

THE DEVELOPMENT OF A RISK-BASED COMPUTER
DATABASE TO PRIORITISE THE ENVIRONMENTAL
REHABILITATION OF DEFUNCT AND ABANDONED
COLLIERIES IN THE WITBANK AREA OF SOUTH
AFRICA.

Linda Ann Rapson

A research report submitted to the Faculty of Engineering and the Built Environment, University of Witwatersrand, in partial fulfillment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2004

DECLARATION

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

Linda Ann Rapson

_____ day of _____ 20 _____

ABSTRACT

Abandoned and defunct collieries are a source of great concern to various Government Departments, including the Department of Minerals and Energy and the Department of Water Affairs and Forestry as the legal liability for their environmental management and protection falls on the State. Workers in the mining environment field have come to realise that abandoned mines pose threats to the environment and to public health and safety, and must be assessed. In order to rank abandoned or defunct mine sites, it is necessary to identify all risk factors and consequences in a risk assessment process. The data for each mine is entered into the database, producing a numerical comparison which gives a first cut assessment of the severity of the risks each mine poses. The objective of the database is to be able to identify, quantify and rank the risks in the nature of safety, health and the environment (SHE) and provide information required to address these risks through partnerships with all stakeholders.

DEDICATION

To my family.

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NOMENCLATURE AND DEFINITIONS

Abandoned	A mine having no identifiable owners or operators.
COALTECH 2020	This collaborative program involves representatives from 15 international and 15 national organizations, including all the major mining houses, the Department of Water Affairs and Forestry, the Department of Mineral and Energy, the Department of Environmental Affairs and Tourism, the CSIR and academia (three South African universities).
Consequence	That which is produced by a cause and is important with respect to what comes after.
Defunct	There is an identifiable owner or operator of the mine, but it is not operating.
Goaf	That part of a mine from which the mineral has been partially or wholly removed; the waste left in old workings.
Impact	A forceful consequence, influencing strongly.

LIST OF ABBREVIATIONS & ACRONYMS

CSIR	Council for Scientific and Industrial Research
DME	Department of Minerals and Energy
DQA	Data Quality Assessment
DQO	Data Quality Objectives
DWAF	Department of Water Affairs and Forestry
EPA	United States Environmental Protection Agency
ERA	Environmental Risk Assessment
ETH	Eastern Transvaal (Mpumulanga) Highveld
FAII	Fish Assemblage Integrity Index
ITZC	Inter-Tropical Convergence Zone
MELP	Ministry of Environment, Lands and Parks
MMSD	Mining, Minerals and Sustainable Development, a project of the International Institute for Environment and Development
MRDA	Minerals & petroleum Resources Development Act
NSW	New South Wales

PM	Particulate Matter
RHP	River Health Program
RRT	Risk Ranking Tool
SASS	South African Scoring System
SES	Sponcom Expert System
SHE	Safety, Health and Environment
Simtars	Safety in mines testing and research station
Sponcom	Spontaneous Combustion
T & DB	Transvaal and Delagoa Bay Colliery
TDS	Total Dissolved Solids
UNEP	United Nations Environment Programme Division of Technology, Industry and Economics
USCOLD	United States Committee on Large Dams
WOM	W.O. Mackasey Geological Associates INC.
WP-F92	Department of Water Affairs and Forestry White Paper No. F-92

LIST OF SYMBOLS

%	percent
°	degree
mm	millimetre
m	metre
m²	square metre
m³	cubic metre
m/s	metres per second
mg/L	milligram per litre
mg/m³	milligram per cubic metre
N	Weinert Index
ppm	parts per million

1 INTRODUCTION

Many older mining operations started at a time when there was little or no explicit concern for the surrounding environment. In many instances, old mines were simply abandoned and no attempt was required (or made) to rehabilitate the surface workings when the economic life of the ore body was exhausted. This situation now places enormous responsibility for rehabilitation on the State, and is accompanied by a considerable economic burden (Ashton *et al* 2001:62).

Mine closure is an aspect of mining where historic practices and contemporary, evolving community and government expectations do not coincide. The need to deal with the closure issue is increasing, owing to public health and safety issues and, more recently, to increased awareness of environmental contamination and the importance of environmental preservation.

At present, the mining industry is policed according to an integrated environmental management system administered in terms of the Minerals Act of 1991 (Act 50 of 1991), which states that all South African mines have the responsibility of managing the effects of mining on the environment (Scott, Swart, 2003).

1.1 *Statement of the problem*

Abandoned and defunct collieries are a source of great concern to various Government Departments, including the Department of Minerals and Energy and the Department of Water Affairs and Forestry as the legal liability for environmental management and protection falls on the State. In the absence of existing owners, it is the State's responsibility to achieve mine closure certification. The State is expected to bear the costs, and prioritisation of site clean-up is critical.

1.2 *Proposed solution/hypothesis or argument*

As part of the Collaborative programme, Coaltech 2020 and the Defunct and Abandoned Collieries Task 8.4.1, the author is a member of the team tasked with gathering information for these mines in the Witbank area.

The criteria necessary for risk assessment is to be captured in a database and ranked to determine the priority for action and remediation.

One of the major outstanding environmental problems related to mining is that of abandoned mine sites. It is a legacy of centuries old practices and of inadequate, insufficient or non-existent mine closure. The potential costs of rehabilitation, the lack of clearly assigned (or assumed) responsibility, the absence of criteria and standards of rehabilitation and other factors have delayed action by all parties – industry, governments and communities. Yet, land degradation from old mine operations is well known in almost all countries (UNEP, 2001).

Inadequate, improper or neglected mine closure results in abandoned mine site problems. The topic of abandoned mines is also difficult because of the associated financial and legal liability implications. UNEP has been trying to raise the profile of this important, but so far neglected, issue for a number of years.

Since abandonment is usually sudden and unplanned, governments are often left responsible for mine closure and rehabilitation. Clark *et al* (2000) stated that 'closure and rehabilitation costs [of abandoned mines] must be directly or indirectly born by the State. As such, the abandoned mines represent not only a major liability for the government but for the affected communities, adjacent areas and society at large: the latter must ultimately bear the financial burden of ensuring appropriate closure.'

The issue of abandoned mines is important because it represents many former mining sites that continue to pose a real or potential threat to human safety, health and/or environmental damage. In many areas this is considered a negative legacy of the mining industry and is important because it demonstrates both a lack of care and planning in past practice and adherence to regulations that were inadequate because of the lack of detailed understanding. In general, the presence of abandoned mines negatively influences public perceptions of the industry (MMSD, 2002:1).

In the past, the media and public usually considered mine subsidence or tailings spills at abandoned sites as isolated occurrences. Workers in the mining environment field have come to realise that abandoned mines pose threats to the environment and to

public health and safety, and must be assessed. Attempts have been made in many countries to locate, study and correct problems at abandoned mine sites. A first step in rehabilitation is the identification, location and assessment of abandoned mines (Mackasey, 2000:1).

Historically, it was common practice to 'abandon' a mine site when mineral extraction was completed. The land was left un-vegetated and exposed, while waste materials were left in piles or haphazardly dumped into mine cavities and pits. There was little concern for the environment and no thought of how mining might adversely affect the surrounding ecosystem for years to come. This can be compared with the current situation at many operational mine sites, where the need for rehabilitation is now taken for granted and companies and governments have established legal, financial and technical procedures intended to ensure that mine sites are returned to a socially useful state after operations cease (MMSD, 2002).

Ms Hoskin (UNEP, 2002) noted that the causes of inaction and lack of real progress in addressing this issue relate to: the fact that mine closure practices have changed; that expectations related to proper mine closure have changed; the lack of clearly defined or assumed responsibility; the lack of definition of what *is* an abandoned mine site; the absence of criteria and standards of rehabilitation; and the real and perceived cost of rehabilitation.

The environmental, social and economic problems associated with abandoned mine sites are serious and global. They affect all former mining countries: Brazil, Canada, France, Philippines, South Africa, the United States, etc.

1.3 Project Output

The project output can be summarised as follows:

- Description of a process for decision support;
- List of hazards and issues that is used in assessing the total risk posed by an abandoned mine;
- List of standardised values for consequence, exposure and probability;
- A listing of the critical information that has to be contained in an abandoned mines database;

- A description and structure for the establishment of an abandoned mines database;
- An electronic framework where the information can be entered;
- A first round prioritisation exercise that could be used to allocate funds for the 2003/2004 budget.

1.4 Definitions

Fuggle (1992:4,86) cautions against the incorrect use of the term **environment** and states that 'strictly speaking, reference to **environmental problems** should indicate the impaired interrelationship between human beings and their physical surroundings as the central concern.'

A mine is considered **abandoned** or ownerless if there are no identifiable owners or operators for the facilities, or if the facilities have reverted to federal [State] ownership. Oberholzer (2003) suggests that this definition be broadened and that an abandoned mine 'has ceased to operate, rehabilitation and demolition has not been conducted to acceptable standards and the owners due to various reasons have no intent or are incapable of doing the required rehabilitation and demolition.'

A mine is considered to be **defunct**, derelict or inactive if there is an identifiable owner or operator of the facility, but the facility is not currently operating and there are no approved authorisations or permits to operate (MMSD, 2002).

Other terms commonly used in the mining industry include: inactive mine, orphaned mine, and unattended mine. The term 'orphaned' mine has been used by some to describe sites without an owner. Sites described as 'temporarily shut down' or 'under care and maintenance' would imply that an owner is still actively managing the site. In choosing a definition, the important point is the need to focus on public safety and environment problems, not on who owns the site (Mackasey, 2000).

1.5 The Impact of Abandoned Mines

Public health and safety, environmental status and aesthetic concerns are commonly associated with abandoned mines. Ironically many complaints from the public address the latter. Commonly, little attention has been paid to the 'hidden hazards' posed by

chemical and physical stability attributes. Problems generally arise from one or a combination of four factors: mine closure with little or no reclamation, inadequate government policy, use of a site for a purpose other than mining, and lost or missing site data.

The physical impacts of abandoned mine sites include: altered landscape; unused pits and shafts; land no longer usable due to loss of soil, pH, or slope of land; abandoned tailings dumps; changes in groundwater regime; contaminated soils and aquatic sediments; subsidence; and changes in vegetation. These problems have social and economic impacts on countries and individual communities due to: loss of productive land; loss or degradation of groundwater; pollution of surface water by sediments or salts; fish affected by contaminated sediments; changes in river regimes; air pollution from dust or toxic gases; risk of falls into shafts and pits; and landslides.

In addition to the obvious problems for the community, most of these situations represent a considerable cost to public authorities which are often expected to make the sites secure and prevent ongoing pollution. The public is increasingly demanding action and this visible legacy of the past is producing growing community opposition to current mining activities.

The abandoned sites problem, therefore, continues to cast a shadow over all mining at a time when major operators are improving their operations and are trying to improve the image of their sites and their company. This can be compared with the situation at current operational mine sites where the need for rehabilitation is now expected and often mandated, and for which companies and governments have established legal, financial and technical procedures to ensure that mine sites are rehabilitated to make possible another economic use after the mining operation ceases (UNEP, 2000).

1.6 Why Do We Have an Abandoned Mines Problem?

In a survey of abandoned mines in Canada, WOM Geological Associates (2000) lists the following as the mining related elements that occurred to create the legacy of abandoned mines:

- Mining related;
- Legislative policy and administration related;

- Civic development related;
- Data related.

1.6.1 Mining Related

Mining exploration and development activities can leave behind the following problems: openings to surface, areas of potential collapse (subsidence), mine wastes, mine effluent, and surface structures and machinery. Upon closure, under normal conditions, mining company officials would place bulkheads in the openings, stabilise or fence off areas of potential subsidence, clean up and contain the mine wastes, treat the mine effluents and remove surface equipment and machinery. A number of elements have occurred to create the legacy of abandoned mines: Economic, Technical and National Security (Mackasey, 2000).

1.6.1.1 Economic

Unforeseen events, such as a sudden drop in metal prices, insurmountable mining/milling difficulties, and infrastructure problems cause early closure or left companies bankrupt.

1.6.1.2 Technical

Prior to the introduction of drilling equipment in the 1930's and 1940's, mineral deposits were evaluated by numerous exploration shafts and test pits which were never back-filled.

1.6.1.3 National Security & Political Unrest

Local political problems in some regions may lead to unscheduled closure of a number of mines, although this impact on the Witbank area has not been determined.

1.6.1.4 Small scale mining

The uncontrolled occupation of mine sites by artisanal or illegal miners has occasionally led to a site being abandoned.

1.6.2 Legislative Policy and Administration Related

Swart (2003) suggests that the role of Government can be summarised as follows:

- The 'guardian of the environment' through the Constitution;

- Acting as a responsible mechanism to serve the public and tax payers' interest and to ensure a safe and healthy environment;
- Promoter of sustainable development;
- Final inheritor of remaining problems and mine legacies;
- The Regulator of the mining industry.

Mines have to comply with the South African constitution (Constitution of South Africa, 1996, Section 24(a)) and common law (Swart, 2003). At present, the mining industry is policed according to an integrated environmental management system administered in terms of the Minerals Act of 1991 (Act No 50 Of 1991), which states that all South African mines have the responsibility of managing the effects of mining on the environment (Scott). Other legislation such as the National Environmental Management Act, 1998 (Act No 107 of 1998), the National Water Act, 1998 (Act No 36 of 1998), the Mine Health and Safety Act, 1996 (Act No 29 of 1996) and the Atmospheric Pollution Prevention Act (1965), *inter alia*, provide further controlling measures.

The Minerals and Petroleum Resources Development Act (MRDA), 2002, provides a holistic cradle-to-grave approach to prospecting and mining, fully internalising economic, social and environmental costs to achieve sustainable development of SA mineral resources. Section 46 provides for the Minister to rehabilitate abandoned and ownerless mines / dumps and to register such sites in the title deeds of land and to transfer the liability for maintaining the rehabilitation work being undertaken to the responsible land owner (Swart, 2003:6-7).

The general approach to pollution control and environmental management in South Africa entails a management strategy based on a single environmental medium affected – air, water or land (Brown, 1997). The regulatory authorities responsible for the management of the environment are organised as follows:

- Air Department of National Health;
- Water Department of Water Affairs and Forestry;

- Land Department of Agriculture together with various other Departments. For example, control over mining activities is exercised by the Department of Mineral and Energy (DME).

The three main regulatory authorities have developed different organisational structures to suit their regulatory approach. However, the present arrangement fails to recognise the transfer of pollution across environmental boundaries. It also does not provide for a regulatory mechanism to ensure that environmental management is effective and efficient. The result is the absence of clear responsibilities, the overlapping of institutional boundaries, the exclusion of areas which require attention and a duplication of effort (Brown, 1997).

Few government mine reclamation policies and regulations existed until the latter part of the twentieth century. Nothing was in place to provide governments with financial security in the event of a mining company going bankrupt and being unable to cover the costs of rehabilitation. Ineffective government enforcement, usually due to lack of capacity, also contributes to the number of abandoned mines. Governments control the permitting system and have a duty to keep updated records and ensure that operators do not abandon operations irresponsibly.

Legislation that existed in the mid-1900's addressed the emplacement of bulkheads in openings to surface and the re-vegetation of tailings. Standards or guidelines were generally non-existent. There were no or few requirements to clean up sites or to ensure the physical and chemical stability of mine wastes. Penalties for non-compliance were minimal.

Mining related Acts are in place for the administration of abandoned mines and mine reclamation. The impact of abandoned mines on water is controlled under the National Water Act 36 of 1998. It protects water and limits effluent discharge by the industry. Before promulgation of the Water Act 54 in 1956, many mines were abandoned without implementation of adequate pollution control measures. In order to address the problem of pollution, the State has assumed responsibility for the provision of water pollution control measures to mitigate impacts from the mines abandoned before 13 July 1956 (DWA F-92). The provision of pollution control measures at abandoned

collieries, and the responsibility for costs to institute these measures, were established in an agreement called the Fanie Botha Accord reached between the mining industry and the South African Government on 19 January 1976 (DWAF, 1992 and Van den Berg, 2000). The Fanie Botha Accord, in summary, states that:

- Pollution control measures, the maintenance of such measures and all costs pertaining to mines and works abandoned before July 1956, would be the responsibility of the State;
- In respect of mines or works abandoned subsequent to July 1956, where measures had been instituted to the satisfaction of the State, the State will take responsibility for the maintenance and betterment of the pollution control measures taken.

Should mining or works at any stage be resumed at a previously abandoned mine, the company resuming the operations will be responsible for any existing pollution control measures on the portion which is to be reworked, and for any additional pollution control measures required in respect to the resumed operations.

Mining company policy and government legislation was focused on worker health and safety issues, not on impacts to the environment. Some companies did however make considerable effort for mine closure, placing bulkheads in openings, fencing off areas, and producing detailed maps showing the location of all closed out features contained on the property.

Government management of mine environment issues, including abandoned mines, has been inconsistent. As with few other countries in the world, the South African Bill of Rights is unequivocal in guaranteeing every citizen 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:

- prevent pollution and ecological degradation;
- promote conservation;
- secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development (Reed, 2003:8).

1.6.3 Civic Development Related

Until recently, little or no requirements existed for a developer or government agency to have regard for abandoned mines. As a result civic structures (buildings, roads, etc.) have been placed on or adjacent to sites without any testing for chemical or physical stability of the abandoned mine features. In many cases the developers were unaware that their project was being constructed on or near an abandoned mine site. Many developers assumed that such sites would be red flagged when they made application for necessary permits (Mackasey, 2000).

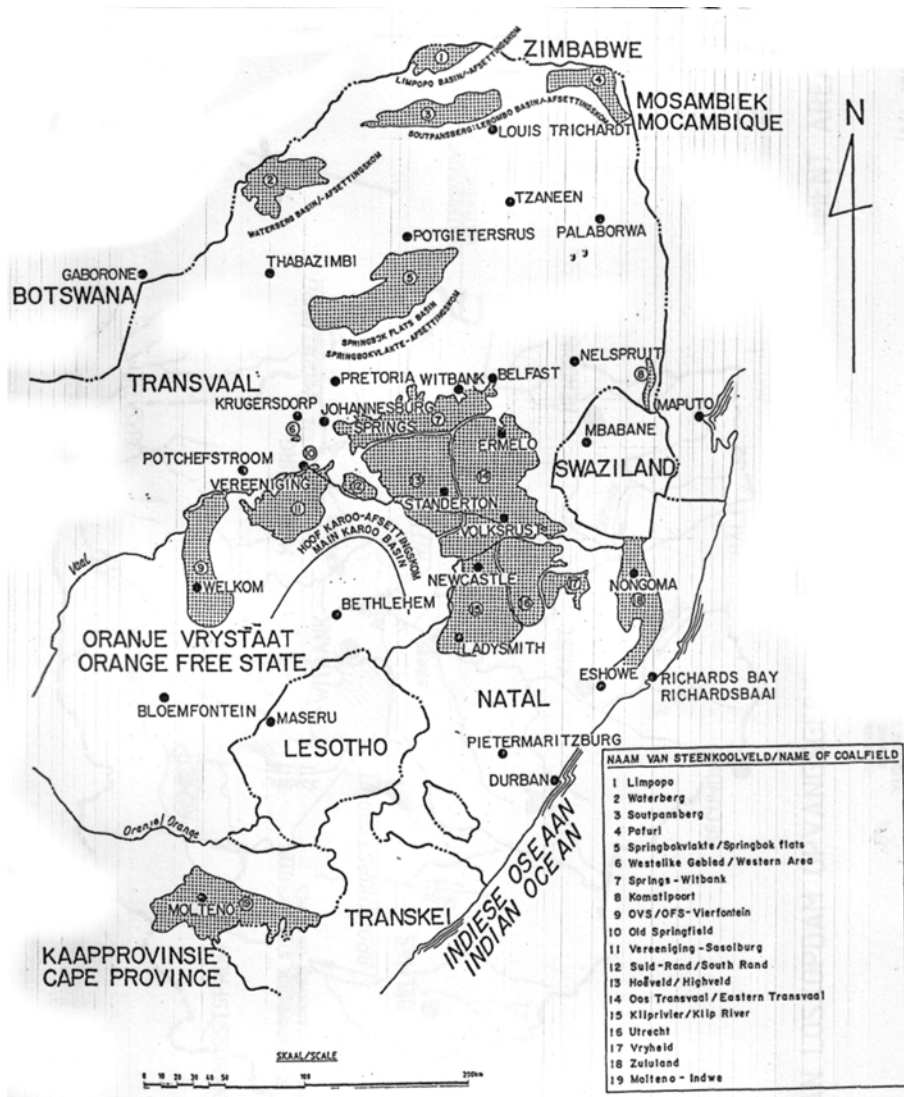
1.6.4 Data Related

During the operating life of a mine, records and maps are stored in fireproof vaults on site. Copies of the documents would be given to government agencies on a periodic basis and on closure of the mine. With unscheduled mine closures, this data was commonly not made available (Mackasey, 2000). Before 1925, all geological data, in the form of borehole records, was in the hands of individuals and mining houses.

2 THE WITBANK COALFIELD

2.1 *Geographical Location*

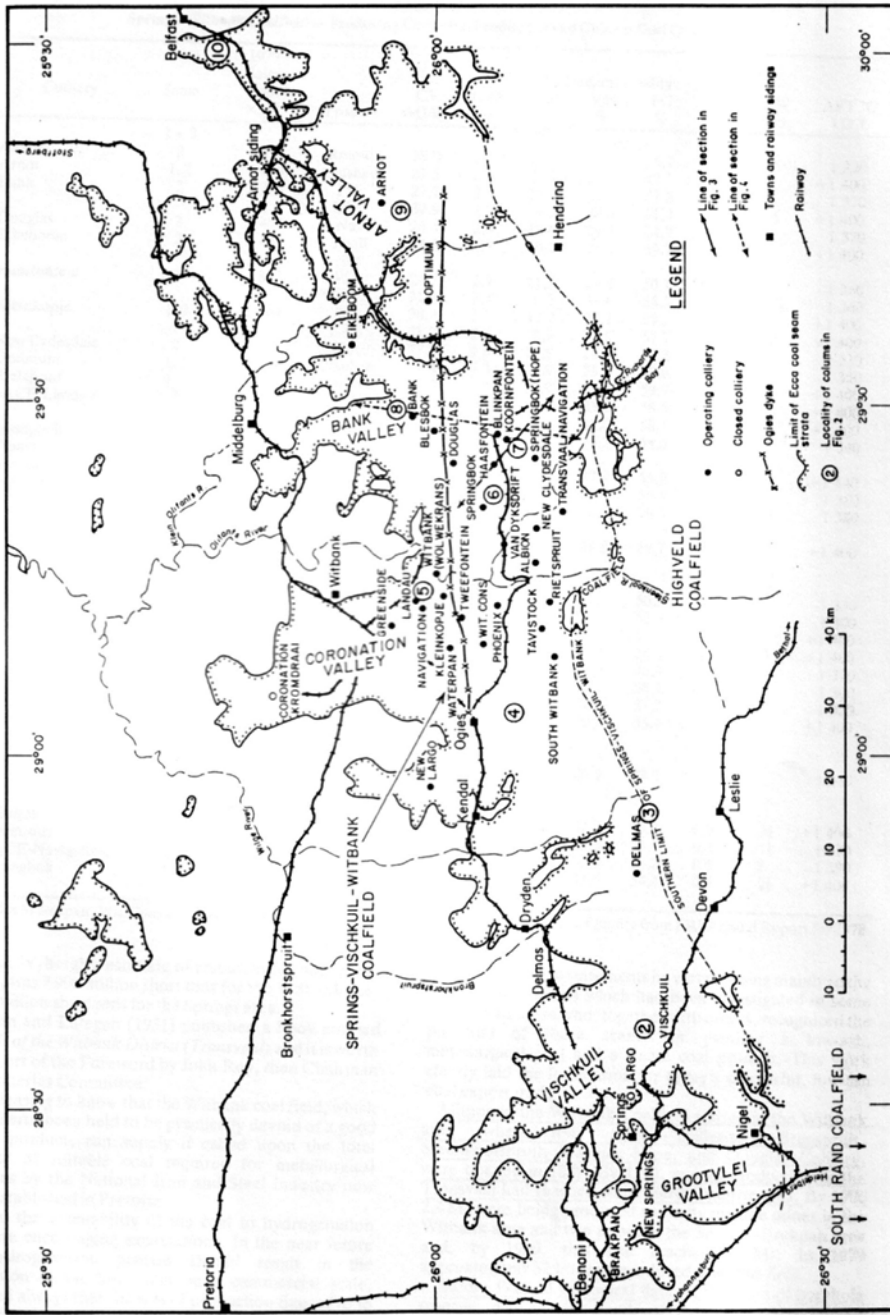
The extent of the major coal reserves and the general location of the Witbank Coalfield in the Province of Mpumalanga (Transvaal) is indicated in Figure 2-1.



Source: DWAF, WP – F92

Figure 2-1 Location of Witbank Coalfield

The Springs-Witbank Coalfield extends over a distance of 180km from the Brakpan and Springs areas in the west, to Belfast in the east and about 40km in the north-south direction as detailed in Figure 2-2.



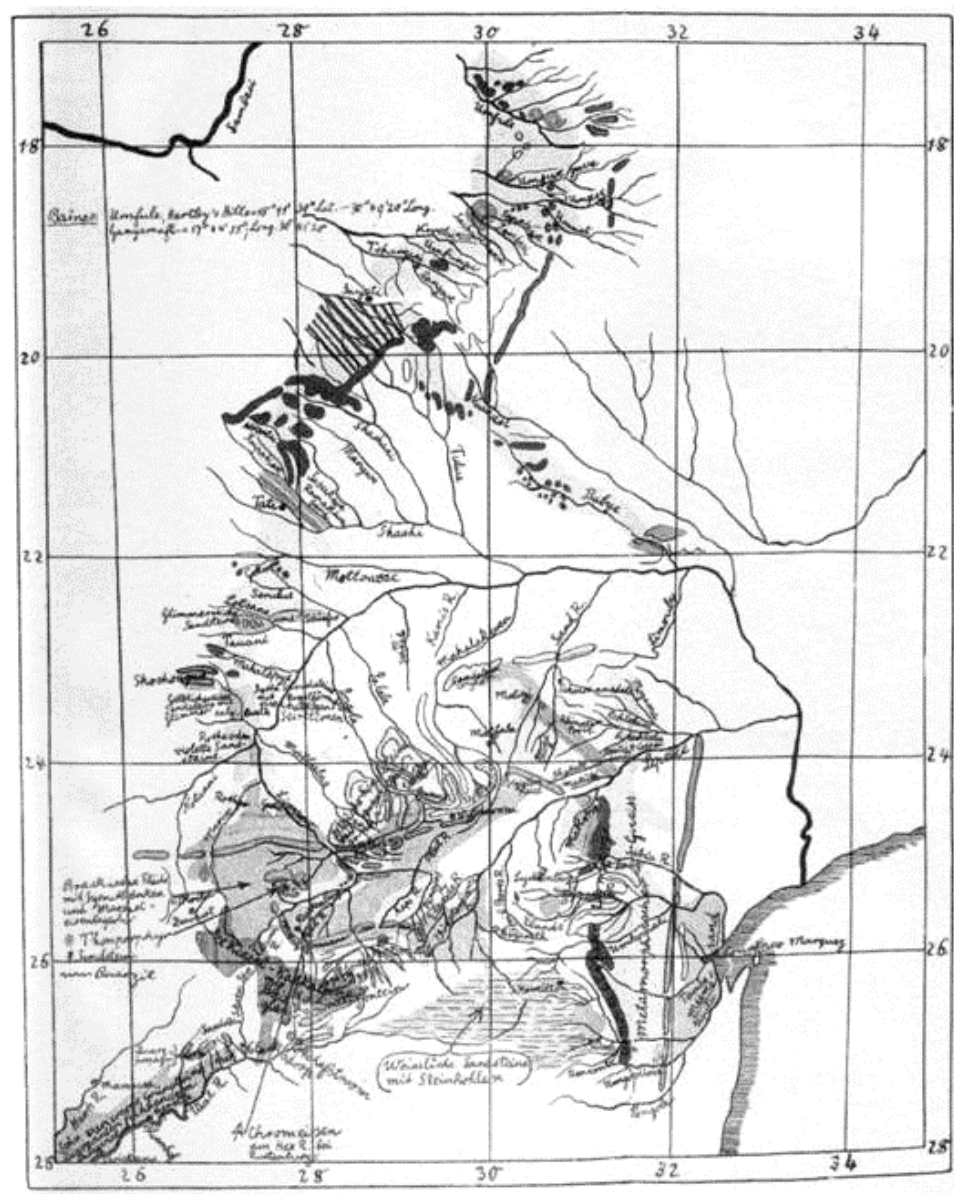
Source: Smith p 1970

Figure 2-2 General locality plan of the Springs-Witbank Coalfield

2.2 History

As a result of the abundance of shallow seam coal deposits in the Witbank region, large areas have been subjected to extensive surface and underground coal mining since the 1800's. Exploitation of these resources created numerous adverse impacts associated with coal mines operating prior to the enactment of the South African Mines and Works Act (Act number 27 of 1956). Modern signatures of these earlier impacts include subsidence, failure of the overburden, mine entrances left open, abandoned unstable highwalls, piles of toxic gob spoil material, and the release of acid mine drainage (AMD) that contaminates the surface streams. Although some of the disturbed land is now covered with relatively mature vegetation, remnants of the mining such as voids created near the surface by ground subsidence, unstable highwalls, open portals and acid mine drainage pose hazards to public safety and environmental health (Aparicio et al, 2001).

Records indicate that in about the year 1868 coal was mined in the Witbank area by Dutch settlers and local tribes for their own domestic use (Fourie, 1984). The first geological map of the Transvaal (Figure 2-3), drawn by the German Explorer, Carl Mauch in the early 1870's (Lang, 1995) showed extensive coal deposits lying along the Vaal River and its tributaries.



Source: Lang

Figure 2-3 Early geological map of the Transvaal and Rhodesia

The commencement of commercial coal mining in the Witbank district was linked to the discovery of gold on the Witwatersrand in 1886. Smith (2001:1971) and Lang (1995:26) have identified the first collieries as Brugspruit, Steenkoolspruit, Maggies

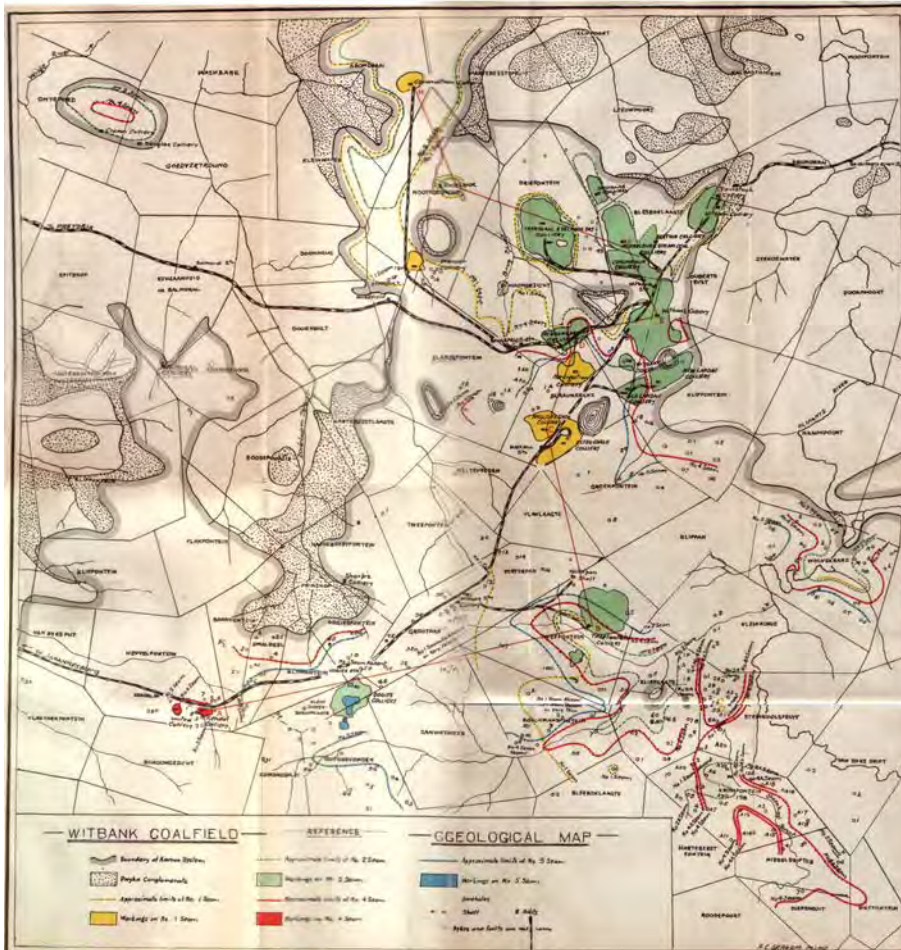
Mine and Douglas Colliery which were all opened in 1889. In 1894 the railway line from Pretoria was extended to Delagoa Bay (Maputo). This, together with the rapid expansion of the gold mines, created a demand for large tonnages of high grade coal and can be regarded as the main cause of the development of the Witbank Coalfield (Fourie, 1984:6-8). Coal mining mingled with farming and the Douglas, Transvaal and Delagoa Bay (T&DB), Witbank and Landau Collieries came into production before 1900. The Douglas was an adit mine, working a seam 1m thick, the coal being hauled out of the mine by mules. The T&DB hauled coal from one vertical and one incline shaft (Lang, 1995:43). Lang states that the Witbank-Middelburg field was 'destined to become South Africa's greatest'. The principal companies working in this coalfield at the time were the T&DB, the Witbank, the Douglas and the Transvaal Consolidated. In 1903, Neumann's Witbank Colliery founded the township of Witbank (Lang, 1995:51). By 1906, 11 collieries were working the Witbank coalfield (Lang, 1995: 52).

By 1907 the South African coal mining industry was well established and sales reached approximately 4.8 metric tonnes. Most of the collieries in the Transvaal were operating without profit and many actually incurred losses as a result of the severe competition in the industry.

Graham (1931:3-21) describes the area under review in 1931 to be 'taken from Kendal Colliery (Farm Heuvelfontein) on the south-west to Coronation Colliery (Kromdraai) on the north, thence from the now dormant Douglas Colliery (Goedvertrouw) on the west to the presently undeveloped areas of the south-east.' This area comprised the following collieries as indicated on the map (Figure 2-4):

- Kendal;
- Tweefontein and Waterpan;
- Minnaar;
- Clydesdale;
- Landau;
- Navigation;
- Schoongezicht;
- Witbank (Central and Southern);
- Middelburg Steam;

- Transvaal and Delagoa Bay;
- Douglas;
- Coronation.



Source: Graham p 3

Figure 2-4 Witbank Coalfield (circa 1931)

By 1946, the modern coal industry was taking shape. Of the 34 large collieries in the Transvaal, 23 were in the Witbank-Middelburg Coalfield (Lang, 1995:128). By 1966 coal sales in South Africa amounted to 46 million tonnes. The rapid increase in the oil price since 1973 saw another demand for coal develop (Fourie, 1984:6-8).

Mining methods (Section 2.10) in the Witbank Coalfield were restricted to underground mining using conventional bord and pillar methods until the early 1970's when large opencast mines were established to produce high quality coal for the export market and the nearby thermal power stations. During this time, a sharp rise in the domestic demand for coal was experienced due to an increased growth in the economy, with a corresponding rise in the demand for electricity and the energy crisis in 1973. During this time, mergers within the coal mining sector created lucrative long-term investment opportunities and raised much-needed capital, resulting in the expansion of operating mines and the opening of new mines (Moolman and Fourie, 2002:2). Examples of these are Optimum Colliery, Kriel, Duvha, Rietspruit, Arnot and Middelburg Mine (Fourie, 1984:6-8).

2.3 Geology

The major coal bearing strata in South Africa are associated with the Permian age Karoo basin and primarily occur on the southern and eastern flanks of the Kaapvaal Craton. The coal-bearing strata in the Witbank Coalfield were formed in the epicontinental environment and occur within the Vryheid formation (Bullock and Bell, 1997:61-63).

The irregular northern margin of the coalfield is defined by the sub-outcrop of the Vryheid Formation against the pre-Karoo rocks of the Transvaal Sequence, the Waterberg Group and volcanics associated with the Bushveld Igneous Complex. The southern margin of the coalfield is clearly defined over the central portion of the area by pre-Karoo granite and tselite hills which separate the Witbank Coalfield from the Highveld Coalfield. To the east and west of the central portion the southern boundary is poorly defined and the demarcation in the vicinity of Delmas, Leslie and Hendrina is rather arbitrary (Smith,2001:1969).

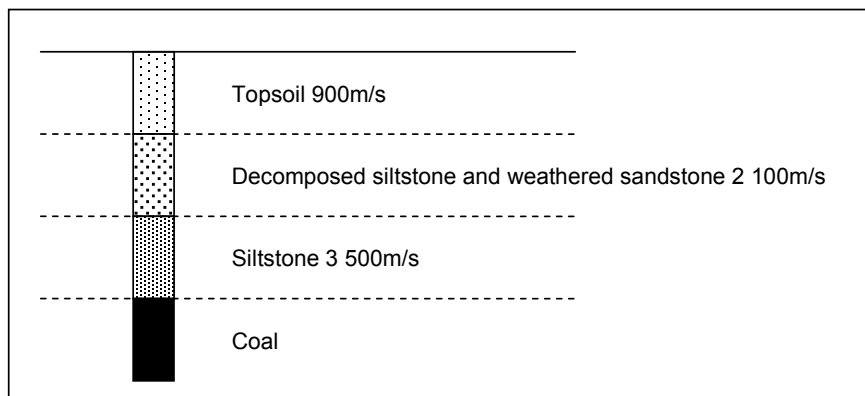
The Witbank Coalfield consists of a shallow basin of sediments deposited on an uneven floor of metasediments and metavolcanic rocks. Up to present, no faults of any considerable magnitude have been encountered in the mine workings of the Witbank Coalfield (Fourie, 1984:12).

The coal seams of the Witbank area are inconsistent in thickness and the individual seams are often split by hard sandstone, siltstone or shale partings resulting in an inter-relationship between coal seams and interbedded parting (Fourie, 19984:128).

2.3.1 Stratigraphy and Sedimentation

The five classically recognised coal seams of the Witbank Coalfield, are numbered from the base up as Numbers 1, 2, 3, 4 and 5 respectively. In the early development of the coalfield, they were rarely all present or consistent in quality with production largely from the main or second seam from the bottom, varying from 1 to 2m in thickness of which 0.5 to 1m could be mined economically. The coal lay at a depth of 30m or less (Lang, 1995:43). Parting thickness between seams remains constant over much of the field, but becomes variable towards the northern limits of the coalfield where stratigraphic units are generally thinner. The strata in which they occur consist mainly of fine, medium and coarse grained sandstones, together with mudstone, shale and carbonaceous shale.

The following typical layering (Figure 2-5) was found to be present in the Witbank area by Wagner Nel Consultants (1996). The rock strength is expressed as seismic velocities.



After Wagner Nel

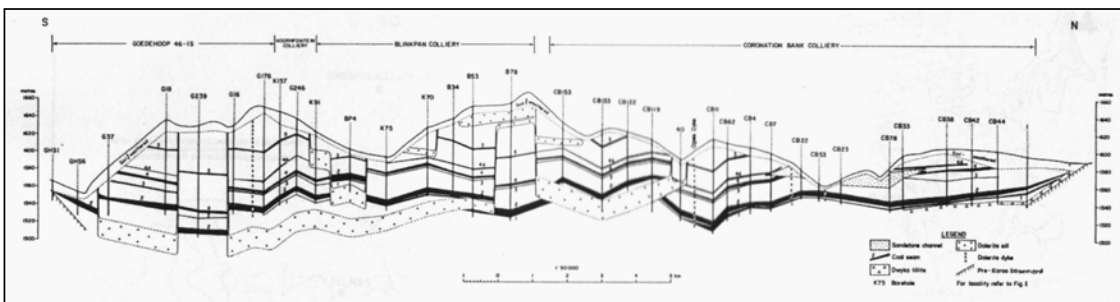
Figure 2-5 Typical layering

Coal seams are discontinuous over prominent palaeotopographic highs. Various ridges can be clearly recognised (Smith, 2001:1972).

Dolerite intrusions, in the form of dykes and sills, have adversely affected most areas of the coalfield, the most prominent being the Ogies Dyke, which is a post deposition feature striking East to West. Burning associated with dykes varies considerably and burnt zones of less than 10m wide to the Ogies Dyke width of 300m occur and as much as 20% of the in-situ coal may have been destroyed (Smith, 2001:1974).

2.3.2 Topography

The coal seams in the Witbank Coalfield are mainly flat lying to gently undulating, with a general southerly dip of about 1 in 100. Coal seam topography and areal distribution are commonly controlled by pre-Karoo topography. Steep dips of as much as 1 in 8 are encountered where seams (Numbers 1 - 3) abut against pre-Karoo hills. The Numbers 4 and 5 seams have a more regular disposition and their distribution is largely limited by present day surface topography (Smith, 2001:1972).

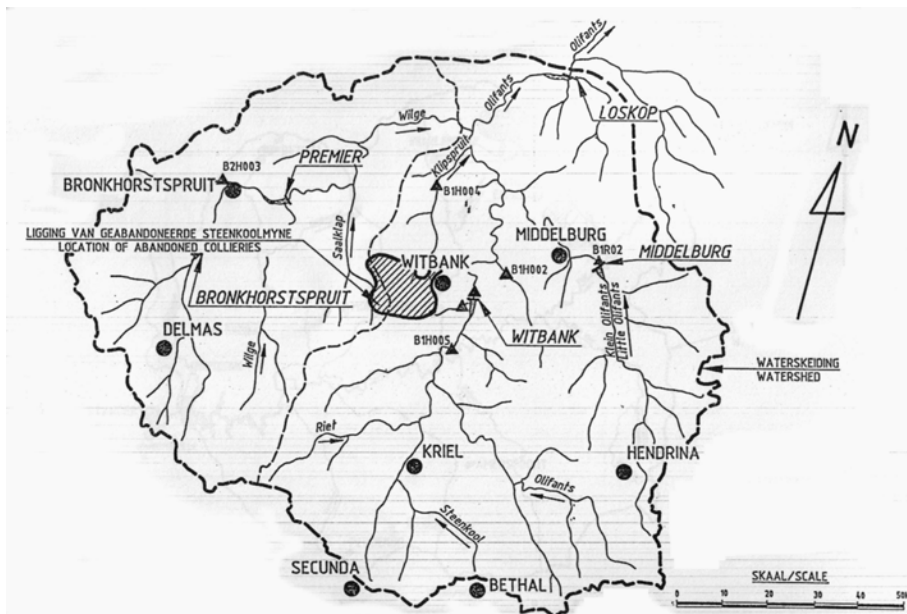


After Smith, p 1975

Figure 2-6 North-South exaggerated profile across the central Witbank Coalfield

2.4 Catchment

The Olifants basin is located between 22.5° and 26.5° South latitude and between 28.5° and 34.8° East longitude (Ashton *et al*, 2001:285). The Olifants Catchment covers about 54 570 km² and is subdivided into 9 secondary catchments. The total mean annual runoff is approximately 2400 million cubic metres per year (RHP, 1999). The Loskop Dam Catchment area is illustrated in Figure 2-7.



Source: DWAF, WP – F92

Figure 2-7 Loskop Dam sub-catchment

The upper reaches of the Olifants River Catchment are characterised mainly by mining, agricultural and conservation activities. Over-grazing and highly erodable soils result in such severe erosion that after heavy rains the Olifants River has a red-brown colour from all the suspended sediments.

Thirty large dams in the Olifants River Catchment include the Witbank Dam, Renosterkop Dam, Rust de Winter Dam, Blyderivierspoort Dam, Loskop Dam, Middelburg Dam, Ohrigstad Dam, Arabie Dam and the Phalaborwa Barrage. In addition, many smaller dams in this catchment, have a considerable combined capacity (RHP, 1999).

The Olifants basin encompasses an important ecological transition zone that marks the junction of four separate bio-climatic regions. The area is considered to be very important in terms of the diversity of its fauna and flora and also contains several important conservation areas. In addition, the Olifants basin supports a very large population, including some of the region's poorest rural communities, as well as

numerous urban areas and farming communities and important forestry areas (Ashton et al, 2001:286).

In the southern portion of the basin, the extensive, carbon-rich sedimentary rocks of the Karoo System contain enormous economic reserves of coal and are the site of intensive coal mining activities.

Most of the basin consists of relatively undulating terrain separated by ranges of steep-sided hills and mountains.

2.5 Hydrology

The Little Olifants - Riet sub-catchment consists of the area drained by the upper reaches of the Olifants, Little Olifants and Riet rivers and their tributary streams, down to the point where the Olifants River joins the Wilge River at the Loskop Dam. The Olifants, Little Olifants and Riet rivers drain a relatively small area that includes the coal-mining towns of Witbank and Middelburg located to the east of Pretoria. The sub-catchment receives additional water via three inter-basin transfer schemes from the Vaal, Usutu and Komati systems, whilst relatively large discharges of treated domestic and industrial effluent from Witbank and Middelburg supplement flows in the Olifants and Little Olifants rivers. All rivers and streams in this sub-catchment are perennial.

The sub-catchment contains four water supply dams, one of which (Loskop Dam) also supplies water for the extensive irrigation agriculture areas downstream of this sub-catchment. The other dams all supply domestic and industrial water to the towns of Witbank and Middelburg as well as the numerous collieries and smaller settlements in the sub-catchment. In addition, the sub-catchment has numerous small farm dams that trap runoff in seasonal channels and supply this water for limited livestock watering (Ashton et al, 2001: 295).

The sub-catchment also contains an enormous number of small wetlands. These are formed at the uphill side of protruding dolerite formations (typically dykes and sills) that dip gently to the south. These dolerite formations act as impermeable barriers and water collects on their uphill sides, saturating the soils. The downstream end of each

wetland is usually marked by a dolerite exposure where the water reaches the ground surface and flows over the dolerite barrier. This system of inter-connected wetlands provides an extremely important attenuation mechanism that ensures water is released throughout the year, thereby maintaining perennial stream and river flows in this sub-catchment. However, mining activities (blasting, ground clearing, overburden stripping, acid mine drainage) have damaged or broken several of these dolerite formations in recent years. This has resulted in increased summer flows, reduced attenuation and therefore lower winter flows, and a steady decline in water quality in downstream reaches (Ashton et al, 2001:295).

2.6 Pedology, agriculture and land use

The land capability is divided into classes: arable land, grazing land, wetland and wilderness land. Most of the soils are highly suitable for commercial agriculture when sufficient water is available. Virtually all of the areas with suitable soils, particularly the area downstream of the Loskop Dam, are contained within the jurisdiction of formal irrigation boards or Government Water Control Areas. Further away from the main river channels, and downstream of the coal mining operations in the upper parts of the sub-catchment, land use is given over to small- and medium-scale livestock farming operations. A relative small variety of crops are produced on the irrigated and rain-fed areas, primarily maize, lucerne, potatoes and sunflowers.

2.7 Settlements

Several towns (e.g. Witbank and Middelburg) and numerous smaller settlements and farming communities are present in the upper reaches of the sub-catchment. Population numbers and density initially decline with increasing distance from the upper reaches, and then increase again in the intensively farmed irrigation areas. Light and heavy industry is present in the towns of Witbank and Middelburg, with many industries geared specifically to meeting the needs of the extensive coal-mining sector in the region.

2.8 Climatic features

Because of its geographic position, the prevailing wind systems, including tropical cyclones from the Indian Ocean, have a strong influence on the climate of the Olifants basin. The most important of the rain-bearing winds are the southeasterly wind

systems that bring rainfalls from the Indian Ocean. In some years, unusual southward movements of the Inter-Tropical Convergence Zone (ITCZ) have been sufficient to influence rainfalls in the northern parts of the Olifants basin for short periods of time.

Air temperatures across the Olifants basin show a marked seasonal cycle, with hottest temperatures recorded during the early Summer months and lowest temperatures during the cool, dry winter months. Rainfalls are also highly seasonal, falling predominantly as intense convective thunderstorms during the warmer summer months. (Ashton et al, 2001:289).

Evaporation rates across the Olifants basin are both high and variable, ranging from some 2.4-2.6 metres per annum in the eastern areas of the basin to some 1.7 metres in the cooler, mountainous regions in the southwestern portion of the basin. In view of these evaporation rates, and the quantity of rainfall received each year, several portions of the Olifants basin show clear evidence of the dominance of physical weathering processes (with Weinert N values greater than 5.0 (explained in Section 5.3.2)). These areas are located predominantly in the eastern and northeastern portions of the basin and along the lower reaches of the Olifants valley. Virtually all of the rest of the Limpopo basin is subject to chemical weathering processes, either seasonally (Weinert N values below 4.0) or continually (Weinert N values below 2.0) (Ashton et al, 2001:290).

2.9 Population

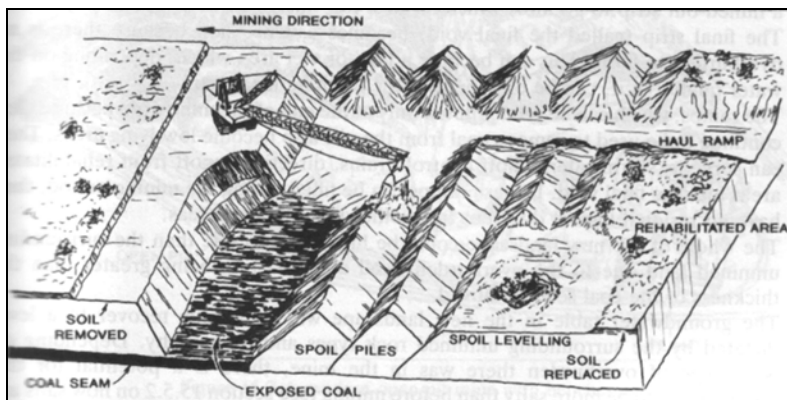
The total population of the Olifants basin is estimated to be approximately 10.5 Million, with South Africans comprising some 85% of the basin population. The Olifants basin also contains a large proportion of the population of South Africa's Gauteng Province, as well as parts of the populations of the Northern and Mpumalanga Provinces. The Olifants basin contains virtually all of the important coal mines and thermal power stations, as well as critically important agricultural areas, towns and cities. Consequently, the Olifants basin is correctly considered to house the energy heartland of South Africa. Similar to other parts of southern Africa, land is a critically important resource throughout the Olifants basin and the livelihoods of residents and the national economies of both basin states depend on access to land (Ashton *et al*, 2001: 288).

2.10 Mining Methods

Complete disruption of the surface always occurs when surface mining methods are used. This affects the soil, surface water and near-surface groundwater, fauna, flora and all types of ground use.

2.10.1 Surface Mining

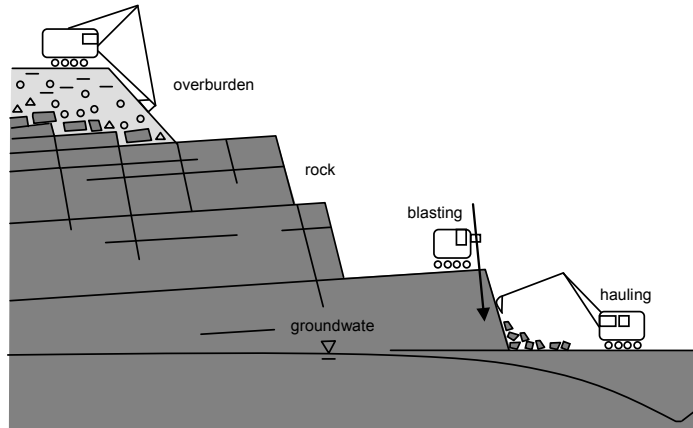
Opencast or strip mining started in 1976 and is used when the deposit is horizontal or gently dipping and within about 60m of the surface such as the shallow-lying South African coal seams (Fuggle and Rabie, 1992:340 – 341). An example of strip mining with concurrent rehabilitation is shown in Figure 2-8.



Source: Fuggle and Rabie, p 341

Figure 2-8 Strip mining with concurrent rehabilitation

Open pit mining, illustrated in Figure 2-9, is used if the near-surface ore body is massive and it occurs in a steeply dipping seam or seams. The objectives for land use following open pit mining are more limited than that for strip mining because insufficient waste or tailings are available to fill the pit. The main objective is usually to make the pit walls safe and to landscape the dumps. The pit may be used as a disposal site or filled with water for use or recreation.

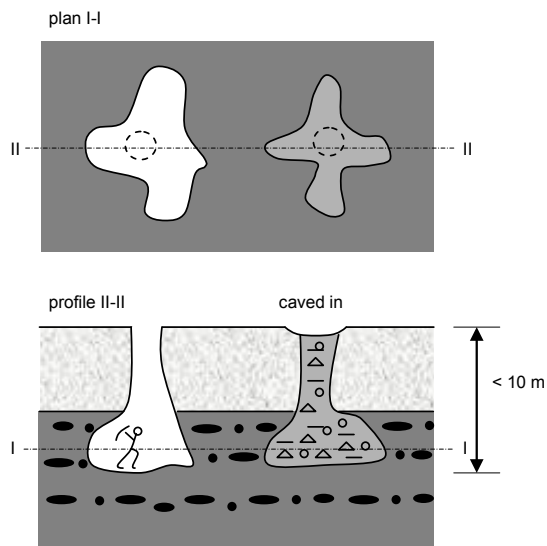


Source: Genske

Figure 2-9 Open pit mining

2.10.2 Shallow underground mining

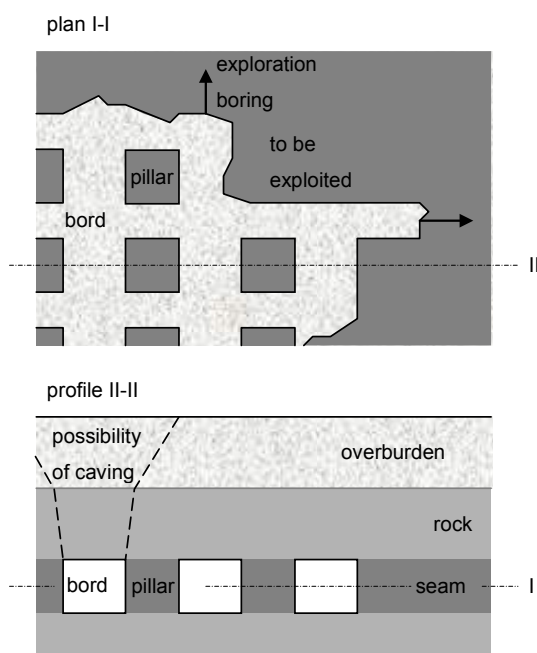
Early mining was very often only a temporary land use. Being totally extractive, mining is not sustainable and without heavy machinery the impacts were minimal as indicated in Figure 2-10.



Source: Genske

Figure 2-10 Early sub-surface mines were bell-shaped pits only a few metres deep

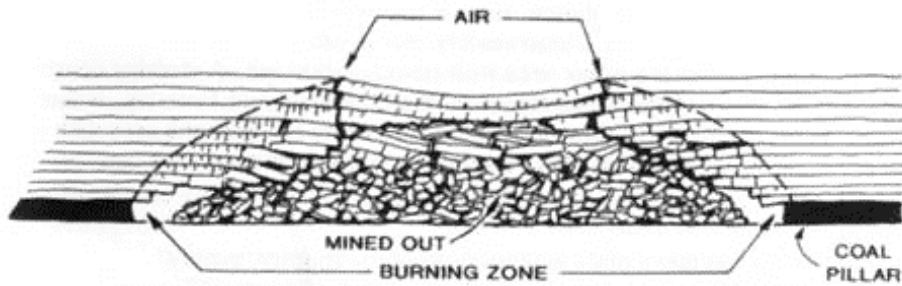
Bord and pillar mining is the method most often employed historically in coal mines in the Witbank Coalfield. After sinking a shaft down to the coal seam, the seam is mined by extracting coal from the bords or rooms and leaving a regular pattern of pillars behind to support the overlying strata as illustrated in Figure 2-11. Before the advent of modern pillar design in 1967 (Fuggle And Rabie, 1992:346), miners often left pillars which were too small, or robbed them on their retreat from the coal face, to support the roof indefinitely.



Source : Genske

Figure 2-11 Bord and Pillar mining

Subsequent to mine closure, areas of the roof often collapsed into the bords as illustrated in Figure 2-12. If the collapse continues through to the surface, air enters the old underground workings igniting the residual coal. This spontaneous combustion often further weakens the pillars causing further collapse.

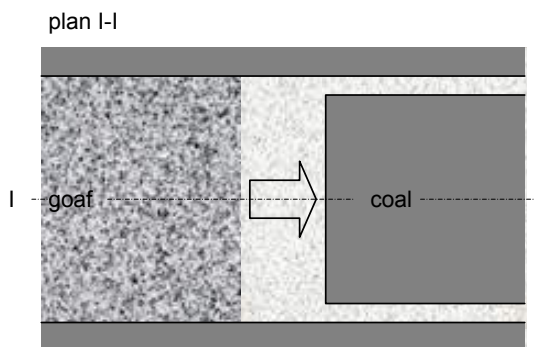


Source: Fuggle and Rabie, p 347

Figure 2-12 Collapse in old shallow bord and pillar workings

2.10.3 Deep underground mining

A limitation of bord and pillar coal mining is that a significant quantity (up to 40%) of coal is left behind in pillars which support the roof. Various methods of pillar extraction (stooping) have been developed to remove these pillars so as to optimise coal recovery. Other methods such as rib pillar extraction, shortwall mining and longwall mining (Figure 2-13) have been developed with the aim of recovering the maximum amount of coal directly. Collectively, these methods are referred to as increased extraction or high-recovery coal mining methods (Fuggle and Rabie, 1992:348).



Source: Genske

Figure 2-13 Longwall mining

The main environmental concerns with increased extraction methods relate to the lack of roof support following mining. The impacts include subsidence of the surface, the

cracking of the strata between the coal seam and the surface and subsequent dewatering of aquifers in this zone.

3 CONCEPT, SCOPE & LIMITATIONS

All of the mining companies who are active in this area collaborate actively in joint research programmes to devise solutions for this perennial problem. At the present time, a very ambitious project, named 'COALTECH 2020' has been launched to discover alternative ways of dealing with the variety of problems faced by collieries in this area, and to extend the economic lifespan of the mines. This programme involves representatives from 15 international and 15 national organizations, including all the major mining houses, the Department of Water Affairs and Forestry, the Department of Mineral and Energy, The Department of Environmental Affairs and Tourism, the CSIR and academia (three South African universities). This concerted, collaborative approach has already led to improvements in both the understanding of the various problems and in the management of some of the water problem areas (Beukes, 2003).

3.1 *Underlying philosophy*

While this project's aim is to investigate the extent of all the consequences of abandoned mines on the environment and the subsequent impact on the local community, limited access to the sites as well as the sensitivity and confidentiality of some of the data will restrict the project to accessing public domain information. The software model to be developed will give a first-cut risk assessment and the balance between specificity and generality will be biased towards the latter. The model will thus be developed from the current knowledge base specific to collieries situated in the Witbank Coal field.

Limited literature is available to support the assessment and quantification of these risks and field surveys will be beneficial.

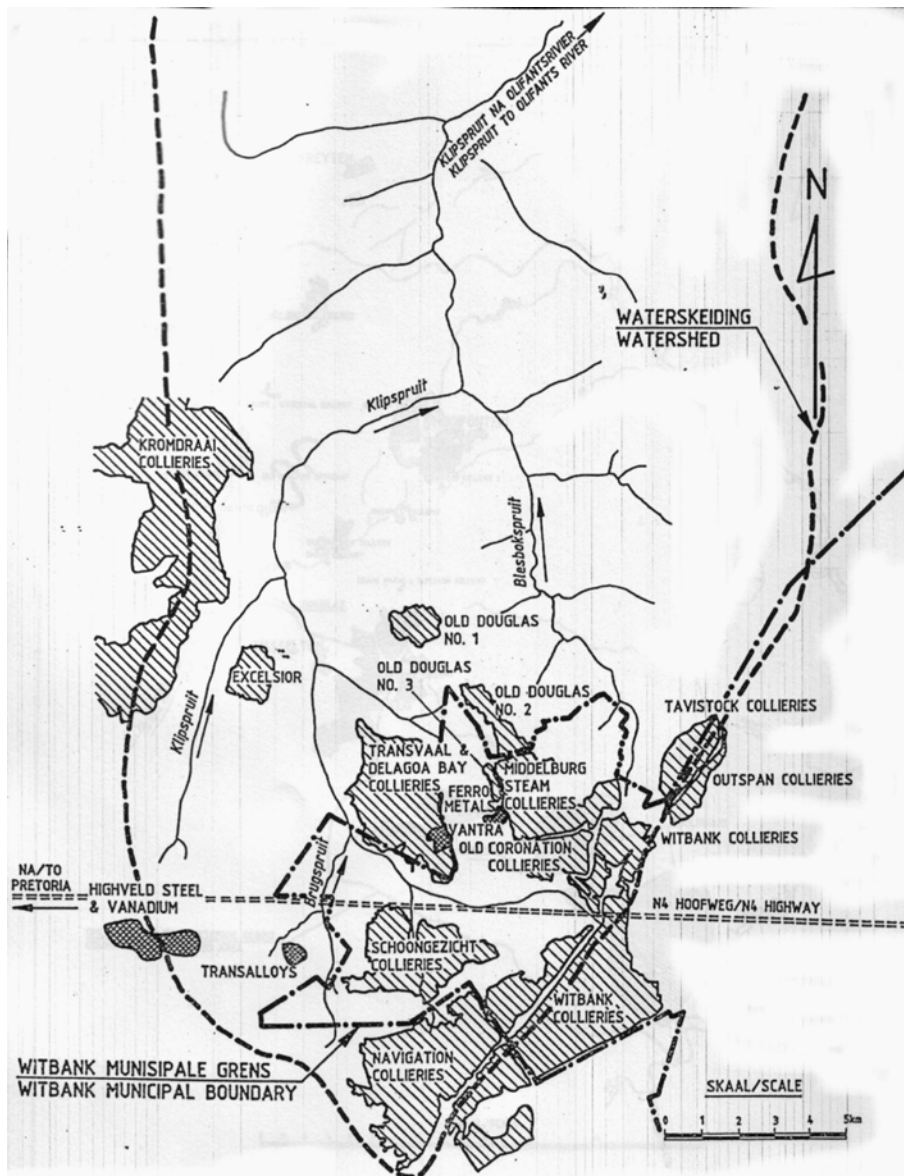
In a field of frequently moving rehabilitation goalposts, cumulative impacts incurred over decades of operation and patchy enforcement of legal obligations, total post-closure liability by the state imposes considerable pressures on the DME's budget (Reichardt , 2001:2B-1).

While many have seen these derelict sites, and there are many references in the literature, there have been few systematic surveys to quantify how many sites really need attention. There has been even less work to quantify the nature of associated problems so as to prioritise remediation efforts.

4 DEFUNCT & ABANDONED MINES

The following data on abandoned mine is derived from available literature (DWAF (1992), Lang (1995), Veldsman (2003), Waygood (2001)). Some inventories include isolated small trenches and test pits as they fall within the definition of 'mine' as described by legislation. The quality of inventory data, as demonstrated by the survey, is very limited. Many abandoned mine sites have been recorded on the basis of library research only. While fewer than 60% of known abandoned mines appear to have had limited field inspections, most have had little or no test work for physical or chemical stability.

The location of abandoned collieries in the Klipspruit catchment identified in the DWAF White Paper, WP-F92 are indicated in Figure 4-1.



Source: DWAF, WP-F92

Figure 4-1 Location of collieries in the Klipspruit catchment area

A comprehensive list of abandoned and defunct collieries is presented in Appendix A. An attempt has been made to give geographic locations and a brief description of the history for each mine. It is acknowledged that there may be some duplication of the

mine names and that some of the mines listed as abandoned or defunct may, in fact, fall within the mining license of an operating mine and thus be included in the life of mine plan for that particular mine.

5 IMPACTS OF MINING ON THE BIO-PHYSICAL ENVIRONMENT

The environmental impacts at the time of mining and the residual impacts of abandoned mines are significant. For instance (Fuggle and Rabie, 1992:346 – 348), in the Witbank area fires are still burning. Random and unplanned surface subsidence occurs, rendering the land unsafe. Dangerous ground results where collapse has not yet taken place but may do at any time. Near-surface aquifers may also break, draining water into the collapsed workings. Rain falling on these areas goes straight into the workings adding to the water load. This water becomes acidic and high in salt concentrations. Because many of these workings occur in places where the coal seam outcrops on the surface, acidic seepage emerges along the outcrop or from adits, causing severe water pollution in streams draining the area. Significant air pollution occurs due to the sulphurous fumes.

The highveld has been extensively farmed and therefore little natural environment remains. For these reasons coal mining on the highveld has little residual impact on natural ecosystems. In areas less stable than the highveld and with greater biological diversity, surface rehabilitation is more difficult (Fuggle and Rabie, 1992:352).

From a water quality perspective, South African coalfields occur in the worst possible location since most occur in the vulnerable upper reaches of major river systems such as the Witbank coalfield in the Olifants catchment. Because of this, measures to control water pollution are uppermost in most rehabilitation programs (Fuggle and Rabie, 1992:352).

The chemical and physical impacts associated with surface and underground mining operations are described to provide an overview of the specific types of impacts that are normally associated with coal mining. In several cases, it was difficult to determine the specific impact exerted by a mining operation, because the impact(s) also

depended on the degree of management control exerted during mining. Based on defined criteria, Ashton *et al* (2001) suggests that the impacts of mining should be classified into high, medium and low impacts. These descriptors will then used to describe the scale and variety of impacts linked to mining activities. It is also important to take cognisance of the dimensions of exposure as listed in Table 5-1 when assessing the spatial and temporal framework for the development of the assessment tool.

Table 5-1 Dimensions of exposure

SPATIAL	Local, regional, global
TEMPORAL	Short-term/acute, seasonal, long-term/chronic
CHEMICAL	Organics, inorganics
ENVIRONMENTAL MEDIA	Air, water (precipitation, groundwater, surface water), soil, sediment, biota (food chain)
ENVIRONMENTAL SETTINGS	Agricultural, industrial, residential
CHEMICAL / BIOLOGICAL FATE CHARACTERISTICS	Speciation, reactivity, degradability, volatility, phase equilibrium constants, complexation, bioaccumulation, bio-magnification
ENVIRONMENTAL TRANSPORT AND TRANSFER	Advection, dispersion, deposition, washout, degradation, partitioning, erosion, runoff, volatilisation, re-suspension, sedimentation
RECEPTORS	Human (children, occupation sensitive, general population), wildlife (fish, birds, reptiles, mammals)
EXPOSURE ROUTES	Inhalation (gases, particulates), ingestion (plant, meat, milk, aquatic food, water, soil), dermal contact, external dose (radio-nucleotide)
RISK ENDPOINTS	Human (cancer, non-cancer), ecological (individual, species, communities, habitats)

After Whelan, p 59

Direct environmental impacts associated with abandoned collieries are largely confined to relatively restricted areas in the vicinity of the appropriate geological formation and downstream in the catchment where the mine is located (Ashton et al, 2001:55-56).

Cumulative impacts describe those situations where several impacts from different processes and activities combine to exert a greater set of (usually adverse) effects than those that would be predicted from the original activities. An example of this type of situation would be the combination of adverse effects that a community would

experience if it were exposed simultaneously to atmospheric emissions of gases, wind blown dust and effluent discharged from a mining operation. A second example would be the situation where effluents and discharges from several abandoned mines in a single catchment exerted a set of combined effects or impacts on the river system draining the basin (Ashton et al, 2001:55-56).

Impacts are described in terms of the type and extent of each impact on the surrounding environment and community. Examples of these descriptors are detailed for water in Table 5-2.

Table 5-2 Impact descriptions used in this study

Descriptor	Type and Extent of Impact
Very large / Very high	Impacts are considered to be very serious and require continual management attention; Impacts often consist of gross damage or disturbance to water resources and aquatic ecosystems, rendering these unfit for other water users and requiring extensive remedial actions; Impacts often extend for considerable distances from the site of origin.
Large / High	Impacts are considered to be serious and require frequent management attention and remedial actions; Impacts often have large-scale (extensive) effects on water resources and aquatic ecosystems, with deleterious effects on water resources, aquatic ecosystems and other water users.
Medium	Impacts are considered to be important, but seldom require frequent or continual management attention; Impacts may be experienced as temporary or continual loss of amenity or deterioration in water quality, and can extend over both small and large areas; Other water users are likely to experience moderate loss of amenity, and may need to implement remedial treatment of the water before use.
Low	Impacts are considered to be important but are easily controlled by routine management actions; Impacts can be experienced as low-intensity nuisances over a relatively large area, or as minor disturbances over a smaller area; Other water users are unlikely to experience significant loss of amenity and seldom need to implement remedial actions before using the water.
Very low	Impacts likely to consist of minor disturbance to aquatic ecosystems or local water resources; Impacts often temporary in nature or, where they occur continually, extend over a very small area.
Negligible	Impacts are unlikely to have a measurable or discernable effect on water resources or water quality, often due to the innocuous nature of the waste material or to the lack of mobility of the waste material in a specific geographic area.

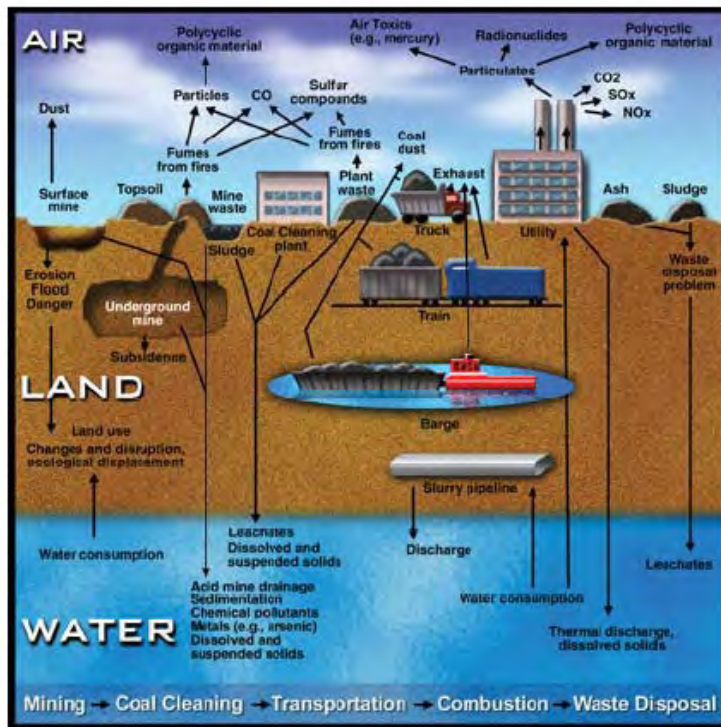
After Ashton et al pp 26-27

Clearly, any large mining operation is likely to have a proportionately greater impact on the environment than a smaller mining operation located in the same area. However, it is important to note that most large mining operations also tend to employ more effective and efficient environmental management programmes than their smaller

counterparts. This feature tends to reduce the relative size and intensity of impacts associated with larger operations. Indeed, many small mining operations very often cannot afford to implement effective environmental management programmes and their impacts on the environment are sometimes disproportionately large. This is clearly evident in the case of small-scale and artisanal mining operations, where little or no attention is directed towards minimising impacts on the surrounding environment. As a consequence, Ashton et al (2001:54) has often found it extremely difficult to assign specific proportions of environmental impact to different scales of mining operations where these occur on close proximity to one another. Down and Stocks (1997:17-18) found no simple relationship between the scale of workings and the subsequent environmental and social impact when the mine is abandoned.

The same study states that individual site factors are of extreme importance in controlling both the nature and extent of the impact from abandoned mines. The population density (both the local communities and accessibility of the area) can strongly influence environmental and socio-economic issues. Likewise, geology, topography and climate have been shown to be key factors (Van Zyl (2002), Naude (2000), Envirogreen (2000)).

The impacts of coal mining on land, water and air are illustrated in Figure 5-1.



After Clean Air Task Force

Figure 5-1 Impacts and contaminants from coal affect land, water and air.

The extraction process and method of coal mining is considered to play a contributory role in the impacts and consequences.

The impacts of coal mining in the Witbank Coalfield are outlined below.

5.1 Atmosphere

In a report on the Environmental Status of Discard and Slurry Facilities, Badger Mining has identified smoke, fumes, heating, gas emissions and dust as the major environmental hazards (Grobbelaar, 2003). Underground and surface mines are responsible for the emission of methane gas (Cook, 2002). Methane gas emissions constitute a health risk and, because methane is a major greenhouse gas, contribute towards global climate change. Another form of air pollution associated with coal

mining is the gaseous emissions from smouldering coal dumps and from underground fires in abandoned coal mines.

The ability of the atmosphere to absorb pollutant discharges is dictated largely by the mechanisms of pollutant transport, dilution and dispersion. Fuggle and Rabie (1992:423) suggest that these three mechanisms are, in turn, affected by a number of variables including pollutant nature, emission point characteristics, meteorological conditions and surface terrain.

The Eastern Transvaal Highveld (ETH) is characterised by climatic conditions which are highly adverse for the dispersion of atmospheric pollutants, namely high atmospheric stability, clear skies and low wind speeds generally associated with a high pressure system prevailing over the region. Moist, unstable conditions and rainfall are confined almost exclusively to the summer period. The dry, stable winter period is obviously of greatest significance for accumulation of atmospheric pollution. During winter, inversions of temperatures occur almost every night at the surface, to a depth of between 150 and 300m, while elevated inversions occur with high frequency, on average at a height of about 1 200 to 1 400m above ground. This elevated subsidence inversion is steep enough to preclude vertical dispersion of pollutants above this level on most days throughout the year (Fuggle and Rabie, 1992:424).

The air pollution caused by the stockpile of burning coal dumps in the ETH is a subject of great concern, but monitoring is in its infancy (Fuggle and Rabie, 1992:425). They suggest that it is possible to predict which dumps are likely to combust spontaneously from a knowledge of temperature profiles and method of construction/compaction of the dumps, however the rate and extent of combustion are less readily predictable. Understanding the pattern of emissions from these dumps is complicated since the coal discards have variable factors affecting combustion (Moolman, 2004). Particulate emissions are unknown, but an unsubstantiated figure of 5% of the total SO₂ emissions has been suggested (Fuggle and Rabie, 1992:426).

Fuggle and Rabie (p 426) state that the value of absolute pollutant amounts in assessing environmental risk is questionable. It is far more important to relate energy activity to atmospheric pollutant concentrations across local, regional and national

boundaries. The relationship between environmental degradation (current or anticipated) and air pollution can thus be more readily quantified, taking into consideration the dilution and dispersion mechanisms of pollutant transport which have already been identified. Specific attention must be given to particulate and acidic deposition.

5.1.1 Dust and airborne particulates

Open-cast mines cause increased levels of dust and airborne particulate matter as a result of blasting and other mining activities in which the vegetation and topsoil are removed. Coal dust from the surface and dumps is characterised by a high water solubility and therefore high bio-availability (Shultz *et al*, 1997). Spontaneous combustion – whether underground or in overburden dumps, is a major source of noxious fumes and particulates.

Particulate matter (PM) refers to the particles which remain suspended in the atmosphere for considerable periods of time. PM consists of a wide variety of particles such as dust, smoke, ash, droplets and microscopic bits of metal. Suspended particles with a diameter of less than 10mm can be inhaled into the respiratory tract, causing lung damage and exacerbating problems such as asthma. PM, therefore, constitutes a human health risk. The type of PM i.e. silica versus trona (potash) as well as the concentration thereof are also factors to be considered (Moolman, 2004).

5.1.2 Smoke, Fumes and Gases

Smoke and gases (mainly sulphur dioxide, carbon monoxide and dioxide and the oxides of nitrogen) are produced from burning coal discard dumps (Fuggle and Rabie, 1995:357).

Coal, coal discard and other carbonaceous material give out heat when exposed to air. The phenomenon of spontaneous combustion is one of the major hazards encountered in old abandoned and defunct underground coal mines and discard dumps. Coal undergoes self-oxidation at ambient temperatures producing heat on a continual basis until the mass of coal ignites. As a result of spontaneous combustion hazardous gases are released. As the temperature increases, different gases are released.

An assumption made by Sesogut *et al* (2002) is that the centre of spontaneous combustion is a source of carbon monoxide as well as heat and that carbon monoxide production is universally accepted as a sign of spontaneous combustion.

Sulphur Dioxide (SO₂) is a colourless gas with a strong pungent odour. It is released when substances that contain sulphur (such as a fossil fuel) are burned, and is one of the components of classical smog. SO₂ is toxic to plants at very low concentrations (less than 0.1 ppm) and, at concentrations of 1 to 2 ppm, can cause respiratory problems in humans. As a result, even at relatively low concentrations, SO₂ emissions may constitute a health risk and may cause ecological damage in areas surrounding the source of emission. Ammonia (NH₃) is released during the heating process with similar effects.

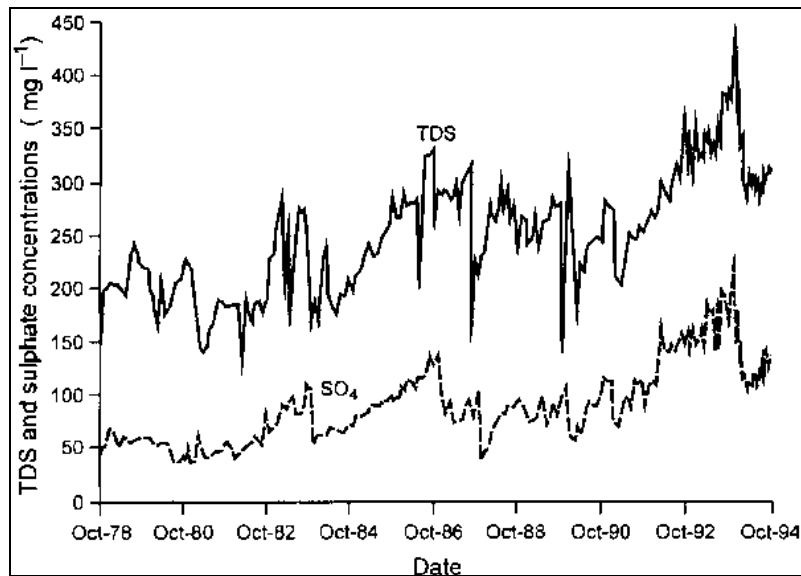
Methane (CH₄) is emitted when the coal is de-stressed and fractured as part of the mining operation, with further, but reducing, emissions occurring for some time after from the adjoining strata and seams. The gas generally contains some ethane and higher hydrocarbons as well as carbon dioxide (AEA, 2003). The AEA have determined that residual emissions continue in abandoned mines and have resulted in explosions. They caution against the current practice of sealing the tops of shafts for safety reasons without providing vents to reduce pressure build-up and possibly leading to an unsuspected or uncontrolled escape of gas.

5.2 Water

The Department of Water Affairs and Forestry (WP F-92) states that polluted water associated with abandoned coal mining operations constitutes one of South Africa's largest single sources of water pollution particularly in the Loskop Dam (Upper Olifants River) and the Grootdraai Dam (Upper Vaal River) catchments. Water pollution emanating from abandoned collieries in the Witbank district adversely affects water quality in the Loskop Dam catchment. The level of precipitation received at a site plays a role in the related effects of an environmental assessment analysis. A surface and groundwater baseline must be established in order to monitor the effects of an abandoned mine on the aquatic environment.

The water discharged from coal mining operations is saline, often acidic (with sulphuric acid being formed as water leaches through the sulphur compounds in the coal) and contains heavy metals. Heavy metals may become toxic to aquatic life through bioaccumulation. Surface water and groundwater resources may be affected by the chemical runoff from coal dumps and open mine pits. Water pollution has been shown to be the most serious environmental problem associated with mining. Smith *et al* (2001) has identified acid mine drainage (AMD) caused by abandoned coal mines as the greatest cause of water pollution in the state of Pennsylvania, USA, with over 4 000km of streams affected. Discussions with various key players (CSIR, DME, DWAF etc.) in the Coaltech 2020 Collaborative program indicates that water pollution is similarly the major impact from abandoned coal mines in the Witbank catchment area.

Coal mining is a major potential source of diffuse water pollution. Sulphate is a good indicator of salinity arising from this form of pollution. Approximately 70-80 per cent of the sulphate load in the Witbank catchment emanates from diffuse sources and can be attributed to coal mining. This increase in diffuse pollution has resulted in a gradual decline in water quality in the Witbank catchment. Water quality in the dam itself has declined from 50 mg/L sulphate and 100 mg/L total dissolved solids (TDS) to over 150 mg/L sulphate and 400 mg/L TDS. The concentrations of these two variables over a 16-year period are given in Figure 5-2. In some reaches of rivers and streams in the catchment this deterioration has been more pronounced and, in some cases, water quality has deteriorated from a natural baseline level of approximately 50 mg/L to over 1 500 mg/L sulphate (Brown, 1997).



Source: Brown

Figure 5-2 TDS and sulphate concentrations in the Witbank Dam

From a DWAF perspective, Swiegelaar (2003) has identified the following aspects which would be of interest in the risk analysis:

- actual water quality impact;
- potential water quality impact (surface and ground water);
- immediate water users;
- water uses;
- alternative sources for domestic water supplies;
- size of affected area;
- number of people affected;
- control measures currently on impacted area;
- contact person / person in control.

The other major water quality issues identified by Brown (1997) are:

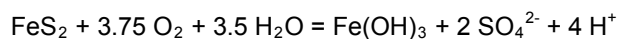
- Eutrophication. Phosphorus is the limiting nutrient in the dam and the concentration of total phosphorus has not changed significantly over the past decade. However, the transparency of the water in the dam has increased by an order of magnitude over the same period of time. This is mainly due to the

increase in TDS which has enhanced the flocculation of clay particulates resulting in an increase in light penetration.

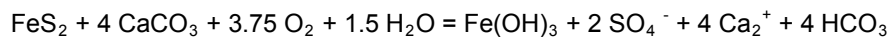
- Elevated levels of compounds toxic to the natural aquatic environment occur in some reaches of streams in the catchment. These compounds are predominantly metals and ammonia. Acid mine drainage associated with coal mining mobilises metals. Aluminium, iron and manganese are the main metals of concern. Ammonia originates from sewage effluents.

5.2.1 Acid Mine Drainage

AMD is formed from the oxidation of sulphur, chiefly present in coal and overburden rocks as pyrite. As long as the strata is intact (unmined) the process is sufficiently slow to prevent the occurrence of acid drainage. However, mining exposes the pyrite to oxygen and water, allowing rapid oxidation of the pyrite and dissolution of the products, acidity, sulfate and iron according to the equation



AMD can be neutralised and the pyrite oxidation process inhibited in the presence of calcareous strata



Thus local variations in geology and the presence or absence of high sulphur and calcareous stratigraphic intervals can have an effect on water quality. The balance of potentially acid-forming strata with the availability of potential neutralisers, particularly calcium carbonate, plays the dominant role in determining whether a mine will produce acid or alkaline drainage. It also plays an important role in determining whether metals found in mine drainage such as iron, manganese and aluminium will be produced (Smith, 2001:44).

The acidification of the water has immediate deleterious effects on aquatic ecosystems. A direct effect is the conversion below pH 4.2 of all carbonate and bicarbonate into carbonic acid, which dissociates into carbon dioxide and water. This destroys the bicarbonate buffer system in the water, which acts as a control on acidity. Secondly, since many photosynthetic organisms use bicarbonate as their inorganic carbon source, their ability to photosynthesise is limited or destroyed altogether as bicarbonate decomposes and becomes less available. Thirdly, decomposition (and hence nutrient

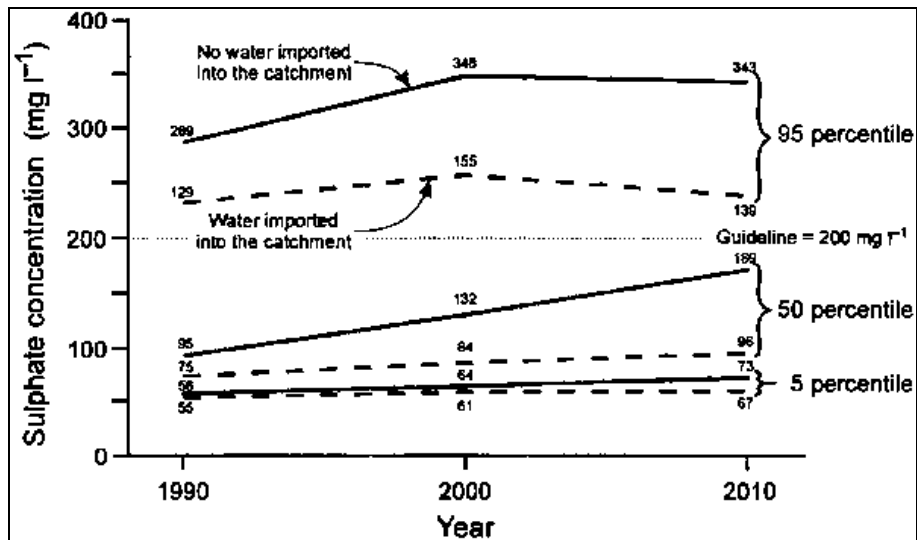
cycling) will be reduced and eventually cease, in water bodies severely affected by acid inflow. Fourthly, acid waters kill some organisms by destroying ionic balances, or damaging cell components or carbonate exoskeletons. However, the most important effects of acidification of water are the changes that result in the speciation of metals. The solubility, mobility and bio-availability of metals are generally increased by acidification of water. This is probably the result of the combination of washout processes in rocks and soils in the catchment, enhancing the mobility of metals, and the active remobilisation of metals from aquatic sediments (Ashton *et al*, 2001:55).

5.2.2 Salinity

The sulphate management objective for the dam itself was set at 155 mg/L (95 percentile value). This is approximately 23 per cent lower than the user requirement of 200 mg/L. This margin allows for:

- Further mining, industrial and agricultural development;
- Potential malfunctioning of water pollution control systems;
- Current knowledge gaps on the future potential impact of atmospheric deposits, high- extraction coal mining and open-cast mining technique;
- Lack of adequate information to establish accurately water user requirements, particularly that pertaining to the natural aquatic environment.

Present sulphate concentrations are presented in Figure 5-3 with the predicted level achievable with a 45% reduction in non-point source colliery pollution.



After Brown

Figure 5-3 Present and predicted sulphate concentrations in Witbank Dam

5.2.3 Metals and ammonia

Control of metals and ammonia will be affected by restricting the maximum allowable free and saline ammonia and metal concentrations in discharges from mining and industrial complexes. The maximum allowable concentrations of free and saline ammonia at various pH levels is presented in Table 5-3.

Table 5-3 Maximum allowable concentrations of free and saline ammonia in discharges

pH of discharge	Free and saline ammonia concentration (mg/L NH ₃ -N)		
	15 °C	20 °C	25 °C
6.5	10.0	10.0	10.0
7.0	3.4	4.4	4.8
7.5	1.1	1.7	1.3
8.0	0.62	1.1	0.76
8.5	0.36	0.37	0.27
9.0	0.13	0.14	0.12

After Brown

The maximum allowable heavy metal concentrations are presented in Table 5-4.

Table 5-4 Maximum allowable concentrations of heavy metals in discharges

Heavy metal	Maximum allowable concentration (mg/L)
Aluminum	150
Cadmium	2
Chromium	200
Copper	20
Iron	1,000
Lead	10
Manganese	500
Mercury	0.1
Nickel	100
Selenium	30
Zinc	200

After Brown

5.2.4 Siltation

Siltation is the process whereby fine solid particles build up on the bed of a river or lake and is the result of an excessive load of suspended solids in a river or rivers. Mining operations produce large quantities of dust and finely powdered rock, with much rock having been ground to particle sizes below 0.2 mm. Though the materials that are dumped after removal of the commodity being mined have fine particle size and reasonable physical characteristics that could permit plant growth and retain adequate amounts of water, these materials have been formed from hard un-weathered material and so may not contain much of the finest clay material and lack organic or microbial activity. The result is that mine dumps may be very unstable, easily blown by wind when they are dry and eroded by heavy rain when wet. The action of rain and wind thus removes fine particles into nearby water systems, leading to a build up of suspended solids and ultimately siltation (Ashton *et al*, 2001:58).

5.3 Ground & Soil

The most serious threats to the soil resource in South Africa described by Fuggle and Rabie (1992:181) are erosion, compaction, acidification, salinisation and infestation by weeds and pathogens.

5.3.1 Terrestrial Pollution

Discard coal dumps, which comprise the solid waste (mine residue) produced during coal mining operations, are placed on the land surrounding a coal mine. These dumps are prone to spontaneous combustion if they are not sufficiently compacted, presenting a potential threat of injury or death to anybody in the proximity of the coal dumps at the time of such an occurrence. Discard coal dumps are also significant sources of air pollution, especially with regard to particulate matter. Furthermore, they are intrusions upon the landscape, causing aesthetic impacts.

5.3.2 Weathering

Natural weathering processes exert a marked influence on soil formation and also on the types and quantities of materials that enter aquatic systems from the surrounding landscape. Whilst climatic features as well as the parent rock material, degree of vegetation cover and prevailing land use, control the specific type and extent of weathering processes that are active within a given area, weathering zones can be delineated on the basis of the degree to which chemical or mechanical weathering processes are dominant. A useful index of weathering processes is provided by a simple relationship between annual precipitation and evaporation. This dimensionless index, the Weinert N value (Ashton *et al*, 2001:66), is calculated as:

$$N = \frac{12 \times E_J}{P_A}$$

Where:

E_J = Mean evaporation (in millimetres) for the month of January, and

P_A = Mean annual precipitation (in millimetres).

Where specific monthly evaporation data are scarce, taking 10% of the total annual evaporation can approximate January evaporation values. The specific types of weathering processes that predominate in regions with different Weinert N values are shown in Table 5-5.

Table 5-5 Weathering characteristics associated with different Weinert N values

Weinert Index Value	Weathering Characteristics
0.00 – 2.00	Predominantly chemical weathering
2.01 – 4.00	(Wet) Seasonal dominance of chemical weathering
4.01 – 5.00	Approximately equal chemical and physical weathering
> 5.00	Dominance of physical weathering processes

After Ashton et al p 66

Mechanical weathering processes dominate in arid areas with low rainfall and high evaporation rates, causing the fragmentation of primary minerals such as quartz into smaller fragments and soils are predominantly sandy. Conversely, in warm, humid and wet landscapes chemical weathering processes dominate soil formation, giving rise to extensive deposits of secondary clay minerals. In zones where intermediate rainfall and evaporation values are recorded, both mechanical and chemical weathering processes are equally important. Mechanical weathering processes increase in importance as the rainfall declines and chemical weathering processes decrease in importance as determinants of soil formation.

Mines located in areas where Weinert N values are less than 2.00 usually show distinctive contributions to water quality and often require concerted management attention to prevent, minimize and/or remediate problems related to water pollution. Conversely, mines located in areas where Weinert N values are substantially greater than 5.00 usually show little or no contribution to local water quality and often allow mine management considerable leeway in their pollution control efforts.

Moolman (2004) suggests that further research investigating the effect of past mining activities on the weathering characteristics of this region might prove useful in determining future risks and assist in the identification of appropriate rehabilitation methods.

5.4 Ecology

Ecology is the scientific study of the inter-relationship between living organisms and their habitat and is usually restricted to living organisms other than human.

5.4.1 Destruction of Habitat

Natural habitats, or terrestrial ecosystems, are completely destroyed through open-cast strip mining. This may result in the loss of important or valuable species and prevents the recreational use of the land being mined. The aesthetic impact of open-cast strip mining is phenomenal.

5.5 Socio-Economic

During a discussion of inherited a closure and legacy issues at the GMI Conference held in Toronto in May 2000, Limpitlaw (2000), suggested that indirect and often neglected impacts of mine closure result through urbanisation. A mine-dependent population that has migrated to an area and is now out of work turns to marginal activities (including illegal mining) with subsequent degradation of the surrounding environment through de-forestation and the development of squatter camps. Here, it is also pertinent to acknowledge the positives (both direct and indirect) that mining has brought to the region, including job creation (Moolman, 2004).

5.5.1 Health Risks

Two categories of health risks associated with an abandoned coal mine can be distinguished:

1. Risk of immediate injury or death. This risk results from the possibility of rock falls (caused by the subsidence of underground mines), burning material, methane explosions, unstable highwalls, pits and illegal access to old workings, etc.
2. Risks related to prolonged exposure to harmful conditions and/or substances. Long-term exposure to air pollution associated with spontaneous combustion and dust can lead to emphysema, tuberculosis, silicosis and pneumonia.

5.5.2 Loss of Productive Land

Productive land may be lost where open-cast mining is undertaken and above underground mines because of subsidence. Such a loss is an opportunity cost, with any earnings that may have been reaped from the productivity of the land being foregone by mining the land instead.

A flowchart of possible residual bio-physical impacts of abandoned collieries is graphically presented in Figure 5-4.

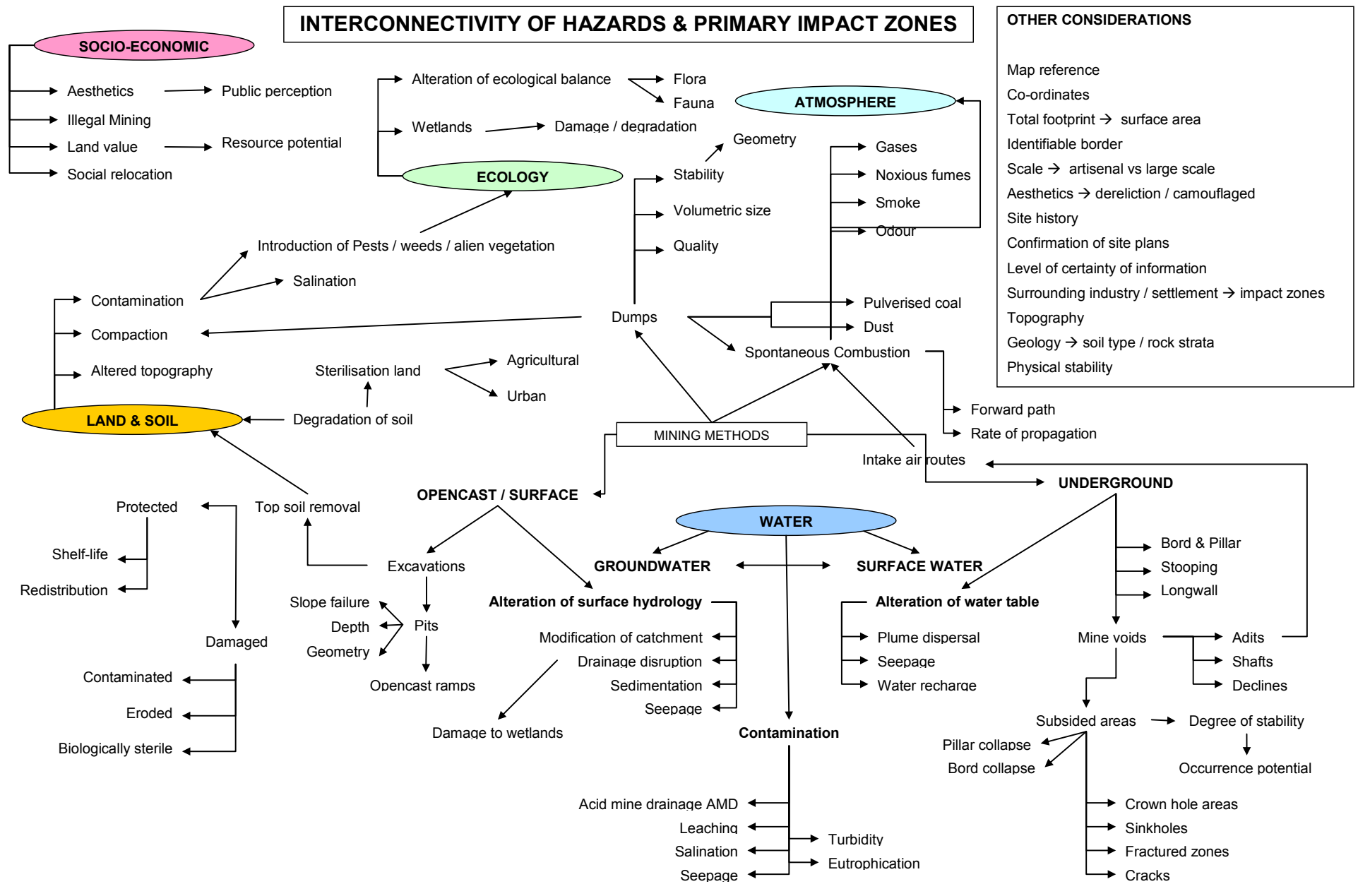


Figure 5-4 Interconnectivity of Hazards & Primary Impact Zones

The bio-physical hazards resulting from abandoned collieries and the subsequent impact on the environment have been tabulated and are presented in Appendix B.

The consequence of each category of mining related action on the environment is presented in Appendix C. The consequences are presented as:

- Environmental;
- Health;
- Safety;
- Economic losses;
- Social dislocation.

6 ACCEPTABLE RISK CRITERIA

Once the exposure to the environment has been assessed, Hansen (2002) describes the necessity to define the boundary between acceptable risk and unacceptable risk and to define the boundary of the affected land footprint. The US EPA (1996) has identified the need to define the endpoints in any risk assessment process. These explicit expressions of the actual environmental value to be protected are difficult to measure. Hansen (2002) suggests the use of surrogate assessment endpoints that are biologically and deterministically linked to the assessment endpoints. The use of standards, such as water quality criteria, is particularly useful. For the purpose of this report, it is important to determine the standards which will be used as benchmarks to determine these parameters.

6.1 *Air Quality*

The National Environmental Management: Air Quality Bill, seeks to repeal the Atmospheric Pollution Prevention Act, 1965 (Act. 45 of 1965) which provides for the performance of mines with respect to air pollution. The draft Bill provides the framework for the reform air quality governance through the establishment of national norms and standards (Department of Environment Affairs, 2003). Particulate matter is the primary pollutant created by land surface disturbances such as mining.

6.2 Water Quality

Water quality objectives are set by the Department of Water Affairs and Forestry at strategic locations in each catchment. The water quality objective at a particular location is a quantitative statement of the water quality that must be maintained at that particular point to ensure suitability for use. In the Witbank Dam catchment, the recognised water uses are domestic, power generation, mining, recreation, the natural aquatic environment and irrigation.

A selection of water quality data (presented in Table 6-1) have been obtained to demonstrate some of the different effects that deep versus shallow coal mining has on water quality, and to show the changes that take place when mine water seeps, or is discharged into, surface streams.

Table 6-1 Selected water chemistry data

Parameter	Sampling Sites				
	Deep Underground Mine	Shallow Underground Mine	Surface Flow (Close to source)	Surface Flow (0.75 km from source)	Surface Flow (1.5 km from source)
pH	8.06	6.78	3.41	3.20	3.12
EC (mS/m)	164	228	120	212	219
Ca	186	561	60	139	144
Mg	89	107	38	83	91
Na	120	15	46	44	40
Cl	13	3	66	52	44
SO ₄	910	1,767	562	1,460	1,509
Al	-	< 0.1	27	110	107
Co	-	0.04	0.92	1.63	1.58
Fe	-	21	2.7	5.6	11.8
Mn	-	3.2	25.5	37.5	36.7
Ni	-	0.1	0.39	1.13	0.94
Zn	-	0.36	0.74	2.05	1.95

Data adapted from Ashton et al p 300

The available evidence suggests that the extensive areas of coal mining in this sub-catchment have had, and will continue to have, very high impacts on the sub-catchment's water resources and particularly, the water quality of all streams and

rivers. The primary cause of these impacts is the extensive acid mine drainage where water of low pH, with high concentrations of total dissolved salts and metals, enters local water courses and results in a complete change in the water chemistry. The large volumes of acid mine drainage and the long period of time over which these discharges and seepages have taken place has resulted in the impacts still being discernable (as altered water chemistry characteristics) over two hundred kilometres downstream from the Witbank and Highveld Coalfields (Ashton *et al*, 2001:301).

The management strategies and water quality objectives focus on:

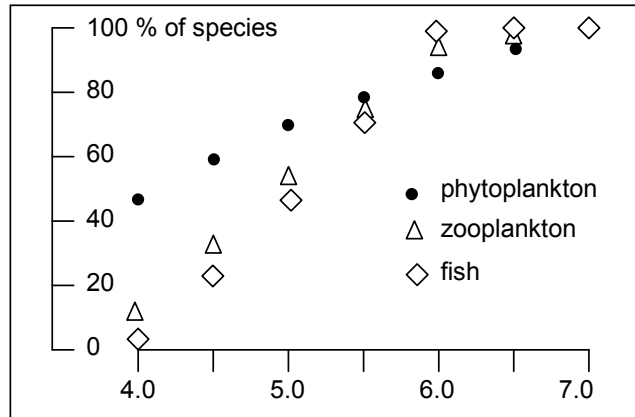
- Acid mine drainage;
- Salinity, with sulfate as the selected indicator of salinity;
- Eutrophication, with phosphorus as the limiting nutrient;
- Toxic constituents, particularly heavy metals and ammonia.

6.3 River Health Indicators and Indices

A multitude of factors determine the health of a river ecosystem: its geomorphological characteristics, hydrological and hydraulic regimes, chemical and physical water quality, and the nature of in-stream and riparian habitats. It is impractical to monitor each of these factors in detail. Therefore, the South African River Health Programme (RHP) focuses on selected ecological indicators that are representative of the larger ecosystem and are practical to measure. Since resident aquatic communities reflect the effects of chemical and physical impacts in a time-integrated manner, they are regarded as good indicators of overall ecological integrity (RHP, 1999).

6.3.1 Aquatic Invertebrate Fauna

A variety of invertebrate organisms (e.g. snails, crabs, worms, insect larvae, mussels, beetles) require specific habitat types and conditions for at least part of their life cycles. Changes in the structure of aquatic invertebrate communities are a sign of changes in overall river conditions. As most invertebrate species are fairly short-lived and remain in one area during their aquatic life phase, they are particularly good indicators of localised conditions in a river over the short term (RHP, 1999).



Source: Genske

Figure 6-1 Lake acidification causes a decrease in aquatic species

The South African Scoring System (SASS) is the biological index used for assessing aquatic invertebrate fauna. This index is based on the presence of families of aquatic invertebrates and their perceived sensitivity to water quality changes (RHP, 1999).

6.3.2 Fish

Fish, being relatively long-lived and mobile, are good indicators of long-term influences on a river reach and the general habitat conditions within the reach. The numbers of species of fish that occur in a specific reach, as well as factors such as different size classes and the presence of parasites on the fish, can be used as indicators of river health (RHP, 1999).

The Fish Assemblage Integrity Index (FAII) is based on a categorisation of a fish community according to an intolerance rating which takes into account trophic preference and specialisation, requirement for flowing water during different life-stages, and association with habitats with unmodified water quality. Results of the FAII are expressed as a ratio of observed conditions versus conditions that would have been expected in the absence of human impacts (RHP, 1999).

6.3.3 Riparian Vegetation

Healthy riparian zones maintain channel form and serve as filters for light, nutrients and sediment. Changes in the structure and function of riparian vegetation commonly result from changes in the flow regime of a river, exploitation for firewood, or use of the riparian zone for grazing or ploughing (RHP, 1999).

6.3.4 River Habitats

Loss of habitats is regarded as the single most important factor that has contributed towards the extinction of species in the last century. The destruction of a particular type of habitat will result in the disappearance of certain species. Examples of river habitat types are pools, rapids, sandbanks, stones on the riverbed, and vegetation fringing the water's edges.

As the availability and diversity of habitat are major determinants of whether a given system is acceptable to a specific suite of biota or not, knowledge of the availability and quality of habitats is very important in an overall assessment of ecosystem health (RHP, 1999).

6.4 Soil and Ground

The 1980's brought widespread awareness, both in mining and agricultural circles, of loss of agricultural production due to mining activities. The Mpumalanga coalfields affect 8% of South Africa's arable land and 51% of the high potential land (Schoeman, 2001).

Schoeman (2001) has developed a soil profile database for opencast mines for Coaltech 2020. The major parameters are presented. Compaction of soil has a direct impact on the root distribution patterns, with roots failing to penetrate materials with bulk densities greater than approximately 1.5Mg/m^3 . The high variability in pH values and the low values frequently encountered in deeper cover soil layers may be crop-limiting. In fertile soils, the pH_{water} should be between 5.5 and 7.0. Sites need to be characterised in terms of their fertility status, bulk density, clay mineralogy and water-holding capacity.

Schoeman (2001) has identified that much of the cover soils consist of structureless sandy loam to sandy clay loam, derived from orthic, red, yellow-brown and plinthic soil horizons. The cover soil depth ranges from 0.55m to 1.05m and overlies spoil materials containing between 30% and 70% fine to coarse rock fragments via an abrupt transition. The high bulk density, coupled with hardsetting behaviour is a widespread phenomenon and can be rated as the primary problem affecting land use.

Additional factors important to pasture development identified during this study are:

- Biomass production and growth curves;
- Nutritional value as determined by the chemical composition, digestibility and nature of the digested products. This also gives an indication of airborne pollution if the ash content is measured;
- Macro- and micro-elements in soils and plants.

The economics of pasture development and agriculture on abandoned coalfields will also be determined by the removal of topsoil and the extent of invasion by natural vegetation. Schoeman (2001) has shown that the vegetation dynamics depend on the physical environment (climate and/or soil conditions) and management (burning, grazing, mowing and fertilizer application). He has shown that only land with deep cover soils (topsoil) is suitable for cash crops.

7 RISK

Risk is broadly defined by Cardenas (2003) as the 'likelihood that a harmful consequence will occur as the result of an action or condition. It involves the combined evaluation of hazards and exposure.' Oberholzer (2003) defines risk as 'the chance of something happening that will have an impact upon objectives' measured in terms of:

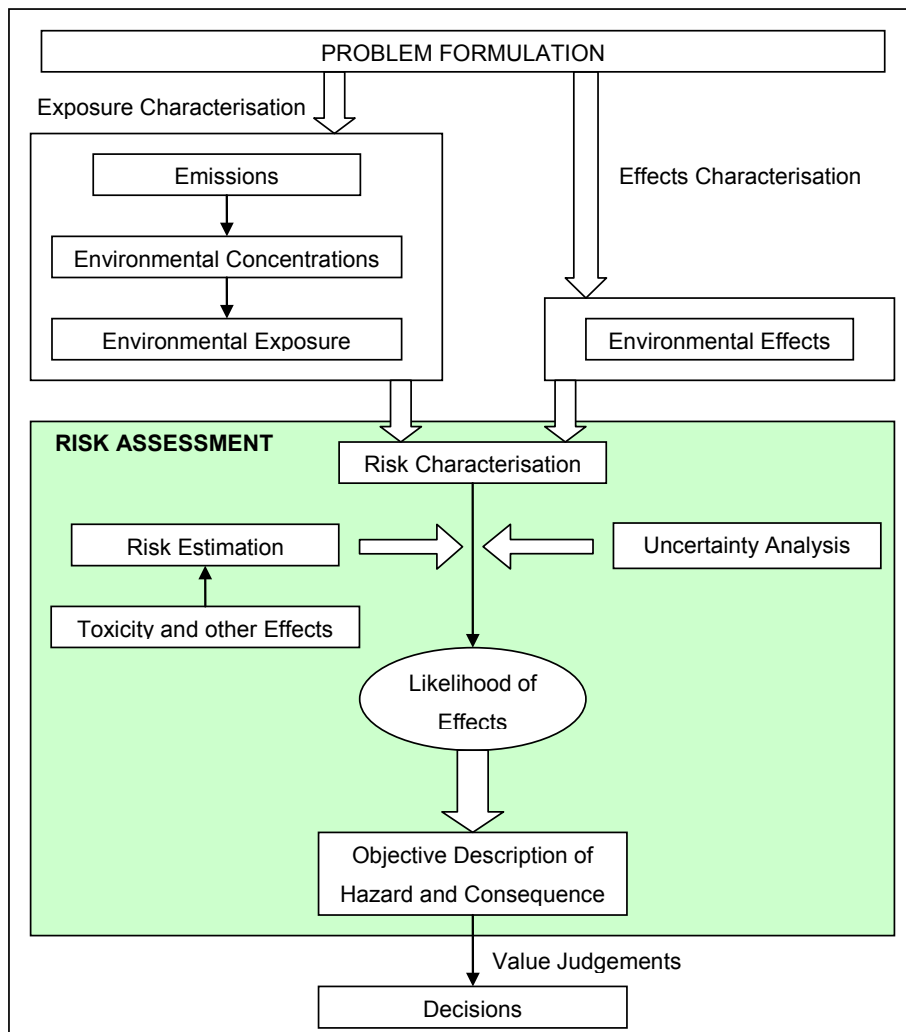
- Likelihood;
 - Exposure
 - Probability
- Consequence.

Risk = (Likelihood of an event) x (Consequence of the occurrence)

Abkowitz (2002) expands this concept to include 'incidents and trends, either man-made or natural in cause, that have the potential to inflict harm to human health and / or the ecosystem and could include physical assets or the economy (i.e. business and social disruption).' Vieira (2001) indicates the importance of clarifying the incidents or events in the context of the evaluation. In this report, the events refer to historically damaging mining practices and their on-going legacy, while environmental and socio-economic consequences of abandoned collieries mean, in hierarchal order: fatalities, accidental injury, property damage, resources loss etc.

7.1 Risk Assessment

Environmental risk assessment (ERA) uses facts and assumptions to estimate the probability of harm to human health or the environment that may result from exposure to pollutants, toxins or management decisions. Essentially, every aspect of the risk assessment process and a remediation project contains uncertainty as illustrated in Figure 7-1. If this uncertainty is neglected or assumed away, poor decisions can be made that adversely impact the outcome (Bensen *et al*, 1998:110). It is crucial that the risk assessment is consciously conservative (Pulles, 2003) so as to provide clear, defensible and traceable data.

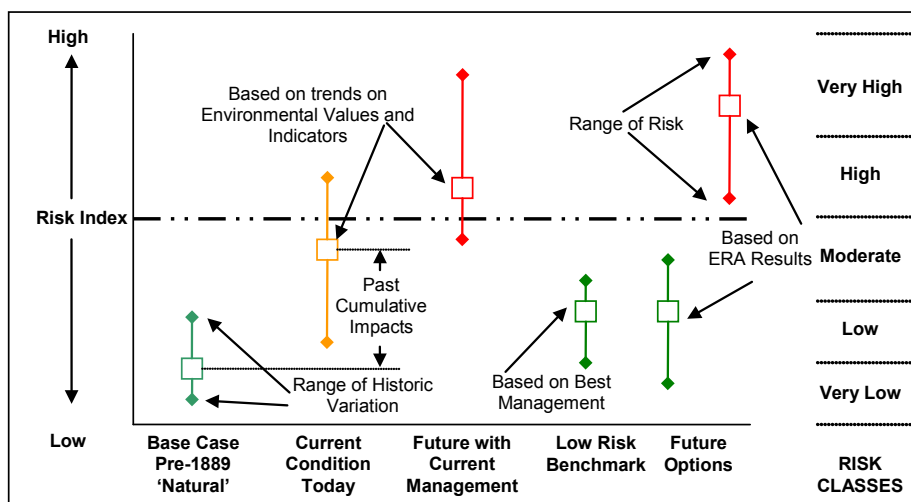


Modified after Cardenas p 11 and Hansen p 302

Figure 7-1 Environmental risk characterisation

Environmental risk assessment is based on a comparison of environmental indicators as they change over time. Environmental risk is defined by the Ministry of Environment, Lands and parks as an ‘estimate of the likelihood or probability of an adverse impact on the environment resulting from human activities’ (MELP, 2001:vii). Current and predicted future ranges of conditions are compared against the historic range of variation for those conditions as indicated in Figure 7-2. The difference in risk between current and historic conditions is the result of past development and disturbance. Future conditions are based on the trends and long-term implications of

continuing present management, or the predicted outcomes of potential alternative management options.



After Ministry of Environment, Lands and Parks, p 4

Figure 7-2 Conceptual framework for ERA

Data Quality Assessment (DQA) is the scientific and statistical evaluation of data to determine if the data obtained is of the right type, quality and quantity to support their intended use (EPA, 2000:1-1). Two fundamental questions that must be asked are:

1. Can the decision be made with the desired confidence and give the quality of the data set?
2. How well can the sampling design be expected to perform over a wide range of possible outcomes?

Because environmental conditions will vary from location and time from one to another, the adequacy of the sampling design approach should be evaluated over a broad range of possible outcomes and conditions and limits on the decision errors must be developed (EPA, 2000:1-5). The goal of this activity is to develop numerical probability limits that express tolerance for committing false rejection or false acceptance decision errors as a result of uncertainty in the data. A false rejection error occurs when the null hypothesis is rejected when it is true; while a false acceptance error occurs when the null hypothesis is not rejected when it is false (EPA, 2000:1-5).

Subsequent management of risks must focus on the adequacy of scientific evidence. Since the elimination of all risk is impossible, it is a decision making process that includes:

- Assigning priorities to different risks;
- Determining necessary funding to reduce risks to an acceptable level;
- Deciding where the greatest benefit will be realised from limited funds;
- Determining an acceptable level of risk;
- Planning and enforcing monitoring processes.

It is critical that the Government is able to assess the true risk and avoid the over-estimation of a sensational risk where people are most upset, compared to the under-estimation of risks from familiar on-going causes which may have a greater impact.

8 RISK CHARACTERISATION

The traditional hazards associated with mining are falls of ground, explosions, fire and an inrush of water.

8.1 *Inrushes*

An inrush is a low probability, but high impact event. McCarthy and Harvey (1998) identified that 78% of inrushes in collieries in Britain between 1851 and 1970 were caused by contact with abandoned old workings. A much greater frequency of contact with the exploited workings is to be expected in intensively exploited bedded deposits. The probability of inrushes could not be determined for the Witbank coalfields.

8.2 *Subsidence*

Subsidence of the ground surface can be regarded as ground movement that takes place because of the extraction of mineral resources. Underground mining methods tend to result in subsidence. The impact on the environment gives rise to various degrees of damage that can range from slight to catastrophic and can be responsible for flooding and lead to sterilisation of the land.

In the Witbank Coalfield, stratified coal deposits have been worked by partial extraction methods whereby pillars are left in place to support the roof of the workings. In pillared

workings, the pillars sustain the redistributed weight of the overburden and are subjected to added compression. Stress concentrations tend to be located at the edges of the pillars and the intervening rocks tend to sag (Bell *et al*, 1999:139). Pillars in the centre of a mined out area are under greater stress than those on the periphery. Collapse in one pillar can bring about collapse in others in a chain reaction. The yielding of a large number of pillars can bring about a shallow broad subsidence over a large surface area, with the displacement radiating inwards towards the maximum subsidence. Slow deterioration and failure of pillars may take place after mining operations have long ceased (Bell, 1999:139).



Source: Bullock, p 64

Figure 8-1 Collapse of a pillared area in the Witbank Coalfield

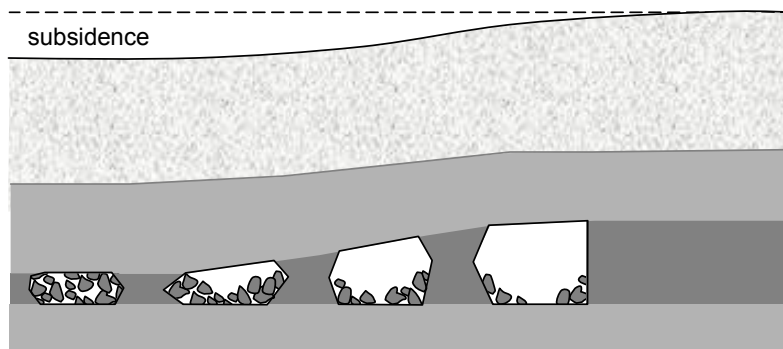
Ground movements depend on the mine layout, in particular, the extraction ratio and geology, as well as the topographic conditions at the surface. They tend to develop rather suddenly, the major initial movements lasting, in some instances, for about a week, with subsequent displacements occurring over varying periods of time. The initial movements can produce a steep-sided bowl-shaped area. Nonetheless, the shape of the profile can vary appreciably and, because it varies with mine layout and geological conditions, it can be difficult to predict accurately. Normally, the greater the maximum subsidence, the greater is the likelihood of variation in the profile. Maximum profile slopes and curvatures frequently increase with increasing subsidence (Bell, 1999).



Source: Bullock

Figure 8-2 Crown-hole

The extent of subsidence is normally governed by the presence or absence of underground boundary pillars.

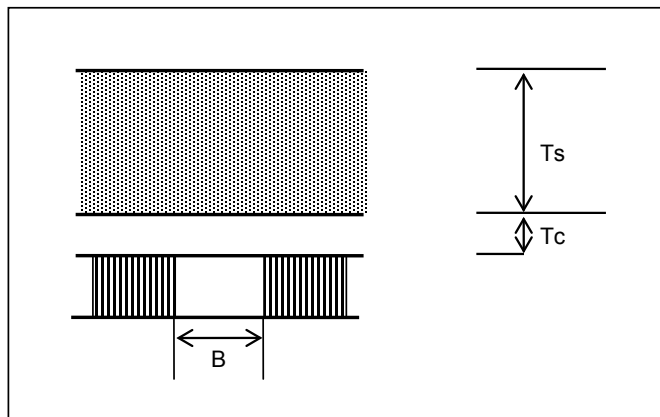


Source: Genske

Figure 8-3 Pillar overload may lead to failure

A quantitative assessment of subsidence prediction in shallow bord and pillar mines by Missavage *et al* is reported by Wagner Nel (1996) to be invalid for typical mining conditions in the Witbank Coalfield. A model developed by Fourie is therefore cited as the most suitable (Wagner, 1996:5-1). Consider a slab, with thickness T_c m being supported by coal pillars at a distance of B m apart as illustrated in Figure 8-4. The load acting on this slab consists of unconsolidated or soft over-burden of thickness T_s

m. Failure of the slab, resulting in subsidence will occur when the tensile strength at the extreme lower face of the slab exceeds the allowable tensile strength in the rock.



After Wagner Nel p 5-2

Figure 8-4 Typical Pillar and Slab

It can be concluded (Wagner, 1996:5-3) that areas overlying shallow bord and pillar workings are vulnerable to subsidence and bord failure when:

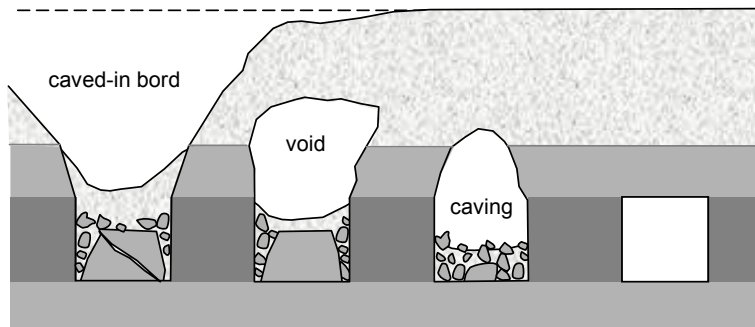
$$\frac{(5Ts + 6Tc) \times B^2}{Tc^2} \geq 200$$

where Ts = thickness of soft, unconsolidated overburden overlying the workings (m)

Tc = thickness of unconsolidated, hard overburden (m)

B = bord width

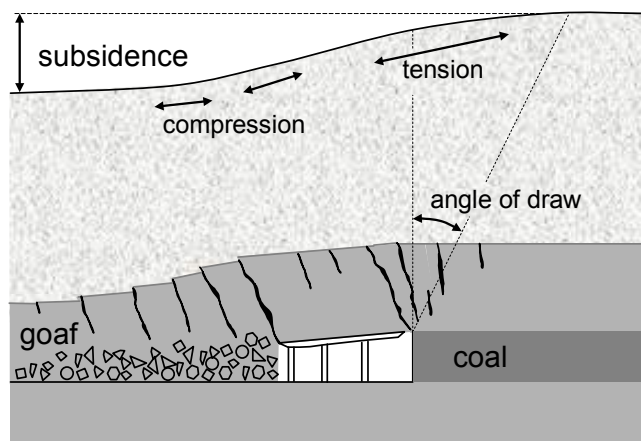
The extraction of coal removes support from the overlying strata causing them to sag into the void space created. The sag is propagated upward to the surface until a total collapse results in a caved-in bord.



Source: Genske

Figure 8-5 A model for caving

The coal mine subsidence theory described by the Colorado Schools of Mines (2003), concludes that the maximum surface subsidence cannot be greater than the thickness of the coal bed mined. The surface position of the boundary between areas of subsidence and no subsidence is defined by the 'angle of draw' as presented in Figure 8-6. This is the angle between a vertical line drawn upward to the surface from the edge of the underground opening and a line drawn from the edge of the opening to a point of zero surface subsidence. The angle of draw typically varies from 25 to 35 degrees. The larger the angle of draw the wider will be the zone on the surface in which subsidence can occur.

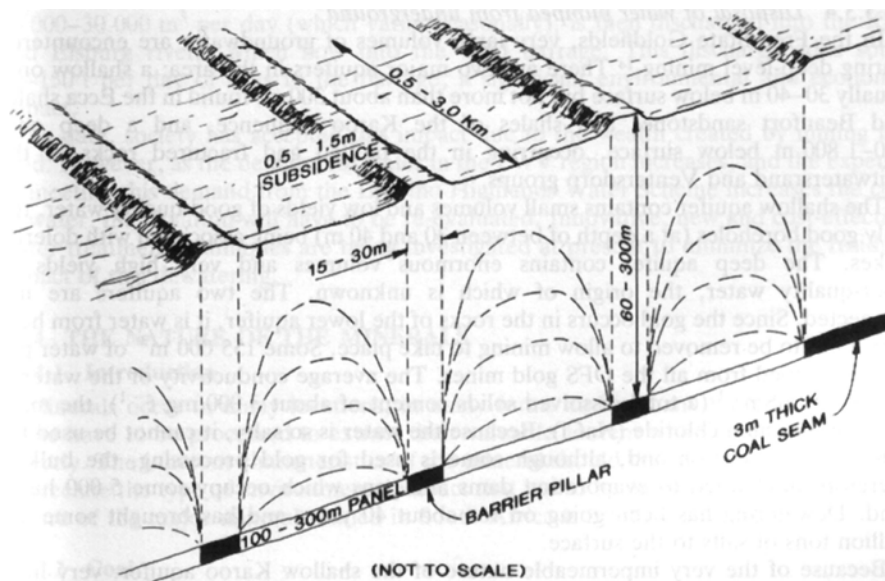


Source: Genske

Figure 8-6 Angle of Draw

After cessation of mining, subsidence may continue to occur in a steady, gradual manner, or it may stop for a period, to be followed by failure at some later date (Colorado School of Mines, 2003).

An undulating topography resulting from subsided land over the mining panels and non-subsided land over the barrier pillars and roadways which are left between panels following longwall mining is shown in Figure 8-7.



Source: Fuggle and Rabi p 349

Figure 8-7 An example of undulating topography

8.2.1 Subsidence Hazard Zones

Subsidence hazard zones are those areas where ground subsidence may occur as a result of past mining activities. The Colorado School of Mines (2003) suggests the development of a Subsidence Hazard Map to represent those areas where the land surface may possibly be affected by subsidence or collapse related to underground or surface mining of coal.

The following criteria are used:

- Surface Mines;
 - The hazard zone boundary will lie at a distance beyond the outer limits of the bottom of the pit at a distance which is equal to three times the nominal depth of the pit plus an additional 2m.
- Underground Mines;
 - Relatively low-dip mine workings (horizontal to 30° dip)
 - The hazard area boundary will lie beyond the mapped boundaries of the mine at a distance which is determined by a 35° angle of draw plus a 20m safety zone.
 - Steeply dipping mine workings (30° – 70°)
 - If the ground surface over a mine in steeply dipping beds is nearly horizontal then the subsidence hazard boundaries on the footwall side of the mine will lie 10m beyond the extension of the footwall to the surface.
 - The subsidence hazard zone boundary on the hanging wall side of the mine will lie beyond the mapped workings at a distance equal to the maximum depth of the mine plus a 10m safety zone.
 - Near-vertical and vertical mine workings (70° to vertical)
 - If the ground surface is nearly horizontal then the subsidence hazard zone boundaries of a mine in a nearly vertical or vertical bed will lie beyond the mapped boundaries of the mine at a distance equal to the maximum depth of the workings plus a 10m safety zone.

While not applicable to the Witbank coalfield, the following criterion must be considered in a future phase of this Coaltech project in which the coalfields of Kwa-Zulu Natal are to be investigated and assessed:

- For surface and underground mine workings where the deepest part of the mine is at an elevation lying above much of the surrounding topography, the topographic contour of that elevation becomes the hazard boundary.

8.2.2 Areas of no subsidence

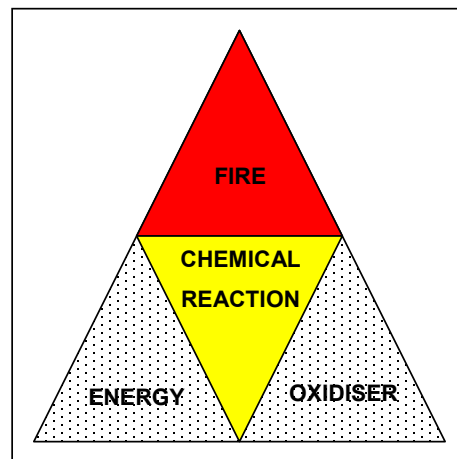
Certain areas conform to generally accepted and proven safety mining practice and will therefore not be subjected to the risk of failure and subsidence. Wagner (1996:5-3) suggest that these areas would include:

- Main haulage and travelling ways where large pillars were left on either side of the travelling way;
- Areas not mined due to the presence of dyke intrusions;
- Areas where coal of low quality is present and could not be mined economically at the time mining took place.

The subsidence profile of these three alternatives can be summarised as shown in Figure 8-8 (Wagner, 1996:5-3).

8.3 Spontaneous Combustion

The propensity of colliery waste to combust spontaneously is related to the specific ability of seams to self heat during or after mining. The instances of burning coal wastes are increasing with the increase in percentage of coal mined by open cut methods. This coal is often blended with the overburden and may result in numerous pockets of heating across and through the wastes (Clarke *et al*, 1997). Estimation of spontaneous combustion risk liable to self-heating remains an issue of environmental expertise even after mine closure (Michaylov, 2002:27). In order to identify the risk of underground fires, the Fire Pyramid, an accepted basic theory on fire, is described by Wagner (2001:6-1) and illustrated in Figure 8-9. The inter-relationship between four components - fuel, energy, oxidiser and chemical reaction must be considered.



Source: Wagner p 6-1

Figure 8-9 The Fire Pyramid

Michaylov has made a literary review of available models to predict spontaneous combustion and has developed the SES (Sponcom Expert System) for assessment of spontaneous combustion risk. The following important natural and technogenic factors for estimation of spontaneous combustion risk were incorporated into SES:

- S¹ Self-heating ability of coal seams;
- S² Thickness of coal seam;
- S³ Slope of coal seam;
- S⁴ Release of methane;

- S⁵ Tectonic faults;
- S⁶ Fitting of ventilation flow to the caved areas;
- S⁷ Presence of pillars, unmined coal seams, co-seams that belong to the zone of caving in the caved out area;
- S⁸ Natural temperature of coal in the massif;
- S⁹ Temperature and humidity of ventilation flow in risky zones for self-heating ability.

These characteristics are used for calculating the spontaneous combustion risk according to the dependence:

$$D_s = \sum_{i=1}^9 S^i$$

According to the value of D_s sites are categorised as:

<i>Lower risk</i>	$D_s < 22$
<i>Threatened risk</i>	$23 < D_s < 39$
<i>Risky</i>	$40 < D_s < 60$
<i>Higher risk</i>	$D_s > 60$

When a spontaneous combustion is registered in the same seam in the vicinity of the site under assessment, a category of spontaneous combustion risk one higher than that determined must be appropriated.

It can be concluded that the combustion process will occur in the presence of all four elements identified by the Fire Pyramid and will be interrupted, controlled or stopped with the removal of any one of them. Michaylov (2002:33) has also shown that the surface heating ability decreases with an increasing depth.

Moolman (2002) has identified the total risk for the development of spontaneous combustion to include coal properties, geological factors, environmental factors and mining properties as follows:

- Coal properties
 - Rank
 - Petrology
 - Moisture

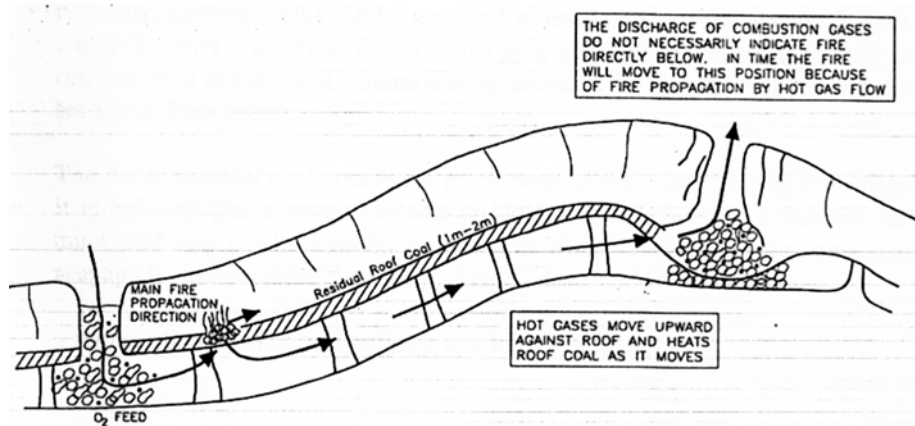
- Friability
- Porosity
- Seam gas
- Sulphur (pyrites)
- Geological factors
 - Seam thickness
 - Multi-seam
 - Faults and intrusions
 - Depth
 - Strata
- Environmental factors
 - Wind direction
 - Rainfall
 - Barometric pressure differences
 - Convection
 - Diffusion
 - Coal temperature
- Mining properties
 - Ventilation
 - Mining method
 - Mine layout
 - Rate of mining
 - Drilling and blasting
 - Water
 - Mining height
 - Housekeeping
 - Recovery

8.3.1 Fire propagation

A fire propagation theory based on the reported history of fires and subsidence, surface subsidence patterns as depicted from aerial photography at various times, the topography of the coal seams and mining activities and the physical phenomena that causes warm combustion gases to move along the roof towards higher elevations has led to the development of a fire movement and prediction model for the abandoned

T& DB Colliery and is presented by Wagner (1996:6-2 – 6-3). The model is considered to be applicable for the whole of the Witbank Coalfield and is therefore described in this report.

The theory is based on the assumption that fire will rapidly move in the direction in which combustion gases flow (i.e. away from the fire) due to the preheating effect of the warm gases against the residual coal roof surface. This direction has been defined as the main propagation route, and is mainly dictated by the roof topography as depicted in Figure 8-10.



Source: Wagner

Figure 8-10 Propagation Theory – Prediction of Fire Movement

Problematic fires can be expected to occur in high residual coal areas. Cognisance must be made of dense coal occurring in flooded areas of the mines. These areas should remain trouble free unless the water level lowers for some reason such as seepage at a greater rate than the recharge rate.

8.4 Mine Residue Deposits

Historically, the planning of mine residue deposal sites was based on minimum cost, the availability of land and the safety of underground workings. Mine tailings and coal discard accounted for 74% of the total waste stream in South Africa in 1990. The total area of land covered by mine residue in 1981 was 10 700 ha, mostly in the Transvaal and Orange Free State (Fuggle and Rabie, 1992:355).

The main types of pollution resulting from residue deposits are water pollution and air pollution. Both aesthetics and the change of land-use can also be significant.

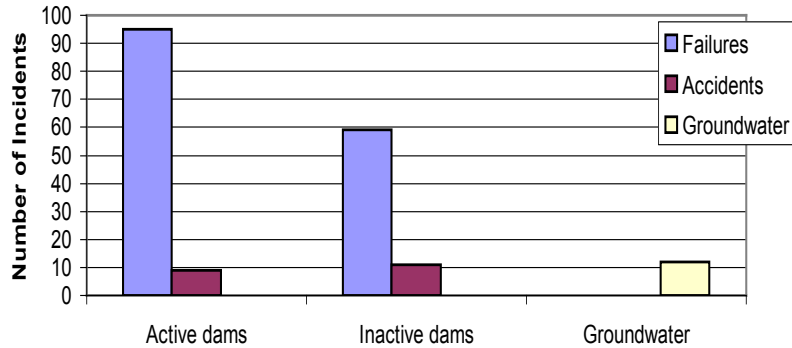
In order to minimise the risk of spontaneous combustion, Fuggle and Rabie (1992:359) suggest that compaction of the discard dump to reduce the air voids to less than 15% is necessary. In addition, these voids must contain sufficient moisture to reduce the actual air content to less than 10%. To assist in maintaining this inert, moist environment rainwater falling on the dump should not be allowed to run off.

Fuggle and Rabie (1992:359 - 360) list various factors which must be considered when determining the impact of dumps on the environment as follows:

- A steep slope (32° – 38°) erodes less than other slopes until a slope of 8° is reached;
- To accommodate a certain volume of waste in a dump of the same height, more land is required for a gently sloping than a steeply sloping dump. More land is therefore permanently alienated;
- Because more rain collects on the larger dump area, there is more chance for a larger volume of water being polluted;
- A water-control structure must be present as close to the dump as possible to effectively isolate it from the outside water environment;
- Access to the dump must be limited.

8.5 Tailings Dams

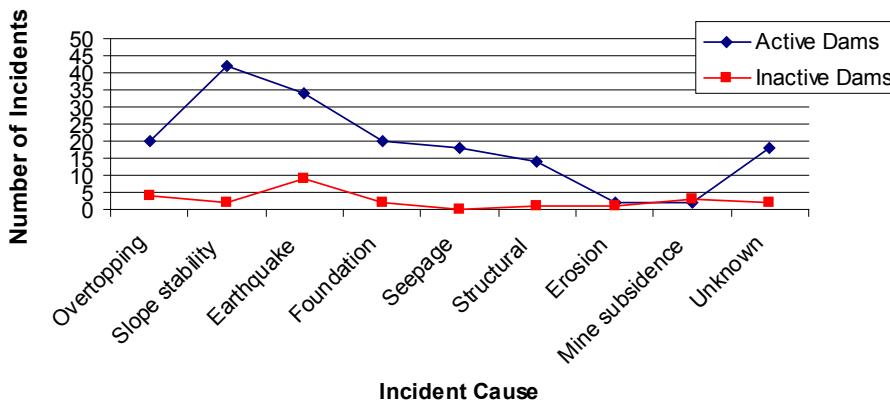
Strachan (2001) showed that tailings dam incidents (in terms of failures and accidents) result from a number of factors, including overburden topping, static and seismic instability, seepage and internal erosion. A comparison was made in terms of the tailings dam status (active and inactive dams) in Figure 8-11.



After Strachan p 51

Figure 8-11 Tailings dam status comparison

The results show that inactive dams account for significant failures and accidents. The cause of incidents were further categorised as presented in Figure 8-12. The estimated frequency of failure of a tailings impoundment is estimated by Strachan to be 1 : 1000 for a major failure and 1 : 100 for a minor failure. Any failure has direct and indirect economic impacts on the mining industry and is unacceptable due to human, environmental and negative publicity aspects.



After Strachan p 52

Figure 8-12 Tailings dam incident cause summary

The incident survey shows that while there is no over-riding cause or mechanism for all failures a range of incidents have been recorded at inactive dams.

9 METHODOLOGY

The Risk Ranking Tool (RRT) developed as a result of the above discussions is not intended to determine absolute risk levels for abandoned or derelict mine sites. As mentioned previously, the sensitivity of data combined with the absence of many parameters required to formulate a detailed assessment of the collieries requires a simplification of the process. The RRT for the Witbank Coalfield provides broad indications of relative risk that allows different mine sites to be ranked in order of risk levels according to established parameters by comparing overall totals.

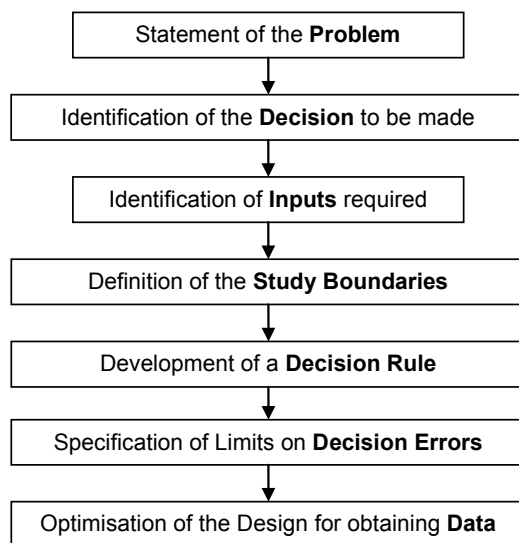
9.1 Key Factors

The following factors have been identified as playing a key role in the development of the Risk Ranking Tool:

- A well-defined, representative and comprehensive list of issues;
- A well-defined universal method of adjudicating the consequences of every issue;
- A representative method of describing the exposure of predetermined elements to the issues;
- The derivation, calculation and prediction of probabilities of occurrence for the issues;
- Incorporation of systems risk to cope with change;
- Standardised use of the process to evaluate all mines under consideration in the same way.

9.2 The DQO Process

The Data Quality Objectives (DQO) Process (EPA, 1994) is a systematic planning tool based on the Scientific Method for establishing criteria for data quality and for developing data collection designs. The seven re-iterative steps to be considered are presented in Figure 9-1.



After EPA, 2000 p 2

Figure 9-1 The DQO Process

The DQO Process leads to the development of a quantitative and qualitative framework for study (EPA, 1994:5). Since most environmental problems present a complex interaction of technical, economic, social and political factors, it is critical to the success of the process to define the problem completely and in an uncomplicated format (EPA, 1994:10-22). Thus the spatial boundary must be defined as a geographic area and the temporal boundary must be clarified in terms of the time frame under consideration. Any practical constraints on data collection such as the inability to gain site access or the unavailability of personnel must be identified.

The methodology used in the process of developing the Risk Ranking Tool can be simplified to three primary dynamic and interactive phases:

1. Identification and site characterisation

Determines and quantifies all potential areas of threat or hazard and is conducted via desktop research and site visits.

2. Evaluation by scenario

This measures environmental risk in terms of socially acceptable consequences and informed judgements as to the likelihood of scenarios occurring and their consequences.

3. Analysis of results

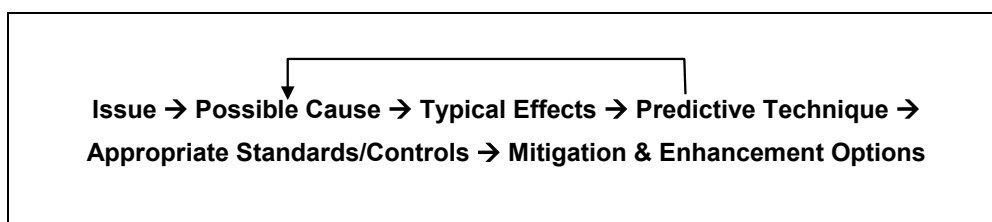
Analysis of the information according to different criteria and scales to prioritise remediation and rehabilitation works. The New South Wales Department of Mineral Resources (NSW, 2001:2-1) suggests that these include:

- By scenario;
- By mine feature;
- By mine site;
- According to environmental parameters;
- According to socio-economic parameters;
- According to human health and safety parameters;
- Combinations of the above.

The estimation of risks involves recognising what the potential hazards are and quantifying them. In reality the problem is at least 3-dimensional involving probability of failure, danger and time.

The Risk Ranking Tool uses information obtained from various sources, including maps, internet sites, government agencies, mining houses and abandoned mine site inspections to characterise the mine site and surrounding features.

Figure 9-2 is a schematic representation of the most appropriate logic to be used in the development of a risk matrix as identified by Renger *et al* (1994:77)..



After Renger

Figure 9-2 Schematic representation of the logic

Using this thought process, possible issues to be considered when assessing the impact of an abandoned colliery on groundwater are presented in Table 9-1.

Table 9-1 Issues considered for the impact of an abandoned colliery on groundwater

ISSUE HAZARD IMPACT	POSSIBLE CAUSE CONTRIBUTING FACTORS	TYPICAL EFFECTS CONSEQUENCES	PREDICTIVE TECHNIQUE	STANDARDS / CONTROLS
AMD decant	Oxidised sulphide (↑TDS, ↑salinity, ↓pH, ↑dissolved metal ions Fe,) Area mined Period of activity Geology Meteorological – rainfall Mine status – when last mined Position of mine relative to aquifer (above / below / within / through) Access of water to and from mine (direct adits etc) Interconnectivity between mine and aquifer	Toxic to aquatic life Dramatic changes in ecosystem Changes in structure and chemical composition of soil Persists for centuries Mobility of AMD Plume Reduced crop yields	Water chemistry data Boreholes Weinert N weathering index Dewatering rate	Water Quality Standards
Disrupted flow	Geology Broken dolerite formations	Hydrology ↑Summer flows ↓Attenuation ↓Winter flows	Flow pattern – historic data	
Alteration of water table	Geology Hydrology Topography	Drainage disruption Seepage	Flow pattern – historic data	
Discolouration	↑dissolved metal ions Fe, Mn	Aesthetic	Visual	Water Quality Standards
↑Turbidity	↑SS and colloids Adsorbed metal ions ↓light penetration ↓photosynthesis ↑Eutrophication	Smother aquatic life Toxic – aquatic & terrestrial Aesthetic Health	Visual	Water Quality Standards

Hodgson *et al* (2001) investigated and evaluated the current impact of closed underground mines on the quality and quantity of groundwater resources, generating an impact rating system RISKY from their observations. RISKY is flexible and can be adapted as more information becomes available and is user friendly. The underlying concepts used in the development of RISKY, have been expanded during this project to incorporate physical and socio-economic information on abandoned collieries to allow total mine risk assessment.

Categories and classes used for evaluation of the mines are sufficiently general to be used for mines where a minimum of information is available. This predictive tool offers an evaluation to be used as a first approximation based on sound scientific principles and the best available information. Having all the information in a spreadsheet allows

quality control reviews and checking for data accuracy as well as relatively simple updating of data.

The immediate objective of this project was to identify abandoned and inactive coal mine sites and their associated features, collect required field data and prepare a database. Once all the data is compiled, the DME will work with partners including key industry players and collaborative partnerships such as Coaltech, etc., to identify, prioritise, propose, and fund reclamation projects, which can improve the ecosystem and protect human health and safety, including:

- rehabilitation of natural water courses directly affected by mining operations;
- collection and treatment of polluted mine water;
- treatment of surface soil wherever this is affected by mining activities;
- monitoring of results for a specified period after the completion of remediation.

9.3 Identification and Site Characterisation

Mine features have been grouped as follows:

- Surface Mining
 - Open cuts
 - Pits
- Underground workings
 - Adits
 - Shafts
 - Cracks
- Waste Rock, Rubble and Tailings Dumps
- Containment Structures
 - Tailings dams
 - Impoundments
 - Evaporation dams
- Beneficiation Plant
- General Site
 - Offices
 - Hostels
 - Workshop

- Village
- Roads
- Equipment
- Services

9.4 Evaluation by Scenario

Owing to the similarities of the coalfields of New South Wales (NSW) and South Africa (Lind, 2002), an internet search for the risk assessment process used by collieries in that region of Australia was conducted. Personal communication with Brisebois (2003) enabled the researcher to view the Guidance Manual – Application of Risk Tool to Assess Abandoned and Derelict Mine used by the NSW Department of Mineral Resources (NSW, 2001). The similarities in approaching the risk assessment and ranking process were noted and additional features for the Witbank Coalfield incorporated to create an adaptation of the NSW Risk Tool.

For each of the mine areas listed in Section 9.3, a number of possible scenarios that could lead to an environmental and/or socio-economic and/or health & safety impact, can be identified as presented in Table 9-2.

Table 9-2 Derelict and Abandoned Mine Site Impact and Hazard Scenarios

	Surface Mining
S1	Accidents
S2	Discharge of contaminated runoff / AMD / leachate
S3	Unstable walls / slopes
	Underground Workings
U1	Accidents
U2	Discharge of contaminated runoff / AMD / leachate
U3	Gas / Noxious Fumes / Smoke
U4	Spontaneous combustion
	Waste Rock, Rubble and Tailings Dumps
D1	Discharge of contaminated runoff / AMD / leachate
D2	Spontaneous combustion
D3	Unstable dump structure
	Containment Structures
C1	Accidents
C2	Contaminated leaks
C3	Overtopping by contaminated materials
C4	Structure failure and release of contaminated materials
	Beneficiation Plant
P1	Contaminated runoff / leachate
P2	Dust emissions
P3	Unstable built structures (including subsidence)
P4	Unstable land surfaces (including subsidence)
	General Site
G1	Contaminated runoff / leachate
G2	Dust emissions
G3	Unstable built structures (including subsidence)
G4	Unstable land surfaces (including subsidence)

Adapted from NSW, 2001 pp 4-1 – 4-2

The alpha-numeric reference codes used indicate the major mine site risk areas with the numbering purely alphabetical as no ranking of the scenarios has been considered at this point of the risk identification process.

9.5 Values for Consequences and Probabilities

9.5.1 Consequences

For each relevant scenario, consequence ratings for environment, and/or socio-economic and/or health & safety must be allocated. The consequence rating reflects the scale of the impact and is allocated on a scale of 1 to 5, where 1 indicates a negligible impact and 5 a catastrophic impact. Where the consequence is irrelevant or there is no consequence, a value of 0 is recorded. Consequence criteria for the environment, socio-economic, human health and safety issues are presented in Table 9-3.

Table 9-3 Consequence Criteria

Score	Rating	Environment – (Land/Water/Flora/Fauna)	Socio- Economic	Human Health & Safety
5	Catastrophic	Irreversible* impact on indigenous flora and/or fauna within and beyond mine site boundaries And/or irreversible* impact on land and/or water resources within and beyond mine site boundaries.	Destruction of potentially significant “heritage” structures or sites And/or claims for damage to property, stock, crops, public facilities, land use amounting to > R100 million and/or public complaints at National level	Multiple fatalities And/or widespread serious impact on public health from mine site contaminant(s).
4	Major	Irreversible* impact on indigenous flora and/or fauna within mine site boundaries or reversible impact beyond mine site boundaries with a natural recovery period of > 2 years And/or irreversible* impact on land and/or water resources within mine site boundaries or reversible impact beyond mine site boundaries with a natural recovery period of > 2 years.	Major irreparable damage to potentially significant “heritage” structures or sites And/or claims for damage to property/stock/crops/public facilities/land use amounting to between R10 million and R100 million and/or complaints at State level	Single fatality And/or serious health impact on multiple persons from mine site contaminant(s).

* Irreversible impact = permanent loss of species and/or habitat in local population or community, or permanent degradation of land surface and water quality.

Table 9-3 Consequence Criteria Continued

Score	Rating	Environment – (Land/Water/Flora/Fauna)	Socio- Economic	Human Health & Safety
3	Serious	<p>Reversible[#] impact on indigenous flora and/or fauna within mine site boundaries with a natural recovery period of > 2 years or a reversible impact beyond mine site boundaries with a natural recovery period < 2 years</p> <p>And/or reversible[#] impact on land and/or water resources within mine site boundaries with a natural recovery period of > 2 years or a reversible impact beyond mine site boundaries with a natural recovery period < 2 years.</p>	<p>Major repairable damage to potentially significant “heritage” structures or sites</p> <p>And/or claims for damage to property/stock/crops/public facilities/land use amounting to between R1 million and R10 million and/or public complaints at Local level.</p>	<p>Accident potentially resulting in a permanent disability</p> <p>And/or serious health impact on one person from mine site contaminant(s).</p>
2	Minor	<p>Reversible[#] impact on indigenous flora and/or fauna resources outside mine site boundaries with a natural recovery period of < 1 year or a reversible impact on flora and/or fauna within mine site boundaries with a natural recovery period of 1 to 2 years</p> <p>And/or reversible[#] impact on land and/or water resources outside mine site boundaries with a natural recovery period of < 1 year or a reversible impact on land and/or water resources within mine site boundaries with a natural recovery period of 1 to 2 years.</p>	<p>Minor repairable damage to potentially significant heritage structures or sites</p> <p>And/or claims for damage to property/stock/crops/public facilities/land use amounting to between R100,000 to R1 million and/or public complaints at Community level.</p>	<p>Accident requiring medical treatment but unlikely to result in permanent disability</p> <p>And/or transient health impact on one or more persons from mine site contaminant(s).</p>

[#] Reversible impact = situation will naturally recover if the threatening process (i.e. overgrazing, acid drainage, erosion) is eliminated or remedied.

Table 9-3 Consequence Criteria Continued

Score	Rating	Environment – (Land/Water/Flora/Fauna)	Socio- Economic	Human Health & Safety
1	Negligible	<p>No detectable temporary or permanent change to off-site indigenous flora and/or fauna and/or off-site land and/or water resources</p> <p>And/or no impact on indigenous flora and/or fauna resources within mine site boundaries with a natural recovery period of >1 year</p> <p>And no impact on land and/or water resources within mine site boundaries with a natural recovery period of > 1 year.</p>	<p>No detectable damage to potentially significant heritage structures or sites</p> <p>And/or claims for damage to property/stock/crops/public facilities/land use amounting to less than R100,000 and no public complaints.</p>	<p>No medical treatment required</p> <p>And no measurable health impact on persons from mine site contaminant(s).</p>

After NSW Risk Tool Manual pp 4-3 – 4-5 and Forbes, 2002

For any particular scenario many factors influence the consequences and a number of considerations must be assessed. The NSW Risk Tool report suggests that the risk assessor needs to consider the following consequence considerations:

1. Are substances harmful to people, flora or fauna present?
2. Is the surrounding land of a sensitive nature?
3. Is surface water within the impact area?
4. Is human habitation within the impact area?
5. Is infrastructure within the impact area?
6. Is sensitive flora / fauna within the impact area?
7. Will groundwater be negatively impacted by leachate?
8. Do water bodies present a threat of drowning?
9. Are there hazardous precipices?
10. Are there hazardous shafts / holes / pits?
11. Are structures present which pose confined space hazards?
12. Are there escape mechanisms in shafts / holes / pits / confined spaces?
13. Are chemicals present?

Additional consequence considerations identified for Witbank include:

14. Is there access for illegal mining?
15. Is the site used as a thoroughfare?
16. Is the site illegally occupied?
17. Is there a risk of burning injuries / death as a result of fires?

9.5.2 Probabilities

For each relevant scenario, a probability or likelihood rating of that level of consequence occurring must be allocated. Likelihood ratings are allocated on a scale of one through five, where one indicates the scenario is unlikely to occur and five indicates the scenario is certain to occur. The descriptions for the probability criteria are presented in Table 9-4.

Table 9-4 Probability criteria

Rating	Definition
5	Certain: Is occurring now or is known to have recently occurred
4	Almost Certain: Expected to occur more than once per month
3	Likely: Expected occurrence of between once per month and once per year
2	Possible: Expected occurrence between once per year and once in ten years
1	Unlikely: Expected occurrence of less than once in ten years

After NWS p 4-8

The NSW Risk Tool Manual lists the following questions which should be answered before a judgment on the probability of a level of consequence occurring can be made:

- 1. Have there been related complaints?
- 2. Is there evidence that the scenario has occurred nearby?
- 3. Is site security adequate?
- 4. Is there evidence of recent visitation?
- 5. Is there a record of previous incidents?
- 6. Is there evidence of wind erosion?
- 7. Are water bodies easily accessible?
- 8. Is there evidence of contaminated drainage?
- 9. Is there evidence of leaching occurring?
- 10. Is there evidence of progressive deterioration of high wall?
- 11. How many mine shafts/holes/pits are there?
- 12. Is there evidence of current or previous underground fires?
- 13. Is combustible material present?
- 14. Is there evidence of impacted flora/fauna in the area?
- 15. What is the angle of slope?

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Table 9-5 illustrates the method used to calculate the severity from a series of consequences and probabilities. This matrix is useful in determining the total risk of each parameter under investigation. The risk assessment scores are calculated by multiplying the consequence rating by the corresponding probability rating for each

environmental risk and/or socio-economic risk and/or risk to human health and safety. Overall risks of each scenario are calculated by adding these risk scores. If any scenario is not considered relevant the risk ranking is assumed to be zero. If the probability of spontaneous combustion occurring at a particular site is certain it will score a five for probability. Depending on the severity of the consequence, i.e. total destruction of the natural environment or a human death, this may also score five. The total risk for spontaneous combustion in this instance is therefore twenty five and falls within the High Risk category (5 x 5 = 25).

Table 9-5 Matrix to assess the severity of the consequences and probability of a risk

		PROBABILITY				
		1	2	3	4	5
CONSEQUENCE	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

Severity	Score
Very High	20 – 25
High	10 – 16
Medium	4 – 9
Low	1 - 3

PROBABILITY		CONSEQUENCES	
5	Certain / Common	5	Catastrophic
4	Almost Certain / Has happened	4	Major
3	Likely / Could happen	3	Serious
2	Possible but Not likely	2	Minor
1	Unlikely / Practically impossible	1	Negligible

After CSIR MineRisk Africa

9.5.3 Risk Assessment Scores

As described above, the methodology selected to reflect the level of risk is represented as a numerical score, with lower risks scoring lower values.

The NSW Risk Tool (2001) is not intended to determine absolute risk levels for abandoned or derelict mine sites. The methodology used in that assessment and modified for incorporation in the development of a Risk Ranking Tool for the Witbank Coalfield provides indications of relative risk that allows different mine sites to be ranked in order of risk levels according to established parameters. The overall totals are compared. Due to the absence of verifiable data for determining the probability and associated consequence for each parameter, the Risk Ranking Tool uses the degree of presence of a particular parameter as an indication of risk. The scoring process is directly related to the severity level determined from Table 9-5, i.e. Low, Medium, High or Very High. This scoring process is directly linked to the risk associated with each parameter in a direct one-to-one relationship.

10 THE DEVELOPMENT OF THE RISK RANKING TOOL

Parameters to be assessed / included in the analysis of results are categorised as before:

- Environmental risks;
- Socio-economic risks;
- Human Health & Safety risks.

The NSW Risk Tool Manual (2001:5-2) cautions that, when analysing risks, the decision maker should be aware that overall risks associated with a number of scenarios may mask risks associated with a single scenario. To overcome this potential problem, it is suggested that risks associated with individual scenarios and site features should be considered in addition to the overall risk associated with a mine site. The risk calculation spreadsheet must therefore include a column in which any scenario exceeding the benchmark standard or threshold is identified.

The advantages of determining acceptable risk levels based on numerical scores include:

- Better evaluation due to predetermined criteria;
- Identify further information requirements;
- Allow conformity in evaluation process;
- Single risk value per site;
- Reduced or expanded in scope;
- Traceable process that would withstand scrutiny;
- Values can be changed;
- Allow for the calculation of residual risk reduction after controls have been implemented;
- Allow various controls to be cost beneficially evaluated in terms of risk reduction per rand spent.

A limited number of scenarios have been identified for the purposes of this risk assessment to ensure that a relatively quick analysis and first cut ranking can be made.

10.1 Key Design Principles

The key design principles are as follows:

- Transparency;
- Traceable throughout the process;
- Common method of evaluation for all situations – state wide;
- Allow the benefit of the rehabilitation to be determined in terms of risk reduction;
- Alteration and enhancement of the process as more and better information becomes available;
- Ease of maintenance;
- User friendly and transportable;
- Give the same results irrespective of user or venue.

10.2 Overriding Considerations

The identification of overriding considerations is an important step. These are issues that dominate the outcome of the risk assessment. The four overriding considerations

identified (Moolman, 2004) as applicable to abandoned and defunct collieries in the Witbank area are:

1. Spontaneous combustion – open voids and / or exposed coal seams;
2. Subsidence – Depth below surface < 40m in conjunction with the overlying geology type;
3. Water – Acid mine drainage;
4. Community proximity < 1km.

10.3 Subordinate Considerations

The next step is the identification of other considerations to be included in the risk ranking system. For ease of data capture, these are broken down into a series of separate input forms as shown in Figure 10-1 to Figure 10-5 . An auto-loading Beta version of the Risk Ranking Tool is included on the CD.

(NOTE: As mentioned before, the discussion included in Section 9.5 could not be used in the development of the Risk Ranking Tool. Currently only 3 criteria for each parameter are considered and no allowance is made for the probability of occurrence of each event. Enhanced sensitivity analysis depends, however, on the availability of data. I have requested assistance from various individuals and companies, and am still awaiting their responses before I will be able to continue with enhancing the program. I have not been able to quantify probabilities with sufficient confidence levels.)

The program has been subdivided into a series of scenarios, namely:

- General Issues;
- General Site;
- Dumps / Spoils: waste, rock, rubble and tailings;
- Surface Mine;
- Underground Mine.

The parameters detailed for each scenario are tabulated as per the characterisation process and prediction model described by Roy (2003) and an example of the screen layout for each is presented below. Parameters are scored 0, 1 and 3 depending on the degree of concern regarding the status of each issue. Should additional data be

required, that parameter scores 2 as a reflection of the uncertainty associated with the absence of data. It will then be necessary, as a next step, to collect additional data so that the parameter can be quantified as presenting a low or high risk. Screen capture images of the various forms are included in the body of the report.

10.3.1 General Issues

The list of General Issues presented in Table 10-1 reflects the physical, geographic and social status of the site under consideration.

Table 10-1 General Issues

Parameters	Risk factor for each individual parameter (N_i)
Additional Data Needed	2
Footprint	N₁
< 25 Ha	0
25 – 100 Ha	1
> 100 Ha	3
Geology	N₂
Impervious and Competent	0
Fractured	1
Porous and Fractured	3
Access	N₃
Limited Access	0
Access – Footpaths / Illegal Occupation	1
Illegal Mining	3
Location	N₄
Irrelevant	0
Community > 1km	1
Community < 1km	3
Size of Community	N₅
< 50 Families	0
50 – 200 Families	1
> 200 Families	3

Therefore, the total risk presented by the General Issues scenario is $\sum N_i$ with the maximum value, being 15, representing the highest risk.

General Data For Abandoned Mine

Data for: *Abandoned Mine*

Physical and Geographic Features

GENERAL ISSUES

Footprint

< 25 Ha	25 - 100 Ha	> 100 Ha	Additional data needed
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Geology

Impervious and Competent	Fractured	Porous and Fractured	Additional data needed
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Access

Limited Access	Access - Footpaths/Illegal Occupation	Illegal Mining	Additional data needed
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Location

Irrelevant	Community > 1km	Community < 1km	Additional data needed
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Size Of Community

< 50 Families	50 - 200 Families	> 200 Families	Additional data needed
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Figure 10-1 Screen layout for General Issues

10.3.2 General Site

The list of General Site parameters presented in Table 10-2 reflects the physical status of the site under consideration while also reflecting safety and contamination (water and air) risks.

Table 10-2 General Site

Parameters	Risk factor for each individual parameter (N _i)
Additional Data Needed	2
Infrastructure	N₁
Not Present	0
Unstable Load / Built Surfaces	1
Extensive Structural Failure	3
Beneficiation Plant	N₂
Not Present	0
Some Structural Failure	1
Discharge of Contaminated Leachate	3
Tailings Dams / Evaporation Basins	N₃
Not Present	0
Some Structural Failure	1
Discharge of Contaminated Leachate	3
Water Treatment Impoundments	N₄
Not Present	0
Some Structural Failure	1
Discharge of Contaminated Leachate	3
Dust / Gases	N₅
None	0
Airborne Particles < 3 days per week	1
Airborne Particles > 3 days per week	3

Therefore, the total risk presented by the General Site scenario is $\sum N_i$ with the maximum value, being 15, representing the highest risk.

General Site Data For Abandoned Mine

Data for:
Abandoned Mine

Physical and Geographic Features

GENERAL SITE

Infrastructure	Not Present	Unstable Load / Built Surfaces	(Extensive Structural Failure)	Additional data needed
Beneficiation Plant	Not Present	Some Structural Failure	Discharge of Contaminated Leachate	Additional data needed
Tailings Dams and Evaporation Basins	Not Present	Some Structural Failure	Discharge of Contaminated Leachate	Additional data needed
Water Treatment Impoundments	Not Present	Some Structural Failure	Discharge of Contaminated Leachate	Additional data needed
Dust / Gases	None	Airborne Particles < 3 days per week	Airborne Particles > 3 days per week	Additional data needed

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Figure 10-2 Screen layout for General Site

10.3.3 Dumps / Spoils – waste, rock, rubble and tailings

The list of parameters associated with Dumps and Spoils presented in Table 10-2 reflects their status on the site under consideration while also reflecting safety and contamination (water and air) risks.

Table 10-3 Dumps / Spoils – waste, rock, rubble and tailings

Parameters	Risk factor for each individual parameter (N _i)
Additional Data Needed	2
Dumps / Spoils	N₁
Not Present	0
< 1 000 000 m ³	1
> 1 000 000 m ³	3
Structure	N₂
Stable < 10°	0
Stable Slopes with limited erosion 10° - 38°	1
Unstable Slopes > 38°	3
Spontaneous Combustion	N₃
Not Present	0
Limited Smoke Visible	1
Visible Smoke and Flames / Smell	3
Future Risk of Spontaneous Combustion	N₄
No Exposed Coal	0
Exposed with Limited Weathering	1
Exposed Carbonaceous Material / Shale	3
Runoff	N₅
None	0
Seasonal – Wet Weather	1
Discharge of Contaminated Runoff (AMD)	3

Therefore, the total risk presented by the Dumps / Spoils scenario is $\sum N_i$ with the maximum value, being 15, representing the highest risk.

Data for: *Abandoned Mine*

Physical and Geographic Features

DUMPS / SPOILS - waste, rock, rubble and tailings

Dumps / Spoils

Not Present

Size / Volume < 1000.000m³

Size / Volume > 1000.000m³

Additional data needed

Structure

Stable < 10 Degrees

Stable Slopes with Limited Erosion
10 - 38 Degrees

Unstable slopes > 38 Degrees

Additional data needed

Spontaneous Combustion

Not Present

Limited Smoke Visible

Visible Flames and Smoke / Smell

Additional data needed

Future risk of Spontaneous Combustion

No Exposed Coal

Exposed with Limited Weathering

Exposed Carbonaceous Material /
Shale

Additional data needed

Runoff

None

Seasonal - Wet Weather

Discharge of Contaminated Runoff
(AMD)

Additional data needed

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Figure 10-3 Screen layout for Dumps / Spoils

10.3.4 Surface Mine

The list of parameters associated with Surface Mines presented in Table 10-2 reflects their status on the site under consideration while also reflecting safety and contamination (soil, water and air) risks. Should no surface mining activity have been present on the site, the data capturer is able to skip this form and so automatically return a zero score for these parameters.

Table 10-4a Surface Mine

Parameters	Risk factor for each individual parameter (N _i)
Additional Data Needed	2
Depth of Pit, Sinkholes and other unprotected Excavations	N₁
< 2m	0
2 – 5 m	1
> 5m	3
Excavations	N₂
< 10% of Total Footprint	0
10% to 30% of Total Footprint	1
> 30% of Total Footprint	3
Spontaneous Combustion	N₃
No Exposed Coal Seams	0
Exposed Coal Seams with Weathering	1
Exposed Underground Workings (Re-mining)	3
Topsoil	N₄
Sufficient Topsoil Present	0
Removed	1
Removed Resulting in Erosion / Channelling	3
Alteration of Hydrology	N₅
None	0
Drainage Disruption	1
Modification of Catchment Area	3
Volume of Water Discharged	N₆
< 100 m ³	0
100 m ³ to 1 000 m ³	1

Parameters	Risk factor for each individual parameter (N _i)
> 1 000 m ³	3

Table 10-5b Surface Mine (Continued)

Parameters	Risk factor for each individual parameter (N _i)
Acid Mine Drainage	N₇
None	0
pH 4.2 to 9.0	1
pH < 4.2	3
Salinity	N₈
Sulphates < 155mg/L	0
Sulphates between 155mg/L and 200mg/L	1
Sulphates > 200mg/L	3

Therefore, the total risk presented by the Surface Mine scenario is $\sum N_i$ with the maximum value, being 24, representing the highest risk.

Surface Mine Data For Abandoned Mine

Data for:
Abandoned Mine

Physical and Geographic Features

SURFACE MINE
Depth of Pit, Sinkholes and Other Unprotected Excavations

< 2m	2 - 5m	> 5m	Additional data needed
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No Surface Mine?

Excavations

< 10% of Total Footprint	10% - 30% of Total Footprint	> 30% of Total Footprint	Additional data needed
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Spontaneous Combustion

No Exposed Coal Seams	Exposed Coal Seams with Weathering	Exposed Underground Workings (re-mining)	Additional data needed
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Topsail

Sufficient Topsoil Present	Removed	Removed, Resulting in Erosion / Channeling	Additional data needed
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Alteration of hydrology

None	Drainage Disruption	Modification of Catchment Area	Additional data needed
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Volume of Water Discharge

< 100m ³	100m ³ to 1000m ³	> 1000m ³	Additional data needed
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Acid mine drainage

None	pH 4.2 - 9	pH < 4.2	Additional data needed
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FLTR NUM

Figure 10-4 Screen layout for a Surface Mine

10.3.5 Underground Mine

The list of parameters associated with an Underground Mine presented in Table 10-2 reflects their status on the site under consideration while also reflecting safety and contamination (soil, water and air) risks. Should no underground mining activity have been present on the site, the data capturer is able to skip this form and so automatically return a zero score for these parameters.

Table 10-6a Underground Mine

Parameters	Risk factor for each individual parameter (N _i)
Additional Data Needed	2
Adits, Shafts, Sinkholes and Excavations	N₁
Sealed	0
Unsealed and Fenced	1
Unsealed and Unfenced	3
Subsidence – Failure of Pillars / Overlying Strata	N₂
Very Deep Mining > 120m	0
Mining Depth between 40m and 120m	1
Very Shallow mining < 40m	3
Spontaneous Combustion	N₃
No Exposed Coal Seams / Not Present	0
Exposed Virgin Coal Seams	1
Open Voids / Exposed Workings	3
Safety	N₄
No Reported Accidents	0
No Lethal Accidents in 1 Year	1
Accidents resulting in death this year	3
Volume of Water Discharged	N₅
< 100 m ³	0
100 m ³ to 1 000 m ³	1
> 1 000 m ³	3

Table 10-7a Underground Mine (Continued)

Acid Mine Drainage	N₆
None	0
pH 4.2 to 9.0	1
pH < 4.2	3
Salinity	N₇
Sulphates < 155mg/L	0
Sulphates between 155mg/L and 200mg/L	1
Sulphates > 200mg/L	3

Therefore, the total risk presented by the Underground Mine scenario is $\sum N_i$ with the maximum value, being 21, representing the highest risk.

Abandoned Mine
Physical and Geographic Features

UNDERGROUND MINE
Adits, Shafts, Sinkholes and Excavations

No Underground Mine?

Sealed	Unsealed and Fenced	Unsealed and Unfenced	Additional data needed
Subsidence - Failure of Pillars / Overlying Strata			
Very Deep Mining > 120 m	Mining Depth Between 40m and 120m	Very Shallow Mining < 40 m	Additional data needed
Spontaneous Combustion			
No Exposed Coal Seams / Not Present	Virgin Seam Exposed	Open Voids / Exposed Workings	Additional data needed
Safety			
No Reported Accidents	No Lethal Accidents in 1 Year	Accidents Resulting in Death this Year	Additional data needed
Volume of Water Discharge			
< 100m3	100m3 to 1000m3	> 1000m3	Additional data needed
Acid mine drainage			
None	pH 4.2 - 9	pH < 4.2	Additional data needed
Salinity			
Sulphates < 155mg/l	Sulphates Between 155mg/l and 200mg/l	Sulphates > 200mg/l	Additional data needed

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Figure 10-5 Screen layout for an Underground Mine

10.3.6 Total Risk

The data captured in each of these screens is presented in a summarised format in which the individual scores are added and presented as an accumulated total as indicated in Figure 10-6. The overriding parameters of concern as presented in Section 10.2 are highlighted on the right of the screen whenever they have scored three individually to alert the data capturer to their presence. The overall risk is determined by adding the individual scenario / form scores to obtain an aggregated total. Since 30 parameters are included in the Risk Ranking Tool, the maximum risk associated with any particular abandoned or defunct mine site is 90. The severity of the risk is presented in the bottom right corner of the screen. The breakdown of the severity ranking as used in the software is presented in Table 10-8.

Table 10-8 Severity

Severity	Score
Very High	61 – 90
Medium	31 – 60
Low	1 - 30

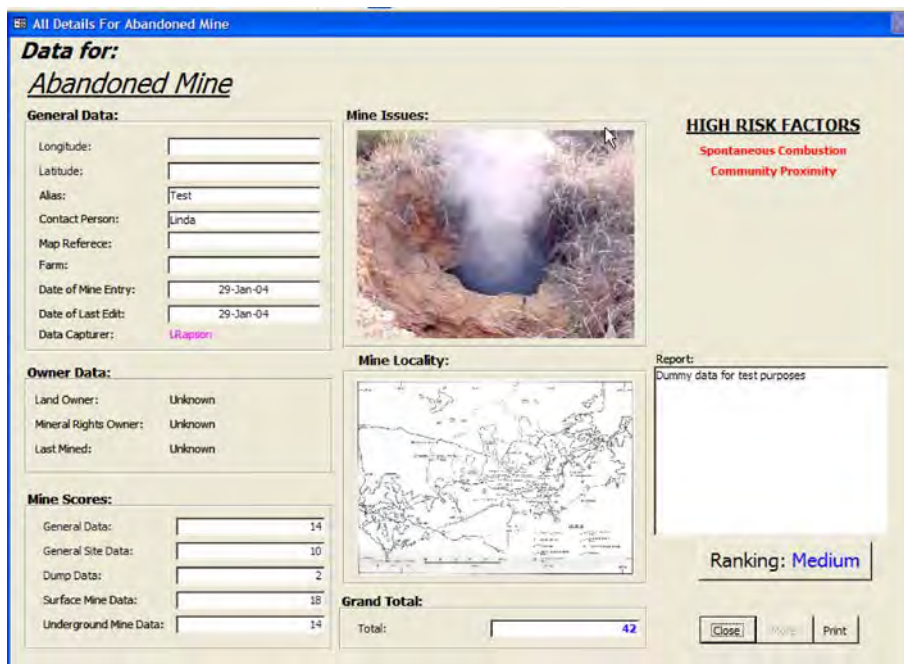


Figure 10-6 Screen layout of summary

10.4 Data Entry

The entry of data is interactive with a user-friendly graphical interface created in Microsoft Access ©. The program opens with a brief description of the Risk Ranking Tool as illustrated in Figure 10-7.

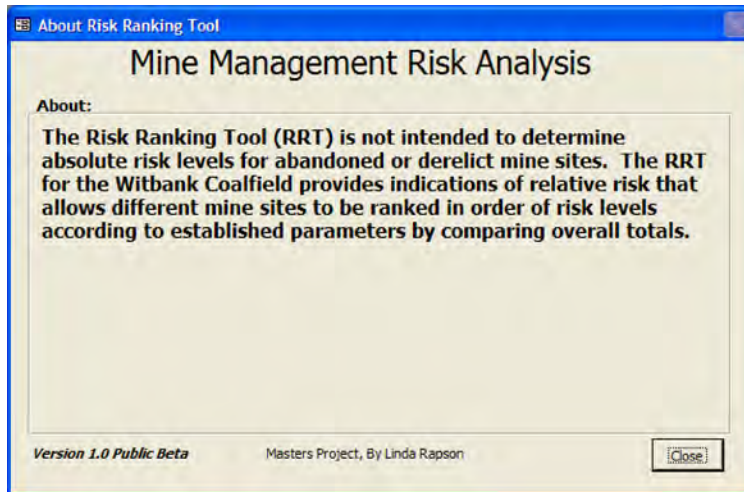


Figure 10-7 Main Screen

The user is then offered a number of options depending on whether new data is to be added, existing data is to be edited or a summary of data is to be viewed as presented in the screen capture of the switchboard in Figure 10-8.



Figure 10-8 Switchboard

The process of adding new data is simple. The user is taken through a series of screens starting with a main screen (Figure 10-9) in which the mine is identified and its co-ordinates recorded. Ownership details as well as the last date mined are also captured. In order to facilitate the report generation process, images of the mine as well as a locality map are also saved at this point. Additional data may be captured in the Report section of the screen.

The screenshot shows a software window titled "Add in a Mine..." with a main heading "Create a New Mine". The window is divided into several sections:

- Mine Data:** Includes text boxes for "Mine Name" (containing "Abandoned Mine"), "Alias" (containing "Test"), "Contact Person" (containing "Linda"), "Map Referece", "Farm", "Longitude", and "Latitude". The "Data Capturer" field is populated with "LRapson".
- Mine Locality:** Features a map showing a geographical area with various points and lines.
- Mine Issues:** Contains a photograph of a mine site with a large, dark, circular opening in the ground.
- Owner Data:** Includes text boxes for "Land Owner", "Mineral Rights Owner", and "Last Mined".
- Report:** A text box containing the text "Dummy data for test purposes".
- File Paths:** At the bottom, there are two "Browse" buttons. The first is for "Mine Locality" with the path "C:\Program Files\Risk Ranking Tool\Software\images\maps\Defau". The second is for "Mine Issues" with the path "C:\Program Files\Risk Ranking Tool\Software\images\Mine Pics\De".
- Buttons:** "Continue" and "Cancel" buttons are located at the bottom center.

Figure 10-9 New data entry

The next screens to be completed are the same as those presented in Figure 10-1 to Figure 10-6. The search facility shown in Figure 10-10 is available using the co-ordinates, mine name or risk score as the locators.

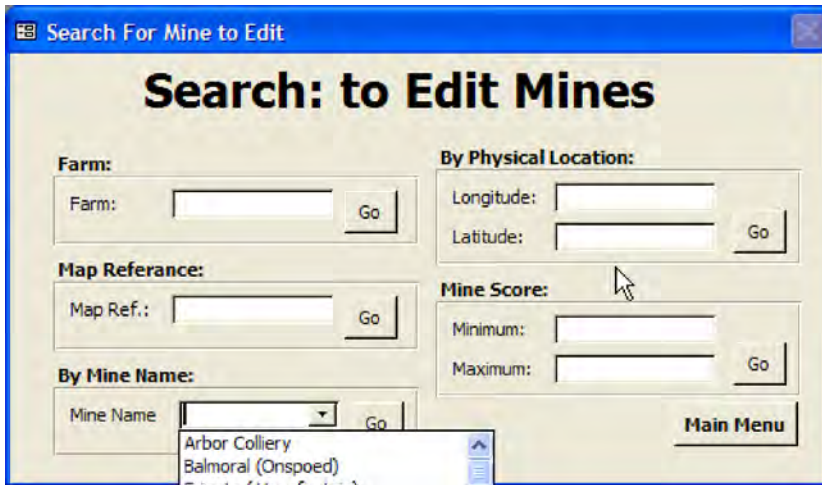


Figure 10-10 Search facility

Since one of the major outputs required from the RRT is a ranked prioritisation of the mines in accordance with the total values, a search facility according to a maximum and minimum score is included and returns a form as illustrated in Figure 10-11. Details of any mine may be viewed by selecting the mine of interest.

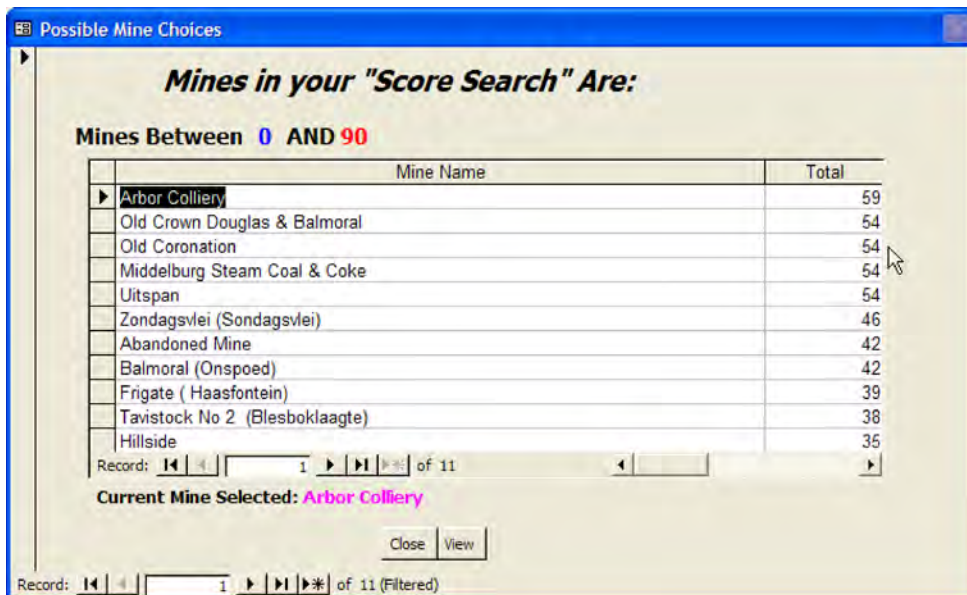


Figure 10-11 Search facility based on a minimum and maximum score

To cater for changes and additions to the captured data stored in the RRT database an editing option is available (Figure 10-12).

Edit Mine Details For Arbor Colliery

Edit a Mine's Data

Mine Data:

Mine Name:

Alias:

Contact Person:

Map Reference:

Farm:

Longitude:

Latitude:

Data Capturer: **Lrapson**

Mine Locality:

Mine Issues:

Owner Data:

Land Owner:

Mineral Rights Owner:

Last Mined:

Report:

Mine Locality:

Mine Issues:

Figure 10-12 Edit facility

11 DISCUSSION

11.1 *Ranked Mines*

The RRT model has been tested with available data. As a first step, Swiegelaar (2003) identified the following mines included in Appendix A to be of most interest to the Department of Water Affairs and Forestry:

- Arbor
- Frigate
- Hillside
- Middelburg Steam
- Old Coronation
- Old Douglas
- Tavistock
- Uitspan
- Witbank
- Zondagsvlei

Available data for these mines was stored in the RRT and cumulative totals for each thus obtained. A copy of this data is included in the Beta version copied on the accompanying CD. The mines were ranked according to the total scores achieved. The data is presented in Table 11-1.

Table 11-1 Ranked Mines

Ranked Position	Mine Name	Score
1	Arbor	59
2	Middelburg Steam	54
2	Old Coronation	54
2	Old Douglas	54
2	Uitspan	54
3	Zondagsvlei	46
4	Balmoral	42
5	Witbank	40
6	Frigate	39
6	Tavistock	39
7	Hillside	35

The results need to be tested for accuracy by key players in the industry and those with an in-depth understanding of all the issues involved as an average of 50% of the parameters scored 2, indicating that additional data is required to quantify the risk.

11.2 Limitations and Knowledge Gaps

The output of this project, namely the Risk Ranking Tool, suffers severe limitations due to the limited data available on issues pertaining to defunct and abandoned collieries. While the issues are fairly well documented, the parameters to be assessed have not been measured or documented in any great detail. This has led to a shortcoming in the project deliverable. It has not been possible to conclusively rank the list of mines presented in Appendix A. Too many of the sites require additional data. Field mapping and characterisation of the sites is necessary to determine the areal extent of the mining impacts and consequences on the local environment and communities.

11.3 Priorities

After a discussion with Lodewijks (2004), it has to be noted that the large conglomerate mining houses have data which is sensitive. Government and industry need to lay down a fairly substantial legal framework to encourage the divulgence of all known data without the threat of repercussions.

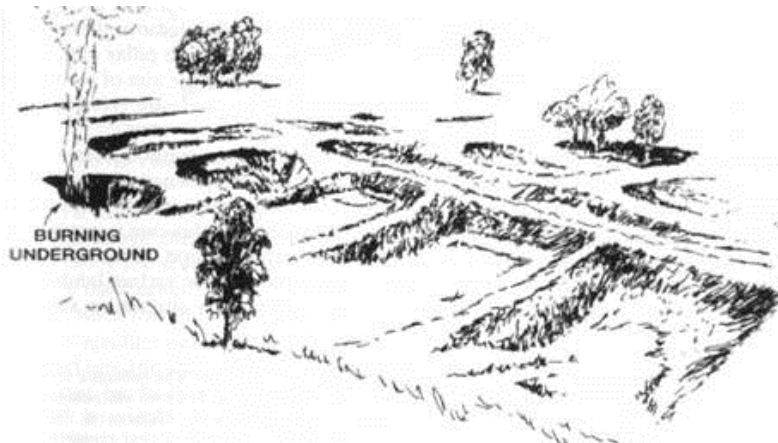
In order to meaningfully rank the mines to determine those requiring the most urgent attention, it will be necessary to undertake field trips in order to collect the missing data.

12 REHABILITATION

Rehabilitation of these old workings is difficult because of the danger of collapse (Figure 12-1) and because rehabilitation was not planned as part of the original mining operation. In some cases it is not possible until the fires have burnt out. Many attempts have nevertheless been made. These include:

- Filling the collapsed areas with rubble;
- Bulldozing the sides of the collapses to safe slopes;
- Backfilling the workings with non-combustible material such as gravel, soil or ash;
- Flooding the workings.

While none of these methods has solved the water pollution problem, some have been partly effective in stopping the fires. Trenching around the burning areas and backfilling the trench has been attempted to stop the fires spreading with only limited success, since the fire often jumps the trench. Forced collapse of the roof of the old mine by blasting has also been attempted, but the outcome of the blast is not always predictable (Fuggle and Rabie, 1992:347).



Source: Fuggle and Rabie, p 347

Figure 12-1 Collapsed bord and pillar workings near Witbank

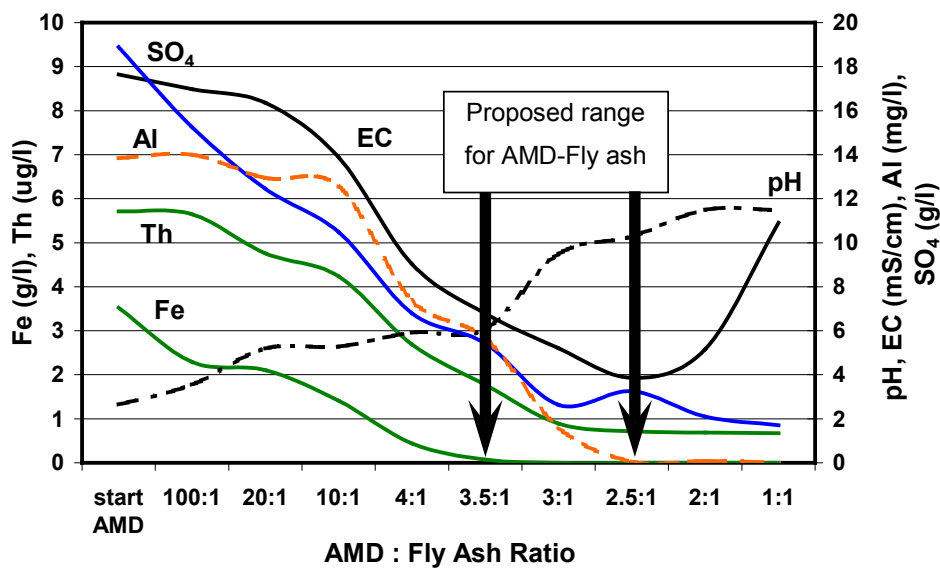
Fuggle and Rabie (1992:348) suggest that re-mining these old areas before collapse or burning is the best overall solution since it removes the source of both combustible material and water pollution. Unfortunately this is often not economically feasible. Another option is to fill the whole area with power station fly ash.

Apart from any socio-economic aspects, the physical reclamation of an abandoned mine will include some or all of the following measures (UNEP, 2001):

- permanent sealing of underground workings and all mine openings, prevention of water and gas leakage that could cause adverse impacts to neighbouring mines or to the environment;
- ensuring that any open pit or open cut features are stable and do not pose a risk to humans, animals or the environment;
- removal of all material and equipment lying at the surface;
- demolition of surface buildings and structures unless there is a productive use for them;
- all steps necessary to ensure the safety of tailings and slurry ponds, spoil heaps, waste dumps, stock piles and any other surface features that might pose an environmental or human hazard;
- clearing areas formerly used for the mine surface facilities;
- restoration of surface land including clean up of the premises, levelling the ground and re-vegetation;
- establishing the nature of any water remaining in the open pit and treating it if necessary;
- ensuring that there is easy access to the water in the open pit to allow animals, children and adults who might fall in a way out, or backfilling the open pit;
- rehabilitation of waste dumps including surface drainage, redesign of slopes to an acceptable angle and re-vegetation;
- restoration of land affected by mining subsidence including refilling/levelling of the affected ground, wherever feasible, and re-vegetation.

Remediation measures are undergoing fairly extensive research and field trials (Beukes, 2003) and include mechanical methods, biological methods and the use of waste products.

Ilgner (2003) has demonstrated the positive effect of the interaction of fly ash with AMD (Figure 12-2).



Source: Ilgner (2003)

Figure 12-2 AMD and fly ash interaction

Fencing off the affected area is the last resort in dealing with the environmental hazards and prevents the properties from being used in an inappropriate way. The aim is to find a more sustainable solution to transforming the affected area into land that adds value to the company, the environment and the communities in the vicinity (Moolman and Roedhammer, 2002).

13 RECOMMENDATIONS

13.1 *Priority Systems*

It will be necessary to prioritise the allocation of remedial work funds based on factors such as proximity to populated areas, public safety and environmental protection. While the socio-economic issues resulting from abandoned and defunct mines, may to a degree, be resolved by the rehabilitation of the sites, cognisance must be taken of the artisanal workings offering a source of fuel and income. The social dimensions of this practice must be reviewed carefully (Envirogreen, 2000).

13.1.1 Data Storage

It is essential that maps and other important records of abandoned and defunct mines be put in places of safekeeping. To this end, the University of Pretoria has established an Office for Mine Closure.

13.1.2 Data Sharing

Government and mining houses should ensure that information on abandoned mines is known and available to all services involved with land use planning.

13.1.3 Standards

There is a need for the development of 'standards' for risk assessment for abandoned sites.

13.1.4 Resources

More resources are required to adequately inventory and assess abandoned mines.

14 CONCLUSION

The case for rehabilitation of abandoned sites is the same as that for active mines. The difference is that the assignment of responsibilities is different. For abandoned sites it often lies with unidentifiable owners, and has thus led to non-action.

Accordingly, there is now a good case for starting to consider how to respond to the abandoned and defunct sites issue at the international level:

- Resource degradation is everybody's problem; it is an issue in every mineral-rich country;
- It has a similar public rationale to rehabilitation of existing operational sites;
- It is inevitably a part of the wider debate on sustainable mineral development;
- It is a part of the image problem for the entire industry, with consequences for companies' future 'license to operate (UNEP, 2001).

Public pressure on chemical risks has led many governments to take action and contaminated site clean-up programmes now have a well-documented history. Some of those programmes and some of the methodologies that have been developed could be applied to the context of abandoned mine sites. Contaminated site programmes have led to the development of national approaches to assessment, preparation of inventories, prioritisation, objective setting and development of action plans. These programmes could provide useful models for the mining industry.

Although there have been few attempts at quantification, it is generally understood that the issue of abandoned or defunct mine sites is a major unresolved environmental and social problem for the industry, for communities and for governments. Potential impacts include a range of health and safety problems, and extensive economic impacts due to resource degradation and water pollution. So far, there are only a small number of systematic programmes to deal with the issue. However, experience with similar problems in contaminated industrial sites and with rehabilitation of operational mines has provided sufficient elements to allow for a serious start on the abandoned sites problem (UNEP, 2001).

15 APPENDICES

APPENDIX A Defunct, abandoned and ownerless mines

	Colliery & DME Ref. No.	Farm	Co-ordinates		Locality / District	Owner					Remarks	
			Map ref	Latitude		Longitude	Surface Rights	Mineral Rights	Operator	Underground		Opencast
1	Aangewys Coal Mine (C572)	Aangewys 81 IS	2629 AD Bethal			south of Kriel						
2	Acme 1 (A124)	Klipfontein 568 JR	2528 DD Balmoral	25 59' 40"	28 57' 10"	south of Balmoral			Possibly Anglo Coal	Underground		
3	Acme 2 (Dwaalfontein)		2528 DD	25 59' 20"	28 54' 50"	west of New Largo			Unknown			
4	Albion		2629 AB			Middeldrift 42 IS - south of Douglas		Ingwe				Ingwe plan to mine it
5	Alfontein Colliery	Klipfontein 568 JR	2528 DD Balmoral			west of New Largo						(No DME Ref. No.)
6	Alpha	Heuwelfontein 215 IR	2628 BB Kendal			northwest of Ogies. Just north of Khutala Resource area						Old General Mining 1972 (C. Goodale). Possibly mined out. South of Alpha Consolidated Colliery
7	Alpha Consolidated (D 564)	Viakfontein 569 JR	2528 DD Balmoral and 2628 BB Kendal			east of New Largo				Underground		Last worked 1964. Used as oil storage facility for Strategic Fuel Fund.
8	Anglo French	Blaauwkrans 323 JS	2529 CC Witbank					Anglo Coal				Only shaft. Part of Navigation) (Goodale)
9	Anthracite Syndicate (D292)	Zondagsvlei 9 IS and Smaldeel 1 IS	2628 BB Kendal and 2629 AA Ogies			north of Schoongezicht		Ingwe				Now Part of Khutala Resource area
10	Arbor Colliery (A110)	Viakfontein 213 IR	2628 BB Kendal	26 03' 30"	28 53' 25"	west of Ogies. south of Arbor			Unknown	Underground	Opencast	Opencast mine is large in extent. Transvaal and Hamilton Colliery borders Arbor Colliery.
11	Amot (old) (also Coronation Amot)	Springboklaagte 416 IS	2529 DD Wonderfontein			between Middelburg and Belfast		Possibly part of Amot (Eyesizwe)				Possibly part of Eyesizwe
12	Bailey		2529 CC Witbank			southwest of Witbank		Anglo Coal				Only a shaft. Portion of Anglo Coal Schoongezicht Landau Colliery.
13	Balmoral (N/P)	Honingkrans 536 JR	2528 DD Balmoral			north of New Largo						Karoo outlier (Goodale) (See Old Crown and Balmoral Colliery) Small open pit
14	Balmoral (Onspood)	Honingkrans 536 JR	2528 DD Balmoral	25 47' 50"	28 57' 30"	north-west of Balmoral		Constantia Coal Enterprises (Last known)			Opencast	

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
15	Bankfontein (part of Middelburg Mines)	Brakfontein 350 JS	2529 CD Middelburg			south of Middelburg/ north of Schoongesicht/Bank Colliery		Ingwe				Ingwe is going to mine the old pillars. (There is a new opencast mine with the name of Brakfontein. On the farm Bankfontein 216 IR. Metorex Pty Ltd. Wakefield Investment. Mine M1/1 on Banzi's mining map. Coal Seam 2. GME Witbank.)
16	Bankfontein & Seale		2529 DA	25 41'	29 36' 30"						Opencast	Three large pits
17	Bapsfontein		2628 BA	26 05' 10"	28 32' 40"	west of Delmas			Unknown		Opencast	
18	Beesting							Anglo Coal				See Oogies Navigation Colliery. (Resource area)
19	Belfast Steenkoolmyn (200/221)	Steynsplaat 360 IT	2530 CA Belfast									Re-opened
20	Blackhill Colliery (A88)	Blaauwkrans 323	2529 CC Witbank			southwest of Witbank		Anglo Coal				Portion of Anglo Coal Schoongezicht Landau Colliery.
21	Blesbok	Blesbokvlakte 24 IS	2529 CD Middelburg			south of Middelburg		Anglo Coal				Part Of Bank
22	Blesboklaagte											See Tavistock and Uitspan
23	Blinkpan	Broodsnyersplaats 25 IS	2629 AB Van Dyksdrift					Ingwe				Still mining. Pull last pillars. No resources left
24	Bordex Mine					approximately 10km east of Hendrina on the Carolina road					Opencast	
25	Brakfontein (D580)	Brakfontein 264 IR and Dieplaagte 262 IR	2628 BB Kendal			southeast of Delmas On road to Secunda. (Possibly just an adit into the No. 5 Coal Seam		Ingwe				Small resource Ingwe not going to look at it. (Contact person with possibly more information is Terry Fox 011 615 7840).
26	Brenthurst											No Information
27	Brugspruit											No Information. GME At Witbank thinks that it is possibly northwest of Witbank Water Affairs
28	Caerkay Colliery	Kafferstad 79 IS	2629 BA Hendrina			11 kilometers south west of Hendrina						Very small.
29	Castle Colliery (N/P)	Hartebeestfontein 537 JR	2528 DD Balmoral			north of New Largo						See Hartebeestfontein Colliery
30	Clydesdale (at New Clydsdale)							Eyesizwe				Still mining
31	Clydesdale (old Witbank)		2529 CC Witbank			At Witbank on Greenside Mining area		Anglo Coal				

	Co-ordinates				Owner							
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground	Opencast	Remarks
32	Coal Farms Limited	Van Dyks IR	2628 BB Kendal			north east of Delmas/ 3,5 Kilometres north east of Arbor, close to						Visser is of the opinion that it is only a name, a hole in the ground and 30metres of alternated coal and shale. Size from DME maps 150 x 100 metres.
33	Coniston Colliery (A 137)	Brakfontein 264 IR	2628 BB Kendal			southeast of Delmas, north of Leslie, 23 km south of Arbor. west of Matia						Possibly in karst (Visser) Very small
34	Coronation	Blesbok 296 JS										
35	Coronation (A 149) (Landau)	At Kromdraai 279 IS and Coronation 280 IS	2529 CC Witbank and Macmaar			west of Witbank		Anglo Coal				The name Coronation changed to Kromdraai, and is now Landau. Also Bank Coronation. The first mine was on the farm Hartbeestspruit 281 JS. Size 5km. X3 km. Coronation 1 and 2 only shafts.
36	Coronation Colliery (B42)	eastern portion of Driefontein 297 JS	2528 CC Witbank			west of Witbank just north of KwaGuqu, east of Ferrobank						
37	Crown and Douglas Collieries (C137)	Onspoed 500 JR	2528 DD Balmoral			west of Witbank (Small out layer), Just above Douglas Colliery		Benicon Mining				Also Old Crown Douglas and Balmoral Colliery. Small
38	Delmas	Hawerklip 265 IR, Brakfontein 264 IR, Dieplaagte 262 IR, Middelburg 266 IR and Enkeldebosch 391 IR	2628BD			south of Delmas		Ingwe				Now belongs to Kuyasa Mining; still mining - Try to sell the Colliery
39	Douglas Colliery (N/P)	Leeupoort 283 JS and Driefontein 297 JS	2528 CC Witbank			north of T and DB Colliery west of Witbank		Ingwe				Small Size 1,2 x 1,0km
40	Douglas Colliery (was B 51)	Goedvertrouwd 499 JR	2528 DD Balmoral			north of Balmoral and New Largo		Benicon Mining				
41	Douglas Colliery ex Witbank	Wolvekrans 17 IS	2529 CD Middelburg			southeast of Witbank		Ingwe				Part of Douglas, Wolwekrans Section
42	Douglas No. 2	Leeupoort 283 JS						Ingwe				same as Douglas No. 1
43	Douglas No. 3							Ingwe				same as Douglas No. 1
44	Douglas No.1 (old shaft)	Driehoek 297 JS & Leeupoort 283 JS				east of Witbank		Ingwe				Part of Douglas
45	Dwaalfontein											See Acme 2
46	East Rand Colliery (Speekfontein portion 9)	Speekfontein 336 JS	2529CD					Ingwe				There is possible still a small mine. (Mined out) See Speekfontein
47	Eastside							Jensha Mining				

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
48	Eensaam	Possibly Eensaamheid 534 JR	2528 DD	25 53' 15"	28 57' 40"	Balmoral area			Unknown	Underground		Underground
49	Engela	Uitkyk 290 JS	2529 CD Middelburg			west of Middelburg						
50	Excelsior	Bochpoort 211 IR	2528 BB Kendal			south of Arbor Station						There are two with the same name. This one only a mark on 1:50 000 Topographical Map (DME office Pretoria)
51	Excelsior	Nooitgedacht 300 JS	2528 CC Witbank			Next to Coronation		Anglo Coal				Coronation Excelsior is part of Anglo Coal Landau resource. Figure 1. Size 1,0 x 1,0 km.
52	Ferrobank	Driehoek 296 JS										
53	Frigate (Haasfontein)		2629 AB	26 01'	29 21'	west of Hendrina, south of Witbank			Frigate Plant Hire (Last known)		Opencast	
54	Fortam Colliery	Vogelstruispoort 484 JT (or 384 JT)	2530 CC (BELFAST?)			Belfast - Next to road						
55	Fortuna Colliery	Rietfontein 72 (Old Number)										They mined the area in 1900 to about 1907
56	Goodyear Colliery (N/P) 2528 DD Balmoral	Klipfontein 566 JR				west of New Largo						Very Small
57	Graspan Colliery	Rietfontein 286 JS	2529 CD Middelburg			west of Middelburg 800 metres south of Rietfontein Colliery and the Graspan Colliery as indicated on 1:50 000 Topographical Map						Two Collieries on farm. Size: 100 x 100m
58	Groenvlei	Groenvlei 353 IT	2530 Belfast?									(only on 1:50 000 topographical map). There is an old Coal mine on the farm Groenvlei 353 IT. Possibly very small
59	Groves Colliery (N/P)	Klipfontein 586 IS	2528 BB Kendal			Wes of Alpha Cons Colliery						Very small, only a mark on map
60	Haartbeestfontein	Haartbeestfontein 537 JR	2528 DD BALMORAL					Stuart Coal ?				
61	Haasfontein	Koornfontein 27 IS	2629 AB Van Dyksdrif			Koornfontein		Anglo Coal				Mined out. See Frigate
62	Hamilton Colliery (D253)	Vlakfontein 213 IR	2628 BB Kendal			north east of Delmas, south of TC and Sterling						
63	Hartbeestfontein (N/P)	Hartebeestfontein 537 JR	2528 DD Balmoral			north of New Largo						
64	Harties Colliery	Klipfontein 586 IS	2528 BB Kendal			Wes of Alpha Cons Colliery						Very Small only mark on map

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
65	Heuningkrans (B110)	Honingkrans 536 JR	2528 DD Balmoral	25 53' 15"	28 39' 15"	north of New Largo		Anglo Coal last mineral rights owner		Underground		Heuningkrans Alias Honingkrans and Klipfontein. Underground. Last mined about 20 years ago
66	Heuningskrans											See Klipfontein/Heuningkrans
67	Highveld Colliery (D343)	Vaalpan 68 IS	2629 AA Ogies			Between Matla and Kriel		Anglo Coal				Very small
68	Hillside Colliery (I)	Elandsfontein 309 JS	2529 CC WITBANK			south of Clewer						Small opencast possibly still mining (Goodale)
69	Hillside Colliery (II)	Heuvelfontein 215 IR Ptn. 9	2628 BB KENDAL	26 03' 10"	28 58' 25"			Metorex (Indirectly)			Opencast	possibly mined out
70	Honingkrans											possibly only an adit - Mine Sand. No locality. See Heuningkrans
71	Kafferstad Coal mine (D270)	Kafferstad 79 IS	2629 AD Bethal and 2629 BA Hendrina			11 kilometers south west of Hendrina						Very small. Size 50 x 50 metres
72	Kendal or Kendal United (C157)	Heuvelfontein 215 IR	BB Kendal and 2629AA Ogies			west of Ogies, 1,0 km south of Kendal		Ingwe				Possibly two mines. One portion inside Ingwe resource area. Ingwe will mine it. Size 2,0 x 1,5 km
73	Kleindraai		2529CC									Areas adjacent to Kromdraai. Opencast
74	Kleinwater	Kleinwater 801 JS	2528 CC WITBANK									No information. See Rondebult
75	Kleinwater											
76	Klipbank Koolmyn	Kafferstad 79 IS	2629 BA Hendrina			11 kilometers south west of Hendrina						Very small.
77	Klipfontein Colliery (A114)	Honingkrans 526 JR	2528 DD Balmoral	25 57' 30"	28 56' 10"	north of New Largo			Previously Stuart Mining. 1988 Effect Bricks		Opencast	(also A and B); there is an A and B; B is north of A and Balmoral. Size 1 x 1 km.
78	Klipfontein Colliery (A75)	Klipfontein 568 JR and Honingkrans 536 JR	2528 DD	25 54' 20"	28 57' 05"	?west of New Largo		Anglo Coal last mineral rights owner		Underground		See also Heuningskrans and Heuningkrans. Last mined in the 1940's
79	Klippootjie (Oil Bunker)	Klippootjie 321	2629 AA Ogies			south of Ogies						
80	Kollie Koolmyn	Kleinwater 801 JS	2528 CC Witbank			west of Anglo Coal Coronation (Landau Colliery)						No DME Ref. No
81	Kraansport		2629 BA Hendrina	26 13'	29 37' 50"	south-west of Hendrina						Rehabilitated. Last mined about 30 years ago
82	Kriel Colliery (D573)	Onverwacht 70 IS						Anglo Coal			Opencast	Part of Anglo Coal Kriel Mine

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
83	Kromdraai (adjacent areas)	Kromdraai279 JS	2529 CC Witbank	25 48' 30"		Witbank - northwest of Witbank		possibly Anglo Coal				Anglo Coal is still mining as Landau Open Cast. Was Coronation 2, became Komdraai. Now Landau Pit.
84	Landau 3							Anglo Coal				Part of SACE Landau
85	Landau No. 1	Klipfontein 322 JS, Landau 359 JS	2529 CC Witbank			south of Witbank		Anglo Coal				Under Landau. Future reserves/resources. (Part of SACA Landau). Ceased mining: 1950
86	Landau No. 2		2529 CC			south of Witbank		Anglo Coal				Part of SACA Landau. Ceased mining: 1950
87	Leeuwfontein	Leeuwfontein 219 IR	2628BB Kendal			8,0 km south of Kendal						
88	Maggies Mine	Vaalkranz 29	2629 AB Van Dyksdrift			At Koornfontein mine (Visser) or south of Van Dyksdrift on the river						Mined out (Visser). Mrs. du Plessis of DME office at Witbank promise to sent information.
89	Mavela Colliery	Goedehoop 315 JS	2529CD Middelburg			Middelburg		Benicon Mining				reapply with DME Witbank to mine
90	Middelburg Colliery	Rondebosch 403 JS	2529 DC Pan			At Nasaret just east of Middelburg						
91	Middelburg Steam Coal and Coke (B42)	Blesboklaagte 296 JS	2529 CC Witbank			west of Witbank		Anglo Coal				Anglo Coal busy with rehabilitation. Ceased mining: pre 1956
92	Minnaar	Grootpan 7 IS	2629 AA Ogies			east of Ogies west of Minnaar Station north of the railway line		Ingwe				(Mined out) Size 1,0 x 0,3 km. On the same farm just south of the railway line 1,5 x 1,5 km mined out area.
93	Mooifontein											See Ou Kopermyn
94	Navigation (SACE)	Blaaukrans 323 JS	2529 CC Witbank			north of Greenside south of Clewer		Anglo Coal				Anglo Coal is going to mine in future
95	New Fortuna Colliery (D24)		2628 DA Balfour			8 km west of Balfour at Fortuna Station						Very small. Size.150 x 400 metres
96	New Largo B (Winning)		2528DD Balmoral	25 55' 20"	28 58' 15"	south of Balmoral		Anglo Coal last known owner of mineral rights		Underground		Closed in 1960's.
97	New Largo (Wilge)	Honingkranz 536 JS, Roodepoortje 326 JS, Klipfontein 568 JS, Viakfontein 569 JR	2528 DD Balmoral and 2529 CC Witbank					Anglo Coal				
98	New Schoongezicht (A150)	Blesbokvlagte 24 IS	2529 CD Middelburg			south of Bank Colliery		Anglo Coal				Anglo Coal Blesbok Mine together with Bankfontein Colliery, Bank Colliery and Blesbok Colliery.
99	Nichus Coal Mine	Kafferstad 79 IS	2629 AD Bethal			3 km southeast of Steenkoolspruit						
100	Old Coronation					Klipspruit catchment						Ceased mining: 1948

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
101	Old Douglas 1					Klipspruit catchment						Ceased mining: 1939
102	Old Douglas 2					Klipspruit catchment						Ceased mining: 1945
103	Old Douglas 3					Klipspruit catchment						Ceased mining: 1952
104	Old Crown Douglas and Balmoral Colliery	Goedvertrouwd 499 JR	2528 DD Balmoral									See Balmoral
105	Old Premier	Nooitgedacht 300 JS	2529 CC WITBANK									
106	Old Vischkuil	Vischkuil 274 IR				Endicott						Very poor quality about 16 CV
107	Ongezien Hidrokool Mine	Goedvertrouwd 499 JR	2528DD Balmoral									Poor Quality, not many
108	Onspoed											See Balmoral (Onspoed)
109	Oogies Colliery (A78)	Kleinzuikerboschplaat 5 IS and Goedgevonden 10 IS	2629 AA Ogies			south of Ogies		Anglo Coal				Size 3,5 x 1,5 km. previously belong to Duiker
110	Oogies Navigation Colliery	Oogiesfontein 4 IS	2629AA Ogies			2,0 km north of Ogies		Anglo Coal				See Beesting
111	Ou Kopermyn (Mooifontein)		2529 DC	25 52' 05"	29 42' 20"			Frazer Alexander			Opencast	Last mined 1985.
112	Paardeplaats Koolmyn (N/P)	Paardeplaats 380 IT	2530 CA Belfast			Belfast - Near Belfast						Very small
113	Patterson Pit		2529 DC	25 50' 55"	29 39' 50"			Unknown			Opencast	Last mined about 20 years ago. Possibly clay not coal.
114	Perfecto Colliery (N/P)	Klipfontein 568 JR	2528 DD			west of New Largo						Very Small
115	Phoenix (old) (D313) (Duiker/Total)	Klipplaat 14 IS	2629 AA Ogies			At Phoenix mine		Duiker				Part of Phoenix mine, Duiker will mine
116	Polmais Colliery	Goedehoop 315 JS Rem. of Ptn. 12 (Ptn. of Ptn. 100 and Ptn. 18 and 19)	2529 CD			south of Middelburg						Still mining (GME Witbank)
117	Premier Coal Colliery (A27)	Nooitgedaght 300 JS	2529 CC Witbank			west of Witbank						
118	Prinshof Colliery	Prinshof 2 IS PTN 2, 3 and 7	2629AA	26 01' 05"	29 01' 55"	At Ogies		Ed Young & Sons Mining			Opencast	Rehabilitation problem (Mined out)
119	Raleigh (D352)	Eikeboom 476 JS	2529 DC Pan			At Eikeboom Colliery. Near Middelburg, Arendsfontein Spruit.		Ingwe				A small mine on Eikeboom Colliery property. Ingwe have mined around the old mine. Shaft has been closed (Daan Horn).

	Co-ordinates					Owner						
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground	Opencast	Remarks
120	Rietfontein ex Vaalbank (D495)	Rietfontein 286 JS	2529 CD Middelburg			Middelburg - west of Middelburg, east of the Graspan Colliery as indicated on 1:50 000 topocadastral map.	Middelburg Municipality	Middelburg Municipality				Possibly 38 Mt Good reserve (Visser). GME Witbank indicated that they want to rehabilitate the mine (There is also talks that the Middelburg municipality want to go out on tender). Kumba Resources is not involved as implicated by people in Industry. Size of mine was about 100 x 200m
121	Rietspruit	Hartbeestfontein 39 IS, Rodepoort 40 IS	2629AA Ogies					Ingwe				Busy closing it. Mined out by opencast
122	Riverside					south-east of Witbank. Adjacent to Middleburg mine	Scharrighuisen (Surface rights)				Opencast	Metorex might be responsible for rehabilitation
123	Rondebult Colliery (Kleinwater)	Rondebult 303 JS	2529 Witbank	25 49' 45"	29 03' 30"	Next to Highveld Steel	Opencast section: Unknown Kleinwater: Mr Schoeman (Surface) Underground: Mr du Preez (Surface)	Opencast section: Unknown Kleinwater: RMB (Mineral) Underground: Rondebult Colliery (Mineral)		Underground	Opencast	Very small open pit. There are two sites. The rehabilitation on the southern pit was good but they are still busy with the northern pit. There is possible a new company that is interested to taking over. (GME Witbank)
124	Samuel Koolmyn (A105)	Paarde Plaats 380 IT	2529 DB Languitsig and 2530 CA Belfast			Just west of Belfast; south of Glisa Quarry (Coal and clay)						
125	Sandstrhele Colliery (N/P)	Dieplaagte 262 IR	2628 BB Kendal			Part of Brakfontein						Very small
126	Sarie Marais or New Sarie Marais Colliery (B123)	Heuvelfontein	2628 BB Kendal			west of Ogies, 2 km north east of Kendal						Very small
127	Schoongezicht		2529 CD Middelburg			Middelburg - south of Middelburg / north of Bank		Anglo Coal				Ceased mining: 1952
128	Schoongezicht (old) (A115) (SACE Navigation)	Schoongezicht 308 JS	2529 CC Witbank			west of Witbank		Anglo Coal				Anglo Coal indicated Seams 1 2 and 5. Also Amalgamated Collieries and S A Schoongezicht (DME)
129	Sondagsvlei (Zondagsvlei)											See Zondagsvlei
130	Springbok No. 2							Anglo Coal				Anglo Coal still mining
131	Springbok No. 5							Anglo Coal				Still mining
132	Station (B97)	Blesboklaagte 296 JS	2529 CC Witbank			Adjacent at the east of Witbank						
133	Station 1 & 2	Blesbok 296 JS										

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
134	Steenkoolspruit							Ingwe				Possibly two. One at Douglas. It is Ingwe and included in their Resource
135	Steenkoolspruit (D427)					6 km southeast of Wakefield		Anglo Coal				mine at Kriel (Goodale). Size 100 x 100 metres.
136	Sterling											See Transvaal Colliery
137	Tavistock	Blesbok 296 JS										Ceased mining: 1949
138	Tavistock (old)					south of Witbank		Duiker				Part of Tavistock Colliery
139	Tavistock and Uitspan (A109 and B97)	Blesboklaagte 296 JS and Uitspan on Witbank Municipal area	2529 CC Witbank	25 49' 45"	29 14' 15"	north of Witbank				Underground		Also called Tavistock 2 and Blesboklaagte. Addressed in the 1992 White Paper.
140	Teutfontein		2529 DC	25 46' 10"	29 38' 05"	east of Middelburg, west of Belfast					Opencast	Consists of a pit and numerous dumps.
141	Transvaal and Delagoa Bay (T & DB) Colliery (D 353)	Driehoek 297 JS & Schoongezicht 308 JS	2529 CC Witbank			west of Witbank/ north of Schoongezicht by Paxton						Ceased mining: 1953
142	Transvaal and Natal ex Uiykyk (Spelling according to DME Plans) (A28)	Uitkyk 290 JS				south of Middelburg		Possibly Ingwe				Small about 1,0 x 1,0 km
143	Transvaal Colliery (TC) and Sterling (C115 and D272)	Vlakovarkfontein 213 IR	2628 BB Kendal			north east of Delmas, 2 Kilometres south of Arbor						
144	Transvaal Navigation											
145	Transvaal Navigation (NB)	Vlaklaagte 45 IS	2629 AB Van Dyksdrif			At TNC		Ingwe				(It is old TNC) Pillars left Important Ingwe not going to look in it again
146	Tweefontein United	Vlaklaagte 330 JS	2529 CC Witbank			Adjacent (southwest) to Greenside		Duiker				eastern portion of Tweefontein Collieries division Waterpan Colliery. Size 2,0 x 2,0 km. Duiker will mine the coal.
147	Uitkyk (A34)	Uitkyk 290 JS	2529 CD Middelburg			Middelburg - southwest of Middelburg		Ingwe				Old shaft full of water. Small resource that can possibly be mined. Rail line is running through property.
148	Uitspan	Uitspan 293	2529 CC	25 50' 30"	29 14' 10"	north of Witbank	Ten Cradock Avenue (Pty) Ltd - surface & mineral rights	Ten Cradock Avenue (Pty) Ltd - surface & mineral rights		Underground		Addressed in the 1992 White Paper.
149	Uitspan	Blesbok 296 JS										see Tavistock and Uitspan. Ceased mining: 1949
150	United	Heuvelfontein 515 (DME)	2628 BB Kendal			west of Ogies						

	Co-ordinates					Owner					Remarks	
	Colliery & DME Ref. No.	Farm	Map ref	Latitude	Longitude	Locality / District	Surface Rights	Mineral Rights	Operator	Underground		Opencast
151	Vaalbank (A28)	Vaalbank 289 JS and Rietfontein 286 JS	2529 CD Middelburg and 2569 DC Pan			Middelburg - south of Middelburg		Ingwe				On Middelburg Mine area, Mined opencast, nothing left. Size about 500 x 800 metres
152	Van Dyksdrift							Ingwe				
153	Versters Colliery (N/P)	Klipfontein 566 JR	2528 DD Balmoral			west of New Largo						
154	Voortrekker Colliery	Elandspruit 291 JS	2529 CD Middelburg			In vicinity of Mooiwater Quarry closes to the southern boundary of the farm west of Middelburg.						
155	Wakefield and New Wakefield Collieries (D428/9)	Aangewys 81 IS	2629 AD Bethal			south of the town of Kriel						Property size 1,2 x 0,7 Kilometres. Adit in bank close to river. Possibly mine the No 5 Coal Seam.
156	Waterpan Duiker	Tweefontein 13 IS	2629 AA Ogies			north east of Ogies		Duiker				Very small. On Duikers coal rights area.
157	Welgedacht	Welgedacht 74 IR	2628 BA and AB					Ingwe				Possibly part of Ingwe
158	Weltevreden Colliery (A89)	Weltevreden 324 JS	2529 CC Witbank			Adjacent to Greenside		Duiker				eastern portion of Tweefontein Collieries division Waterpan Colliery.
159	Westside Colliery	Rondevly 208 IR and Dwarsfontein 209 IR	2628BB Kendal	26 02' 50"	28 46' 50"	northwest of Argent		B&E Silica			Opencast	Was Side Minerals (de Korte)
160	Wildebeestfontein Colliery (B86)	Wildebeestfontein 327 JS	2629 AA Ogies	26 01' 00"	29 03' 40"	north of Ogies				Underground		Underground. Last mined in the 1930's.
161	Witbank Central											Possibly the same as Witbank Colliery
162	Witbank Colliery (B97 and B127)	Witbank Municipality area (Klipfontein 322 JS?)	2528 CC Witbank			south of Witbank						Ceased mining: pre 1956
163	Witbank South	Witbank Municipal Area	2529 CC Witbank			south of Witbank		Ingwe				Pillar. Great potential. Part of Ingwe resources
164	Witklip (old adit)					southeast of Delmas						DME Witbank indicates that it is possible Ingogo Coal Holdings
165	Zondagsvlei		2629 AA	26 05' 05"	29 01' 35"	west of Bethal					Opencast	Situated on a slope next to a tributary of the Saaiwaterspruit.
166			2629 AA Ogies			Between Oogies Navigation Colliery and Wildebeestfontein						Size 200 x 200 metres

APPENDIX B Hazards and Impacts

Mining related actions	Atmosphere	Ground Water	Surface Water	Land and Soil	Ecology	Socio-Economic
Surface Mine	Dust emissions	Alteration of water table	Alteration of surface hydrology	Altered local topography	Alteration of ecological balance	Aesthetics
Depth of pit	Gas Release	Plume dispersal	Drainage disruption	Compaction	Fauna	Air quality
Excavations	CO, CO ₂	Seepage	Modification of current catchment area	Contamination	Flora	Illegal mining
Spontaneous Combustion	Methane	Water recharge	Sedimentation	Salination	Intoduction of pests and weeds	Restrict unmined ore
Topsoil removed	Products of Spontaneous Combustion	Contamination	Seepage	Intoduction of pests and weeds	Degradation of agricultural land	Land value
	Fumes	AMD	Wetlands - drainage	Degradation of agricultural soil	Degradation of urban land	Alternative land uses
	Odour	Leaching	Contamination	Erosion (Wind and water)	Drainage & degradation of wetlands	Productivity of land
	Smoke	Salination	AMD decant	Loss of topsoil		Sterliisation of land
			Deoxygenation	Pits		Public perception
			Discolouration	Slope failure		Social relocation
			Increase in turbidity	Sterilisation of agricultural soil		Community displacement
			Leaching			Informal migration to area
			Salination			
Underground Mine	Dust emissions	Alteration of water table	Alteration of surface hydrology	Contamination	Alteration of ecological balance	Aesthetics
Failure of pillars / overlying strata	Gas Release	Disruption of aquifer	Drainage disruption	AMD decant	Fauna	Air quality
Open adits & shafts	CO, CO ₂ , NO _x	Plume dispersal	Modification of current catchment area	Openings to surface	Flora	Illegal mining
Seepage	Methane	Seepage	Sedimentation	Adits, shafts	Intoduction of pests and weeds	Restrict unmined ore
Spontaneous combustion	Products of Spontaneous Combustion	Water recharge	Seepage	Cracks	Degradation of agricultural land	Land value
	Fumes	Contamination	Wetlands - drainage	Sinkholes	Degradation of urban land	Alternative land uses
	Odour	AMD	Contamination	Spontaneous Combustion	Drainage & degradation of wetlands	Productivity of land
	Smoke	Leaching	AMD decant	Subsidence		Sterliisation of land
		Salination	Deoxygenation	Collapsed pillars		Public perception
			Discolouration	Bord collapse		Social relocation
			Increase in turbidity	Sterilisation of agricultural soil		Community displacement
			Leaching			Informal migration to area
			Salination			
Dumps	Dust emissions	Alteration of water table	Alteration of surface hydrology	Altered local topography	Alteration of ecological balance	Aesthetics
Spontaneous Combustion	Gas Release	Plume dispersal	Drainage disruption	Compaction	Fauna	Air quality
	CO, CO ₂ , NO _x	Seepage	Modification of current catchment area	Contamination	Flora	Illegal mining
	Methane	Water recharge	Sedimentation	Salination	Intoduction of pests and weeds	Restrict unmined ore

Mining related actions	Atmosphere	Ground Water	Surface Water	Land and Soil	Ecology	Socio-Economic
	Products of Spontaneous Combustion	Contamination	Seepage	Introduction of pests and weeds	Degradation of agricultural land	Land value
	Fumes	AMD	Wetlands - drainage	Degradation of agricultural soil	Degradation of urban land	Alternative land uses
	Odour	Leaching	Contamination	Erosion (Wind and water)	Drainage & degradation of wetlands	Productivity of land
	Smoke	Salination	AMD decant	Loss of topsoil		Sterilisation of land
			Deoxygenation	Slope failure		Public perception
			Discolouration	Sterilisation of agricultural soil		Social relocation
			Increase in turbidity			Community displacement
			Leaching			Informal migration to area
			Salination			
Water Treatment Impoundment	Odour	Contamination	Alteration of surface hydrology	Altered local topography	Alteration of ecological balance	Aesthetics
		Leaching of chemicals	Drainage disruption	Compaction	Fauna	Air quality
		Seepage	Sedimentation	Contamination	Flora	Land value
			Seepage	Salination	Introduction of pests and weeds	Alternative land uses
			Contamination	Introduction of pests and weeds	Degradation of agricultural land	Productivity of land
			AMD decant	Degradation of agricultural soil	Degradation of urban land	Sterilisation of land
			Deoxygenation	Failure of dam wall		Public perception
			Discolouration	Sterilisation of agricultural soil		Social relocation
			Increase in turbidity			Community displacement
			Leaching			Informal migration to area
			Salination			
			Sludge production			
			Disposal issue			
Tailings Dam & Evaporation Basins	Initial dust emissions	Alteration of water table	Alteration of surface hydrology	Altered local topography	Alteration of ecological balance	Aesthetics
		Plume dispersal	Drainage disruption	Compaction	Fauna	Air quality
		Seepage	Sedimentation	Contamination	Flora	Illegal mining
		Water recharge	Seepage	Salination	Introduction of pests and weeds	Restrict unmined ore
		Contamination	Contamination	Debris accumulation	Degradation of agricultural land	Land value
		AMD	AMD decant	Degradation of agricultural soil	Degradation of urban land	Alternative land uses
		Leaching	Deoxygenation	Failure of dam wall		Productivity of land
		Salination	Discolouration	Pits		Sterilisation of land
			Increase in turbidity	Sterilisation of agricultural soil		Public perception
			Leaching			Resource potential
			Salination			Alternative use
						Social relocation
						Community displacement
						Informal migration to area

Mining related actions	Atmosphere	Ground Water	Surface Water	Land and Soil	Ecology	Socio-Economic
Beneficiation Plant	Initial dust emissions	Contamination	Contamination	Contamination	Alteration of ecological balance	Aesthetics
	Initially	AMD (limited)	AMD (limited)	Fuel, chemicals and coal	Fauna	Air quality
		Fuel, chemicals and coal	Fuel, chemicals and coal	Metal Leaching	Flora	Land value
		Metal Leaching	Metal Leaching	Structures	Intoduction of pests and weeds	Alternative land uses
					Degradation of agricultural land	Productivity of land
					Degradation of urban land	Sterliisation of land
						Public perception
						Resource potential
						Alternative use
						Derelict or usable
						Social relocation
						Community displacement
						Informal migration to area
Infrastructure	Dust emissions	Contamination	Alteration of surface hydrology	Contamination	Alteration of ecological balance	Aesthetics
Offices	Initially	AMD (limited)	Contamination	Dumping (landfill)	Fauna	Air quality
Hostels		Fuel, chemicals and coal	Fuel, chemicals and coal	Fuel and chemicals	Flora	Land value
Workshop		Metal Leaching	Metal Leaching	Sewage	Intoduction of pests and weeds	Alternative land uses
Village		Sewage Effluent (initially)		Equipment	Degradation of agricultural land	Productivity of land
Roads				Abandoned	Degradation of urban land	Sterliisation of land
Equipment				Structures		Public perception
Services						Resource potential
						Accessibility
						Alternative use
						Derelict or usable
						Social relocation
						Community displacement
						Informal migration to area

APPENDIX C Consequences

	Atmosphere	Ground Water	Surface Water	Land and Soil
Surface Mine Depth of pit Excavations Spontaneous Combustion Topsoil removed	Environmental Health Respiratory diseases Noxious gases / Particulates Safety Decreased visibility Economic losses Social dislocation	Environmental Loss & migration of fauna Loss of aquatic life Health Deterioration in water quality Safety Economic losses Social dislocation	Environmental Eutrophication Loss & migration of fauna Loss of aquatic life Loss of flora Health Deterioration in water quality Safety Drowning Economic losses Social dislocation	Environmental Loss & migration of fauna Loss of aquatic life Loss of flora Health Safety Falling accidents Trapped / Buried Economic losses Social dislocation
Underground Mine Failure of pillars / overlying strata Open adits & shafts Seepage Spontaneous combustion	Environmental Health Respiratory diseases Noxious gases / Particulates Safety Decreased visibility Economic losses Social dislocation	Environmental Loss of aquatic life Health Safety Economic losses Social dislocation	Environmental Eutrophication Loss & migration of fauna Loss of aquatic life Loss of flora Health Noxious gases Particulates Safety Falling accidents into workings / burning coal Infrastructure damage Trapped / Buried Economic losses Social dislocation	Environmental Loss & migration of fauna Loss of aquatic life Loss of flora Health Noxious gases Particulates Safety Falling accidents into workings / burning coal Infrastructure damage Trapped / Buried Economic losses Social dislocation
Dumps Spontaneous Combustion	Environmental Health Respiratory diseases Noxious gases / Particulates Safety Decreased visibility Economic losses Social dislocation	Environmental Loss & migration of fauna Loss of aquatic life Health Contact / ingestion diseases Safety Economic losses Social dislocation	Environmental Eutrophication Loss & migration of fauna Loss of aquatic life Loss of flora Health Contact / ingestion diseases Noxious gases Particulates Safety Drowning Economic losses Social dislocation	Environmental Loss & migration of fauna Loss of aquatic life Loss of flora Health Noxious gases Particulates Safety Falling accidents into workings / burning coal Infrastructure damage Trapped / Buried Economic losses Social dislocation

Consequences Continued

	Atmosphere	Ground Water	Surface Water	Land and Soil
Water Treatment Impoundment	<p>Environmental</p> <p>Health</p> <p>Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Loss & migration of fauna Loss of aquatic life</p> <p>Health Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Eutrophication</p> <p>Loss & migration of fauna Loss of aquatic life Loss of flora</p> <p>Health Contact / ingestion diseases Safety Drowning</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Health</p> <p>Safety</p> <p>Localised spill</p> <p>Economic losses Social dislocation</p>
Tailings Dam & Evaporation Basins	<p>Environmental</p> <p>Health Particulate matter</p> <p>Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Health Contact / ingestion diseases Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Eutrophication Loss & migration of fauna Loss of aquatic life Loss of flora</p> <p>Health Contact / ingestion diseases Safety Drowning</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Health Safety</p> <p>Localised spill</p> <p>Economic losses Social dislocation</p>
Beneficiation Plant	<p>Environmental</p> <p>Health Particulates Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Loss & migration of fauna Loss of aquatic life</p> <p>Health Contact / ingestion diseases Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Loss & migration of fauna Loss of aquatic life Loss of flora</p> <p>Health Contact / ingestion diseases Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Health</p> <p>Loss of life Safety Regionalised spillages</p> <p>Economic losses Social dislocation</p>
Infrastructure Offices Hostels Workshop Village Roads Equipment Services	<p>Environmental</p> <p>Health</p> <p>Contact / ingestion diseases Safety Chemical contamination</p>	<p>Environmental</p> <p>Loss & migration of fauna Loss of aquatic life</p> <p>Health Contact / ingestion diseases Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Loss & migration of fauna Loss of aquatic life</p> <p>Loss of flora</p> <p>Health Contact / ingestion diseases Safety</p> <p>Economic losses Social dislocation</p>	<p>Environmental</p> <p>Health</p> <p>Safety</p> <p>Economic losses Social dislocation</p>

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