A STRATEGY FOR THE MANAGEMENT OF ACID MINE DRAINAGE FROM GOLD MINES IN GAUTENG

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ACRONYMS

AMD	Acid Mine Drainage
AP	Acid Generation Potential
ARD	Acid Rock Drainage
CGS	Council for Geosciences
CSIR	Council for Scientific and Industrial Research
DME	Department of Minerals and Energy
DWAF	Department of Water and Forestry
DWA	Department of Water Affairs
DEAT	Department of Environment Affairs and Tourism
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GTT	Government Task Team for Mine Closure and Water Management
HIA	Health Impact Assessment
IIED	International Institute for Environment and Development
NEMA	National Environmental Management Plan
NP	Neutralization Potential
NNP	Net Neutralization Potential
NWA	National Water Act
NWRS	The National Water Resource Strategy
MoU	Memorandum of Understanding
MMSD	Mining, Minerals and Sustainable Development Project
PPP	Polluter Pays Principal
SIA	Social Impact Assessment
WHO	World Health Organization

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A STRATEGY FOR THE MANAGEMENT OF ACID MINE DRAINAGE FROM GOLD MINES IN GAUTENG

1. Executive Summary

Mining has played an important role in the development of South Africa. Now, decades after many of the South African gold mines have been abandoned and several others are reaching the end stage of productivity, there has been a focus on the development of new mine closure strategies and policy guidelines. For these frameworks to be consistent with international standards (IIED, 2002; Clark and Clark, 1999) and the Constitution of the Republic of South Africa (RSA, 1996), mines must minimize long-term environmental, social, and financial liability; ensure safety around former mine sites; maintain geotechnical stability; promote cost effective and timely closure; assure sustainability; and attain regulatory compliance over time.

One aspect of mine closure pertains to mine water management, which addresses the large quantities of mine polluted water referred to as acid mine drainage (AMD) or acid rock drainage (ARD). There is a wide acceptance that AMD is the largest liability the mines face since it is responsible for the most costly environmental impacts caused by mining and is therefore the industry's greatest technical challenge (Boocock: 2, 2002; Mitchell, 2000; USEPA, 1994). It has also been suggested that AMD and mine closure in general are tremendous liabilities for the government since failure to adequately address these issues can result in a loss of confidence in the government (Adler *et al.*, 2007; Turton, 2006).

At present, there is an emphasis placed on the initial and ongoing operations to address AMD by government, private industry, and public advocacy groups. While South Africa has made monumental progress in shifting policy frameworks to address mine closure and mine water management, and the mining industry has changed their practices to conform to new regulations, there remain vulnerabilities in the current system. To allow recent technological innovation and the existing organizational frameworks to be harnessed

to prevent environmental and socio-economic degradation, it is important for existing weaknesses to be analyzed to lead to policy recommendations.

Based on a thorough literature review and discussions with South African governmental officials, mining representatives, and other stakeholders, this report has been developed as a review of AMD as well as the current technologies and policy frameworks in place to prevent, predict, and treat AMD. Furthermore, these are evaluated from a policy standpoint to identify ways to make the current political climate more conducive to utilization of new technologies within the context of constitutional imperatives stipulating the need for job creation and sustainable development planning. Special attention is paid to the province of Gauteng, which contains the mines of the Witwatersrand Basin, and is the most important region of South Africa in terms of the value of minerals produced and its ability to draw foreign direct investment (FDI). Many of these gold mines are approaching closure and are, in compliance with new legislation, looking into methods to treat and prevent AMD.

Two broad classes of problems have been identified in the existing policy frameworks used to address AMD. Firstly, the delegation of powers between various government departments at the national, provincial, and municipal levels is unclear. This problem is exaggerated by the fact that government departments lack the manpower to make frequent site visits to mines and surrounding areas to verify compliance with these guidelines. Secondly, the existing frameworks place the government in the position of having to be reactive rather than proactive. This is evident in the pricing structures and enforcement mechanisms used to discourage pollution using the polluter pays principal (PPP), as well as the legal framework which outlines requirements for environmental impact assessments (EIAs).

If the government is not able to manage public perception in addressing these issues and working towards economically viable processes, there will be dramatic consequences. To make it more favourable for the mining industry to consider the utilization of new technologies for water treatment, government departments need to retain their employees and frameworks need to be made more proactive. Consideration can also be given to changing the pricing structure outlined by the PPP, modifying the way in which EIAs are conducted and used, and establishing new policies and financial incentives to aid in making new water treatment facilities more sustainable over the long-term.

2. Aims

This report presents progress that has taken place from October 2006 to February 2007 in the form of a contract between the Council for Scientific and Industrial Research (CSIR) and the Thuthuka Group (Pty) Ltd. Work in this document meets the specifications outlined in the project terms of reference under "Task 5." Accordingly, progress has been made on the following five tasks to contribute to the eventual establishment of a water treatment plant at the Greenside Colliery and Namakwa Sands:

1) Utilization of available resources including key players in the field, primary policy documents, and other written work to:
    a. gain a better understanding of current legislation with regard to AMD in Gauteng
    b. identify specific interests and perspectives
2) Identify social, health, economic, and political risk associated with AMD pollution loads;
3) Identify available technologies used to predict, prevent, contain, and treat AMD;
4) Identify current problems in existing policy frameworks that may prevent utilization of the latest technologies;
5) Develop policy recommendations about how to proceed with regard to AMD to ensure that the process is fully accountable to the South African Constitution and progressive democratic ideals.

3. An Overview of Acid Mine Drainage

3.1 What is AMD?

AMD is highly acidic water, usually containing high concentrations of metal, sulphides, and salts as a consequence of mining activity. There are five major sources of AMD, which include, but are not limited to, drainage from under-ground mine shafts, runoff and discharge from open pits, mine waste dumps, tailings and ore stockpiles (Mitchell, 2000: 119; Boocock, 2002: 1). Although the chemistry of AMD generation is straightforward and typically involves the oxidation and subsequent leaching of pyrite or its dimorph marcasite (FeS_2), or pyrrhotite (FeS_{1-X}), the final product is a function of the geology of the mining region, presence of micro-organisms, temperature and also of the availability of water and oxygen (Mitchell, 2000:121; USEPA, 1994:6). These factors though, are highly variable from one region to another (for chemical reactions see Figure A2). For this reason, the prediction, prevention, containment, and treatment of AMD must be considered carefully and with great specificity.

Although AMD is one of the most challenging environmental and technical problems for the mining industry, it must be noted that this, along with other aspects of mine water management, is just one component that must be considered in the context of mine closure, and the consequences associated with AMD can be prevented only if they are approached within the context of a comprehensive mine closure strategy.

3.2 A Brief History

AMD it is not a new phenomenon. One of the oldest documented mining regions in the world, the Rio Tinto region in Spain, had problems associated with AMD beginning over 2000 years ago (Balkau and Parsons,1999; Boocock, 2002: 2). In fact, it is said that its name, which means “Red River” was actually derived from the fact that the water was red as a result of iron-rich mine waste that was discharged (Mitchell, 2000:118). Since then, there have been thousands of documented cases of AMD and it is becoming increasingly visible as more mines approach closure around the world. It is projected that over 25 major mines are expected to close in the developing world over the next decade, several of which are in South Africa (Limpitlaw, 2004:1; World Bank, 2002).

3.3 AMD in South Africa

Following the discovery of diamonds and gold in Southern Africa and the subsequent development of platinum, chromium, manganese, vanadium, iron ore, and coal reserves, the country was transformed from a relatively underdeveloped region to a fairly modernized nation with widespread infrastructure and an increasingly diversified economy. As of 1999, mining directly contributed to approximately 6.5% of GDP and 33.5% of total export revenues (Viljoen and Reimold, 1999). To increase profits through the removal of minerals that would otherwise remain buried deep within the Earth's crust, elaborate pumping systems were employed in the beginning of the 20th century to remove water from mine shafts, a process which has become known as mine dewatering. Although this method was successful, there were also many unintended consequences, which include but are not limited to the modification of the water table, the creation of sinkholes, and elevated levels of aquatic, air, and soil pollution (Adler *et al.*, 2007; IIED, 2002).

After some mines were decommissioned several decades ago, the pumping at the mine subsided, allowing water to fill the mine shaft. This time though, the water and sulphides within the shaft were exposed to oxygenic conditions, causing it to become highly acidic. At the beginning of 2002, AMD came to the public's attention when water started to decant onto the surface near Krugersdorp on the property of Harmony Gold Mine (Pty) Ltd (Fourie, 2005). Since the mine polluted water was spilling out in such close proximity to the Sterkfontein Caves and the nearby nature reserves, and since there are such strong sentiments about the relationship between the mining industry and the government, AMD became a very visible and highly political issue within the country. People knew Krugersdorp was not unique and that soon, they could expect similar outcomes in other mining towns.

In response, the South African government has been making an effort, through the establishment of new legislation, to better enforce existing laws and to generate new legislation which would better predict, prevent, and prepare for such disastrous consequences (DME, 2002; IIED, 2002). This will be further discussed in the legislation section. Although the new legislation is much improved, it has not been able to reverse the cumulative effects of AMD that have been felt over several decades. There have been numerous other incidents that have grasped public attention. These include, but are not limited to, sales of mine waste sites (Tempelhoff, 2007), relocations of entire townships (Sapa, 2004), and the environmental damage caused by illegal tailings dump at Namakwa Sands (Herbst, 2007).

Although many mines and the South African Government have been depicted as being negligent because of the damages caused by AMD and other water related consequences of mine closure, there have been monumental steps forward in utilizing new technologies to treat AMD in large-scale treatment plants. Approximately 15 years after Anglo Coal recognized serious AMD problems at their newer facilities in Witbank, a state of the art water treatment plant is close to being completed (Günther, 2007; Günther *et al.*, 2006). With the ability to treat 20 mega litres of polluted water a day with greater than 97% efficiency, the plant not only is a benefit to the environment and to the community through the supply of clean water and jobs, but it also is able to make a significant profit (Günther *et al.*, 2006). Although this was an Anglo investment, several other coal mining companies like BHP Billiton that are buying into the plant are being able to treat their waste there as well (Günther, 2007). Plans for expansion are on the horizon. In this sense, South African coal mining companies are serving as world leaders. There is, however, no reason that a similar plant could not be built in South African gold mining regions using targeted technologies. Plans for the building of such a water treatment facility for Harmony Gold Mines are underway.

3.4 Risks Associated with AMD Pollution Loads in South Africa's Gold Mines

There are many risks associated with AMD pollution loads. The recent decant near Krugersdorp and other similar incidents, however, emphasize that it is challenging to differentiate between consequences unique to AMD and those that are more generally related to mine closure. Although South African mine closure policies are becoming more comprehensive, the ability of existing plans to prevent and address AMD are limited, in many respects, by the enforcement of policies of the past. If proper mine closure frameworks were enforced during the entire lifetime of the mines in South Africa, the risks of AMD would have been drastically reduced at present because preventative measures would have been in place. Since the majority of AMD generation at South African gold mines takes place deep below the Earth's surface and has been neglected for decades, the severity of impacts and the costs of AMD remediation are much greater than they would have been if preventative measures had been taken in advance (Warhurst and Norhona: 15). For the most part, risks associated with AMD can be divided into four categories, namely: (1) environmental (2) socio-economic (3) political and (4) financial. These are discussed below.

3.2.1 Environmental Impacts of AMD

The environmental impacts of AMD are numerous. Not only is AMD associated with surface and groundwater pollution, but it is also responsible for harming aquatic sediments and fauna, degrading soil quality, and allowing heavy metals to seep into the environment. The costs of the environmental damage, however, extend beyond having to pay for clean-up of contaminated areas. In many instances, affected areas take decades to restore themselves to their natural state, and ecosystems in surrounding areas that are dependant on their surroundings may be drastically impacted in the short and long-terms. Because of the different chemistry above and below ground, the environmental impacts associated with AMD vary based on its location. Accordingly, environmental risks associated with AMD will be discussed in two different categories, namely: (1) under-ground features and (2) above-ground features (Pulles *et al.*, 2005: 5.14).

For the most part, the environmental risk associated with AMD under-ground is related to decreased water quality and the resulting ground instability. As groundwater becomes highly acidic, many of the geochemical processes including chemical weathering become more severe. For example, once oxidation of pyrite and other sulphides becomes prevalent and the pH decreases, the dolomitic rock layer through which mine shafts are sunk may begin to dissolve more rapidly. This process, along with the dewatering of the mine shafts, contributes to the formation of sink-holes. This is a long-term risk that poses serious safety and land use concerns. Additionally, the acidification of groundwater is also dangerous since many people and animals rely on groundwater supplies for their survival. Because the geohydrology is variable from one region to another, and because the flow of water under-ground is not completely understood, AMD in under-ground workings must be considered to pose serious environmental risk until shown otherwise by way of suitable quantitative geohydrological assessments.

The environmental risks associated with AMD above-ground relate to the health of ecosystems through the degradation of water quality following mine decant onto the surface; illegal dumping of AMD into rivers, streams and other surface water systems; or through seepage into the environment around improperly sealed waste management sites (Pulles *et al.,* 2005: 5.15). The influx of foreign substances into the environment, including highly acidic water, nitrates, sulphides, and heavy metals like arsenic, cadmium, copper, silver, and zinc, in this manner has a radical impact on entire ecosystems through not only the destruction of aquatic and terrestrial sediments and fauna, but also through the creation of new niches that support acidophilic species that are able to survive in the new environments (USEPA, 1994:1). These changes, in many cases, can take many years and even millennia to be corrected and have drastically reduced ecosystem biodiversity (Limpitlaw, 2004: 2). The seepage of heavy metals into the soil as a result of AMD and the use of mine polluted water for the irrigation of crops has secondary effects on soil quality, even in areas that are far removed from decant cites. Since heavy metals can inhibit photosynthesis, there can be dramatic changes in the growth and survivability of native species (Regis and Emelina, 2006).

3.2.2 Socio-economic Impacts of AMD

Access to clean water is universally accepted to be a precondition for economic and social development (Molden and Merrey, 2002; Gilbert *et al*., 1997), therefore, it is unsurprising that AMD is accompanied by socio-economic consequences. Socio-economic consequences of AMD can be divided into a number of categories; however, for ease of explanation, they will be discussed here in the context of human health, employment, productivity, and cultural impacts. At some level, however, these divisions are of limited meaning since legitimate arguments can be made to show how each of these categories are directly related to one another.

3.2.2.1 Human Health

AMD has been linked with numerous health-related consequences. In many cases, groundwater may be contaminated by AMD, and consumed without individuals being able to detect pollutants. By the time the effects are realized, treatment is often ineffective. Although very few epidemiological and toxicological studies have been conducted in the Gauteng region, the levels of various contaminants in the water have been measured to determine relative risk to individuals living in these areas based on reported trends in other areas. Because AMD is so highly acidic, metals including arsenic, manganese, aluminium, iron, nickel, zinc, cobalt, copper, and radium can become dissolved in the water (USEPA, 1994; Warhurst and Noronha, 2000). The toxicity of heavy metal consumption is highly variable depending on the metal consumed and on the route of exposure. If polluted water or agricultural products grown by using polluted water are consumed over the long-term, there are measurable consequences, including a decrease in cognitive function, increased rates of cancer, and appearance of skin lesions (Ashan, 2004; Bellinger *et al.*, 1992). Exposure to relatively small amounts of heavy metals and other industrial chemicals by pregnant women has also been shown to have dramatic consequences on the developing foetus. These impacts range in severity depending on the length of exposure and on the stage of foetal development, but typically affect neural development and result in severe mental retardation and/or consequences associated with social development (Grandjean and Murata, 2007; Grandjean and Landrigan, 2006; Bellinger *et al*., 1987)**.** According to recent studies conducted by the South African Council for Geosciences (CGS), acid mine water in some areas also contains high levels of radioactivity. In some cases, there may be as much as 16 mg of uranium per litre, which exceeds the World Health Organisation's limits by a factor of 1,000 and has been shown in epidemiological studies to cause similar health related consequences (Coetzee *et al.*, 2005, 2006). Additionally, high concentrations above 600 mg of sulphate per litre can cause vomiting and diarrhoea (USEPA, 1999).

The high concentrations of metals, sulphides, and other salts in water can also cause water to become obviously polluted. For example, high concentrations of sulphides in water cause the water to taste extremely bitter and salty and high levels of certain minerals in the water can cause the water to change colour. For example, iron oxides will cause the water to turn red (Mitchell, 2000: 119). In these cases, people will stop drinking that water; however, this can also result in dehydration or in the sacrifice of water used for hygiene and sanitation practices. This can also lead to relocation, which will be discussed below.

3.2.2.2 Employment and Productivity

Since the mining industry plays a tremendous role in supplying income and employment to individuals in surrounding communities, AMD and mine closure has serious consequences (Warhurst and Norhona, 2000; Claassen, 2006: 21). In mining towns, mining becomes the way of life and is able to increase the population, spurring growth and opportunity through the support auxiliary business. Following closure, these employment opportunities disappear, and the community struggles to survive. Unemployment skyrockets, and those who once subsided on agriculture are no longer able to farm because the water quality and water availability is often compromised. Because much of the water is polluted, it becomes difficult to maintain livestock or produce agricultural goods. Additionally, the degradation of soil quality that may occur as a result of AMD makes it more difficult to grow certain crops and limits available land (Warhurst and Noronha, 2000: 81-99).

The health consequences associated with AMD also cause problems. The illnesses caused by the consumption of mine-polluted water can cause chronic illness which limits the productivity of individuals within these areas. Also, because the water can have sizable impacts on future generations if consumed during pregnancy, the impacts of AMD are long lasting. Even in cases where families move away from the affected areas, the impacts will remain when the new generation is unable to perform within a work setting.

3.2.2.3 Socio-Cultural

AMD's impact on health as well as unemployment and productivity can also have impacts on the culture of many of these former mining towns. As economic opportunities become scarcer, there is a great potential for an increase in social pathologies which is expressed in the form of alcohol abuse, crime, vandalism, theft, sexual promiscuity, as well as an increase in HIV/AIDS. Additionally, AMD may cause population displacement, which has an entire class of socio-economic consequences of its own (Limpitlaw, 2004; Warhurst and Noronha, 2000; WCD, 2000).

3.2.3 Political Impacts of AMD

The indirect negative publicity associated with treating AMD is substantial. The South African Government is still in a process of overcoming a legacy of poor water resource management, as a joint result of over-exploitation of the environment and a historical collaborative relationship with the mining industry (Adler *et al.*, 2007). Simultaneously, there are also challenges in balancing the need for continued development and expansion along with the constitutionally mandated and internationally supported sustainable development goals. Because AMD is such a highly politicized issue, the lack of real and visible action to successfully address AMD issues on a timely basis has the potential to de-legitimize government as well as its endeavours to achieve sustainable development (Adler *et al.*, 2007; Turton, 2006). Although there has been very little focus on the political expenses of AMD and mine closure, it is a critical issue that deserves a great deal of attention. Without confidence in the current government to address these problems, South Africa could risk its position as a leader on the African continent in these areas and the new legislation will not be taken seriously.

3.2.4 Financial Impacts of AMD

One of the most compelling arguments in support of elaborate preventative measures to prevent AMD is financial. Numerous studies have been conducted to suggest that AMD costs the government, the mining industry and other businesses a great deal of money over the long-term, both directly and indirectly.

In a recent report prepared by the Office of the Supervising Scientist and the Australian Centre for Mine Site Rehabilitation Research, an in-depth evaluation of the anticipated cost of treating AMD was presented. According to this report, the total costs of AMD in Australia were expected to reach approximately $80 million annually with an estimated cost over $1,000 million over a span of approximately 15 years. This exurbanite expense is not unique to Australia and similar expenses were also reported in Canada, the United States, and other countries (Mudder and Harvey, 1998).

AMD also causes industry to pose a significant liability. Because the mines are interconnected under-ground, there is a large risk for mining companies who may be among the last in operation since "the cumulative impact resulting from all the mines in a region could be imposed upon the last mine in the region to cease operations" (Pulles *et al.*, 2005: ix). This poses a "financial risk which can become a driver of disinvestment in the mining industry with a resultant potential loss of jobs and associated economic activity" (Pulles *et al.*, 2005: ix). AMD and other issues associated with mine closure have also been shown to have an impact on foreign direct investment (FDI). According to a recent study presented at the OECD Global Forum on International Investment, issues like AMD have caused sizable decrease in foreign investment, over time (Boocock, 2002). This loss is significant for business interest, but could also have a tremendous impact on South Africa as a leader on the African continent.

Additionally, the removal of highly acidic water from mining locations during mining operation may cost the mines a great deal of money since the water in some cases is so highly acidic that it can erode the pipelines. The replacement of this infrastructure is extremely expensive and can also decrease mine productivity over time (Günther, 2007). Also, without proper water treatment facilities, the disposal of mine polluted water can remain a significant cost for an indefinite period of time.

4. Technologies for AMD Mitigation

For the past several decades, a great deal of research has been under way to develop methods to predict, prevent, and treat damage associated with AMD. At present, the international community is still searching for the most efficient methods. In this section, an overview of prediction, prevention, and treatment methods is outlined, along with their various strengths and weaknesses.

4.1 Prediction

Because the geology and hydrology varies so intensely from site to site, predicting the potential for AMD generation is difficult, costly, and of questionable reliability (USEPA, 1994: 2; Mitchell, 2000:122). There are however, several methods currently being used to predict AMD generation, in isolation or in combination. Although these methods are unable to treat AMD in any way, they are helpful in allowing appropriate officials to vastly improve their economic, technical, and environmental solutions. The more accurate the prediction method is, the better regulatory authorities are able to assess plans for closure and waste management plans and to ensure that the economic costs of AMD treatment are fully accounted for.

For the most part, there are two techniques used for prediction of AMD, namely: (1) tests and (2) mathematical models. For the data acquired from each of these methods to be meaningful, however, it is necessary for individuals involved to have an understanding of the physical and chemical processes contributing to AMD formation to know how to set up predictive tests or models and to meaningfully interpret results.

4.1.1 Tests

There are two classes of tests that can be used to assess risk of AMD generation, namely: (1) static testing and (2) kinetic testing. Of these, static tests are conducted more rapidly and are therefore more cost effective. Furthermore, the data produced from these tests are easily analyzed since there are pre-established standards used as indicators. On the other hand, the kinetic tests are typically more consistent and reliable once the data is collected and analyzed over a several month long period.

The most common static test used to determine acid generation potential is a form of acid-base accounting which measures the net neutralization potential (NNP). This measurement is defined as the ratio of the NP to AP. If the ratio is greater than two, the risk of AMD is relatively low. If the ratio is less than one, the risk of AMD is quite high. If the value is between one and two, the area must continue to be monitored to ensure the neutralizing minerals are not depleted or made uncreative.

The commonly used kinetic tests all operate under the same principal but use different methods. In each case, the goal is to generate data through laboratory simulation of the environmental conditions to predict the rate of acid formation. For example, column tests are often used in which natural conditions are constructed and monitored under similar pH, temperature, metal and salt concentration. To be able to make the simulation conditions as close as possible to the natural conditions, a year may be required for data collection (Mitchell, 2000).

4.1.2 Mathematical Models

The use of mathematical models to predict long and short-term AMD generation, alone, or in combination with other predictive techniques, is fairly common. These models are classified into two categories, namely: (1) empirical modelling and (2) geochemical modelling. The predictive power of the models created through these techniques, however, are only as strong as the information and assumptions on which they are based. Furthermore, the greater the amount of information used to create the models, the more accurate they become.

Empirical models, as one would expect, are based on repeated observation and are based on large data sets. Since the equations built are based on data being collected from a single location, they are highly specific and can not be generalized for all cases. Additionally, the data and observations project trends; however, if the information collected is limited in scope, it may be difficult to differentiate between signal and noise. For this reason, long-term predictions may not be very reliable using this method.

In contrast, geochemical models, which use in depth knowledge about chemical and physical processes leading to AMD formation to build systems of equations, may be applied towards different areas, since they allow for mathematical modifications to reflect characteristics specific to a given region such as particle size, mineralogy, sulphide concentration, flow rate, water available, and special variation. Theoretically, geochemical models can be used to predict trends on the scale of a month to several hundred years (Mitchell, 2000).

4.2 Prevention

Once an area has been identified as being at risk for AMD formation, it is necessary for preventative measures to be taken. These measures can be classified into two different categories, namely: (1) reduction of AMD generation and (2) reduction of oxygen and AMD migration. In a sense, the division between these two categories is artificial since by preventing AMD generation, the migration of AMD is also reduced. Nonetheless, in practice, these two categories are very different (Mitchell, 2000: 125).

4.2.1 Reduction of AMD Generation

AMD is mostly reduced through the exploitation of the biogeochemical characteristics that lead to its formation. In most cases, this occurs through treatment measures that inhibiting chemical processes by coating surfaces with materials targeted towards certain outcomes. For example, fatty acid amines are used to coat pyrite making it hydrophobic and hence unable to react well with oxidizing ions. It is, however, unclear if this mode of treatment prevents micro-organisms from furthering organic processes that may contribute to AMD formation. Similarly, innate molecules like iron phosphate have also been used to coat pyrrrhotite and prevent oxidation. Results using these methods have thus far been promising, but it is unclear if this is an economically viable solution.

Many compounds have also been used to directly modify the biological activity that contributes to acidification in AMD sources. If metabolism can be prevented in acidophilic bacteria using bactericides and neutrophilic bacteria using thiol-blocking agents, the soil and vegetative covers can stabilize and AMD formation can be reduced. Many of these compounds are commercially available and have been used under highly acidic and neutral conditions as preventative treatment (Mitchell, 2000).

4.2.2 Reduction of Oxygen and AMD Migration

Engineering solutions play a large part in reducing oxygenic conditions and AMD migration by building physical barriers between under-ground mine workings, waste storage facilities, and the outside environment. Although many of these methods require significant investments of time and money, as well as sophisticated technical understanding of the environment, these methods have and continue to be used all over the world.

By using impermeable barriers to minimize sulphide oxidation by sealing off under-ground mine workings from oxygenic conditions, the static water under-ground will become anoxic within a short period of time as oxygen is consumed by chemical and biological reactions under-ground. Additionally, grout, cement, and impermeable slurry walls can be used to prevent the influx of oxygenic water under-ground. Although these barrier methods are somewhat successful, they come at a high cost of construction and have a high risk involved since the consequences of their failure are high. Trenches have also been built to force contaminated water from under-ground, up to the surface for treatment (Mitchell, 2000).

4.3 Treatment

Although the proactive measures taken to predict and reduce the formation and migration of AMD are successful in reducing secondary consequences and allowing officials to develop appropriate frameworks, AMD can not be eradicated completely through these means. For this reason, and because in many instances regulatory bodies are reactive rather than proactive, treatment often becomes the primary rather than secondary response to AMD.

The method chosen to treat AMD must not only be cost effective, but must also ensure that effluent standards will be met while producing minimal quantities of waste. The sophistication and the chemical and physical needs of the process must be specific to the chemical characteristics and quantity of the AMD to be treated, but also must be specific to the climate, terrain and projected life of the mining facilities and water treatment plant. There are four classes of treatment systems, namely: (1) active; (2) passive; (3) active passive hybrid; and (4) metal recovery. For the most part, active systems that primarily rely on neutralizing reagents are more expensive than passive systems that typically rely on biochemical processes to reduce reagents and neutralize acidity. Metal recovery systems umbrella all three categories and are being developed as new, innovative water treatment methods for the future (Mitchell, 2000).

4.3.1 Active Processes

Active processes for the treatment of AMD usually involve the neutralization of acids through the addition of lime and other related chemicals including limestone, hydrated lime, soda ash, caustic soda, or ammonia (treatment document). Treatment of AMD through liming involves five steps (Mitchell, 2000: 130). After the water to be treated is collected, the water to be treated must be equalized so there is a uniform content. Secondly, Fe^{2+} must be oxidized to form Fe^{3+}, then the water must be neutralized and precipitate metals as hydroxides, and then sedimentation to separate water from solids through the use of coagulants. Lastly, the sludge produced through the treatment process must be disposed of.

Liming technologies are beneficial since they typically require a limited amount of space, are reliable and predictable, and are unaffected by temperature variability. There are, however, many disadvantages. There is a relatively high maintenance cost of using these chemicals to treat water since there are often build-ups of calcium carbonate and carbonate making it difficult for water to be transported from one holding tank to another. Additionally, it is difficult to remove metals from AMD using this method. Additionally, the sludge created through this process tends to be chemically unstable and of no commercial value.

Newer active processes are currently being used that have a denser, more manageable end-product. The high density sludge process yields 10-35% solid waste product and the NTC process can produce as much as 50% solid product. This is compared to the liming process which yields 2% solid waste (Mitchell, 2000).

4.3.2 Passive Processes

Passive processes for the treatment of AMD have been studied for approximately 30 years. Only fairly recently, within the past 15 years, have these systems been implemented on a full-scale at treatment sites around the world. The concept behind passive treatment is to allow the naturally occurring chemical and biological reactions that aid in AMD treatment to occur in the controlled environment of the treatment system. For this reason, designing a passive treatment system for AMD not only requires an understanding of the mine water chemistry, but also of the biochemical processes of the environment to be exploited.

Generally, passive technology involves utilizing constructed wetlands and allowing soil and microbial organisms to remove reduced metals in the acid mine water through their natural metabolic processes. Passive treatment has many advantages over conventional active treatment systems. The use of chemical addition and energy consuming treatment processes is virtually eliminated with passive treatment systems. Also, the operation and maintenance requirements of passive systems are considerably less than active treatment systems. The disadvantages of wetlands systems are that there are seasonal variations in the efficiency of water treatment, they are most productive in treating small flows and require large amounts of space and long periods of time. In addition, some aspects of using passive processes are not completely understood. Research is being conducted to further determine how to dispose of waste associated with these systems and what the effect of metal-contaminated substrates on the local and regional food chains are (Mitchell, 2000).

4.3.3 Hybrid System Processes

Hybrid systems utilize biochemical reactions to neutralize AMD acidity and to remove metals, but also typically involve the use of passive systems to complete water treatment. One example of this involves the use of bioreactors to reduce sulfates and remove metals at low pH at a low operation cost with minimal energy consumption (Neculita *et al.,* 2007). Another method involves using microbial mats, along with other active systems. Neither of these methods is widely practiced and they therefore require further research to “scale-up” reactions to make them useful for treating large quantities of polluted water (Mitchell, 2000).

4.3.4 Metal Recovery Processes

One of the newer types of AMD involves a combination of both active and passive processes in the effort not only to neutralize AMD, but also to recover pure metals and other compounds involved in the process. Although the capital costs associated with these new technologies are high in comparison to other active and passive processes, there is the potential to use a large portion of the waste to support new industry and to profit through the development of satellite companies. Thus, water treatment facilities that are able to recover waste products in the form of usable, sellable material are not only able to treat water to acceptable standards, but also are able to create jobs, and spur economic growth in a sustainable way. Although many of these methods are being used, there are very few that can be used on the large scale necessary to treat quantities produced by the mining industry. It is therefore important to investigate these technologies and to continue to investigate and experiment with these methods to allow them to become more widely spread and easy to use (Mitchell, 2000).

An example of a technically sound and cost-effective solution to the AMD problem in South Africa is the integrated Limestone Neutralization Process, which has been implemented on a full scale with the construction of plants (construction value of ZAR 100 million) having taken place. In addition, the Western Utilities Corporation (WUC) was created as a result of an agreement between the three government departments (Department of Water Affairs and Forestry, Department of Minerals and Energy and Department of Environmental Affairs and Tourism) and the three mining houses in the Western Basin (Harmony Gold Mine, DRD and Mogale Gold) in order to rehabilitate the water source on the Witwatersrand Basin, and, more specifically, to accept responsibility for resolving the AMD problem in the area, eliminating or reducing water ingress into mining voids and implementing a treatment process for AMD at the source of contamination (Motaung *et al.*, in press).

The WUC has in the meantime contracted CSIR, amongst other technology suppliers, to pilot the limestone/sulphide integrated process and to thereby demonstrate the extent to which it is technically and economically feasible. The CSIR integrated process is designed to achieve neutralization as well as metal and sulphate removal by making use of the least expensive chemicals in the most cost-effective way (Motaung *et al.*, in press). Another technology that is being used by the CSIR is the RAD7 instrument, which measures the concentration of Radon in a particular water source (either surface or groundwater) and is linked specifically to exploring potential radionuclide contamination associated with gold-mining activities (Hobbs, 2008).

5. South African Legislative Framework for addressing AMD

The recognition of a broader context of the impacts associated with AMD and mine closure greatly expands the scope of government responsibilities to verify that the mining industry adequately recognizes and prepares for the consequences that are likely to ensue before, during, and after mining operations and that these plans are carried out to the satisfaction of all stakeholders (Warhurst and Norhona, 2000; Limpitlaw, 2004:2).

Since AMD directly affects the mining industry, the environment, and surrounding communities, it is not easily regulated by a single piece of legislation or a single government agency. Instead, AMD in South Africa is primarily addressed through three government departments: (1) DME; (2) DWAF; and (3) DEAT and several major pieces of legislation that are primarily enforced at the national level. There are, however, scores of other policies related in one form or another to AMD through their relevance to waste management, water quality standards, mine closure, and environmental protection at the national, provincial, and municipal levels. In this section, the primary pieces of legislation will be discussed in detail, an overview of the secondary pieces of legislation will be given.

5.1 Primary Legislation

There are four major pieces of legislation that are used to regulate AMD in South Africa, namely: (1) The Constitution of the Republic of South Africa, 1996 (Act 108 of 1996); (2) the National Water Act, 1998 (Act 36 of 1998); (3) the National Environmental Management Act, 1998 (Act 107 of 1998); (4) the Minerals and Petroleum Resources Development Act, 2002 (Act 28 of 2002). These are discussed below.

5.1.1 The Constitution of the Republic of South Africa, 1996 (Act 108 of 1996)

On 4 February 1997, The Constitution of the Republic of South Africa, 1996 (No. 108 of 1996), was approved by the Constitutional Court. As one of the most progressive government documents in the world, South Africa's Constitution is known for the process by which it was adopted, as well as for its content. Not only does it emphasize key social justice issues and the necessity for job creation, but it also discusses water resource management in the context of sustainable development and job creation.

More specifically, the provisions of the Bill of Rights of the Constitution of South Africa contain three fundamental objectives for managing South Africa's water resources. First and foremost, the Constitution stipulates that there must be equitable access to water for all. Secondly, it states that water must be used efficiently and effectively to work towards sustainable use. Thirdly, the Constitution stipulates that natural resources must be used to promote justifiable economic and social development (RSA, 1996: Section 24(b)). Since the Constitution is primary, all other legislation and policy frameworks on water resource management are firmly embedded in the Constitution of South Africa, and must be consistent with the aforementioned imperatives.

5.1.2 National Water Act, 1998 (Act 36 of 1998)

The National Water Act, 1998 (Act 26 of 1998), referred to as the NWA, is the principal legal instrument relating to water resource management in South Africa. This act includes comprehensive provisions for the protection, use, development, conservation, management, and control of South Africa's water resources and replaces the old notion that water rights are tied to land ownership. Instead, water is treated as a natural resource which is to be distributed in an equitable, efficient manner to meet basic needs of the South African people, with DWAF as the central custodian. In addition, the NWA suggests that public participation is a key requirement to the distribution of water to support sustainable development and that water user licences are required for industry (DWAF, 1998). Although the NWA is a complete document on its own, the National Water Resources Strategy (NWRS) has been developed to provide a framework for its implementation. As a part of the plan, the NWRS outlines plans to decentralize responsibility and authority for water resources over time through the empowerment of local authorities. A number of other supporting documents have also been established (DWAF, 2004).

Of particular relevance to AMD is the NWA's definition of the treatment of pollution, namely "the direct or indirect alteration of the physical, chemical or biological properties of water resource" (DWAF, 1998: Sec 21 1996) and the management practices for the treatment of waste before it is deposited onto land or allowed to enter a water resource. Eleven activities requiring authorization are also defined, many of which have bearing on mining activities and which relate to AMD and particular attention is paid to the discharge of mining waste. It is specified that permission must be obtained before waste disposal into the environment, since stockpiles and tailing dumps are a major source of water pollution emanating from mining activities. In addition, the NWA outlines one of the most central concepts used to address damage caused by AMD and other industrial waste, namely the 'Polluter Pays Principal' (PPP) (DWAF, 1998: Sec. 19-20). This legal philosophy requires that those who are responsible for producing, permitting, or causing pollution should be held liable for the clean up costs and the costs of legal enforcement associated with that of pollution (DWAF, 1998; Taviv *et al*., 1999).

5.1.3 National Environmental Management Act, 1998 (Act 107 of 1998)

The National Environmental Management Act, 1998 (Act 107 of 1998), NEMA, is the most important piece of legislation pertaining to environmental requirements. Administered by the DEAT, NEMA provides or cooperative governance by establishing guidelines for decision-making on environmental matters. As the principal frameworks for environmental issues, NEMA has direct relevance to the implementation of the National Waste Management Strategy (NWMS) which designates DEAT as the lead agent for environmental regulation (DEAT, 2005). Of particular relevance to mining and the prevention of AMD is the description of what is required in Environmental Impact Assessments (EIAs), and Environmental Management Programs (EMPs) and the activities that are required for these studies to be compiled (DEAT, 1998c: Sec. 5). It also provides a framework for assessing the implications and risks of various broad development scenarios and could, for example, suggest land-use options that result in better management of river catchments and rangelands.

The EIA is defined as “a process that assesses the impact of a planned activity on the environment – physical, social and economic – providing decision makers with an indication of the likely consequences of development actions. When it is an integral part of the planning process, EIA enables potentially negative impacts to be mitigated (and positive impacts to be maximised) early in the design stages. Through the EIA process, the developer can improve the way a project is planned, implemented and, in some cases, decommissioned” (Tarr, 2003). As of 2004, EIAs were required as a statutory pre-requisite for the development of new mining projects and also for the renewal of mining licenses for existing mines. The overarching goal of EIAs and resulting EISs and EMPs is to minimize environmental impact during and after mining operations, along with the associated socio-economic impacts. Typically compiled by consultants hired by industry representatives, the EIA is done to determine potential environmental impacts of the proposed project and establish an EMP to monitor and mitigate risk during operation and following closure (Sassoon, 2000). This is done, following the feasibility assessment and finalization of the mine plan, as a reaction to the desire to set up an economically viable business venture. The EIA is then used as a management tool to inform the governmental decision making process about the initial design and implementation of a mining project. For an EIA to be approved and the mining license to be acquired, DEAT, along with DME and DWAF need to approved its contents (Herbst, 2007).

5.1.4 Minerals and Petroleum Resources Development Act, 2002 (Act 28 of 2002)

The Minerals and Petroleum Resources Development Act, 2002 (Act 28 of 2002) (MPRDA) which came into effect on 1 May 2004, was written to replace the Minerals Development Act of 1991 and represents the South African Government’s official position on the acquisition and exploitation of mineral resources. This piece of legislation is designed to transform the mining industry to promote equitable access to mineral resources, encourage investment in mining exploration and to promote private enterprise through small scale mining projects. At the same time, the plan is geared towards allowing for socio-economic development and environmental sustainability within the mining sector. To implement this strategy, a licensing system was developed that would allow all individuals to have equal access to acquire mining licenses and to promote small-scale mining projects. According to the 2007 MPRDA Amendment Bill (DME, 2007) Section 39, anyone applying for a prospecting right, mining permit, reconnaissance permit, exploration right or the renewal of any of such documents has to also apply for environmental authorisation in the prescribed manner must submit a basic assessment report and a standard environmental management plan in order to begin prospecting, exploration and mining activities. Environmental sustainability and well-being is thus also addressed as part of the MPRDA legislation.

More specific to AMD, the Minerals and Petroleum Resources Development Act of 2002 addresses pollution and waste management in part IV of the regulations. The principles outlined for waste management are consistent with international best pra1ctice for waste management, but are rather general. For example, it is stated that generation and production of waste and mine residue should be avoided when possible, or should be minimized, re-used or recycled. According to the act, if waste must be disposed of, it should be done in a "responsible and sustainable manner." It should be noted that the Minerals and Petroleum Resources Development Act does not define mining waste, but makes reference to "residue deposit" and "residue stockpile" in Section 40 and states that disposal of waste must be taken up with other government departments (DWAF and DEAT). In Section 42, the act discusses more specific details about how residue stockpiles and deposits are to be managed (Oelofse, 2006; DME, 2002).

The Minerals and Petroleum Resources Development Act also outlines South African mine closure regulations (DME 2002: Sections 33,42; Pulles *et al*. 2005: 2.6). In these sections, the basic requirements for mine closure are outlined and the cumulative impacts of mining must be determined and must be based on the "natural boundaries" of the resources of concerns. The process of applying for mine closure certificates is also described. The closure plan included in the EMP, contains a description of closure objective, a summary of regulatory requirements, summaries of the environmental risk report, and results of rehabilitation, and must be approved before the mining company can be absolved from all liabilities associated with the post-closure management.

5.2 Secondary Legislation

For the most part, the secondary legislation relating to AMD has been drafted in support of the primary legislation. These documents may elaborate on the philosophies and guidelines set forth in the primary documents and deal with safety, water conservation and distribution, or hazardous waste including but not limited to radioactivity. One piece of legislation that is of note is the National Environmental Management: Waste Management Bill that is being drafted by DEAT which will regulate mining waste in accordance with other previously established standards (DEAT 2000a; DEAT 2000b; DEAT 1998a), requiring reside dumps and stockpiles to be licensed as waste disposal facilities (Oelofse, 2003; DEAT, 1998c) For more detail, see Oelofse, 2006. The secondary legislation is particularly valuable since the creation of new bills and acts that allows for greater specificity of existing legislation and which allows for existing primary frameworks, like the NWA, NEMA and MPRD to be made more pro-active in the future.

6. Areas for Improvement and Policy Recommendations

The liberalization of investment regions worldwide, the growing emphasis on environmental regulation and sustainable development, and the increasing conditionality of loans on prior environmental and social impact studies indicate that there is an urgent need for analysis of current policies to inform decision making in industry, donor agencies, and government among others. While South Africa has made monumental progress in shifting policy frameworks in recent years to address mine closure and mine water management and the mining industry has changed their practices to conform to these new regulations, there remain areas for improvement. To allow recent technological innovation and the existing organizational frameworks to be harnessed to prevent environmental and socio-economic degradation, it is important for existing vulnerabilities to be analysed and for policy recommendations to be made.

In this section, two areas for improvement will be discussed within the existing South African policy framework, namely: (1) coordination and enforcement of the existing policies and (2) the reactive nature of existing policies. Following this discussion, key policy recommendations will be made.

6.1 Coordination and Enforcement within Government and between Government and other Relevant Actors

Effective management of AMD through the enforcement of applicable legislation is dependent on coordination between the various governmental departments at the national, regional, provincial, and municipal levels. Collaboration between departments is not always easy. The South African Constitution and other primary legislation allocates certain responsibilities to various institutions, however, to allow for provincial and municipal leadership as well as stakeholder involvement, it is often unclear which government department is responsible for enforcing a certain aspect and at what level. Additionally, many government departments lack the manpower to make frequent enough site visits to mines and surrounding areas to verify compliance. In this section, these difficulties are highlighted as they relate to current mine closure and waste management strategies.

Since the legislation relating to AMD and the mine closure strategies is administered by three government departments, there are elaborate coordination schemes between the three departments that stipulate modes of cooperation. In some cases, as in the NEMA and the NWRS there are inclusions within the legislation that instruct how interdepartmental coordination is to be used. For example, in the application for a mining license, the EIA and resulting EMP as well as a Social and Labour Plan must be submitted to DEAT; however, prior to approval, DWAF and DME must review the conditions and visit the site to verify compliance with their legislation. To improve efficiency of the authorisation process and minimise potential conflict and ambiguity, NEMA provides for the establishment of Environmental Management Cooperation Agreements (Oelofse, 2006; NEMA; DWAF, 1998). A Memorandum of Understanding (MoU) between the three government departments, DEAT, DWAF, and DME, has been signed to ensure cooperation and coordination in this regard. Additionally, an interdepartmental committee called the Government Task Team (GTT), has been established to address mine closure and water management practices and is composed of members from all three governmental departments (DME, 2005; DME *et al.*, 2005: 4).

Although many believe the conflict between national, provincial, and municipal powers with regard to mining have been fully addressed by the delegation of powers in the Constitution (Dale, 1997), there remain a few ambiguities that need to be addressed. According to the Constitution, the National Government is empowered to pass legislation pertaining to the environment, pollution control, and soil conservation (RSA, 1996: Section 4). Although DEAT, DME, and DWAF are charged with administering policies in these areas, regional or provincial representatives from these national agencies are empowered to enforce these policies at a more local level (RSA, 1996: Section 5). In terms of mining waste, provincial government are responsible for establishing a detailed inventory of all potentially polluting sites within their jurisdiction and for developing hazardous waste management plans to ensure industries have access to appropriate waste disposal facilities. The plans should also include waste minimization, recycling and re-use initiatives for both industrial and mining waste. Hazardous waste reduction at source and responsible disposal including alternative treatment options should feature in the initiatives. Municipal governments are empowered to legislate on matters listed in Part B of Schedules 4 and 5 of the Constitution (RSA, 1996) which include control and management of waste as well as water and sanitation services. Both provinces and municipalities are empowered to administer any laws which they have passed. In all cases though, national government may override provincial or municipal authorities in instances in which it becomes necessary to maintain national security, economic unity, essential national standards, to provide minimum standards for the rendering of services, or to prevent unreasonable provincial action which will be prejudiced or to the interest of another province or the whole country (Oelofse, 2006).

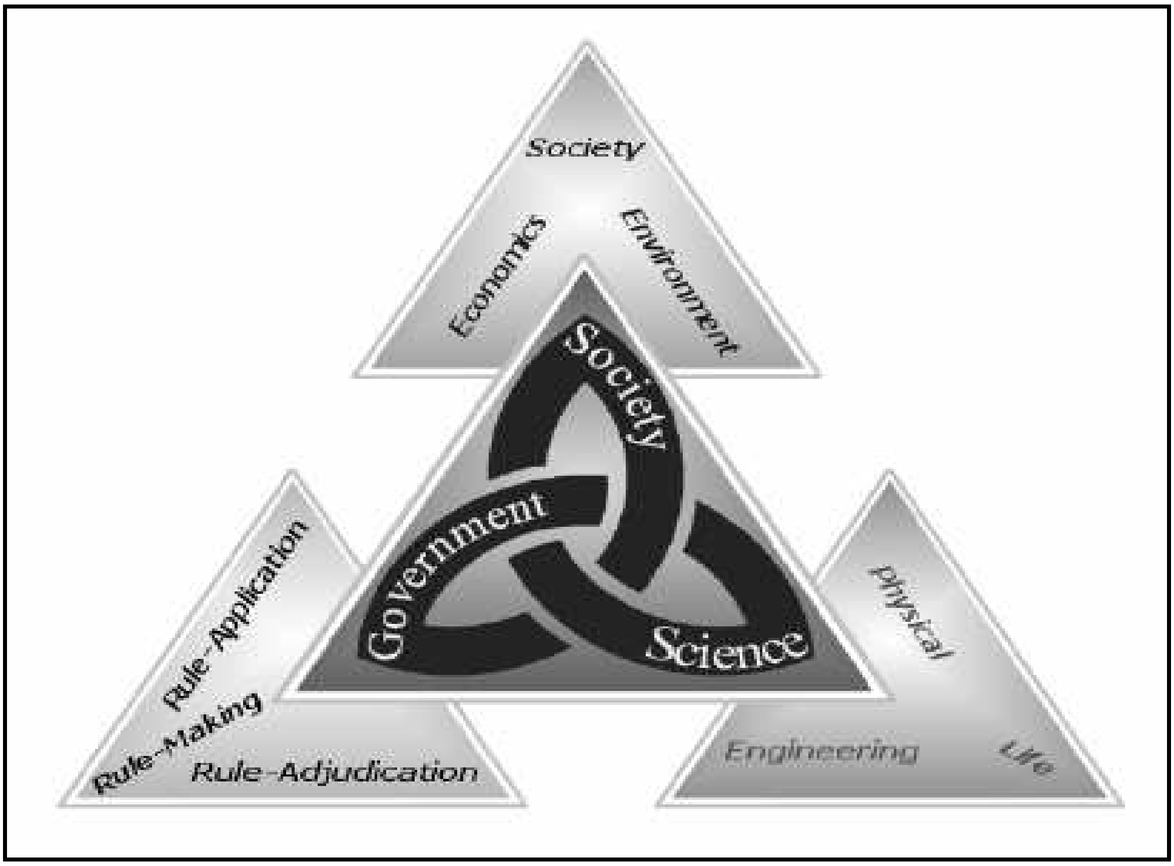
The Constitutional allocation of legislative and administrative competence has important consequences for integrated pollution control and waste management but has further exacerbated difficulties in integrating pollution control between national, provincial and local authorities. By creating concurrent legislative competencies between different spheres of government, the possibility for conflicting legislation is created. For example, water quality standards will be imposed at a national level; however, local governments are responsible for legislation concerning the treatment of water and sanitation services. There is potential for legislative conflict in this situation, as well as likelihood that instead of promoting integration, it will create division. This is a result of the seemingly *ad hoc* appearances in sections 4 and 5 of the Constitution of certain pollution control functions without, apparently, the whole picture having been adequately considered. The Constitution however clearly requires that the responsibility for waste management functions is to be devolved to the lowest possible level of government in accordance with the right to self-determination (RSA, 1996: Section 235; Oelofse, 2006). This problem is exacerbated by the fact that some government departments are not only understaffed, but also have alarming turnover rates from year to year. For this reason, new representatives must be hired and informed about the legislation they are charged with enforcing. Although the learning curve is quite steep, this contributes to it that many of the foot soldiers in charge of regulation lack institutional memory and may not fully grasp the implications of the policies themselves in the context of the existing division of labour.

Much of the confusion over the division of powers between various government departments and national, provincial, and municipal government could be eradicated over time as various authorities get used to new legislation and better understand their individual roles in the larger context. However, given the high rate of turnover at the various government departments and the relative shortage of technically trained individuals, it is likely that a new course of action is desired. Consideration can be given to the establishment of contractually enforceable term limits for personnel hired under DWAF, DEAT, and the DME. Another possible solution is that benefits structures could be established for government employees that would encourage individuals to stay longer. This could include, for example a system of delayed bonuses, pay raises, better health coverage, and other enticing opportunities following a specified period. Another possibility would be to require all employees at the time of departure to record their experiences working with other departments at various levels to enable future workers to learn from their experiences.

While the above section refers to problems of cooperation and coordination within government, such problems also extend to the broader domain of institutional cooperation, planning and coordination between institutions that include but are not limited to the government level. These institutions include national government departments, research councils, municipalities, as well as private sector consultancies and mining houses (Cobbing, in press). Other, not necessarily institutional, actors are civil society-based groups, who are actively engaged in and concerned about the AMD-related problems in the West Rand. These include, among others, the Potch Petitioners, the Pelindaba Working Group and the Public Environmental Arbiters, all of whom have a vested interest in the enforcement and upholding of environmental justice in the West Rand area.

One can argue here that one of the major problems related to the AMD issue in the West Rand is that of a lack of quality and interaction between each of the so-called "actor clusters" in Turton *et al.*'s (2007) Trialogue model, made up of the elements of government, society and science (see Figure 1). The government actor-cluster can be sub-divided into the legislature, executive and judiciary; the society actor-cluster is made up of civil society, the economy and the natural environment within which these are situated;

and the science actor-cluster consists of the natural sciences, the social sciences and tertiary education institutions, which provide human capital.



Trialogue Model depicting the interfaces between the government, society and science actor clusters (Turton *et al.*, 2007)

Complex relationships exist within and between the three actor-clusters and these have to be managed carefully if a sustainable management of mine closure and the resolution of related mine water pollution problems in the West Rand is to take place. What is of particular importance is the quality of the two-way interfaces between each of the three actor-clusters i.e. government, science and society. Complex problems such as those related to mine closure and the management of AMD require close collaboration and communication between the different stakeholders in question in order to avoid a situation where non-cooperation could take place if fellow stakeholders are seen as rivals rather than partners (Cobbing, in press). An example would be a lack of successful cooperation between different government departments mandated to oversee the area, or between specific government departments and civil society groupings with a human rights-based interest in the situation on the West Rand.

A case in point where such cooperation between stakeholders will be essential is the proposed "Toothfairy" Project or "High Confidence Study of Children Potentially Affected by Radionuclide and Heavy Metal Contamination Arising from the Legacy of Mine Water Management Practices on the Far West Rand of South Africa". The objective of the proposed study is:

> *To determine, with a high level of confidence, if there is any evidence of human health risk within a population that has had chronic exposure to heavy metals and radionuclide contamination in subsets of the geographic areas that have been reported in Water Research Commission Report No. 1095 (Wade et al., 2002), Water Research Commission Report No. 1214 (Coetzee et al., 2006), and the National Nuclear Regulator's Brenk Report (NNR, 2007), in order to address public concern, restore eroding investor confidence and form the foundation of effective public policy intervention* (Turton, 2008).

Such a study will of course require an extensive and excellently qualified and experienced technical steering committee and field team, both made up of national and international scientists, working alongside an oversight steering committee concerned with scrutinising and overseeing the ethical side of the project (Turton, 2008). The Trialogue Model appears to be a suitable approach for the proposed project, because it allows for a wide range of interested and affected parties from the different actor-clusters to participate in the various components of the project. A concerted effort will be made to ensure that different actors and parties cooperate effectively in order to conduct the study and communicate the findings to the members of society who are directly affected by the AMD-related problems in the West Rand. This will be a definite challenge and test to determine the extent to which the Trialogue Model can effectively be applied in practice.

6.2 Proactive Versus Reactive Governance

AMD and other problems associated with mine closure and mine water management are large scale problems that can not easily be addressed over the short-term. Instead, policy frameworks need to plan for the future, using time as an asset not an impediment. Although many of the current South African policies are geared towards mitigating risk, many of them create problems by neglecting some of the more long-term consequences of the problems they aim to solve. In this section, three major concerns will be highlighted, each in the context of the need for more proactive governance. First, there will be a discussion of the Polluter Pays Principle (PPP) followed by a discussion of the shortfall of the EIA and lastly, a discussion of sustainability of AMD treatment and prevention.

6.2.1 Polluter Pays Principle

The Polluter Pays Principal (PPP), as outlined by the NWA, stipulates that those who are responsible for producing, permitting, or causing pollution should be held liable for the clean up costs and the costs of legal enforcement associated with that pollution (DWAF, 1998: Sec. 19-20; Taviv *et al*. 1999). In this sense, the PPP requires that a charge system be put in place so that there is an incentive for polluters to decrease the quantity and to improve the quality of their discharge. In so doing, a penalty scheme must be established that encourages compliance over the long-term and allows industry to change their protocols without being economically crippled (Taviv *et al.*, 1999: 3-15). Even if an appropriate pricing structure is in place, however, the philosophy is of limited value in being able to address non point source emissions and cumulative impacts that occur as a result of mine closure and AMD.

Before a waste charge system can be implemented, as required by the PPP, a regulatory authority must first identify the polluter or polluters responsible and measure how much of what pollutant was released into the environment. If a polluter cannot be identified and a causal relationship cannot be established, the PPP becomes unenforceable and fails to produce desired results. In the case of AMD, it is extremely difficult to determine a direct source for pollution. Since AMD can form under different circumstances, most of which lead to environmental pollution through non-point sources, it is nearly impossible to trace the polluter with any reasonable degree of accuracy. For example, many gold mines are connected under-ground, allowing water to flow between one basin and another. In this way, the polluted water in one company's shaft may partially belong to another mining company.

Establishing a price structure to account for environmental degradation and the other impacts caused by AMD is also difficult. Although many of the damages associated with mine waste can be evaluated outright, the cumulative impacts of this damage may not be noticeable in the short-term. In the case of AMD, many of the damages are cumulative and result in changes in human and environmental health, as well as a change in the social dynamics of surrounding areas. By placing a monetary value on the pollution associated with AMD in association with the PPP, future consequences can be neglected and therefore sustainable development is de-emphasized.

Given that the PPP is a regulatory mechanism that has been shown, in the past, to be successful in decreasing the amount of environmental degradation through reducing pollution to archive environmental management, it is important to modify frameworks to allow for the PPP to be used in a proactive rather than reactive fashion. Currently, the PPP is applied once there is a major environmental crisis. If, however, it were to be applied pro-actively through more regular mine site visits and through modification of pricing schemes to better account for cumulative impacts and discharge from non-point sources. Frequent site visits would allow regulatory authorities to have a better sense of the activities and waste management practices of each mine, which would make enforcement much easier. Additionally, when it becomes impossible to measure a single company's contributions to pollution in any given area, the government can consider entering into a pre-formed agreement between the various mining groups, based on production, consumption, spatial extent of activity or other characteristics to estimate the pollution load for each party (Taviv et al., 1999: 5-3). Such an agreement, however, takes years to establish and could result in unnecessary litigation. Although these discussions have been under way for sometime, it is unclear if any agreement has been finalized. The newly formed GTT could revisit this issue and work towards other preventative measures.

6.2.2 Shortfall of the EIA

Although EIAs are required in most countries prior to the initiation of new mining projects and are now considered international best practice, they can, in many respects be considered as a lip-service to legislation since they are reactive, short-sided, and largely incomplete or inaccurate. Currently, many of the environmental and socio-economic aspects that are uncovered as a result of the EIA are addressed retrospectively or viewed “as a hurdle that has to be crossed before the negotiations for project approval can begin” (Sassoon, 2000: 101). Additionally, the EIA fails to gain an accurate portrayal of socio-economic, political, and health related consequences of mining activities, thus indicating a lack of commitment to take a more integrated approach to project environmental and developmental considerations of mining activities.

The reactive nature of EIAs, along with their incomplete and inaccurate projects, is inherent in the way in which they are conducted. Since the EIA is created following the feasibility study of a mining project, it is often based on incomplete geotechnical information and engineering designs. Furthermore, EIAs are conducted at the beginning of the project; however mining projects and the surrounding areas are not static, but rather change over time. According to Meredith Sassoon, “to grant a mining project environmental approval ostensibly for the whole of its life, on the basis of the EIA, tacitly implies a static situation” (Sassoon, 2000: 106). For these reasons, the information on which the legislation is based may lead to inaccurate projects that may underestimate impacts. Some have also objected to the fact that many mining companies are now hiring their own employees to manage and enforce the EMPs. Although many of these individuals have a technical background, they are often mining engineers turned environmental engineers. Although extremely knowledgeable and dedicated to their task, many of these people lack the understanding of environmental issues to see the broad based environmental picture and therefore fail to establish unified, consistent viewpoints. To address these problems, consideration should be given to acquiring more technical information and more developed plans prior to the EIA, requiring renewals of EIAs on a more regular basis, and to requiring environmental engineers rather than mining engineers to be responsible for implementing EMPs.

The EIA process also tends to neglect several important socio-economic aspects. Although the South African EIA is geared towards not only assessing the environmental, but also the socio-economic risks affiliated with a new mining ventures, these assessments are often superficial and incomplete. Since many of the economic and socio-economic impacts of mining activities require an understanding of technical knowledge to predict long-term concerns based on cumulative impacts, these risks are often left out of the EIA altogether (Warhurst and Noronha, 2000: 81-99). Similarly, the current EIA architecture does not require true health impact assessments (HIAs). Rather, the HIA is a sub-section of the larger EIA and relies only on the information collected from the EIA itself. Other health aspects related to mine closure and mine water management are approached from an occupational point of view. For these reasons, the health conclusions included in the EIA are of limited to no value and therefore fail to produce useful conclusions. Instead, these assessments should be conducted by doctors or epidemiologists who would adhere to the stipulations set out by the World Health Organization (WHO), be able to better assess health conditions of people in neighbouring areas, be able to more accurately predict the changes in health, based on the project, be able to assess the cost of these implications and be able to reasonably develop measures to prevent, minimize, and mitigate impacts (WCD, 2000: 284).

The EIAs and resulting EISs and EMPs also address mine closure in a superficial manner. Typically, it is agreed that after the mine is decommissioned, the site should be left safe with some degree of re-vegetation with a commitment to accepting rehabilitation as an integral part of the project and design. In South Africa, all new mines must have a mine closure plan prior to gaining a mining license (DME, 2002), however; there is not a set method for addressing sustainability in terms of water treatment plant operation. Mining representatives agree that water treatment plants, similar to the one established at Anglo Coal in Witbank and the plant under way with Harmony Gold, are most likely the way of the future (Herbst, 2007; Günther, 2007); however, it is unclear who will maintain responsibility for these plants over the long-term. Manipulation of ownership and transfer of physical assets and liability is common practice in avoiding financial liabilities, and an absence of a plan in this regard presents a problem for the future. At present, mining companies with water treatment facilities plan on absolving themselves from the responsibility of having to manage the water treatment plants in the future by hiring private companies to maintain operation and manage equipment. It is suggested that there be a contingency plan for the government, if necessary in the future, to be able to maintain operation of these plants in the event that the company becomes bankrupt or the business no longer remains profitable.

6.3 Recommendations

- There should be a continued investment in new technologies to predict, prevent, and treat AMD. Particular attention should be paid to hybrid systems and metal recovery processes which not only treat AMD, but also provide drinkable water, employment, and usable materials.
- To limit coordination and implementation problems between various government agencies at the national, provincial and municipal level:
    - Government may consider providing economic incentives or contractual agreements to retain employees.
    - Agencies can hire more staff and provide leadership training at the municipal level.
    - Delegation of powers should continue to be made more specific through secondary legislation.
    - GTT should be utilized to its full potential to aid in interdepartmental coordination
    - Consideration should be given to employing and testing the Trialogue Model in practice and to strengthen the interfaces between the actor-clusters.
- To make legislation become more proactive:
    - The EIA process should be altered to make it less reactive. Consideration should be given to the following:
        - More detailed engineering plans and geotechnical information should be gathered prior to conducting the EIA
        - EIAs should be reassessed on a regular basis

- EIAs should pay attention to cumulative socioeconomic impacts
- Mining companies should consider hiring environmental engineers to oversee EMPs rather than mining engineers who will be able to have a broader understanding of environmental concerns

- Separate HIAs should be done according to WHO standards. These studies should be conducted by health professionals and should include epidemiological and toxicological studies of mining communities and should not rely only on information collected through occupational and environmental data collection processes
- Pricing schedules of PPP should be restructured to better address non-point discharge sources and cumulative impacts caused by more than one polluter
- New guidelines should be considered to make water treatment plants more sustainable over the long-term. To prevent the negative impacts associated with AMD, especially political consequences, government may wish to:
  - Provide subsidies for the establishment of large-scale treatment facilities
  - Look into using trust funds to support the operation of water treatment in the event that the operation is no longer profitable

APPENDIX 1

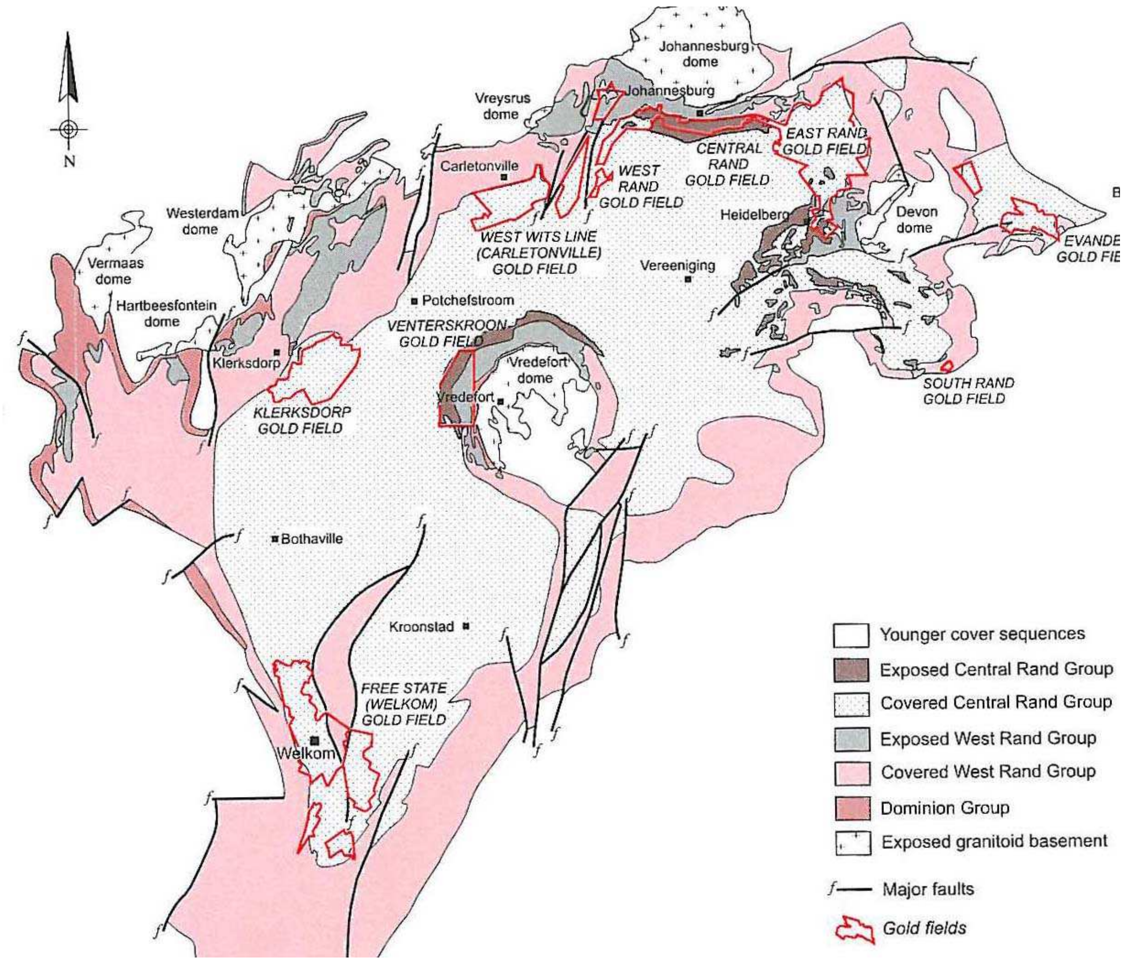


Figure 1: Witwatersrand Goldfield –

Above is a map depicting the relative location of the different groups in Gauteng's Witwatersrand Goldfield. These groups include: the Younger cover sequences, The Exposed Central Rand Group, the Covered Central Rand Group, the Exposed West Rand Group, and Covered West Rand Group, the Dominion Group, and the Exposed granitoid basement. Additionally, the major gold fields are marked in red and major faults in black. Gold was first discovered in the Central Rand in the 1850s but did not become a lucrative industry until the 1870s. Subsequently, gold was discovered in the West Rand and Far West Rand and these areas were developed starting at the turn of the 20th century. Now, as many of these mines are approaching closure, AMD is becoming a major issue in the area (From Robb andRobb 1998).

APPENDIX 2

(A) $4FeS_{2(s)} + 14O_{2(g)} + 4H_2O_{(l)} \rightarrow 4Fe^{2+}_{(aq)} + 8SO_4^{2-}{}_{(aq)} + 8H^+_{(aq)}$

(B) $4Fe^{2+}_{(aq)} + O_{2(g)} + 4H^+_{(aq)} \rightarrow 4Fe^{3+}_{(aq)} + 2H_2O_{(l)}$

(C) $4Fe^{3+}_{(aq)} + 12\,H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)} + 12H^+_{(aq)}$

(D) $4FeS_{2(s)} + 15O_{2(g)} + 14H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)} + 8SO_4^{2-}{}_{(aq)} + 16H^+_{(aq)}$

(E) $FeS_{2(aq)} + 14Fe^{2+}_{(aq)} + 8H_2O_{(l)} \rightarrow 15Fe^{3+}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 16H^+_{(aq)}$

Figure 2: Basic Chemistry of Acid Mine Drainage –

AMD is complex and therefore can not be fully described by a few reactions. In this figure, a few reactions are shown to illustrate how AMD is formed. In addition to what is shown, sulphides of copper, zinc, cadmium, lead, arsenic and other heavy metals will undergo similar geochemical reactions resulting in the contribution of toxic metal ions into mine waste water. Other factors such as the presence of acidophilic bacteria can accelerate sulphide oxidation. **A.** Iron II ions and acidic hydrogen ions are released into the waters that runoff from the mine drainage tunnels or tailings piles, **B.** Iron II ions are oxidized to form iron III ions as shown in the following reaction, **C.** The iron III ions now hydrolyze in water to form iron III hydroxide, releasing more hydrogen into the environment further reducing the pH. **D.** Sum of equations 1-3. Here we see that pyrite is oxidized, free hydrogen ions into the water and coating the stream bed with iron III hydroxide.

APPENDIX 3

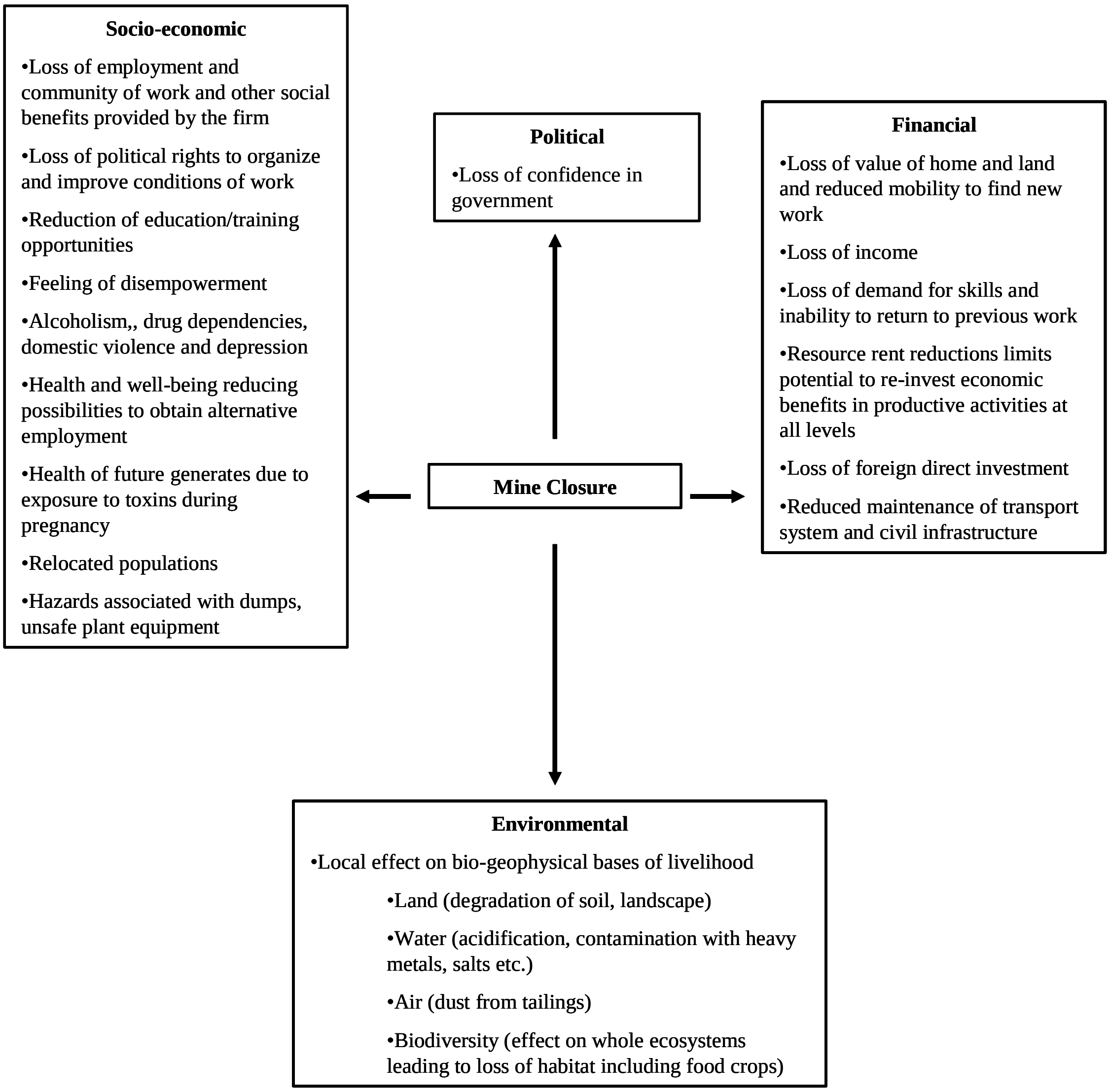


Figure 3: Sceme of Impacts Related to Mine Closure and AMD –

When mines are decomissioned and cease operation and other service and supply industries dissolve, there are a whole host of impacts that can be discussed in the context of environmental, socio-economic, financial, and political issues (Adapted from Warhurst and Naronha, 2000: 86).

APPENDIX 4

Aspect Requiring Regulation	Government Department Responsible
Environmental Coordination	Dept of Environmental Affairs and Tourism
Air Pollution	Dept of Environmental Affairs and Tourism Local Government
Domestic and Non-Hazardous Industrial Wastes	Dept of Environmental Affairs and Tourism Dept of Water Affairs and Forestry Local Government
Hazardous Waste	Dept of Environmental Affairs and Tourism Dept of Water Affairs and Forestry Dept of Transport
Transportation of hazardous substances	National Dept of Health Dept of Transport
Soil Quality (and use of pesticides)	Dept of Land Affairs Dept of Agriculture
Marine Pollution (i.e. from coastal mining activities)	Dept Environmental Affairs and Tourism Dept of Transport Dept of Water Affairs and Forestry
Radioactive Waste	Dept of Minerals and Energy Dept of Environmental Affairs and Tourism National Dept of Health Dept of Water Affairs and Forestry National Nuclear Regulator
Water Pollution	Dept of Water Affairs and Forestry Local Government
Mine Waste	Dept of Minerals and Energy
Waste on roads	Provincial Administrations
International Conventions	Dept of Foreign Affairs Dept of Environment Affairs and Tourism Dept of Trade and Industry Dept of Transport Dept of Water Affairs and Forestry

Table 1: State Institutions Involved in the Administration of Waste Management and Pollution Control –

The above table shows the various aspects of waste management and pollution control that are monitored at the state level on the left and the department responsible for the regulation on the right. Given that virtually all national departments, provinces, and local authorities are responsible for administering one or more laws in relation to mine water managment, it is understandable why enabling institutions and procedures that encourage and require interdepartmental collaboration are so important. (Table modified from DEAT and DWAF, 1997; Oelofse, 2006).

GLOSSARY

Acid Mine Drainage –Highly acidic water, usually containing high concentrations of metal, sulphides, and salts as a consequence of mining activity including but not limited to drainage from under-ground mine shafts, runoff and discharge from open pits, mine waste dumps, tailings and ore stockpiles. Acid mine drainage is commonly referred to as acid rock drainage.

Apartheid - Afrikaans or Dutch word meaning "separateness" used to describe the social policies of the National Party in South Africa from 1948-1994 which were designed to keep White and Black South Africans from mixing.

Aquifer - An under-ground geological formation containing water and is the source of groundwater for wells and springs.

Assessment -The process of collecting, organising, analysing, interpreting data. In the case of an environmental impact assessment, the assessment leads to the creation of a statement, which discusses findings in the context of an issue of interest.

Decant – To flow or pour out. In the context of this paper, "decant" refers to the flowing of acid mine drainage out of an abandoned mine shaft.

Dewater - A verb used to describe the removal of water from a compartment at a rate that exceeds water replacement. This process progressively lowers the natural water table.

Dimorphic – Having two distinct forms.

Governance - The right to participate in and make decisions with regard to a nation's affairs, which is critical in democratising the state and society. Characteristics of good governance include: political accountability, freedom of association and participation, a sound judicial system, bureaucratic accountability, transparency, freedom of expression, and capacity building. All these aspects are essential to sustainable development.

Gross Domestic Product - A measurement of the total value of goods and services produced by a domestic national economy during a given period, usually one year. Total GDP is obtained by adding the value contributed by each sector of the economy in the form of profits, compensation to employees, and consumption of capital; however, the contributions to the economy arising from foreign investment within the country can not be taken into account as a part of this figure.

Mining - The extraction of valuable minerals or other materials from below the Earth's surface. Materials commonly recovered through mining include bauxite, coal, copper, diamonds, iron, gold, lead, manganese, magnesium, nickel, phosphate, platinum group metals, salt, silver, tin, titanium, uranium, zinc, clay, sand, gravel, granite, and limestone.

Mine Closure - A term used to describe the process of shutting down mine operation. The objectives for closure of a typical hard rock mine include minimizing long-term environmental liability, attaining regulatory compliance and maintaining geotechnical stability, while closing as quickly and cost effectively as possible - in a manner that returns the land to a safe and stable configuration for post-mining uses.

Mitigation – Measures designed to avoid, reduce or remedy adversity.

Oxidize – A chemical reaction in which an element or compound donates an electron to a reduced element or compound, usually to oxygen. In the context of this paper, oxidation of sulphides contributes to the formation of acid mine drainage.

pH- A measure of the activity of hydrogen ions (H+) in a solution used to determine how acidic or basic a solution is. The pH of a given solution is given on a log scale from 0 to 14 with 0 being extremely acidic and 14 being extremely basic and 7 being neutral. Acid mine drainage can have a pH as low as pH 2.

Post Closure – Post-closure is the point in time beyond which no further monitoring or passive management is needed or required.

Sinkhole- A depression in a land surface connected to a subterranean passage, generally occurring in limestone regions and formed by collapse of a cavern roof or dissolving of the subterranean minerals.

Stakeholder- Any individual, group, institution, or business unit that is affected by or have an interested in a particular activity or set of activities

Social Justice- An ideal condition in which all members of a society have the same basic rights, security, opportunities, obligations and social benefits

Sulphide –A compound containing sulphur with an oxidation number of -2, with another chemical element or a radical thereof.

Sustainable Development- To achieve economic and social goals of the present without compromising the needs of future generations; attention paid to conserving resources, protecting the environment, and ensuring human health and welfare.

Water Table - The level below the land surface at which the subsurface material is fully saturated with water. The depth of the water table reflects the minimum level to which wells must be drilled for water extraction.

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