, forms the second largest source of contamination. This is due to the increased presence of sulphides and heavy metals, both of which are susceptible to weathering. This will prove difficult, however, because the practices involve the extraction and the processing of millions of tonnes of reef-bearing ore that, once worked, are dumped onto tailings dams scattered across the country-side. The volumes involved here are considerable, especially if one considers that only a few hundredths of an ounce of the respective minerals are recovered from each ton of ore, and most of the mined ore is ultimately dumped as waste rock or becomes tailings. All of these activities facilitate the mass exposure of iron pyrite, which then encourages the mobilisation and concentration of toxic metals, and the generation of toxic radioactive waste dumps.

What is discouraging is that while the approach to a solution has been of a fairly reductionist nature, only one solution[13] has seriously been considered to address the AMD threat. In this regard, the launch of the Centre for Sustainability in Mining and Industry is encouraging, although there are concerns as to the extent of freedom that they will have in identifying appropriate solutions, especially as the centre is funded by mining companies. It is also likely that a debate will arise as to the costly nature of solutions, although questions must be asked as to what comparisons are being made! While solutions may be deemed expensive, the resulting inaction will be even more detrimental to the environment and human well-being.

As an area of priority, the solution must include the restoration and then protection of our collective water resources for the Gauteng province, especially considering the long lead time associated with the development of water treatment plants. An argument that is supported by various stakeholders, who suggest that AMD could potential serve as a

[13] During the recent British Petroleum threat in the Gulf of Mexico – more than a 1000 technologies were reviewed.

potential resource. Although there are discrepancies regarding the actual volume of AMD, it may be sufficient to supplement another augmentation system – therefore, it is surely worth pursuing. For this, *"[hydrological], ecological, economic and socioeconomic assessments should be an integral part of"* Gauteng's water management strategy (ISGWAS, 2007), and the mining industry in particular, should be encouraged to adopt water reconciliation strategies, for usage efficiencies, in the treatment of return water.

As a solution to South Africa's AMD problem, some parties are suggesting that the country could reduce the extent of this threat by gradually decoupling its reliance on its natural resources (Swilling, 2010). However, the South African economy grew on the back of the mining industry and, while the contribution to GDP may have declined somewhat, it is still a prominent element of the economy. South Africa's mineral wealth has been estimated at a staggering $2,5 trillion (Marais, 2011) and mining (gold, platinum & coal) still contribute to the socio-economic development of the country and the country's energy strategy is coal-based - a situation that is unlikely to change for the next thirty years. In fact, global predictions by Bringezu (2011:79) indicate that the 'used' extraction and harvest of abiotic and biotic components is expected to double between 2000 and 2030, and there will be a two- to three-fold increase of 'unused' extraction (over that of 'used'), as a result of declining grades. Therefore, until such time as nations are able to make such a transition, it seems inevitable that mining operations will continue and thus preventative measures must be introduced to manage AMD.

Mining in itself is not sustainable as it entails the depletion of a resource, but its associated activities can be carried out in a more sustainable manner, specifically by enforcing an improvement in the management of the environment - the practice of dissolving environmental risks down to reputational risks must be eliminated. If mining, which is an important asset for the economic growth of a developing nation is to continue – and it is pretty certain that it will (World Bank, 2004) - then ways must be found to encourage more sustainable mining practices. In this regard, particular attention must be given to managing the exposure of iron pyrite, which is the greatest problem – as this is what gets the ball rolling concerning the mobilisation of heavy metals.

Regarding water treatment, perhaps what is required is an innovative solution, similar to that adopted in the cleanup of the Rhine River in Germany, where companies were required to position their 'waste' discharge up-stream of their intake. In fact, as with the Witbank mine water treatment scheme, perhaps it should be required of all mining companies that their treated water be supplied to their own communities.

**TRANSPARENCY CONCERNING SUSTAINABILITY**

While mining in its self is not sustainable, attention must be paid to ensuring that mining activities are conducted in a sustainable manner (where possible). This process will need to be transparent, to prevent a similar occurrence as with AMD. It was with similar activities in

mind that the United Nations Environment Programme (UNEP) together with the Coalition for Environmentally Responsible Economics (CERES) launched the Global Reporting Initiative (GRI) to monitor and measure progress towards and shortcomings of sustainable development (Singh *et al.*, 2008). The initiatives was envisaged as sustainability reporting practice, which involved the measuring and disclosure of organisational performance, to internal and external stakeholders, concerning progress towards sustainable development goals (GRI, 2007a).

Although the GRI process (for which there are some excellent indicators[14]) is strongly recommended, as it draws organisational attention to 'sustainability', it also so presents challenges. A positive aspect is that sustainability reporting is awakening the consciousness of mining companies to the consequences of their actions and is applying pressure on these and similar organisations to be more transparent about their activities, and the impact thereof. However, the challenge associated with the GRI sustainability reporting process is that it addresses mainly the disclosure of information – it does not really affect the degree of sustainability. Whereas many organisations are utilising the GRI sustainability reporting process, the initiative is only a reporting guideline against which compliance can be tracked, as opposed to actually tracking sustainability performance.

A review of sustainability reporting in South Africa confirms this. In the 2010 review on sustainability reporting by Sustainability Services (2010) results showed that of the top ten positions, mining companies occupied the top nine positions. To clarify, this is not a reflection of how sustainable these organisations are, but rather a reflection of how compliant their 'reporting' is to the GRI guidelines. Mining companies are adopting GRI as a marketing tool, as the market is seen by companies to be perhaps having a stronger influence than legislation – symptomatic in South Africa, perhaps of government's poor role as regulator. For the sustainability reporting initiative to be meaningful, targets must be legislated; for example, ecosystem management goals must be integrated into all sectors of the economy (particularly mining), culminating with clear accountabilities at a government level, and cascading into the private sector.

If one looks at AMD from a sustainable resource perspective, national and provincial governments should be working together with industry and societal groups to develop programmes for economy-wide sustainable resource management, that give consideration environmental and socio-economic implications (Bringezu, 2010). Solutions could involve the introduction of certificates and labels on mining products, informing buyers of the origin of the final products and the associated environmental conditions – similar to the Kimberly Process for diamonds.

[14] These include, for example: EH10: percentage and total volume of water recycled and reused, EH12: the impact to biodiversity, and MM1 (EH12): addresses the rehabilitation of land. EN21: that deals with total water discharge by quality and destination, and MM3 (EH22): deals with the total amounts of overburden, rock, tailings and sludge's, and their associated risks (GRI, 2007b).

**ROLE OF THE MINING INDUSTRY**

Firstly, mining companies should be encouraged to internalise all their liabilities and the remediation thereof, as part of their social responsibility. If it need be, this must be enforced through appropriate legislation. Where, typically, mining houses have externalised their liabilities, in the bigger picture they should be establishing how material these risks are from the perspective of attracting investors. This is not only part of their corporate social responsibility; unless organisations begin to manage and gradually reduce their liabilities they will appear less attractive as an investment opportunity. In due course, and perhaps in line with the United Nation's principles for responsible investment[15] (UNEP, 2006) - companies that carry environmental, social and governance risks, will appear less attractive to investment houses, who will become increasingly more focused on serving the long-term interests of their beneficiaries. An example of this is the United Kingdom's Pension Act 2000, where it is *"mandatory for fund managers to disclose to what extent social, environmental and ethical considerations affect their investment strategy"* (Halliday, 2007).

In the context of the evolution of AMD (for which we know government had a hand in), investment houses will no doubt track the associated liabilities of organisations. As awareness grows, investments houses will map out the environmental, social and governance risks, through performance outcome based indicators, in assessing the impact of different liabilities to the market capitalisation of respective investment opportunities (Duncan, 2011). Such information will assist in determining the 'current fair value', which will affect buy or sell decisions. This will result in a massive turn-around, where investment funds are unlikely to hold shares of companies whose activities result in the degradation of the environment. The challenge now is whether investment houses are able to attach a value to these risks. If they are, this would surely impact the market capitalisation of mining organisations – something that government and mining houses probably fear the most.

**ROLE OF CIVIL SOCIETY**

Civil society must serve as the source of ethical norms and must be able to keep the government in check, in terms of ensuring that it acts in their interests. The people of South Africa must not shrink away from what is right; they must challenge the government on what is ethically right. The AMD problem is not an intellectual one, it is a moral one, and while we must acknowledge that mankind is part of nature, we need a moral framework for objective truth as opposed to one of manipulation and moral decay. Seeing that all major civilisations in history that were driven by lust greed and power have collapsed, what will become of us?

In the context of AMD, civil society must challenge government to take ownership and to address the threat. Government should be held accountable for the notion of non-declining

[15] Currently, within South Africa, there are two asset owner signatories and twenty two investment manager signatories (UNEP, 2006).

stock of capital assets, in particular that of the environment (Halliday, 2007), and must be pressured into utilising their broad range of institutions (DEA, MRC, NHLS, NIOH and NRF, to name a few) to fully investigate the full implications of mining.

## 5.5 Summary

Sadly, in South Africa, mankind has yet to grasp the importance of environmental integrity (a healthy balance between both the abiotic and biotic components) to a vibrant economy. Although awareness is growing, we continually pursue economic gain at the expense of our environment. Here the question must be asked: why do we continue to destroy the very system that provides us with our ecosystems, services and our natural resources, such as the pollination of crops; the removal of carbon, timber from our forests, fish from our rivers, dams and oceans; and, aesthetically, plants? Could this be due to mankind's ignorance - that we simply do not realise the importance of ecosystems or the pivotal role that they play in our survival and well-being! Or, could it simply be just be a result of mankind's greed, in which case according to Latouche (2010) what is needed is a different societal model - one that promotes human relations and common interests within the context of a sustainable ecological footprint, as opposed to hyper-individualism fuelled by consumerism.

For South Africa's (and thus the Witwatersrand's) economy to flourish, the country must discover ways of decoupling economic growth from environmental degradation. Sustainable development is not about sustaining ignorance and greed; it is about the survival of all living organisms, for which environmental legislation must be promulgated. Our ecosystems are being stretched as it is; regardless, we continue to destroy them or at least disrupt their ability to function. Is it our intention to cut off the very hand that feeds us? Surely mankind needs to become more environmentally aware and socially responsible.

The perception that ecosystems and their services are free needs to be addressed; they need to be seen as an asset, and until this is rectified not much will change. Natural capital must be recognised as the resource that underpins human capital, and the degradation of this asset must be registered in a manner similar as economic capital is reflected on our national accounts.

On the Witwatersrand destruction is not being caused to arid /unproductive land and polluted water sources, but often to pristine environments (water sources in particular as argued by Oelofse, 2008). While the recent sense of urgency to address AMD is acknowledged, it is unacceptable that the threat has been allowed to amplify over time as a result of poor legislation and, clever manoeuvring by mining companies. The situation has now resulted in the amassing of some 6 000 'ownerless' mining operations across the Witwatersrand and a problem that sits squarely in the hands of the innocent taxpayer. Sadly, through these actions government - our very protector (turned perpetrator) - has exposed

the Gauteng province to enormous environmental, social and economic risks, which is totally unacceptable. Such a stance is reiterated by Liefferink (quoted by Mammburu, 2010b) in her statement: *"it is unethical and immoral that mining companies will maximise profits at the cost of; future generations, our communities and our environment"*.

The abuse of our ecosystems by the greed of certain industries is unacceptable and unsustainable. This applies especially where the ecological carrying capacity of the Witwatersrand, the ecosystems and the species that survive in them are being severally tested beyond their capacity to regenerate. The opposing trajectories of our declining ecosystem services and increasing demands need to be addressed, as we can no longer expect our ecosystems to counterbalance our unsustainable practices.

In this regard, therefore, it is hoped that the barriers to addressing AMD will very soon be eliminated in the greater interest of the country. South Africa's solution to the current AMD issue must go beyond disallowing current unsustainable practices to continue, by addressing the problem at its source. It is not about finding a new engineering solution (such as another expensive augmentation system to address the pending water shortage in Gauteng), which will allow the very practices that not only pollute our water but that create numerous environment social and economic risks to continue. All of which will just serve as an extension of our self-destructive economic system that has been allowed to undermine our environmental support systems (Brown, as quoted in Dresner, 2002).

The appropriate solution is about understanding the direct and indirect relationship and consequences between people and ecosystems as related to mining activities, in the context of the delicate biosphere that is vital for all life. Understanding the relationship of human well-being and ecosystems (which is dependent on environmental integrity) is vitally important, and unless mankind is able to understand how ecological, social and economic systems relate to one another, he will continue to battle to establish a framework for sustainability (Robinson and Tinker, 1997, as cited in Blewitt, 2008:28). If current trends in the depletion of resources and ecosystems are allowed to continue, our planet will simply become unbearable for all living organisms.

South Africa has some of the largest mineral deposits in the world, and through the related beneficiation activities of such assets the country has become the one of the most polluted in terms of toxic and radioactive waste. Governments' future support in addressing AMD in a sustainable manner is vital in preventing the expansion of the AMD threat to other provinces. For what should have been a comprehensive solution, government's vested interests have narrowed this down, now government together with the mining industry and other stakeholders must find a way of mitigating the environmental consequences associated with mining.

However, it remains a concern that practices will continue with scant regard for our environmental integrity and human well-being – unless government displays the correct

political will. The logic, policies, programmes and decision-making assessment mechanisms all exist – the question is: does the political and commercial will?

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## ANNEXURE 1: Some of the technical work/studies undertaken on Acid mine drainage in South Africa:

| No. | Solution | Emphasis | Approach | Party / Source | Challenge |
|---|---|---|---|---|---|
| 1 | Improved densification of sludge. | Reduction of voluminous sludge generated as a result of neutralisation. | Reductionist | (Bosman, 1974) | Resultant chemical precipitate (voluminous sludge) of heavy metals. |
| 2 | Neutralisation of acid water with lime or limestone. | | Reductionist | | Resultant chemical precipitate (voluminous sludge) of heavy metals. |
| 3 | Biological sulphate reduction of AMD | Biological removal of sulphate through the use of recycling sludge bed reactors. | Reductionist | (Poinapen, 2005) | Requires excessive volume of organic matter (sewage). Heavy metal accumulation. Lengthy retention times. |
| 4 | Desalination | Desalination of neutralised acid mine drainage. | Reductionist | | Resultant chemical precipitate (voluminous sludge) of heavy metals. Undesirable salts remain in solution. |
| 5 | Barium-precipitation | Precipitation of sulphate | Reductionist | | High chemical costs and voluminous sludge. |
| 6 | Transformation of Fly Ash into Zeolitic Crystalline Phases | Utilisation of fly ash as a neutralising agent & preparation of high capacity ion-exchange adsorbents from co-disposal solid residues. | Reductionist | (Somerset *et al.,* 2005) | Resultant chemical precipitate (voluminous sludge) of heavy metals. |
| 7 | Ground and airborne geophysical surveys. | Identification of potential groundwater pollution pathways. | Systems | (Coetzee *et al.*, 2009) | |
| 8 | Biological treatment of heavy metal contaminated acid mine drainage | Use of alga as an alkaline to precipitate heavy metals. | Reductionist | (Van Hille *et al.,*2001) | Bioaccumulation & thus adverse impacts to plant metabolism. |
| 9 | Mine water treatment plant & by-product recovery | Neutralisation of acid water and removal sulphur and metal by-products | Systems | Western Utilities Corporation | Cost-effective treatment and near zero waste processes. |
| 10 | Irrigation of crops with lime-treated acid mine drainage | Investigated potential use & the impact to soil and crops. | | (Jovanovic *et al.*, 1998) | Possible contamination of crops and soil with heavy metals will result in crops becoming dangerous for consumption. |

## ANNEXURE 2: Overview of the risks associated with the Witwatersrand Basin's. Source DWA AMD report

| Basin | Main areas / Risk | Drainage System | Elevation | Rise rate m/day | Pumping | Treatment Capacity | Decant | If left Unattended | Immediate requirements (DWA) | Med to Long term (DWA) |
|---|---|---|---|---|---|---|---|---|---|---|
| Western Basin | Mogale City/ Randfontein.<br><br>Ecological | Tweelopie Spruit, and upper tributary of the Crocodile River System & Marico systems | Decanting into the surface environment since 2002. | Flooded | Cessed in the 1990's | 12 Ml/day | Max; 60 Ml/day Ave; 15-20 Ml/day | Decanted in Sept 2002. | Additional 20 Ml/day neutralisation plant. Upgrade of pumping & treatment facilities. | Water quality management (i.e. salt loads in river systems). |
| Far Western Basin | Cradle of Humankind World Heritage Site | Crocodile River System | Mines still operational | | | | | Not deemed urgent at this stage. | | Potential impact to overlying dolomitic aquifers. |
| Central Basin | Catlin Shaft at Simmer & Jack Mine. S West Vertical Shaft at ERPM. Dolomitic aquifers to the south, ERPM in Boksburg and Durban Deep in Roodepoort.<br><br>Geotechnical | Elsburg & Natal Spruits, the Klip river Crocodile River System & Vaal River systems | 510 mbs, or 1155 mamsl (Dec 2010) | 0.3-0.9m / day Ave. 0.5 | Cessed at ERPM in Oct 2008 | | Will decant in 2-3 years | Possible flooding of the underground attractions at Gold Reef City. Impact to dolomitic aquifers to the south of Boksburg. | New 70 Ml/d pumping facilities. Neutralisation plant of matching capacity, or refurbishment of HDS treatment plant (ERPM). | Water quality management (i.e. salt loads in river systems). |
| Eastern Basin | Grootvlei Mine. Nigel CBD Blesbok Spruit and a Ramsar-listed wetland<br><br>Ecological | Blesbok Spruit, Ramsar wetland, | 700 mbs, | 0.3 – 0.6m / day | 75-108 Ml/day. Although not sufficient | No treatment for some time | Decant into Nigel in 5 yrs | The pump station will flood in 30 days | Maintain pumping capacity & return neutralisation plant to service | Water quality management (i.e. salt loads in river systems). |

MBS: Metres below surface

MAMSL: Metres above mean sea level

## Annexure 3: Implications of heavy metal exposure[16]. Source: Kilic, 2010; Hayes, 1997; Blaurock-Busch, 2010; EPA, 2009.

| ATSDR 2007 Ranking | Substance Name | Max. contaminant level mg/L (ppm) | Source of contaminant in drinking water | Potential health effects, associated to long-term exposure. |
|---|---|---|---|---|
| 1 | Arsenic | 0.01 | Occur naturally in the earth's crust, erosion of natural deposits | Skin damage, circulatory problems and increased risk of cancer. Death |
| 2 | Lead | 0.015 | | Increased risk of stomach and respiratory cancer. Kidney cancer. Acute or chronic damage to the nervous system. |
| 3 | Mercury | 0.002 | | Damage to the brain and the central nervous system. Psychological and development changes in young children. |
| 7 | Cadmium | 0.005 | | Renal dysfunction, obstructive lung disease and lung cancer, and damage to respiratory systems. Kidney damage. |
| 18 | Chromium | 0.1 | | Skin irritation and ulceration. Kidney and liver damage, and damage to circulatory and nerve tissue. Accumulates in aquatic life, adding to the danger of eating fish. |
| 42 | Beryllium | 0.004 | | Intestinal lesions. Fatal scarring of the lungs, lung cancer |
| 49 | Cobalt | | | Lung, heart, kidney and liver effects. Cell damage, bleeding, coma and even death. |
| 53 | Nickel | 0.1 | | Chronic bronchitis, lung and nasal cancer. |
| 74 | Zinc | 5 | | Impaired iron/copper metabolism and immune function, demineralisation of the skeleton. |
| 109 | Barium | 2 | | Increase in blood pressure |
| 117 | Manganese | 0.05 | | Mental and emotional disorder. Chronic liver diseases |
| 128 | Copper | 1.3 | | Anaemia, liver and kidney damage, and stomach and intestinal irritation. |
| 180 | Uranium | 30 µg/L | | Highly carcinogenic and mutagenic, nephro and neuro-toxic. Leads to kidney failure, seizures, mental retardation and overt brain injury. |

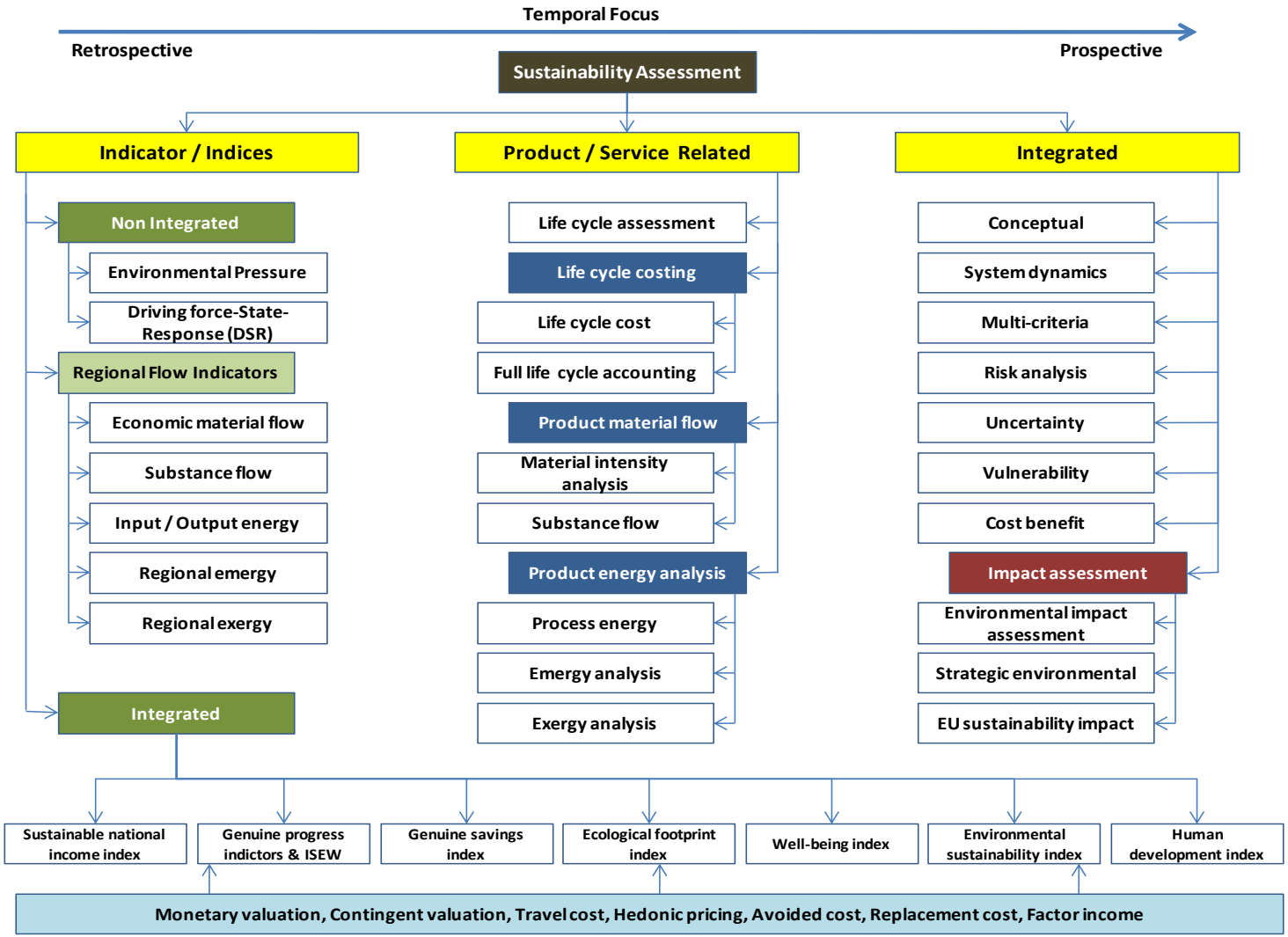
[16] Included in the above table, is a list, *"in order of priority, ranking substances that are most commonly found at facilities and which are determined to pose the most significant potential threat to human health due to their known or suspected toxicity and potential for human exposure"* (Blaurock-Busch, 2010). It must be noted that the order of priority may differ substantially in the Witwatersrand. The list is prepared by the United States Agency for Toxic Substances and Disease Registry (ATSDR) and the Environmental Protection Agency. The table also reflects the, Maximum Contaminant Level (MCL) – which is "the highest level of a contaminant that is allowed in drinking water", as advised by the EPA (2009).

## ANNEXURE 4: Millennium Development Goals, MTSF Strategic Elements and Outcomes. Source (UNEP, 2010)

| | MILLENNIUM DEVELOPMENT GOALS | | MTSF STRATEGIC ELEMENTS | | OUTCOMES |
|---|---|---|---|---|---|
| 1 | To eradicate extreme poverty and hunger. | 1 | Speeding up growth and transforming the economy to create decent work and sustainable livelihoods. | 1 | Improved quality of basic education. |
| 2 | To achieve universal primary education. | 2 | Massive programme to build economic and social infrastructure. | 2 | A long and healthy life for all South Africans. |
| 3 | To promote gender equality and to empower women. | 3 | Comprehensive rural development strategy linked to land and agrarian reform and food security. | 3 | All people in South Africa are and feel safe. |
| 4 | To reduce child mortality. | 4 | Strengthen the skills and human resource base. | 4 | Decent employment through inclusive economic growth. |
| 5 | To improve maternal health. | 5 | Improve the health profile of all South Africans. | 5 | A skilled and capable workforce to support and inclusive growth path. |
| 6 | To combat HIV / AIDS, malaria and other diseases. | 6 | Intensify the fight against crime and corruption. | 6 | An efficient, competitive and responsive economic infrastructure network. |
| 7 | To ensure environmental sustainability. | 7 | Build cohesive, caring and sustainable communities. | 7 | Vibrant, equitable and sustainable rural communities with food security for all. |
| 8 | To develop a global partnership for development. | 8 | Pursuing African advancement and enhanced international cooperation. | 8 | Sustainable human settlements and improved quality of household life. |
| | | 9 | Sustainable resource management and use. | 9 | A responsive, accountable, effective and efficient local government system. |
| | | 10 | Building a developmental state, including improvement of public services and strengthening democratic institutions. | 10 | Environmental assets and natural resources that are well protected and continually enhanced. |
| | | | | 11 | Create a better South Africa and contribute to a better and safer Africa and world. |
| | | | | 12 | An efficient, effective and development oriented public service and an empowered, fair and inclusive citizenship. |

Note: In numerical order and not corresponding order.

## ANNEXURE 5: Framework of Sustainability Assessment tools. Source (Ness *et al.*, 2007)



## ANNEXURE 6: A comparison of environmental sustainability assessment framework mechanisms

| Assessment Tool | Framework category & Emphasis | Advantages | Constraints | Source |
|---|---|---|---|---|
| Driving force-State-Response (DSR) | Linkage based:<br>• Understanding of actions & activities affecting the state of the environment. | • Cover full spectrum of cause & effects.<br>• Useful in understanding; driver, pressures, changes, exposure & effect on health, the environment & sustainability.<br>• Adopted by OECD for environmental reporting.<br>• Widely utilised.<br>• Utilised by UNCSD in the categorisation of the 1st 134 SD indicators. | • Retrospective<br>• Effectiveness constrained by Linkages<br>• Oversimplification of interactions leads to poor management decisions<br>• Difficulty in determining inter-linkages<br>• Not a comprehensive tools in terms of solutions | (Waheed *et al.,* 2009) |
| Life Cycle Assessment | Material Flow:<br>• Environmental impact analysis, of the inputs & outputs of products / services – across the value chain (from cradle to grave). | • Evaluates effect of technology associated with Products / Services.<br>• Part of ISO 14,000 environmental standards. | • Does not consider economic & social issues.<br>• Adopts a static view, thus future environmental impacts are unknown.<br>• Difficulty in integrating economic and ecological analysis.<br>• No widely accepted standard methodology.<br>• Retrospective & Data hungry process.<br>• Exchange between economic & natural | (EPA, 2001) |
| Environmental Impact Assessment or Sustainability Impact Assessment | Impact based:<br>• Analysis of potential developmental impacts on the environment. | • Well entrenched.<br>• Promotes sustainability. | • Evaluates the three pillars of sustainability in isolation.<br>• Integration of issues is done retrospectively.<br>• Adopts a static view & does not consider impacts that manifest overtime.<br>• The environment and ecosystems are viewed as externalities. | (Haywood *et al .,* 2009) |

**ANNEXURE 7: A reference map of the West Rand. Source: Google Earth (2011)**