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Suvania Naidoo

Acid Mine Drainage in South Africa

Development Actors, Policy Impacts, and Broader Implications

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Preface

In South Africa, acid mine drainage (AMD) has become a highly contested issue as a technical and scientific matter. Also contested are its policy implications for the mining sector, water security and socio-economic sustainability. What is more complicating is that a difference in its definition exists between two groups of role-players, namely, the South African government on the one hand and consultants/activists/NGOs on the other hand. This book explains these differences, the situation of AMD in each of the three basins of the Witwatersrand goldfields, in the Vaal River System, South Africa and the socio-economic implications caused by AMD. It was found that these definitions determine how the issue is understood and what solutions these role-players propose. One of the main objectives was to determine whether the South African government's policy response is appropriate given the socio-economic impacts of AMD and imperatives of sustainable development. The conclusions include no clear indication in policy as to what the socio-economic impacts are and how they should be responded to. While most of the studies on AMD in South Africa are in the fields of engineering, chemistry, hydrology and mining management, this book's approach is from a social science perspective and not entirely from a technical point of view. This approach is still underdeveloped, and only a few South African researchers/activists have done similar research.

Water is the most crucial resource and is important to ensure that the basic needs of South Africans are satisfied. Safe clean water for drinking and for the sectors that assist in attaining South Africans' other basic needs, such as in areas of agriculture and mining is vitally important for economic growth. South Africa's water systems are already severely harmed by climate change, different forms of pollution and poorly managed sewerage systems. Therefore, water as a resource will become much scarcer in the future. South Africa is reportedly the 30th driest country in the world, with an average annual rainfall of about 460 mm. In recent years, South Africa has been exposed to water shortages, and these conditions will only worsen in the future.

The mining industry constitutes a large part of the research, including its contribution to the AMD problem and how it can assist in addressing it. The research conducted for this book involved experts from government departments, environmental activists, the private sector, tourism and agriculture. Policy recommendations are included in response to the many socio-economic impacts which were not addressed in the key policy documents on AMD. The significance is that not much research has been done so far from a social science perspective on this topic, and therefore it leaves a gap in the available research. The public relevance of this topic is increasing daily in view of the alarming predictions about water security in the future, and climate change is complicating it even more.

The foundation laid with this research can be developed more comprehensively later on. Water management in South Africa is challenged by many factors: increasing levels of pollution caused by dysfunctional local municipal sewerage systems, industrial waste, agricultural run-offs, climate change, demands on food security and AMD in coal and gold-mining areas. Water security issues are already prevalent in KwaZulu-Natal and Gauteng. In KwaZulu-Natal (Durban), the possibility of water shedding, due to the lack of rain, is already contemplated. Goal 6 of the United Nations' new *2030 Agenda for Sustainable Development* provides a global framework for analysing the South African predicament.

Pretoria, South Africa Suvania Naidoo

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This book has been developed from my master's dissertation and some of the content that previously appeared in an article that I published in the Springer journal *Environment, Development and Sustainability* in 2015 entitled *"An assessment of the impacts of acid mine drainage on socio-economic development in the Witwatersrand: South Africa"*. Some of the sections from the article overlap with the content in this book. I would like to thank Springer for allowing me to publish this book.

Research is impossible without the assistance of the enormous support from mentors, academics, specialists in the field and family and friends. This book would not have been possible if I did not have such assistance.

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This book is dedicated to my father Preggy T. Naidoo—*who was a man of many talents.*

Contents

Abbreviations

l	Litre
µg	Microgram
AMD	Acid mine drainage
CANSA	Cancer Association of South Africa
CBD	Central business district
CEO	Chief executive officer
CGS	[South African] Council for Geosciences
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DMR	[Gauteng Provincial] Department of Mineral Resources
DRD	Durban Roodepoort Deep
DST	Department of Science and Technology
dti	Department of Trade and Industry
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
ECL	Environmental critical level
EIA	Environmental impact assessment
EMP	Environmental management programme
ERPM	East Rand Proprietary Mines Ltd
FSE	Federation for a Sustainable Environment
GCIS	Government Communication and Information System
GDARD	Gauteng Department of Agriculture and Rural Development
GDP	Gross domestic product
HDSM	High-density sludge management
HDST	High-density sludge treatment
IDC	Interdepartmental committee
IMC	Inter-Ministerial Committee on Acid Mine Drainage
JSE	Johannesburg Stock Exchange

Ml	Megalitres (million litres)
MEND	Mine Environment Neutral Drainage
MPRDA	Minerals and Petroleum Resources Development Act, 200 (Act 28 of 2002)2
MRA	Mine residue area
MWMU	Mine Water Management Unit
NEMA	National Environmental Management Act, 1998 (Act 107of 1998)
NGO	Non-governmental organisation
NNR	National Nuclear Regulator
NWA	National Water Act, 1998 (Act 36 of 1998)
NWRS	National Water Resource Strategy
PFM	Platinum group metal
SAHTC	South African Human Rights Commission
TCTA	Trans-Caledon Tunnel Authority
TDF	Tailings disposal facility
WCED	World Commission on Environment and Development
WMA	Water management areas
WRC	Water Research Commission
WSCSA	Water Stewardship Council of Southern Africa

Chapter 1
Overview of AMD in South Africa

'Water is life. Both natural and human systems are critically dependent on water. It is the primary requirement for the survival of human beings, as also for their socio-economic development and healthy ecosystem' (Prasad 2003, p. xiii). This statement depicts the importance of water as a resource for human beings and the earth. To exemplify its importance, 'water is unlike any other substance in the world', it has qualities that make life possible, and without it, 'there would be no life' (Taljaard 2015, p. 19). This indicates that any harm to our water system could negatively impact on human life, the earth and humankind's aim towards a sustainable future.

According to Section 24 of the Constitution of the Republic of South Africa, 1996 (Act 108 of 1996) (the Constitution): Everyone has the right to an environment that is not harmful to their health and well-being; and to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:

1. Prevent pollution and ecological degradation.
2. Promote conservation.
3. Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.

Therefore, any human activity that violates this right should be severely dealt with to ensure minimal harm to the environment and to the people. Natural resources are vital for human beings' existence and future life and, therefore, needs to be protected. South Africa's strategic document called the National Development Plan (RSA 2012, p. 37) states that South Africa has exploited its mineral wealth with little or no regard for the environment and this needs to change to ensure protection of the natural environment while allowing the country to benefit from its mineral deposits.

In South Africa, water is regarded as a social, environmental and economic good. 'Nevertheless, after basic human needs and the requirements for maintenance of ecosystems have been satisfied, there will inevitably be competition for access to the remaining available water' (DWAF 2008, p. 12). Yet 'South Africa is a country

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that is bereft by a water security dilemma; whilst on the economic front, the country is driven by a strong mining industry' (Azarch 2011, n.p.). What is evident is that these two significant trends—water and mining—placed closely to each other have become increasingly unstable due to the increased inflow of 'highly acidic water into the country's water system' as a result of acid mine drainage (AMD) (Azarch 2011, n.p.). This has led to the endangerment of, and threats to, both communities and ecosystems along many water systems in South Africa, including the Vaal and Limpopo rivers (Azarch 2011, n.p.).

With the increasing water quality challenges that South Africa is now facing due to 'current water behaviour and infrastructure integrity challenges, as well as historic poor practices' such as acid mine drainage, the South African government has the responsibility to address these challenges due to the right-based constitution and ultimately because it is the responsibility of the government to realise those rights (Naidoo 2014, p. 24).

This book firstly concentrates on AMD as a phenomenon in water management in South Africa and what its impact on sustainable development is or could be. AMD is understood by different people in different ways, depending on their particular interests and institutional affiliation, such as to a government department, business, consultancy, and non-governmental organisation (NGO) or activist group. One category of interpretation of AMD refers to 'highly acidic water, usually containing high concentrations of metals, sulphides and salts as a consequence of mining activities' (CSIR 2009, n.p.). The drainage from abandoned underground mine shafts seeps into surface water as the mine shafts fill with water. This is a narrower interpretation of AMD and concentrates only on underground water decanting from mine shafts. The other interpretation category extends the notion of AMD to include the phenomenon of acid rain as a catalyst for AMD originating from tailings dams. This form of AMD is a result of chemical interactions between acid rain and the dust formed on tailings dams or 'mine dumps'. The mine dust on the tailings dams always includes radioactive particles (i.e. uranium) which exacerbate the AMD effect (Turton, personal communication, 2013).

Secondly, this book is concerned with mining and the quality of water in South Africa and the impacts of AMD. AMD is evident mainly where there is gold and coal mining. The effects of gold mining are seen in the three basins of the Witwatersrand in the Gauteng Province in South Africa. Coal mining takes places in Mpumalanga province in Witbank and Middleberg and also has the potential to impact on Limpopo province, in the Waterberg area and in KwaZulu-Natal province. AMD is even known to be possibly prevalent in the Northern Cape province where copper mining is predominant. The focus of this book is on AMD in the Witwatersrand gold-mining area which is in the Gauteng Province, South Africa, due to the fact that this is where the first serious incidents of AMD occurred and immediate attention was given to this area by the South African government as well as the relevant role players. However, there are other provinces in South Africa that are known to have impacts of AMD as mentioned above. Below are two maps to illustrate. Figure 1.1 provides a map of the nine provinces in South Africa, and Fig. 1.2 provides a map of the type of mining that takes place to illustrate where the incidents of AMD has already and may occur.

Fig. 1.1 Map of South Africa (Source: Ezilon Maps 2015)

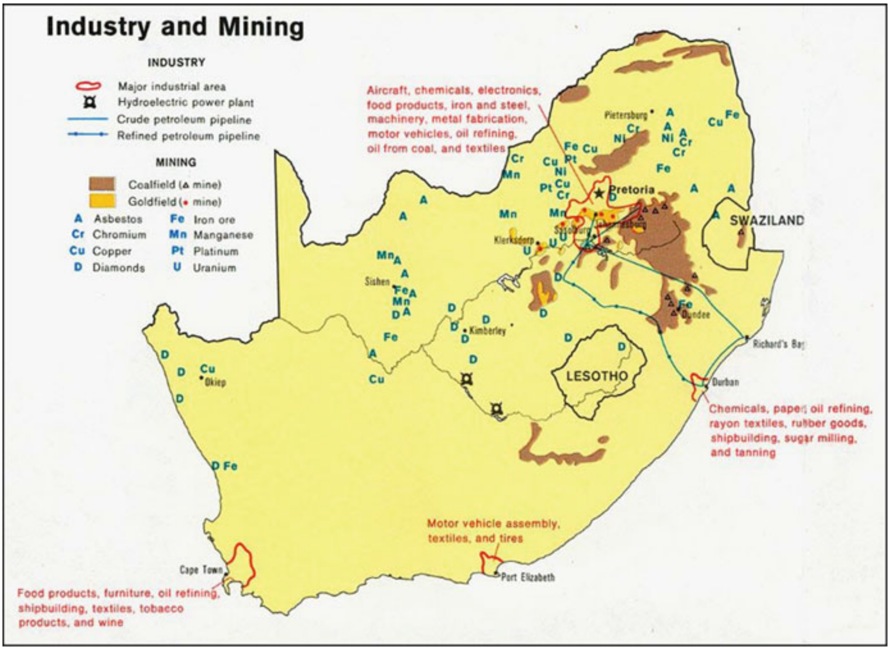

Fig. 1.2 Map of industry and mining in South Africa (Source: University of Texas Libraries 2005)

The growing concerns that have surfaced, and are increasing on a daily basis, surrounding the issue of acid mine drainage are of the utmost importance and should be addressed more urgently. 'Acid mine drainage [is] described as one of the most significant environmental threats facing South Africa, an already water scarce country' (Mail & Guardian 2011). This alone indicates the severity of these concerns and the need for action to be taken. 'The problems posed by acid mine drainage will have implications far into the future, with impacts likely to continue for many years' (Reuters 2011). Water plays a vital role in the process towards a sustainable future; any harm that hinders this process should be looked into, and dealt with, immediately to mitigate the problem.

This book looks at the development actors who are involved in the issue of AMD and investigates the uncertainty still present about how AMD is affecting socio-economic development. The role players are many, but the mining industry and government have the biggest roles as they are the parties responsible for the environmental crisis being experienced today. In Chap. 5 the responsibility of government and its policy approach in response to this environmental crisis are discussed in more detail. In 1886 immense gold resources were discovered in South Africa, especially on the Witwatersrand. This allowed the mining industry to play a central role in the country's economic, social and political environment (Adler et al. 2007, p. 34). The mining industry made it possible for the country to rapidly grow economically and this on its own secured government's support for the industry. The problem, however, stemmed from the fact that environmental harm and the severity of the impact of mining activities on several aspects of society were underplayed. Scholars therefore concluded that 'in the process of development, mining is one of the core industries contributing towards the deterioration of the environment in terms of air, water and land pollution' (Tiwary et al. 2005, p. 421). This has led to the current growing crisis encapsulated in the concept 'acid mine drainage'.

When discovered, the Witwatersrand basin of the goldfields had the world's largest gold reserves, and half of the gold that had ever been mined since 1886 came from these reserves. In 2002 the first incidences of AMD appeared on the West Rand near Krugersdorp in the Gauteng Province and, for the first time, raised serious concerns and awareness in the public domain about the effect of mining on the environment. AMD became increasingly prominent due to the ongoing debate, its growing media coverage and the harm caused to the environment and scarce water resources. Despite greater exposure to this phenomenon, much of it was clouded in speculation, sensation and lack of clarity about its impact on society in general. Over time, more clarity emerged about its scientific (i.e. geoscientific, chemical and engineering) characteristics, but the same cannot be said about its socio-economic impact.

The potential consequences of AMD in respect of water quality, health hazards, policy challenges and sustainable mining have already been raised. A range of problems can be identified in this context.

The first problem is the government's policy response to AMD. So far, such a policy is not yet fully developed and integrated and consists of:

The South African government's Inter-Ministerial Committee (IMC) on acid mine drainage's (established in 2010 to coordinate government's response to AMD) expert report

The initial budget allocation in 2011 to arrest the problem on the East Rand in Gauteng Province

The decision to allocate AMD as a project to the Trans Caledon Tunnel Authority (TCTA) (a state-owned specialised liability management body whose mission is to finance and implement bulk raw water infrastructure) in the Central Basin of the goldfields

The attempts to improve preventative measures through better implementation of the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) (MPRDA)

Policy decisions regarding who must take responsibility for the environmental impact of AMD are not yet finalised. Therefore, in 2011, the national assembly of the Portfolio Committee on Water and Environmental Affairs did not exclude legal action against mining companies (PMG 2011). In contrast, a company such as DRDGOLD Limited (Durban Roodepoort Deep) proposed a formula to determine proportional responsibility by the mining companies for AMD contamination. The implication was that the government must take responsibility for the remainder. None of these matters has reached the stage of a policy decision (PMG 2011). In South Africa—the African National Congress (ANC)—the ruling political party's policy discussion document on mining, 'Maximising the Developmental Impact of the People's Mineral Assets: State Intervention in the Minerals Sector', dated 5 March 2012 (ANC 2012), also did not refer to AMD as a policy concern.

The latest measures that will be established by the Department of Water and Sanitation (DWS) (previously the Department of Water Affairs) include a Mine Water Management Unit (Frankson 2015, n.p.), to address the problem of AMD in South Africa. This unit will work together with other government departments, such as the Department of Mineral Resources and Department of Environmental Affairs (previously called Department of Environmental Affairs and Tourism) along with the relevant water experts, to address the problem that will lead to a review of policy on how AMD is managed (Frankson 2015, n.p.).

The policy dimension raises a number of issues, including the following:

- Given South Africa's general human development paradigm, how sensitive is this emerging AMD policy framework towards the demands and requirements of sustainable development?
- Is the primary focus of the emerging policy framework in the first instance a technical response or does it include a consciousness of the need to address the social effects of AMD in the context of sustainable development?
- As regards the possible value of it as a precedent for future similar situations, can this policy framework become an ideal example of how to approach policies that have to combine the pressures of economic development, environmental or ecosystemic sensitivity and human security?

The second problem is concerned with the social dynamics of AMD and its developmental impact. Sustainable development is used as the prism through which the phenomenon is analysed. It attempts to determine the social impact of AMD on different actors in the Vaal River system in South Africa, which includes the catchments of the upper, middle and lower Vaal water management areas (from Kuruman in the west to Ermelo in the east and Johannesburg in the north to the Lesotho border in the south) (DWAF n.d.). It is also important to determine whether there is a civil society response in the form of activist movements and media activism that emerged as a result of the increasing prominence of AMD. Which activities or aspects of the lives of those concerned are directly or indirectly affected by it? How do those affected respond to these effects? Are those involved in the government's attempt to articulate a policy response in the form of consultation or other forms of participation?

Guedes (2010, p. 69) and Adler et al. (2007, p. 34) elaborated on these social costs and how they relate to some of the actors. According to Guedes (2010, p. 69), an important point to acknowledge is that the mining industry believes that it cannot be held responsible for the consequences of derelict and ownerless mines. However, in the same breath, the government also remains adamant in the belief that it cannot be held responsible for the clean-up that is needed due to the fact that it will cost billions of rand to do so (Guedes 2010, p. 69). The Chamber of Mines of South Africa works closely with government and the affected mining companies to reach suitable solutions.

This book addresses whether the evolving policy response and the social dynamics of AMD are sufficiently synchronised and does this have the potential to find a way to deal with similar dilemmas in future, such as the proposed fracking in the Karoo and mineral explorations at Verlorenvlei in the Western Cape province (in South Africa) or mining near Mapungubwe, a world heritage site, in Limpopo province (in South Africa).

The research approach used relied on primary research sources. Key informants were identified which are experts in the field, and interviews were conducted with each of them. Media and official policy documents were used to strengthen the validity and reliability of arguments presented and were compared with the information found in the interviews. Key informants play a crucial role in any research endeavour and are valuable sources of information. The institutions concerned included the Cradle of Humankind World Heritage Site, the Department of Water Affairs, the Gauteng Provincial Department of Mineral Resources, The Department of Science and Technology, the Chamber of Mines of South Africa, AgriSA and environmental activists Anthony Turton and Mariette Liefferink.

The structure of this book is summarised as follows, Chap. 2 provides a global context of AMD; it looks specifically at countries where AMD is prevalent such as Australia, the USA and Canada. Chapter 3 provides an overview of the existing literature on the AMD in South Africa. The key concepts, including AMD and sustainable development, are defined. The importance of water and its place in sustainable development are discussed. In Chap. 4 the nature of AMD as a concept is discussed. The Vaal River system is used as a case study; this is also the area in the Gauteng Province of South Africa that has seen the worst impacts of AMD. The current state of the phenomenon in the three basins of the Vaal River system is presented as a means of developing an understanding of the scope of AMD in the Witwatersrand and the resultant challenge facing the policy-makers to find a sustainable solution for AMD. Chapter 5 discusses the policy response to AMD in the gold-mining sector. It discusses the government's policies and processes on addressing AMD, including the Inter-Ministerial Committee's (IMC) expert report. The chapter also considers the role that NGOs and activists have played in this regard. Chapter 6 looks at the socio-economic impact of AMD on different sectors of society. The chapter explains the impact that AMD has had or can have in future on the environment and human beings and what the possible solutions are. Chapter 7 presents the main points and arguments that emerged from the book and provides a summary of AMD and whether there is a sustainable future for South Africa.

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Chapter 2
The Global Context of AMD

2.1 Introduction

In many regions of the world, there is now a failure to invest adequately in water services. These services include the treating and reusing of water efficiently, 'mainly because policy-makers and economic planners do not fully appreciate the importance of water'. This is now increasing the issue of water shortages in many parts of the world. This will contribute to a situation within 20 years, when the global demand for water will be far greater than the supply (Creamer 2015, p. 3). The world's population tripled in the twentieth century, while the use of renewable resources has increased six times; in the next 50 years, the world's population is expected to increase by another 40–50 %, and therefore water resources will be under severe pressure (Creamer 2015, p. 4). These concerns will continue to increase due to the growing population and the impacts on water systems. Therefore, water stress is not only unique to South Africa, but it is a global problem, with many countries experiencing the same impacts.

The purpose of this brief chapter is to look at AMD from a global perspective and to understand that AMD-related issues are not unique to South Africa but are being experienced in several parts of the world. Due to the challenges that South Africa faces with regard to AMD, 'we have the opportunity to up our game in the acid mine drainage arena and become a leading producer of acid mine water and salinity solutions' (Naidoo 2014, p. 24). This chapter therefore looks at the negative impacts of AMD on the water systems in other countries to identify the similarities or differences in the issues concerning AMD that are experienced.

'Acid mine drainage is a significant and costly environmental impact of the mining industry worldwide' (Coetzee et al. 2010, p. 4). The effects are seen in surface and groundwater resources long after mining activities have stopped and are a known global problem in many abandoned mine sites.

Abandoned mines are sites where 'advanced exploration, mining or mine production ceased without rehabilitation being implemented at all or completed. They are found virtually in all regions with a history of mining' (IIED 2002, p. 3).

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The reason why mines—throughout history—were left abandoned is because it became the norm to abandon the mine site when there were no longer minerals to extract. On the other hand, according to the Environmental Mining Council of BC (2006, p. 2), 'once a mine is in operation, water protection must remain the highest goal of the company, even if it means reduced mineral productivity. Adopting this common-sense ethic is the only way we can ensure that the golden dreams of mining do not turn into the nightmare of poisoned streams'. This hasn't been the case in the past in those regions where abandoned mines have had negative effects on their water systems. In the late twentieth century, it was realised that abandoned mines were a threat to the environment and needed to be addressed (IIED 2002, p. 10). The issue has extended to what it is today because countries that had a long history of mining—at the time—did not consider the negative impacts that mining would bring in the future, and environmental regulations of mining activities in most cases were not implemented. Therefore, the biggest problem that we have with abandoned mines is acid mine water (IIED 2002, pp. 10–12).

South Africa has many abandoned mines, including gold, coal, copper and 134 abandoned asbestos mines (including 400 abandoned asbestos dumps) known to create health hazards (IIED 2002, p. 9). In South Africa, abandoned mines are controlled under the Water Amendment Act 58 of 1997. This act protects water and limits waste discharge by the industry. However, before the Water Act 54 in 1956, many mines were abandoned without implementation of sufficient pollution control measures (IIED 2002, p. 9).

AMD is not a phenomenon only found in South Africa. Abandoned mine sites in countries such as Australia, Canada and the United States of America (USA) also experience similar environmental challenges. In order to develop an appreciation for the global context of AMD in relation to the situation in South Africa, its prevalence in a few other countries is explored in the next sections.

2.2 AMD in Australia

Australia is known to be rich in minerals which have significantly contributed to the country's economy. According to Australian government sources (2007), coal was discovered near Newcastle in New South Wales (see the map in Fig. 2.1 for orientation) in the 1700s and later in the south and west of the settlement. The first metal mined in Australia was lead in South Australia in the mid-1800s. Gold was first discovered in New South Wales in the early 1800s. The gold rush of the 1850s enabled the Australian colonies to become famous for their mining. Australia was producing almost 40 % of the world's gold at that time. A few years later, Australia became an important producer of tin with the discovery of the metal in Tasmania (see the map in Fig. 2.1). In the late nineteenth century, copper and gold mines were established in Queensland (see Fig. 2.1), lead and zinc in New South Wales, gold in Western Australia and iron ore in South Australia. In the early twentieth century, mining activity in Australia began to decline despite the rise in the value of mineral

Fig. 2.1 Map of Australia (Source: Maps of World n.d)

production, and only lead, zinc and copper deposits were the major finds. With the discovery of new metals such as aluminium, nickel, tungsten, uranium, oil and natural gas, the country became a renewed interest for their mineral resources and is a nation that is known to be one of the world leaders in mineral resources. Companies like BHP Billiton and the Rio Tinto group have become associated with the main mining activities in Australia. With the Chinese economic boom in the 2000s and its demand for mineral commodities, Australia's geographical proximity to it counted in its favour to increase its exports to China.

Due to the fact that the country is so prominent in mining, because of its minerals, it makes one aware that management of water resources needs special attention, because mining is a large consumer of water.

The management of water resources in Australia is said to be an intricate process. As a federal union, this process differs between the Australian states and territories. Water management in Australia includes water pricing and economic regulations, water planning and management, water markets, water supply and services and water quality management (WRC 2016, pp. 2–3).

There is no nationwide inventory of abandoned mines in Australia, and it is therefore the responsibility of the federal states and territorial governments to obtain this data (IIED 2002, p. 5). In Western Australia, the Department of Minerals and

Energy is developing a database of abandoned mines by identifying outstanding risks and then seeing which sites are a priority with regard to safety and environmental harm. This programme commenced in July 1999, and at that time the Northern Territory had not yet undertaken similar measures to establish a database of abandoned mines but was planning to complete it by 2002 (IIED 2002, p. 6). In Australia an indication of the devastating environmental effects of mining is that large areas of dry forest that were exposed in the gold rush in the 1860s still have not yet recovered (IIED 2002, p. 12).

In the late 1990s, the Australian state and territorial governments took steps to require mining companies to be proactive in their management of potential and current acid-generating wastes (Harries 1997, p. 6). Governments are increasingly aware that AMD can become a liability where the state and territory governments will be responsible for remediation of mine sites due to not having proper and effective mechanisms in place. In 1996, the Queensland Department of Mines and Energy adopted a policy combating AMD, but it noted that there would be disagreements on what would be the best practice among experts.

The management of acid-generating wastes and methods used in Australia depend on the properties of the waste, the climate conditions and how sensitive the receiving environment is (Harries 1997, p. 5). Some of these strategies that are used for management of potentially acid-generating wastes to control the environmental impacts are isolation of the potentially acid-generating material so that it is enclosed above and on the sides by low hydraulic conductivity material, selective placement of potentially acid-generating tailings under non-acid-generating tailings, placement of water covers to reduce ingress of water and oxygen, placement of soil multilayer covers use of specific waste dumps for isolation of potentially acid-generating wastes, mixing of wastes with acid neutralising material to increase the acid neutralisation, establish surface water controls and construction of water treatment facilities to ensure water meets discharge criteria and use of bactericides to reduce bacterial activity in acid-producing materials (Harries 1997, p. 5).

The Australian mine sites use several methods to monitor the effectiveness of waste management strategy used for sulphidic wastes such as monitoring seepage water quality and volumes and measurement of water balance to name a few (Harries 1997, p. 5). The sites that had acid-generating material were managed according to waste characterisation and water quality.

2.3 AMD in Canada

According to the Government of Canada (2016, p. 2), Canada is one of the top destinations for exploring and mining investment. Canada is a supplier of over 60 minerals and metals. The key commodities include primary aluminium, cobalt diamonds, gold, nickel, platinum group metals, salt, tungsten and uranium (Government of Canada 2016, p. 2).

Fig. 2.2 Map of Canada (Source: Martin's AP Human Geography 2012)

Major mining regions have been developed throughout various provinces in Canada. These include the Labrador Trough on the Quebec, Newfoundland and Labrador border where iron ore, is developed, the Abitibi gold belt in Quebec and Ontario, and nickel and copper platinum group element mines of the Sudbury region in Ontario (see Fig. 2.2). Uranium mines are found in Saskatchewan (province in Canada), the metallurgical coal and copper–gold mines in British Columbia (province in Canada) and diamond mines in the Northwest Territories (Government of Canada 2016, pp. 2–3). In summary, Canada is also a producer of more than 60 mineral and metals and more than 200 producing mines. The total value of mineral production in Canada reached C$45 billion. This shows that mining has significantly contributed to the economy and provided immense employment opportunities (Government of Canada 2016, p. 6).

With the economic growth due to the mineral wealth in Canada, federal, provincial and territorial governments also have legislative frameworks that include an environmental assessment process prior to mineral exploration approval and all mine development proposals (Government of Canada 2016, p. 14).

The Canadian Mine Environment Neutral Drainage (MEND) programme was established by mines and provincial, territorial and federal government agencies in 1989 in response to the recognition that AMD is the core environmental issue.

The mines in Canada were required to establish trust funds to cover the costs of AMD effects caused by mine wastes. A survey conducted showed that there were immense amounts of waste rock that were potentially acidic that came from metal mines and industrial mineral tailings (Coetzee et al. 2010, p. 4). The Canadian mineral industry generates one million tonnes of waste rock and 950,000 tonnes of tailings per day, which adds up to 650 million tonnes of waste per year (Environmental Mining Council of BC 2006, p. 3). In Canada, 'there are an estimated 351 million tonnes of waste rock, 510 million tonnes of sulphide tailings and more than 55 million tonnes of other mining sources which have the potential to cause AMD' (Environmental Mining Council of BC 2006, p. 3). Acidic drainage is identified as the largest environmental liability facing the Canadian mining industry, and to clean up these acid-generating mines will cost between \$2 billion and \$5 billion (Jennings et al. 2008, p 4).

A survey done on abandoned mines in Canada indicated two mining-related elements that occurred to create the legacy of abandoned mines: (1) economic elements (unexpected closure of mines leaving mining companies bankrupt) and (2) national security elements (mines that operated in Canada during the Second World War immediately closed with the Lend-Lease Act of 1941 and not much was done to rehabilitate these mines) (IIED 2002, p. 3). There are many other contributing elements to the legacy of abandoned mines which included the following: regulation, whereby no measures were in place to provide governments with financial security in the event of mine closure due to bankruptcy, therefore no rehabilitation could take place; ineffective government enforcement arising from a lack of capacity; the loss of mine data due to information not being stored adequately; political unrest leading to unplanned closure of a large number of mines; the impact of small-scale mining led to no control over illegal mining which resulted in the site being abandoned when mining activities ceased.

Abandonment of mines is unexpected and sudden in most instances. 'Closure and rehabilitation costs must be directly or indirectly born by the state' because it is the communities who are effected in the end and the environmental impacts are detrimental (IIED 2002, p. 4). More than 10,000 abandoned mines are on the inventory in Canada and only 60 % have been physically assessed. There also are other provinces in Canada that have inventories but they are not accessible (IIED 2002, p. 6). These abandoned mines generate acid-producing wastes, and MEND developed indicative costs of managing the wastes by using a range of treatments which include collecting and treating seepage water from waste rock and tailings, placing a water cover on tailings, placing a soil cover on tailings and transporting of waste rock to the pit (Harries 1997, p. 16). The estimated cost to treat AMD was extremely high, and in order to reduce these costs, an independent costing analysis sponsored by MEND was prepared (Harries 1997, p. 16).

2.4 AMD in the USA

Mining activity is said to contribute to the economic activity in every state in the USA. The USA is known for its minerals such as coal, copper, gold, iron, silver, uranium and zinc, as well as its production of oil and natural gas. Ten states with the largest contribution of mining to the gross domestic product (GDP) are Wyoming, 20 %; West Virginia, 17.3 %; Nevada, 8.7 %, Montana, 6.1 %; Arizona, 5.8 %; Kentucky, 4.8 %; Utah, 4.2 %; New Mexico, 3.5 %; Idaho, 3.2 %; and Alaska, 3.1 % (see Fig. 2.3) (NMA 2014).

Despite being known for the mining activity in each state, the USA has a large number of abandoned mine sites where AMD is an extensive issue (IIED 2002, p. 7). These problems are mainly due to coal mining in the eastern states 'where over 7000 km of streams were considered to be seriously affected by acid drainage from coal mines' (Harries 1997, p. 18). Hard rock mines in the western USA (Idaho and Colorado) are found to have water quality problems. According to Harries (1997, p. 18), the US Forestry Service estimated that 8000–16,000 km of streams in the USA were affected by AMD from active and inactive mines and waste rock piles.

Due to the liability associated with AMD caused by abandoned mine sites, conservative control strategies and payment of large performance bonds are assisted upon. Numerous abandoned coal mine sites in south west Pennsylvania were reclaimed between 1980 and 1992, and wetlands were constructed on 11 sites to reduce AMD through the use of soil cover (Harries 1997, p. 19).

Fig. 2.3 Map of the USA (Source: Maps of World n.d)

2.5 Conclusion

It is evident that AMD is not only an issue that is unique to South Africa, but in many parts of the world where mining activity has taken place, there will be the risk of an abandoned mine site and therefore the risk of AMD. It is clear that the occurrence and impact of AMD in all the countries where it is predominant happened for the same reasons. This is firstly due to the fact that no clear policies were in place to prevent it from happening or to assure that the mining industry, which is ultimately responsible for the damage caused, pay for the clean-up. What is unique to all the cases where AMD is seen is that there are treatment mechanisms in place to ensure that the problem is dealt with.

Water is one of the resources that is most often polluted by abandoned mines. What is important to account for is the social, economic, environmental and political implications that follow. These social impacts are similar to the ones discussed in Chap. 6 of this book. These impact directly on the people in terms of employment and health hazards, for instance. The economic implications include the large funds required for the rehabilitation of the abandoned mine sites which the government and the people have to provide. The environmental impact is the harm to water resources first and foremost. The political impacts stem from who must take responsibility for the damage done. All these impacts are also common to South Africa and will be discussed later.

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Chapter 3
Water Mining and Development in South Africa

3.1 Introduction

The objective of this chapter is to conduct a brief evaluation of some of the published literature available on the topic of this book. Therefore, this chapter presents a limited review of the existing information that is available on AMD. The intention is to inform readers of the existing research and the reporting that has been done so that they can understand the broader context in which this topic is located and the current state of knowledge on the topic. The implication is that the discussion also identifies areas in which further research is required.[1]

The literature review is structured in such a way that it addresses some of the main fields and concepts relevant to this research. The two key elements of the research topic are (1) water and (2) sustainable development, and from these, related elements are derived. Sustainable development on its own is both a complex phenomenon and an ever-expanding concept. Therefore, the relevance of water for sustainable development is the focus. Given the nature of the book, the concept of water will be confined to sustainable water management and consumption in South Africa and more specifically in Gauteng and the Vaal River system.

Another element of the research topic is the impact of mining on water quality and, by implication, its impact on sustainable development. For this reason, a brief literature review of mining (and, more specifically, gold mining) was conducted. A brief summary of the significance of the mining industry in South Africa and the negative impacts of the mining industry is provided. This brings one to the specific focus, and that is to review the literature on AMD in South Africa. Almost all the provinces in South Africa are likely to be effected by AMD, except for the Western and the Eastern Cape. Gauteng Province remains among the most affected areas where 'the AMD sources sat atop the continental watershed, the waters of which

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[1] Parts of this chapter derive from Naidoo, S. (2015). An assessment of the impacts of acid mine drainage on socio-economic development in the Witwatersrand: South Africa. *Environment, Development and Sustainability Journal, 16*(6), 1045–1063.

S. Naidoo, *Acid Mine Drainage in South Africa*, SpringerBriefs in Environmental Science, DOI 10.1007/978-3-319-44435-2_3

ultimately drained into the Vaal, Orange and Limpopo rivers' (Esterhuizen 2012b). The three main areas in Gauteng are the Western, Central and Eastern basins of the Witwatersrand which have seen considerable decant (decant is an overflow of underground mine water at the surface) but mainly in the Western Basin (Esterhuizen 2012a). It should be reiterated that the focus of this book is not from a technical perspective, which includes the engineering, mining, geological and related aspects of the AMD issue but on its social and developmental significance.

In addition to the different components of the topic, the different types of publications and sources in which the information is available are identified. The first type is published academic research literature, especially in the form of journal articles, book chapters and conference proceedings. Second, the issue of AMD receives increasing attention in the media. Thus, identifying how the issue is presented by the media is essential. Third are legislation, policy documents and official reports published by the departments involved which include other authorities.

The purpose of this chapter is not to discuss substantially the issues related to AMD but rather to identify trends in the research, thematic focus areas and different approaches in the literature. Substantive discussions will follow in the specific chapters hereafter.

In the following sections, attention is paid to specific facets of the literature review.

What tends to be common in most of the literature on the topic is that mining activities are vital for economic growth. However, once operations have ceased, the problem arises for various reasons, which are mentioned later in this chapter. The main questions still remain, which are: what will be done after the harm from human activities has negatively impacted on the environment and how are these issues going to be addressed? With regard to the numerous areas being affected, how can the problems that AMD has caused to the environment and the negative impacts that the mining industry brings with it be managed and hopefully prevented?

3.2 Understanding the Key Concepts

In this section the key concepts, including AMD and sustainable development, that are used frequently in this book are defined or conceptualised. At the same time, explanation of the key concepts as they are presented in the existing literature serves the purpose of setting out the key elements of the conceptual framework on the topic of this book.

3.2.1 Acid Mine Drainage

Acid mine drainage has commonly been described as 'the single most significant threat to the environment' (Ochieng et al. 2010, p. 3352). In the existing literature, it is defined as 'acid water that is formed underground when old mine shafts fill up with water, which oxidises with the sulphide mineral iron pyrite. It can then decant into the environment causing acid mine drainage' (Guedes 2010, p. 67). AMD can be formed from coal and gold mining, both in surface and underground mines (Leonardi 2011, p. 2). Another definition is that AMD is 'highly acidic water, usually containing high concentrations of metals, sulphides, and salts as a consequence of mining activity' (CSIR 2009, n.p.). There is a tendency for the concept to be defined in a rather technical manner, but to recap, the purpose of this book is from a social perspective. The following conceptualisations of AMD in the existing literature are therefore useful:

According to Cobbing (2008, p. 452):

> corrosion of sulphide minerals in the presence of water can generate large amounts of acidity. When mine operations stop, dewatering pumps may be turned off and water levels start to return to their natural level, this process is known as "rebound". The water comes into contact with rock that contains sulphide minerals that have been exposed through mining activities and the pH of the water may drop considerably due to the resulting chemical reactions. This acidic water could dissolve into other minerals in the rock, which can lead to high concentrations of pollutants such as lead, zinc, aluminium or cadmium in the water and high salinity generally. The polluted acidic mine water may then overflow at the ground surface and at times in enormous quantities which results in the problem known as acid mine drainage.

According to the South African government's IMC (Coetzee et al. 2010, p. 4), acid mine drainage has a seriously significant as well as costly environmental impact on the mining industry worldwide. When AMD is formed due to the closure or abandonment of mines, it affects surface and groundwater.

In Chap. 4, definitions or descriptions of AMD are discussed, and a more detailed analysis of the phenomenon will be presented based on the research conducted for this book, mainly in the form of interviews. The different definitions or interpretations of the concept will then become clear.

3.2.2 Sustainable Development

The overarching concept used in this book is sustainable development. The theoretical point of departure when conducting this research was that an investigation into the socio-economic impacts of AMD should be located within the framework of sustainable development. It determines the parameters and criteria for identifying what should be investigated, who should be investigated and how the relationship between human activity and the environment should be approached. Sustainable development is a 'dynamic concept'; it is a term that is of the utmost importance to human beings and the environment (United Nations 2008, p. 20). In this section, the concept 'sustainable development' is explained in the way that it will apply to this book, and the intention is not to provide a comprehensive literature review of all its aspects and manifestations. 'Development' is its foundational concept, and for the purpose of this topic, it will not be discussed further. It is presumed that it is such a broad discipline in its own right, developed by so many scholars that no justice would be done to try to capture all its nuances here.

In the literature review, it appears that development and human well-being tend to be vital concepts when defining sustainable development. However, it is insufficient to limit sustainable development to this (United Nations 2008, p. 20). The first principle of conservation is development, stating that "sustainable development depends on good environmental management and in turn good environmental management depends on sustainable development' (RSA 1997, n.p.).

'When the Rio Earth Summit convened in 1992, the world came of age. The decision to promote sustainable development was a defining moment in the history of social progress, peace and development' (RSA 1997, n.p.). This in itself explains the significance and relevance of promoting and aiming for a sustainable future. In 1987, the World Commission on Environment and Development (WCED) (in United Nations 2008, p. 18) defined 'sustainable development' as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. This definition means that the earth's resources should be used in such a way that these resources are preserved for future generations. Thus, the process of sustainable development aims for development that is continuous and that increases the well-being of life over a long period (United Nations 2008, p. 20).

The overall objective of sustainable development is to increase the well-being of an ecosystem (i.e. humans and the natural environment) over time; it is a development path that can be continued over a very long period (United Nations 2008, p. 20). According to the United Nations (2008, p. 20), 'simply being sustainable does not make a development path desirable. It also matters whether it is the sort of development path that society wants to follow and this depends on what determines well-being for its members'.

Thus, sustainable development is to ensure both the well-being of those currently living and the potential for the well-being of future generations (United Nations 2008, p. 21). This represents an integrated view. According to this integrated view:

> A framework for measuring sustainable development must be able to illustrate – in a perspective of both time and space – whether and for whom freedom to pursue well-being is increasing or declining, how access to and appropriation of resources are distributed, how the negative effects of resource use are distributed and to what extent resources are used in a responsible manner with regard to meeting current and future needs. This is the measurement of sustainable development and must focus on both the options of the current generation and on the prospects for those yet to come (United Nations 2008, p. 20).

Also mentioned in the United Nations report (2008, p. 22) is that if the present needs are met, the poorest people in the world will be affected. Disparity between rich and poor will decrease as societies have preferences regarding equity among their own members and between themselves and other societies. Thus, the way resources are distributed will, in fact, have an effect on current well-being. According to the Government Communication and Information System (GCIS) (2010, p. 366), with the large mineral reserves in South Africa, it is evident that the mining industry also plays a big role in 'the war' against poverty and underdevelopment in South Africa. Thus, the industry will have a negative impact in striving towards a sustainable future and preserving the earth's resources.

The existing literature presents sustainable development as a visionary development paradigm. Over the past 20 years, governments, businesses and civil society have accepted sustainable development as a guiding principle (IISD 2010, p. 5). However, not much has been implemented. Thus, unsustainable trends are continuing. Sustainable development embodies integration and understanding and acting on the complex interactions that exist between the environment, economy and society (IISD 2010, p. 6). The interdependence of these three pillars must be acknowledged. Sustainable development as a process is vital, and the following statement shows why: the alternative would be 'accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development' (IISD 2010, p. 7). This statement also represents the reason why the WCED was created to address this very issue. It is vital to 'enhance growth with care for the environment' (IISD 2010, p. 10). The main view of governments and businesses is that sustainable development is 'continued economic growth made more environmentally sensitive in order to raise living standards globally and break the link between poverty and environmental degradation' (IISD 2010, p. 10).

If critics tend to believe that sustainable development will be difficult to achieve, and will take immense time and effort, then the aims and visions that humankind has for obtaining a sustainable future may not be reached. The continuous crisis and harm to the environment (including in the form of AMD) is only worsening the environmental crisis. Therefore, the questions raised in the literature are how will the lives of the poor be improved if sustainable development remains unsuccessful and how will the three pillars of (1) economic development, (2) social equity and (3) environmental protection be addressed (IISD 2010, p. 12).

Another factor raised in the literature that will require consideration in the path to ensure that the process of sustainable development is successful is the increased population growth. It means 'humanity's demands on the planet have increased over the last 45 years. Thus, provision of many critical ecosystem services (water, biodiversity, fibre and food) will be compromised due to the impact of human development' (IISD 2010, p. 15).

The aim and goals of sustainable development will definitely become difficult to obtain if the challenges that the environment faces are not reduced and eventually eliminated. The issues that AMD has brought about, and its contribution to environmental degradation and the human element, are examined.

3.3 Water and Sustainable Development

South Africa is now well endowed with an abundance of freshwater resources; throughout time, the country has managed to attribute this resource in support of a strong economy and vibrant society (WRC 2016, p. 1). Water is 'truly the most precious natural resource that South Africa, as a water-scarce country, will ever possess, yet we treat it with contempt' (Taljaard 2015, p. 19). Due to the serious water shortages that the country is presently experiencing, this indisputably questions the availability and management of the resource. According to Taljaard (2015, p. 19), in the government and municipal sector alone, more than 37 % goes to waste. This alone shows that the resource is not used sustainably. According to the Water Research Commission in South Africa (WRC 2016, p. 1), there are concerns around pollution and the quality of the resource; water security for both social and economic development has been raised and must be addressed as they lead to major concerns on social, economic, environmental and political impacts on the lives of business and the people.

In 2015, 17 Sustainable Development Goals were set in order to ‘transform the world’ (United Nations 2015). These goals were established to interlink and balance the three dimensions of sustainable development: environment, economy and society (as discussed in Sect. 3.3.2). Goal six aims to ensure availability and sustainable management of water and sanitation for all; this goal is directed at water and aims to address water resource management and the services provided as both are essential for sustainable development. This goal comprises of three general themes ‘of targets’ which are crucial, namely, (1) water sanitation and health, (2) reducing pollutant and untreated waste water discharge into rivers and water bodies and (3) reducing water scarcity by protecting water sources and increasing the efficiency of water use and better governance (ICSU 2015, p. 35).

In line with the above, the next relevant goal is goal 12 which aims is to ensure sustainable consumption and production patterns. This goal focuses on limited resources. It is specified that the targets are not meant to be over-ambitious but the aim is to achieve efficient use of natural resources and to address what the major criteria for sustainable management and efficient use of natural resources are and how progress for implementation can be measured (ICSU 2015, p. 59). At present, this would be ideal yet is far from being reality.

This brings us to the second conceptual element of the research topic, and this is the role that water plays in sustainable development. The research assumes that water is not merely one of the many elements of an ecosystem but plays a quite specific role in most development processes. As part of this role, it is theoretically assumed that the clean water appropriate for human consumption, industrial development, agricultural production and other usages is an absolute requirement for any form of development. The absence of such quality water, either where there is a water shortage or in the form of contaminated water, will be detrimental for development in general. At the same time, water is also a key element of the natural environment and most ecosystems. Development in general often has a detrimental impact on the natural quality of water and, therefore, on environmental sustainability. As a result, from a conceptual or theoretical point of view, it is assumed in a theoretical, systems approach that water plays a dual role: (1) it is a key ‘input’ factor and an essential requirement for almost any form of development, and (2) on the ‘output’ side, very often it is directly affected as part of the natural environment by the implementation of development and its impact on the natural environment. Given the mobility and fluidity of water, any negative impact on it cannot be contained within a specific location. Therefore, in terms of systemic ‘output’, water as a medium extends the potential negative impact much further than the place of origin. This is the point of view that AMD is approached from. On the basis of existing literature, the relationship between sustainable development and water is developed further in the sections that follow.

3.3.1 Why Clean Water Is so Important?

The existing literature indicates that clean water is vitally important, first and foremost, because it is ‘essential for survival and growth of human beings and natural systems’ (Prasad 2003, p. 1). ‘Access to clean water is universally accepted to be a precondition for economic and social development’ (Oelofse et al. 2007, p. 4). According to the South African Department of Trade and Industry (DTI) (2013, n.p.), ‘water is a critical element to sustainable socio-economic development and the eradication of poverty’. Water is also a vital resource for drinking, household use and food production. Thus, water is vital to continue with daily human activities, such as irrigation, bathing, washing, cleaning, cooling and processing (Hoekstra et al. 2011, p. 1). Freshwater is becoming scarce, and the competition for it is increasing, which is of concern to many regions in the world, with almost 50 countries facing severe water stress (WWF 2008, p. 2). ‘Agriculture, industry, household distribution and consumption to the production of hydroelectric power and the maintenance of recreational areas, the activities and bodies that intervene directly in the use of the water resources available are many’ (Cravidao and Matues 2003, p. 36). Therefore, a proper well-designed management system is necessary to minimise natural conflicts and to establish rules and priorities among users of the resource.

If the effects of AMD are not reduced, controlled and eventually eradicated, the negative impact and extensive harm that it will bring to South Africa’s water system will be immense and will eventually collide with human beings’ daily uses of water that are necessary for survival and will severely hinder the process of sustainable development.

‘South Africa has limited water resources and is regarded as the 30th most water scarce country in the world’ (DTI 2013, n.p.). Water thus plays a ‘critical function’ in the South African economy, because about 60 % of the total national water usage is absorbed by agriculture and irrigation (DTI 2013, n.p.). ‘While global resource availability is likely to keep pace with increased general consumption, frequent local and regional shortage will continue to threaten our existence and challenge present governance and management systems’ (RSA 1997, n.p.). Thus, water usage must be addressed, and the means of obtaining water must be guaranteed and not be put at risk (e.g. in the form of AMD). Since 1994, the democratisation of South Africa has allowed for a decrease in disparities between the different sectors of the South African society with regard to access to resources whereby water remains essential. One also finds that the increase in exploitation of water resources to meet the increasing demands in South African catchments and the ‘intensification of associated impacts on water quality need to be addressed' (Mukheibir and Sparks 2003, p. 5). Constant awareness of the importance of water for the daily survival of human beings and also for commercial businesses that can lead to growth in the economy is essential.

3.3.2 The Importance of Water for Sustainable Development

Once the importance of water in general has been demonstrated, the question arises: How does the existing literature integrate it with sustainable development? Water is used for consumption, yet human activities pollute vast volumes of water (Hoekstra et al. 2011, p. 1). For sustainable development to be successful, the risk to this resource needs to be limited. Water resources will always 'influence the activities of mankind and the economic and social advancement of communities' (Cravidao and Matues 2003, p. 36). Therefore, in order for the resource to be sustainable, 'analysis, planning and management of water resources must thus be viewed as an integrated whole in accordance with the cultural and economic progress of the society' (Cravidao and Matues 2003, p. 36).

It is widely known that the availability of South Africa's freshwater resources is being used to its full potential and is already under stress of being exhausted (Department of Agriculture 2008, p. 8). 'South Africa's economy is highly dependent on natural resources for food and energy production. To achieve sustainable development, it must be recognized that the economy and the environment are co-dependent, i.e. that economic instability leads to environmental degradation, and responsible environmental management makes economic sense' (Department of Agriculture 2008, p. 8).

Billions of people are suffering due to a lack of clean water. Approximately 2.5 billion people around the world live in communities that lack proper sanitation. This can lead to the contamination of water used for drinking, bathing and washing clothes (Martin-Osuagwu 2010, p. 13). How to manage water is said to be 'one of the greatest challenges of the 21st century' (Cravidao and Matues 2003, p. 36).

According to Cravidao and Matues (2003, p. 36):

> Today, water is a world heritage, and, as with other types of heritage, it has to be governed by an international culture. Because of scarcity, because of local conflicts it causes, because of its importance to public health worldwide, because of the environmental requalification and valorisation that it promotes and also because of its symbolic value. Thus, it's a resource and a risk.

This means that many countries throughout the world stand the chance of facing severe water shortages which will mostly affect the poor, as it becomes even more difficult for them to meet their basic needs.

The Witwatersrand metropolitan area in South Africa (which potentially can be affected by AMD) has a population of 11 million people. The area is increasingly dominated by Johannesburg, and many satellite towns and cities spawned by the gold-mining activities of the last century. It is said to be one of the largest concentrations of humans that has developed away from a sustainable water resource. Therefore, the history of the water issue in Johannesburg is the story of Rand Water, which is also based in sustaining a major urban conurbation that is far greater than the actual limits of this city alone (Turton et al. 2006, p. 314).

3.3.3 What Are the Developmental Implications of Contaminated Water in South Africa?

The literature on water issues in South Africa is in most instances still speculative about the possible social implications of compromised water resources. According to Adler et al. (2007, p. 37), without access to clean water there could be social unrest and civil war in the country. There could be racial tension, and the failure of government to provide clean water could result in violent public acts and disputes which could, overall, lead to immense conflict in the country. In February 2014 such outbursts of community demonstrations about water supply took place in Brits in the Northwest province (Stone 2014).

'Water resources management in South Africa has changed from the old riparian scheme based on landownership to a system which recognises water as a common resource, with the state acting as a trustee' (Cobbing 2008, p. 453). In line with the definition of sustainable development, 'the basic needs of people followed by the allocation of sufficient water to sustain the environment, takes priority over other uses of water' (Cobbing 2008, p. 453).

The National Environmental Management Act (Act no 107 of 1998) (NEMA) and the MPRDA have laid down new obligations for the mining and other industries, which include the requirement to monitor and remediate pollution of water resources (RSA 1998, 2002). Modern South African law in general also recognises that rehabilitative management of mines needs to continue after extractive operations have ended and that planning for the mine closure phase should always be in place.

In the past, the ways in which mine pollution has been managed in South Africa was not adequate, and the continuous water problems are often due to the ongoing mining activities. However, the most serious water quality problems may only occur once the dewatering (i.e. pumping) by the mining companies ceases and the mines are closed.

3.4 The Significance of the Mining Industry

3.4.1 The History of Mining and Mining Rights in South Africa

Extensive literature exists on mining in South Africa (Handley 2004; Pogue 2006; Adler et al. 2007; Viljoen 2009; Tang and Watkins 2011). The latest book that appeared is by Jade Davenport (a journalist for *Mining Weekly*), titled *Digging Deep: A History of Mining in South Africa* (Davenport 2013). The history of mining is included here primarily to provide a context and historical perspective in order to understand the specific issues of AMD. The background information below has been taken from a publication by Adler et al. (2007), titled *Water, mining and waste: An historical and economic perspective on conflict management in South Africa*. This publication provides a detailed and insightful understanding of the history of mining, its importance and aspects associated with the mining industry in South Africa.

According to the South African Government's IMC (Coetzee et al. 2010), South Africa's mining history has generated immense economic benefits and continues to play a crucial role in ensuring the country's position in the global market. However, these resources can also be problematic. 'Africa's variable and unreliable resources have contributed to numerous conflicts predominantly water, agriculture and livestock' (Adler et al. 2007, p. 33). Since the 1880s in South Africa, such conflicts have arisen from European settlers' access to mineral resources which increased the problems in the water sector. The government policies during the apartheid era favoured the mining industry at the expense of the masses. As a result, since South African democratisation in 1994, it has been difficult to uphold citizens' new constitutional rights of equal access to water and other natural resources. If citizens continue to remain without drinkable water while the mining industry continues to visibly pollute the water without consequences, then government risks losing its legitimacy.

In order to understand the current problems (such as AMD) associated with the mining industry, one needs to understand South Africa's past. This is essential to developing a better policy and solutions to address the conflict with mining that has arisen and, ultimately, to ensure that citizens have access to potable water in the long term.

In 1886, 'immense gold resources' were discovered in South Africa, especially in the Witwatersrand, and the mining industry played a central role in the country's economic, social and political environment (Adler et al. 2007, p. 34). Since then, 'Johannesburg has grown from a dusty mining town to a major urban and industrial conurbation that houses and sustains a quarter of the total population of South Africa, accounting for 10 % of economic activity on the entire African continent' (Turton et al. 2006, p. 313). South Africa's minerals are highly diversified, profitable and plentiful, and this led to government giving the industry the benefit of the doubt by allowing it to maximise its profits and externalise costs.

In the early days, the gold economy was an extractive industry not based on the notion of sustainability, and, thus, there were no considerations about its possible long-term effects. This was substantiated and supported by water policies that 'classified water used by the mines separately from water used by other industries, the mining-based economy developed in the Far West Rand which held the largest gold deposit in the world' (Adler et al. 2007, p. 34). However, these deposits made extraction technically complex and physically dangerous (due to dolomite aquifers), and therefore, 'to extract the maximum amount of gold the industry employed an elaborate pumping system to draw groundwater from the sunken shafts' (Adler et al. 2007, p. 34). The consequences of this included compromised ground stability, which also caused the groundwater to be exposed to pyrite and other minerals, which had an adverse impact on quality through acidification and subsequent heavy metal contamination.

Complaints from farmers already began to surface in 1905 but not much was done by government until 1956 when an interdepartmental committee (IDC) was established to investigate the effects of mine dewatering practices and their termination in most instances. The long-term consequence of dewatering the mines was that the value of the additional gold production over a period of 60 years was at least 3.5 times more than if the mines were not dewatered. However, sufficient mine closure plans were not developed, and regulatory measures were considered 'amicable agreements' rather than new and enforceable legislation. Government continued to profit from the industry by collecting approximately 57 % of all mining profits in the form of taxes and levies (Adler et al. 2007, p. 34). Government allowed entrepreneurial and profit interests of large mining houses to merge with that of the state. Government was expected to act on behalf of its citizens to set standards to regulate the industry and to ensure that those standards were adhered to but instead 'government allowed its definition of mineral ownership, based on Roman-Dutch common law to justify its passive position toward the industry in support of an unsustainable, yet highly lucrative extractive process' (Adler et al. 2007, p. 35). Through this, the government allowed the mining industry to gain control.

One of the best-known social science experts in the field of South African mining and AMD, Anthony Turton, is of the opinion that AMD should be understood in terms of the historical evolution of the government's policy towards mining. He states that the crucial problem is that the existing mining policy reflects a historical legacy in which powerful financial interests coincided with the interests of a racially defined political elite, which saw government becoming an agent rather than a controller of the mining industry (Anthony Turton, personal communication, 24 April 2013). He explains how as a commercial entity gold mining had its origins in the Anglo-Boer War (1899–1902); the main purpose of which was to capture the South African mineral resources for the benefit of the British Empire. He identified the following four historic phases in the historical development of mining, which are essential to understand in order to find a solid solution for AMD:

3.4.1.1 1886–1902: The Pre-industrial Phase of Mining

This phase of mining was characterised by low levels of technology and capital, developing at this time an ill-defined resource (Anthony Turton, personal communication, 24 April 2013). The mining operations were mostly of a narrow nature with inadequate underground development away from the surface outcrops of the main reef. The Anglo-Boer War allowed for changes in terms of which the consolidation of all gold resources came under sovereign British control.

3.4.1.2 1902–1961: The Industrial Phase of Mining

This phase was generated by the initial sovereign control over the resources by the British, which allowed the consolidation of the many small leases into units that could be more profitably developed by means of deep-level and capital-intensive mining. Rand Water Board was given the responsibility of developing water resources for the exploitation of the goldfields, of which gold-mining companies had formal representation. In the Western and Far Western basins, the depth of these mine workings was initially limited by the existence of a massive dolomitic aquifer that extends in compartmented form, from the East Rand in Gauteng Province, in a crescent south of Johannesburg, to the West Rand also in Gauteng Province (Anthony Turton, personal communication, 24 April 2013).

3.4.1.3 1961–1994: The Deep-Level Phase of Mining

This phase was characterised by dewatering of the dolomites in the Western and Far Western basins, authorised by a formal commission of inquiry that began its work before independence from Britain. The committee's work was rushed by the transition of South Africa to the status of a pariah state: arising from the Sharpeville Massacre (1960) and the severing of ties with the British Commonwealth (1961). This brought about a very rich period of gold extraction during which profits were maximised by externalising costs. In this phase the mining industry became a strategic partner with the state, continuing the policy of apartheid while making significant profits 'via the externalisation of [a] costs model sanctioned by the regulatory authority' (Anthony Turton, personal communication, 24 April 2013).

3.4.1.4 1994 to Present

This phase of mining is characterised by the advent of democracy. It overlapped with the gradual scaling down of mining operations as the economics of old mines approaching the end of their useful lives became marginal due to a low gold price in real terms and falling recovered grades. Ownership of mines had passed to smaller entities, and in this time deep-level mining operations spiralled down, together with cessation of the pumping of water in the Western Basin in 1996 (Anthony Turton, personal communication, 24 April 2013).

With the transition to democracy in 1994, the philosophy regarding ownership of natural resources also changed. In the past, the landowner had first right and access to the water and mineral resources that were on the land. However, with the new constitution and the MPRDA (RSA 2002), this form of ownership changed. 'Natural resources have now become the people's collective property, with government acting as a custodian' (Adler et al. 2007, p. 34). It means that the 'old-generation rights' of private ownership had to be converted into 'new-generation rights' granted as permits by the Department of Mineral Resources for a specified period. It amounted to a form of 'nationalisation' of mineral (as well as water) rights.

The fact that government and the mining industry had developed a history of cooperation over the years, as well as the understanding that the economic model supported this interaction, allows one to identify the weaknesses that exist and recognise the critical need for new, strong and coherent legislation.

The discussion of the literature in this section highlighted the relationship between the mining sector and government and suggested that the government's policies over time are an important factor to be included in one's understanding of mine water management, including AMD. In Chap. 5, the government's response to AMD since 2002 is discussed further. This book, therefore, utilises public policy as a lens through which AMD can be approached. The same applies to the socio-economic impacts of AMD (see Chap. 6), which will require policy responses.

The third conceptual element of this research topic—after sustainable development and the developmental role of water—is the public policy domain. Cloete et al. (2006, pp. 16–17) considered a number of public policy definitions and concluded that public policy 'is a functional perspective on the process of government'; it is not always explicitly articulated but can also be government practices; policy emphasises value judgements, ethics, values, society and relationships; public policy as a process is accentuated; and the importance of management, governance and institutional arrangements in policy must be appreciated. In the most reductionist form, Harold D. Lasswell's (Farr et al. 2006, p. 579) classic notion of public policy as the public process of determining who gets what, when and how still remains useful.

Public policy is a well-established disciplinary domain within sustainable development. This book follows in that tradition and thus regards sustainable development as an overarching policy objective. Policy instruments such as water management are then utilised in pursuit of that objective. The pillars of sustainable development are also axiomatically regarded as policy principles applicable to the various policy instruments. In this context AMD in South Africa can be treated as a public policy issue.

3.4.2 The Economic Significance of Mining in South Africa

South Africa has often been described as a world leader in mining. The country has been known for its profusion of mineral resources and has been responsible for great proportions of world production. South African mining companies are therefore essential role players in the global industry and so are the reserves (Kearny 2012, n.p.). Historically, South Africa's economy has been built on gold and diamond mining, as demonstrated by the fact that gold accounts for more than one third of exports, and in 2009 the diamond industry was the fourth largest in the world. It is also a key producer in coal, manganese and chrome (Kearny 2012, n.p). This underscores why it is evident that South Africa's mining industry has been and continues to be known as 'the bedrock of Africa's economic powerhouse' (GCIS 2010, p. 366). This enables the mining industry, along with other related industries, to be essential for South Africa's socio-economic development. However, with the major contributions that this industry has made to the country, it has still seen a serious decline in its contribution to South Africa's gross domestic product (GDP) over the past 10–20 years (GCIS 2010, p. 366). According to the National Budget Speech in 2016 (Gordhan 2016, p. 7), platinum, gold, iron ore and coal, which are South Africa's major exports, have seen immense declines in global demand and prices. This impacts negatively on the economy in terms of reduced export earnings, lower revenue, declining investments and job losses.

Despite these declines, mining has contributed significantly to the economy or economic growth in South Africa. South Africa is a country that is wealthy in terms of mineral resources and the growth that it creates for economic development. 'South Africa is one of the world's and Africa's most important mining countries in terms of the variety and quantity of minerals produced', and it has the world's largest reserves of chrome, gold, vanadium, manganese and the platinum group minerals (PGMs) (Mbendi 2012). Thus, mining remains crucial and significant to South Africa's economy, for instance, 'the Witbank coalfield represents the largest conterminous area of active coal mining in South Africa. These coal fields are known to produce coal for power generation which covers 48 % of the country's total power generating capacity for both export and domestic consumption' (Hobbs et al. 2008, p. 419).

Mike Rossouw (in Creamer 2010) states that mining has a major role to play in nation-building and that management of mining activity should focus on that which is needed to build a sustainable mining industry. He added that 'we've got to exploit our natural wealth to the maximum benefit of all the people in this country' (Creamer 2010). There are many who believe that these valuable metals and minerals should be left unexplored and that South Africa should move on to the so-called value-added approach. There are, however, other countries, such as China, that use their resources to their maximum potential and this is what boosts their economic growth which, in turn, is crucial for social transformation. South Africa has 80 % of manganese reserves and resources in the world, but only 15 % of manganese is produced, compared to China, which produced more than 35 %, while having less than 5 % of the world's manganese reserves and resources. According to Rossouw (in Creamer 2010), a country can only be socially transformed through a strong economic base, and the mining industry is what can enable such transformation in South Africa. It is, therefore, evident that the mining industry is extremely important and significant for South Africa.

According to the official *South African Yearbook 2010/11* published annually by the GCIS, mine management forms an essential part of the management of mineral resources in South Africa. In order for this to be managed, the Department of Mineral Resources has to conduct research to improve mine environmental policies, which includes legislation and strategies. It should also provide strategic guidance on mine environmental management, mine rehabilitation, water, ingress, mine environmental legacies and sustainable development. The legacy of mining, which dates back more than a century, has created numerous derelict and ownerless mines that are now leading to severe environmental concerns and health hazards for communities that live in close proximity to these mines. The rehabilitation of these mines needs to be put at the forefront of the department's priority (GCIS 2010, p. 368).

A draft strategy on Regional Mine Closure in the Witwatersrand and Klerksdorp–Orkney–Stilfontein–Hartebeestfontein gold-mining areas has been developed to address the cumulative mining-related impacts and to work towards sustainable closure of mines in the areas of concern (GCIS 2010, p. 368). Susan Shabangu, Minister of Mineral Resources, has established the Rehabilitation Oversight Committee within her department to drive the implementation of a rehabilitation programme for all mines that were licensed before the Minerals Act, 1991 (Act 50 of 1991) (Minerals Act), and the MPRDA came into effect. The costs of this programme and the implementation plan were finalised, and an amount of R52 million has been allocated to the programme (GCIS 2010, p. 368).

The mining industry, as mentioned above, is a significant industry in the economic growth of South Africa. It covers a 'wide-ranging spectrum of minerals in which South Africa has an exceptional geological/mineral endowment' (GCIS 2010, p. 369). Mineral production has been a key contributor to foreign-exchange earnings and employment in South Africa. In the 1980s the gold sector accounted for almost all mineral-related income. From then, up until 2010, gold has fallen from its prominent position as the main contributor to mineral sales. Employment in the mining industry has seen a decrease of 17.1 % from 1997 to 2003. Thereafter, employment figures started to increase since the proliferation of the MPRDA in 2004, peaking at 527,000 in 2008 before the blow of the global financial and economic crisis (GCIS 2010, p. 369).

From 1986 to 2007, the percentage decline of the mining contribution to the national GDP should be interpreted in the context of the apparent economic diversification and faster growth of other sectors, such as manufacturing, financial services and construction, to which the mining industry also contributed. Regardless of the fact that there have been increases and decreases in the country's economy in the past, the mining sector has been essential and vital to the economic growth. The industry contributed 9.5 % to gross value added, 9 % to total fixed capital formation and more than 30 % to the country's total export revenue, and it employed 2.9 % of the country's economically active population, with just over half a million direct jobs and more indirect jobs (GCIS 2010, p. 369).

The sector further contributes 18 % to the country's corporate tax receipts. The listed mining companies represent over 30 % of the market capitalisation of the Johannesburg Stock Exchange (JSE) and, even though the mining industry consumes 15 % of national electricity, it contributes more than 95 % to the generation of electricity in the form of coal for power stations (GCIS 2010, p. 369).

South Africa is known for its mineral wealth, which is found in the following well-known geological formations and settings:

- *The Witwatersrand Basin* yields some 93 % of South Africa's gold output and contains considerable resources.
- *The Bushveld Complex* is known for their platinum group minerals (PGMs, chromium and vanadium-bearing titanium-iron ore formations, and large deposits of industrial minerals.
- *The Karoo Basin* extends through Mpumalanga, KwaZulu-Natal, the Free State as well as Limpopo provinces.

The world's largest mineral reserves are found in South Africa. This includes PGMs, 87.7 % in total; manganese, 80 %; chromium, 72.4 %; gold, 29.7 %; and alumina-silicates. South Africa also produces over 40 % of ferrochromium, PGMs and vanadium mineral commodities globally (GCIS 2010, p. 372).

Even though South Africa is known for its gold production, it was mentioned already that it entered a decline phase, which will lead towards termination of operations by approximately 2020. There has been a decrease in production by 15 % from 252.6 tons in 2007 to 212.7 tons in 2008, dropping from the world's second-largest producer to the fourth largest (GCIS 2010, p. 373). This was due to mining of lower-grade ore, influenced by higher rand gold prices and the temporary closure of shafts to maintain infrastructure. 'About 4.1 % of South Africa's gold production was beneficiated to coins and jewellery locally during 2008, generating revenue of R2 billion' (GCIS 2010, p. 373).

In the Witwatersrand, the geology and gold mines of the Ridge of White Waters are world renowned. Almost half of the gold ever mined came from the extensive Witwatersrand conglomerate reefs that were discovered in 1886 near the Johannesburg city centre. The Witwatersrand is the greatest goldfield known to humankind. More than 50,055 tons of gold has been produced from seven major goldfields distributed in a crescent-like shape along a 350 km-long basin from Welkom in the Free State to Evander in the east (GCIS 2010, p. 373).

Mining remains a key industry in South Africa; one that creates economic growth and, in turn, enhances the country's economic development. Thus, when a country is rich in resources that bring crucial benefits, it is necessary to ensure that the industry continues to develop. However, despite the enormous significance of the mining industry, it is also responsible for negative impacts, and this will be discussed in the next section.

3.4.3 The Negative Impact of Mining in South Africa

'In a water-constrained country such as South Africa, the quality of water determines its suitability for use' (Hobbs et al. 2008, p. 417). Pollution occurs in both surface and groundwater and is a serious environmental issue that coal and gold mines must deal with (Hobbs et al. 2008, p. 417). 'As a consequence AMD from ownerless coal mines in the catchment creates tremendous long-term environmental liabilities for government' (Hobbs et al. 2008, p. 417). However, what is evident is that the private industry 'applying technological innovation to manage AMD plays a vital role in the prevention of environmental and socio-economic degradation through its contribution to sustainable mine water management. (Hobbs et al. 2008, p. 418).

South Africa's gold-mining industry commenced in the 1880s and has played an uplifting role in creating some of the country's most important historical milestones, while shaping certain sectors of South African society (Azarch 2011, n.p.). The increasingly difficult issues in the mining industry have caused some mines to shut down as a result of 'depletion of the finite resources found within them. With the abruption of mining activities, an ecological process has begun whereby water in these underground mines rises to its previous levels and comes into contact with sulphide minerals, thus becoming highly acidic. The water then reacts with other minerals, which in turn produce other pollutants in the water such as aluminium, lead, zinc, uranium, radium as well as bismuth' (Azarch 2011, n.p.). According to Hamilton (2011, p. 14) the gold-mining industry has made a major contribution to Johannesburg over a period of about 120 years, but in the process it 'has left us with a looming environmental catastrophe – acid mine drainage'.

In the existing literature, AMD has increasingly become a topic of discussion and of growing concern. 'As a city founded on mining, Johannesburg's legacy is the wealth created, as well as the damage left behind by the careless mining practices of the past' (Guedes 2010, p. 67). However, these increasing concerns led to the mining industry now being governed by legislation to reduce its impact on the environment.

An important, but contentious, point that appears increasingly in the literature is that the mining industry believes that it cannot be held responsible for the impact of 'derelict and ownerless mines'. At the same time, the government also remains adamant that it cannot be held responsible for the 'clean-up' that is needed since it would cost billions of rand to do so (Guedes 2010, p. 69). The Chamber of Mines works closely with government and the mining companies affected to reach suitable solutions. The chamber is now part of the IMC that has been mandated to address and advise government on this issue. The committee has appointed a panel of experts (including officials from the DWA, scientists from the Council for Geoscience, Mintek, CSIR and the South African Water Research Commission (WRC)) to assist. Possibilities for plans of action have been drawn up and risks on the AMD issues assessed (Chamber of Mines of South Africa 2010).

Mine owners took advantage of weak governmental regulation by externalising their costs. According to Adler et al. (2007, p. 34), there is a strong commercial motivation for mining companies to explore possible transfers of water management costs to the government. When a mine can deflect certain short- and long-run production costs to third parties, such as those associated with negative socio-economic and environmental effects, the mine's private costs will be much less and its profits much higher (Adler et al. 2007, p. 34). The 'third parties' who must carry the social costs tend to be the surrounding communities and other stakeholders (Adler et al. 2007, p. 34).

The social costs of mining are difficult to predict and regulate. Thus, in the short term, these delayed or unpredictable costs make the total social cost appear to be low and phenomena such as AMD to be less controversial. The costs associated with mining include development and operational costs for a specific mine; the cost of prospecting, sinking mine shafts, pumping groundwater, cooling shafts and developing and employing water treatment facilities; and the costs involved in complying with other environmental regulations (Adler et al. 2007, p. 35).

When the revenue streams of mines decline and their long-term prospects are negative, their only option is mine closure. Environmental and social remediation or rehabilitation represents costs for mining companies for which they are not prepared or, when liquidated, they cannot afford. In many instances, the rehabilitation of mining operations becomes a cost for the public sector. These costs include the costs of human and environmental health and compensation for the social welfare of the former mineworkers and surrounding communities (e.g. mining-related health problems). In recent times some mining companies were ordered in court judgments to compensate their former mineworkers for health problems developed in their mines.

The environmental impact of mining takes years to become apparent and for its effects to show. By the time that the environmental and socio-economic consequences become noticeable, the mine has already closed or has become insolvent and therefore can no longer be compelled to contribute to remediation, either financially or through other actions (Adler et al. 2007, p. 35). The historical relationship between government and the mining sector and the emphasis on mining's contribution to economic development in South Africa have led to a public perception that the government is unable or unwilling to properly regulate and manage mine water and mine waste (Adler et al. 2007, p. 36).

Since 1997 South Africa has produced almost 468 million tons of mineral waste per annum gold mining approximately accounted for "221 million tons, or 47 %, of all mineral waste produced in South Africa, thus making mining the largest single source of pollution and waste (Oelofse et al. 2007, p. 1). It is now widely assumed that AMD is responsible for the most costly environmental and socio-economic impacts. The pollution caused by gold-mining waste is illustrated by the developments in the West Rand area where decanting from gold mines started in 2002. The West Rand case demonstrates some of the technical, socio-economic and governance challenges faced by the industry and regulators in managing the negative impacts that arise from mine waste (Oelofse et al. 2007, p. 1).

In addition to scholarly publications, government departments and NGOs involved with AMD also publish official documents or comments and reports in the media and on the social networks. The impact of mining on a wide range of sectors often receives their attention, for example, according to the Department of Mineral Resources, the mining industry has to abide by sustainable development principles (DMR 2012, p. 5). Mineral resources are non-renewable in nature; thus, exploiting such resources must balance connected economic benefits with social and environmental needs, without restricting their use for future generations. Every mining company must implement elements of sustainable development commitments, and this includes implementing environmental management systems, also ensuring that mining activities do not have an effect on the health of communities and should be taken into consideration (DMR 2012, p. 5).

The increase in mining throughout the country may be beneficial for certain sectors of the South African economy, as more mines lead to economic growth. However, other sectors often tend to suffer from mining such as agriculture, tourism and biodiversity, because important natural resources are lost in the process (CER 2013). The Federation for a Sustainable Environment (FSE), an NGO that is involved in environmental activism, tends to be concerned about the unsustainable use of the country's natural resources.

In conclusion, according to the IMC (Coetzee et al. 2010, p. 37), mine flooding (and, by implication, also AMD) is not something new; this problem has been around for centuries. The reason why it is a concern now is due to the extent of the problem and the fact that more mines are now left ownerless and abandoned than in the past. Once the mines are abandoned, pumping of the underground mine water stops, and with the rising water levels, acidic water starts to form.

3.5 Conclusion

The purpose of this chapter was twofold: (1) to present a review of the literature that already exists on AMD in South Africa, and other aspects of mining and sustainable development, and (2) to develop a conceptual framework on the basis of this literature that can be applied in this research.

The first conclusion is that extensive literature exists on mining in South Africa and also on the technical–scientific aspects of AMD (such as the IMC expert report) but very little exists on its socio-economic impacts. The discussion about the current state of AMD in Chap. 4 will emphasise this conclusion. This lack of research and publications serves as additional justification.

The second conclusion is that the literature on sustainable development and its relationship with water sufficiently incorporates the elements of human development, socio-economic development, community-focused analysis and environmental impact relevant for AMD to serve as a basis for the conceptual framework. The disciplinary focus of public policy within sustainable development will constitute the third element of the framework. It implies that the conceptual approach of this research is grounded in, or integrated into, the literature it used as the foundation for the research.

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Chapter 4
The Nature of Acid Mine Drainage in the Vaal River System

4.1 Introduction

The purpose of this book is to consider the possible socio-economic implications of AMD in the Vaal River system. It is therefore necessary first to develop an overall understanding of the state of AMD in this area. Research has been done in this respect until early 2016 to determine the latest state or nature of the phenomenon.[1]

Such an approach gives the researcher and reader an indication of the magnitude, severity and urgency of the problem. It sheds light on whether AMD poses an impending crisis or whether it is a manageable problem. On what scale is the potential or real threat for human beings and the environment? What is AMD's potential impact on socio-economic sustainability in the region?

It is not the intention of this book to reach an independent conclusion about the scientific state of AMD, because it is not a geoscientific or engineering study. It depends on the different scientific studies already available in this field, as well as the opinions of AMD experts, reporting in the media and affected stakeholders. The objective is rather to determine if there is a consensus about AMD as a phenomenon in the Vaal River system. If it does not exist, why not, and what are the different opinions? Such an evaluation is also relevant for Chap. 5, which deals with the responses of government, NGOs and the private sector to AMD. Their understanding of the current state of AMD determines their proposed response.

In Chap. 3 the existing literature on the topic was discussed. In this chapter (Chap. 4), the research conducted was to determine the nature of AMD in South Africa, and what its potential developmental significance could be is presented. The latter aspect, with a few rare exceptions, is almost nowhere to be found in the existing literature. The chapter concentrates on the Vaal River system (as a case study) and specifically the three basins in the Witwatersrand and Gauteng Province, South

[1] Parts of this chapter derive from Naidoo, S. 2015. 'An assessment of the impacts of acid mine drainage on socio-economic development in the Witwatersrand: South Africa'. Environment, Development and Sustainability Journal, Springer 16 (6): 1045–1063.

S. Naidoo, *Acid Mine Drainage in South Africa*, SpringerBriefs in Environmental Science, DOI 10.1007/978-3-319-44435-2_4

Africa. The various role players in the AMD debate present different, and sometimes conflicting, views. These opinions are explained.

Different sources were used to determine the current state of affairs in the three basins in the Vaal. They include the expert report submitted to the IMC; consultant reports; interviews with government officials, NGO staff and consultants; and media reports that also relied on government officials, NGOs and experts' comments and information.

4.2 Acid Mine Drainage

AMD affects many provinces in South Africa, which include in particular Gauteng, Mpumalanga, North West and the Free State. Its potential threat to the Johannesburg central business district (CBD), and other economic and population centres, has also become clearer in the last few years (Guedes 2010, p. 69).

A major environmental problem relating to mining in many parts of the world is uncontrolled discharge of contaminated water from abandoned mines. This is one of the manifestations of AMD. 'Acid mine drainage [originating from underground mine water] is produced when sulphide-bearing material is exposed to oxygen and water. The production of AMD usually, but not exclusively – occurs in iron sulphide-aggregated rocks. Although this process occurs naturally, mining promotes AMD formation simply by increasing the quantity of sulphides exposed' (Oelofse et al. 2007, p. 2). AMD is characterised by low pH (high acidity) and high salinity levels in the water emerging from underground as well as surface water polluted by mine waste (DEAT 2008, p. 1). AMD is said to originate from both surface and groundwater workings, waste and development rock and tailings and piles and ponds. AMD is not only associated with surface and groundwater pollution but is also responsible for the degradation of soil quality and aquatic habitats and for allowing heavy metals to seep into the environment. The South African government's view is that 'an exacerbating characteristic of AMD is its persistence—it is extremely difficult to rectify' (DEAT 2008, p. 1).

It is important to note that the general public's view of AMD—which only includes underground acidic mine water that contaminates surface water—does not encapsulate all its manifestations. What happens not only underground but also above the mine shafts with the mine waste is very important to take into account. Therefore, 'AMD probably presents the single most important factor dealing with tailings and waste rock and their impact on the environment' (Oelofse et al. 2007, p. 2). Moreover, it is important to consider the possible impact that AMD can have on long-term pollution, as AMD could continue for years after mines have closed and tailing dams (or popularly known as mine dumps) decommissioned. It is widely assumed that AMD is responsible for costly environmental and socio-economic consequences. Therefore, significant improvements are made in developing policy frameworks that can address mine closure and mine water management. The mining industry is also changing its practices and routines to conform to new legislation and regulations, but there are still persistent vulnerabilities in the current system.

It is assumed that AMD is increasing in its severity to the extent that the mining waste can result in profound, often irreversible, destruction of ecosystems. This view is one of the contested points in the debates in the South African context. Environmental activists and NGOs generally maintain a pessimistic view. They even say that in certain instances, it might be impossible to rehabilitate the polluted sites at all, because pollution is so severe that there is no method to remedy this destruction. The scientists and researchers in the field, however, are more pragmatic and use examples to demonstrate measurable improvements in the quality of aquatic life or changes in the pH levels of water systems, especially those in the Western Basin near Krugersdorp. This point is a good illustration of an ongoing tendency in the AMD debate in South Africa that will be discussed in other parts of this book as well, where there are differences in opinion, often among scientists but also between the scientists and public activists. Shanna Nienaber is notable for her research on this matter.

In South Africa the occurrence of AMD tends to be increasingly common in several parts of the Witwatersrand and the Highveld coalfields in Mpumalanga Province close to Middelburg and eMalahleni (formerly Witbank). Acid mine water began to decant in significant quantities from defunct flooded underground mine workings on the West Rand in the Gauteng Province in August 2002. In 2008, one of the government departments affected by it made the following observation about the Western Basin:

> In South Africa, an example of AMD is occurring on the West Rand in Gauteng Province. Acid mine water started to decant from defunct (closed) or flooded underground mine workings on the West Rand in August 2002. Decant has subsequently been manifested at various mine shafts and diffuse surface seeps in the area. Up until early 2005, and completion of storage and pumping facilities to contain and manage on average of 15 ML/d of decant, the AMD found its way into an adjoining natural water course and flowed northward through a game reserve, and towards the Cradle of Humankind World Heritage Site. (DEAT 2008, p. 2)

AMD is not only linked to surface and groundwater pollution but is also responsible for the degradation of soil quality, for harming aquatic sediment and fauna and for allowing heavy metals to seep into the environment. However, many stakeholders involved in the matter maintain the view that it can be managed. According to Oelofse et al. (2007, p. 3), AMD can be controlled best by controlling water entry into the site of acid formation by diverting the surface water away from residue storage areas, by preventing groundwater infiltration into the mine workings, by preventing hydrological seepage into the affected areas and by controlled placement of acid-generating waste.

In a similar vein, according to Kearny (2012, p. 12), 'Acid Mine Drainage does not have to be a problem. The water can be treated to produce drinkable quality, and the polluting elements can be turned into useful products. However, finding a way to finance a solution that balances the rights and obligations of all the parties involved have proven to be difficult'. The South African government's IMC supports a similar sentiment and its research document states that the issue of AMD will need to be controlled, managed and treated. Steps that need to be taken have been researched and studied globally and in South Africa.

According to the IMC (in Coetzee et al. 2010, p. 3):

> AMD is a significant and costly environmental impact of the mining industry worldwide. The legacy of mining continues to affect surface and groundwater resources long after mining operations have ceased. AMD is a common problem at abandoned mine sites around the world today. The oxidation of sulphur-rich mine wastes by interactions with water and oxygen and the consequent release of AMD is one of the main environmental challenges facing the mining industry.

4.3 How Acid Mine Drainage Is Defined Among the Various Actors

The way in which AMD is defined tends to be very crucial, because it essentially determines how the phenomenon is assessed. The narrower it is defined, the easier it is to be addressed. A narrow definition that concentrates on a specific aspect that can be restricted or confined will therefore be easier to address. A definition broader in its scope that includes more complex phenomena is obviously more difficult to address. Therefore, if a spokesperson claims that AMD is under control, it often depends on the definition used in that case. Two broad categories of definitions are used: one that concentrates exclusively on underground mine water which turns acidic and then decants at the surface to contaminate surface water systems and another category which, in addition to the underground water, also includes radioactive acid water formed by the interaction between acid rain and tailing dams and which results in a limited radioactive responsive. These categories are broadly associated with the South African Government's definition, in the first instance, and civil society activists, researchers and consultants, in the second. The first category of definitions of AMD, in particular, is found in both the literature review discussed earlier and in the personal interviews with government officials conducted for this research. After comparing the different definitions of AMD, one can form a better understanding of how this issue has become the emergency it is today.

First the definitions that look at AMD from a broad perspective and that are mainly associated with researchers and consultants such as Anthony Turton or activists such as Mariette Liefferink are discussed. According to Turton, a number of different acid-forming processes are known but all of them involve similar chemical elements, and they include acid rock drainage and AMD. Another distinction can be made between surface manifestations and subsurface manifestations that are all caused by the oxidation of pyrite which produces acid in the presence of oxygen and bacteria. The necessary condition for this to occur is a minimum acid level of pH5. Thus, in summary, according to Turton (Personal Communication, 24 April 2013), 'AMD' is defined as 'water that is acidic arising from the oxidization of pyrite, below pH5', thereby referring to this aspect of AMD on which most stakeholders have reached consensus.

The next element of AMD is controversial and especially government representations do not refer to it at all. It affects mine residue areas (MRAs) on the surface where the fine sludge or residue of the crushed mine rocks is stored in tailing dams. Below the pH5 acid level, according to Turton, when acid rain comes into contact with the mine dust on the tailing dams, there is a 'mobilisation of uranium' which does not happen above pH5. The radioactivity of uranium combines with the high acidic and salt levels of the mine water to form a more complex form of contaminated mine water. Thus, pH5 is the defining threshold, especially in the Witwatersrand goldfields for both forms of AMD. This conclusion about the catalyst effect of acid rain, according to Turton, was the result of the latest research on the chemistry of AMD and the formation of acid. At present rainfall with a pH of as low as 3 has been observed in the Vaal River system, and acidic rain falling on top of mine dumps triggers the initial formation of acid, which drops the pH and then triggers the second phase. Turton is one of the first persons to accentuate the importance of acid rain in combination with AMD, with the implication that even if the underground formation of acid water can be reduced or arrested, it will not be the end of AMD. However, acid rain is a phenomenon that has not yet been brought to the attention of the South African public and has not yet been looked at by the media when discussing AMD (Anthony Turton, Personal Communication 24 April 2013). During an interview with AgriSA, interviewees were asked about their understanding of acid rain. They responded that there was an impact but that it was limited and they were not aware of this with regard to AMD (Nic Opperman, Adriaan Louw and Meiring du Plessis, Personal Communication, 22 November 2013).

AMD occurs in many parts of the world, but, in the opinion of Turton, it is locally specific, because of the South African geology and hydrology. It is a nuanced situation and nuanced by localised conditions: the water situation in general and mine water in particular are not the same everywhere. The case of 'the silver bullet, one size fits all' definition of AMD does not apply in South Africa and, more specifically, not in the Vaal River system (Anthony Turton, personal communication, 24 April 2013).

Mariette Liefferink is an environmental activist of the FSE who provides services to communities and addresses the injustices regarding the environment such as AMD. Liefferink's main focus is on radioactivity which overlaps with Turton's linkage of acid rain to AMD. She states that the gold mining industry in South Africa is in decline, and therefore an increasing number of mines are decommissioned. As a consequence, the risks of AMD are increasing, because mining companies are no longer taking responsibility for managing the underground water and the tailing dams. In her view, decanting of AMD after the closure of mines is an enormous threat and could become more severe if remedial activities are not implemented as soon as possible (Mariette Liefferink, personal communication, 4 April 2013). Waste from gold mines, according to her, constitutes the single biggest source of waste and pollution in South Africa, and AMD is responsible for the most costly environmental and socio-economic impacts. AMD can continue for years to come after mines have been closed and tailings dams decommissioned. AMD, according to her, can lead to long-term exposure of polluted drinking water and can pose a threat to human health in the form of increased rates of cancer, decreased cognitive functions and the appearance of skin lesions (Liefferink 2012). Heavy metals in drinking water can also compromise the neural development of the foetus which can lead to mental retardation (Liefferink 2012). Liefferink's implied definition, underlying her description of the implications of AMD, is very similar to Turton's, except that she concentrates more on the radioactive dimension, while he considers it less prominent and, therefore, also posing less of a threat to the environment.

The next category includes definitions from a narrower perspective and is presented by two persons who work in the sphere of government or are closely related to it. Their definition of AMD is markedly different from Turton's and Liefferink's, and this can explain why the official government view of the current state of AMD is less alarming than those of Turton and Liefferink. Bashan Govender from the national DWA (Bashan Govender, personal communication, 25 February 2013) defines AMD in terms of how it is formed. He embraces the conventional approach about how mine water becomes acidic. According to him, in gold mines the iron sulphide reacts when it comes into contact with oxygen and water and produces extremely acidic water. This water then dissolves other metals and salts in the mines, and when the water decants on the surface, it constitutes AMD. Due to the dissolving of salts (which results in high saline levels) and the high acid levels, this leads to a low pH level which will not sustain any aquatic life in the water, and when it reaches the natural environment, it will disrupt plant life. Govender adds that since the late 1990s, many mines have closed down in Gauteng because of the economic downturn and a decline in gold as a commodity. These closures meant that the water in the mines was left to rise to the surface without any management of its possible consequences (Bashan Govender, personal communication, 25 February 2013). It is clear that this definition and discussion of AMD does not include any reference to the problems caused by tailing dams and acid rain, and their contribution to AMD. It is confined to underground mine water and how the decanting should be managed.

Peter Kelly from the DMR (Peter Kelly, personal communication, 6 March 2013) follows the same approach as Govender, because he also concentrates on underground mine water and how it can affect surface water systems. He explains how evident it is that the water decanting from the mines is acidic and generally polluted, because when it comes into contact with the surface water, one can see the iron particles which have a bright red colour (Peter Kelly, personal communication, 6 March 2013). He also does not refer to the systemic problems caused on the surface by tailing dams and the complication of acid rain for AMD.

In conclusion, the discussion has demonstrated that AMD in the Vaal River system is defined in at least two different ways, while within these two groups of definitions, internal nuances are also present. These differences and nuances are important to understand in order to grasp the main issues in the AMD debate and also to determine its possible socio-economic consequences.

4.4 The Vaal River System

This book is confined to the Vaal River system as a case study and, therefore, it is necessary to provide a brief description.

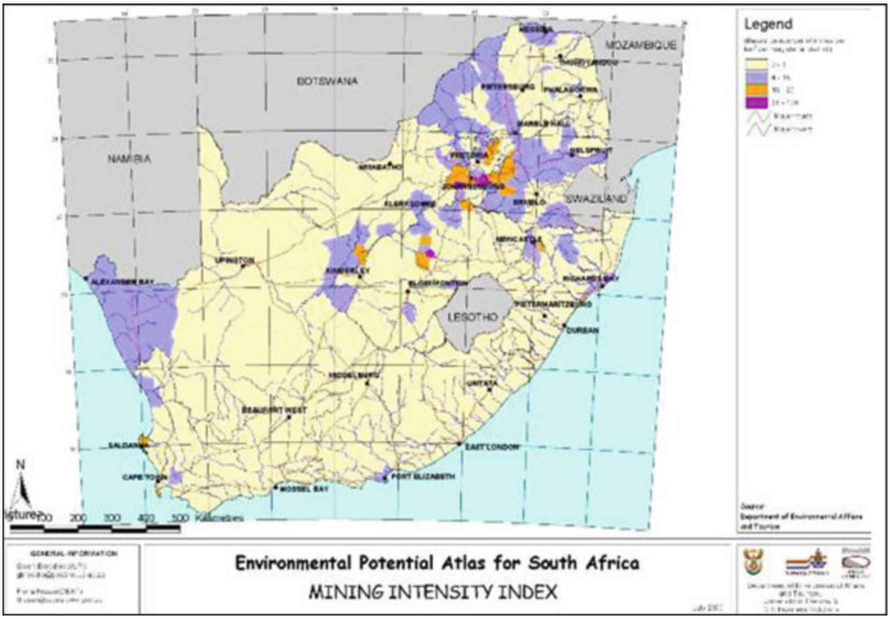

Fig. 4.1 Environmental potential address for South Africa: mining intensity map (Source: Van Viegen et al. 1997)

The Vaal River system is the main geographical focus of this study, and it is affected by one of the most concentrated mining areas in South Africa. The map (Fig. 4.1) illustrates the mining activity in South Africa.

The Vaal River is 1120 km in length, and it supports about 12 million consumers of water in Gauteng and other areas (DWAF 2009, n.p.). The main tributaries of the Vaal River are the Harts, Vals, Waterval, Bamboes Spruit, Blesbokspruit, Mooi, Vet, Renoster, Riet, Wilge, Klip and Liebenbergsvlei rivers. There are three water management areas (WMAs) in the Vaal River system: the Upper, Middle and Lower Vaal WMAs. The one most relevant to AMD is the Upper Vaal WMA 8. The Vaal River system is one of the most important elements of the 19 WMAs in South Africa, and the other main river systems are the Orange, Limpopo, Olifants and Tugela river systems (DWAF 2009, n.p.).

The Vaal River system originates on the eastern Highveld plains in the Ermelo area. 'Shallow hollows and low hillocks form a natural sponge where water collects in pans, vleis and streams. These streams link up and the Vaal River is born, flowing westward on a long course, without rapids or waterfalls, broadening into a large river' (Rand Water 2012). The Vaal Dam is known as the most important dam in the system due to it being the primary supplier of water to the 'economic heartland of South Africa' in Gauteng. It is managed by the Rand Water Board (Rand Water 2012). Some of this water originates from Lesotho, and through the Lesotho Highlands Water Project (managed by the TCTA), it is pumped to Clarens in the eastern part of the Free State Province and from there fed into the Vaal River system.

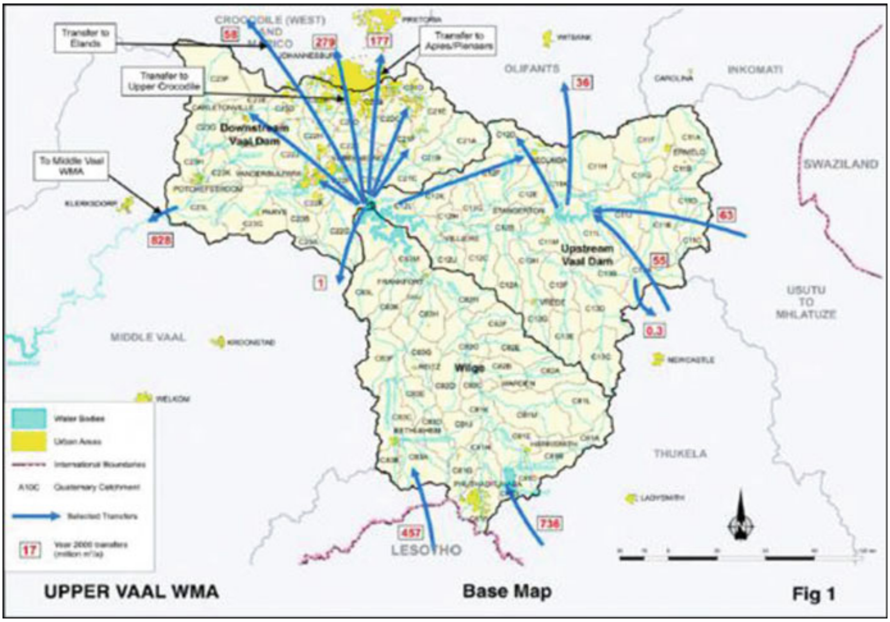

Fig. 4.2 Upper Vaal water management area 8 (Source: Basson and Rossouw 2003)

Figure 4.2 illustrates the Upper Vaal MWA 8 and the main area of focus of this research.

The Vaal River system is the most crucial source of water in South Africa. It is 'not only crucial to human life, but to agriculture, industry, aquaculture and an entire aquatic ecosystem' (Cele 2009). The economic activities especially in the Gauteng Province and the traditional mining areas are, however, also the cause of serious deterioration of the water quality of the river (Cele 2009). It poses the classic dilemma of developing countries which require a delicate balance between economic growth and development, on the one hand, and sustainable human development which is sensitive about the natural environment, on the other.

In 2010 the DWA undertook a series of Reconciliation Strategy Studies for all large water river systems supplying the metropolitan areas in South Africa with water. These studies set out to identify future water requirements for each area in close collaboration with the users which included methods to reduce the demand, to study possible further resource development options and to develop strategies to ensure continuing supply of water for the next 25–30 years. Several stakeholders were involved in the committee which included the DWA, provincial and local governments. The committee was set up to monitor the implementation of the strategies, update the strategies with new information when needed, make recommendations to the institutions responsible for the strategy and communicate progress to the stakeholders and the public (Van Wyk et al. 2010, pp. 1–2).

According to van Wyk et al. (2010, p. 2):

> The area supplied by the Vaal River System stretches far beyond the catchment boundaries of the Vaal River and included most of Gauteng, Eskom's power stations and Sasol's petrochemical plants on the Mpumalanga Highveld, the North-West and Free State goldfields, Kimberley, several small towns along the main course of the river, as well as irrigation all along the main stem of the river and the large Vaalharts Irrigation Scheme.

A considerable amount of water is channelled from the Thukela, the Usutu and the Senqu–Lesotho rivers to the Vaal River. It is used as a channel to transfer water to the Upper, Middle and Lower Vaal WMAs. 'Significant water transfers out of the Upper Vaal WMA occur through the distribution system of Rand Water to urban and industrial users in the Crocodile West and Marico WMA' (Van Wyk et al. 2010, p. 2). Water has also been transferred to the Olifants WMA in order to supply the power stations in that region.

The Vaal River System Reconciliation Strategy identified several actions to ensure that sufficient water would be available to users. One of these included undertaking a feasibility study to reuse water, with underground mine water from gold mines being a priority (Van Wyk et al. 2010, p. 3). These actions were approved by the top management of the DWA and the then minister. AMD is one of the 'key contributors to salinisation of the integrated Vaal River System' (Van Wyk et al. 2010, p. 3).

4.5 The Status of Acid Mine Drainage in the Three Vaal River Basins

In the introduction to this book, it was indicated that the purpose of this chapter is partly to determine the current nature and state of AMD in the Vaal River system. It was also indicated that the system is divided into three basins. This section therefore takes a closer look at the current situation in the basins, the potential threat of drainage and what the expectations are for the near future. Figure 4.3 illustrates the areas surrounding each of the three basins, and Fig. 4.4 provides an additional map illustrating the Vaal River system and the basins.

Firstly, a number of general observations have to be made. The attention generally given to AMD is divided between two regions: (1) the gold- and uranium-producing mines on the Witwatersrand, where AMD commenced in 2002 mainly in the Western Basin, and (2) the coal-producing mines on the Highveld in Mpumalanga Province. The experience of Carolina became a well-established precedent of the complications there.

The management of mines, and especially of their closure, is a critical factor for appreciating the complications of AMD. As discussed in Sect. 3.4.2, the economic significance of mining, the mining industry has created much development for South Africa and has contributed highly to the country's economic growth. However, in Sect. 3.4.3 some of the negative impacts of mining were highlighted, such as

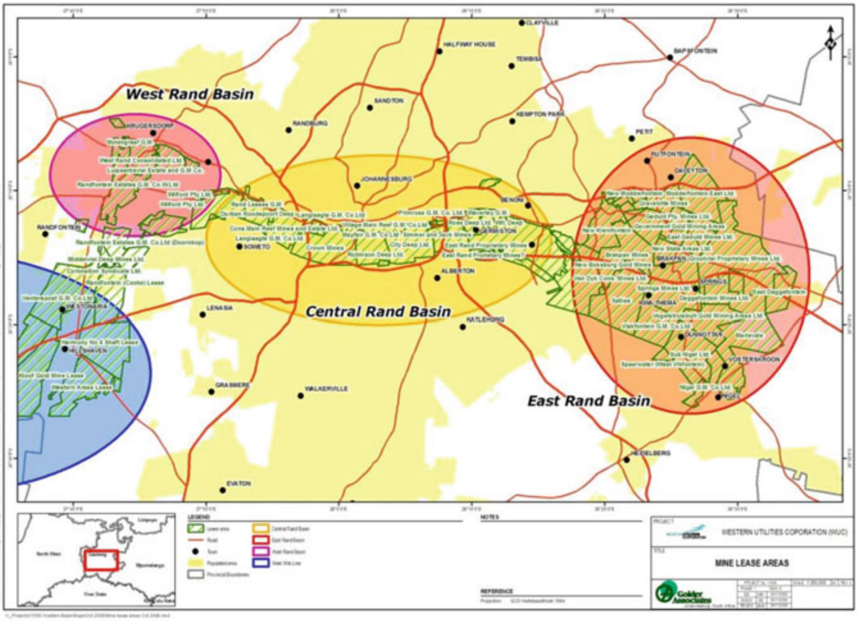

Fig. 4.3 The three basins in the Witwatersrand (Source: Liefferink 2012, Federation for a Sustainable Environment)

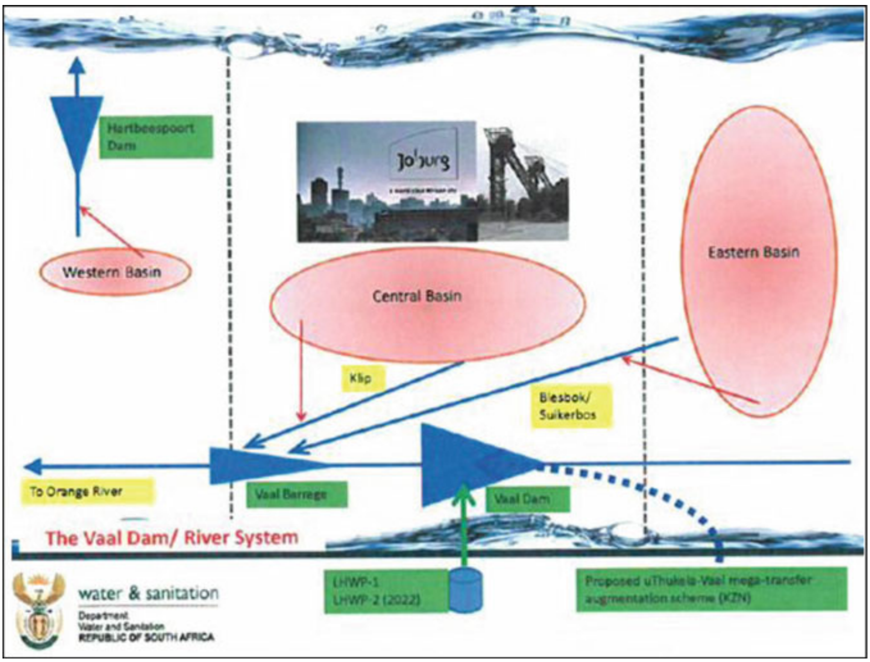

Fig. 4.4 The Vaal River system (Source: DWS 2014, Briefing portfolio committee on water and sanitation)

abandoned mines, which is linked to the focus of this book, namely, AMD. 'South African mining companies are not fulfilling their obligations to set aside money for mining clean-up operations before they are officially closed' (Wait 2012a). This particular media response in the *Mining Weekly* highlights the continuous concerns of environmental degradation in the mining areas, stating that the large number of ownerless and abandoned mines and AMD incidences have shown there is a need for improved environmental maintenance and rehabilitation in the mining sector (Wait 2012a). Profits made from mining were not used to pay for the environmental damage.

'While jobs and revenue generated by mining are essential to the South African economy, the costs of mining borne by the environment, mine neighbours, downstream water users and the taxpayer are an unacceptable consequence of a poorly managed sector' (Wait 2012a). Thus, while the economic significance of mining is highlighted here, at the same time, one is confronted with the extreme dilemma of the cost to the environment (Wait 2012a). These problems largely concern the quality of environmental management programmes or the fact that the plans are not adequate and do not consider longer-term water quality issues.

Though not directly the subject of this book, the situation in Mpumalanga, and specifically in Carolina, is informative of the possible impact of AMD and it has received substantial public attention, including its socio-economic (especially health) impacts. Carolina residents are already suffering from the consequences of AMD and during 2012 have not had access to tap water for months, due to the water being contaminated with chemicals such as sulphate, aluminium, chromium, manganese, cobalt, lead, zinc, copper and nickel. It is assumed that if affected water is consumed, it will lead to chronic health problems for residents, especially diarrhoea (Yende 2012, n.p.). In March 2014, an article in the media reported on the quality of water in Mpumalanga, stating that nearly 4 million people who live there have been cautioned not to use their tap water—without sterilising it first (Masinga 2014, p. 10). Access to water in Mpumalanga is said to 'top the list' of service delivery challenges 'providing people with access to piped water does not guarantee them safe drinking water because, despite the fact that 85 percent of Mpumalanga's population already has access to piped water, diarrhoea remains the second leading cause of death among children under 5 after acute respiratory infections' (Masinga 2014, p. 10). High content of aluminium was found in the water and according to the World Health Organization (in Masinga 2014, p. 10), and high levels of aluminium in water is known to cause diarrhoea.

The media is playing an important role in creating more public awareness about AMD. An important element of the potential impact of AMD is the public perception about its state of affairs, and in that respect the media is the most important role player to influence or determine that perception. Masondo et al. (2011, n.p.), for example, described AMD as 'a ticking time bomb beneath the country's richest province'. The severe weather that occurred in January 2011, which caused human deaths, also raised the levels of toxic water in Gauteng's mines. Public involvement is encouraged to create more awareness and to put pressure on the stakeholders to implement a response plan.

A significant comment in *The Star* (Wende 2011, p. 14) was that 'it is time for those of us who are not experts on this matter to begin asking questions and demand that role-players take action'. Experts stress that serious decanting that will start to affect parts of Central Johannesburg is imminent. This media comment states that citizens need to take a more active stance and understand what is happening and that the government should take responsibility for the long-term damage to the environment. 'AMD is an issue that will affect millions of people all around Gauteng' (Wende 2011, p. 14). This 2011 media article stressed the issue of decanting taking place in the West Rand and starting to increase in the Central Basin. Other media reports have already begun warning about the possible impact on central Johannesburg (Wende 2011, p. 14).

One of the most comprehensive studies so far on AMD was done by an expert group for the government's IMC in 2010. According to the IMC (Coetzee et al. 2010), there is an overall understanding of the AMD issues in South Africa. The IMC document did not regard the situation as critical and concluded that there was still sufficient time to address these issues and that decisions relating to mine water, its potential impacts, management strategies and treatment technologies in the Witwatersrand goldfields would be made. The areas that were under investigation for AMD interventions were the Witwatersrand goldfields, Mpumalanga (Carolina), KwaZulu-Natal coalfields and O'Kiep Copper District. The Vaal's Western, Eastern and Central basins were regarded as priority areas. Though not alarmist about the situation at the time, the report concluded that these areas were in need of immediate action. The Western and Central basins were said to be most affected in 2010.

Peter Mills (personal communication, 20 February 2013) from the Cradle of Humankind, in a more recent general assessment of the AMD threat, stated that the water quality was not in a good condition in the Western Basin and that the Central and Eastern basins would not decant, because the government would not let it happen. He said that if nothing was done, then the Central Basin would start decanting by 2014 and the Eastern basin by 2015.

The most important measuring instrument for determining the potential AMD threat is the environmental critical level (ECL), which is the highest level that mine water is allowed to rise before extreme impacts of water in the mine shafts are experienced. If pumping of underground water is the preferred approach towards containing the threat of AMD, mine water must be kept below the ECL. According to Mills, the government keeps a close watch on the ECL and will, therefore, not allow central Johannesburg or the Gold Reef City theme park to flood.

From the interviews with AMD experts, it emerged that rainfall patterns are an important consideration that has to be included in an assessment of AMD. Mills stated that the rainy season of 2010/2011 had spiked this problem and Govender (Bashan Govender, personal communication, 25 February 2013) agreed, stating that mine dumps could only absorb a certain quantity of water, and once it did, the rest had to come out at some point. Govender stated that during 2002/2010, the rainfall pattern was not as bad as in the 2010/2011 period. This he described as an abnormal rainy season and one of the wettest. The Western Basin filled up and could no longer handle the volume of water, which was partly the issue. He also stated that there could be aggressive seasons ahead that required planning. In 2015 it was reported that since the growing awareness of rising water levels in 2010, 'much has been accomplished since and there are plans to do more' (Environment News 2015, p. 1). It was further mentioned that 'the total flow of water in these three basins is 170 million litres a day, enough to fill more than 60 Olympic-size swimming pools. Thirty million litres of it comes from the Western Basin. The Central Basin flow is 60 million litres, and the Eastern Basin is 80 million litres' (Environment News 2015, p. 2).

A more detailed discussion of the three basins is provided below.

4.5.1 The Western Basin

The Western Basin around Krugersdorp was the first area where major decanting of acidic mine water had taken place since 2002. It might therefore also be regarded as the area most affected by AMD so far. Two areas in the basin have received substantial public attention, (1) the Cradle of Humankind as part of the Sterkfontein caves, which is a World Heritage Site, and (2) the Krugersdorp area, and specifically the environmental impact of AMD on the nature reserve and the Tweelopiespruit.

General agreement exists that AMD has become a public issue since its emergence in 2002 (personal communications: Mariette Liefferink, 4 April 2013; Peter Kelly, 6 March 2013; Peter Mills, 20 February 2013; Bashan Govender, 25 February 2013 and Anthony Turton, 24 April 2013). Since 2005 increasingly more attention has also been paid to the Cradle of Humankind in particular. This phenomenon has been researched for more than 8 years already and is the focus of public attention.

When the last gold mine in the Krugersdorp area stopped underground operations in 1998, dewatering pumps were switched off and the natural regional groundwater levels started to rise to levels last seen many decades ago. Already in 2008 there was strong evidence that inputs such as sewage waste also contributed towards deteriorating the regional water quality, although little attention has been paid to this (Cobbing 2008, p. 454).

According to Ho (2011, n.p.), since 2002 there has been toxic water in the Krugersdorp Nature Reserve. The acidic water is affecting the wildlife in the water. However, also of concern is the fact that it may cause blindness and damage to the retina of both humans and animals.

The scale of contamination is enormous. 'Seepage and percolations from sludge dams amount to 24 tonnes of uranium water entering that region's water basins and river systems annually, this includes the Vaal River' (Ho 2011, n.p). This remains a problem that extends across the gold mining areas in Gauteng, and in the West Rand it is a threat to the fossil wealth of the Cradle of Humankind. The residents in the Krugersdorp area who are reliant on borehole water are affected by mine water decanting. They have raised concerns about the 'orange colour of the water' which is the result of sulphur compounds present in acidic water. The South African Council for Geosciences (CGS) also warned that the acidic mine water in some

Fig. 4.5 West Wits Pit (Western Basin, Krugersdorp) (Source for photograph: Researcher)

areas contained high levels of radioactivity which may increase the risks of cancer (Oelofse et al. 2007, p. 6).

In 2013, some observers described the Western Basin as 'a write-off' (Mariette Liefferink, personal communication, 4 April 2013). During a tour, in 2013, to the Western Basin and the Krugersdorp area with environmental activist and CEO of the FSE, Mariette Liefferink, the extent of the AMD crisis became real. Liefferink explained how mine water in the observed areas had severely decanted, and she also explained the nature and severity of the decanting phenomenon and provided her views on why this was the situation in the Western Basin. Figures 4.5, 4.6, 4.7, and 4.8 illustrate the sites visited in the West Rand.

Liefferink predicted that while the Western Basin had already started decanting and experienced flooding, the other basins would soon follow. According to her estimation, only about 21 % of the Vaal Barrage was not yet toxic. What is alarming in her argument is her concern for the Western Basin, stating that it was already fully flooded which had enormous ramifications for the area. In addition to the water quality, she also warned that acid rock dumps in the area contained about 6000 tonnes of heavy metals that could potentially also dissolve into the water. Liefferink described her overall response to AMD as 'a band aid approach' in the sense that AMD would continue and would remain unaddressed. In 2014, a media article referred to Liefferink, who stated that the basin now has '400 km2 of mine tailings dams made up of 380 potentially radioactive mine residue deposits, including 270 mostly unlined tailings dams containing 6-billion tons of iron pyrite tailings and

Fig. 4.6 Robinson Lake (Western Basin, Krugersdorp) (Source for photograph: Researcher)

Fig. 4.7 Robinson Lake (Western Basin, Krugersdorp) (Source for photograph: Researcher)

Fig. 4.8 Mariette Liefferink explaining the radioactivity caused by AMD (Source for photograph: Researcher)

600,000 tons of low-grade uranium' (Solomons 2015, p. 1). Liefferink went on to add that these tailings dams are a significant diffuse source of AMD, as they cannot be maintained in an oxygen-free environment, and when it rains these tailings dams produce AMD (Solomons 2015, p. 1).

Bashan Govender from the national DWA commented on the Western Basin in February 2013, stating that the flow was in a northerly direction towards the Tweelopiespruit. People have complained about not being able to use the water. There have not been complaints from areas that are serviced by Rand Water. However, he stated that water was rising on a daily basis (Bashan Govender, personal communication, 25 February 2013).

According to Mills (Peter Mills, personal communication, 20 February 2013), some geologists believed that the Cradle of Humankind could be under threat, but others did not. As an official of the Management Authority of the Cradle of Humankind, he explained the water dynamics of that area. According to him, as its name indicated, the Witwatersrand extended along a ridge ('rand'), and all the mines were on top of it. From Randfontein, some of the river systems flowed north and others south to the Orange and Vaal River systems. The Blesbokspruit runs from Krugersdorp and collects the sewage water that is decanting into the system. In the nearby Tweelopiespruit, the mine water decants and flows straight into the river system, down into the Rietvlei Dam and into the Cradle of Humankind. It then joins the dolomite formations in the area of the Sterkfontein caves, and the water separates into two directions. Some of the water flows into the dolomitic compartments, and some remains on the surface and flows into the Crocodile River that enters into the Hartbeespoort Dam. Thus, the river loses water that enters the dolomite formations where its acidic level is partly neutralised by the alkaline nature of the dolomitic elements. Some of this underground water joins the river again where the water table is close to the surface, and by the time it reaches the Crocodile River, the water is no longer the same as it is near Krugersdorp. Therefore, Mills concluded that contamination was from surface water. He stated that the mining companies were responsible for that and should take responsibility. At the same time, Mills warned that if the public reacted in too much haste and demanded too much of a response too quickly it could be counterproductive. It could place too much unnecessary stress on this issue, which could delay any results. Mills conceded that AMD had some visible effects on the Cradle, but these effects were more visible in the river above the Cradle than in the Crocodile River itself (Peter Mills, personal communication, 20 February 2013). Thus, the impact was more on the surface, closer to the point of decanting, but it remained difficult to state what percentage of the Cradle was affected by the acidic mine water.

The media in general presented a more serious assessment of the situation in the Cradle. In April 2005 the media started drawing attention to the West Rand basin with specific warnings that the Cradle of Humankind was being affected by AMD (DEAT 2008, p. 2). There were reports that ‘South Africa’s renowned Cradle of Humankind in Gauteng, home to one of the world’s richest hominid fossil sites, is under threat from highly acidic water pollution and it is also threatening to drown the Sterkfontein caves’. This is in line with the conclusion in the IMC’s document in 2010 that the Western Basin was of critical concern to the government (Coetzee et al. 2010).

Another perspective (Hamilton 2011, p. 14) was that the West Rand and the area around the Cradle of Humankind, which was once ‘our pristine waterways of the Witwatersrand’, were by 2011 extremely acidic and hopelessly polluted, with the damage increasing daily. At that time, according to Hamilton (2011, p. 14), the Sterkfontein caves were clear of AMD, but monthly water quality monitoring was undertaken and joint reporting by the CSIR and the CGS experts were to ensure that the site was not compromised due to unregulated closure of mines or mines that were simply abandoned at the end of their production cycle. The area around the Cradle calls for a sustainable approach to mine and water management so that for the future, clean water can be secured for the protection of the fossils in the Cradle of Humankind and also for the communities that rely on the water from the rivers.

Govender made the point that the three basins were not interlinked by aquifers or tunnels, and, therefore, whatever was pumped into the Western Basin had no effect on the other basins. The basins were all separated by geological formations. ‘It is a contained system – what you pump in the one basin, has no effect on the other basin’ (Bashan Govender, personal communication, 25 February 2013). This was also reiterated by a media report stating that ‘geological boundaries prevent acid mine water from flowing from one basin to the next’ (Environment News 2015, p. 2). In the Western Basin, Govender stated, decanting had stopped, and water that was substantially reduced in heavy metals was now delivered in the river system. A salt content of about 40–50 % and its low pH level were not suitable for the environment.

Govender explained that it was not the ideal solution, and the challenging factor was that the treated water was still very high in sulphates which, in itself, was not toxic, but the water was not considered ideal for human use because it could cause gastro-intestinal disturbances. It was also neither suitable for agriculture nor for domestic use, which meant that it was neither usable for human consumption nor did it allow aquatic life to be restored gradually. According to Govender (personal communication, 25 February 2013), the treated water was still ten times better than the untreated AMD water. However, Liefferink (in Solomons 2015, p. 2) states that the level of sulphate in the Western Basin was noted to be 2500 mg/l while the safe level of drinking water should not be higher than 200 mg/l.

According to Govender (personal communication, 25 February 2013), the project to treat the Western Basin commenced when the DWA upgraded an existing plant in Carletonville. In mid-2012 the plant was already operational and able to treat AMD. It is pumping the water from an underground mine system to the surface, and treating it to a 'suitable standard and then discharging it into the environment'. The result is that decanting of AMD onto the surface and into the river system had stopped altogether and that now the water flowing down the river system was of improved quality as opposed to raw and untreated AMD. Govender also stated that the DWA had managed to 'eradicate the decanting of raw AMD into the Krugersdorp Game Reserve'. In summary, Govender concluded that in the West Rand, water had been flowing onto the surface uncontrollably up until the end of 2012, but once the DWA managed to get the plant going, it was able to stop the water before it flowed uncontrollably though the Krugersdorp Game Reserve.

The DWA also confirmed that decanting of AMD had stopped in the Western Basin and that was done by upgrading an old Rand Uranium plant in Carletonville and pumping the drainage from the basin. 'There has been an improvement of water quality in Tweelopiespruit into which AMD has been decanting' (Mouton 2013). A long-term feasibility study that was conducted included identifying the damage already caused by AMD, as well as the aim that water should remain below the ECL. What is essential is that this long-term feasibility study also looked at the possibility of treating the water to drinking standard so that it could be used by industry and agriculture (Mouton 2013). However, a media report in 2015 (Jordan 2015, p. 6) stated otherwise, as 'some farmers along the contaminated Tweelopiespruit downstream from an acid mine water flashpoint say their borehole water is now too polluted to drink'. There is a reported '30 million litres of acid mine water that is decanting from an old mine shaft near Randfontein, where it is being neutralised and piped into the Tweelopiespruit by DWS' (Jordan 2015, p. 6). The same article reported that the toxic flood cannot be controlled by the emergency treatment plan; this was confirmed by the Department of Environmental Affairs (DEA) (Jordan 2015, p. 6).

Turton (communication, 24 April 2013) also agrees that in the Western Basin, the last decant was reported in September 2012. In his view, in 2013 the pH of the void ranged between 5.8 and 6.2 which was above the critical threshold of 5 and, therefore, makes it more alkaline. Anything below 5 means that uranium is soluble, but when it is above 5, uranium precipitates into the void and no longer into the decanted water. A water plant has also been commissioned and is currently being tested to the regulatory protocol. Turton stated that once the regulatory requirements had been met according to the standards of DWA and formal authorisation granted, the pumps would be switched on and the void levels would be drawn down to the ECL within 3 years (Anthony Turton, personal communication, 24 April 2013).

Liefferink's view (personal communication, 4 April 2013) on the current state of the Western Basin is more pessimistic. She is critical of the approach on the West Rand that after 10 years it is now treated by adding lime to the water. When lime is added, the heavy metals drop out of the water but precipitate in the pipes. When water flows into rivers, it appears to be clear but the invisible toxins lie below. In the Sterkfontein caves, she said that the water levels were rising and some plants could not grow in the poor conditions. The water appeared to be clean, but once lime was added, the heavy metals in the water started showing. Acid mine water had flowed into the Krugersdorp Game Reserve, and Liefferink said that she had asked the management authority what had happened to the heavy metals found in the water, but she had not received a clear response (Mariette Liefferink, personal communication, 4 April 2013).

The refurbished emergency treatment plant in the Western Basin is now treating about 30 million litres per day of acid mine water that is discharged into the environment (Environment News 2015, p. 2). According to this report (Environment News 2015, p. 2), the Western Basin remains above the ECL of 160 m below surface, and it will take up to 4 years at the present pumping rates to drop the water level below the ECL. In 2016, the problem in the Western Basin still persists; Anthony Turton states that the Western Basin has been monitored by him, but reducing AMD to below average levels has not yet been reached fully (Matthews 2016, p. 3).

He further explains that in the Western Basin, AMD discharge has been reduced by the drought, to below the average levels, but it still hasn't been stopped completely (Matthews 2016, p. 3). 'Government has spent money to neutralise the water flowing out of a shaft at the old West Rand Consolidated Mine in the Western Basin, but the water flowing into the Tweelopiespruit is not completely treated and the pumping at the shaft is not enough to bring the level of the tainted water down to environmentally critical levels' (Matthews 2016, p. 3). From this we learnt that the high rainfall patterns (as discussed in this chapter) have worsened the AMD situation and make it more difficult to pump the acid water at faster rates; this is confirmed by Turton's point of the drought reducing the prevalence of AMD. Therefore, when there is less rainwater filling the mines, it is only the underground water that is causing AMD, and therefore, it becomes more manageable to treat it and to keep the levels stable. In Canada (Sect. 2.3) a cover is placed on the tailings to prevent the rainwater from going into the mine. This could be a suitable solution that could be used in the cases of the Witwatersrand, South Africa.

4.5.2 The Central Basin

Peter Mills of the Cradle of Humankind explained that the Central Basin extended from Durban Roodepoort Deep (DRD) mine in Roodepoort in the west to the East Rand Proprietary Mines Ltd (ERPM) mine in Germiston in the east over a distance of about 45 km and an area of 251 km^2. The whole area was interlinked and it could be treated as one void (Peter Mils, personal communicaton, 20 February 2013). He mentioned that up until 2008, the ERPM mine was still functional and that it was the only mine working in the whole central region. It was also the only mine pumping underground water out to prevent it from rising in the basin and to ensure that the mine could continue with its mining operations. During the pumping there was an incident when a gas bubble burst through the water and, as a result, people lost their lives. The National Department of Mineral Resources informed the mine that they had to make the necessary arrangements to ensure that this did not recur, but they were unable to do so. Therefore, the pumping had stopped following this incident. Since September–October 2008, the water has been rising by an average of 300 mm a day.

Prof Frank Winde (Wait 2012b) from North-West University stated in 2012 that there was a wide range of possibilities to be explored in containing decanting mine water. He also mentioned that the mining industry and government have had enough time to look for a solution for AMD in the Central Basin. This means that the issue was not treated as severe and should it become uncontrollable, then it is due to government's lack of attention and preventive measures.

Several observers predicted earlier that central Johannesburg and other parts of the Central Basin would soon experience flooding of acid mine water. According to Liefferink (personal communication, 4 April 2013), the Central Basin would have started decanting by September/October 2013.

Bashan Govender was questioned about the prediction that there would be water seepage in the centre of Johannesburg and about the situation in the Johannesburg CBD. He responded by saying that the buildings were at a higher elevation than what the mine water could reach. It means that the foundation structures of the buildings are above the level that can be affected by decanting water. According to him, the DWA had conducted geotechnical investigations to confirm that if the water did rise to the level that created a surface impact, then the vulnerable construction components of these buildings would be above that level. He added that the DWA saw a greater risk in a situation when the water decanted into the river system and then affected the water systems such as the Kliprivier, Tweelopiespruit and the Blesbokspruit rivers in Johannesburg and the Vaal River. Developments in central Johannesburg, according to him, would not affect the Vaal Dam because the dam is situated west of the Eastern basin. Even if acidic water were to enter the river systems that originate in the Eastern basin, it would flow into the river system downstream of the Vaal Dam. This meant that the water from the Vaal Dam was still safe. Govender mentioned that water usage in the 'downstream environment' was of concern, because the people living downstream and using it for agriculture, for resorts and for their purification works, would be impacted.

One of the focus points that serves as a barometer of AMD prevalence in the Central Basin is the Gold Reef City theme park. It is located south of central Johannesburg next to the Apartheid Museum and not far from Soweto. The park was designed around a decommissioned gold mine that is now used for underground tours guided by former miners. It is important as it is one of Johannesburg's main tourist attractions. A media report on the Gold Reef City theme park being under enormous threat had surfaced on 14 March 2013 in the *Times Live* online. The article stated that ‘the Department of Water Affairs is racing against time to halt rising acid mine drainage in the Central Basin under Johannesburg’ (Mouton 2013). The article stated that the mine water was expected to reach the ECL by September 2013. According to a DWA spokesperson (Mouton 2013), the department was not sure that it would be able to address this in the required time frame while excessive rain would also worsen the situation. This could have had severe impacts on South Africa’s well-known historical museum, because if the theme park becomes flooded, it will certainly have a negative effect on tourism (Mouton 2013).

During the research fieldwork, the interviewees were asked for their opinions on how severe the threat of AMD to the Gold Reef City theme park was. In an interview with Bashan Govender from the national DWA, he was questioned on the media reports and the ongoing news that Gold Reef City was in danger of being flooded. His response was that ‘without a doubt, we are working on a very tight timeline’ (Bashan Govender, personal communication, 25 February 2013). He also explained that the water had not yet reached the ECL. However, if it did reach that point, then it could start to react to underground water and the underground tours would not continue, and there would be a chance that the tourist mine museum which is above ground at Gold Reef City would be flooded. From there it would flow directly into the Vaal River system. However, as long as it remained below the ECL, Gold Reef City would be safe. Govender said that Gold Reef City would start pumping out water from the mine shafts but would not be able to treat this water. According to him, at the time of the interview in February 2013, Gold Reef City Management ensured that an adequate process was followed so that the shaft did not become flooded and that the water level did not approach the ECL. Govender gave an important explanation for the situation and that is that Gold Reef City was also pumping surface water that accumulated after heavy rainfalls which was not yet acidic. A significant portion of the water that is pumped into the Vaal River is therefore not a result of AMD and does not carry the same levels of acid and sulphates.

In an interview with Anthony Turton, who has an ongoing relationship as a consultant with the Tsogo Sun hotel group (i.e. Gold Reef City owned by Tsogo Sun), he indicated that the hotel group announced early in 2013 that it would invest a further R470 million in Gold Reef City, which is an indication of the group’s confidence that the theme park had a long-term future. Turton emphasised the fact that Tsogo Sun had a very good understanding of the risk related to the environment. He stated that if the ECL had been reached in the Central Basin, then the lower levels of Gold Reef City would be flooded but not the above-ground museum area. The park management would have to limit the level at which visitors would be allowed to go underground. Even in the worst-case scenario, according to Turton, the decanting would not be as bad as that of the Western Basin. Turton explained that implementation of the plans was behind schedule, because some environmental NGOs were challenging the fact that proper emergency measures were not used. ‘It is a case where law and reality aren’t really applicable, it comes down to a judgment call of emergency over reality’ (Anthony Turton, personal interview, 24 April 2013).

The media paid substantial attention already in 2012 to the measures taken at Gold Reef City to prevent decanting and to pump the mine water into the Vaal River system. In October 2012 the *Sunday Times* featured a media report about the effects of pumping treated acid mine water into the Vaal River system. According to the report (Jordan 2012, p. 10), the government had given permission for an emergency plan to be undertaken, to pump partially treated acid mine water into the Vaal River before it could flood Johannesburg and other areas on the reef: 'pumping it into the Vaal, a major source of water for South Africa's commercial farming sector will go ahead without a study of the potential impact on the river'. It was expected that environmental groups would criticise this approach, because they had warned the government long in advance of the impending dangers (Jordan 2012, p. 10). Government was urgently trying to prevent the acid water overflowing out of Johannesburg's Central Basin before it reaches the first known exit points, including the Gold Reef City mine museum (Jordan 2012, p. 10). The proposed solution was to follow a neutralisation process (i.e. to use underground pumps to pipe water from the Central Basin to a treatment plant where it will be partially treated). The neutralised water will then be released into the Vaal River, where it will be diluted further with clean water from the Lesotho Highlands Water Project (Jordan 2012, p. 10).

According to Mariette Liefferink (in Jordan 2012, p. 10), this pumping of neutralised water could have a severe impact on the Vaal River. In 2015, a senior manager at DWS had recapped that the short-term solutions have already cost the department R2 billion. They would have to further fund the building of desalination plants to treat AMD to reduce the sulphate or sulphuric acids in the water from the Vaal River system (Solomons 2015, p. 3). Furthermore, DWS believes that the impact of the salt load on the Vaal River system needs to be reduced, because while neutralising acid mine water is the first phase, the second phase involves desalinating the water pumped from the treatment plants (Environment News 2015, p. 2). This is presently done by releasing large quantities of freshwater from the Vaal Dam. This could be detrimental in the long term as it poses possible risks to the Vaal River system from 2017/2018, because the dilution process will be unsustainable (Environment News 2015, p. 3). DWS presents the view that even though these challenges to the Vaal River system are perilous, once the salt load is removed, the purified water can be reused. This solution is still pending and will be enforced once agreement has been reached by those on the Inter-Ministerial Committee of AMD.

Liefferink further reiterated that these impacts on the Vaal River system were known and have been stressed for a long time by academics and the public who have been directly affected since 1996 and from the decant that started in 2002 in the Western Basin. The government therefore had sufficient time to identify alternative and more acceptable treatment and preventive processes (Jordan 2012, p. 10).

It is not only Gold Reef City that became the focus of attention in 2012 but also the ERPM mine in Germiston which is used as a site for pumping mine water. Its priority status is very high, and therefore the Minister of Water Affairs in 2012, Edna Molewa, has given the treatment plan for the Central Basin 'emergency status' (Jordan 2012, p. 10). It has been said that 'essentially if the department does not implement certain remedial measures, rising subsurface acid mine drainage in the central basin may yield undesirable environmental and socio-economic impacts' (Jordan 2012, p. 10). Thus, pumping of the neutralised acidic mine water into the Vaal River will serve as a short-term intervention necessary for environmental and socio-economic protection (Jordan 2012, p. 10).

According to Govender (personal communication, 25 February 2013), on 8 January 2013, the pumping site in Germiston was handed over to the Group Five construction company, but there was no infrastructure at the site. All that exists there is an abandoned mine shaft. Therefore, according to Govender, commissioning of this infrastructure will be extremely costly. However, the mining company (not mentioned) that owns this shaft has made it available to the DWA to use for the project. This is an example where a mining company has partnered with the state to deal with the environmental challenge at hand. The mine shaft is directly adjacent to the mine water neutralisation facility where two pumps extract the acid mine water. The pumped and treated water is then discharged into a nearby river system. This is similar to what is happening on the West Rand near Krugersdorp where the water contains very high levels of metals and sulphates and has a very low pH reading (i.e. high acid levels). In the treatment process, some of this will be neutralised and some of the salts reduced. The process extracts 90 % of the surface harmful metals and brings the pH to a level that is suitable for the environment. The treated water is then discharged into the river system.

According to Govender (personal communication, 25 February 2013), the waste from the treatment process in the Central Basin will be stored at the massive mine dumps in Johannesburg. With the treatment or neutralisation process, the waste sludge containing the iron and other metals, which are the by-products of the treatment or neutralisation process, is stored in the dumps, while the water is released into the river system. As seen before in the definitions of AMD, NGOs and activists are wary of what happens with the MRA. The treatment process in the Central Basin near Germiston will most possibly enhance the levels of harmful mine residues, and when it is combined with extensive rainfall (sometimes acid rain, as mentioned by Anthony Turton), it can then create a new cycle of water contamination. In March 2014 (News24 2014, p. 1), AMD pumps were installed in the Germiston area which will treat about 57 million litres of water a day and discharge it into the Klip River (a tributary of the Vaal River). The claim is made that it will not have any negative impacts on the Vaal.

From the Gauteng provincial government's point of view, Kelly (Peter Kelly, personal communication 2013) also confirmed in March 2013 that measures were already in place under the DWA to commence pumping from South West Vertical Shaft in the ERPM mine in Germiston. However, he also cautioned, 'I do not think this will be done in time, and this is the downfall, because it took so long for a decision to be made because of the serious amount of money that this is going to cost' (Peter Kelly, personal communication, 6 March 2013). Unfortunately, there was also some infighting and politicking between the DWA and the mining company involved, namely, DRDGOLD (the owners of ERPM). However, an agreement was reached at the end of 2012, and construction work commenced in January 2013. By June 2013, according to Turton, in the Central Basin engineering design and procurement had been completed and construction begun by some of the most skilled engineers in the country, and there was no cause for concern as the schedule for time and the budget seemed to be met (Turton 2013). According to Govender, the agreement is that the treated mine water would be discharged into the local Blesbokspruit and would then flow into the Vaal River. The pH (and, therefore, the acid level) of the water would be brought to a neutral standard, and the irons would be removed, though salts and sulphate may still remain evident. Sulphate remains the main problem in the water and will end up in the Vaal River (Bashan Govender, personal communication, 25 February 2013). Sulphate is a salt of sulphuric acid which causes the saline content of the water to be too high for both human consumption and for several agricultural products. In May 2014, 'the newly constructed R319 million plant near Germiston in the Central Basin was tested and pumping, treatment and release of pre-treated AMD at this plant reached full capacity' (Bobbins 2015, p. 2).

4.5.3 The Eastern Basin

The situation in the Eastern basin is dominated by the Grootvlei mine in Springs. Its holding company was Pamodzi Gold, which had been provisionally liquidated and thereafter administered by the struggling Aurora Empowerment Systems (Plaut 2011). Aurora became notorious for the fact that its directors, including South African President Jacob Zuma's nephew, Khulubuse Zuma, and former President Nelson Mandela's grandchild, Zondwa Mandela, refused to pay the wages of about 700 Grootvlei miners for more than 2 years (Plaut 2011). In February 2011 the company also stopped pumping the underground mine water. The result was rising levels of water that infiltrated the surrounding mines such as Sub Nigel. Sub Nigel was also used as an underground training centre for miners but because of the rising water levels, it had to be relocated to another mine (Naidoo 2011).

In April 2011 the South African Human Rights Commission (SAHRC) became directly involved in the AMD issue because of the Grootvlei fiasco. It expressed its concern about the detrimental environmental impact of inactive and decanting mines. In March 2011 the SAHRC established a Committee on Environmental Justice and Mining to advise the commission on issues related to mining and its impact on human settlements and the natural environment.

The SAHRC was concerned about the current and potential impacts of AMD on the Eastern basin and the Blesbokspruit. It raised both the potential human rights and socio-economic impacts as concerns. The commission understood that 'mining activities have undermined the quality of water supplies and crops in the area and has negatively affected human health and the health of wildlife and ecosystems in the surrounding environments' (SAHRC 2011). As a human rights issue, the commission was concerned that AMD had the potential to threaten the realisation of a number of human rights in the South African Constitution, including the rights to food, water and an environment that was not harmful to one's health and well-being (SAHRC 2011).

By May 2013 the situation in the Eastern basin was regarded as critical. The main reason was that the liquidation of the Grootvlei mine had delayed progress. Negotiations were continuing to secure land and access to the mine.

In 2013, the magnitude of the AMD potential on the East Rand was much greater than in the other basins. A simple comparison demonstrates this as follows:

Volume of AMD to Be Treated

Western Basin—27 ml/day
Central Basin—57 ml/day
Eastern basin—82 ml/day

Breach of the ECL if Pumping Does Not Commence

Western Basin—already breached
Central Basin—September/October 2013
Eastern basin—November 2014 (Cornish 2013)

According to Bashan Govender from the national DWA (personal communication, 25 February 2013), another potential socio-economic complication is that if this area is allowed to be flooded and the water reaches the dolomite formations in the area, it can affect the existing low-cost housing. If the dolomite structures are constantly flooded and then again dewatered, it can weaken the stability of the dolomite. Differences of opinion about the potential impact still exist. Some argue that AMD will not act as aggressively with dolomite, while others say that it will. Govender was of the opinion that there was a good chance that the local communities would experience the impacts, but scientific studies had not yet proven this.

The Eastern basin is thus the region where commercial mine pumping has continued the longest (until 2011), while in the Western Basin it was stopped in 1996 and in the Central Basin in 2008 (Cornish 2013). Ironically, the Eastern basin is now the one most problematic to commence with pumping as part of the government's AMD response. In the Western Basin, the capacity of the existing Rand Uranium plant has been increased by threefold, while in the Central Basin the Trans Caledon Tunnel Authority, Group Five Civil Engineering and a host of contractors are involved in developing the biggest treatment plant in South Africa near ERPM's South West Vertical Shaft (Cornish 2013).

In May 2014, a media advisory report was released (DWA 2014, n.p.), stating that the pumping, treatment and release of treated AMD in the Eastern basin for the testing plant commenced. There were two noted phases: one train will be operated, and water released from May, and then progressively a second train will be put in operation in the weeks to follow (DWA 2014, n.p.). Towards the end of 2014, plans for this basin were still in the finalisation process (Bobbins 2015, p. 2).

According to Environment News (2015, p. 2), the emergency plant that was established in the Western Basin between 2011/2012 currently treats 30 ml/day which is discharged into the environment. The Central Basin currently is being treated at 56–60 ml/day; therefore, the acid mine water will remain below the ECL if treated at this rate. In the Eastern basin, a similar plant was built which is said to be completed in mid-2016; this plant will treat acid mine water between 80 and 110 ml/day, which is necessary to keep the water below the ECL. These figures are in line with the above figures that were intended for treating AMD in each basin in 2013 (Environment News 2015; DWS 2014).

4.6 The Current Situation of Acid Mine Drainage and How Various Actors Relate to It

In the discussion so far, reference was made to various role players involved in some or other way with AMD. In this section, their involvement is summarised, which will give an indication of their influence in the way AMD is dealt with or is presented to the public. The actors include the three spheres of government, NGOs, the media, the business community involved in mining, consultants and specialists with a commercial interest.

Intergovernmental relations play a critical part in dealing with AMD. According to schedule 4 Part A of the Constitution (RSA 1996), the following are concurrent powers shared by the national and provincial governments relevant for AMD: agriculture, environment, health services, industrial promotion, pollution control, soil conservation and welfare services. In Part B the following are relevant municipal competencies: municipal planning, health services, and water and sanitation services limited to potable water supply and domestic waste-water systems.

Provincial government should be responsible for establishing a detailed inventory of all potentially polluting sites within their jurisdiction and for developing hazardous waste management plans. These plans should include waste reduction, recycling and reuse initiatives for both industrial and mining waste.

However, national government remains responsible for overriding provincial or municipal authorities where it becomes of necessity to 'maintain national security, economic unity, essential national standards, the provision of 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' (Adler et al. 2007, p. 36).

The national government's responsibility towards AMD is exercised mainly by the DWA (now called the Department of Water and Sanitation [DWS]) and DMR. Before 2009, the DWS also included environmental affairs. The DWS is supported by the Trans Caledon Tunnel Authority, which is directly involved in the Central Basin but which is primarily responsible for managing the Lesotho Highlands Water Project. National government established the IMC in 2010 to coordinate the government's policy on AMD. The IMC receives support from a wide-ranging spectrum of research bodies. In the search for alternative long-term solutions, the DST also plays a supportive role.

At provincial level, the DMR plays an equally important part in monitoring and managing the AMD threat in the Vaal River system. As a parastatal, the Rand Water Board is the main water-providing body in the area of this book.

Several NGOs are actively engaged in the AMD field. Best known is the FSE headed by Mariette Liefferink. Earthlife Africa also has a monitoring project on AMD. NGOs follow their own specific approaches to the matter. Some concentrate on public awareness and use the media extensively or stage demonstrations and protests. Some use the courts for interdicts or judgments against mining companies to influence mining practices or water spillages. Some activists, such as Liefferink, also serve on government-appointed bodies and can, therefore, influence decision-making processes. According to Peter Mills, when asked about the role of NGOs and if he believed that they were making a contribution in assisting with the issues of AMD, he said that activists such as Mariette Liefferink have contributed and the water was cleaner now in places that were seriously affected (Peter Mills, personal communication, 20 February 2013).

The media plays an important part in shaping public opinion about the current state of AMD. Specialised media such as *Mining Weekly* or *MiningNe.ws* report on the technical and policy aspects of the issue but, so far, have paid very little attention to the socio-economic impacts. The general media such as *The Sunday Times* make use of the comments of environmental activists or researchers, and, as a result, the socio-economic aspects are more prominent. Social media are increasingly used and Anthony Turton's Facebook page is a good example of such use.

Stephinah Mudau from the Chamber of Mines (personal communication, 19 March 2013) mentioned that the ongoing media reports on AMD were slightly over-exaggerated and nonfactual and that they were not based on scientific evidence. She said that there were short- and medium-term actions and that companies were doing their work and trying their best to address this issue.

The business sector is one of the most important stakeholders in the AMD issue. It includes the mining companies, and most of them are also members of the Chamber of Mines. It also includes companies that are both involved in mining and rehabilitation such as Mintails. Associated with this sector are consultants and researchers such as Anthony Turton and specialists such as Peter Mills of the Cradle of Humankind or interest representatives such as AgriSA. In the next section, the focus is especially on the mining sector.

4.7 The Mining Industry and Acid Mine Drainage

'There are 3000–4000 new mining operations taking place, but, how can we mine when there is no water' (Liefferink 2013; Mariette Liefferink, personal communication, 4 April 2013). This statement depicts the reality of issues that surround the AMD debates. The effects that it has on the environment and on surrounding communities can be immense if not addressed in time. This will have an overall impact on aims to ensure a sustainable future. Kelly (personal communication, 6 March 2013) has similar views. He stated that 'where there is mining, there is AMD'. He added that where there was mining activity, human beings would always be involved. This meant that mining activities would always have some impact on people and the environment.

According to Liefferink (personal communication, 4 April 2013), the legacy of gold mining is that the mining companies do not include post-closure costs to their budgets but only the costs and impacts while mining is still in operation. Kelly (personal communication, 6 March 2013) of the DMR and Mudau (personal communication, 19 March 2013) of the Chamber of Mines are of the same view when it comes to this issue. They both believe that the issues that have stemmed from AMD are due to the legacy of mining, but the problem lies in solving it today and who is responsible for the financial costs of this lengthy process. Liefferink estimated that about R2.2 billion would be needed to fund the AMD issue. She further stated (in Solomons 2015, p. 2) that the government is addressing the flooding of the basins which is a 'reactionary approach to the problem instead of addressing the root causes of AMD'; by this she refers to tailings dams, polluted wetlands and waste-rock dumps. However, from possible policy amendments (this will be discussed in Sect. 5.6), this proves to be different based on current and future practices, as it seems that government is moving towards a proactive approach to address the problem, as the general understanding is that a proactive approach will address the long-term issues of AMD and propose long-term solutions instead of concentrating mainly on the pumping of acid mine water solution in the short-term or reactionary approach (Matthews 2016).

The Chamber of Mines as the representative of most gold mines exists to 'serve its members and promote their interests in the South African mining industry' (Chamber of Mines of South Africa 2008). The vision of the Chamber of Mines is 'to achieve a policy, legislative and governance framework, which is widely supported and which will allow the mining industry to convert as great a part of the country's abundant mineral resources into wealth for the benefit of South Africa' (Chamber of Mines of South Africa 2008). On the question of how the Chamber of Mines was involved in the AMD issue and what its role was with regard to a way forward, Mudau (19 March 2013) stated that the chamber served in government structures and there had been discussions about short- and medium-term solutions to AMD, while others had invested money in managing and pumping AMD water. Various mines had also made contributions, for example, Rand Uranium mine in the Western Basin. Mudau was asked to provide the chamber's view on the issues of AMD, and she responded by saying that she believed that AMD was a legacy issue for the mining sector and should, therefore, be viewed from a legacy perspective. The best practice guidelines are in place, robust legislation is in place and government programmes are in place as well as feasible solutions to determine AMD problems.

Govender (personal communication, 25 February 2013) stated that mining industries dated back to the 1800s and that mining has been going on for over 100 years. He agreed that it tended to be a legacy issue that the government and the people faced. During the same time periods of active mining, water flowed into the mine system naturally.

Mudau (personal communication, 19 March 2013) emphasised the important contribution that the mining industry made to the South African economy and the GDP, and she did not believe that AMD limited this contribution. According to her, significant financial resources had been used to limit the impact and deal with the issues of AMD. However, she was of the view that mining companies had to be more careful if they were operating from a legacy perspective. Mines would now have to have a new approach to mining and there were laws with which they had to comply; for example, mining companies have to conduct an environmental impact assessment (EIA), as well as compliance monitoring. Social and labour plans are also in place. She also mentioned that mines were now bound by social, environmental and economic responsibilities and were becoming more sensitive to environmental standards.

One of the most sensitive issues in the AMD debate is about who must take responsibility for the costs of AMD treatment and mine water management in general. What is the responsibility of the current and former mining companies? The procedures regarding the rules and regulations of mine closure are now vital, and new mining companies will have more measures to implement and responsibility with regard to the environment than previously. Mudau pointed out that there were different processes to mine closure now and that they started at the pre-feasibility stage but evolved over different stages of the life cycle of the mine. Section 4.3 of the MPRDA outlines the closure process of a mine, including 'issuing a closure certificate' (Stephinah Mudau, personal communication, 19 March 2013).

Mudau also reiterated that the National Water Act, 1998 (Act 36 of 1998) (NWA), and MRPDA (Act 28 of 2002) had the necessary safeguards in place that indicated to mining companies the correct procedures and regulations that they should follow. Mudau believes that sustainable development was already being promoted by the Chamber of Mines and that mines could not be granted a licence if sustainable development was not respected and promoted.

All interviewees were asked what the approach should be in cases where mines were abandoned, closed or mining companies were liquidated, while AMD from these mines contributed to the overall mine water problem and environmental pollution and degradation. Mudau responded that the DWA should enforce the law and intervene if there were companies that did not comply with it.

Referring to several media reports in 2013 that stated that the DWA would take legal measures to ensure that the mining companies that were or are responsible for AMD would take ownership of the problem, Mudau's response about its feasibility was that she did not know how it would be enforced or how the DWA would identify the responsible entities. In the past, according to her, there were better ways of dealing with legacies instead of 'chasing after companies' (Stephinah Mudau, personal communication, 19 March 2013). The fact remains that the majority of the mining companies responsible for the environmental damage caused by AMD were liquidated and no longer existed. How would these companies then be made liable for the damage? Mudau was of the opinion that it would become a task of the DWA, because 'it is not legally possible' to make the companies liable. At the same time, according to Mudau (personal communication, 19 March 2013), the functional companies that were responsible for environmental pollution or degradation must pay according to what was stipulated in the NWA.

The opinion of Peter Kelly of the DMR (personal communication, 6 March 2013) was that individual mining companies were responsible for protecting individuals in the mine and the safety of workers. Mining companies should also remain responsible for the clean-up of AMD. Kelly also raised the point that the only problem was that many of the mining companies responsible for the pollution were no longer in existence or had been liquidated and could, therefore, not pay for the clean-up. This situation arises from past inadequate mine closure legislation. The current situation is that all new mining companies have to establish in advance a rehabilitation fund as part of their mine closure management plan. Kelly (personal communication, 6 March 2013) also mentioned that despite the fact that they were responsible for the clean-up, they also had a large part to play in the economic growth of the country and are a crucial industry.

The current procedure requires an extensive EIA process that is carried out by mining companies before they can receive a mining licence. Kelly (2013, personal interview) also referred to the rehabilitation fund that all new mines must establish for the mine closure phase. Kelly (personal communication, 6 March 2013) observed, however, that despite these new measures, ‘a community and a mine do not get along well together and people aren’t happy when there is mining activities that takes place where they live’.

4.8 Conclusion

Various aspects of AMD were discussed in this chapter in order to develop a broad overview or perspective of what the current state of affairs regarding AMD in the Vaal River system is. The chapter presented the argument that such a perspective depends on how AMD is defined.

The first conclusion reached in this chapter is that two broad categories of definitions emerged from the research: one that concentrates almost exclusively on the underground mine water that is rising to the surface, and then becoming acidic and rich in sulphate salts, and the other category of definitions extends the first to include also acidic and radioactive water formed by surface interactions between acid rain and the mine dust on the tailing dams. The fact that the latter category is presented as an integral part of AMD is one of the most important conclusions of this book.

Conclusions about the current status of AMD in the three basins, mainly based on the first category of definitions, are the following.

AMD first appeared in the Western Basin in 2002. It breached the ECL and affected the Krugersdorp Nature Reserve and the Tweelopiespruit. The problem in this basin still persists. It also reached the Cradle of Humankind but so far has had a limited impact on the cave fossils and, therefore, on the tourism activities. Pumping of mine water is concentrated at the Rand Uranium mine, and the water is treated. The quality of this treated water is a bone of contention among the different role players. All of them agree that it is not yet suitable for human use but some refer to improved aquatic life, while others are concerned about the water coming from the mine residue areas.

In the Central Basin, the predictions about decanting in the Johannesburg CBD did not materialise, and predictions about its impact on Gold Reef City also vary. No surface decanting was present in this basin, and a huge pumping project by the TCTA was in progress in Germiston which will contain the water levels below the ECL.

The Eastern basin was the cause for most concern, mainly because of the uncertain future of the Grootvlei mine in Springs. It is also the basin with the biggest volume of mine water to be contained. The main pumping activity is planned to take place at the No. 3 shaft but the Grootvlei mine-ownership situation must first be resolved. The first decanting was predicted for November 2014. At the time of writing this chapter, a plant was built in the Eastern Basin, which is said to be completed in mid-2016; this plant will treat acid mine water to keep the water below the ECL.

In conclusion, depending on the AMD definition applied in the assessment, the underground mine water situation appears to be relatively under control, but the water treated in the process is not yet suitable for human use. However, once the second category of definitions is applied, a completely different situation materialises, because many tailing dams or other mine residue areas are still in existence and pose a major threat to the quality of water in most of the river systems associated with the Vaal River. They cause additional types of water contamination and the response to them forms part of the discussion in the next chapter.

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Chapter 5
The Policy Response to Acid Mine Drainage in the Gold-Mining Sector

5.1 Introduction

In Chap. 4, the nature of the Vaal River system and the significance of AMD in South Africa were discussed. The situation in each of the basins in the Witwatersrand was explained. AMD is caused by abandoned mines or those that became liquidated and were no longer active and had to shut down their operations. Thus, the problem is not new but one that has been developing and becoming more severe throughout the years, especially since 2002, when there have been cases of harm to the environment. What is transparently evident thus far is that AMD is a concern and the parties concerned, irrespective of who remains responsible at this stage, have to ensure that consistent and adequate clean-up takes place so that the earth's resources can be preserved and the principles of sustainable development are abided by.[1]

The government and the mining industry have established close ties over the years, because the mining industry was an essential sector that contributed significantly to the South African economy. What needs to be appreciated is that without this industry, economic development would be slow in the country and the possibility of it remaining stagnant would, to a certain extent, exist. Thus, the only means to address AMD and to achieve this goal is to focus on a way forward that includes a working relationship between the government and the mining industry. There have always been policies and laws in place to promote a clean and sustainable environment and ways to ensure that it stays this way. However, adherence to such laws and policies cannot always be ensured, and the impending AMD crisis is proof of this.

This chapter concentrates on the views of the government and the measures that have been implemented to address the crisis at hand. Policies and the various processes and possible solutions that are being followed at present are referred to. The Trans Caledon Tunnel Authority (TCTA) and its role in the AMD issue are discussed,

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[1] Parts of this chapter derive from Naidoo, S. 2015. 'An assessment of the impacts of acid mine drainage on socio-economic development in the Witwatersrand: South Africa'. *Environment, Development and Sustainability* journal, Springer 16 (6): 1045–1063.

S. Naidoo, *Acid Mine Drainage in South Africa*, SpringerBriefs in Environmental Science, DOI 10.1007/978-3-319-44435-2_5

as well as the Inter-Ministerial Committee (IMC) expert report and its contents, which include the short- and long-term plans to address AMD in the three basins along the Witwatersrand area. The Gauteng Department of Agriculture and Rural Development (GDARD) is also discussed with regard to its plans and implementation process for addressing AMD. Several government or policy documents are referred to in this chapter that discuss what should be done to mitigate the impending AMD crisis. What is evident in the AMD debate is that solutions are being pushed and 'apportioning blame' to the parties involved is no longer going to address or solve this issue. This chapter also looks at the roles of the private sector, that is, mining companies, and development and environmental consultants, which include civil society, NGOs such as FSE, and activists such as Anthony Turton, who have made immense progress and provides a way forward. These debates are discussed in this chapter.

The discussion is introduced by the existing legislative framework applicable to mining insofar as it deals with water management and its relevance to the different aspects of AMD.

5.2 Policy on Mine Closure and Water Usage

Legacies of mining activities in South Africa are faced with legal and financial responsibility to address the water-related impacts of many abandoned and ownerless mines (DWAF 2008, p. 5). These mining companies have never been required to take on the legal liability for the damages caused (Fig 2011, p. 313). It, however, remains extremely difficult to allocate the proportion of damage for which each mining company is responsible, given the fact that these companies are no longer in existence. Thus, there should be processes that are adhered to when a mine closes, and this should be bound by law. When a mine closes, there should be assurance that the mine has a plan to implement, sustain, protect and preserve the water quality and quantity upstream and downstream of the mine after mine closure and that those who are dependent on that water are identified and protected (DWAF 2008, p. 5). Due to the fact that the responsible mining companies cannot easily be held liable, 'there should be clear demarcations in law about what liabilities the state should assume' (Fig 2011, p. 313).

According to DWAF (2008, p. 6), when a mine closes, there are a few stakeholders who have to be considered and have different objectives with regard to the closure. First is the mine, who wants to close with as little costs as possible and also to prevent post-closure costs. Second is the authorities whose objective is to minimise the exposure to short- and long-term risks which depend on state finance and implementation of a sustainable post-closure land use plan. Third is the communities, who want to preserve a viable socio-economic structure after mine closure and to minimise the environmental impacts and pollution of water resources. Thus, the post-closure risks of mines must be minimised, and the sustainability must be maximised.

So, in actual fact, a mine closure plan must be sustainable over a life cycle of a mine (DWAF 2008, p. 6). Several policies are significant in this research, but AMD has emerged as a serious issue, because these policy stipulations and the legal framework are not practised in reality. The following are important national acts that have some consequences for AMD:

1. The National Water Act (NWA) (Act 36 of 1998)
2. The National Environmental Management Act (NEMA) (Act 107 of 1998)
3. The Minerals and Petroleum Resources Development Act (MRPDA) (Act 28 of 2002).

The NWA, which was administered by Department of Water Affairs and Forestry (now called the DWA) is the principal act that governs water resource management in South Africa. The ‘polluter pays’ principle supports this act and has direct implications for the mining industry which closely relates to AMD. This stipulates that those who are responsible for producing, allowing or causing pollution should be held liable for the costs of clean-up and the legal enforcement.

The act determines that pollution or degradation of the environment must be prevented or resolved. ‘The current perception that mine closure is unachievable needs to be addressed through technical as well as policy guidance. The implications of section 19 of the NWA that a mine be held responsible for its impact on water resources even after achieving certified formal mine closure from the Department of Minerals and Energy (DME), remains the basis for long-term water management employing a risk-based approach’ (Hobbs et al. 2008, p. 428). The lack of action to address the issues of AMD successfully on a timely basis will only harm the process of sustainable development. The TCTA is an important implementation instrument of the NWA and has also become directly involved with the AMD issue. It is a state-owned entity that has been established in terms of government Notice No. 2631 in the *Government Gazette* No. 10545 of December 1986. The notice was then replaced with Government Notice 277 in the *Government Gazette* No. 21017 of March 2000, which was circulated in terms of the NWA (TCTA 2011). The TCTA’s aim is to provide a sustainable water supply in the Southern African region and is directly involved in South Africa’s Lesotho Highlands Water Project. TCTA provides advisory support to the DWA on the AMD project that has been implemented since 2010 (Bashan Govender, personal communication, 25 February 2013).

The NWA states that sustainability and equity are identified as central guiding principles in the protection, use, development, conservation, management and control of water resources. These principles recognise the basic human needs of the present and future generations: the need to protect water resources, the need to promote social and economic development through the use of water and the need to establish suitable institutions in order to achieve the purpose of the act (RSA 1998a). The national government, through the Minister of Water Affairs, is responsible for achieving the principles of this act on behalf of the nation. The minister, thus, has ultimate responsibility for fulfilling certain obligations relating to the use, allocation and protection of, and access to, water resources (RSA 1998a). Section 3, public trusteeship of the nation's water, states the following:

1. 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.
2. Without limiting number 1, the minister is ultimately responsible to ensure that water is allocated equitably and used beneficially in the public interest, while promoting environmental values.
3. The national government, acting through the Minister, has the power to regulate the use, flow, control of all water in the Republic.

Mining legislation in South Africa has existed for many years, and the MPRDA includes very specific requirements for mine closure (RSA 2002).

One of the main objectives of the MPRDA that is related to this research is to give effect to section 24 of the constitution by ensuring that the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner while promoting justifiable social and economic development and ensure that holders of mining and production rights contribute towards the socio-economic development of the areas in which they are operating (RSA 2002).

According to section 3 of the MPRDA (RSA 2002), the state being the custodian of the mineral and petroleum resources, acting through the minister, may:

(a) Grant, issue, refuse, control administer and manage any reconnaissance permission, prospecting right, permission to remove, mining right, mining permit, retention permit, technical co-operation permit, reconnaissance permit, exploration and production right; and
(b) In consultation with the Minister of Finance, determine any levy, any fee or consideration payable in terms of any relevant Act of Parliament.

According to section 39 (3)(b)(i–ii) of the act, which deals with the environmental management programme (EMP) and environmental management plan, an EIA must be conducted within 180 days of the date on which he or she is notified by the regional manager to do so (RSA 2002). An applicant who prepares an environmental management programme or plan must investigate, assess and evaluate the impact of his or her proposed prospecting or mining operations on the environment and the socio-economic conditions of any person who might be directly affected by the mining operation.

According to section 43 (1), issuing a closure certificate, the holder of a mining right remains responsible for any environmental liability, pollution or ecological degradation and the management thereof, until the minister has issued a closure certificate to the holder concerned (RSA 2002). Section 48 (1)(a) of the MPRDA states that closure objectives and how they relate to the mining operation and its environmental and social setting must be included in the environmental management programme (EMP) that is developed during the planning stages of the mining operations (RSA 2002). According to DWAF (2008, p. 18), it is crucial that should there be any decisions regarding closure requirements and whether proper closure processes have been adhered to, it must be done together with government representatives who have the responsibility of protecting the environment, as well as social issues and any other affected parties.

The NEMA contains certain principles in section 2 that are applicable throughout the country to the actions of all organs of state that may affect the environment and will apply together with all other appropriate and relevant considerations, which include the state's responsibility to respect, protect, promote and fulfil the social and economic rights in Chap. 2 of the constitution (RSA 1998b). It must serve as a general framework within which environmental management and implementation plans must be formulated. It must serve as a guideline by reference to which any organ of state must exercise any function when taking any decisions in terms of NEMA or any statutory provision regarding the protection of the environment, and it must serve as principles by reference to which a conciliator under NEMA must make recommendations and, lastly, guide any law concerned with protection or management of the environment (DWAF 2008, pp. 41–42).

These laws and principles have been in the process of being drafted for years, and the legislation that governed the mining sector remained the same, even as changes were made in government departments. The major concern then is why there is such a crisis and why is there so much uncertainty about who is responsible for the clean-up and the extensive costs regarding AMD. The fact remains that irrespective of what the law stipulates and what government's role is as the trustee of natural resources—water and minerals—the problem of AMD and its effect on the water resources and the environment have become a factual reality.

According to Turton (2009), there is no clear policy on mine closure in South Africa that meets both human rights standards set in the constitutional Bill of Rights and the 'polluter pays' principle stated in the NWA. He further adds that the question is still unanswered as to whether mine closure is about mining, water resource management, human health, economic development, legal liability or purely ecological rehabilitation (Turton 2009). Fig (2011, p. 312) states that mining has always been relieved from the impact assessment requirement. Whereas it is compulsory in other industries to obtain an environmental impact assessment for any new projects, in the mining industry, there is an environmental reporting system that is managed by the Department of Mineral Resources, and mining is not open to a more rigorous regulation by the Department of Environmental Affairs. Thus, there is a serious shortfall in these systems, because they only control individual sites and do not examine the accumulated impacts on a region of new development (Fig 2011, p. 312).

5.3 Governance

A common perception is that the water crisis that is experienced worldwide today is 'largely a governance crisis' (Braune et al. 2014, p. 4). The issue of securing water does not only stem from water quantity, quality, supply and demand and financing but also from the strife towards good governance.

To understand the extent and the possible consequences of the issue of AMD and of regulating pollution caused by the mining industry, according to Fig (2011, p. 311), one needs to question whether the people of South Africa have been treated fairly by the government's current legislation and administrative practices. The prime issue—that was also mentioned in Chap. 3 about the relationship between the mining industry and government—is that for over a century, the economy has placed most emphasis on the mining industry and put it at the forefront, even allowing environmental and public health protection costs to be made the responsibility of the taxpayer or the state (Fig 2011, p. 311). The state had not addressed the environmental impacts of the mining industry during the apartheid years. Even though current mine owners are placed under tremendous pressure, the mine owners who must take most of the responsibility are those who profited from South African gold and uranium during the 'boom years' of mining (Fig 2011, p. 311). The ownership benefits for mining companies were great during the productive cycle of gold mining, and those companies should take the primary responsibility today for the environmental impact (Fig 2011, p. 311).

According to Fig (2011, p. 312) post-apartheid governments had observed a common interest between the political elite and the mining industry, and instead of pushing for a balance between growing the economy and protecting the environment, the new laws try to magnify opportunities for new entrants in the mining industry to address the racial economic inequalities of the past, with environmental protection being a barrier to these opportunities.

Being aware of the evolution of water governance and AMD management in South Africa allows one to understand the problem that the state faces in being able to manage liabilities and successfully implement new legislation. According to Hobbs et al. (2008, p. 422), in the cases of mines that closed in the period 1976–1986, the state and the mine owners have to share the responsibility of the post-mine closure costs. However, in the case of the mines that closed after 1986, their owners would remain responsible for all post-mine closure costs. Thus, mine owners had to comply with the EMP for mines that were closed, taking into account the effects that their mining activities have had on the environment (Hobbs et al. 2008, p. 422).

Interviews were conducted with people who are directly involved with some of the stakeholders to determine their views about governance matters. As a representative body of the mine companies, the Chamber of Mines is a key role player in ensuring that the mining sector is properly governed. Mudau (Stephinah Mudau, personal communication, 19 March 2013) said that the Chamber of Mines did not allow mines to be granted a licence if the mine was not sustainable or justifiable. She said that the laws that were now in place made that industry sustainable and that the Chamber was already promoting sustainable development in all its operations.

Peter Kelly from the DMR (personal communication, 6 March 2013) is of the opinion that government should support the mining industry, but if it could not do so and mines did not have a big enough rehabilitation fund, then the government should assist. According to Fig (2011, p. 313), DMR should oversee post-closure plans of all mine owners and the state through the IMC, or the DMR should form a larger fund for addressing the problem of AMD.

Bashan Govender from the DWA (personal comunication, 25 February 2013) stated there was a twofold governance approach to how the state had reacted to AMD. The first was that mining companies were accountable and should solve the problems of AMD on their own. The second approach was that government has, since 2002, been the custodian of water resources and water in South Africa, and, therefore, water resources could not be owned by any individual person. He added that water in this country belonged to the state and therefore to the people of South Africa. The government was just the caretaker on behalf of the state and had to protect the water resources and should intervene to deal with AMD in keeping the water clean. In accordance with the NWA, the minister had to take responsibility to ensure protection of, and access to, water resources (RSA 1998a). Govender added that this was what the DWA had done, but private companies had also exhausted the wealth in the country and had a huge role to play in assisting to address the clean-up of AMD. Govender stressed that the DWA was strongly considering how the mining sector would take responsibility, keeping in mind that this was a legal process and would result in a lengthy time frame (Bashan Govender, personal communication, 25 February 2013).

The 'blame-seeking' debates tend to form constant discussions and constant media reports as to who is responsible for this and how action will be taken to ensure the responsible party is brought to justice. An article that appeared in *Times Live* online (Mouton 2013) states that 'DWA will lay criminal charges against all mining companies—new and old—that may be responsible for AMD problem in Gauteng. At the time, the department apparently drew up an "urgent report" which was meant to be submitted to the Minister of Water Affairs, Edna Molewa (now called Water and Sanitation, Minister Nomvula Mokoyane) which will include a plan of action'. According to this article, DWA is going to try and trace the ownership of the mines since the 1940s and to determine who is responsible for polluting the water in the area and how they can be held liable.

Turton indicates that a wide range of technologies have been tested, and this allows for a robust choice to be made with a different set of cost–benefit options that are defendable to the wary public who pays tax (Kolver 2013). He says that there are two distinct business models. The first is the state option whereby the taxpaying public will be contributing towards the bill which includes the cost for neutralisation of AMD using the high-density sludge (HDS) technology. The second option is the polluter pays principle option, which is one-third of the cost, while the mining industry will consolidate tailings facilities and bring mine-impacted land back into safe public use over the next 20 years (Kolver 2013).

With the government trying to bring the mining sector to the forefront and ensure legal steps are taken so that the industry can pay for the clean-up of the damages that have been caused, much confusion exists in South Africa with regard to the roles and responsibilities between the government departments and who should take on what roles. In the past, confusion existed between the Department of Mineral and Energy (now called the Department of Mineral Resources) and the Department of Environmental Affairs (DEA) with regard to management of mining waste. Both these departments have emphasised the specific requirements on mines before a closure certificate is granted, and the main requirement is a compulsory environmental management plan. Cooperative governance has not been very effective in protecting the environment against the negative impacts of mining waste (Oelofse et al. 2007, p. 7). Peter Kelly from the Department of Mineral Resources (2013, personal interview) does not see AMD as an impending crisis. He added that DWA was taking the lead in addressing AMD and the team had developed a strong enough voice but at times did not get through to the people who had a strong enough voice.

At this stage the most pertinent governance issue in relation to AMD is therefore to determine who must take responsibility for the management and cost implications of all the post-closure problems, of which AMD is an important, but not the only, component. Moreover, in view of the latest experiences with AMD, governance in the form of preventive measures are becoming increasingly important, in the form of EIAs and budgeting for eventual mine closures.

5.3.1 Possible Treatment Technologies and Problems at This Point

Thus far, no permanent or sustainable solution to the problem of AMD has been found. Neither has adequate monitoring procedures to the problem been introduced. Workable measures were not taken initially when the AMD problem first developed and in some instances have still not been carried out. A lack of resources is sometimes blamed for an inadequate response to groundwater in South Africa (Cobbing 2008, p. 456).

According to Cobbing (2008, p. 457), South African legislation governing the pollution of water and the environment is both comprehensive and clear in the legal obligation to curb and remediate such pollution. It is true that the legislation is relatively new, but the obligation to act in a precautionary manner even where a pollution problem may not be fully understood remains. While South African government has been accused of dragging its feet when it comes to enforcing compliance by the mining industry with the new environmental standards, in the experience of the author, South African government departments have allocated considerable time and resources over several years to try to resolve the Western Basin AMD problem.

Thus, it is argued that a shortage of skilled personnel, money or official sanction in the form of legislation seems not to have been limiting factors in addressing AMD in the Western Basin, where it first appeared in 2002. The absence of a 'comprehensive hydrological response' and the time it took to implement partial solutions tend to be more than just a problem of shortage of skills and resources (Cobbing 2008, p. 458).

The following are possible reasons for these problems as identified by Cobbing (2008, p. 458):

> The relatively low profile of groundwater in South Africa – this is the case because almost two-thirds of the country's population depends on this resource for their domestic water needs. The privatisation of water data – a large part of South Africa's leading groundwater lies outside of large, state-affiliated organisations and a large part of this work is contracted

> out by the state to the private sector. The lack of specific expertise at the decision-maker level – many of the efforts that are set out to address the Western basin have been managed by individuals with specific expertise in groundwater. There are cases where expertise exist, however project coordination and the correct input to mitigate the problem are lacking. Inadequate links between South African organisations – for addressing problems such as the AMD in the Western basin relies on high levels of cooperation between stakeholders but such cooperation is not yet apparent in this particular case. A reluctance to make use of international expertise or knowledge – management of water resources can be better facilitated in southern Africa if it is understood as an active dialogue between groups known as "Actor Clusters".

Cobbing's proposal suggested that each cluster could be subdivided into three main elements. The clusters are as follows:

1. The state authorities—legislature, executive and judiciary
2. Society—the civil society, the economy and the natural environment
3. Science—natural sciences, social sciences and tertiary educational institutions which provide human capital (2008, p. 458).

These clusters should 'act in direct equilibrium with each other' (Cobbing 2008, p. 459). This means that project managers need to focus on collaboration and communication with other stakeholders in order for a process to go accordingly. The government needs to ensure that they use the technical and scientific understanding that is available in formulating policy (Cobbing 2008, p. 460). The business and mining community must have clear signals and guidelines that are necessary both from government and from specialist scientists to facilitate long-term planning.

According to Govender (personal communication, 25 February 2013), the government's approach to the Western Basin was not ideal, but the DWA was trying to ensure that the harmful metals were pulled out by reducing the iron concentration and reducing it to drinking water standards. He added that it would make sense to treat the water in the Western Basin to drinkable water standards if there was a community that could benefit from this, as it would be costly to do so otherwise for no purpose. He said the department has realised that there was an environmental impact of water that had a low pH and high iron sulphate, and this was affecting the ecosystem. The department was convinced that it had to contribute a significant amount of input; otherwise, it would negatively affect the aquatic life in the water systems. He stated that this was the same principle used in the Central Basin where the rising water levels in the mines had increased seismic activities around Johannesburg. The department was convinced that it could not allow seismic activity to increase:

> We recognise the challenge of AMD, we recognise what we are doing just to manage the programme in the short-term approach but we also recognise that this is a water-stress country, water down is a substantial amount that could be used to augment water supply. The Vaal River system is in high demand for industry and agriculture, so we should see this as an opportunity and not a threat. In 2012 a feasibility study was done, in 2013 we had the approval to build it up, so there are short-term interventions for how and what they will treat this water with. (Govender 2013, personal interview)

Govender (2013, personal interview) further added that 'if it means that we have to bring the water to a standard where we treat it and drink this water, then the taxpayer will have to pay'. DWS wants the affected municipalities (Joburg, Ekurhuleni and Tshwane, Mogale) to increase their tariffs for the contaminated water that is flowing into the Vaal River. According to The Star (Cox 2014, p. 5), 'Gauteng ratepayers are being asked to foot an R11.2 billion bill to purify acid mine drainage water contaminated by the mining industry—but the City of Joburg is reluctant to increase tariffs to pay for it'.

The Strategy Steering Committee of the Vaal River Reconciliation Strategy considered two options: (1) the limited treatment option and (2) the desalination and reuse option. The limited treatment option supposes that the water from the East, West and Central Rand mining basins will be pumped to the surface and neutralised. The water will then be discharged to one of the Vaal River tributaries and will flow into the Vaal Barrage (Van Wyk et al. 2010, p. 4). Shanna Nienaber from the DST, formerly from the CSIR (personal communication, 12 March 2013), explained how the water was neutralised and put into the Vaal Barrage. If AMD entered the Vaal River system, it would be detrimental. The DWA have been careful that this would not be the case, 'it is one vicious cycle, the problem came through mining and legislation of government at the time and now we have inherited this problem, that is why we are trying to get the mining sector involved and identify how they can assist with this problem' (Bashan Govender, personal communication, 25 February 2013).

The second option also supposes the same process, but once desalinated, it will possibly be used for industrial purposes or as drinking water in Gauteng (Van Wyk et al. 2010, p. 5). It is evident that when this strategy was planned in 2010, it was concluded that despite this being a possible process, only to neutralise the AMD and then release it into the Vaal River, it would lead to future complications for the system. From the fieldwork that was conducted, with the various interviewees, feedback on short-term solutions was discussed. Peter Kelly (personal communication, 6 March 2013) and Bashan Govender (personal communication, 25 February 2013) explained the treatment that was currently taking place and the plans for the basins that were not yet affected.

Shanna Nienaber from the DST (personal communication, 12 March 2013) discussed the short- and long-term solutions to AMD. The information she provided comes from the IMC report. The short-term solution includes that of a high-density sludge management (HDSM) process; this is a partial neutralisation process where lime is added to the water and the water that is released has a lower metal load. She explained, however, that this did not mean that the water was clean; it could still have high salt levels. The long-term solution included looking at all possible options. This included how the problem would be managed, how the water would be purified and at what levels the water would be purified, would this be at a drinking water level or an ecosystem health criteria quality and, lastly, what technologies would be used to do this (Shanna Nienaber, personal communication, 12 March 2013). In 2016, a newspaper article reported on the same process; according to Mariette Liefferink (in Matthews 2016), the TCTA is currently using high-density sludge treatment (HDST), and it is treating the water on an average of 100 Ml/d of AMD in the Western and Central basins, and a 'similar amount of untreated water is flowing into the environment'. Essentially, this treatment method changes the acidity of the water by solidifying the heavy minerals found in it; however, if the acid levels rises again, then the heavy metals will return to a soluble form.

Nienaber stated that three coalitions had emerged around the question of how to address AMD. The first was the dominant coalition which was comprised of government departments—DWA, DMR and DST—and their approach was to 'play it safe'. From 2010 until now, their viewpoint was that they could no longer wait and that they had to act in the short term. Based mainly on the recommendations of the IMC, they commenced with pumping of underground mine water and high-density sludge management or chemical treatment of the acid water as an immediate short-term solution. The long-term technological solutions were still investigated by advisory private companies such as Aurecon (discussed in Sect. 5.4) and a group of scientists who were co-opted to assist the government with its decision-making. The second coalition promoted the view to 'do nothing', because they were convinced that the water would eventually neutralise itself. The third coalition included those who said 'hang on, let's talk about it'. It consisted of NGOs and the scientists excluded from the government group. They felt that the IMC was an exclusive process and that they could have had some ideas to assist in finding solutions and should have been included (Shanna Nienaber, personal communication, 12 March 2013).

In November 2008, the DWA held a meeting which discussed a way forward in managing AMD and which brought about the IMC (Shanna Nienaber, personal communication, 12 March 2013).

5.3.2 Inter-Ministerial Committee on Acid Mine Drainage

5.3.2.1 The Committee's Expert Report

The IMC report of 2010 prepared by a team of experts working in a wide spectrum of disciplines relevant to understanding the nature and implications of AMD serves as a vital and crucial source of information for this book. A team of experts that included director generals of the departments of Mineral Resources and Water Affairs were selected to advise the IMC, which also included the ministers of Mineral Resources, Water Affairs and Science and Technology, the Minister in the Presidency and the National Planning Commission. Their focus was on AMD in the Witwatersrand goldfields (Coetzee et al. 2010, p. 2). The DWA received funds from the National Treasury for the purpose of implementing measures to pump underground mine water to prevent it from reaching the ECLs, to neutralise and remove metals from AMD and to initiate a feasibility study to address the medium- to-long-term solutions (DWA 2012, pp. 1–2).

This expert report referred to international and local research literature on all aspects of AMD which include its formation, control, management, treatment and impacts (Coetzee et al. 2010, p. 2). The report concluded that there was thus an overall understanding of the AMD issues in South Africa. The experts' view was, therefore, that there is ample information available to make decisions that relate to mine water, its potential impacts, management strategies and treatment technologies in the Witwatersrand goldfields. The issue of AMD is said to have an impact in a number of areas in South Africa. These include the Witwatersrand goldfields, Mpumalanga (Carolina), KwaZulu-Natal coalfields and the Okiep copper district. The Western, Eastern and Central basins of the Vaal River system are regarded as the main areas of concern. These areas are said to require immediate action because sufficient measures had not been taken to manage and control the problem. The Mpumalanga coalfields have been noted as a vulnerable area where the impact of mining on the freshwater sources in the upper reaches of the Vaal and Olifants river systems is of serious concern. The severity of the environmental impact in other mining areas of the country needs more information such as monitoring and assessment of risks (Coetzee et al. 2010, p. 8).

Several risks related to the flooding of the mines in the priority areas and the subsequent decant of AMD to the environment have been highlighted. These risks include risks resulting from flooding of the mines and risks due to decant of AMD to the environment. An approach has been adopted to manage these risks in the priority areas. The approach includes decant prevention and management, reducing the rate of flooding and the eventual decant volume (reducing the volume of water to be pumped and treated) and water quality management (there is a different technology to deal with this) (Coetzee et al. 2010, p. 37).

During the interviews conducted with the participants, they were asked how they viewed the IMC report and whether this report was sufficient to deal with the extent of the AMD issues. They had various responses. Peter Mills from the Cradle of Humankind management authority believes that the IMC addressed a small field of AMD (Peter Mills, personal communication, 20 February 2013). Bashan Govender from the DWA mentioned that in late 2010 the entire DWA was informed by its minister about the impending AMD crisis and that is how the IMC came about (personal communication, 25 February 2013). In 2011 the recommendations stipulated in the report were accepted by the cabinet as government policy, which consists mainly of pumping of the mine water and its initial treatment (i.e. sludge management). Govender regarded it as sufficient, although it does not mean that the water is already appropriate for human use.

According to Nienaber (personal communication, 12 March 2013), people who have worked on the IMC report had the best intentions, are highly qualified and have a very detailed understanding of the situation. However, when compiling the report, they were constrained by time, and as the technical experts on the issue, they may not have recorded the thought processes that underlie the recommendations. Nienaber observed that the NGOs were not part of the IMC or the technical task team and that they had much criticism. They believed that high-density sludge management, for instance, was not a solution, because the treated water was not purified. However, the response from the team members was that something had to be done rather than nothing at the time. According to Nienaber, there was thus miscommunication between the IMC and their task team and the rest of society.

5.3.2.2 The Options Identified in the Report

When the report was compiled in 2010, the status situations in the three basins were as follows: the Western Basin was fully flooded above the ECL and has been decanted to the surface since 2002. In the Central Basin, pumping had ceased at most of the mines, and the water level in the basin was rising. In the Eastern basin, pumping was taking place only in the Grootvlei mine (until 2011) so that the water could be maintained at around 700 m below surface. In response to this situation, the report identified four objectives, namely, (1) management of flooding and/or decant, (2) ingress management, (3) water treatment and (4) monitoring. Options were identified under each objective. A discussion of these options follows, as well as their advantages and disadvantages. All four objectives are derived from the IMC report and are taken from Coetzee et al. (2010, pp. 55–61).

The first objective is to manage the flooding and/or decant of the basins. The first option was to pump water and to keep it well below the ECL. This option could ensure environmental protection, but it would be financially costly. The second option was to pump water from a level shallower than the ECL and, therefore, closer to the surface. This could lower the cost of pumping but would more likely place the environment at risk. The third option was to allow the decant in areas where younger surficial cover rocks acted as a seal above the mine void, which would avoid pumping costs. However, this option could lead to seepage and secondary decant points developing; water could rise into dolomitic layers causing groundwater contamination and sinkhole formation, and it does not allow for seasonal balancing of volume for water treatment. The fourth option was to construct a tunnel to create an artificial decant channel. It would not involve pumping costs and would ensure that the decant occurred in a controlled process. However, capital costs of the tunnel would be high, the environment would not be fully protected unless the tunnel could be constructed below the ECL, and it did not allow seasonal balancing of water treatment volumes. It would also involve long-term maintenance costs, and there was a risk of tunnel failure. The fifth option was to provide a tunnel to a remote pumping station to reduce pumping costs. This would allow for the location of the abstraction point for water according to the optimal location for a treatment plant but would limit access to the underground workings and complicate construction. It did not remove the requirement to pump water. Given the focus of this book, one can conclude that the options stipulated under this objective fail to highlight the human element and the impact that AMD can have on socio-economic development if this option were to be implemented. If costs are lowered, then the environment stands the chance of being at risk, the actual risks to the environment are also not indicated. The impact that this will have on people and communities that live in surrounding areas are not discussed, nor are the health implications that could stem from the decant (Coetzee et al. 2010, pp. 55–56).

The second objective is ingress management to prevent mines from being filled by surface water. The first option was to seal the areas of surface ingress such as riverbeds and old mine workings, for instance. This option can reduce the long-term water management costs, lower the water volumes and may result in more options for management and for some of the projects being implemented by mines. The disadvantage of this option is that some of the projects may require high capital costs. The second option is to abstract clean water from overlying aquifers before it enters the mine void. This option can keep water clean, reduce ingress and provide a source of clean water to local users. However, it will need to be adequately managed in dolomitic areas to prevent subsidence. This objective gives the option to have clean water, but whether it is of drinkable quality is not indicated. Households need water for hygienic purposes but also for drinking and cooking purposes. There are many users that need access to clean water, such as the tourism sector, Eskom for electricity and agriculture. Thus, clean water can be used and needed for various crucial purposes (Coetzee et al. 2010, p. 57).

The third objective is water treatment. The first option is to neutralise and remove the iron. This is the lowest-cost option. It can remove the heavy metals and can be implemented within a short period. The pretreatment stage is necessary for the most advanced treatment methods, and it can return conditions to those that existed during active mining. However, this option does not fully address the problem of salinity, and the treated water will not be suitable for all the users who need water, be it at household level, for tourism, agriculture or business. Furthermore, this option will require facilities for sludge disposal. The second option is desalination. This option is proven with a limited number of commercial biological sulphate removal, membrane treatment and chemical precipitation plants. It produces clean water that can be used for any purpose, including for drinking. The salts can be removed completely from the river system, and it may produce saleable by-products that could offset some or all the costs. However, there will clearly be high capital and operating costs involved, and not all the technologies have been tested fully. The membrane processes can have high costs, and there will be a need for waste management (Coetzee et al. 2010, pp. 57–58).

The third option is to discharge water without treatment. This will not cost anything, but there will be serious effects on the downstream environment, and this will increase salinity of downstream river systems. One can predict that this option does not account for the human element. A large number of people who depend on this water for their own use or those living in the surrounding areas will experience the effects of the polluted water, such as health implications. The fourth option is in situ treatment which does not require a fixed plant, and relatively clean water can be abstracted from the mine void. Active and ongoing operational personnel will be required, but permanent presence on-site is not required. This option will require chemicals, operations staff, intermittent field maintenance, electrical power and low-frequency monitoring. However, it will also require a system with good mixing characteristics and enough points of access to the void water, which is not the case in the Witwatersrand mines. There will also be relatively inefficient mixing, which requires large input of reagents. The fifth option is for passive treatment, especially the use of natural wetlands through which the polluted water must move and be filtrated. This is seen as a low-cost option and moderate capital investment with periodic reinvestment to replace depleted wetlands media. It is a self-sustaining process that requires periodic maintenance and intermittent monitoring. This may require replacement or supplement of materials at low frequency. The natural energy sources of gravity flow, solar and bio-chemical energy, can be utilised, and it will require little intervention. However, this option creates contaminated areas in treatment systems and is generally regarded as being unsuitable for the large volumes and poor quality of the water expected from the Witwatersrand. It will require extensive monitoring to evaluate success and an additional carbon energy source for bacterial processes. The treated water will be of poorer quality and be more variable than the other options (Coetzee et al. 2010, pp. 58–61).

The fourth and last objective is monitoring. The first option is for no monitoring to take place, and this has low costs, but there will be no way to evaluate the improving or deteriorating conditions and no early warning information will be available. The second option is to maintain the current monitoring regime. It will involve no extra costs but the current regime has proven to be inadequate to assess the extent and degree of problems, and there will be no early warning capacity. The third option is improved monitoring systems that will allow the assessment of problems and solutions and will provide early warning capabilities. The disadvantage is that it will mean higher costs, and additional strain will be placed on resources unless monitoring activities are well sourced (Coetzee et al. 2010, p. 61).

An evaluation of the objectives and options identified in the IMC report to address the water treatment in the Witwatersrand area shows that the report did not use sustainable development considerations as one of its criteria for determining the approach to AMD. In the process of considering all the options, their advantages and disadvantages were identified in a technical and financial sense, but they did not include that of preserving water as a natural resource for human use and tend to only look at how to address the issue in the short term. The possible risks to the environment are indicated under some of the options, but these risks are not discussed in detail as to their possible impact on the environment. The socio-economic impacts are completely absent from the identified disadvantages.

In Chap. 6 of this book, the socio-economic impacts are discussed in detail. However, for the purpose of illustrating why the failure of the IMC report to highlight them is so important, some of the health implications are mentioned here. Mariette Liefferink is an activist who tends to focus more on the social impacts of AMD, and how it affects people and their health. She also looks at the environment and believes that the damage caused could be irreversible. According to her, all wetlands in the Witwatersrand contain heavy metal contaminants. Leukaemia is one of the health impacts that are known to arise from this (Mariette Liefferink, personal communication, 4 April 2013). The health impacts of uranium particles being inhaled can have a detrimental impact on human beings. Highly soluble uranium compounds may remain in the alveoli. On the one hand, soluble uranium compounds dissolve and pass across the alveolar membranes into the bloodstream, where they may exert systemic toxic effects, while, on the other hand, insoluble particles may form in the lungs for years and can cause chronic radiotoxicity expressed in the alveoli.

After the IMC expert report, in 2011, a multidisciplinary team was requested to undertake a feasibility study of the technical options in the report for the long-term management of AMD. The team had to make a careful assessment and integrate all possibilities for the use or discharge of raw, neutralised or desalinated AMD that would meet the objective of reducing the salt load in the Vaal River system to acceptable levels and that would not have an unacceptable social or environmental impact (DWA 2012, p. 7). The concern is that this assessment and integration of options were not included in the IMC report.

5.3.2.3 Recommendations Made by the Expert Report

In the IMC report, the team of experts included eight recommendations based on the possible options that were discussed in Sect. 5.3.2.2. The team of experts was of the opinion that 'sufficient information exists to be able to make informed decisions regarding the origins of the mine water, potential impacts, management strategies and treatment technologies' (Coetzee et al. 2010, p. 85). These recommendations were adopted as the framework of the government policy on AMD. They are discussed below as they were identified in the IMC report. The recommendations are included here as an indication of the public policy dimensions that should be evaluated in terms of the sustainable development principles discussed in Chap. 3. The discussion relies on Coetzee et al. (2010, pp. 88–92).

The first recommendation was that it would be necessary to pump water from the mine voids in the three basins to prevent decant and to ensure that water levels were maintained at or below the ECLs. In the Western Basin, the ECL was to remain at 150 m below the decant level to ensure protection of the dolomitic groundwater resources in the Cradle of Humankind World Heritage Site. In the Central Basin, the water level had to be maintained at least 150 m below surface at the South West Vertical Shaft in Germiston. It was further recommended that a level of 50 m below this should be maintained in order to protect Gold Reef City which attracts about 3000 tourists per day. Pumping from a deeper level would be necessary to protect the underground resources of interest to newcomers in the mining industry in the affected area. The basis for this was to protect the dolomitic aquifer to the south of Boksburg. In the Eastern basin, the ECL is to be 400 m below surface measured from the likely decant point at Nigel, in order to prevent the rise of the mine water into the overlying dolomitic aquifer (Coetzee et al. 2010, pp. 88–90).

Construction of new pumping infrastructure was recognised as urgent for the Western and Central basins in order to manage the flooding of these basins and to remove the risks associated with the uncontrolled decant of AMD. In the Eastern basin, the pumping was to be maintained to allow access to underground workings. It was added that state assistance must be continued and maintained in the Grootvlei mine. It should be noted that the government's immediate response in 2011, when pumping at Grootvlei was terminated, was that Finance Minister Pravin Gordhan allocated R225 million over a 3-year period in the national budget to deal with AMD, and more than half of it was earmarked for the Grootvlei mine on the Eastern Witwatersrand basin (Mouton 2013).

In the national budget speech in 2012, Pravin Gordhan set aside R422 million for short-term interventions to deal with this problem, with a total of R2.2 billion to solve the AMD problem (Mouton 2013).

The second recommendation was that of ingress control to reduce the rate of mine flooding and the water volumes that had to be managed. Research conducted by the CGS identified areas in the three basins where measures were to be implemented to reduce the ingress of water into the mine void. This will also reduce the volume that needs to be pumped from the mine void and treated. From this water, management costs will be reduced in the medium to long term. In addition to preventing ingress, prospects have been identified in the Eastern basin where clean groundwater that enters the mine void but runs the risk of becoming polluted can be abstracted before it enters the underground workings. It could thus become a source of clean water. The recommendation was made for it to be fully looked into and implemented. To implement ingress prevention measures could take years to complete, because it would include applications for a water use licence and concluding agreements with landowners. Thus, during this period, it would be necessary to pump and treat a larger volume of water than after the measures have been implemented (Coetzee et al. 2010, p. 90).

The third recommendation is water quality management. The report observed that water pumped from the mine voids would at first be of poor quality and would need to be treated before it could be discharged into the river systems or utilised. The treatment could be limited to neutralisation and the removal of metals from the water before discharging it into the river systems. The outcome of this is that it would lead to the same conditions as those established during the period of active mining. This is not a long-term sustainable solution due to the fact that the salt loads in the affected river systems are already high. In the medium to long term, removal of the saline mine water from the river systems must be taken into consideration as a reduction of the pollution source. In the extreme long term, according to the report, it is possible for the water quality in the mine void to improve as oxygen is not included from the flooded voids, and contaminants that are present are flushed from the system. If this is the case, water levels may be allowed to recover to their natural levels, as long as this does not lead to uncontrolled flooding issues or unintended geotechnical impacts (Coetzee et al. 2010, p. 90).

The fourth recommendation was about monitoring. The success of the suggested programme can only be verified through a detailed monitoring of the water in the mine voids and the affected environments. The investigations conducted when identifying treatment options have also found several shortcomings in the present monitoring of water quality and the flow in the areas downstream of mining activities. Thus, these shortcomings need to be acknowledged and solutions need to be provided in order for the medium- to long-term strategies to be optimised for AMD management, especially where there are impacts on the Vaal River system. In the short to medium term, seismic events need to be monitored. It can be identified whether the immediate surroundings of mining areas will be prone to seismic activities or whether they are moving away, which will, in turn, imply that there might be a potential risk of geological activities at some distance from the mining areas. It is further stated that the information gathered over time would be useful for microzonation studies. This will also show the changes that occur in the seismic risks to which the infrastructure within the urban areas surrounding the Central Basin will be exposed. As part of this recommendation, a multi-institutional monitoring committee was proposed to conduct the implementation of the required monitoring and assessment programmes. The committee can observe changes in the quality of mine water, and this may impact on the future management strategies (Coetzee et al. 2010, p. 91).

The fifth recommendation was directed at addressing other AMD sources. The flooded mine voids are not the only form of AMD in the Witwatersrand. The tailings and other waste materials that are formed by mining are also major sources of AMD. But it is stated that the absence of comprehensive flow monitoring networks in the priority areas prevents quantification of the impacts. This also brings about the need for improved monitoring. Continuous studies and counteractive measures will be vital to reduce the impact of such AMD sources (Coetzee et al. 2010, p. 91).

The sixth recommendation was that further research was required to identify and optimise sustainable solutions in the medium to long term. Even though measures must be implemented in the short term, according to the report, there are still some areas of uncertainty where solutions need to be found in order for sustainable medium- to long-term solutions to be implemented (Coetzee et al. 2010, p. 92).

The seventh recommendation was to investigate the feasibility of an environmental levy on operating mines. This includes investigation of the feasibility of an environmental levy that needs to be paid by operating mines to cover the costs of the legacies of past mining needs, including AMD (Coetzee et al. 2010, p. 92).

The eighth recommendation was about ongoing assessment and future actions. This is to highlight that the above recommendations are merely an immediate way forward to lessen the already critical impacts. It is stated that these recommendations are there to stabilise the situation and to understand AMD and the gaps that exist by conducting ongoing research and following up on processes in the priority areas and its potential impacts on the environment. The report concluded that AMD problems will have implications for the future, and its impacts will most possibly continue. Management of this process and ongoing assessments will therefore be vitally important (Coetzee et al. 2010, p. 92).

5.3.3 Role of the Trans Caledon Tunnel Authority

In April 2011, an entity of the DWA, the TCTA, who manages water projects, was brought in to implement measures to protect water resources (TCTA 2012; DWA 2012, p. 2) particularly in the Central Basin. The TCTA is one of the most important state institutions involved in implementing the IMC policy recommendations. The key objective of the TCTA in this regard was to prevent AMD from entering into the natural environment and, in the cases where it is entering the natural environment, to take measures to treat the water to a suitable standard.

The TCTA is one of the bodies that takes responsibility for the short-term solution, namely, 'the high-density sludge management solution' which has been much disputed among role players in AMD (TCTA 2012). This is due to the fact that some role players regard it only as treating the symptoms of AMD and not providing a long-term solution. In addition to this, the treated AMD is not regarded as sufficiently safe for human consumption and agricultural use. As an entity of the DWA, the TCTA has been given this task, because it is the only body that has sustainable bulk infrastructure and the necessary pumping capacity to conduct this task (Shanna Nienaber, personal communication, 12 March 2013). The water that TCTA is treating through the high-density sludge management system is pumped into the Vaal Barrage. The problem for the TCTA is that there is not enough money to treat this indefinitely, and it is not commercially attractive for the TCTA, because the treated water is not clean enough to sell. The water quality is slightly better than the raw decanted AMD. The TCTA's preferred long-term solution is reverse osmosis so that it can then sell the water to Rand Water or Sasol who will need it. Sasol needs water that is cleaner than drinking water. However, Rand Water publicly stated that it would not buy this treated water, because of the public perception that the water was still acidic and unsafe to drink and, thus, would resist using it (Shanna Nienaber, personal communication, 12 March 2013).

According to Turton (2013c), these possible risks can be technically managed and "the Rand Water Board investigation into the potential threat of AMD plumes to the hydraulic infrastructure that sustains the economic capital of Africa [i.e. Johannesburg] has yielded the first known high confidence hazard assessment methodology capable of indicating the exact location of risk within'. According to him, the assurance can now be given that the risks that stem from AMD in the Witwatersrand goldfields are not in line with that which is projected in the media (Turton 2013c). This is substantial progress for the risk reduction of the problem. The Minister of Water Affairs has appointed the TCTA as the overall project manager, which Turton describes as a 'world-class institution' that obtains the necessary skills that are needed to bring the different mining projects in the various mining basins to a successful finish (Turton 2013c).

So far, the policy response to AMD by the national government received attention. The focus shifts now to the provincial government of Gauteng which is mainly responsible for the Witwatersrand. DWS and TCTA recommends that an 'AMD tariff be introduced to Vaal River system users to fund the operations and maintenance of AMD infrastructure. This means adding the AMD tariff to Gauteng water bills' (Cox 2014, p. 5). However, this has to be in agreement with the municipalities affected, and if they decline, then there will be serious water shortages.

Sections 5.3.1 and 5.3.3 explained how taxpayers will have to 'pay the bill' for purifying AMD and more specifically those living in the areas that are affected. According to a media report in The Star (Cox 2014, p. 5), the question remains, 'why must only the Vaal River users be expected to pay, and why is the cost not spread nationally because mining benefitted the national economy and not only the Vaal River users. AMD is an environmental problem that resulted from mining activities'.

The council suggested that the national government fund this project and focus on the mines making the contribution instead of the taxpayers taking on the responsibility (Cox 2014, p. 5). A final decision has not been made.

5.3.4 Gauteng Provincial Government Policy Response: Gauteng Department of Agriculture and Rural Development

The Gauteng Department of Agriculture and Rural Development (GDARD) identified MRAs as a possible provincial priority for the reclamation of land in its future 5-year programme. The aim of this is to make land available from the MRAs in

Gauteng to be used for other government priorities (Hartnady et al. 2011, p. 7). The objectives of this included the following:

Evaluating the current problems caused by mining activities and to suggest how they could be dealt with
Quantifying the amount of land under mining activities and classifying them in terms of impacts and prospective reclamation
Investigating which mining areas could be made available to be used for other purposes
Providing preliminary and conceptual recommendations on the short-term priorities for the reclamation of the mining sites which could be economically sustainable (Hartnady et al. 2011, p. 7)

MRAs refer to tailings disposal facilities (TDFs), including dams or dumps, waste rock dumps and open cast excavations, water storage facilities and return water dams, tailings spillage sites near TDF dams and mixtures of building material and mine waste (Hartnady et al. 2011, p. 7) According to Hartnady et al. (2011, p. 7), there are estimated 380 MRAs in Gauteng, most of which are made up of the residues of gold mining. The majority of MRAs are radioactive because the Witwatersrand gold-bearing ores contain almost ten times more uranium than gold (Hartnady et al. 2011, p. 8). The radioactive tailings coexist in these MRAs alongside the iron sulphide mineral pyrite 'which reacts in the presence of oxygen and water to form a sulphuric acid solution – the major cause of acid mine drainage (AMD)' (Hartnady et al. 2011, p. 8). There are three main concerns that relate to MRAs that are located in Gauteng: (1) the air quality, especially dust pollution from MRAs, (2) water flux and water quality and (3) geotechnical safety concerns that lead to the dangers of ground instability and collapse above abandoned mine workings as well as unsealed mine shafts that present a threat and danger to the settlements that are nearby (Hartnady et al. 2011, p. 8).

According to Hartnady et al. (2011, p. 11), insufficient monitoring and evaluation tend to be the cause for not being able to address the problems caused by MRAs. An approach to deal with this issue will include a multidimensional representation committee—which has also been recommended in the IMC report—in order to follow disaster management principles. This committee will facilitate the development of guiding principles of data sharing and monitoring requirement of MRAs. This also includes those that are responsible for the data and the maintenance thereof and enforcing policies that are in line with funding and monitoring such as the Mine Rehabilitation Act, which monitors the impact caused by mining activity. A report in The Star newspaper in 2014 referred to this 5-year plan mentioned above, to address the AMD problem; however, the plan did not pay attention to specifics, and the debate continues to centre around finding long-term solutions (Taylor 2014, p. 6).

The GDARD feasibility study on mine residue areas has identified eight elements, each of which will require separate action. The purpose of this is to identify and reach policy consensus on these eight elements (Hartnady et al. 2011, p.14). They are discussed below. With regard to the scientific and technical elements of the

MRA reclamation issue, elements 1–3 are in line with the human rights outlined in section 24 of the constitution (RSA 1996).

Element 1 is environmental pollution, including atmosphere- and water-borne contaminant transport and toxic and radioactive soils. Element 2 is geotechnical stability, which includes possible risks of subsidence collapse of undermined or dewatered/rewatered ground and the failure of MRA dams. Element 3 is monitoring and evaluation, which include instrumental networks and information systems for monitoring air quality, surface water quality and groundwater quality.

Elements 4–6 deal with technical and social issues. Element 4 is human health, which involves the epidemiological approach to all aspects of MRA-related or MRA-induced conditions. Element 5 is communication that needs to exist between the various actors in the regulatory environment, polluters and those affected by actions taken by regulators. Element 6 is safety and security, which is a feature of the MRAs.

Elements 7–8 refer to social and socio-economic development goals that would be supported by an effective strategy for MRA reclamation. Element 7 is job creation, which includes the possible options of using local labour for rehabilitation and some long-term land uses or reclaimed land. Element 8 is economic viability, the objective of which is to rehabilitate as much of the impacted land as possible. These elements are discussed in more detail in the report looking at how the problem occurred, the appropriate policy responses and the risks that could arise if action is taken or if it is not taken.

For the purposes of this research, element 1 and element 4 are discussed in more detail.

5.3.4.1 Environment Pollution (Element 1)

MRAs are known to be the source of radioactive dust, water pollution and soil contamination. Dust is known to be a huge health risk for several reasons, and if inhaled it can cause damage to the lung tissue. Thus, dust is a health risk and can reduce the quality of life for many people. Water pollution is associated with abandoned mines and is also closely linked to the AMD problem. MRAs are closely associated with these underground mine voids, so there are concerns of water ingress into these voids, which is of great importance. Soil contamination includes the presence of dumps, tailings and slime dams in the surface environment. This takes place where people are contaminated by elevated levels of radiation after unauthorised entrance to a mine site or by living on or near settlements closely situated to a mine on the contaminated MRAs or abandoned mines. Direct access to mine sites can also expose the public to risk due to radon exposure, inhalation and ingestion of radionuclides and chemotoxic metals and the physical danger that is tied to mining areas (Hartnady et al. 2011, p. 15).

The policy response to environmental pollution includes several components. Dust should be suppressed. Monitoring and evaluation should take place in a well-structured manner. The management of water ingress is a crucial element of success for any AMD policy in the future, and it has also been included in the IMC report on AMD. MRA sites will provide the basis for determining the physical location of each hazardous source. Lastly, the nature of a direct-access pathway of environmental degradation and the requirements of MPRDA Regulation 62 require special attention to affected parties who could be the victims of ongoing pollution and the potential future land users (RSA 2002). If all this is not adhered to, the human health risk will increase over time, and this will also put pressure on government (Hartnady et al. 2011, p. 16). With regard to the water pollution, the volume of decanting AMD will become larger, and groundwater in the areas adjacent to the different mining basins can become contaminated, which will affect agriculture.

5.3.4.2 Human Health (Element 4)

In respect of Element 4, human health, several human health risks arise from MRAs, and each is driven by root causes. They can negatively impact on the right to a healthy life for all citizens as stipulated in the constitution which will, in turn, have a legislative impact on local and provincial government. The problem arises where dust from TDFs and sand dumps can lead to respiratory diseases. Close distance between the informal settlements and TDFs can expose humans to toxicity that arises from heavy metal exposure and where there are radioactive elements in the tailings. The increasing levels of AMD can also become a source of future hazard as groundwater can become polluted, which exposes poor and vulnerable communities to further health hazards (Hartnady et al. 2011, p. 19). The proposed policy response is that all the MRAs be surveyed and mapped with a view of determining the physical location of each source of hazard, be it chemical, radiological and physical. If no action is taken, ‘the existence of human health risks will also undermine future development aspirations of the Gauteng government by impacting negative on the overall health of residents’ (Hartnady et al. 2011, p. 19). However, to reduce human health risks, informal settlements will need to be rearranged. However, the residents of these informal settlements could resist removal.

5.4 Developing Long-Term Solutions to Acid Mine Drainage

Aurecon is a private company that provides engineering, management and specialist technical services to public and private sector clients globally (Aurecon 2013). The DWA put out a tender advertising of an 18-month feasibility study for a long-term solution to deal with AMD in the three underground mining basins. Aurecon was the successful bidder (DWA 2012, p. 2). In an interview with Shanna Nienaber (2013), she stated that DST sat in on DWA meetings with Aurecon. The situation in March 2013 was that Aurecon was providing advisory services for the DST to assess and evaluate alternative approaches to water treatment and water management as a means to improve the quality of water produced by the TCTA treatment process of AMD.

An inception report compiled by the DWA discusses the short-term interventions to addressing AMD. These interventions include (1) investigating and implementing measures to pump the underground mine water to prevent it from crossing the ECL, (2) implementing measures to remove metals from AMD and (3) developing a feasibility study (DWA 2012, p. 3). This inception report looks at all the same interventions with regard to long- and short-term interventions to maintain or neutralise the water so that it does not reach the ECLs. A key element mentioned in this report as part of the long-term solutions to address AMD that is relevant for this research is 'the possibilities for the use or discharge of raw, neutralised or desalinated AMD which will meet the objective of reducing the salt load on the Vaal River System to acceptable levels and which do not have an unacceptable social and environmental impact' (DWA 2012, p. 7).

In Sects. 5.3.1 and 5.3.3, the possibility of an increase in water tariffs is discussed in order to pay for AMD treatment and, more specifically, for the municipalities affected to raise their water tariffs. The municipalities were resistant to do so. However, if this option does not work, then 'water availability could drop from 3000 million cubics to 2500 million cubics a year'. This decrease arises from the need to use freshwater from the Vaal Dam to dilute the partially treated AMD water to contain sulphate levels being released into the natural river system, while a long-term solution is still pending (Cox 2014, p. 5). According to the DWS (2015, n.p.), this is not the ideal solution; it is a partial solution, and at present they are using 1:5–6 l of clean water to desalinate, but the ideal would be to use 1:14 l of clean water to neutralise the acid mine water, and this is not a good practice.

In September 2015, the Minister of Water and Sanitation, Nomvula Mokanyane, released a media statement saying that she is aware of all the media reports and statements from scientists commenting on government's plans to manage acid mine water for future use (DWS 2015, n.p.). In spite of this, no decisions have been made, and while a feasibility study has been completed to ensure the development of the most suitable solution for acid mine drainage in the Witwatersrand, the department is still engaging relevant stakeholders, experts and organisations, including the public. The minister added that only once all the information has been assessed will an informed decision be made (DWS 2015, n.p.). Therefore, there is still no long-term solution to AMD, and such solutions are still being sought by the DWS.

In October 2015, a media report stated that the DWS Minister has been promising to release the report regarding the long-term solution, and this still has not been done (Matthews 2016, p. 3). Liefferink further added that 'a failure to implement a long-term treatment of AMD is resulting in prolonged reliance upon funding from the general fiscus, increase of the salt load in the Vaal River, which can only be mitigated by the Vaal Dam'; this is further leading to serious economic impacts due to the recent droughts (Matthews 2016, p. 3).

In addition to this, the national budget of 2012 stated that R2.2 billion was allocated to solving AMD. In the 2013 national budget speech, it was mentioned that R2.5 billion was allocated to the expansion and longer-term plans of R15 billion in mining projects (Gordhan 2013, p. 11). The concern of addressing acid mine drainage was mentioned under 'continued spending towards environmental programmes'. However, the national budget speeches in 2014 and 2015 (Gordhan 2014; Nene 2015) made no specific reference to the impact of AMD. This could be understood as the government no longer viewed AMD as being severe and urgent as it was in 2011 and 2012. It could further be interpreted as that the issue is under control and that other threats (sewerage for instance) to our water systems are more significant than that of AMD.

The aim of Chap. 4 was to develop an overall understanding of AMD and determine the magnitude, severity and urgency of the problem. When the AMD issue became a crisis and was prominent in the media during 2011–2012, AMD was placed at the forefront of the agenda. The government responded with urgency and placed much emphasis on the issue. It is not a conclusion but merely a possibility that AMD will be treated in the short to medium term, and focusing on a long-term solution does not seem vital for the government. This is due to the fact that the 2014, 2015 and 2016 national budget speeches all mention that mining is declining and that there needs to be a focus on the mineral wealth that is necessary for economic growth. However, there is no mention of the fact that mining has had enormous negative impacts which needs to be addressed at the same time as focusing on the mining industry for economic growth. There is a need to place emphasis on the fact that structures and processes need to be in place to prevent the problems—that stress our water systems and harm the environment and people—that arise from mining activity.

5.5 Consultants, Activists and Non-Governmental Organisations

The AMD debate has been ongoing for over a decade now, which has led to numerous public fights and attempts to place blame on some and 'seek redress from well-meaning activists' (Turton 2013c).

According to Turton (2009), the civil society is emerging as a key policy entrepreneur that derives its energy from public opinion after years of exploitation from the government and the mining industry that stemmed from their ambition to hold those responsible for abusing human rights. He adds that a range of NGOs have been taking on the issue of AMD, including the FSE under the lead of Mariette Liefferink.

Liefferink continuously stresses the urgency and impact of radioactivity that has been caused by AMD. According to Fig (2011, p. 312), the national nuclear regulator has not succeeded in protecting the public from the radioactivity associated with AMD. In 2010 the impacts of uranium and other radioactive substances in the Wonderfonteinspruit catchment did not note any danger to communities; however, this was challenged by radiation exerts. Liefferink (personal communication, 4 April 2013) stated that radioactivity would harm communities and the people who lived in areas surrounding mines.

The community of AMD specialists in South Africa is very diverse and does not only include government officials and policy-makers or the scientists at the main science councils but also mining and business specialists, consultants who are used by either government or the private sector and activists in the NGO sector. All of them have their own interpretation of what AMD entails, how serious a threat it poses and what the steps should be to avoid a crisis or to find a long-term and sustainable approach to it.

For the purpose of identifying policy responses originating from outside the government sector, two prominent people—Anthony Turton and Mariette Liefferink—can serve as case studies.

5.5.1 Anthony Turton

Turton (personal communication, 24 April 2013) describes himself as both a consultant and an activist. As a consultant (Touchstone Resources), he regards himself, in the first instance, as a political scientist and not a mining scientist; he obtained a doctoral degree in the politics of water management in Southern Africa (Turton 1988). Some of his best-known work as a consultant is done for companies such as Mintails and major banks (Turton 2013b). During his previous employment at the CSIR, he was instrumental in raising public awareness about AMD and its possible impacts (Turton 2013b).

Turton's approach is to publish extensively and to act as a public speaker. At the same time, he is often part of a technical team that concentrates on the use of technology and engineering science in searching for solutions that can also introduce new business opportunities for mining companies. His view, in general, is that the IMC's approach (which is implemented by the TCTA in the Central Basin) of pumping underground water to below the ECL is not a long-term solution but mainly deals with the symptoms of AMD. Derived from his description or definition of AMD (discussed in Chap. 4), which is not limited to acidic underground water but also includes surface water from the tailings dams that interact with acid rain in the MRAs, Turton's approach to AMD focuses very much on the MRAs.

The business model of Mintails in which Turton is involved consists of reprocessing the gold mines' tailings dams, extracting the remaining gold from the sludge and relocating the residue to a 'super dump' (Anthony Turton, personal communication, 4 April 2013). In addition to producing gold, this process also reduces the formation of surface-generated acidic and radioactive water; it will reduce the prevalence of mine dust near residential areas which is responsible for serious respiratory illnesses; it will create new space at the previous MRAs for residential developments and other spatial developments; and it will centralise management of the MRAs at the 'super dump' (Anthony Turton, personal communication, 4 April 2013). Turton stated that Mintails had compiled principles to guide its approach to the future solutions for the AMD problem where responsible. This included finding an inclusive approach to the management of MRAs, and the surface TDF was essential to solve the AMD problem. The removal of existing TDFs and other contaminated dumps should be encouraged, where land can be rehabilitated and used for social and economic purposes. The consolidation of TDFs should be encouraged as part of an inclusive MRA management process to increase the life of mining from 2020, which will create employment opportunities and ample time for effective rehabilitation of all mine-impacted landscapes (Anthony Turton, personal communication, 4 April 2013).

Fig 5.1 Anthony Turton and the researcher (Source: author's photograph collection)

Complementary to the business approach, Turton maintains that his activist role is still necessary for enhancing public awareness about AMD. He uses social media such as Facebook but warns against sensationalism, especially about the radioactive dimension of AMD and inappropriate use of litigation against mining companies which sometimes have counterproductive outcomes (Turton 2013a). He acknowledges that since the first known decant in the Western Basin in 2002, the AMD issue has been characterised by an inadequate response by all the stakeholders involved. The trustees of the Water Stewardship Council of Southern Africa (WSCSA) hold the view that there needs to be a change from 'blame-seeking to solution-seeking behaviour'. Turton (2013c) is also of the opinion that negative media coverage will only wrongly alert the public and that the public has not been adequately informed. Turton as a case study, therefore, combines scientific, business and public awareness approaches in his search for more cost-effective and sustainable solutions than those adopted by the government since 2011 (Fig. 5.1).

5.5.2 *Mariette Liefferink*

Mariette Liefferink, as the second case study, approaches AMD mainly from the perspective of an NGO or community-based organisation and concentrates on the social impact of AMD. She serves on government-appointed committees, informs ministers and works with many key players to ensure that there is some way forward to resolving the problem (Fig 2011, p. 315). Her main objective is to create public awareness and to identify 'hot spots' that are responsible for detrimental social and environmental effects. Liefferink's activism on AMD and raising of the public's awareness have been noticed by a significant number of people in the field. Fig (2011, p. 315) describes Liefferink as 'working tirelessly for a number of years… not only has she been a public advocate of the need for solutions, but has personally kept the media and affected communities informed, mobilising resources to draw attention to the problem in new and creative ways'.

Liefferink not only serves on government and parastatal bodies (e.g. the nuclear energy regulator) but also as a civil society representative. She uses the media extensively to influence public opinion and to highlight the consequences of government actions or lack thereof. In one particular instance she warned about the acidic and radioactivity threat of mine water that could affect central Johannesburg when it reached the anticipated critical point in 2013 (Noseweek 2013, p. 10). She explained how pumping was to take place in an attempt to prevent radioactive AMD from flooding the streets of Johannesburg where 'deadly liquid' was predicted to reach the ECL (Noseweek 2013, p. 10). She stressed the issue that if AMD was not prevented, Gold Reef City stood the chance of being flooded, and AMD would 'eat away Joburg's subterranean infrastructure, contaminate its dolomitic aquifers and start percolating upwards to seep out the ground in the CBD and Boksburg' (Noseweek 2013, p. 10). She also warned that the rising water was likely to increase the seismic activity on the Witwatersrand and cause more sinkholes in dolomite areas. She stated that mining companies, political authorities and the nuclear regulator had been aware of these issues since 2002, but no emergency plans were in place, and the radioactive water was flowing into the wetlands or was being pumped into nearby lakes and dams.

In her public awareness campaign, Liefferink focuses extensively on the radioactive water in the Johannesburg area and the surrounding towns. Her approach is to activate public support against the consequences of AMD and radioactive mine water. Part of her approach is to confront key stakeholders directly, and, as a result, she has been appointed to serve on several committees and boards. She also takes parliamentary members on tours and has conducted many workshops with thousands of people informing them of the seriousness of the issue (Noseweek 2013, p. 14).

Her organisation, FSE, is often involved in litigation with mining companies or addressing instances where abandoned mines or residue areas pose a direct environmental or health threat to communities (Funke et al. 2013, p. 193). Litigation becomes then an instrument of pressure against those who violate the official water management regime. At the same time, those cases also enhance public awareness about the AMD complications. Funke et al. (2013, p. 193) described Liefferink as a 'news carrier' of AMD that she educates the people by making them aware of the issues at hand and she chases after the government to address these issues. Liefferink's activism 'goes beyond protecting the environment for the environment's sake and focuses on the effects environmental damage has on the public's health and well-being' (Funke et al. 2013, p. 200). This was also evident during the researcher's tour with Liefferink on the West Rand. On the one hand, she discussed the impact of AMD but, at the same time, provided assistance in the form of food to the children in Kagiso informal settlement.

Liefferink does not necessarily publicly propose alternative models or business approaches to the government's strategy. Her cause is more to call for sustainable and vigorous implementation of existing government policies. She, however, differs from government on the radioactive issue: she considers it a much more omnipresent factor than most of the officials do. She also differs from Turton on the business approach and Mintails' approach. In a qualified sense, she is critical of the fact that 'many persons and companies want to financially profit from the current situation' (Liefferink 2013). On behalf of FSE, she insists that 'scientifically sound' environmental impact assessments and public participation of short- and medium-term treatment of AMD and public involvement for the long-term treatment must be brought back. In this regard, she endorses North-West University's Prof Frank Winde's criticism of Mintails' tailing water treatment technology, because its environmental impact is still unknown (Liefferink 2013) (Fig. 5.2).

The two cases illustrate the different approaches of Turton and Liefferink in proposing solutions for AMD. Both share an activist approach that emphasises the importance of influencing public opinion in policy-making and governance and the public watch-dog role civil society can play. They also differ in their approaches: Turton acts more as a business consultant, while Liefferink serves on government bodies. She uses litigation as an enforcement instrument, while Turton does not. Liefferink regards the radioactive threat of AMD at a much higher level than Turton. Both of them have played exceptionally important roles to elevate AMD to the level of a public issue. What is significant is the fact that both have become indirectly very important role players in the evolution of the policy on AMD.

Fig 5.2 Mariette Liefferink and the researcher (Source: author's photograph collection)

5.6 The Latest Policy Response

From this chapter, it is apparent that the issue of governance tends to be one that is significant in order for the issues surrounding water pollution and scarcity to be reduced. Participative and proactive management mechanisms are necessary for changes to happen. Throughout this chapter, policy issues regarding AMD were discussed. In Sect. 5.4, we were made aware of the fact that no long-term solution to AMD has been made. All the role players involved are awaiting this decision, and there are no clear indications of when this will be done.

In a brief interview in February 2016 with Bashan Govender from DWS (personal communication, 22 February 2016), he mentioned that the department will be looking at all options to exploit efficiencies of projects implemented in 2016, 'with a multi-faceted view of ensuring environmental/water resource protection and socio-economic benefits'. The most recent development by the DWS is the establishment of a Mine Water Management Unit (MWMU) to evaluate the impacts AMD on the environment. The unit 'might also result in a policy review of re-alignment of how AMD is managed" (SAnews 2015, n.p.). This unit has not yet been finalised.

DWS has been communicating with other government departments and stakeholders for further options to manage AMD in the Witwatersrand. Some of these options include research to sustain future planning and improve decision-making, applying cost-recovery mechanisms to ensure that the mining industry contributes to reducing AMD (Environment News 2015, p. 3). South Africa has developed in terms of unstable policy frameworks to planning and water authorisation for mining as well as enhancing mine water management, but there are still many weaknesses in the current policies (SAnews 2015, n.p.).

What is also evident in the new policy development is that mention is made of the socio-economic impacts. According to the DWS, 'the reason why we should be concerned about mine water, is simply that the acid contaminant and associated dissolved metal are toxic to most forms of organisms and pose a risk to human health and aquatic or water-dependent ecosystems' (Frankson 2015, n.p.). However, in spite of the fact that this is pointed out, there is no mention of exactly what these socio-economic impacts are and how they will address it.

5.7 Conclusion

In this chapter, the focus was on the different responses to AMD. The first was the question of governance and on how water management is conducted in South Africa and how appropriate it is to address AMD. It raised the contentious issue of who is responsible for funding the rehabilitation of closed or abandoned mines which is a major contributor towards AMD. In the discussion, it has become clear that AMD is a 'legacy' problem caused partly by the fact that an unnaturally close relationship between the mining sector and the government in the past effectively exempted the mining houses from preparing for mine closure and the resultant effects. Part of the response to AMD in the past number of years is therefore also to pay renewed attention to a sustainable policy on mine closures.

The government's main instrument in response to AMD is the IMC, the options it identified and the recommendations it made. Most of them were accepted as the government's formal policy framework on AMD. The policy consists mainly of pumping the mine water from existing shafts and keeping the water level below the ECL. The pumped water is then treated, but the sludge residue still has to be managed. Most of the evidence presented in this book reached the consensus that the treated water is not yet ideal for human consumption, and, therefore, better long-term solutions are still being investigated. In this chapter, it is concluded that the IMC expert report concentrated on the technical–scientific aspects of AMD but did not attend at all to its socio-economic impacts. The establishment of Mine Water Management Unit is the latest development; however, this is not finalised by DWS. The shortcoming in the government's policy response is accentuated in the approach followed by activists such as Anthony Turton and Mariette Liefferink. This chapter demonstrated that they also differ in their approaches. They are, however, both critical of the current approach, because it is regarded as a short-term solution dealing only with the symptoms of AMD and does not provide a long-term solution that will be sustainable in a socio-economic sense.

The absence of a socio-economic focus in the policy response is therefore the motivation for the next chapter.

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Chapter 6
Socio-economic Impact of Acid Mine Drainage

6.1 Introduction

In the previous chapters, the nature and scope of AMD were discussed. The different responses to AMD were also identified. In view of the fact that the objective of this book is to investigate whether the government's policy response is appropriate for the dynamics of AMD, it is important to determine what its socio-economic impacts are or could be. The impacts of AMD can then be linked to the policy response. This chapter, therefore, discusses the socio-economic impacts of AMD. It incorporates the environmental, social, economic and health impacts that contaminated mine water has or could have on communities who live in areas surrounding a mine.

Even though the mining sector is such a big consumer of water—as mining needs water to conduct their activities—agriculture is the biggest water consumer in most countries in the world and consumes almost 70 % of the world's freshwater (Parris 2010). In this chapter, agriculture is chosen as a specific focus area, because it is the sector potentially most affected by water problems, and it also combines different socio-economic aspects. On the one hand, agriculture depends on a sustainable environment in the form of quality soil, water and atmosphere. On the other hand, agriculture delivers products essential for human life. Contaminated water can have a severe impact on both aspects of agriculture and on society as a whole.

During the fieldwork stage of this study, an interview was conducted with representatives from AgriSA. AgriSA is part of an organised agriculture and an organisation that promotes the development, profitability, stability and sustainability of commercial agriculture in South Africa through its involvement in, and input at, the national and international policy level (AgriSA 2013). The interviewees provided crucial insight into how AMD impacts agriculture. This will be discussed later.

This chapter refers to case studies of farmers' experiences of contaminated water that negatively impacted on their farming activities. Lastly, this chapter proposes possible solutions to reduce these negative impacts.

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6.2 The Economic, Environmental, Social and Health Impacts of Acid Mine Drainage

There are several negative impacts associated with AMD-related pollution loads, including financial risks, environmental, socio-economic, health and political. These impacts are discussed in an integrated manner in this section due to the nature in which they relate to one another. From media reports, it has become evident that there are clear socio-economic issues regarding AMD and those who will be potentially affected by it. Shanna Nienaber (personal communication, 12 March 2013) believes that the strategic issue is the water supply in the Vaal Dam. The whole of Gauteng is a massive water hub, and water security has become a major problem. AMD is a long-term problem that needs to be dealt with. It is a threat to people who live closest to areas of water spillage, to those who depend on boreholes and to those growing vegetables in the affected areas. This becomes part of a strong case to make because it impacts on people who live in mining areas in general, and it is difficult to separate AMD from the issues of tailings dams from the issue of dust that blows off these dams to the soil quality that is affected. In this regard, Nienaber (personal communication, 12 March 2013) states that this is not just an AMD problem but an integrated problem.

AMD is complex; not all these areas are affected in the same way and neither do all of them have the same levels of pollutants (Shanna Nienaber, personal communication, 12 March 2013). Nienaber states that communities are affected, especially those who are near tailings dams, and it is not just the groundwater that is polluted but also the run-off from the tailings dams themselves. There is a big debate between scientists and communities about the impact of rain on the surface which causes seepage of mine water and water from tailings dams.

The WRC is deeply involved in AMD and long-term water quality management. From 2005, the WRC has increased its focus to include AMD with the emphasis on tools for long-term water quality management in underground collieries, including the quantification of the potential and magnitude of AMD under South African open-cast conditions (Frost & Sullivan 2011, p. 4). The research conducted included the impact of mine water-related research in South Africa. These impacts are discussed in line with its current and potential benefits (Frost & Sullivan 2011).

In Chap. 5 it was already observed that the IMC policy document had overlooked the socio-economic impacts caused by AMD, and they were not placed at the forefront of the agenda. The IMC report mentions as a 'concluding point' that risks of mine water decant include serious negative ecological impacts on the receiving environments and local and regional impacts on the Vaal and Crocodile River systems that could affect fitness for use of the receiving water resources to downstream water users. 'AMD will aggravate an already upward trend associated with salinisation of the receiving river systems, necessitating additional dilution releases to be made and subsequently risking water supply security within the integrated Vaal River System' (Coetzee et al. 2010, p. 87).

More public awareness of mine water spilling out into the environment and, at the same time, strong sentiments that exist between the mining industry and the government have made AMD a highly politicised issue. Mine closures and the related increase in AMD have also had serious economic consequences for communities who were previously supported by the mining sector. Mine closure has, in certain instances, led to the loss of job opportunities and, therefore, increasing unemployment rates. ‘Subsistence farming is often the last resort for such communities, but AMD may render the available water resources unfit for agricultural use’ (Oelofse et al. 2007, p. 6).

The economic implications of AMD when it causes local flooding are that it can increase the risk of ground deformation and attack structures made by human beings such as concrete building foundations, the liners of landfills and waste dumps. In some parts of the UK, this is known as one of the main causes of freshwater pollution. Cobbing (2008, p. 452) states that ‘AMD problems generally improve naturally with time, with pH rising and dissolved load falling, but this can take decades or longer’. What becomes questionable here is that given these facts, one needs to see the measures that the identified institutions are taking to reduce the risk of it reaching a crisis stage. Even though it is possible for AMD problems to improve ‘naturally’ with time, as mentioned above, this can be beneficial for the environment, but what then happens to the human element in the meantime.

Tourism is an important economic sector in South Africa. The potential impact of AMD on tourist facilities should be considered. According to Peter Mills (personal communication, 20 February 2013), some people believe that the Cradle of Humankind World Heritage Site will be destroyed by the acidic effect of AMD on the underground fossils, but he feels this can be disputed. When asked about the effects of alarmist media reports on the possible impacts, he responded that ‘tourism is growing; the only impact that there has been is a rise in the water table at the Cradle and the high rainfall season caused this. Before the rainy season the water table remained at the same level as before decant started in 2002’ (Peter Mills, personal communication, 20 February 2013). He added that no one knew what the exact impacts of AMD were. In his mind, the impacts on the Cradle were not negative and were rather limited. He believed that there had not been many negative impacts on tourism, but it had harmed farmers. Hypothetically, according to him, if hotels were to be established around the area, then there would be a need for an alternative source of better-quality water. He stated that ‘there are more pressing issues than AMD, all the fossil sites are above the water levels and speculation about the Cradle being under threat is not true at this point’ (Peter Mills, personal communication, 20 February 2013).

Anthony Turton (personal communication, 4 April 2013) also looked at the economic impacts caused by AMD and how they could be changed. The most significant is the coexistence of poverty spatially located in close proximity to MRAs (as discussed in Chap. 5). About 1.6 million people now live in informal settlements that are situated close to MRAs. Turton explained why MRA land was used more by informal settlements. In the 1900s the population of what is now Gauteng consisted of 0.7 million people, which increased to 6.2 million in 1994 and will grow to 20 million in 2020. Thus, in terms of households, one will see a growth from 1.8 million units in 1994 to 4.7 million in 2020 (Anthony Turton, personal communication, 4 April 2013). It is evident that there is not enough land to keep up with the increase in formal settlements. Turton's proposed solution is to remove the TDFs, by consolidating them into 'super-dumps engineered to twenty-first-century standards, with a potential yield of 5445 ha of land that could be brought into the revenue stream of local authorities through rates and taxes'.

By removing the TDFs, future acid generation will be prevented and make significant areas of land available for new developments. Where there are informal settlements on MRA land, residents could be contaminated by heavy metals such as uranium, and some people have lost their lives after falling through unprotected openings into the mine void. Houses in those areas run the risk of being redlined by financial institutions, making it impossible to sell them, or of being excluded as collateral surety for the raising of capital from a bank. This will have clear implications for poverty eradication.

According to Turton (personal communication, 4 April 2013), the second significant socio-economic impact of AMD and its economic implications relate to the eradication of the apartheid era heritage which is still evident in the form of segregated communities. Large MRA land is often a physical barrier between the historically black township areas and the historically white suburbs; for example, Kagiso, a township in Krugersdorp, is spatially separated from the rest of Krugersdorp due to the existence of an extensive MRA that is owned by Mintails (a company whose main gold-mining activities are on the Western Basin of Witwatersrand goldfields). Enormous illegal mining activity is currently taking place in this area, and there have been cases where miners have lost their life. The way in which rehabilitation of MRAs can end this divide is to create land that would link these historic divides in the way Mogale City (the local municipality in the West Rand area in Gauteng) wants to do with part of the Western Basin MRAs (Figs. 6.1 and 6.2).

The third socio-economic impact of abandoned mines is that illegal mining activities (known as *zama zama*) take place, which lead to the criminalisation of communities (Anthony Turton, personal communication, 4 April 2013). This has several harmful consequences such as risks to individual informal miners who have no financial or other benefit structures and who are constantly exposed to death or injury. There is the risk of the loss of the breadwinner in an impoverished family should an accident occur, which can be caused by several factors, including illegal mining activities; the creation of criminal networks needed to process illegal gold, stolen copper and jewellery; the creation of new ingress points into the void as shallow stopping continues; the erosion of structural integrity of roads; and the creation of dangerous openings into the earth that can later become a hazard to the children who play in the area. Lastly, illegal mining often means the opening of closed shafts in order to gain access to shaft pillars which are rich in ore grade but which are still needed to provide support for the structural integrity of old underground workings (Anthony Turton, personal communication, 4 April 2013).

The economic impact of the developments in the Eastern basin, especially at the Grootvlei mine after the holding mining company had been liquidated and taken over by Aurora Empowerment Systems, was far-reaching. It included the majority

Fig. 6.1 Kagiso township on the West Rand (Source: author's photograph collection)

Fig. 6.2 Impact of AMD on the soil in the Kagiso township on the West Rand (Source: author's photograph collection)

of the workers in the Grootvlei mine who would not have received payment should the mine have flooded and being forced to move to hostels in the area due to desperation. The electricity and water supply to the hostel were cut off, the catering services had stopped, the toilets were not usable, and the medical attention was ceased. This created problems for the workers and led to strikes where the workers had to eventually accept hand-outs to ensure their survival. Their diets had changed, as some were eating thin maize porridge. The workers who were diabetic did not obtain an adequate diet and complained of their medication not being effective. Sanitation was a problem, and the facilities did not comply with the minimum acceptable standards. In addition, there was insufficient water for bathing. Some of the workers could not afford to keep their children in school due to lack of income and their inability to pay school fees and transport. For other workers, the lack of income led to family structures being broken because they could not support their wives and children (Fig 2011, p. 309).

Another area of socio-economic impacts is the environmental dimension. The environmental risks associated with AMD include surface and groundwater pollution in the form of heavy metal uptake in the environment, the degradation of soil quality and the harming of aquatic fauna.

AMD has several environmental impacts that will be extremely costly to undo. AMD associated with gold-mining activities frequently includes radionuclides as most of the heavy metals and radionuclides are not only linked to surface water pollution but are also responsible for degrading soil quality and aquatic habitats and for allowing heavy metals to seep into the environment (Frost & Sullivan 2011, p. 23). As mentioned in Chap. 4, acidic water started to decant from the underground workings of defunct flooded mines on the West Rand in 2002 already and AMD affected the natural water course that flows through the Krugersdorp Game Reserve towards the Cradle of Humankind World Heritage Site. It caused damages to the ecosystem and the wildlife in the game reserve (Frost & Sullivan 2011, p. 24). The WRC's research into mine water management aims to reduce the negative environmental impacts that have been caused by mining activity in the area. The research aims to reduce the degradation of soil quality, which will increase land for farming and will, therefore, increase agricultural production. It will prevent surface water pollution, which will lessen the deformities at birth and defects in animals; there will be more aquatic life and livestock; and, lastly, it will limit the groundwater pollution which will improve the quality of drinking water (Frost & Sullivan 2011, p. 24).

Arguably the most serious concern about AMD is its possible health impacts on human beings. The contaminated groundwater might unknowingly be consumed by individuals, with medical treatment often ineffective by the time the symptoms materialise (Hobbs et al. 2008, p. 421). Health-related issues that have surfaced include the following examples: 'in Delmas, near Johannesburg, where typhoid fever related to poor groundwater quality has killed people on two separate occasions' (Cobbing 2008, p. 452). In Standerton (in Mpumalanga Province, South Africa), residents were fearful of diarrhoea outbreaks due to the unsafe tap water, and even though this was not confirmed, there was concerns of high levels of aluminium found in the water (Masinga 2014, p. 10). A landowner reported that unclean water was polluting one of Gauteng's most important aquifers to undrinkable standards and that sulphate level above 500 mg/l can lead to diarrhoea (Jordan 2015, p. 6). Such problems could start affecting the other areas if not addressed.

The socio-economic impacts are more often referred to in media reports and mentioned by activists and NGOs trying to mitigate the effects of the AMD.

Taylor (2013, p. 10) discusses how the polluted water systems can affect the health of communities. While a focus in this book is on the impact of AMD on public health, very often water quality is affected by a combination of factors, and the singular impact of AMD cannot always be isolated effectively. According to Dr Jo Barnes (in Taylor 2013, p. 10), who is an expert in epidemiology and community health, the health crisis due to high levels of pollution and sewerage in the water goes as far back as 1998, and the necessary action is often not taken. An example is that of the Eerste River in Stellenbosch (in the Western Cape province), where 'in the dry season when natural water levels are low, parts of the river can be 80 percent sewerage effluent'. In the past, people who lived alongside the river had to evacuate their houses because of the lack of water safety of the river (Taylor 2013, p. 10). With sewage already polluting the water, the additional impact of AMD on the river systems near these communities will only be more detrimental. Some farmers even struggle to export their crops, because they are grown using contaminated water. However, during an interview with the representatives of AgriSA, they concluded that there was no empirical evidence to demonstrate that AMD had an immediate effect on farming in the area. However, the case in Stellenbosch provides insight into the possible socio-economic impacts of polluted water, while case studies discussed later can direct one towards the possible impacts caused by AMD in the three river basins (Opperman et al. 2013, personal interview).

According to Liefferink (2013), all wetlands in the Witwatersrand contain heavy metal contaminants. Leukaemia is one of the health impacts known to arise from this. She uses the example of Robinson Lake on the West Rand and explains how there is no aquatic life left and how soil and vegetation are negatively affected by AMD. Immense effects on health are known to arise from the inhalation of uranium particles:

> Highly insoluble uranium compounds may remain in the alveoli [air sac] whereas soluble uranium compounds may dissolve and pass across the alveolar membranes into the bloodstream, where they may exert systemic toxic effects. There is also known to be insoluble particles that are absorbed into the body from the alveoli. Insoluble particles may reside in the lungs for years, causing chronic radiotoxicity to be expressed in the alveoli. (Liefferink 2013)

Health implications caused by people living nearby mine sites was discussed in Sect. 5.3.4, in the form of two elements, namely, environment pollution and human health. Direct access to mine sites causes many health-related hazards, and this exploits the right that citizens have to live a healthy life as stipulated in the constitution. The health impacts are also reiterated by Taylor (2013, p. 10), who states that polluted water can carry respiratory illnesses and heart viruses. Liefferink (2013) noted that the water that Rand Water sold was of good quality, but it had not been tested for heavy metals. Liefferink added that up until 2003, the World Health Organization and the South African Bureau of Standards regarded water with a high uranium concentration (i.e. 2 μg/l) as unsafe to drink. However, the DWA regards 80 μg/l as safe, while the global freshwater average is 0.4 μg/l (*Noseweek* 2013, p. 11). Liefferink states that there are thousands of vulnerable, malnourished, immunity-comprised people who live in shacks among the abandoned mines in the Far West Rand and they are exposed to radioactive poisoning; 'uranium contaminates the food they grow, the fish they catch and the air they breathe' (*Noseweek* 2013, p. 11).

The National Nuclear Regulator (NNR) stipulates that half of the sites measured in the Wonderfonteinspruit area exceed the safe limit for external radiation (*Noseweek* 2013, p. 11). Liefferink (*Noseweek* 2013, p. 11) states that the damage that this is doing to the people is not known exactly and she adds that ‘for all the counting of uranium levels in the water, soil, plants and animals over the past two decades, no-one has bothered to do any epidemiological studies on the people’. She adds (*Noseweek* 2013, p. 11) that even if a small amount of uranium is ingested, it chemically attacks the kidneys and the brain, can disrupt the endocrine system and can affect the immune system. The poorer people who live along the mine dumps will experience this and may be ill for years to come.

The health impacts resulting from contaminated water on human beings tend to be increasing as more and more activists and media reports are providing information on actual incidences that have occurred. These illnesses that arise include cancer, which results from ingestion and exposure to unsafe levels of radionuclides (Frost & Sullivan 2011, p. 34). Mine water pollution in the Western Basin and communities that live in those areas are the most exposed to the risk that comes with decanted mine water drainage. Mine water causes illnesses that lead to death or absenteeism from work, and this leads to loss of income for a family, especially through the death of the income earner (Frost & Sullivan 2011, pp. 34–35).

The health risk caused by tailings dams can be reduced by the improved management of dust. A significant component of tailings dams consists of uranium and other heavy metals, and dust that arises from mine dumps also carries a significant load of health-related risks. Dust management objectives can only be achieved once the tailings have been placed in a final resting place and fully rehabilitated to include revegetation (Anthony Turton, personal communication, 4 April 2013).

Representatives and officials of the government are hesitant to concede that AMD can have these consequences or impacts. Acknowledging the socio-economic impacts will depend on how cost-effectively they can be addressed. Peter Kelly (personal communication, 6 March 2013) stated that if the technical solutions to AMD were adequate, then the social impacts would be minimal, and thus ‘government cannot afford for the technical solution to not be successful’.

6.3 Negative Socio-economic Impacts of Acid Mine Drainage: Agriculture as a Case Study

6.3.1 The Krugersdorp Game Reserve

There are several useful case studies that depict the impacts that AMD has had on agricultural activities. The first case study is not about agriculture on its own but about the impact on animals in general. The Krugersdorp Game Reserve has experienced mass water pollution since 2002 as a result of uncontrolled discharge of contaminated water from abandoned mines within those catchment areas. This has led to a drastic increase in the animal mortality in the reserve. It was reported that little has been done to try and find workable solutions, and complications with the animals' health had developed shortly after they had been in contact with polluted water. Two mining companies had placed water treatment plants near Krugersdorp, and irrespective of their neutralising of the acidity, the metal concentration in the treated water was still higher than normal where it flows into the Tweelopiespruit just before the Krugersdorp Game Reserve. Even though the water is treated, it is 'murky brown and turns plant life orange, a result of high iron and manganese levels' (Frost & Sullivan 2011, p. 30). Pollution coming from the mines has caused groundwater contamination in the Tweelopiespruit. A more recent report (Jordan 2015, p. 6) mentioned similar concerns that 'farmers along the contaminated Tweelopiespruit downstream from an acid mine water flashpoint say their borehole water is now too polluted to drink' (Jordan 2015, p. 6).

There has been a decline in aquatic life and numerous animal mortalities, which are all connected to the Tweelopiespruit pollution caused by mining and attributed to the quality of water (Frost & Sullivan 2011, p. 30). The company African Bush Adventures, who manages the reserve, wrote to the DWA about the death of aquatic life and buffalo and rhino babies that had to be aborted (Frost & Sullivan 2011, p. 30). Acid water leaking from old mines underneath Johannesburg is so heavily polluted that it is affecting tourist sites including the hippo dam and a lion enclosure at a well-known game park (Jordan 2015, p. 6).

6.3.2 Lotter Farm Krugersdorp

The second useful case study of the impact of AMD is that of farmer Dawie Lotter who conducted his farming activities outside Krugersdorp next to a mine water treatment plant. The plant was set up to deal with AMD, but his land could not be farmed and became unusable due to decanted water flooding it. This resulted in deposits of toxic metals and acid that seeped into the sand and turned orange. It even stopped the grass from growing. According to Lotter (in Frost & Sullivan 2011, p. 33), farming used to be very profitable until his land became contaminated with AMD due to mining activity within the area. He added that he had imported horses which he reared and trained on his land, but within 2 years, eight of the horses had died and the rest were ill, which forced him to sell them. Lotter's brother also tried to make a living from rearing cattle and sheep off the land, but he also experienced losses within a few months and had to sell the rest of the flock. Thus, this land was rendered unusable and the Lotters reached to an agreement with the mining company to buy out the farm (Frost & Sullivan 2011, p. 33).

6.3.3 Farming Activities in the Fochville District

The third case study is the water pollution in a mining town called Fochville (in Gauteng Province) district. Since 1998, the farmers in the Fochville area had noticed that the quantity and quality of their crops and produce and livestock production were declining. They speculated that it was caused by the salt load and heavy metals from mine effluent flowing into the Leeuwspruit Catchment. A farmer residing in that area, Pieter Rheeder, had been forced to stop his farming activities due to the poor groundwater quality, which impacted negatively on the plants. The only available water, which was the borehole water, was also deteriorating and became unfit for human and animal use (Frost & Sullivan 2011, p. 34).

6.3.4 Wonderfontein Catchment Area

The fourth case study is that of the Wonderfontein Catchment area. This area is situated between Johannesburg and Potchefstroom and includes the richest gold mines in the world (Frost & Sullivan 2011, p. 36). Gold ore from these mines also contains uranium, and approximately six billion tons of tailings contain about 600,000 tons of uranium which is exposed to the biosphere (Frost & Sullivan 2011, p. 36). The services of the Cancer Association of South Africa (CANSA) are available to the residents in Randfontein and Carletonville to monitor their health conditions. Residential areas that are in close proximity to the mining operations as well as CANSA have been confronted by the local NGOs to identify what the possible risk of cancer is in this environment. In 2008, three CANSA employees went on a visit to a tailings area in Carletonville and were exposed to dust, because they were seated in an open vehicle. They experienced symptoms of headaches, loss of appetite, eye irritation, sore throats, nausea, severe diarrhoea and skin rashes (Frost & Sullivan 2011, p. 36). The chemical and physical properties of the tailings dust in the area were analysed to determine why the employees had become ill. The outcome was that the CANSA employees' illness was due to being exposed to and possible inhalation of specific deposits of tailings dust that was both radioactive and arsenic (Frost & Sullivan 2011, p. 36). This is directly related to Turton's and Liefferink's definition of AMD in Chap. 4.

The agricultural sector is involved in experimentation to determine how the negative impacts of AMD and contaminated water can be overcome. According to representatives from AgriSA (Nic Opperman, Adriaan Louw and Meiring du Plessis, personal communication, 22 November 2013),

> In the Wonderfonteinspruit one always hears of farmers complaining about radionuclide contamination of the crops that are produced; there is also the salinity aspect. A lot of experimental work is being done with the use of the water in the gold fields (treated water) and this has been successful, there is a possibility that agriculture can make a contribution to solving some of the problems associated with contaminated water from which they can benefit. The Grootvlei, for instance, has neutralised the water. In the Blesbokspruit farmers were successfully irrigating with that water.

Thus, AMD and the issues that surround it are known to have numerous socio-economic consequences, but addressing these issues step by step can lead to finding a means to an end.

6.4 Possible Solutions to the Socio-economic Impacts (Mainly in Agriculture)

Water is essential for the social, economic and environmental good of humans, animals and plant life, and it is essential that water-related policies are implemented in ways that pay attention to the poor so that they too can meet their basic needs (DWAF 2008b, p. 12). ‘Government policy since 1994 has focused strongly on equitable and sustainable social and economic development for the benefit of all South Africa’s people’ (DWAF 2008b, p. 10). All national legislation mentions that socio-economic aspects need to be taken into account, to achieve efficient and effective water use. In 2008 the Department of Water Affairs and Forestry updated the National Water Resource Strategy (NWRS). The driving principle for this change was the vision for a ‘robust and accountable water sector, which successfully meets demands for water security and reliable and effective water services, and enables equitable, environmentally sustainable economic growth and social development in South Africa’ (DWAF 2008b, p. 10). A few important principles stemmed from this process, which are significant in this research. The decisions regarding the use of water must balance the economic, social and environmental dimensions of water. Sustainable service provision and water management rest on a strong partnership between citizens and government with mutual accountability (DWAF 2008b, p. 10). However, with the fast pace required to address AMD and to prevent further harm to the environment, the socio-economic impacts do not seem to be accounted for or are not prioritised, and neither is there much discussion nor are workable solutions presented for how they will be addressed.

Peter Kelly (personal communication, 6 March 2013) views AMD as more of a technical issue than an environmental one and believes that only if the technical issues are not addressed adequately can they become an environmental issue. A technical issue means that it would ultimately need a technical solution. The problem with such an approach is that the socio-economic impacts are overlooked. When the environment receives priority, then human health is not entirely considered or placed as a concern. Kelly however, hoped that AMD could be managed in the future, that the implications would not be far too horrific to consider and that the social implications would not be too extensive.

In addition to the fact that the South African government has policies in place to protect the country’s water resources, there are also policies in place that protect the rights of the public. The government departments who are in charge of ensuring that the water resources are used in a sustainable manner and that can sanction transgressions, however, are not empowered also to enforce remedies to the socio-economic impacts. Thus, there needs to be a ‘working together approach’ by all the role players to ensure that everyone played their part in solving this issue. Those responsible must clean up the damage; the government as the custodian of the water resources has to play its role in addressing AMD by ensuring all available advice on the environmental and socio-economic impacts and on the health of people become available to addressing AMD from an approach that favours all, that is, protecting the water, the environment and the citizens who live in the affected areas.

When planning for the closure of a mine, the anticipated social impacts should also be included. Communities will be affected by mine closures, and if they are directly affected, then water management strategies, health and safety issues and possible employment opportunities should be considered as proposed strategies to counter the negative impacts. Closure should, however, be planned in such a way that it will not have a negative impact on other water users (DWAF 2008a). Such negative impacts include that of taxpayers having to foot the bill as might be the case in light of government's approach to address the AMD issue and to provide clean water to the citizens (as stated in Chap. 5).

Gauteng is a growing province and is also growing in economic and industrial needs. For these reasons more water is needed in this area. Therefore, the second phase of the Lesotho Highlands Water Project is under way. The TCTA currently pumps water into the Katse Dam to Clarens as part of the Lesotho Highlands Water Project scheme. The water is then channelled by river to the Vaal Dam for service in Gauteng. This is costly, because it requires sophisticated infrastructure and that the Lesotho Highlands is also the second source of water (Shanna Nienaber, personal communication, 12 March 2013).

Alleviating the economic impacts includes revenue generation, mine water irrigation and crop production. Crop irrigation using treated mine water can be profitable, environmentally friendly and economically sustainable. Thus, using neutralised and desalinated mine water can have the potential benefits of increased agricultural productivity at regional and country level due to commercial crop production on a large scale using mine water for irrigation. In October 2015, a similar approach was suggested and mentioned in a media report (Solomons 2015, p. 5), stating that mines could use neutralised AMD water for their own processes or the AMD water could be enclosed in a holding area to be evaporated out of the system or it could be used for certain agricultural practices.

By treating the water using water treatment plants, society can gain significant benefits such as the provision of clean piped water and suppression of dust for communities living in and near the mining areas. The use of research by industry in metal removal processes, water treatment processes and environmental rehabilitation processes produces useful industrial materials. By-products such as gypsum derived from water treatment processes can be used to manufacture building materials, fertilisers and mining products. Ferrite can also be used in other mining operations if metals are removed. The points mentioned above can all lead to job creation (Frost & Sullivan 2011, pp. 9–10).

During an interview with AgriSA, the interviewees were asked if treated mine water could become an alternative source of water which was not accessible in the past or if it was by coincidence that it became part of the available water resources. The response was that if referring to the total water balance, this water was always there but it was pumped out over a period. When this pumping took place, it was pumped out of the water system completely, but 'we do not have good-quality water resources available like there was in the Witwatersrand before the Goldfields' (Nic

Opperman et al, personal communication, 22 November 2013). Will the treated mine water create new opportunities for agriculture? AgriSA was of the opinion that agriculture was already experiencing a water deficit and the demand was still growing but that it would stabilise if water could be released from the dams. At the same time, the released water could be used to dilute the treated mine water pumped into the rivers and the other forms of river pollution. The danger, however, was that if water released to dilute the water to an acceptable quality was not well managed, less water for household use would be available, and the quality of the water for domestic users might also be lowered (Nic Opperman et al., personal communication, 22 November 2013).

The use of treated mine water for agricultural irrigation can create jobs, as an additional labour force would be needed to meet the demands that come with the increased production. The use of mine water for irrigation has implications for South Africa in general and the agricultural production along the Vaal River. It offers benefits including stabilisation of dry land crop production with supplementary irrigation, production during the dry seasons and a cost-effective method of reducing the additional mine drainage. Increased amounts of water can be made available to the farming community and can be used for irrigation of high-potential soils such as in the coalfields in Mpumalanga province where water resources are already restricted. A large number of jobs could be developed which would advantage the local community and South Africa as a whole (Frost & Sullivan 2011, p. 14).

According to Jovanovic et al. (1998, p. 112), the coalfields in Mpumalanga province in South Africa underlie one of the most important high-potential agricultural areas in the country. 'The area in which the coal fields occur is a major catchment for rivers supplying water to the industrial and mining heartland of Gauteng, the national Eskom power grid, important irrigation schemes and the Kruger National Park' (Jovanovic et al. 1998, p. 112). Most South African coal deposits contain pyritic formations, and when exposed to oxygen, water and iron pyrite, they are oxidised to sulphuric acid and iron sulphate. This leads to increased quantities of AMD forming. The high acidity of this water excludes it from being discharged into natural streams, because the environmental impact would then be severe. Disposing mine waste water is an issue and becomes a concern from an ecological viewpoint. If discharged into the natural environment, lime-treated AMD can cause salination of soil, rivers, dams and catchment areas. 'Lime-treated AMD has in the past only been used for dust alleviation on dirt roads and irrigation of lawns' (Jovanovic et al. 1998, p. 113). In contrast, Frost & Sullivan (2011, p. 15) are of the opinion that treated water could be used for irrigation of agricultural crops and for higher-potential soils, and 'filtering saline water through the soil, and thereby precipitating gypsum in the profile, could limit environmental pollution'. The high costs of AMD treatment could thereby be balanced to some extent by commercial farming's income (Jovanovic et al. 1998, p. 113). The use of this lime-treated AMD water could be used for irrigation of agricultural crops and could solve water shortage problems and benefit communities (Jovanovic et al. 1998, p. 119).

According to Opperman et al. (personal communication, 22 November 2013), the case in the Blesbokspruit in Gauteng is similar to that in Mpumalanga. AgriSA was not aware of similar cases in the Western Basin, but in the Wonderfonteinspruit, the farmers are now using the treated water. A question of interest that arose from this was that in terms of volume, much water was already being treated and was available for agricultural use, but why was it not being used more? AgriSA's response was that the lime-treatment process was being investigated further and could be developed more. Furthermore, some farmers were authorised to use effluent water or could apply for a licence, but there were risks involved in using the water. The DWA was also investigating this option (Nic Opperman et al., personal communication, 22 November 2013).

According to Opperman et al. (personal communication, 22 November 2013),

> The perception is that the mines that are responsible for this were around for a very long time and, as part of their operations, they had to dewater and part of their conditions was to neutralise but this was not always done and the water was dumped into the streams and formed part of the Vaal River system. Government had supported these mines through pumping subsidies to keep these mines alive and they had to pump water that seeped in from other mines. The salt load then had to be dealt with. The DWA tried to manage the salinity in the Vaal system but the levels increased and affected the users downstream who had then to manage with these increased salinity levels. The additional water that has to be diluted puts [South Africa's] water resources in dire straits because there is not enough water to do this, especially in Gauteng. In addition to neutralising the water, there are plans to desalinate it with reverse osmosis and this is not to create additional drinking water but to remove the salinity. When irrigating with this water, the plants extract the water component and it concentrates all the salts in the water. If this is done with the neutralised AMD, a significant percentage of salt precipitates and this does not affect the quality of the soil or cause harm to the plants. This will enable up to 50 per cent of salinity being removed and less diluted water is needed.

Thus, from the explanation above, agriculture remains part of the solution to treating acidic affected water.

The social impacts are many and tend to be overlooked completely when AMD is being addressed by government departments. Consultants and activists are more likely to bring to light to what these impacts are and cases where these impacts have occurred and will fight for a solution. Contaminated water tends to have numerous direct and indirect impacts on society, and they link closely to the environmental impacts mentioned above as well as contamination of land that leaves farming activities unsuitable (Frost & Sullivan 2011, p. 31). Pollution of farming land by decanted mine water can lead to toxic elements leaking into the soil. This will have an impact on the communities who live nearby, forcing them to relocate and suffer all the inconveniences that come with relocation. Mine water also has effects on different animals. Animals act differently when they come into contact with contaminated water. What is common is that animals suffer miscarriages, deformities and birth defects that affect their joints and cause diarrhoea (Frost & Sullivan 2011, p. 31).

The research conducted by the WRC is meant to play a crucial role in reducing the negative social impacts that mine water has had in South Africa. There are known cases where land for faming has been lost and peoples' livelihoods have been comprised as the outcome of mine water contamination (Frost & Sullivan 2011, p. 31). The WRC's research on the use of mine water has benefits for the society and include reduced pollution of farming land, which will improve crop production and enhance standards of living, and limited polluted surface water, which will increase livestock and household income, which, in turn, will enhance livelihoods and improved quality drinking water, reducing mortality among communities (Frost & Sullivan 2011, p. 32).

6.5 Conclusion

The objective of this chapter was to identify the instances of the socio-economic impact of AMD. As indicated in the literature in Chap. 3, the knowledge on this aspect of AMD is rather limited or under-researched. Much more attention is paid to the geoscientific and engineering aspects of AMD. Certain limitations make original research of the socio-economic dimensions exceptionally difficult, such as the ostensible political sensitivity of the matter, the unpredictable cost implications, the negative reputation it can present to the mining business community and foreign investors and the fear of sensationalism.

The results in this chapter are, therefore, limited. Impacts in the areas of the environment, health, social welfare and economics were identified. Most obvious are the environmental impacts, though their extent is not yet fully known. Tourism appears to be almost untouched by the AMD concerns, while the main unknown area is the health implications of AMD and MRAs.

Agriculture presents an important test case that can determine the impact of both the contaminated mine water and acid rain, the environmental impact on river systems from which irrigation is done, the practical agricultural use of treated mine water and the by-products of the treatment process.

In conclusion, the research cannot yet present a definitive assessment of the socio-economic impacts of AMD, and, therefore, the need for much more research in this field is identified. Identification of these impacts is partly dependent on how AMD is defined (as discussed in Chap. 4). As a result, huge differences of opinion exist between government officials and the NGO activists about the very nature and impact of AMD.

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Chapter 7
AMD and a Sustainable Future for South Africa

The aim of this book was to investigate and determine from a sustainable development perspective whether the South African government's evolving policy response is sufficiently synchronised or sensitive to the social dynamics of AMD in the Vaal River system. Three objectives were derived. The first was directed towards the government's policy response to AMD and how it evolved. The second objective was to determine the socio-economic implications of AMD in the Vaal River system, who are affected by it and how are they affected. Lastly, the third objective was to determine whether the emerging policy would be able to address the impact of AMD on society.

The objectives of the research were, to a large degree, concerned with the government's policy and how it addresses the socio-economic dynamics of AMD. Therefore, public policy within sustainable development was used as the conceptual framework on which the research was based. Qualitative methods were used to conduct the research through the use of key informants who were an essential source of information and who contributed significantly to the conclusions of this book. The use of semi-structured interviews allowed for new information to be gathered from the key informants which was used in combination with official documents, media reports and published literature.

The first main conclusion—and also, arguably, one of its important contributions—is conceptual in nature. The manner in which AMD is defined also determines how it is assessed as a water management, environmental and social problem. It also means that the response to AMD is determined by how it is defined. The conventional definition in the literature is that acidic water is formed underground when old mine shafts fill up with water, which oxidises with the sulphide mineral iron pyrite; this then decants into the environment causing AMD. This conceptual understanding of AMD is also embraced by South African government officials. However, during the interviews conducted for this research, new ways of defining AMD were identified. This included acidic and radioactive water that is formed by surface interactions between acid rain and mine dust on the tailings dams. The link

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between acid rain and acidic mine water was not generally known and hardly referred to as an option or way of defining AMD. A more elaborate definition of acidic mine water that focuses not on the underground mine water but on the formation of mine residue-induced water contamination above ground is the link between acid rain, uranium mine dust and radioactivity. The result is AMD in the context of the combined effect of radioactive rainwater flowing from the mine residue areas, uranium mine dust distributed by wind and underground AMD entering the surface water systems. This research concludes that an effective response to AMD will have to use the latter definition as its point of departure, an approach that is currently not yet used.

In addition to the conceptual aspect, a situational analysis of the occurrence of AMD in the Vaal River system was also required in order to determine the scope and nature of the AMD problem and its impact on South African society. When the research commenced, the media and activists were concerned, regarding the Western Basin as a write-off. The underground water in the basin reached the ECL in 2002, and it has had an impact on the Krugersdorp Nature Reserve, the Tweelopiespruit and also reached the Cradle of Humankind. Numerous media reports predicted that the Cradle would be flooded and tourism would be affected. Pumping of mine water commenced, and it was partially treated, which resulted in decanting being stopped, and by the end of 2013, the water level was kept below the ECL. Initially, no aquatic life was found in the water, and the wildlife in the Krugersdorp Nature Reserve was affected. After conducting the research and interviewing the key informants, it was found that the Cradle had been affected by an inflow of underground water, but it was managed in time. The water was treated, and there was no serious threat to the underground caves and fossils. Tourist activity could therefore continue. What is still unknown is the actual quality of the treated water and whether it is fit for human use. Activists believe that the water is not appropriate for human use, yet some state that the water has improved and that by the end of 2015 even aquatic life existed in the water.

With respect to the Central Basin, the prediction by the various sources was that the Johannesburg CBD would start decanting by September/October 2013, but by the end of 2013, it had not yet materialised. Early in 2013 the tourist centre Gold Reef City also became a topic of concern. However, after interviews with key informants and with a close watch on media reports, it was evident that the water level in the Gold Reef City mine was being managed, had been treated in time and did not reach the ECL. The theme park was therefore not affected as suspected. At the end of 2015, the total flow of water that was pumped into this basin was 60 Ml/d. A newly constructed plant near Germiston was tested, and pumping, treatment and release of pretreated AMD in this plant reached its full capacity.

When the research began, the Eastern basin was viewed as the basin with the least amount of concern. The problems started in 2011 when pumping at the Grootvlei mine was terminated as a consequence of problems with the ownership and management of the mine. The result was that the water level at neighbouring mines increased rapidly. Therefore, decant in this basin is predicted to start in November 2014 if pumping at Grootvlei is not restored soon. What was identified during the study was that this basin has the largest volume of mine water that needs to be controlled—pumping activity is planned at the Grootvlei mine at Shaft No. 3, but there is major dispute over the ownership of this mine, and until this is resolved, pumping activity cannot commence.

The conclusion of this research is that at the end of 2015, the situation appeared not to be out of control. While the Western Basin was initially regarded as the most problematic AMD region, at the end of 2013, more uncertainty existed about the Eastern basin, mainly as a result of the Grootvlei management problems, and not because of technical or policy deficiencies. However, by the end of 2015, the problem still was not completely addressed but was under control whereby emergency plants were established and acid mine water was treated to remain below the ECL.

An uncertain element in this situational analysis is the impact of rainfall. Almost all the key informants referred to the exceptional rainfall in the 2010/2011 season and how it had exacerbated the incidences of AMD. While outside the scope of this research, the same happened in March 2014 and dramatically changed the situation in the Western Basin. The drought in 2015 reduced the AMD discharge to below the average levels but did not stop it completely. An additional conclusion could, therefore, be that rainfall patterns should be more seriously considered as a potential threat in the assessment of the three basins.

One of the major findings in the research was on the issue of mine ownership, mine closures and abandoned mines: who is responsible for the environmental impact of these mines and who should pay the costs for the environmental rehabilitation of these mines? There is, and always has been, legislation in place to ensure that mining companies comply with the rules and regulations, but in reality this proved to be superficial. The government and related departments still have an ongoing process trying to ensure that those who are responsible take ownership for the damages caused. The problem with this approach is that it is time-consuming to identify and find the mining companies that are responsible for the damages caused, because most of them are no longer in existence. The finding is, therefore, that because most of the mining companies that are responsible are not able to pay for the damages, it has become the taxpayers' responsibility.

The first objective of this research was to investigate the different responses from government and the measures that were put in place to address the AMD crisis. An important conclusion of this research is that the government sees AMD primarily as an underground mine water issue that needs to be treated and has not yet been looked at from other angles. The additional proposed responses are treatment and removal of the tailings dams and mine residue areas as a means to supplement pumping of underground mine water, thereby removing the additional elements of AMD as defined by the NGOs and some researchers. The government's IMC report was extensively analysed, and it was found that the report did not address the socio-economic impacts caused by AMD. From the media reports and the responses from various activists in the field, it is evident that there are indeed negative socio-economic impacts on health, agriculture and South Africa's water systems. The government's focus on pumping of underground water is seen as a short-term solution; the long-term solution has not yet been finalised.

The current policy response also includes chemical treatment of the pumped water which includes management of the sludge residue. Both the treated water and the sludge are either not yet appropriate for human consumption or create new mine residue areas. Exceptional rainfall cannot be accommodated in the current approach and exposes the fact that pumping addresses the symptoms of AMD but does not provide a long-term solution. This is vital as it should address the socio-economic impacts that AMD causes. A Mine Water Management Unit is to be established in 2016, but has not been finalised. This unit will take into account the socio-economic impacts, but there is no clear indication of what these are. It should be mentioned that the government's response to AMD is not the only approach, and private companies such as Mintails are engaged in complementary treatment processes such as reprocessing and relocation of tailings dams which are more in line with the alternative definitions of AMD and more targeted towards other socio-economic consequences.

The second objective of the research was to determine the potential or real socio-economic impacts of AMD. These included the environmental, social, economic and health impacts that contaminated mine water could have on communities who live around the mining areas. In the interviews with government officials, interest groups and some researchers, it was found that they did not express serious cause for concern about the socio-economic impacts and this was supported by the fact that the government does not pay much attention to these impacts. However, activists believe that the socio-economic impacts are many and very serious. Thus, once again, there are differences in opinion over this between the various role players.

Agriculture is an extremely important element of the society which can become potentially affected by AMD because it is the biggest consumer of water in South Africa. Agriculture's use of water requires a combined consideration of the impact of AMD on both agriculture's environmental dimension (i.e. the use of land, water and the atmosphere) and its social and economic dimensions (i.e. production of food for human consumption). It is, therefore, a critical test case of the socio-economic impact of AMD. AgriSA, on behalf of the agricultural sector, does not see AMD as an impending crisis for agriculture. It does not have systematic empirical evidence of the negative impact of AMD on any aspect of the agricultural sector. However, the research came across several case studies that illustrate individual instances of declining production of crops, death of animals and, eventually, farmers who had to abandon their farms.

The fact that in the interview AgriSA did not reveal any concern about the possible effects of AMD, while some case studies of the negative effects are available, raises the question of how it can be explained. One possibility is that research into the socio-economic impacts of AMD is in general not encouraged, because the focus is primarily on the geoscientific and engineering research to find a technical solution to the phenomenon. Other forms of research are, arguably, regarded as less of a priority. A second possibility is that AMD is politically too sensitive; it involves the mining sector and foreign investors and is regarded as a strategic sector of the South African economy. From agriculture's point of view, negative reports about AMD impacts might have negative trade repercussions, similar to the ban on red and ostrich meat for a long period and restrictions on citrus exports. It is argued that bad news with cost implications or sensationalism should probably be avoided, while any revelation about the socio-economic impacts will possibly have such an effect.

One of the most serious challenges for this research was to determine—in addition to its agricultural effects—other socio-economic impacts of AMD. As already indicated earlier in the literature (Chap. 3), very little literature exists in this field. Most of the evidence is in the form of anecdotal observation or reports. As a result, there are such diverse opinions between the different role players, and, of course, the media exaggerate one minor impact and make it an enormous cause for concern. This is the case, because they have leading activists and NGOs providing them with information illustrating how severe the issue is. What was found was that the intensity of the problem determined how rapidly it would be addressed. However, irrespective of the scale of the impact, the fact remains that even the smallest impact is a proof that a larger and more extensive impact is definitely possible. This is what Liefferink and other activists are stressing.

Based on the research conducted, including the interviews with the activists, it can be concluded that at this stage no comprehensive empirical statistical data exist in the public domain on the socio-economic aspects of AMD. In the absence of such data, the approach followed mainly by NGOs is to state that case studies of socio-economic consequences do exist and that they can be extrapolated to make a case for the nature (but not the scope or extent) of the socio-economic impacts. The point of departure of such an approach is that mine water from both the surface and underground is often radioactive, acidic and rich in sulphates and metals. This mine water is complemented by radioactive uranium particles in the mine dust. From the interviews, it can be derived that the approach then followed by the activists is to concentrate on the socio-economic dimensions most exposed to these elements. They would be the environmental dimension (especially aquatic life), the possible impact on tourism (at the Cradle of Humankind, Gold Reef City and nature reserves), housing (its threat in dolomitic areas to develop sinkholes that will make residential use unsafe in the areas), the economic dimension (including its impact on the mining sector; on the demand for pure water by industries, Eskom, Sasol and others; and on the safety in Johannesburg CBD, both in terms of possible flooding, and the safety of building foundations and increased seismic activities) and a wide range of possible health implications.

There are, thus, several arguments that suggest that AMD will have many consequences, but there is also no real evidence available yet about the long-term socio-economic impacts that this could actually have. This is an area that will require more attention in the future. As a conclusion, it should be said that the problem that motivated this research in the first instance, namely, uncertainty about the impacts of AMD and especially its socio-economic impacts, could not be completely resolved in this book. The perceptional aspect received much more clarity, and it revealed how different stakeholders perceived AMD and its impact. The policy perspective has been investigated in much more depth, and lack of alignment between the socio-economic implications of AMD and policy measures is also better demonstrated.

The final conclusion regarding whether the government's policy is sufficiently synchronised or sensitive to the social dynamics of AMD in the Vaal River system is, therefore, a qualified 'no'. The policy is more informed by geoscientific and engineering considerations than by the requirements of sustainable development. Should the government's policy approach be directed more towards the alternative definition of AMD that also includes the effects of acid rain, uranium mine dust and removal of the tailings dams to a central point, the conclusion would be more positive. Should a long-term policy be developed that includes the options investigated by Aurecon and others, which would improve the quality of treated water, the conclusion would then also be more optimistic.

The following recommendations are identified that could be further researched. The first recommendation is similar to one of the conclusions and that is that more research on the socio-economic impacts with regard to AMD should be conducted in the future to understand better and to limit the negative impacts that AMD has on health, agriculture, food security and other developmental aspects. The second recommendation is that policy documents on policy-making in general should focus more on the socio-economic impacts. Thus, social scientists should be requested and allowed to become more involved in support of the official processes of policy-making, and at the same time, there is a need for that type of research in the academic/research environment. The last recommendation is with regard to research methodology; more researchers should take part in direct fieldwork and engage with stakeholders in the form of interviews with government officials and not just depend on literature studies—this book demonstrated the importance of such research.