UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

The Role of Legislation and Management Practices in the Coal Mining Industry on the Olifants River Catchment, South Africa

By

Carrie Zermatten

Submitted in partial fulfilment of the requirements
for the degree M.Sc. (Earth Science Practice and Management)
in the Faculty of Natural and Agricultural Science

University of Pretoria

February 2011

DECLARATION OF ORIGINALITY

This document must be signed and submitted with every essay, report, project, assignment, dissertation and/or thesis.

Full names of student:..……Carrie Zermatten……………………………………….

Student
number:…………………28343647………………………………………………….

Declaration

1. I understand what plagiarism is and am aware of the University's policy in this regard.
2. I declare that this ……mini-dissertation……………… (e.g. essay, report, project, assignment, dissertation, thesis, etc) is my own original work. Where other people's work has been used (either from a printed source, Internet or any other source), this has been properly acknowledged and referenced in accordance with departmental requirements.
3. I have not used work previously produced by another student or any other person to hand in as my own.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

SIGNATURE OF STUDENT:.......…………………………………………………

SIGNATURE OF
SUPERVISOR:………………………………………………………………..

SUMMARY

Title of Treatise:	The Role of Legislation and Management Practices in the Coal Mining Industry on the Olifants River Catchment, South Africa
Author:	Carrie Zermatten
Supervisor:	Mr C.C. Callaghan
Department:	Department of Geology, Faculty of Natural and Agricultural Sciences, University of Pretoria
Degree:	MSc. Earth Science Practice and Management

The economic development of South Africa has relied heavily on coal mining and water quality is adversely affected by mining - thus coal mining poses a significant risk to South Africa's water resources. Ensuring judicious use and management of natural capital is always a complex undertaking but the benefits to the mining industry and society as a whole, derived from thoroughly laid-out plans, a supportive but strict regulatory environment and decision-making processes based on sound, scientific information are immense. Value addition to mining products is important to promote conservation of assets and resources. Using the Olifants Water Management Area as a case study, the chemistry of groundwater associated with coal mining was characterised. General concepts regarding the relationship of geology to water chemistry are surmised.

ACKNOWLEDGMENTS

I extend my gratitude to the following people and organisations:

- The anonymous, external reviewers of this mini-dissertation whose comments improved its overall quality and whose and insights put me in good stead to be a stronger researcher
- Professor Pat Eriksson and Mr Christopher Callaghan (University of Pretoria) for their supervision and academic support.
- Professor Jan Marten Huizenga (North-West University) for his patient guidance, insight and giving me access to water quality data.
- Professors Huib van Humberg and Leon van Rensburg (North-West University) for allowing me to carry out this study.
- Doctors Thibedi Ramontja, Fhatuwani Ramagwede, Gerhard Graham and Stewart Foya of the Council for Geoscience for their mentorship in many different forms.
- Doctors Napoleon Hammond (CGS) and Yasushi Watanabe (JOGMEC) for instilling an uncompromising work ethic in me.
- Professor Ferdi Camisani-Calzolari (University of Pretoria) for sharing meaningful discussions with me on the changing face of the mining industry and prickling my interest in new fields of knowledge.
- Professor Bruce Cairncross (University of Johannesburg) for inspiring in me, a core-deep passion for the subject of geology.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ARD	Acid rock drainage
AMD	Acid mine drainage
BECSA	Billiton Energy Coal South Africa
BPG	Best Practice Guideline
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CSIR	Council for Scientific and Industrial Research
d	Day
DME	Department of Minerals and Energy[1]
DMR	Department of Mineral Resources[1]
DWA	Department of Water Affairs [1]
DWAF	Department of Water Affairs[1]
EC	Electrical conductivity
EMP	Environmental Management Program
EWRP	Emalahleni Water Reclamation Project
g	Gram
GASA	Geostatistical Association of South Africa
GDP	Gross Domestic Product
GGP	Gross Geographical Product
GPS	Global Positioning System
GSSA	Geological Society of South Africa
Gt	Gigaton
ICPM-S	Inductively Coupled Plasma Mass-Spectrometry
IDP	Integrated Development Plan
ISP	Internal Strategic Perspective
IWRM	Integrated Water Resource Management
JSE	Johannesburg Stock Exchange
kg	Kilogram
kl	Kilolitre
kt	Kiloton (1000 tonnes)
L	Litre
LM	Local Municipality
m^3/a	Cubic metres per annum
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mg/l	Milligram per litre
ml	millilitre
Ml	Megalitre
Mm^3/a	Million cubic meters per annum
Mmol/l	Millimol per litre
MMDC	Mpumalanga-Maputo Development Corridor

MPRDA	Mineral and Petroleum Resources Development Act
MRD	Mine Residue Deposit
MSB	Marginal social benefits
MSC	Marginal social costs
Mt	Megaton
mV	Millivolts
NEMA	National Environment Management Act
NNP	Net Neutralising Potential
NSoER	National State of the Environment Report
NWA	National Water Act
NWRS	National Water Resource Strategy
ORP	Oxidation-reduction potential
p.a.	Per annum
PAIA	Promotion of Access to Information Act
PAJA	Promotion of Administrative Justice Act
PLATO	South African Council for Professional Land Surveyors and Technical Surveyors
ppm	Parts per million
R	Rand
RQO	Resource quality objectives
SA	South Africa
SABS	South African Bureau of Standards
SACNASP	South African Council for Natural and Scientific Professions
SACRM	South African Coal Roadmap
SAIMM	South African Institute of Mining and Metallurgy
SAM	Social Accounting Matrix
SAMREC	South African Code For Reporting Of Mineral Resources And Mineral Reserves
SHT	Temperature of self-heating
SOE	State of the Environment
Stats SA	Statistics South Africa
TDS	Total dissolved solids
UNCTAD	United Nations Conference on Trade and Development
w.r.t.	with regard to
wt%	Weight percent
WC	Water Conservation
WCI	World Coal Institute
WC&DM	Water Conservation and Demand Management
WCA	World Coal Association
WDM	Water Demand Management
WMA	Water Management Area
WQO	Water Quality Objectives
WRSAS	Water Resource Situation Assessment Study
WSDP	Water Services Development Plan
WUA	Water User Association
XRD	X-Ray Diffraction

[1] Notes on naming consistency

A. Government departments and publications

In May 2009, President Jacob Zuma announced changes to several of the South African Government departments.

The changes included:

1. Separating the ***Department of Minerals and Energy (DME)*** into two separate departments, namely

a) the ***Department of Mineral Resources*** and

b) the ***Department of Energy.***

To be consistent, in this minor-dissertation the department is referred to as "DMR" the publications that have been used and referenced are done so as "DME".

2. The ***Department of Water Affairs and Forestry (DWAF)*** was re-organised and
3. The ***Department of Environmental Affairs and Tourism (DEAT)*** was re-organised, such that

a) The Department of Water Affairs was merged with the Department of Environmental Affairs to make the **Department of Water and Environmental Affairs (DWA);**

b) A new **Department of Agriculture, Fisheries and Forestry (DAFF)** was formed

c) And the **Department of Tourism (DoT)** stands on its own

To be consistent, in this minor-dissertation the department is referred to as "DWA" the publications that have been used and referenced are done so as "DWAF".

B. Town names

In March 2006 the town of Witbank was renamed Emalahleni. However, owing to the fact that all the literature cited makes use of the name "Witbank" - the name "Witbank" has been used in this minor-dissertation in order to maintain consistency.

1 Introduction

The economic development of South Africa has relied heavily on coal mining (Chelin, 2000) and the demand for coal has increased dramatically – both on the domestic- and international fronts. Significant growth is expected in the global coal trade in the next few decades (Mining Weekly, 2010) and an increase of 15% - 50% between 2008 and 2030 in the international coal trade is predicted (WCA, 2011). The World Coal Association (2010) identifies South Africa to be the 5th largest export of coal (67Mt) after Australia (259Mt), Indonesia (230Mt), Russia (116Mt) and Colombia (69Mt). Consequently, supporting the increased demands for coal from South Africa may require a considerable increase in mining efforts.

Water quality is adversely affected by mining and thus coal mining poses a significant risk to South Africa's water resources (DWAF, 2007). Coal mining has taken place in Witbank for many decades. Pollution has accompanied this mining legacy and continues to develop long after coal mines are abandoned or closed. The pollution stemming from coal mining and pertinent to water resources is acid mine drainage (AMD).

The objective of this study is to determine the role of water management as contained in guidelines, policies and regulations relevant to the coal mining industry of the Republic of South Africa; to determine the role of geology on the effects of pollution to groundwater.

Water pollution may originate from coal mining in one or more of the following ways:

1. Exposure of sulphide rich minerals (particularly pyrite and marcasite) and sediments to water exacerbates the generation of AMD e.g. exposed coal seams interact with natural ground waters and/or water used during the actual mining operation in the presence of oxygen (from the atmosphere). The resultant waters are considered strongly acidic (as their pH value may be as low as 2) and highly saline.

2. Infiltration of AMD affected waters into aquifers contaminates groundwater. Vermeulen and Usher (2005) explain that the local geology and depth of mining will contribute to pollution of aquifers and rivers as geohydrological flow paths (either man-made or natural) ultimately decant and/or seep into the adjacent strata and environment.

   The greater the sulphide-content of coal and associated sediments the greater the negative influence – the additional sulphur may become available for reaction to generate AMD.
   The deeper the mining operation the greater the negative influence – the affected waters have greater access via geohydrological flow paths into the environment.

3. Particulate material liberated during mining (e.g. dust generated during extraction of the coal) enters ground waters and increases their dissolved load (i.e. total dissolved solids [TDS] values increase significantly). Subsequently, the potential for precipitation of secondary minerals is increased when waters become saturated.

4. The release of acidifying compounds into the atmosphere contributes to acid rain. Burning of the coal (both operating and abandoned mines) releases sulphur dioxide (SO_2) into the atmosphere. Sulphur dioxide is most commonly returned to the earth's surface as sulphuric acid (H_2SO_4) (Hordijk and Kroeze, 1997). This results in an acidification of ground waters.

By understanding and identifying specific sources of pollution, issues regarding mines' responsibility to

- Prevent pollution,
- Control pollution, and
- Remediate the environment affected by their operations

can be suitably and impartially considered.

The National Water Act (NWA) (Act 36 of 1998) recognises that water is scarce and is an unevenly distributed national resource which belongs to all people. The NWA introduced the concept of Integrated Water Resource Management, comprising all aspects of the water resource - including water quality (DWAF, 2007) and additionally, the use of water for mining and related activities is regulated. The Department of Water Affairs (DWA – previously DWAF) subscribes to the principles of co-operative governance and thus recognises the role of the Department of Mineral Resources (DMR) to co-ordinate environmental management within the mining industry.

Ensuring judicious use and management of natural capital is always a complex undertaking. The rapid population growth and associated need for economic development and meeting of basic needs is considered to be a major driving force affecting resources in South Africa (DEAT, 1999). Nurturing the socio-economic fabric of society and fostering the desire for value addition to mining products is important to promote conservation of assets and resources. Conservation of assets can be achieved in a number of ways - the critical issue is to find the balance where value and reward are equitable.

Even though the geology of the Olifants River catchment area is relatively uniform and coal mining is prevalent in the area, the river water chemistry is diverse. In order to apply proper management practices, it is of critical importance that the processes that control the surface water chemistry be well-understood.

2 Problem Statement

2.1 The Research Problem

The purpose of the study is to determine the role of water management as contained in guidelines, policies and regulations relevant to the coal mining industry of the Republic of South Africa; to determine the role of geology on the effects of pollution to groundwater.

2.2 Sub-problems

The following aspects will be considered in order to address the research problem:

1. Why must the mining industry protect natural resources?
2. What are the best practice guidelines, policies and regulations applicable to water management to the South African coal mining industry?
3. Does coal mining pollute groundwater resources? If so, how are the characteristics of water quantified?
4. What are the major factors of acid mine drainage?
5. What role does the geology of the area play with regard to pollution?
6. Because the mining industry benefits financially from the exploitation of a natural, non-renewable resource which belongs the nation; what options are there (if any) for continuing capital in a way that may also benefit the nation?
7. Is water management policy and legislation effective in retarding groundwater pollution?

2.3 Hypotheses

It is hypothesised that:

1. The guidelines, policies and regulations in place at this point in time, are sufficiently aiding the coal mining industry in successfully retarding pollution of groundwater resources.
2. The geology of the area may indeed be capable of masking pollution because (*in addition* to acid mine drainage) water chemistry may be influenced by water-rock interaction (geohydrology) and dilution (geochemistry).

2.4 Limitations

The following limitations regarding scope, aspects not studied and limits of application are recognised for the study:

1. The study considers the Olifants Water Management Area in Mpumalanga, South Africa – it does not consider the water resources of the entire province.
2. While it was preferred to include a cost-benefit study of cleaning the acid mine drainage (AMD), the data to carry out such a study is unequivocally unavailable.
3. The *extent* of AMD is not delineated.
4. Suitable options for environmental remediation and rehabilitation of areas polluted through coal mining are not covered in this study
5. The study does not consider the extent of input from individual mining operations but rather, it considers the collective effects.
6. Information regarding the flow path, flow rate, contact time, recharge rate, temperature, detailed analyses of rocks encountered en route are needed to identify and isolate reaction rates; however this information is not readily available and thus conclusions reached regarding water-rock interaction are indicative.
7. Information regarding recharge rate, chemistry of recharge and source of recharge (natural run-off, rainfall etc.) is not readily available and thus conclusions reached regarding dilution are indicative.

2.5 Importance of / need for the study

The protection and management of natural resources is vital to achieve sustainability. Adequate management is achieved through the implementation of current best practices and legislation.

From an academic standpoint, the study will show that the benefits to the mining industry and society as a whole, derived from thoroughly laid-out plans, a supportive but strict regulatory environment and decision-making processes base on sound, scientific information are immense. The study will also highlight the importance of channelling capital from mining into alternative areas of value and suggest several such alternatives.

From a practical standpoint the study will show (using the Olifants Water Management Area as a case study) the chemical characteristics of groundwater associated with coal mining vary and that waters affected by AMD are not always recognised as such.

2.6 Research methodology

The research methodology applied to the research problem made use of a systematic compilation of information followed by data analysis and interpretation. The results of which where scrutinised and the ensuing statements and arguments composed accordingly.

2.6.1 Literature review

A review of literature pertinent to the topic was carried out. Sources of information include scientific publications, journal articles, legislation, best practice guidelines, management policies and industry-specific publications.

2.6.2 Consultation with different stakeholders

Discussion and debate was undertaken by the author with various and relevant stakeholders.

2.6.3 Collection of historic data

Inorganic water chemistry data were commercially obtained from the Council for Scientific and Industrial Research (CSIR) (Environmentek) as: “Water Quality on Disc, version 1.0”. The CD contains water quality data for the 2068 monitoring sites in South Africa spread over the different primary catchment areas. Water samples are routinely collected as part of the National Water Quality Monitoring Programme. The water quality data on the disc includes pH, total alkalinity (measured as calcium carbonate [$CaCO_3$] in mg/L) and the concentrations of the following major chemical species: sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), ammonium (NH_4^+), silicon (Si), fluoride (Fl^-), orthophosphate (PO_4^{3-}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and total dissolved solids (TDS) (all in mg/L). Heavy element concentrations [e.g. magnesium (Mg), iron (Fe), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn) and lead (Pb)] were determined from samples collected in 2010. The following sample stations were used for evaluation:

- Klipspruit at Zaaihoek (B1Q004H01)
- Middelburg Dam on Little Olifants River (B1H015Q01)
- Koringspruit at Vaalkranz (B1H020Q01)
- Tweefonteinspruit at Tweefontein (B1H031Q01)
- Blesbokspruit at Blesbok (B1H032Q01)

These stations are representative of the variety of different water chemistries typical in the area.

2.6.4 Collection of Field data

Temperature and pH readings were taken from *in situ* water samples. Such information aids in the general characterisation of groundwater as well as understanding of the likelihood of acid mine drainage (AMD) generation.

2.6.5 Laboratory analysis

Inductively coupled plasma mass spectrometry (ICPM-S) was carried out on water samples to determine the concentration of a variety of elements at very low concentrations. The information learned aids in the general characterisation of groundwater and allows the inference of the likelihood of AMD generation.

2.6.6 Interpretation of data

The data and laboratory results were interpreted and their conclusions presented succinctly within the mini-dissertation. The findings derived from the data interpretation enabled the author to address the objectives of the research problem and, *inter alia*, compose arguments and express judgment regarding the efficacy of management policies and influence of geology on groundwater quality in the study area.

3 Regional Setting

3.1 Regional geological setting

The water monitoring stations used in the study are situated near the town of Witbank in the Mpumalanga Province of South Africa. South Africa's main coal deposits are found near Witbank, in the Karoo Basin (Pinetown *et al.*, 2007). Johnson and others (1997) provide an extensive description of the Karoo Basin; Smith (1990), Smith and others (1993) and Veevers and others (1994) also provide useful reviews on the Main Karoo Basin. The Main Karoo Basin comprises the Karoo and Cape Supergroups.

The Karoo Supergroup

The main Karoo Basin covers an area of approximately 700 000km^2 (but is said to have been much more extensive during the Permian) with the bulk of the Karoo strata – having a cumulative thickness of approximately 12km in the south-eastern portion - occurring in the main basin (Johnson *et al.*, 2006). An almost complete record of the late Carboniferous to early Jurassic transition from glacial through temperate to arid climatic conditions are contained in the rocks of the Karoo Basin (Grodner and Cairncross, 2003; Tankard *et al.*, 1982; Cadle *et al.*, 1993 and Smith *et al.*, 1993). Terrestrial vertebrate fossils, distinctive plant assemblages, thick glacial deposits and pavements; extensive flood basalts and their associated dolerite dykes and sills have aided in making the Karoo Basin world-famous (Johnson *et al.*, 2006).

A largely stable floor – consisting of Craton in the north and the Namaqua-Natal metamorphic Belt in the south – underlies the Main Karoo Basin. Because the Main Karoo basin contains a thick flysch-molasse succession which wedges out northwards of the adjacent craton and because it is situated behind an inferred magmatic arc and associated fold thrust belt (produced by northward subduction of oceanic lithosphere located south of the arc); it is considered to be a retro-arc foreland basin (Johnson *et al.*, 2006). Pinetown and others (2007) describe the subduction event to be that of the palaeo-Pacific Plate beneath the Gondwana Plate during the Late Palaeozoic–Early Mesozoic.

Sediments in the basin are characteristic of their depositional environment and range from glacial to deep marine, deltaic, fluvial and aeolian (Catuneanu *et al.*, 1998). The Main Karoo Basin is complemented by smaller basins of the Springbok Flats, Ellisras, Tshipise and Tuli basins (Figure 1).

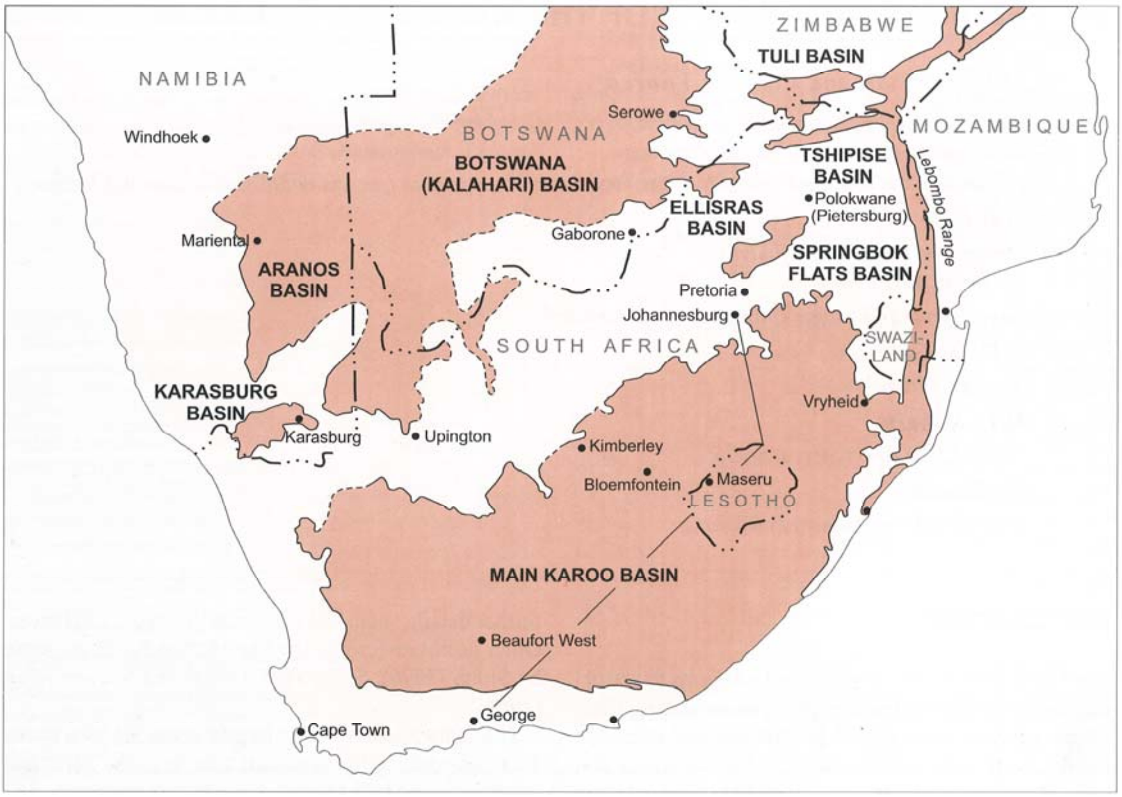


Figure 1. Location of the Karoo basins in South Africa and adjacent territories (modified after Johnson *et al.*, 1996; in Johnson *et al.*, 2006).

Pinetown and others. (2007) explain the evolution of the sedimentary infilling of the Main Karoo Basin: The beginning of Karoo Supergroup deposition is marked by a period of glacial sedimentation and resulted in the deposition of the Dwyka Group. Smith and others (1993) describe that a shallow sea remained after the glaciation and the accumulation of black clays and mud on the submerged platform under cold climatic conditions gave rise to the Lower Ecca Group. The Upper Ecca Group was formed when deltas prograded over the Lower Ecca Group and eventually combined to form broad alluvial plains (Smith and Whittaker, 1986). As a result of floodplain aggradation, deposits of the Beaufort Group formed on semi-arid alluvial plains toward the end of the Late Permian. Progradation of debris fans into the central parts of the basin gave rise to the Molteno Formation and as meandering river systems drained these fans over time, the Elliot Formation was formed. The Clarens Formation constitutes preserved aeolian sand dune deposits and sediments formed by the periodic river floods. The Drakensberg Group, which consists of volcanic flows, overlies the Clarens Formation and marks the end of the Karoo Supergroup formation. The major lithostratigraphic units of the Karoo Supergroup (Figure 2) crop out concentrically around the main basin (Johnson *et al.*, 2006).

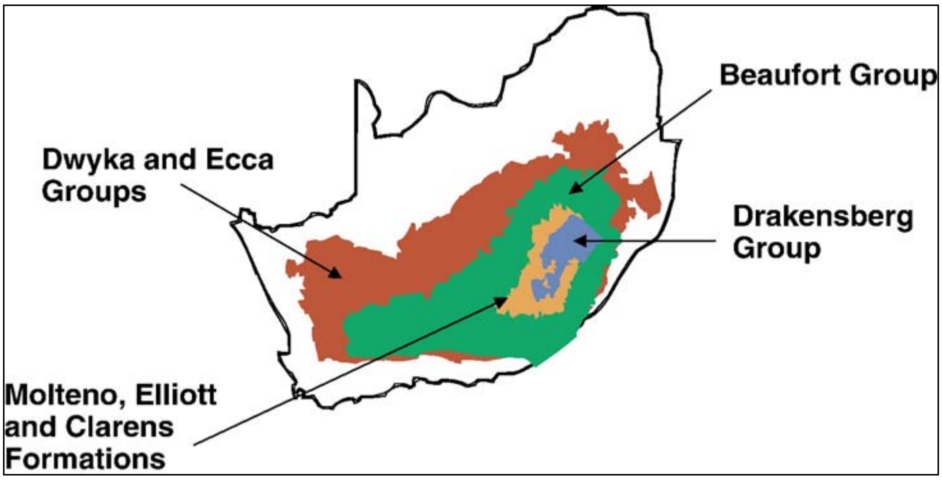


Figure 2 Outcrop of Karoo Supergroup units within the Karoo Basin (from Pinetown *et al.*, 2007).

The sedimentary strata of the Witbank Coalfield represent a continuous, conformable basin fill sequence (Grodner and Cairncross, 2003). Pinetown and others (2007) explain that the rocks of the Vryheid Formation of the Ecca Group cover most of the area (Figure 3) and post-Karoo age dolerite sills and dykes are characteristic of the Witbank and Highveld coalfields. The Vryheid Formation hosts the Witbank coal seams (Pone *et al.*, 2007). Five separate bituminous coal seams, which were deposited under cool, wet climatic conditions, are preserved in the Vryheid Formation.

Cairncross (1990) and Pone and others (2007) state that the Vryheid Formation is comprised of "*glacio-fluvial outwash braid–plain conglomerate and sandstone units, as well as minor glacio-lacustrine and glaciodeltaic sequences*". Furthermore, the thinning of coal seams beneath palaeo-channels has taken place due to incision and palaeo-erosion; indicating that palaeo-topography directly controlled sedimentation patterns in the Witbank Coalfield.

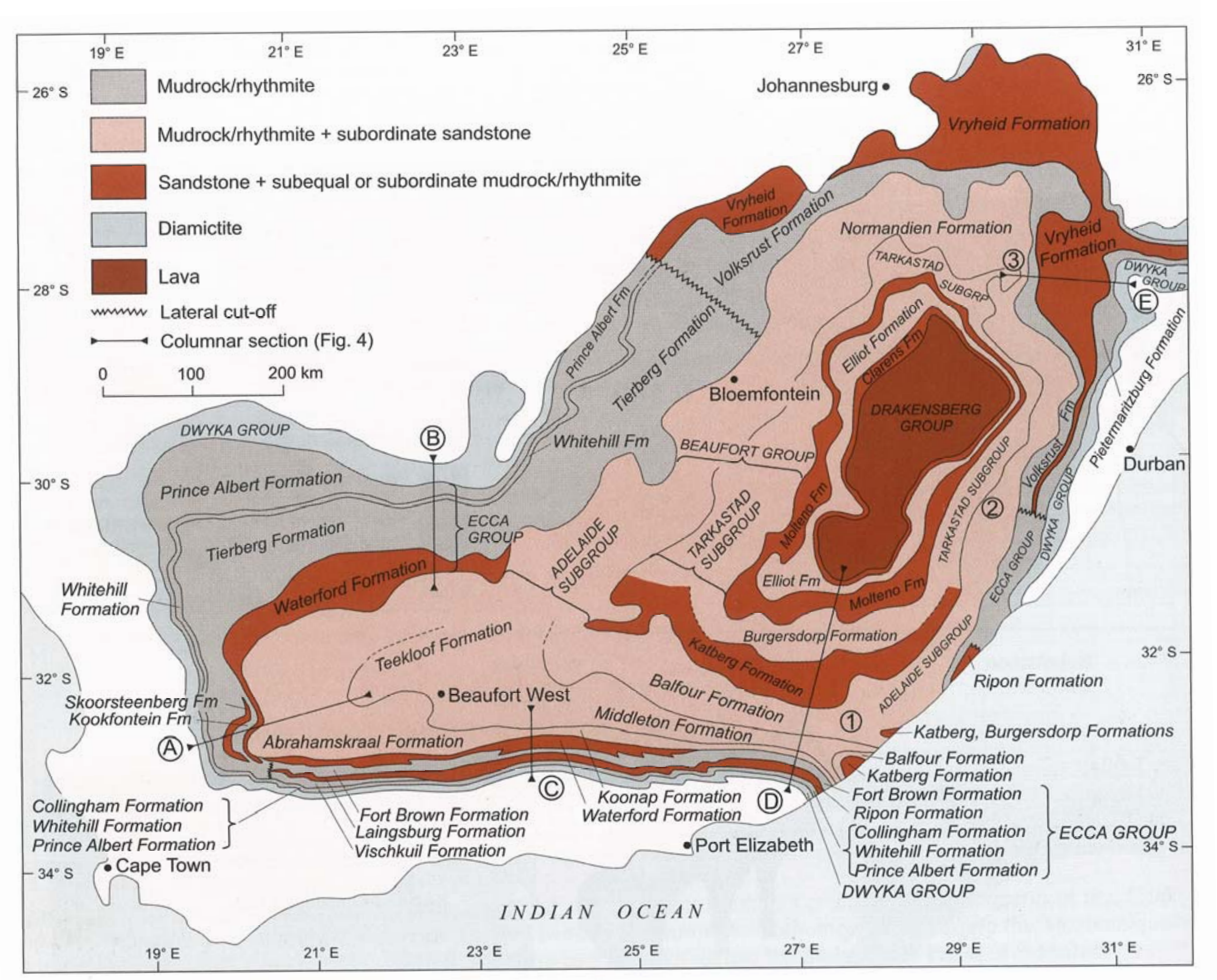


Figure 3. Schematic areal distribution of lithostratigraphic units in the Main Karoo Basin (modified after Johnson *et al.* 1997 in Johnson *et al.* 2006).

3.2 *Local geology*

The local geology for the study area consists of tillites at depth, dolomites, a variety of clastic sedimentary rocks and coal.

During the Proterozoic Eon cyanobacteria flourished as oceans encroached onto the Kaapvaal Craton. Dolomitisation occurred following deposition (through chemical alteration of calcium carbonate to magnesium carbonate). Dolomites where widespread and probably originally covered almost the entire Kaapvaal Craton, and appear in Mpumalanga as part of the Chuniespoort Group (McCarthy and Rubidge, 2005).

Deposition of the sediments of the Cape Supergroup (consisting of mudrocks and sandstones) onto the stable Kaapvaal Craton (in the north) and Namaqua-Natal Metamorphic Belt (in the south) took place during Ordovician – Early Carboniferous. Sedimentation of Karoo units took place from late-Carboniferous (Johnson *et al.*, 2006).

The Vryheid Formation hosts the Witbank coal seams (Pone *et al.*, 2007). Five separate bituminous coal seams, which were deposited under cool, wet climatic conditions, are preserved. Regionally the thickness of formations and coal seams is variable – a schematic representation of the general geology of the area is shown in (Lurie, 1987; Chelin, 2000).

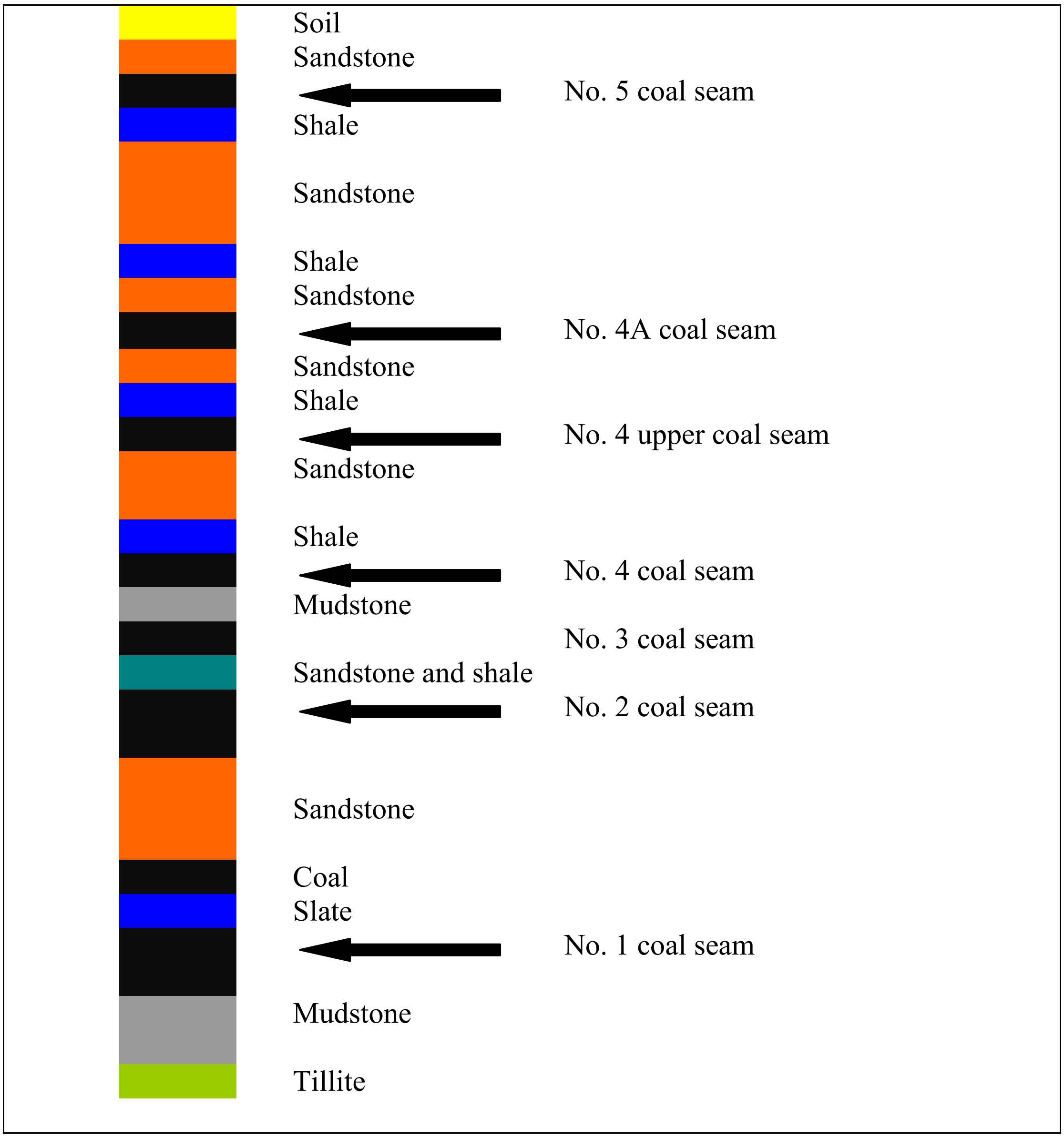


Figure 4. Schematic representation of geology of the study area (Modified after Lurie, 1987; Chelin, 2000).

3.3 Climate

The water monitoring stations used in the study are situated near the town of Witbank in the Mpumalanga Province of South Africa (figure 5a). The climate for Mpumalanga is described in section 3.3.1 (Rainfall) and section 3.3.2 (Topography and drainage).

3.3.1 Rainfall

The Mpumalanga State of the Environment Report (DACE, 2003) reflects that the province has hot summers and mild to cool winters owing to its sub-tropical climate. Average daily temperatures reported are 24°C in summer (i.e. measured in mid-January) and 14.8°C in winter (i.e. measured in mid-June). Rainfall in summer is generally higher than that in winter with an average annual rainfall reported of 767mm.

3.3.2 Topography and drainage

It is well accepted that water is essential to support human life, ecosystems and economic development. Four of southern Africa's major river systems are present in Mpumalanga. The Olifants System Orange River System (Vaal River), Inkomati River System (Crocodile, Sabie, Sand and Komati Rivers) and the Pongola River System (Usutu River) drain almost half of Mpumalanga (i.e. 53%) (DACE, 1999; DACE 2003).

The topography of the study area is considered to be fairly flat with a very gently undulating landscape; gradient is typically less than 1:35 (Chelin, 2000). The Olifants River is one of the major drainage courses in the Olifants River Catchment (CSIR, 2010). Figure 6 shows the Olifants WMA drainage courses and sub-divisions which are relevant to the study.

The Olifants River originates in the grasslands of the Mpumalanga Highveld, flows northwards before it joins the Limpopo River in Mozambique and discharges into the Indian Ocean. The main tributaries to the Olifants River are the Elands, Ga-Selati and Wilge Rivers (on its left bank) and the Blyde, Klaserie, Steelpoort and Timbavati Rivers (on its right bank) (DWAF, 2004).

The upper reaches of the Olifants River Catchment are accepted to be inundated by agricultural, conservation and mining activities. The Olifants River displays a red-brown colour in portions of the middle part of the catchment as a result of the erosion caused by overgrazing. More than thirty dams are present in the Olifants River Catchment – these include the Arabie Dam, Blyderivierspoort Dam, Loskop Dam, Middelburg Dam, Ohrigstad Dam, Renosterkop Dam, Rust de Winter Dam, Witbank Dam and the Phalaborwa Barrage. The combined capacity of the dams in the catchment is considered noteworthy (CSIR, 2010).

Balance between water requirements and availability

The National Water Act (36/1998; S 6(1)) states that the National Water Resource Strategy (NWRS) must "*promote the management of catchments within a water management area in a holistic and integrated manner*" and thus recognises that Integrated Water Resource Management (IWRM) must be achieved by considering the impact of land- and water-based activities on the resource base.

The water balance and availability is impacted significantly by coal mining, particularly in the Upper Olifants sub-area (DWAF, 2004). Potential sources of disruption are mentioned in Chapter 9.

An indication of water stress is derived through comparing water available for use is against total water resources (shown in Table 1 and Table 2 respectively). For the Olifants WMA DACE (2003) reported that, overall, there is a water deficit in the Olifants WMA. Further explanation is that the Upper Olifants sub-WMA is in balance (owing to transferral of required quantities to the power stations) and a deficit is noted for the Middle and Lower Olifants sub-areas (attributed mainly to the provision for the ecological component of the Reserve). Surpluses from local water resources accumulate at Loskop Dam for release to the Middle Olifants sub-area. Provision for the ecological component of the Reserve combined with large demands of irrigation requirements result in a deficit in the Steelpoort sub-area.

Table 1. Water availability per sub-WMA within the Mpumalanga provincial boundary (million m^3/a) (adapted from DWAF, 2002; after DACE, 2003).

Reporting scale		Natural resource		Usable return flow			Transfers in	Total resource available
WMA's	Sub- WMA's	Surface water	Ground-water	Irrigation	Urban	Mining and bulk industrial		
Olifants	Upper Olifants	194	4	2	37	4	171	412
	Middle Olifants	99	70	34	5	1	89	298
	Steelpoort	42	14	3	1	1	0	61
	Lower Olifants	74	11	5	2	8	1	101

Table 2. Sectoral water requirements per sub-WMA within the Mpumalanga provincial boundary (adapted from DWAF, 2002; DACE, 2003).

Reporting scale		Sectoral requirements (volumes in million m^3/a)						Transfers out	Total local requirements
WMA's	Sub- WMA's	Irrigation	Urban	Rural	Mining and bulk industrial	Power generation	Afforestation		
Olifants	Upper Olifants	44	66	6	20	181	1	94	412
	Middle Olifants	336	15	28	14	0	0	3	298
	Steelpoort	69	3	5	17	0	1	0	61
	Lower Olifants	108	8	5	43	0	1	0	101

Water Management

The NWA defines a ***'catchment'*** as "*the area from which any rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points*" i.e. it is considered the geographical unit of land as well as the water resources in and on that unit. It stands to reason then that the dams, estuaries, groundwater resources, lakes, rivers and wetlands excluding the surrounding lands they pass over/ through/ on/ in are "**water resources**".

As part of the progression of the National Water Resource Strategy (NWRS) - South Africa has been divided into 19 Water Management Areas. A **'water management area'** (WMA) as defined by the NWA is "an area established as a management unit in the national water resource strategy within which a catchment management agency will conduct the protection, use, development, conservation, management and control of water resources" which prompts that a '**Catchment Management Agency'** (CMA) is a statutory body established with the role of managing water resources within its Water Management Area. Figure 5 shows the water managements areas of South Africa and their distribution. The water management area of relevance to this study - the Olifants – is indicated in the red text box.

Olifants Water Management Area (WMA)

DWAF (2004) describes that the Water Resource Strategy (NWRS) divides the Olifants Water Management Area (WMA) into 4 sub-areas: the Upper -, Middle - and Lower Olifants Sub-areas and the Steelpoort Sub-area (Figure 6). Approximately 50% of the Olifants WMA's total area (of 54550 km^2) falls within Mpumalanga (DACE, 2003) and the remaining portion falls over the provinces of Limpopo, Mpumalanga and Gauteng.

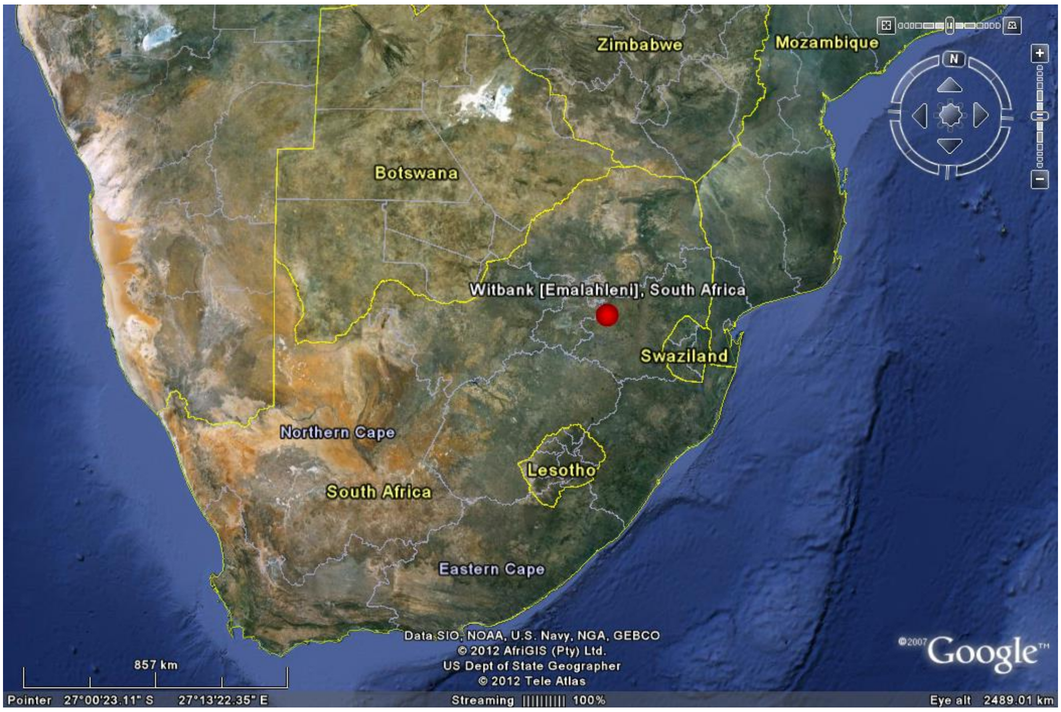


Figure 5a. Showing relative position of Witbank [Emalahleni], Mpumalanga Province, South Africa and general study area (Google Earth, 2009).

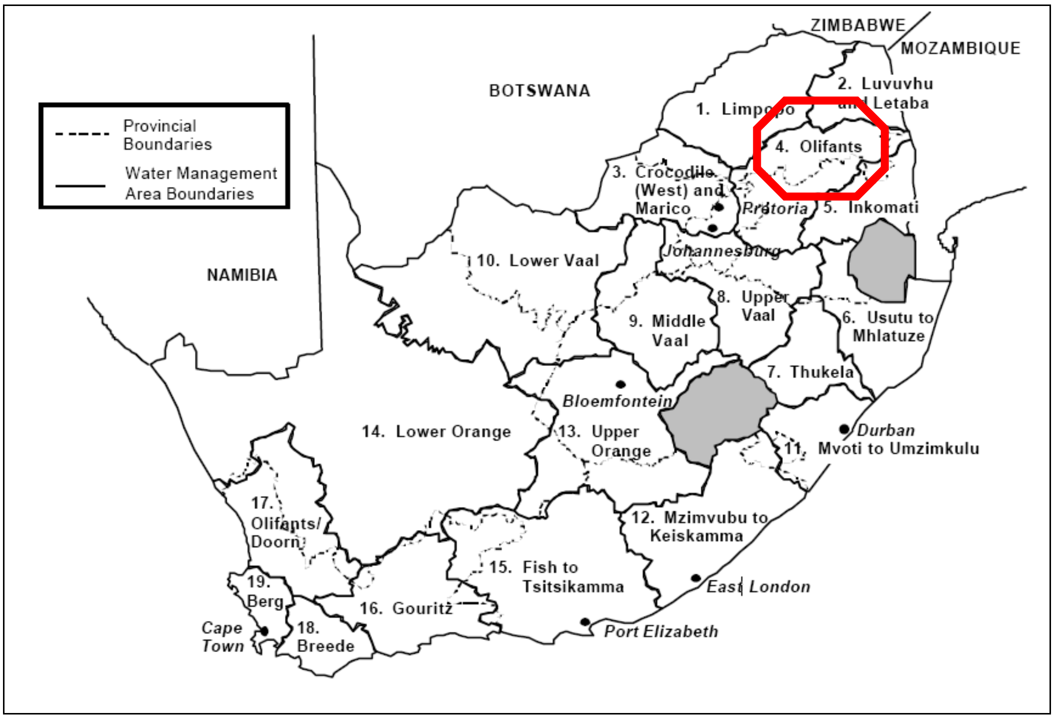


Figure 5b. Water management areas of South Africa and their distribution (DWA, 2002). The water management area of relevance to this study - the Olifants – is indicated in the red text b

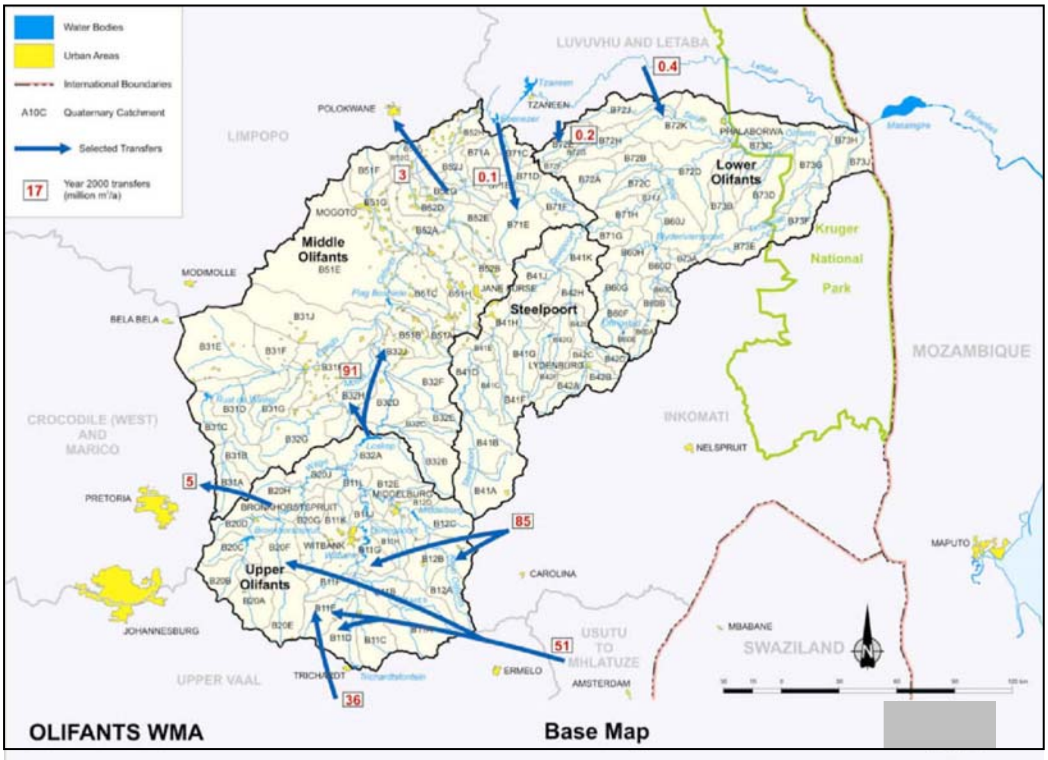


Figure 6. The sub-division of the Olifants Water Management Area (DWAF, 2004).

3.4 Demography

Mpumalanga has a population of approximately 3.5 million people; and with a sex ratio of 94.7:100 (i.e. where sex ratio is defined as the number of men per 100 women), female persons make up just over half of the population of the province (Stats SA, 2004).

It is reported by Stats SA (2004) that

- Approximately 41% of the total population of Mpumalanga lives in urban areas;
- The most common home language is siSwati (31%), followed by isiZulu (26%) and then isiNdebele (12%);
- Along with Eastern Cape and North West, Mpumalanga has the second highest proportion (of 5,8%) of disabled people among all the provinces in South Africa

The population can be viewed comparatively (according to age and population group) revealing that:

- The majority of people in the province (for all population groups) were in the age group 15–64 years (60% for black, 64% for coloured, 68% for Indian and 69% for white population groups).
- The black population had the majority of young people in the age category 0–14 years (36%); while the white population had the highest proportion in the age group 65+ years (8%) where the proportion for other population groups was less than 5% each.

3.5 Urban Development

The province is divided into 4 district municipalities (shown in Figure 7): Ehlanzeni District Municipality; Nkangala District Municipality; Eastvaal District Municipality and Sekhukhune Cross Boundary District Municipality (named such as it crosses over Mpumalanga's provincial border and resides within two provinces). Each of the 4 district municipalities is made up of a number of smaller, local municipalities.

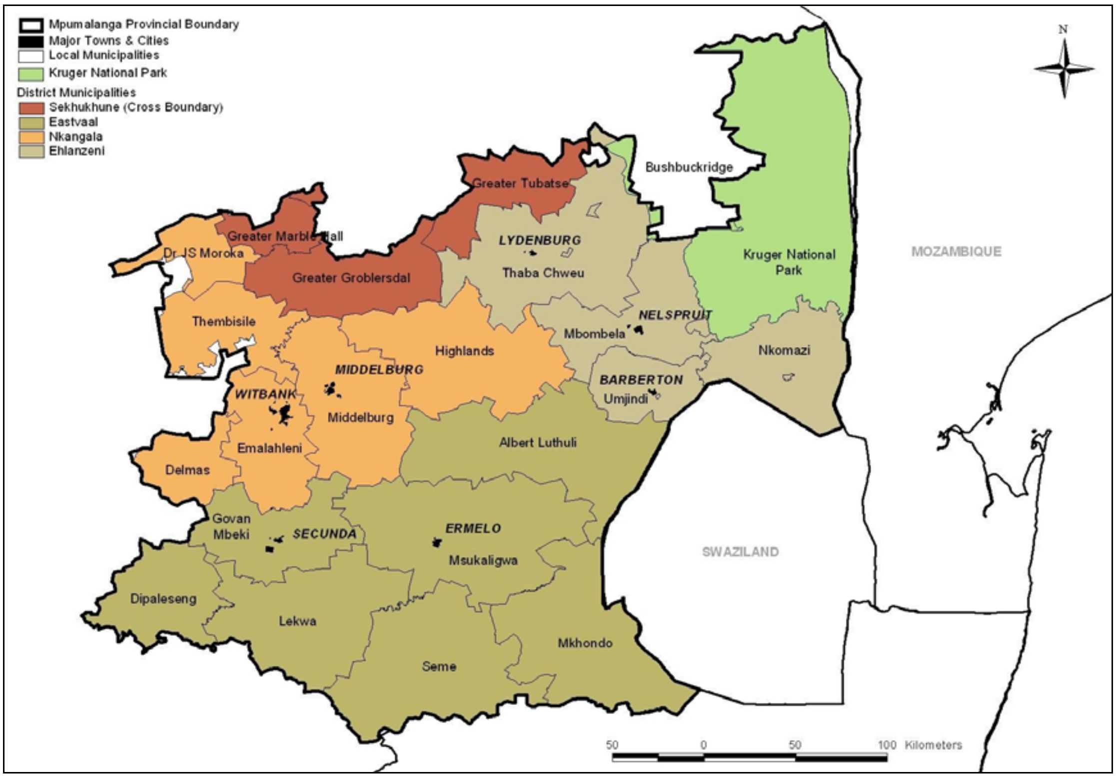


Figure 7. Map showing the municipal boundaries in Mpumalanga province (DACE, 2003).

3.6 Housing and Sanitation

Formal housing dominates as the housing type in Mpumalanga, though Sekhukhune District Municipality has a large number of traditional dwelling households (DACE, 2003)

The most common type of sanitation in Mpumalanga province is pit latrines; though residents of Eastvaal and Nkangala also have ready access to flush toilets. There are, however, a fairly high number of households without access to sanitation: approximately 35 000 households in Sekhukhune; 24 000 households in Ehlanzeni; 17 000 in Eastvaal and less than 10 000 in Nkangala District Municipality (DACE, 2003).

3.7 Water and Electrification

Most households in Eastvaal, Ehlanzeni and Nkangala are believed to have access to water (either in their dwelling, on site or via a public tap) (DACE, 2003). In Sekhukhune District Municipality access to water for most households is either via a public tap or natural water source. Because natural water sources are a critical water source for the people of Sekhukhune, DACE have emphasised the need for these natural water sources to remain unpolluted.

Approximately 70% and 75% non-urban and urban households, respectively, have access to electricity as reported via the National Electricity Regulator.

3.8 Economy

Manufacturing, mining, agriculture and forestry are the primary economic activities undertaken in Mpumalanga. Having recorded the fifth highest average annual economic growth rate (of 3,0%) among all provinces during the period 1996 to 2004, Mpumalanga is credited to hold fifth-largest regional economy in South Africa. Stats SA (2004) states that the Gross Domestic Product per Region (GDPR) contribution of Mpumalanga to the economy of South Africa in 2004 was 6,8%.

4 Coal

4.1 Properties and Classification System of Coal

Coal is an organosedimentary rock formed by the accumulation, compaction and induration of plant remains such that it is composed of greater than 50% (by mass) and greater than 70% (by volume) carbonaceous material (Snyman, 1998). Classification of coal is accepted to be in terms of the three independent variables of type, grade and rank.

Aspects of the classification of coal are narrated by Snyman (1998):
The maceral composition (i.e. the basic organic constituents) of original plant material and the extent of diagenetic alteration experienced determine the **type** of coal.

Peat formation is followed by putrefaction in the diagenetic processes which comprise the formation of coal. *Peat formation* (also referred to as humification) occurs in environments that are moderately oxidising to weakly reducing. Bacterial and fungal activity partly convert the plant matter into humic acids which toxify the stagnant swamp waters in which they lay until ultimately, the micro-organisms are destroyed. The remaining plant material is impregnated by the humic acids and contribute to the induration of the peat until eventually 'humic coal' is formed. Humic coal is characterised by layers of alternating brightness and dullness. *Putrefaction* (also referred to as saprofication) takes place under reducing conditions in moderately stagnant water. Anaerobic bacteria removes the oxygen from the plant material and liberates it (along with hydrogen sulphide and methane) as water and carbon-dioxide. This carbon and hydrogen rich organic material finally produces a sapropelic coal. Sapropelic coal does not have stratification visible to the naked eye.

The percentage of inorganic material in coal determines its **grade** and is strongly influenced by deposition of clastic minerals during the depositional stage of coal formation. The most convenient measure of coal grade is said to be ash content – though ash content of overall mineral-matter content is considered to be variable (Gaigher, 1980; Snyman, 1998).

The increase in temperature and pressure after burial of the original, plant material by younger sediments affect the **rank** of coal. Chemical composition and physical-chemical properties of the plant material are changed during metamorphism. The increasing rank of coal formed from peat and lignite are bituminous (high-volatile followed by low-volatile), semi-anthracite and anthracite.

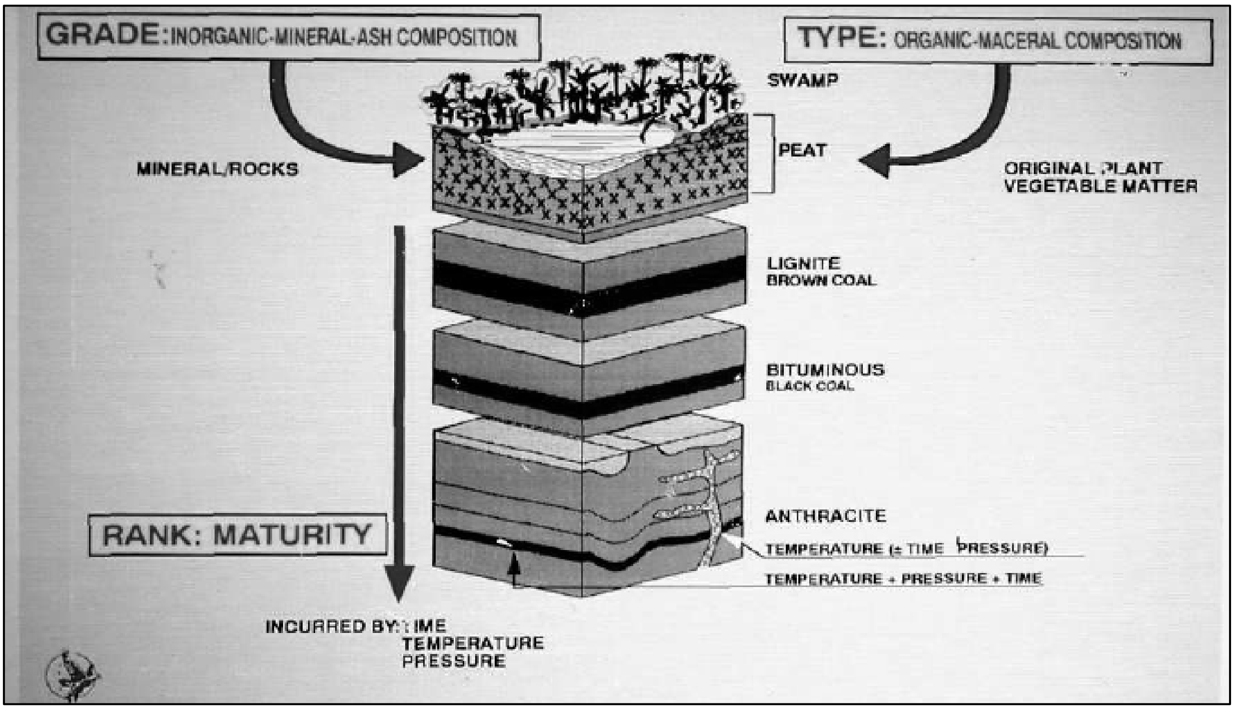


Figure 8. Schematic showing geological characterisation of coal based type, rank and grade (Falcon, 1986 in Pinheiro, 2009)

Table 3. Compositional comparison of coal ranks (after Boggs, 2006)

Class (rank steps)	Fixed carbon limits (wt. percent), dry, mineral- and matter-free basis	Volatile matter (wt. percent), dry, mineral- and matter-free basis	Calorific value limits (Btu/lb), moist, mineral- and matter-free basis
Anthracite	86-98	2-14	—
Bituminous	69-86	22->31	10,500-14,000
Subbituminous	<69	>31	8,300-10,500
Lignite	<69	>31	6,300-8,300
Peat	low	high	low

Source: Data from American Society for Testing Materials (ASTM), 1981, *Annual book of ASTM standards,* Part 26.

4.2 Uses and importance of coal

Coal is used in a variety of industries and its use is dictated by its physical and chemical properties (Figure 9).

Power generation and electricity

Coal is utilised in various sectors although its primary use is that of power generation (BGS, 2007). ESKOM (South Africa's main electricity provider) and smaller, independent power stations use coal to generate electricity through coal burning power stations (Pinheiro, 2009).

Metallurgical industry

Coal is widely used in metallurgical industry (Figure 10). The production of steel from iron requires coke to be burnt in blast furnaces (coke is low in phosphorous and sulphur), liquefies when heated in the absence of air and solidifies into porous, hard lumps as it is processed in an oxygen-deficient atmosphere created by a series of coke ovens. The process produces useful by-products tar and chemicals, which may be sold after further processing, and gas - which may be used in the plant as fuel. Coal - including 'steam coals' - can be used in electric arc furnaces when production steel from scrap by pulverised coal injection. (BGS, 2007). Smelters rely on coal and the industry utilises other coal for other products such as carbon reductants, char and electrode feed (Pinheiro, 2009).

Chemical industry

Synthetic fuels (colloquially referred to as "synfuels") produced include petrol, diesel, carbotar, petcoke (Pinheiro, 2009).

The British Geological Survey (2007) elaborate on liquid fuels as being obtained from sulphur-free coals deficient in nitrogen oxide and particulate matter and are created through direct liquefaction or indirect liquefaction. Direct liquefaction employs solvents to dissolve coal at high temperature and pressure before further refining is undertaken; whereas indirect liquefaction gasifies the coal which is then condensed over a catalyst (known as the Fischer-Tropsch process) to produce a clean, high-quality product. The production of liquid fuels and chemicals on a commercial scale is carried out solely by SASOL.

Manufacturing industry

Coal is consumed in the production of pulp and paper, textiles, agriculture, sugar, tobacco, mining, bricks and tiles, cement, lime, ammonia, fertilisers, explosives as well as in the production of advanced carbons such as carbon fibres, activated carbon and nanotubes (Pinheiro, 2009).

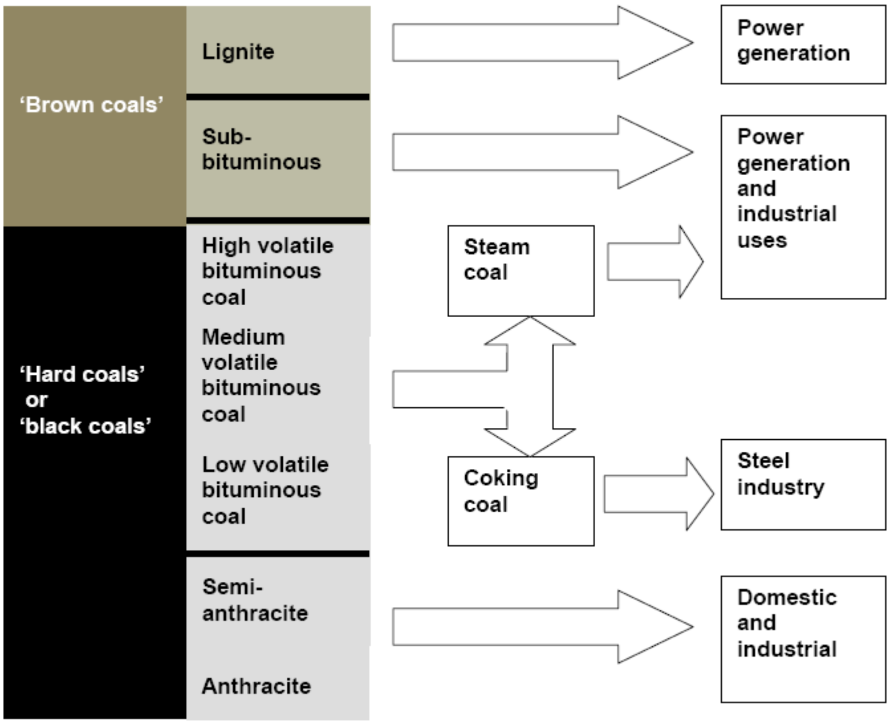


Figure 9. Coal uses by coal type (BGS, 2007).

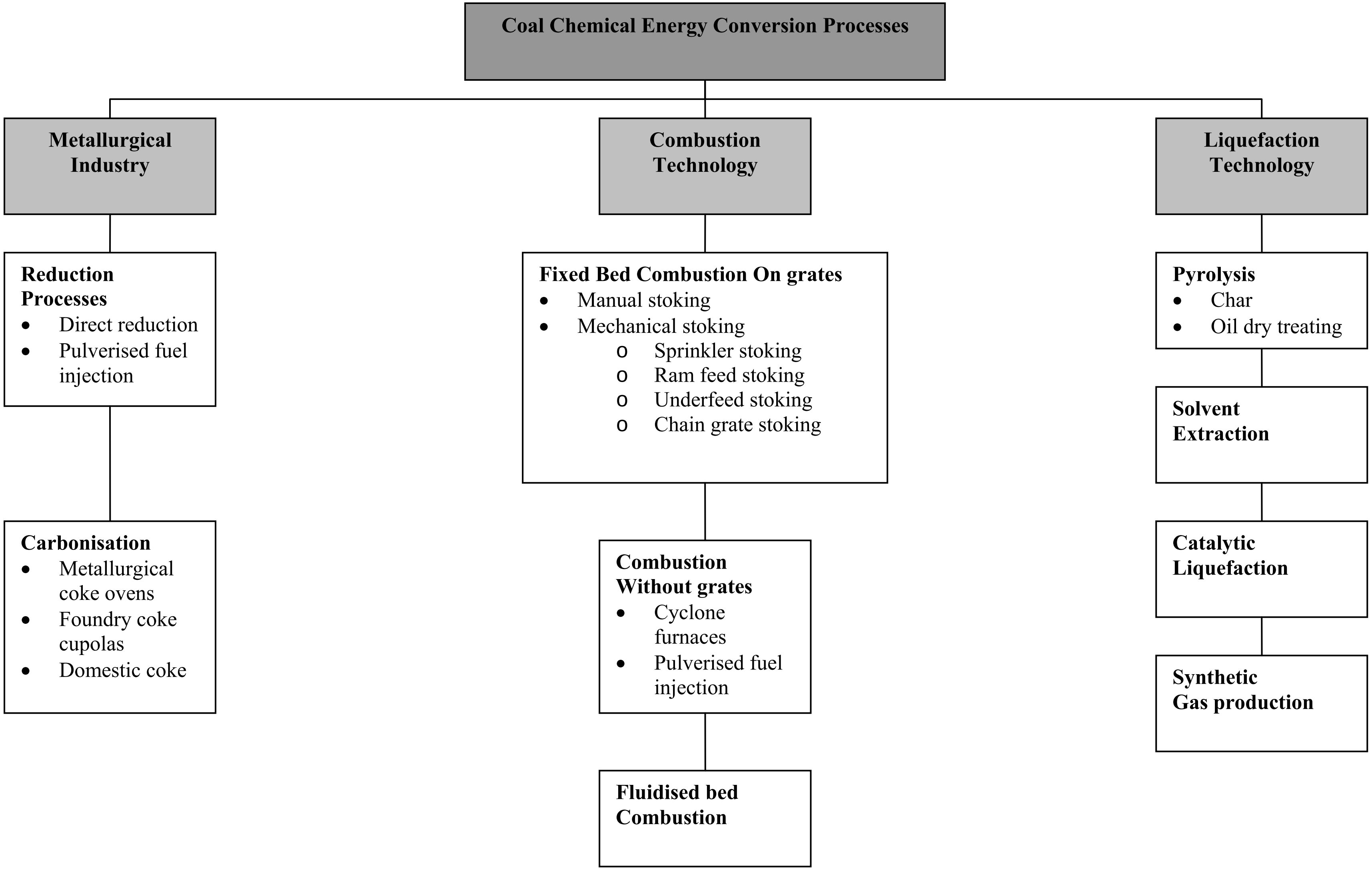


Figure 10. Diagram showing coal chemical energy conversion processes (modified after Pinheiro, 2009).

Coaltech (2010) states that coal-fired thermal power stations generate over 90 percent of electricity in South Africa and coal provides approximately 75 percent of South Africa's primary energy requirements.

It is believed that – because of lack of suitable alternatives - this dependency on coal as primary energy will remain over the next two decades (South Africa, 2002; DME, 2010). The Department of Mineral Resources expressed the government's commitment in identifying, developing and using feasible renewable energy sources (e.g. small-scale hydro-energy and solar, thermal and wind energy) to diversify South Africa's energy sources and reduce the country's heavy dependency on coal (DME, 2008).

4.3 Overview of Coal Mining and Transport in South Africa

The first documented discoveries of coal in KwaZulu-Natal, Mpumalanga and the Eastern Cape Provinces date between 1838 and 1859 (Snyman, 1998).

Mining of the Witbank Coalfield in Mpumalanga is said to have commenced as far back as the 1890's (Pone *et al.*, 2007). Initially small surface mines operated and produced 500Ktpa (kilotons per annum). Larger, more established collieries came into being and the bulk of their production was transported to Johannesburg's goldfields of the Far West-Rand, Free State, Evander and Klerksdorp (Snyman, 1998).

The commissioning of a rail-port system in South Africa in 1907 resulted in an increase in coal production and export; following which an increase in the domestic demand for electricity increased the domestic demand for coal (Lang, 1995). The coal transport system now has dedicated railway lines for transporting coal. Coal is transported to the Richards Bay Coal Terminal (RBCT) (on the east coast) from the coalfields of Mpumalanga Province. Richards Bay - with a capacity of 76 Mt - is one of the largest ports through which South African minerals are shipped (DME, 2008).

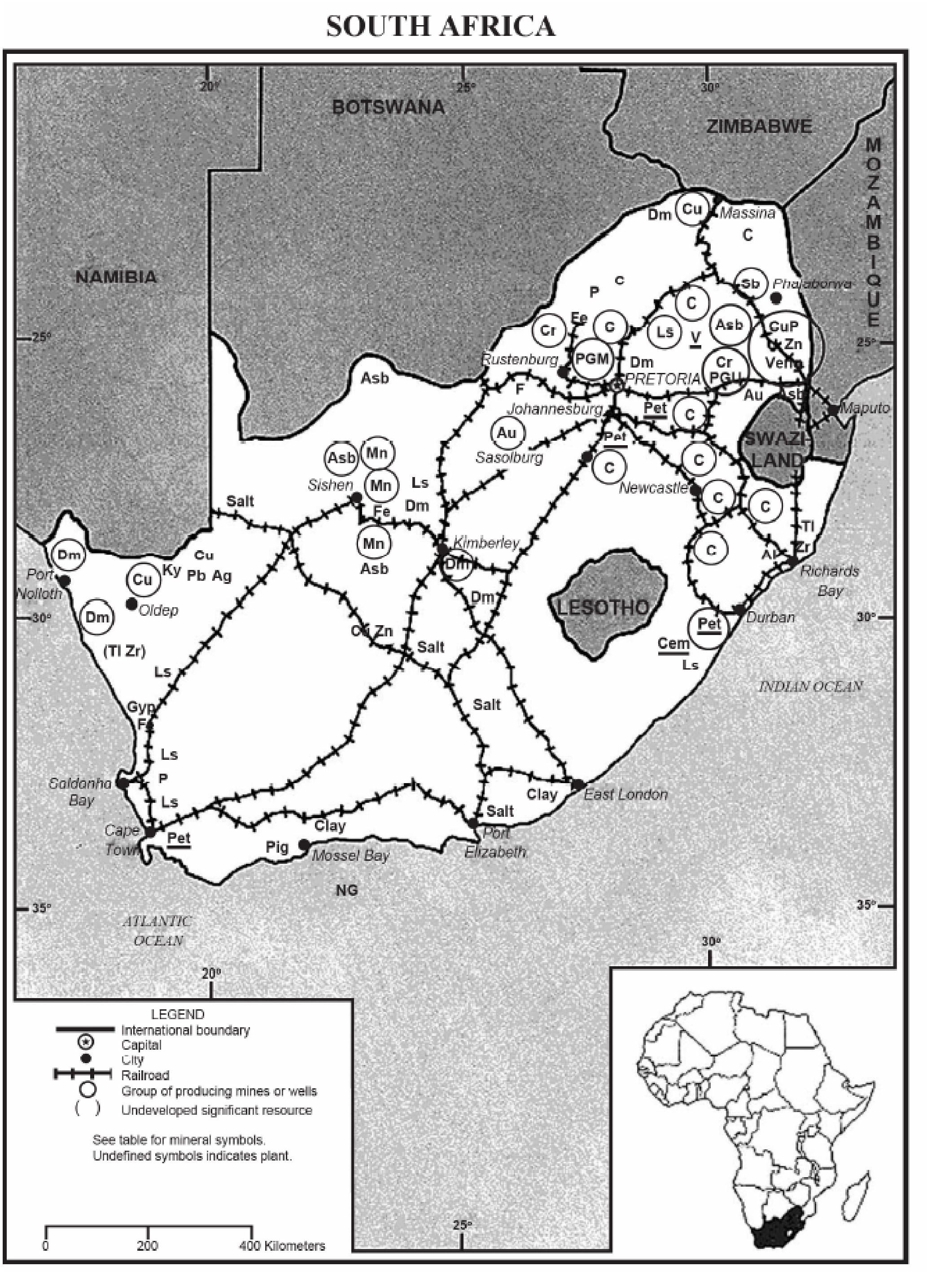


Figure 11. Showing extensive railway network in relation to location of mineral deposits in South Africa. (after Wagner and Hlatshwayo, 2005).

Labelled Asb – asbestos, Au – gold, C- coal, Cr – chrome, Cu – copper, Dm – diamonds, PGM – platinum group minerals, Mn – manganese, Sb – antimony, Zn – zinc).

Steel plants erected at Vanderbijlpark and Newcastle and Sasol plants increased the demand for electricity. Power stations were erected by Eskom to meet the needs of this accelerated industrialisation (Snyman, 1998). Developments in the coal mining industry enabled the expansion of existing mining operations and the opening of new mining operations such that coal production reached 74Mt/a (million tons per annum) by the end of the 1970's (Moolman, 2004).

International interest in South African coal was stimulated following the oil crisis of 1973. South Africa is said to have favourably penetrated the international coal market because of competitive production costs and sound infrastructure in its coal mining operations (Snyman, 1998).

The increase in production continued through the 1990's and in 2005 reached 245Mt (Roberts, 2005). DME (2008) report that South Africa's run-of-mine (ROM) coal production for 2007 was 312,3 Mt and of that 247,6 Mt was of saleable quality.

The cost-effective exploitation of numerous deposits has aided in the establishment of a strong coal-mining industry. The coal-mining industry is diverse – it includes small-scale producers to collieries that are among the largest in the world - and it is estimated that in South Africa 53 percent of coal mining is mined using underground methods and 47 percent is mined using opencast methods (DME, 2008).
The Department of Mineral Resources states that there were 64 operational collieries in South Africa in 2004 (DME, 2010).

Ikaneng, 2008 concludes that five companies within the coal-mining industry (namely Ingwe Collieries Limited [a BHP Billiton subsidiary], Anglo Coal, Sasol, Eyesizwe, and Kumba Resources Limited) account for 85 percent of saleable coal production. Similarly, 11 mines are said to account for 70 percent of production (DME, 2010). Coal production feeds the various local industries in South Africa: 62 percent is used for electricity generation; 22 percent for petrochemical industries; 8 percent for general industry; 4 percent for the metallurgical industry; and 4 percent is purchased by merchants and sold locally or exported.

4.4 Mining methods

The geology, seam thickness and depth of a coal deposit influence the mining method used to mine the deposit (Chelin, 2000). Coal may be extracted during mining using methods such as opencast mining, room and pillar mining or longwall mining. McCarthy and Pretorious (2009) and Snyman (1998) list the mining methods and elaborate on their workings.

Opencast mining is a surface mining method which involves the scraping off of soil cover (which is subsequently stockpiled) and blasting away of overlying rocks to reveal coal seams. This method is suitable to coal seams that are close to surface. Once the coal has been extracted from the pit, the overburden and soil are returned from stockpiles and are used to fill the pit. Ideally the site should then be landscaped and re-vegetated as part of a remediation and rehabilitation plan.

Room and pillar mining is an underground mining method where the mined material leaves empty ‘rooms’ and pillars are left in place to support the roof of the excavation. The number of rooms is dependent on the quantity and quality of the coal and eventually may become linked as to form a network. The pillars are coal bearing and may be mined toward the end of mining, however, this reduces the localised stability of the excavation. Leaving the pillars underground decreases the total amount of recovered coal.

Longwall mining is an underground mining method whereby supports are used to protect the mining face and are moved along the coal seam as mining progresses. This method is suited to thicker seams. The coal seam is extracted in its entirety then the roof of the excavation is collapsed into the mined-out cavity.

4.5 Properties of the Witbank Coalfield

The Witbank Coalfield in the Mpumalanga Province (Figure 12) has its southern boundary from a few kilometres south of the Delmas Colliery in an east-northeast direction to the South Witbank Colliery. A natural boundary is formed, from this point eastwards, by the Smithfield ridge – a series of Rooiberg felsite inliers (Smith and Whittaker, 1986; Snyman, 1998).

The Witbank Coalfield was first mined in 1895 and subsequently developed into one of the most important coalfields in South Africa. The Witbank Coalfield represents an extensive and well-developed portion of the coal mining industry with a number of collieries (Figure 13 and Figure 14). During the 1970s it hosted 28 collieries and by 1995 it hosted 37 collieries – shown in Table 4 (Snyman, 1998).

The 70m thick succession which hosts the five coal seams of the Witbank Coalfield is composed of sandstone with lesser occurrence of siltstone and mudstone Snyman (1998). The seams are numbered 1 through 5.

Pre-Karoo topography significantly influenced the distribution and attitude of the No. 1 and 2 seams. The No. 3 seam is generally considered uneconomic and is commonly less than 0.5m thick. Distribution of the No. 4 and 5 seams is controlled by present-day surface (Snyman, 1998).

Snyman (1998) describes the frequent occurrence of dolerite dykes and sills: the 15m thick and 100km long Ogies dyke which devolatised coal up to 300m either side of it and the common, smaller intrusions to the south of the Ogies dyke.

The No. 1 seam, composed mainly of dull coal, is erratically developed and only represents approximately 2% of the *in situ* resource in the Coalfield. Near the Arnot and Optimum Collieries it reaches a thickness of 1.5m - 2 m.

Approximately 69 percent of the *in situ* resources of the coalfield are held in No. 2 seam. The average thickness of the No. 2 seam in the central part of the coalfield is 6.8m – with up to five benches of different appearance and quality – and thins to 3m in the east (towards Arnot Colliery). Low-ash metallurgical coal and steam coal (for export) may be mined from the lowest three benches. The benches are less prominent elsewhere resulting in selective, underground mining of the lower benches (Smith and Whittaker, 1986 in Snyman, 1998).

The No. 4 seam, composed mainly of dull coal, accounts for approximately 26 percent of the *in situ* resources of the coalfield. The seam varies in thickness between 2.5m and 6.5m. The No. 5 seam, composed mainly of bright coal, represents approximately 4 percent of the *in situ* resources of the coalfield. The average thickness of the seam is 1.8m.

Table 5 shows typical raw and washed coal analyses for seam Nos. 1 to 5 of the Witbank Coalfield. Table 6 lists available maceral analyses (mineral-matter free), R_0V_{rand} (random reflectance of vitrinite in unpolarised light) with corresponding proximate analyses, calorific values, sulphur contents and swelling indices (air-dry basis) of product samples from individual seams (Snyman, 1998). Table 7 shows the variation in the properties of coal products of the Witbank Coalfield. Two arc-shaped zones (the first from Ogies through Greenside Colliery to Witbank and the second from Rietspruit Colliery through Goedehoop and Bank Collieries to the Mavela Colliery near Middelburg) host the higher rank coals (coals where ($R_0V_{rand} > 0,7$ %)

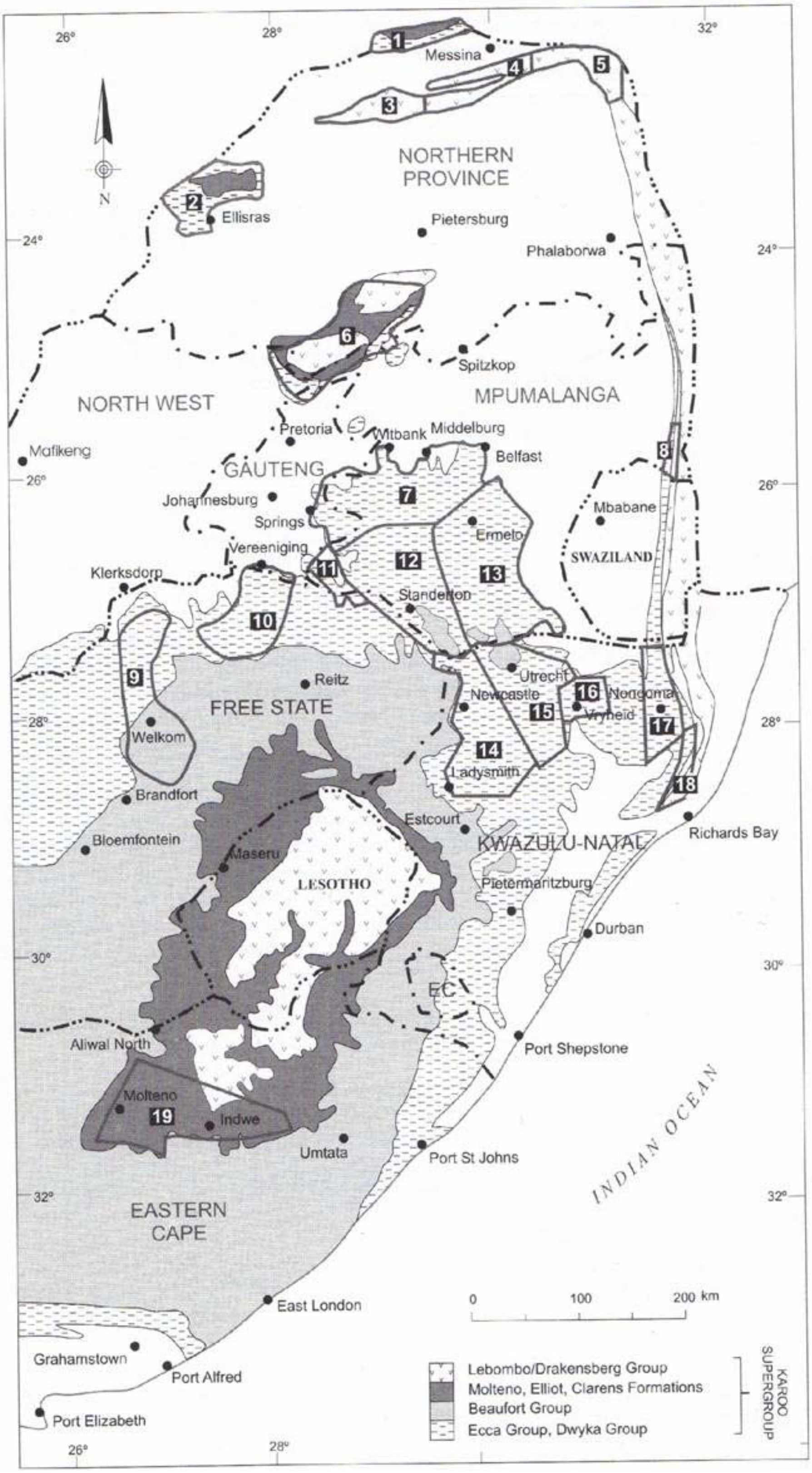


Figure 12. Distribution of Coalfields of the Republic of South Africa (after Snyman, 1998).

(Coalfields numbered as 1 Tuli, 2 Ellisras, 3 Mopane, 4 Tshipise, 5 Pafuri, 6 Springbok Flats, 7 Witbank, 8 Kangwane, 9 Free State, 10 Vereeniging-Sasolburg, 11 South Rand, 12 Highveld, 13 Ermelo (formerly Eastern Transvaal), 14 Klip River, 15 Utrecht, 16 Vryheid, 17 Nongoma, 18 Somkele, 19 Molteno-Indwe).

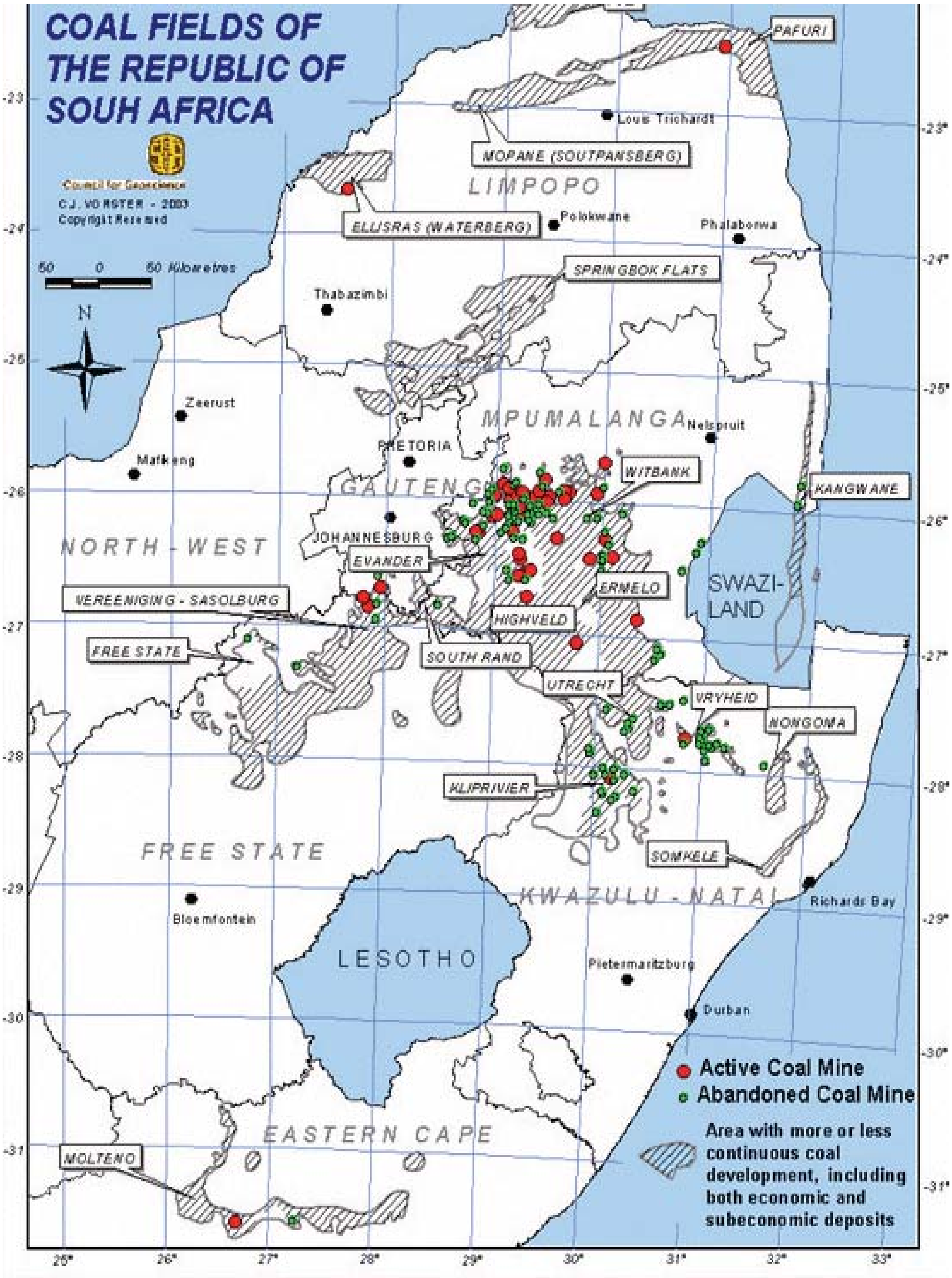


Figure 13. Coalfields of the Republic of South Africa (CGS, 2003).

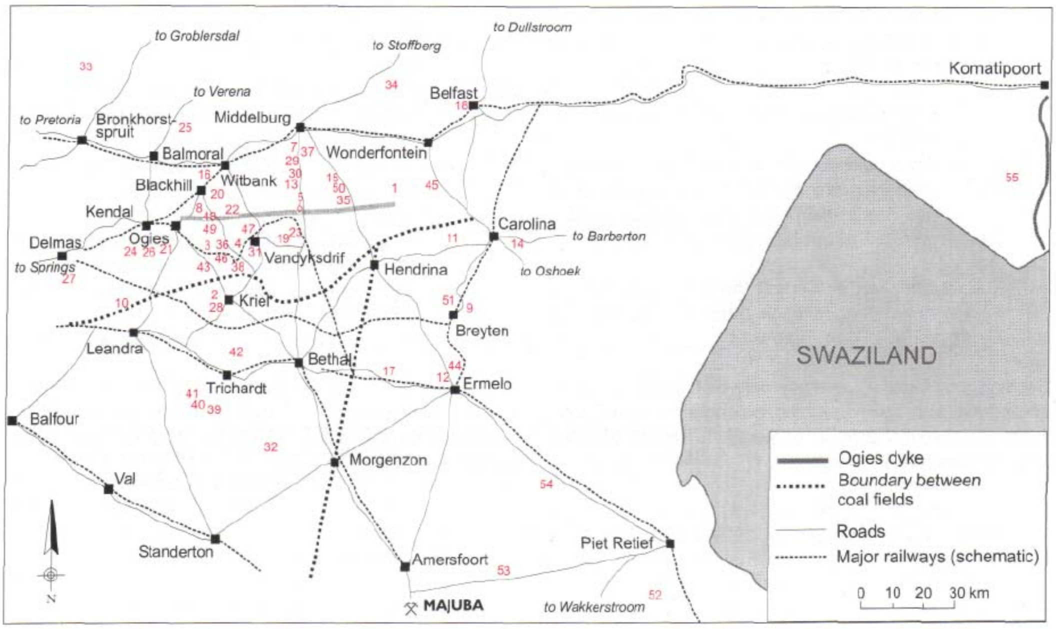


Figure 14. Collieries in Mpumalanga. (after Smith and Whittaker 1986; Jordaan 1986; in Snyman, 1998).

Collieries numbered 1. Anglo Power (Arnot), 2. Anglo Power (Kriel), 3. Arthur Taylor, 4. ATCOM, 5. Bank 2, 6. Bank 5, 7. Blackwattle, 8. Boschmans, 9. Bothasrust, 10. Delmas, 11. Dover, 12. Driehoek (Wesselton), 13. Duvha, 14. Eastside, 15. Eikeboom, 16. Elandsfontein, 17. Ermelo, 18. Glisa, 19. Goedehoop, 20. Greenside, 21. Khutala, 22. Kleinkopje, 23. Koornfontein, 24. Lakeside, 25. Landau (Kromdraai), 26. Leeuwfontein, 27. Leeuwpan, 28. Matla, 29. Mavela, 30. Middelburg, 31. New Clydesdale, 32. New Denmark, 33. Northfield, 34. Olifantslaagte. 35. Optimum, 36. Phoenix, 37. Polmaise, 38. Rietspruit, 39. Secunda: Bosjesspruit, 40. Secunda: Brandspruit, 41. Secunda: Middelbult, 42. Secunda: Syferfontein, 43. South Witbank, 44. Spitzkop, 45. Strathrae, 46. Tavistock, 47. Van Dyks Drift, 48. Waterpan, 49. Witbank Consolidated, 50. Woestalleen (Noodhulp Section), 51. Consbrey Dump, 52. Protea, 53. Mpisi, 54. TBS, 55. Nkomati Anthracite.

Table 4. Collieries producing in the Witbank Coalfield during 1995 (after Prevost, 1997; in Snyman 1998).

Colliery	Seems mined; mining method	Preparation	Approximate annual sales (kt)
Arnot	1, 2A, 2; sm	Crushing and screening	5510
Arthurt Taylor	2; bp, sm	Drums, cyclones, spirals	1900
Alcom (Arthur Taylor)	1, 2, 4, 5; sm	Drums, cyclones, spirals	2400
Bank 2	2; bp	Washing	-
Bank 5	5; bp	Washing	2650
Blackwattle	2; bp	HMS bath	234
Boschmans	2, 4; bp, pe	-	3300
Waterpan	4; bp, sm	-	-
Delmas	2, 4; bp	Washing	2362
Duvha	1, 2, 4; sm	Crushing	10140
Eikeboom	1, 2	Washing	-
Elandsfontein	4; sm & 1 bp	Drums, cyclones, spirals	270
Glisa	1, 2; sm	Crushing and screening	821
Goedehoop	2, 4; bp	Washing	3560
Greenside	1, 4, 5; bp	Washing	3312
Khutala	2, 4; bp	Crushing	7209
Kleinkopje	1, 2; sm	Washing	4820
Koornfontein	2, 4; bp	Washing	5793
Lakeside	2; sm, bp	Washing	661
Landau	1, 2; sm	Washing	2900
Leeuwfontein	2; bp	Washing	470
Leeuwpan	1, 2; sm	Drums, cyclones, spirals	684
Mavela	2; sm	Washing	60+
Middelburg	1, 2, 4; sm	Washing	6446
New Clydesdale	2; sm, bp	Washing	540
Northfield	2, 4; sm	HMS Drums, cyclones, spirals	180
Olifantslaagte	2; sm	Washing	5
Optimum	2, 4; sm	Crushing and screening	12822
Phoenix	1; bp	Drums, cyclones, spirals	900
Polinaise	2; bp	Washing	-
Rietspruit	1, 2, 4, 5; sm	Drums, cyclones, spirals	3110
South Witbank	4; bp	Washing	1500
Strathae	2; bp	Washing	400
Travistock	2; bp	Washing	1200
Van Dyks Drift	2; bp, sm	Washing	7528
Witbank Cons.	2, 4; bp	Washing	1365
Woestalleen	2; sm	Washing	540

sm = strip mining
bp = bord-and-pillar mining
HMS = heavy medium separation
pe = pillar extraction
- = no data available

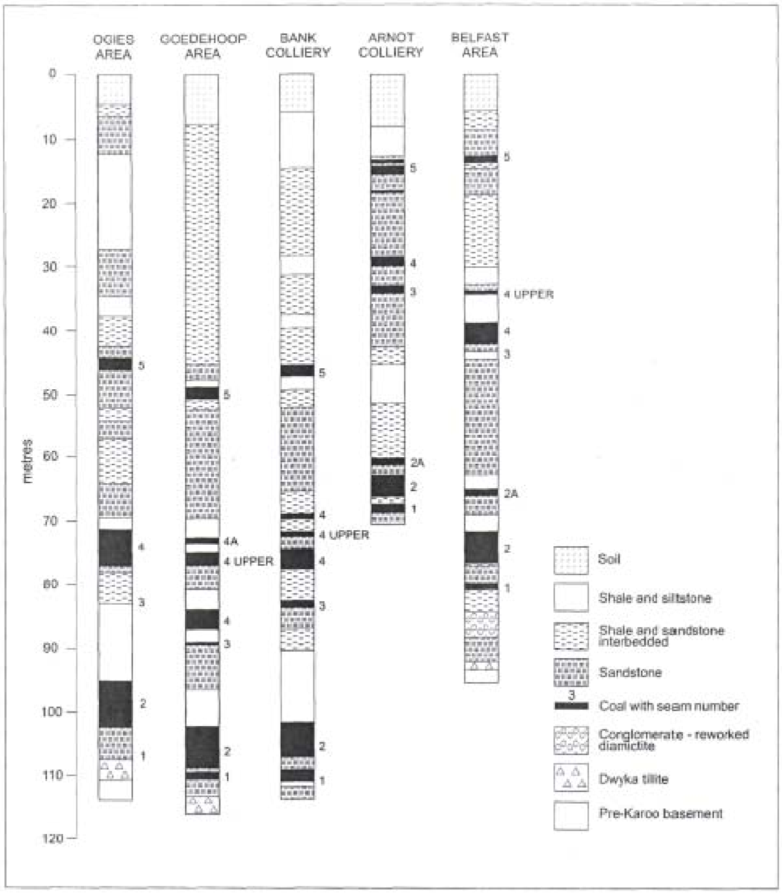


Figure 15. Typical stratigraphic columns in the Witbank Coalfield (simplified after Smith and Whittaker, 1986; in Snyman, 1998)

Table 5. Typical Analyses (Air Dry) : Witbank Coalfield (adapted from Smith and Whittaker, 1986; in Snyman 1998).

	% $H_2$0	**% Ash**	**% VM**	**CV MJ/Kg**	**RD**	**Yield**	**% $H_2$0**	**% Ash**	**% VM**	**CV MJ/Kg**	**S.I.**	**Roga index**
No. 1 Seam												
Witbank area	1.7	25.4	21	24	1.6	38.2	2	9.7	25.2	29.1		
No. 2 Seam												
Ogies area												
Top bench 0.97m	5.6	27.5	20.7	21.1	-	-	-	-	-	-		
Middle bench 0.47m	5.3	23.3	27.5	21.2	1.6	65.5	5.7	14.7	23.6	25.3		
Bottom bench 5.47m	3.7	23.5	23.5	22.4	1.6	64.6	4.5	13.2	26.8	26.3		
No. 2 seam												
Witbank area												
Bench 5 1.00m	1.7	26.6	18.4	20.2	1.6	57.8	2.4	11.5	26.8	29.3	1.5	22
Bench 4 1.96m	2.3	19.2	20.4	25.5	1.6	82.3	2.4	15.8	21.5	26.9	1	0
Bench 3 0.33m	2.1	8.3	27.7	20.6	1.6	98	2.1	7.8	27.9	30.6	1.5	22
Bench 2 1.24m	1.9	18.2	21.3	26.6	1.6	83.1	1.9	14.2	21.8	28.2	1	0
Bench 1 1.26m	1.9	9.1	33.8	30.8	1.6	95.8	1.9	7.7	34.4	31.2	4	62
No. 4 Seam												
Witbank area	2.6	27.6	20.7	22.2	1.6	62.5	2.5	17	22.4	26.1		
No. 4 Seam												
Ogies area	3.8	30.3	22.7	19.9	1.6	62.3	3.9	14.4	27.5	26.5		
No. 5 Seam												
Witbank area	2.5	13.1	32	28.7	1.5	88.7	2.5	9.8	33.4	30	2.5	45

Table 6. Analyses Of Product Samples From Individual Seams, Witbank Coalfield 1990) (after Boshoff *et al.* 1997; in Snyman, 1998) (*PSS = Power Station Smalls).

	Product	**Maceral analysis %**				**% R_0 V_{rand}**	**CV (MJ/Kg)**	**% H20**	**% Ash**	**% VM**	**% S**	**Sw. index**
		V	**E**	**RSF**	**I**							
No. 1 Seam Blackstream (dormant 1997)	Large nut	16	12	33	39	0.59	25.4	3.8	18.5	26.1	0.4	0
Mavela	nut	226	11	20	43	0.64	27.7	2.5	16	27.8	0.6	1
No. 2 Seam Bank	PSS	13	2	35	50	0.68	26.8	2.7	15.4	23.9	0.4	0
Bank	Low ash	37	3	29	31	0.74	30.4	2.6	7.3	28.7	0.3	1
Blackstream (dormant 1997)	Large nut	36	4	21	39	0.6	27.6	4.4	12.1	28.8	0.6	0
Greenside	Mean of 4 products	19	3	32	46	0.7	27.5	2.1	15.2	23.1	0.6	1
Greenside	Low ash	56	4	12	28	0.71	30.9	2	7.3	33.1	0.4	3
Mavela	Mean of 4 products	11	3	32	54	0.78	24.3	3	22.6	20.6	0.6	0
No. 5 Seam Bank	Mean of 3 products	62	6	11	22	0.7	29.3	3.2	11.6	31.4	0.6	2
Greenside	+6mm	50	4	19	27	0.7	28.2	2.4	13.8	32.1	0.4	1

Table 7. Variation In Properties Of Coal Products (Air-Dry Basis): Witbank Coalfield (based on data from Boshoff *et al.*, 1997; in Snyman, 1998).

CV	class interval MJ/Kg	18-20	20-22	22-24	24-26	26-28	28-30	30-32
	% frequency	0.7	0.7					3.5
Ash	class interval MJ/Kg	5-10	10-15	15-20	20-25	25-30	30-35	
	% frequency	12.5	50.7	26.4	8.3	1.4	0.7	
Volatiles	class interval MJ/Kg	20-25	25-30	30-35				
	% frequency	29.2	29.2	59.7				
Intertinite (excluding reactive semi-fusanite)	class interval MJ/Kg	20-30	30-40	40-50	50-60			
	% frequency	10.4	42.5	34.9	12.2			
Reactive semi-fusanite	class interval MJ/Kg	0-10	10-20	20-30	30-40			
	% frequency	0.9	20.4	53.7	25			
R0Vrand	class interval MJ/Kg	0.5-0.59	0.6-0.69	0.7-0.79				
		12.1	55.2	32.7				

4.6 Coal resources and reserves

"*Coal is the most abundant source of fossil fuel energy in the world, considerably exceeding known reserves of oil and gas*" (Anglo American, 2009).

Fossil fuels are non-renewable resources which exist in their unique form in what is considered "fixed stock of reserves". Once extracted, these resources cannot be renewed. Coal is an example of a non-renewable resource as it is formed by specific geological processes over millions of years. The value of non-renewable resources is considered to be variable in terms of chemical properties, physical properties and costs of extraction (which arise from differences in accessibility, locality, quality and other externalities) (Perman *et al.* 1999).

The South African Code For The Reporting Of Exploration Results, Mineral Resources And Mineral Reserves (SAMREC) Code sets out minimum standards, recommendations and guidelines for Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves in South Africa. The first version of the SAMREC Code was issued in March 2000 and adopted by the Johannesburg Stock Exchange (JSE) in their Listings Requirements later that same year. The Code was subsequently revised in 2007 to enhance specific provisions for the reporting of coal and diamonds. The Code does not apply to oil, gas or water.

The SAMREC Code was drawn up by the Working Group of The SAMREC/SAMVAL Committee (the SSC Committee) under the joint auspices of the Southern African Institute of Mining and Metallurgy (SAIMM) and the Geological Society of South Africa (GSSA).
The SSC consists of representatives of

- the SAIMM,
- the GSSA,
- the South African Council for Natural Scientific Professions (SACNASP),
- the Geostatistical Association of South Africa (GASA),
- the South African Council for Professional Land Surveyors and Technical Surveyors (PLATO),

- the Association of Law Societies of South Africa,
- the General Council of the Bar of South Africa,
- the Department of Mineral Resources (DMR),
- the JSE Limited (JSE),
- the Council for Geoscience,
- the South African Council of Banks,
- the Minerals Bureau,
- the Chamber of Mines of South Africa (CoM),
- and the University of the Witwatersrand.

The Code should be applied with the principles of **Materiality, Transparency** and **Competency.**

Materiality in that a Public Report should contain _all_ the relevant information that investors and their professional advisors would reasonably require, and expect to find, for the purpose of making a reasoned and balanced judgement regarding the Exploration Results, Mineral Resources and Mineral Reserves being reported on.

Transparency in that the reader of a Public Report must be provided with sufficient information, which must be presented clearly and unambiguously, in order to understand the report and not be misled.

Competency in that the Public Report must be based on work that is the responsibility of suitably qualified and experienced persons who are subject to an enforceable Professional Code of Ethics.

Section 21 of the SAMREC Code states that "***A 'Mineral Resource'*** *is a concentration or occurrence of material of economic interest in or on the earth's crust in such form, quality and quantity that there are reasonable and realistic prospects for eventual economic extraction*". Characteristics of a mineral resource are known (for example continuity, grade and location) or can be estimated from specific evidence (including sampling and/or information derived from a suitably constrained geological model). Mineral resources are subdivided in order of increasing confident into *Inferred, Indicated* or *Measured categories* and are reported as such.

Coal is a mineral resource which must comply with the reporting standards of the SAMREC Code. The framework reflecting different levels of geoscientific confidence and different degrees of technical and economic evaluation for classifying tonnage and grade estimates is shown in Figure 16. Other relevant disciplines may provide input to geoscientific information in order to estimate Mineral Resources.

The Modifying Factors affecting extraction are considered when Indicated and Measured Mineral Resources (shown within the dashed outline in Figure 16) modified from Mineral Reserves. 'Modifying Factors' are those factors such as economic, environmental, governmental, legal, social, marketing, metallurgical and mining considerations.

Measured Mineral Resources may convert to either

- Proved Mineral Reserves or
- Probable Mineral Reserves if there are uncertainties associated with modifying factors that are taken into account in the conversion from Mineral Resources to Mineral Reserves. This relationship is demonstrated by the broken arrow in Figure 16.

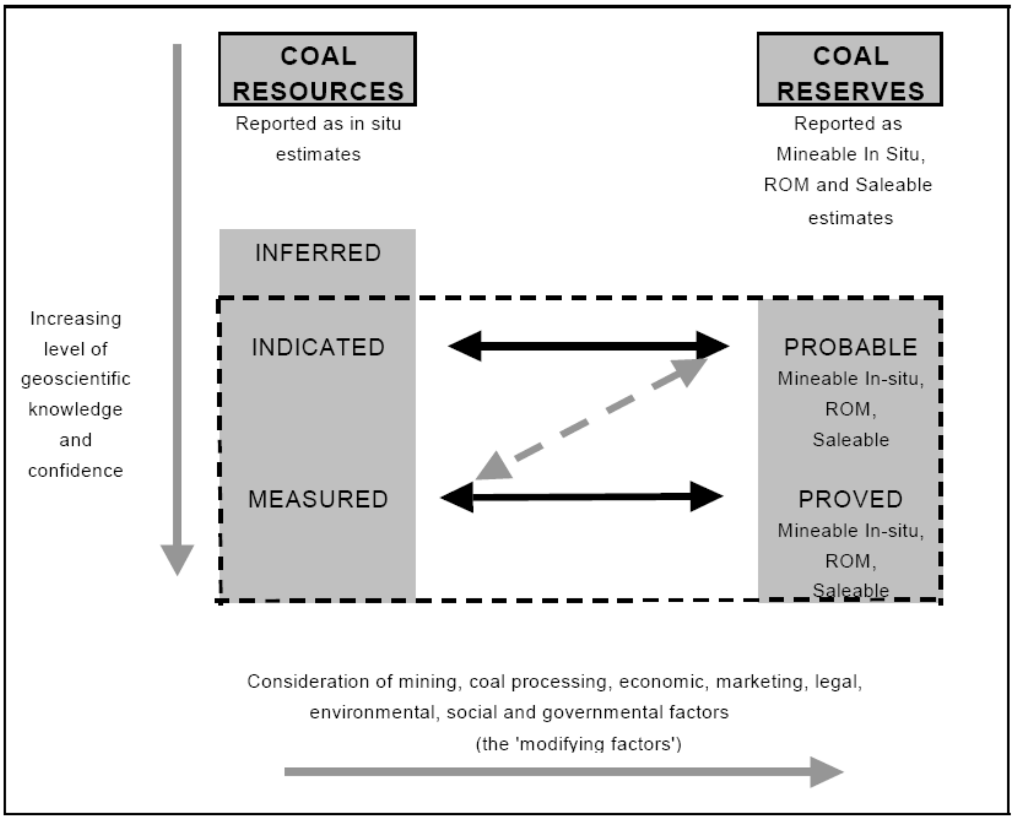


Figure 16. Relationship between Coal Resources and Coal Reserves.

The SAMREC Code establishes standardised reporting terminology. Provisions for the reporting of coal have specifically been included.

Section 44 states that "*an '**Inferred Coal Resource**' is that part of a Coal Resource for which volume or tonnage and coal quality can be estimated only with a low level of confidence*". Information is gathered from outcrops, trenches, pits, workings and/or drill-holes using relevant sampling methods and contributes to the overall geological evidence for the resource. In contrast *an '**Indicated Coal Resource**' (*Section 45) "*is that part of a Coal Resource for which tonnage, densities, shape, physical characteristics and coal quality can be estimated with a moderate level of confidence*". It is based on information from exploration, sampling and testing of material gathered from outcrops, trenches, pits, workings and/or drill holes. Physical continuity is confirmed by locations of the samples. It is assumed that the locations are spaced closely enough to establish the continuity of the coal quality.

"*A* ***'Measured Coal Resource'*** (Section 46 *is that part of a Coal Resource for which tonnage, densities, shape, physical characteristics and coal quality can be estimated with a high level of confidence"*. Detailed and reliable information gathered from exploration, sampling and testing of material obtained from outcrops, trenches, pits, workings and/or drill holes forms the basis for the improved level of confidence. Continuity (of both the coal quality and physical occurrence) is verified by suitably located sample sites.

Section 49 holds that *"a* ***'Mineable In Situ Coal Reserve'*** *is the tonnage and coal quality, at specified moisture content, contained in coal seams, or sections of seams, that are proposed for mining, adjusted by the application of the geological loss factors.* Detailed or conceptual mine planning must be derivable from the information and said planning must have commenced. Section 49 affirms that the assessments at the time of reporting should reasonably justify extraction of the coal. In addition to quoting the estimates separately for underground and surface extraction of the *Mineable In Situ Coal Reserve*, an framework of the proposed mining methods must be furnished. In order of increasing *confidence Mineable In Situ Coal Reserves* are subdivided into the categories of *Probable Mineable In Situ Coal Reserve* and *Proved Mineable In Situ Coal Reserve*.

"The tonnage and coal quality of Mineable In Situ Coal Reserves that are expected after all geological losses, mining losses, mining dilution, contamination and moisture-content factors have been applied" constitute ***'Run of Mine' (ROM) Coal Reserves***. Section 50 also states that the assessments at the time of reporting should reasonably justify extraction of the coal. In order of increasing confidence ROM Coal Reserves are subdivided into Probable ROM Coal Reserves and Proved ROM Coal Reserves. The SAMREC Code specifies that ROM Coal Reserves must be reported.

To this end, no ***current*** Resource and Reserve estimations (i.e. post 2007) are available for South Africa as a whole *or* for the Witbank Coalfield as a whole. Mining Weekly (2010) report that Eskom and the Department of Mineral Resources are to jointly fund The Coal Resource and Reserve Project: a project which intends to update information on South Africa's coal resources and reserves. The project is to be carried out by the Council for Geoscience and will be undertaken in conjunction with the South African Coal Roadmap (SACRM). SACRM is driven by the Fossil Fuel Foundation and with the pledged support of government and the local coal industry aims to evaluate alternatives for the enhancement of economic opportunities and development of South Africa’s coal industry.

The DME (2010) declares that it is imperative to re-evaluate the national coal resource and reserve base in order to facilitate the formation of an efficient energy policy. This sentiment is as a direct result of South Africa’s dependency on coal and the uncertainty regarding the extent of the deposits which are economically feasible to mine. Previous reports do however contain estimates - the Bredell report (1987) estimated South Africa's coal reserves as 55-billion tonnes and 115 billion tonnes of resources (DME, 2010). Snyman (1998) cites Daniel (1992) in stating that over 70% of the known coal resources of Africa are in South Africa and Prevost (1997) in stating that 55.3 Gt (gigatons) of the world’s recoverable hard coal reserves are found in South Africa. The Witbank Coalfield is said to hold 13.4 percent of the total 121Gt *in situ* coal resource and 22.5 percent of the total 55Gt recoverable reserves (Bredell, 1987; Snyman, 1998).

5 Economic and Social Implications of Mining

Coal plays a vital role in South Africa's domestic economy (Snyman, 1998) and has been irrefutably linked with the economic development of the country (McCarthy and Pretorious, 2009).

The DME (2008) reveals that the coal mining industry employed 12.2 percent of the mining industry's total labour force in 2007 (compared to 37.6 percent in platinum group metals [PGM's]; 34.1 percent in the gold mining industry; 4 percent in the diamond mining industry and 12 percent of the mining industry's total labour force mining other minerals). Owing to the higher degree of mechanisation in the coal sector, 17.2 percent of total remuneration for the mining industry was attributed to coal (compared to 36.5 percent for the PGM industry and 39.2 percent for the gold industry).

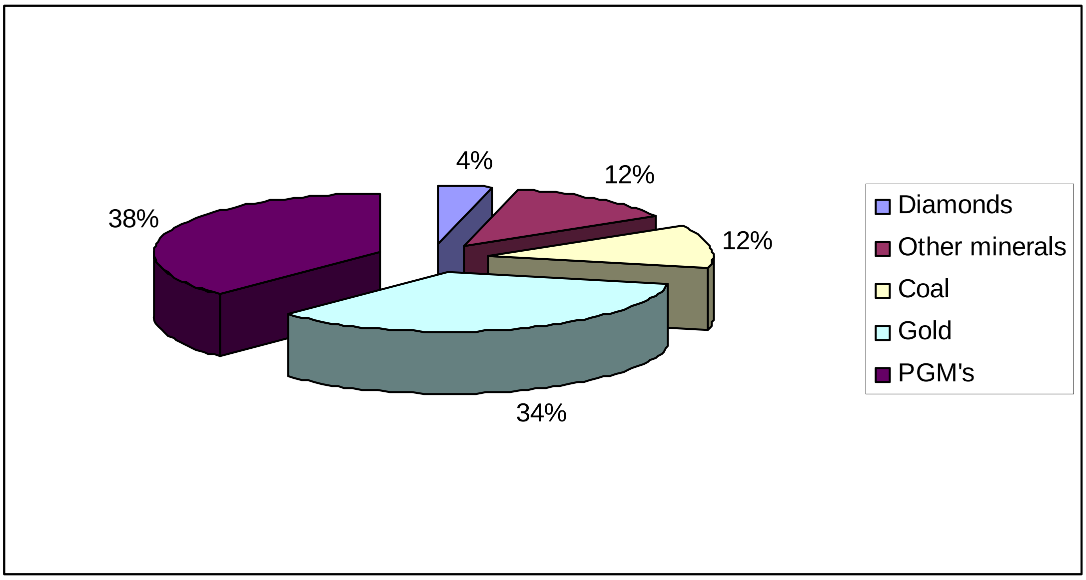


Figure 17. South Africa's Mining Industry: Employment by Sector, 2007 (DME, 2008).

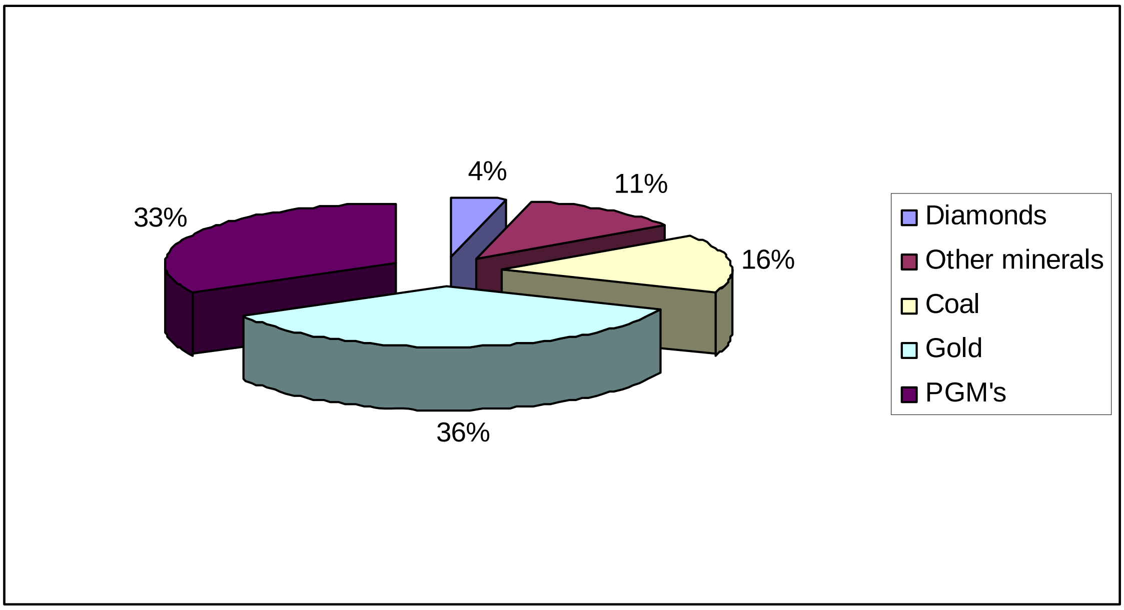


Figure 18. South Africa's Mining Industry: Remuneration by Sector, 2007 (DME, 2008).

Chelin (2000) describes that costs incurred by mining are two-fold: production costs (capital, labour and material inputs etc.) and 'externalities' (no actual payment is borne by the producer but society in general bears a loss - for example, through environmental pollution and degradation).

The Brundtland Report (1987) voices that "*the concept of sustainable development does imply limits – not absolute limits but limitations imposed by the present state of technology and social organisation on environmental resources…*"

A natural resource is said to have an optimum level of use which can be considered economically by weighing the marginal social benefits against the marginal social costs. The net value to society of acquiring goods and services is sufficient to warrant the additional unit of pollution generated to acquire the goods and services. Generally the transaction is viable if marginal social benefits (MSB) = marginal social costs (MSC). Shown graphically in Figure 19 - the optimum level, P_o, occurs at the intersect of the positive slope of the MSC (implying an increase in the social costs incurred with addition of each unit of pollution) and the negative slope of the MSB (suggesting that the goods and services with lower social benefits per unit of pollution are producible at the permitted, increasing levels of pollution) (Tilton, 1994; Chelin, 2000).

By considering cost against pollution shown in Figure 20, Chelin (2000) asserts that the relationship appears to be inverse from that in Figure 19 such that MSB and MSC do not seem to be in opposition with each other and P_0 represents a critical value rather than an optimal value.

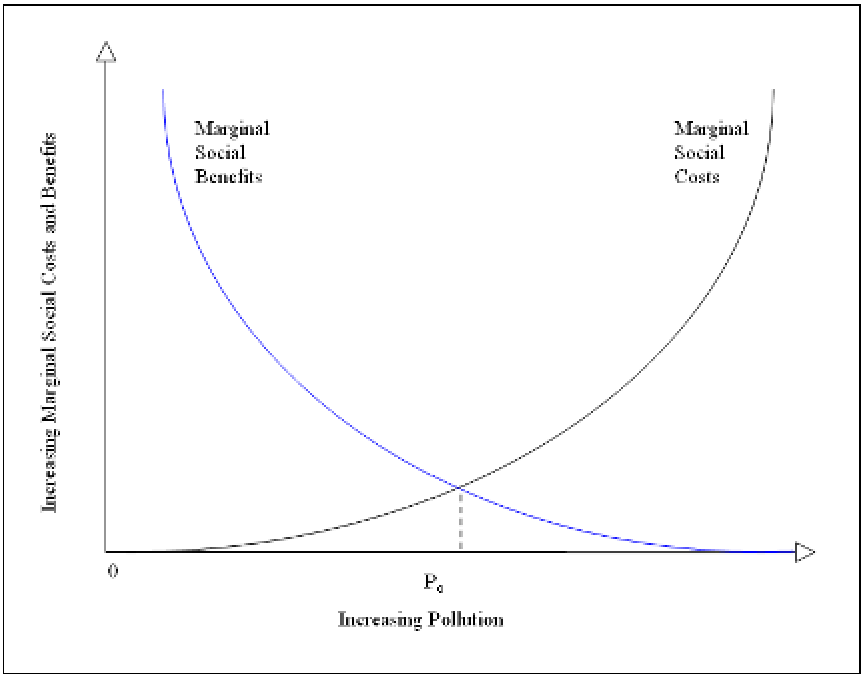


Figure 19. A perceived relationship between marginal social benefits and marginal social cost of pollution (and P_0 as optimum level of pollution) (modified after Chelin, 2000).

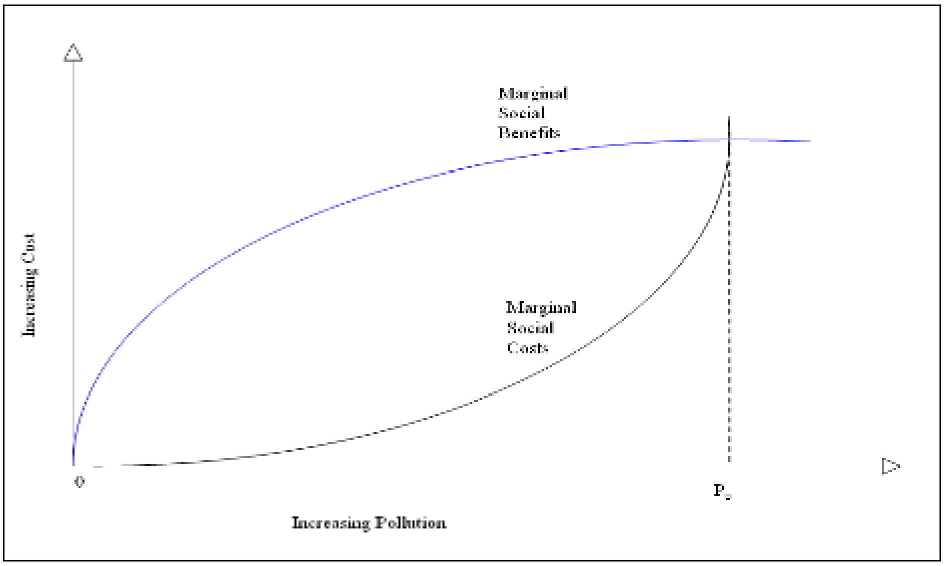


Figure 20. An alternate perception on the relationship between marginal social benefits (MSB) and marginal social cost (MSC) of pollution (modified after Chelin, 2000).

Relationship Between the Natural Environment and Economy

The South African economy was largely established by the mining industry, and mining continues to play an essential role in economic stability (Geldenhuis and Harpley, 1989). Mining, by its very nature, tends to generate pollution and there is a growing cost implication of the safe disposal of [industrial and domestic] wastes which arise during mining. Geldenhuis and Harpley (1989) intimate that the magnitude of the cost is affected by the geology and hydrogeology, the mineralogy of the ore initially mined as well as the climate and microbiology of the waste disposal site.

A schematic representation of the relationships between the economy and the environment is shown in (Figure 21). Perman and others (1999) expand on the economy-environment interdependence of economic activity: the energy in and -out arrows pass through three boxes (representing the three other functions that environment performs in relation to economic activity). The heavy, black-lined box represents a fourth function of the environment (i.e. make available life-support services and other services which keep the entire functioning system intact). The four functions interact with one another (shown by the intersection o the three boxes with the heavy, black-lined box).

Natural resources are used during economic activity located within the environment and involving production and consumption (shown by the solid black lines inside the heavy, lined box). Not all of production is consumed. Some of the output from production is added to the man-made, reproducible capital stock, the service of services which are used together with labour services, in production. Figure 21 shows production using a third type of input - resources extracted from the environment. Waste is generated into the environment during production and consumption activities. Consumption also uses a direct flow of services from the environment to the individuals of a group / populace without intermediate production activities.

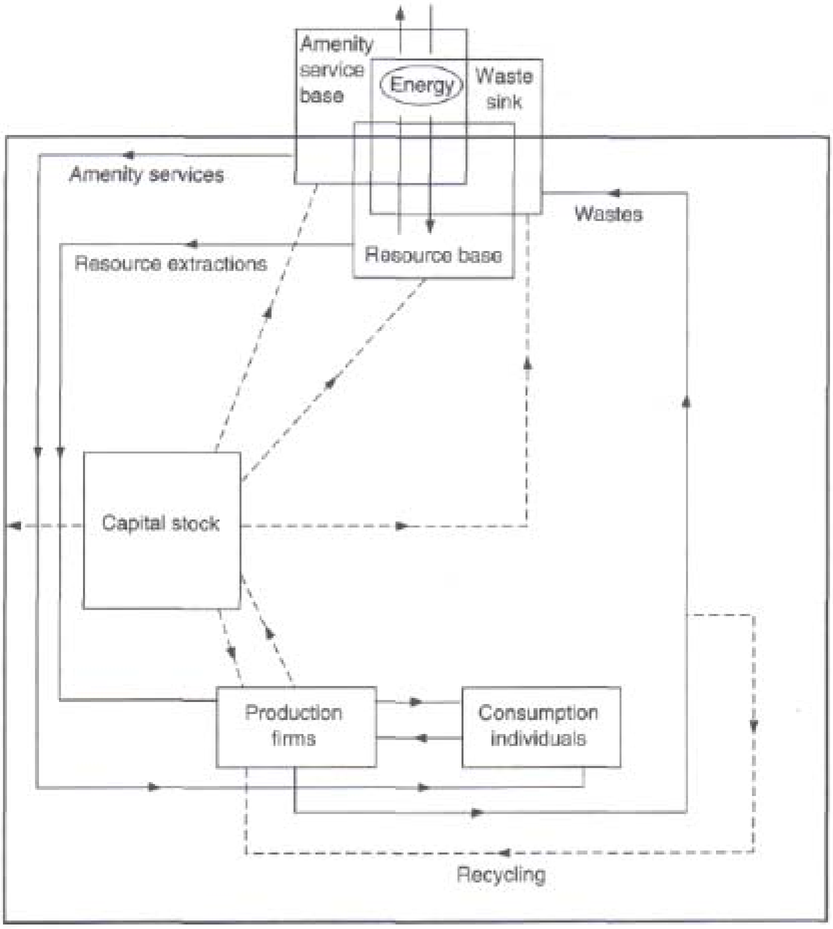


Figure 21. Economic activity in the natural environment (Perman *et al.* 1999).

6 Capital and Opportunities for Continuation of Capital

6.1 Mineral Resources as the Main Source of Capital

The phenomenon of exploiting mineral resources but not deriving the fullest benefit from the resources is idiomatically referred to as “The Dutch Disease”.

Symptoms include a stagnation of exports and an overvalued currency (which ultimately keeps the economy in the primary sector i.e. mining), producers adopting a ‘rent-seeking’ type of behaviour, complacency regarding educating the workforce as a result of the rent stream from natural resources (making service and manufacturing sectors of the economy increasingly uncompetitive), a false sense of security derived from the abundance of natural resources (which facilitates the devaluing of social capital, loss of bureaucratic efficiency and unfriendly economic management which thus retards growth of secondary and tertiary industries) and a spendthrift approach as saving is considered difficult (Callaghan, 2009).

A number of options exist to avoid “the Dutch disease” – first and foremost is to beneficiate mined natural resources with the purpose of value addition. Figure 22 shows the value chain and the components which ultimately render the finished product “valuable”. The reality of the situation is that once a resource is mined and the raw material sold, the party who beneficiates and processes the resource into a saleable or useable product gains an almost superlative advantage. The miner is then at the mercy of beneficiator / processor and has to buy the product at seemingly inflated prices. Because beneficiation is largely a secondary industry, the economy will evade currency volatility as secondary (and eventually tertiary) industries strengthen. The critical issue is to find the balance where value and reward are equitable (Callaghan, 2009).

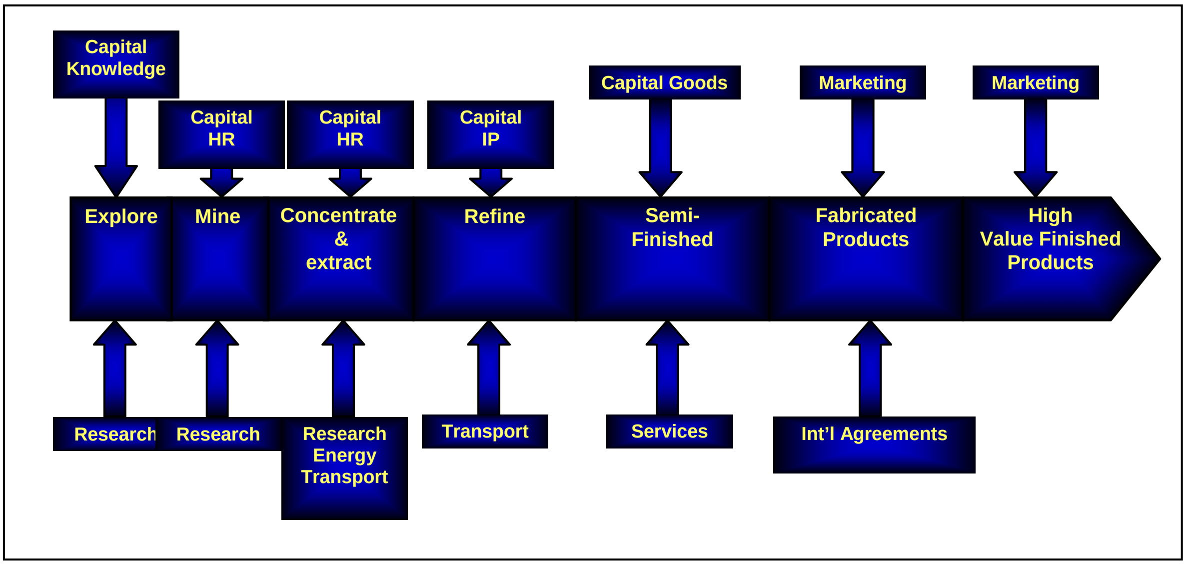


Figure 22. Components of the value chain (after Callaghan, 2009) (HR = human resources, IP = intellectual property).

Other remedies put forward by Callaghan (2009) include formulating a windfall tax on natural resources; ensuring availability of resources (competitively priced) as to entice downstream industries to beneficiate; developing a strong social fabric (through leadership that is transparent and unambiguous and rejects any form of corruption); providing a sound education for all citizens; exercising good financial and management habits (e.g. decreasing foreign debt, investing wisely in education, service delivery and logistical support); nurturing the socio-economic fabric of a society through trust and a sense of mutual support and dependence and fostering the desire for value addition as driven by the State and industry through open communication between the two parties.

6.2 Opportunities for the beneficiation of coal and the challenge of sustainability

There is little opportunity for the beneficiation of coal into products further than those described in Chapter 4.2; however, the re-investment of income into viable, alternative sources of capital is of paramount importance.

The Brundtland Report (1987) forged the way in identifying and defining ‘sustainable development’. In order to continue development in such a way that it meets the needs of the present generation without compromising the ability of future generations to meet their own needs the consumption rate of resources should be optimised; the waste generated should be reduced and human, natural, social, economic and environmental capital should be maintained. This is illustrated in Figure 23.

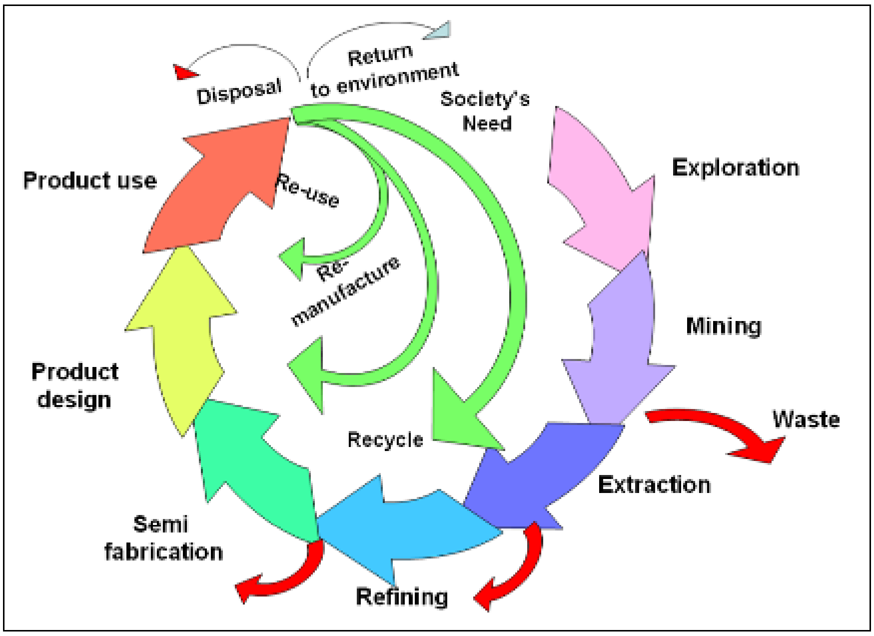


Figure 23. The many areas (with regard to non-renewable, natural resources) challenging sustainability (Callaghan, 2009).

6.3 Sustainable Capital

Coal is a non-renewable, natural resource with limited stock. Once the coal reserves have been depleted, there will be a metaphorical 'nothing left' – hence the dire need for re-investment of capital (i.e. channel portions of the income generated by coal mining and sales to acquiring/boosting other sources of assets).

Conservation of assets can be achieved in a number of ways - alternatives cited in Callaghan (2009) include reproducible, intellectual and human capital. Reproducible capital encompasses assets such as plant, equipment, buildings, infrastructure (such as the erection of water treatment facilities, schools or hospitals – ideally in/near mining communities). Intellectual capital encompasses assets such as "useful knowledge" (disembodied skills such as the development of state-of-the-art metallurgical techniques for the recovery of the natural resource from wastes). Human capital encompasses assets such as skills (training and educating individuals).

Andrews-Speed and Rogers (1999) express that governments which fail to impose transparent, detailed and equitable financial obligations and incentives as part of a regime for mine rehabilitation will 'lose' in the long term – through the environmental degradation or failure to attract investors.

6.3.1 The Key Development Benefit of Mining is Revenue

"Potentially, the most important contribution from mineral extraction is the rise in host-country income" (UNCTAD, 2007).

The Southern Africa Resource Watch (SARW) and others (2009) critique the mining taxation regime in Africa. The report revolves around the central argument that African governments were unsuccessful in optimising mining tax revenue due to them during the boom in mineral prices (spanning c2003 to 2008). The two main reasons cited are that too many tax subsidies and concessions are granted to mining companies operating in Africa and that there is a high incidence of tax avoidance by mining companies. Tax avoidance is carried out measures such as corporate mergers and acquisitions, secret mining contracts and various other '*creative'* accounting mechanisms.

Mineral extraction is described as being an 'enclave' economic activity - mining equipment, financial, technical and managerial services (needed to run the mines) are imported by foreign mining companies into African mineral-rich countries. Very few African firms are considered to be able to provide these equipment and services (SARW *et al.*, 2009). Once extracted, raw ore is exported for further refinement or processing elsewhere. Very little forward or backward linkages into the local or even national economy are created by industrial mining companies thereby failing to realise opportunities to stimulate job creation and further development of the private sector. Considering the capital intensive nature of industrial mining, companies create very few jobs relative to the abundant labour supply in mineral-rich African countries.

The consensus (as reported by SARW *et al.*, 2009) among the International Monetary Fund (IMF), the United Nations Economic Commission for Africa (UNECA) and the United Nations Conference on Trade and Development (UNCTAD) is that the "*paramount development benefit of mining in Africa is the potential to generate public revenue through a transparent tax and budget system*". In contrast, the World Bank maintains that the commitment to sustainable development as part of the bottom line of multinational mining companies, then the transfer of technology, skills and capital from mining may transform the impact of mining on economic and social development. Legal mining frameworks linking mining to local community and wider economic development are not considered to be explicit (SARW *et al.*, 2009); therefore the key instrument through which governments optimise development in the foreseeable future from mining is revenue collected via taxation.

6.3.2 Collecting a Fair Share of Mining Rent

Demand for local, small- and micro-enterprises servicing the mining community may be created from the income from mining employment; but this is viewed as negligible in view of the extensive economic transformation desired by the nation. Crucially, extensive risks to the environment and livelihoods of communities living near mining areas are associated with industrial mining – which generally leads mining activity to *cause* poverty rather than *reduce* it (SARW *et al.*, 2009).

6.3.3 Reaction to Mining Tax Reforms

Given the risky nature of mining, mining companies believe they should be entitled to special tax exemptions. Crashing commodity prices and the lack of availability of finance for new mining investment due to the international financial crisis are often cited by mining companies as reasons why government should grant tax concessions (SARW *et al.*, 2009). It comes as no surprise then, that mining companies are largely opposed to changes proposed or made to mining tax regimes.

6.4 An Example of Conservation of Capital in the Coal Mining Industry

Stenzel (2009) presents that the excess water produced by many mining operations can be reclaimed and re-used. The Emalahleni Water Reclamation Project (EWRP) is the first such large-scale project.

Anglo Coal South Africa, BHP Billiton Energy Coal South Africa (BECSA) and the Emalahleni Local Municipality (LM) have jointly undertaken this public-private partnership. The water reclamation plant is situated in Witbank Coalfields and was commissioned in 2007 (following more than a decade of research and development) (World Coal Institute [WCI], 2008) .

The plant desalinates rising groundwater from a number of collieries and mines therefore preventing the polluted water from decanting back into the local river system and environment. The desalination process is also said to alleviate serious operational and safety challenges, the WCI (2008) does not explain what these challenges are. The EWRP conversion of contaminated mine water into high quality portable water is at a rate of approximately 23 ML/day – of which 18ML are pumped directly into the municipality's reservoirs (as part of the bulk supply agreement with the Emalahleni LM). Collieries and service departments nearby receive water for domestic- and mining activities, rendering the operations self-sufficient (in terms of their water requirements) and by so doing, ease the demand on the water-stressed municipality. The WCI (2008) also comments the provincial government is on a stronger foot to meet its Millennium Development target in ensuring that no household goes without a "*potable, reliable and predictable water supply*". The plant operates at a 99% water recovery rate; the ultimate goal is for the plant to become a zero waste facility through the 100% utilisation of its by-product.

A number of job opportunities have been created by the project during the construction phase of the plant as well as running the plant's day-to-day operations. The WCI (2008) states that 91% of the workforce was recruited from surrounding communities (in an area where unemployment is prevalent) and that Historically Disadvantaged South Africans comprise 86% of the workforce.

Additionally, research has been initiated to investigate the use of gypsum produced by the plant for production of suitable building and mining products. A three-bedroom house was constructed - almost entirely out of gypsum-based building products. This is encouraging because the 'boom' in the construction industry has resulted in a strained supply of conventional building resources (e.g. brick and cement) which has in turn caused an increase in the cost of housing – a negative factor for the target to eliminate housing backlog in South Africa.

The plant received recognition in 2007 for their contribution to the environment and sustainability through the Nedbank Capital's Green Mining Award for sustainability as well as the Mail and Guardian's Greening the Future Awards (for water care and improving business performance through innovative environmental strategies) (WCI, 2008). It is clear that the plant has created a valuable asset from a major liability.

The project illustrates that long-term sustainable projects that benefit the local community and economy can be achieved (Mining Mirror, 2009) through public-private co-operation but require proper planning and execution.

7 Legal Obligation to Secure Protection of the Environment

Environmental matters within the mining area as well as those impacts which migrate outside the mining area (i.e. water pollution) are dealt with by the Mineral Regulation Branch in terms of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA) (Act 28 of 2002), through the Environmental Management Plan or Programme process by the Mine Health and Safety Inspectorate. The Mining Mirror (2009) reports that all new operations are required to apply for a new mining right and existing operations are to apply for a conversation right in adherence with the MPRDA.

To that extent, it is promulgated in the MPRDA Section 5 (4) (a) that *“no person may prospect for or remove, mine, conduct technical co-operation operations, reconnaissance operations, explore for and produce any mineral or petroleum or commence with any work incidental thereto on any area without - an approved environmental management programme or approved environmental management plan, as the case may be”*.

The purpose of Environmental Management Plan (EMP) as described in Section 12 National Environment Management Act, 1998 (NEMA) (Act 107 of 1998) is to “*secure the protection of the environment”* and “*prevent unreasonable actions by provinces in respect of the environment that are prejudicial to the economic or health interests of other provinces or the country”*. It is thus promulgated in the MPRDA Section 37 (2) that “*any prospecting or mining operation must be conducted in accordance with generally accepted principles of sustainable development by integrating social, economic and environmental factors into the planning and implementation of prospecting and mining projects in order to ensure that exploitation of mineral resources serves present and future generations*”.

It has also been enacted that directors of companies may be held personally liable for environmental degradation through the MPRDA Section 38 (1) (e) which states that *“the holder of a reconnaissance permission, prospecting right, mining right, mining* *permit or retention permit is responsible for any environmental damage, pollution or ecological degradation as a result of his or her reconnaissance prospecting or mining operations and which may occur inside and outside the boundaries of the area to which such right, permit or permission relates"* and Section 38 (2) which declares that "*notwithstanding the Companies Act, 1973 (Act No. 61 of 1973), or the Close Corporations Act, 1984 (Act No. 69 of 1984), the directors of a company or members of a close corporation are jointly and severally liable for any unacceptable negative impact on the environment, including damage, degradation or pollution advertently or inadvertently caused by the company or close corporation which they represent or represented*". On application for a mining right the government, through guidelines and formulae, may calculate the size of the trust fund required (per hectare of disturbed land) to be set aside for rehabilitation once the mine is closed (Mining Mirror, 2009).

The Constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996) also confers certain rights in regard to the environment. Section 24 (a) provides that "*Everyone has the right to an environment that is not harmful to their health or well-being*"; and (b) "*to have an environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that -*

- *Prevent pollution and ecological degradation;*
- *Promote conservation; and*
- *Secure ecologically sustainable development and use of natural resources while promoting justifiable social and economic development".*

The South African Government is bound by Section 8 to give effect to this right.

The Council for Scientific and Industrial Research (CSIR) (2010) set out the principles and importance of the National Water Act, 1998 (Act No 36 of 1998) (NWA) in their overview "A New Water Act for South Africa".

The overview describes that sustainability and equity are the cornerstones of the South African water policy. In order to support optimal and sustainable use – it is recognised that aquatic ecosystems need to be protected. Regarding the proposed strategy for sustainable resource utilisation: the NWA has two separate but interdependent components related to:

1. Protection of water resources. This is essential to ensure that current and future generations are supported and able to utilise resources;
2. Within the constraints set by the requirements for protection - water resources must be utilised in the most efficient and effective manner.

To meet the need to manage water resources on an ecosystem basis, as well as allowing a balance between long-term protection and short-term development needs an integrated resource protection approach was adopted (CSIR, 2010). The approach

1. Establishes measurable and verifiable resource quality objectives (RQOs) which define acceptable levels of protection for water resources. These RQOs have four critical components presented by the CSIR (2010) as
    - *a) Water quantity,*
    - *b) Requirements for water quality (chemical, physical, and biological characteristics of the water),*
    - *c) Requirements for habitat integrity, and*
    - d) *Requirements for biotic integrity (health, community structure and distribution).*
2. Imposes source-directed controls for waste discharge, impact generation and rehabilitation (viz. economic and regulatory instruments and self-regulation).

8 Management Policy in South Africa

Policy may be considered – in its narrowest sense - as a prudent course of action taken by government. Policy in modern era can be considered to extend to include a prudent course of action taken by government as well as industry and other stakeholders in terms of regulatory action, assessment procedures, protocols or best practice.

In instances where the prudent course of action is not immediately obvious - research and investigation is required to examine alternatives and to recommend the best way forward. Although research of this nature rarely provides definitive results, it does foster a deeper understanding of the issues concerned and provides a sound base of information to support good decision-making. Development and clarification of policy positions is achieved through policy research.

Wates (1993) identified the need for an efficient regulatory environment for the mining industry to remain competitive and indicated that opportunities exist for the mining industry to prioritise pollution control efforts. Furthermore, Wates (1993) propounded that a prescriptive approach to the regulatory programs designed to control the lowest common denominator is highly undesirable. Defined protocols for the establishment of closure objectives for mine residue deposits allows for the consistent application of best practice standards and the law– a desirable concept from the point of view of both the mining industry and the regulatory authority. At a workshop to prioritise mining related water research and technology transfer needs, Wates (1993) asserted that rehabilitation strategies for coal residue deposits require more urgent attention and, as such, it would be beneficial to the mining industry to pool information and consult international literature to establish broad-based guidelines for closure of coal residue deposits.

The DMR and DWA have, over time, addressed these needs and established Best Practice Guidelines which relate to distinct hazards related to specific minerals throughout the various stages of mining as well as closure and care thereafter.

8.1 Water Quality

Water is an excellent solvent and transport medium for particulates. It therefore tends to become contaminated – both by man-induced processes (i.e. mining, industrial development, effluent disposal etc.) and by natural processes (e.g. erosion, dissolution of salts geologically present in soils etc.). Substances which contaminate water are therefore plentiful. Hohls *et al.*, (2002) list these as:

i. Physical soil and clay particles as well as organic detritus from storm runoff
ii. Microorganisms (e.g. bacteria, parasites and viruses) from the environment, soil and animal and human wastes.
iii. Chemical constituents which can be subdivided into
    a) Major inorganic chemical salts (e.g. sodium, chloride, calcium, sulphate, etc.),
    b) Minor inorganic chemical salts (e.g. ammonia, fluoride, phosphate and iron, manganese, copper [trace metals] etc.) and
    c) Organic substances (e.g. pesticide residues)
iv. Radioactive substances (which under natural conditions usually occur only in minute concentrations).

The quality of water is equally important to the quantity of water available in any evaluation. The factors which determine whether or not the water is suitable for agricultural, domestic or industrial use include the biological, chemical and physical characteristics of the water. The array of chemical constituents often taken into consideration when assessing water fitness for use may be extensive (Table 6) and water quality objectives set by the Department of Water Affairs and Forestry vary per sector and intended use (Table 9). Natural variations of the number of major dissolved constituents is said to be fairly limited (Bell, 1998). Bell (1998) also states that the quality of the water which is percolated to the water table is a reflection of the quality of the water in the zone of saturation and the subsequent reactions that occur between the water and rock. The factors which influence the solute content include:

i. The original chemical quality of the water entering the zone of saturation,
ii. The distribution, solubility, exchange capacity and exchange selectivity of the minerals involved in the reaction,
iii. The porosity and permeability of the rocks.

The residence time of the water is of paramount importance - in this context – as it determines if there is sufficient time for the dissolution of minerals to proceed to the point at which the solution is in equilibrium with the reaction. The rate of groundwater movement (which is normally very slow beneath the water table) affects the residence time significantly.

Bowen (1980) mentions the major components of analysing groundwater quality. Expressing results of **chemical analyses** is done by comparing concentration of solutes in solution as **parts per million** (weight per solute compared with weight of solution) or **milligrams per litre** (weight of solute per volume of solution). **Electrical conductivity** makes use of Total Dissolved Solids (TDS) in the water by measuring electrical conductance of a sample (preferred over resistance measurements as resistance increases with salt content) and reported in mhos/cm. Water is considered brackish when TDS>1000ppm. Water **hardness** is a measure of the content of magnesium ad calcium and is typically expressed as the equivalent of calcium carbonate. Total hardness is measured in parts per million (ppm) and the ratios of Ca and Mg in equivalent weights. **Temperature** (in °C), colour (due to organic and mineral material in solution) and aroma are sometimes noted as part of physical analysis of groundwater. Minerals possess **ion exchange** abilities– usually involving cations – which take place when ions adsorbed on mineral grain surfaces are not the same as those in the groundwater. Eventually equilibrium will be reached and no further exchange will take place unless/until the environment is changed. Pathogenic **bacteria** are identified and colonies quantified when assessing safety and suitability of water.

Table 8. List of constituents considered when assessing fitness for use of water.

Algae
Aluminium
Ammonia
Arsenic
Asbestos
Atrazine
Cadmium
Calcium
Chloride
Chromium(VI)
Colour
Copper
Corrosion
Dissolved Organic Carbon
Fluoride
Indicator Organisms
Indicator Organisms (including Heterotrophic Bacteria, Total Coliforms, Faecal Coliforms, Coliphages, Enteric Viruses, Protozoan Parasites)
Iron
Lead
Magnesium
Manganese
Mercury
Nitrate
Odour
pH
Phenols
Potassium
Radioactivity
Selenium
Settleable Matter
Sodium
Sulphate
Trihalomethanes
Total Dissolved Solids
Total Hardness
Turbidity
Vanadium
Zinc

Major water quality problems stem from mining and other industrial activities (DWAF, 2004). Surface water nutrients are routinely monitored as well as other water quality variables. DWAF (2004) motivate that it is vital to protect the integrity of groundwater reserves as well as ensure good surface water quality. DWA consider numerous constituents when assessing the fitness for use. The NWA recognises four broad categories of water use. These regulate the use of water for:

1. Domestic purposes;
2. Industrial purposes;
3. Agricultural purposes; and
4. Recreational purposes.

The NWA considers **pollution to** mean *"the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it -*
(a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or (b) harmful or potentially harmful". The scope of harm or potential harm extends to the welfare of human beings as well as to the to the resource quality.

The water quality constituents relevant to domestic and irrigated agriculture water use in South Africa are shown in (Table 9). Hohls and others (2002) assert that industry is able to conduct the necessary treatment of the raw water for it to be suitable for their purposes (e.g. industries with specific water quality requirements) or has similar requirements to those of domestic and irrigated agriculture water users.

Table 9. Comparison of water quality objectives for domestic, industrial and agricultural use of water (DWAF, 1996[1,2,3]).

Water Quality Parameter	Target Water Quality Range – Domestic Use	Target Water Quality Range - Industrial	Target Water Quality Range – Agricultural (Irrigation)
Chloride	0 – 100 mg/L	0 - 20 mg/L	0 – 100 mg/L
Fluoride	0 - 1.0 mg/L	Not specified	0 - 2.0 mg/L
Nitrate + nitrite	0 – 6 mg/L	Not specified	Not specified
Phosphate	0 - 0.5 mg/L	Not specified	Not specified
Sodium	0 – 100 mg/L	Not specified	0 – 70 mg/L
Sulphate	0 – 200 mg/L	0 - 30 mg/L	Not specified
Total dissolved solids	0 – 450 mg/L	0 - 100 mg/L	0 - 40 mg/L
pH	6.0 - 9.0	7.0 - 8.0	6.5 - 8.4

The Council for Scientific and Industrial Research (CSIR) (2010) report that a Strategic Environmental Management Plan was commissioned by the Mpumalanga Provincial Government in 1998. this served as an input in plans for Mpumalanga-Maputo Development Corridor (MMDC). Ultimately, the aim of improving transportation and communication infrastructure is to promote development and economic growth along the corridor. The “unique landscape and natural attributes” of the province were also recognised as a potential to stimulate growth in the tourism sector. Increased trade opportunities are anticipated to develop small, medium and micro enterprises in surrounding areas.

The Provincial Government of Mpumalanga recognises that water is scarce but vital resource and – if ecological integrity and economic development are to be achieved – needs to be managed properly (DACE, 2003).

8.2 Best Practice Guidelines for Water Management of Coal Mine Residue Deposits

"Mining adversely affects water quality and poses a significant risk to South Africa's water resources" (DWAF, 2007). Hydrological and topographical characteristics of mining areas can be substantially changed by mining operations affecting evapo-transpiration, soil moisture, surface runoff and groundwater behaviour.

In order to maintain community and government support for mining projects (existing and future endeavours) the impacts on water resources must be managed in an acceptable manner throughout the life-of-mine and into post-closure, both on a local and on a regional scale. Consequently, sound management practices to prevent or minimise water pollution are fundamental for mining operations to be sustainable. A series of Best Practice Guidelines (BPGs) have been developed by the DWA for mines. These BPGs are in line with International Principles and Approaches towards sustainability (DWAF, 2007). The DWA defines a residue deposit as "*any dump, tailings dam, slimes dam, ash dump, waste rock dump, in-pit deposit and any other heap, pile or accumulation of residue"*. The influence of acid mine drainage occurs largely as a result of the presence of sulphides (described in Chapter 9.7) and as such the BPG for mine residue deposits (MRDs) will be considered here. Mine residue deposits are commonly also referred to as mine dumps, tailings dumps or tailings.

Structure of the Best Practice Guideline

Figure 24 shows the outline for the BPG with regard to mine residue types, disposal options and the life cycle phases. The life cycle phases include preliminary inputs, conceptualisation, planning, site investigations, design, commissioning, operation, decommissioning, closure and post-closure care. A robust assessment process to address the potential water management issues associated with a MRD over its complete life cycle is abided by– the main difference being the various types of MRDs and the disposal position is the particular impact pathways that apply to each (DWAF, 2007).

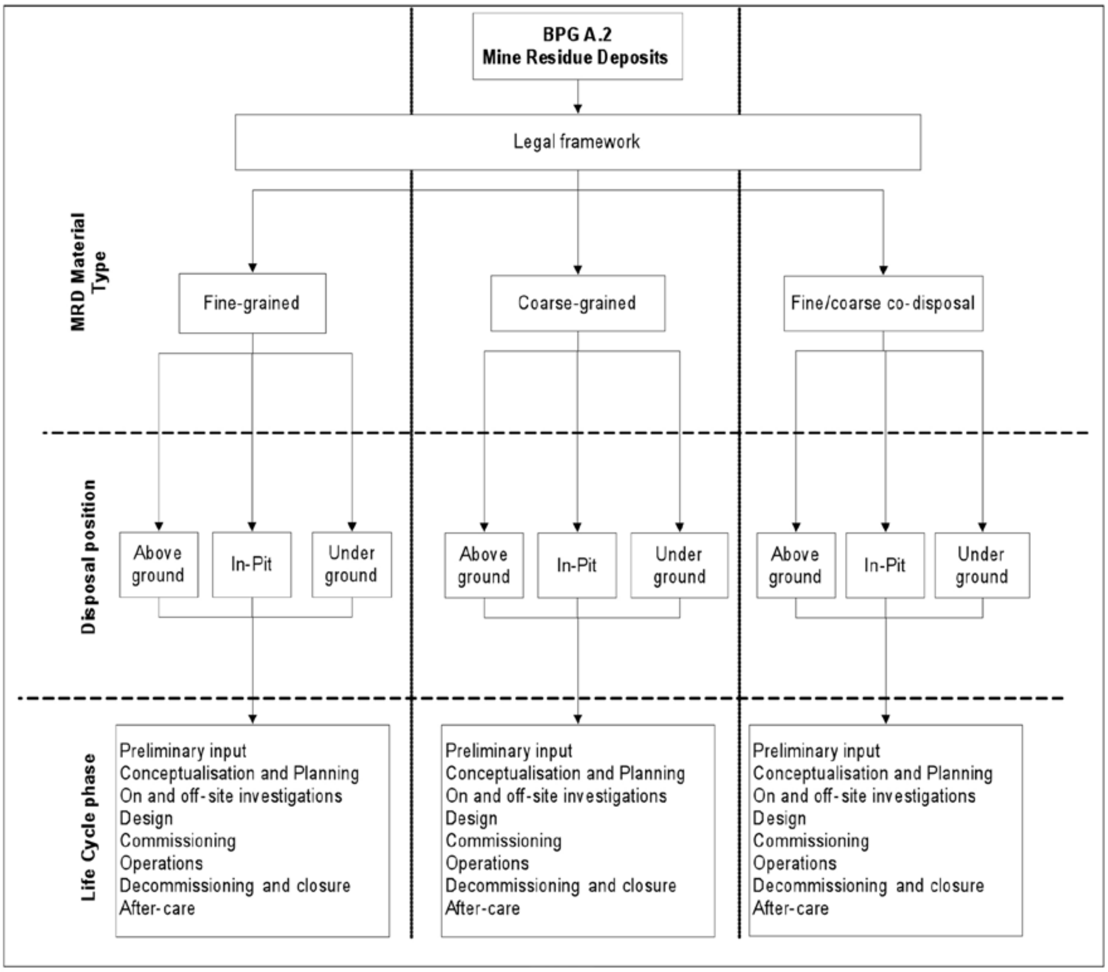


Figure 24. Typical structure of a Best Practice Guideline showing residue types, disposal options and the life cycle phases (DWAF, 2007).

Materials are separated according to their particle size and mineralogy (in mining and mineral processing industries). The residues produced fall into the categories (Table 10):

i. Fine-grained (residue, slimes and coal slurry)
ii. Coarse-grained (waste rock and coarse rejects, e.g. coal discard)

These residues hold particular characteristics which implicate particular transport and handling, storage and management methods and techniques (Table 11).

Table 10. Naming convention for coarse and fine-grained residues of coal (modified after DWAF, 2007).

Mineral	Fine-grained Residue	Coarse-grained Residue	Co-disposal commonly applied
Coal	Slurry	Discard/Reject Overburden Spoil Stockpiles	Yes (Co-disposal MRDs make provision for the co-disposal of fine and coarse-grained residues within the Mineral Residue Deposit facility. Typically, the coarse-grained residue is conveyed to the disposal site by conveyor or truck and the fine-grained residue is hydraulically conveyed).

Table 11. Summary of the various residue deposit (MRD) types and their characteristics (DWAF, 2007).

Type	Description	Pumping and transportation	Discharge	Disposal facility	Supernatant water management	Storm water management
Fine-grained MRD's	Conventional residue	Centrifugal pumping and piping	Open ending, spigotting, cycloning	Impoundment, day wall, cyclone raising	Penstock, floating barge	Storage in return water dam, evaporation, re-use in plant
	Thickened residue	Centrifugal pumping and piping	Open ending, spigotting, cycloning	Impoundment, day wall, cyclone raising	Penstock, floating barge	Storage in return water dam, evaporation, re-use in plant
	Paste residue	Postivite displacement pumping and piping	Top-down and bottom-up methods	Paste stacking	N/A	Storage in return water dam, evaporation, re-use in plant
	Filter cake / dry residue	Non-pumpable	Conveyor/earth moving plant	Dry stacking	N/A	Drainage control measures
Coarse-grained MRD's		Non-pumpable	Conveyor/earth moving plant	Waste rock facility	N/A	Drainage control measures
Fine/coarse co-disposal MRD's		Pumping and piping possible	Open ending	Void backfilling, disposal in or covering of conventional residue storages, elevated waste heaps	N/A	Required for elevated waste heaps

The process advocated by BPGs do not presume the presence or absence of a hazard merely based on the type of mineral being mined. Rather, each residue or waste generated must undergo a screening level hazard assessment as shown in Figure 25. A conservative approach is used during this assessment; the assessment aims to determine a potential water quality hazard associated with a particular residue is present or not.

The guidelines provided in the South African Bureau of Standards (SABS) standard 0286: 1998 should be followed to dispose and manage that reside which has proved to have no potential water quality hazard during the assessment. If a potential water quality hazard is identified, then the residue or waste in question then the detailed process articulated in the DWA BPG series of manuals should be followed. The process involves determining if a potential hazard does exist; then designing, operating and closing the disposal facility for that residue (Figure 26, Figure 27 and Table 12).

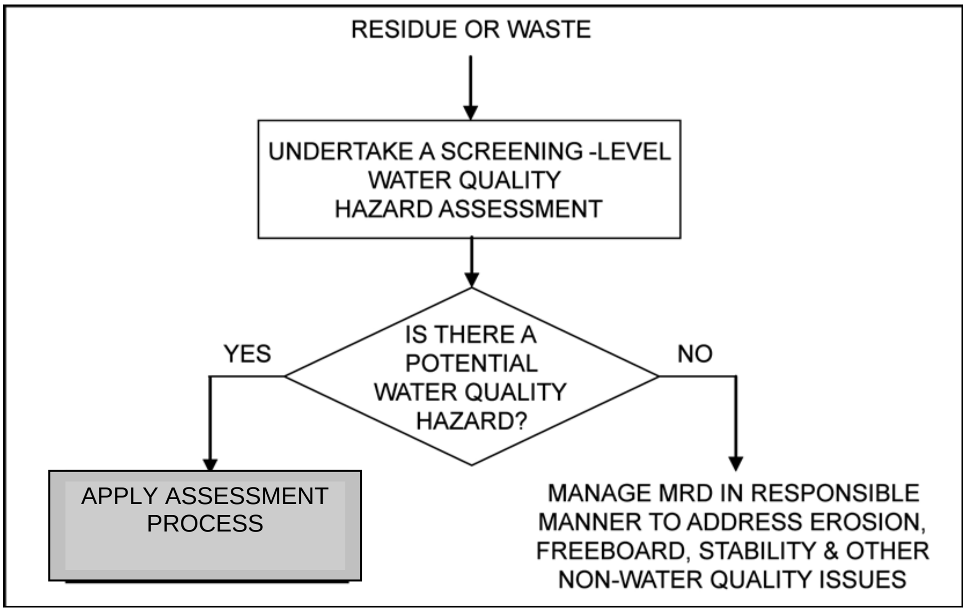


Figure 25. Screening-level assessment process for all Mine Residue Deposits (MRDs) (after DWAF, 2007).

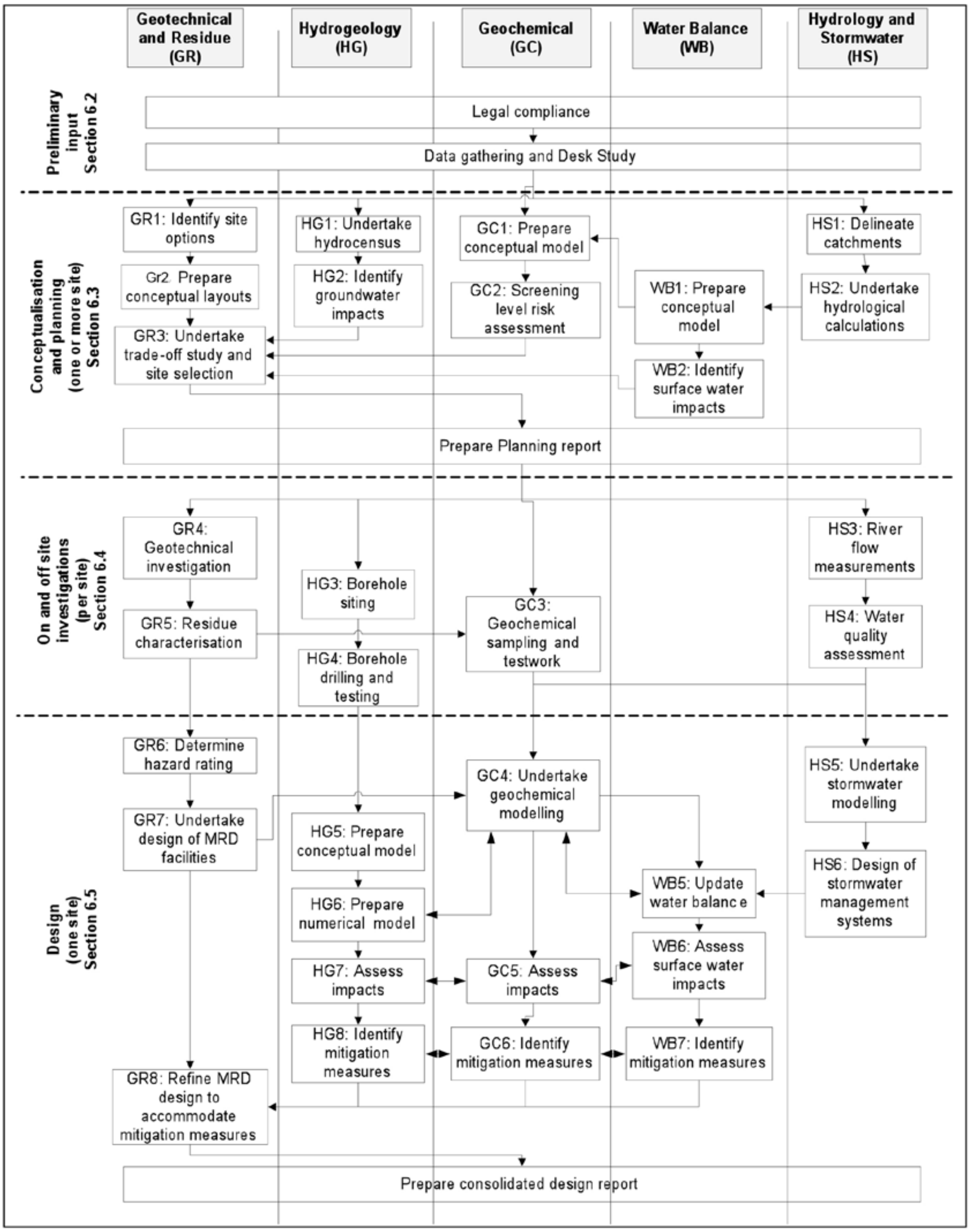


Figure 26. Water management steps included in the design of a deposit – showing integration of tasks in the conceptualisation, investigation and design phases (DWAF, 2007).

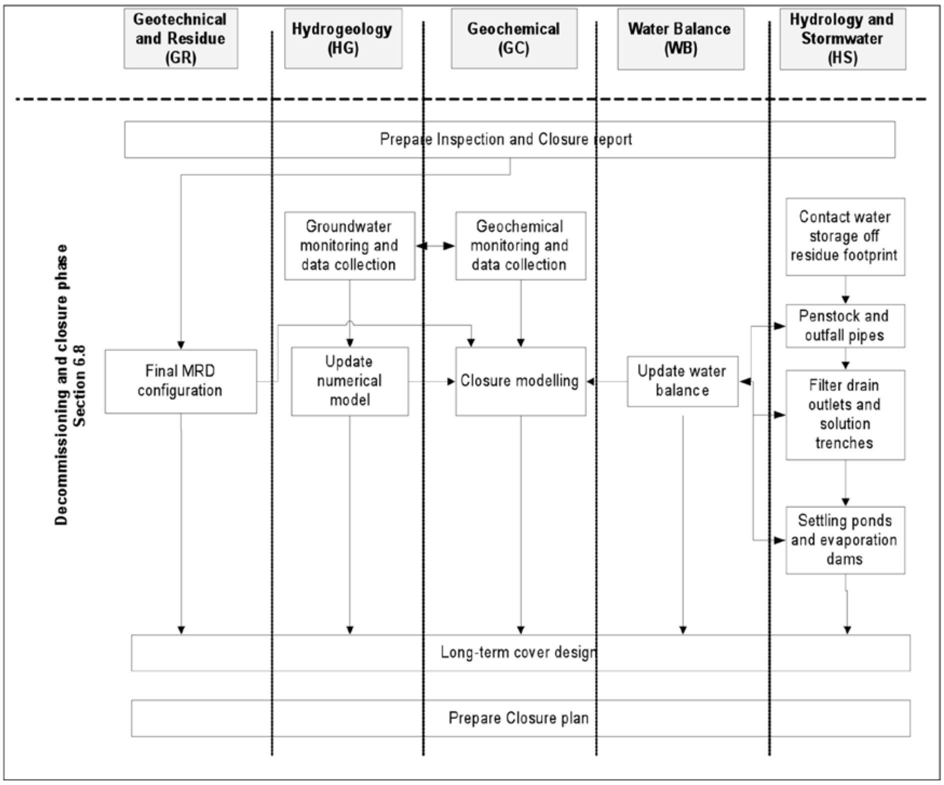


Figure 27. Aspects to consider in the decommissioning and closure phases (DWAF, 2007).

Table 12. Issues, options and techniques for long-term cover design (after DWAF, 2007).

Issues and Consequences	Options and Techniques
Acid Rock Drainage • Internal and external instability • Water Impacts • Acid Soil • Toxic to biotic systems • Gas and thermal emissions • Cover deterioration and failure	• Geochemical characterisation and selective discharge • Cover and capping research studies and design to reduce • water and oxygen reactions • Identification of cover material source and availability • Monitoring of cover performance and integrity • Capture store – release systems • Use as waste backfill in open pits or underground • Neutralisation (e.g. lime) and treatment (stimulation of • sulphate reducing bacteria) • Segregation/isolation/encapsulation • Passive leachate management and treatment
Groundwater • Aquifer contamination • Limitation of beneficial use • Recharge impact • Localised mounding	• Reduce hydraulic head by water shedding • Integrate capture store-release systems • Utilise evapo-transpiration • Cap and cover with capillary break • Drainage diversions • Neutralisation and detoxification of tails seepage • Wetland filtration

8.3 Mine Water Treatment in South Africa

8.3.1 Water Use in Coal Mining

Water is used omnipresently in the coal mining industry; Pulles and others (1995) list a variety of uses , each holding different quality requirements:

- Cooling water
- Dust suppression
- Irrigation
- Potable water
- Process water in plants
- Recreation
- Rehabilitation
- Mine service water

Surface and groundwater environments will be impacted differently by mine effluents owing the different characteristics of mining methods used, location of mining operations and prevailing water management practices.

The priority of the sequence is as follows:

Prevent contamination of water at source → re-use effluent→ treat and dispose of effluents is regarded by Pulles and others (1995) as fundamental in defining the most suitable water treatment or management actions.

8.3.2 Water Associated with Mine Residue Deposits

Inherent in the design, construction, operation and closure of residue deposits is water management. Poor practices with regard to the siting, design, operation and closure of mine residue deposits in the past have attributed to many of the pollution and water management problems facing the mining industry (especially diffuse pollution of surface and groundwater resources). Many older slimes dams are situated directly adjacent to watercourses and a number of these facilities lack adequate under-drainage, runoff and seepage control facilities.

Various characteristics of residue deposits recognised as being important (from a water management perspective) are discussed by Pulles and others (1995) and are outlined below:

a) Site Selection

The selection of appropriate sites for the construction of mine residue deposits is one of the most important elements in the proper management of residue deposits as it cannot be changed at a later date. A site suitable for the construction of a residue deposit must be selected before the feasibility and design planning stages of the process; geohydrology, topography and proximity to rivers and human settlements are taken into account.

Environmental considerations (including short, medium and long term impacts of the site on both the ground and surface water resources) must be carefully contemplated in conjunction with financial and safety aspects of the proposed site.

b) Runoff Control

Runoff from the tops and sides of a residue deposit should be controlled as it directly affects rehabilitation of that deposit. Typically, toe paddocks collect runoff from the sides of residue deposits where it is then evaporated. Precipitation on the top of the residue deposit is usually contained on top, although slimes dams' safety restrictions may apply where water control plays a critical role in terms of dam stability.

c) Under-drainage

Residue deposits should be equipped with properly designed under-drainage facilities to collect the seepage and route it to return water or pollution control dams. These return water dams must in turn be constructed in such a way as to prevent seepage.

d) Seepage Control and Cut-off Drains

Residue deposits should be equipped with seepage control trenches/drains (in addition to under-drainage facilities) to collect subsurface seepage which bypasses the under-drains by extending into an impermeable layer and discharging the seepage to a properly-lined collection facility from where it can be appropriately dealt with. These drains may also be retrofitted to older residue deposits which were not properly designed.

e) Systems for Control of Return Water

Sizing and location of return water dams, lining and seepage control as well as the design of pumping facilities to return the water to its intended user need to be carefully deliberated. Return water systems need to be designed to cope with the rainwater which falls on the residue deposit and with the return water from slimes or slurries pumped to the residue deposit.

Often, return water dams could include upstream settling facilities (to remove suspended solids which may settle out and by so doing reduce the holding capacity of the dams). If settling facilities are not available then the return water dam maintenance programme will make provision for the regular desludging of the dam.

f) Current Practice in South African Mines

Aspects in the management of residue deposits by several South African collieries is shown in Table 13.

Table 13. Management of Residue Deposits by several South African Collieries (after Pulles et al., 1995) (Y = yes, N = no, - = not applicable).

Technology/Process	Alpha Anthracite Colliery	Durban Navigation Colliery	Duvha Colliery	Goedehoop Colliery	Greenside Colliery	Grootgeluk Colliery	Hlobane Colliery	Kleinkopje Colliery	Landau Colliery	Matla Colliery	Middelburg Colliery	Natal Anthracite Colliery	Optimum Colliery	Tavistock Colliery	Tweefontein Colliery	Van Dyksdrift Colliery	Vryheid Coronation Colliery
Runoff control	Y	Y	-	Y	N	N	Y	Y	Y	-	Y	Y	N	Y	N	Y	N
Underdrainage	N	N	-	Y	N	N	N	N	N	-	N	N	-	N	N	N	N
Seepage control/cutoff	N	N	-	Y	N	N	N	Y	Y	-	N	N	-	N	N	Y	N
Rehabilitation up to date	N	N	-	N	N	N	N	N	N	-	N	Y	-	N	N	N	N
Return water control	N	N	-	Y	N	N	N	N	Y	-	N	N	-	N	N	Y	N
Control delivery pipelines	N	N	-	N	N	N	N	N	N	-	N	N	-	N	N	N	N

Residue deposits can generally be considered as one of the most significant sources of diffuse water pollution from the mining industry. In the coal mining industry, many of the older residue deposits are considered to be badly sited and constructed and considerable effort is being expended to upgrade and rehabilitate these facilities. Unfortunately, in a number of cases, the pollution resulting from ongoing seepage cannot be stopped and pollution collection and treatment systems will be required. These residue deposits contribute significantly to the pollution problems at old defunct mines where the State has been assigned pollution control responsibility.

Presently, the mining industry has to deal with the consequences of poor practices of the past - which were condoned and approved by the regulatory authorities at the time. Although these facilities currently pose a major pollution problem (and will continue to so), modernised practices and guidelines should ensure that similar problems do not arise in future from facilities designed and constructed in recent times.

8.3.3 Groundwater Practices

The Environmental Management Program Report (EMPR) procedure has highlighted groundwater aspects and also revealed that many mines have limited knowledge of the groundwater situation encompassing their operations. Groundwater is an important factor in mining operations, particularly with coal mines that are often situated in / directly under aquifers which are being utilised by other users. It can therefore be said that while mining generally has a direct effect on groundwater, groundwater also has a direct effect on mining (Pulles *et al.*, 1995).

The description of groundwater modelling, knowledge of impacts on groundwater, dewatering and groundwater abstraction and groundwater management by Pulles and others (1995) is enumerated below:

a) Groundwater Modelling

One of the fundamental requirements being imposed upon the mines in terms of the EMPR is to obtain a detailed understanding of their local and regional groundwater systems. In most instances this requires the development of a groundwater model which can be used to define impacts of mining and to predict the likely effect of various management strategies.

The detailed understanding of local and regional groundwater systems are required to satisfy Environmental Management Program (EMP) requirements - coal mines are frequently acknowledged as developing or refining and calibrating site-specific groundwater models.

b) Knowledge of Impacts on Groundwater

A thorough understanding of the impacts of mining on groundwater systems is needed in order to properly manage and thus protect groundwater systems. The coal mining industry is said to have benefited in recent years from relevant research projects.

c) Dewatering and Groundwater Abstraction

A common occurrence in coal mines is the underground interception of groundwater which is normally allowed to mix with other contaminated water sources before being pumped out of the mine.

The practice of intercepting water before it becomes contaminated (and therefore before it causes engineering, environmental, production, and safety problems within the mining operation) would generally allow the water to be discharged to the surface water systems without needing to be treated (as it will be uncontaminated - except for the naturally occurring contaminants).

d) Groundwater Management Strategies

Appropriate management strategies have been developed to protect the groundwater resources as a result of sufficient understanding of the local and regional groundwater systems and the impacts of mining. These management strategies may be as far reaching as changing the mining plan and method (e.g. deciding to use room and pillar mining instead of stoping) and sometimes affect residue disposal practices.

Reliable information is vital to groundwater management, consequently, a groundwater management strategy will include a groundwater monitoring strategy.

e) Current Practice in South African Mines

General groundwater management practices for several South African collieries is shown in (Table 14). It is evident that a sound monitoring strategy strengthens the groundwater management strategy (Pulles *et al.,* 1995).

Table 14. Groundwater Management Practices in several South African Collieries (after Pulles et al., 1995) (Y = yes, N = no).

Technology/Process	Alpha Anthracite Colliery	Durban Navigation Colliery	Duvha Colliery	Goedehoop Colliery	Greenside Colliery	Grootgeluk Colliery	Hlobane Colliery	Kleinkopje Colliery	Landau Colliery	Matla Colliery	Middelburg Colliery	Natal Anthracite Colliery	Optimum Colliery	Tavistock Colliery	Tweefontein Colliery	Van Dyksdrift Colliery	Vryheid Coronation Colliery
Adequate flow monitoring	N	N	N	N	N	Y	N	N	N	N	N	Y	N	N	N	N	N
Adequate WQ monitoring	N	N	Y	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Appropriate instruments	N	N	Y	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N
Calibration/maintenance	N	N	N	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N
Continuous monitoring	N	N	Y	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N

8.3.4 Cost of Water Treatment and Purification

The majority of DWA's operational and development responsibilities will be delegated to water management institutions over the next 10 to 15 years. The transfer of all costs and revenues associated with the Integrated Catchment Management will be achieved through the progressive transfer of water resources management responsibilities to Catchment Management Agencies (CMA's). It is predicted that improved revenue streams will be realised over time through the introduction of water use tariffs which suitably reflect the actual costs of water resources management activities

The extent and duration of financial support offered by DWA to water management institutions will become clear as DWA gains knowledge through pilot implementation processes. However, the objective to implement these strategic activities should be without any substantial increases in Exchequer funding.

Extensive financial resources are required to implement the strategies contained within the National Water Resource Strategy (NWRS). The arrangements for funding and the financial implications of the main activities needed to implement the provisions of the National Water Act (NWA) are summarised by DWAF (2004).

Costs are broadly grouped into two categories:

1. Capital costs (which relate to the development of infrastructure), and
2. Operational costs (which relate to activities associated with conservation, control, management, protection and use of water resources).

Compliance with the requirements of the NWA may result in expenditure by individual users, water management and water services institutions. While this has been acknowledged - the extent of such expenditure has not yet been assessed.

Examples of capital expenditure that may be encountered by such individual or organisations are:

- Costs to facilitate the storage and transmission of water,
- Costs related to the treatment of waste-containing water before it may be discharged into a water resource, and
- Costs to refurbish or replace distribution systems (as part of loss control programmes).

Examples of operational expenditure that may be encountered by such individual or organisations are:

- Costs related to monitoring activities (in order to comply with licence conditions). The necessity for and magnitude of such expenditure has not yet been assessed.

a) Capital Costs for the National Water Resource Strategy

DWAF (2004) states that capital expenditure estimates for water resource management are currently limited to those investments which may be required as publicly implemented projects (and which will serve multiple users) during the next 20 to 25 years.

The construction of major water schemes will incur significant costs – indicative costs of these major, government water schemes (

Table 15 and Table 16). Approximately R 20 988 million may be required for the development of major, new, government waterworks initiated over the next 25 years.

Table 15. Capital cost for major, new, government water schemes (DWAF, 2004).

Description	**Cost**
Schemes primarily for irrigation purposes	R 2 132 million
Schemes primarily for urban, domestic, industrial or mining purposes	R18 856 million
Total	**R 20 988 million**

DWAF (2004) emphasises that the information in Table 16 indicates only that the scheme has been investigated as a possible solution to address water availability. The information should be *not* be considered as a preferred option or as a commitment to proceed with the scheme; and given that circumstances may have changed since the investigation – it should not been taken for granted that the schemes are still viable.

Table 16. Indicative costs of major government water schemes (DWAF, 2004).

WMA	Name of dam / scheme [1]	River	Stage of Investigation [2]	Indicative Cost [3] (R million)
Schemes primarily for irrigation purposes				
2	Tzaneen Dam raising and Dam at nWamitwa	Letaba	Feasibility	847
6	Dam at Embiane	Black Mfolozi	Pre - Reconnaisance	110
14	Dam at Vioolsdrif	Orange	Pre-feasibility	200
17	Clanwilliam Dam raising	Olifants	Pre-feasibility	160
17	Dam at Melkboom	Doring	Pre-feasibility	815
Sub-total				**2 132**
Schemes primarily for domestic, urban, industrial or mining purposes				
4	Flag Boshielo Dam raising	Olifants	Construction [4]	270
4	Dam at De Hoop and bulk raw water conveyance infrastructure	Steelpoort	Feasibility	4 000
4	Dam at Rooipoort	Olifants	Feasibility	782
5	Dam at Mountain View	Kaap	Reconnaissance	381
5	Dam at Boekenhoutrand	Komati	Pre-Reconnaisance	691
7/6	Thukela-Mhlathuze Transfer [5]	Thukela/ Mhlathuze	Pre-feasibility	339
7	Thukela Water Project [6]	Thukela	Feasibility	6 736
7	Dam at Springgrove and aqueduct	Mooi	Feasibility	362
8	Klip River Dam	Klip River	Pre-feasibility	371
8	Vaal River Eastern Sub-System Augmentation (pipeline from Vaal Dam to Secunda)	Vaal	Feasibility	2 979
11	Dam at iSithundu	Mvoti	Feasibility	532
19	Berg River Project	Berg	Construction [4]	1 188
19	Voelvlei Dam Augmentation	Berg	Feasibility	225
Sub-total				**18 856**
Total				**20 988**

Notes:

8.3.4.a.1.1.1.1 1 The name of dam site usually refers to the name of the farm on which the dam wall is to be situated.

2, 3 Except for projects under construction (see Note 4) indicative costs (some of which were estimated some years ago) have been adjusted to 2003 levels. Confidence in the estimates depends on the stage of investigation as follows -

- *Pre-reconnaissance: The need for a project is identified and a number of options are investigated at a very low level of detail to select potentially feasible options*
- *Reconnaissance: Potentially feasible options are studied at a low level of detail to identify feasible options and to determine the scope of further investigations.*
- *Pre-feasibility: Feasible options are studied In more detail to select one option for detailed investigation.*
- *Feasibility: Detailed investigations, including extensive fieldwork, are carried out to confirm the technical, environmental, social, economic and financial viability of the selected option.*

4. Indicative costs for schemes under construction are tender prices.

5. Indicative costs are included for transferring water from the Thukela River into the Usutu to Mhlathuze water management area for possible mining and industrial development in the Richards Bay area.

6. The Thukela Water Project is included to represent the indicative costs of a transfer scheme to bring additional water into the Upper Vaal Water Management Area. This could also be achieved via Phase 2 of the Lesotho Highlands Water Project, or by transferring water from the Upper Orange River.

Total capital costs per year

The total estimated capital expenditure (over the next 20 to 25 years) amounts to approximately R1 430 million per year (Table 17).

Table 17. Total capital costs per year (DWAF, 2004).

Description	Cost	Approximate average cost per year
Major new government waterworks	R 20 988 million	R 840 million
Expansion of national monitoring networks	R 1 300 million	R 60 million
Other capital items	(sub-total not available)	R 530 million
Total	**> R 22 288 million**	**R 1430 million**

b) Operating Costs for the National Water Resource Strategy

Commissioning activities

The estimated total cost of commissioning activities is approximately R 1 500 million over the next 15 years (i.e. approximately R 100 million p.a.). The DWA states that commissioning activities have not been undertaken before and therefore the cost estimates are considered as *indicative* until further work is done to obtain more accurate cash flows and estimates. Commissioning activities identified by DWAF (2004) include:

- *The introduction of compulsory licensing,*
- *The establishment of catchment management agencies,*
- *The delegation of operational responsibility for physical infrastructure to water management institutions (and ultimately, the transfer of ownership of infrastructure to these institutions),*
- *The establishment of new water user associations,*
- *The expansion of existing monitoring networks and information systems and establishment of new ones,*
- *The introduction of the water resource management charge, completion of the transformation of irrigation boards into water user associations, and*
- *Dealing with the backlog of individual licence applications.*

Routine operational activities

DWAF (2004) estimate the total annual funding requirement for routine operational activities to be R 1 800 million. This is needed to execute the Integrated Catchment Management component of the Water Trading Account optimally (i.e. activities such as the development of catchment management strategies, water quality management, the control of water use, water demand management and functional support to water management institutions).

The estimated total annual operating costs (Table 18) are R 1 900 million.

Table 18. Estimated total annual operating costs (DWAF, 2004).

Description	**Cost**
Routine operating costs	R 1 800 million
Commissioning costs	R 100 million
Total	**R 1 900 million**

c) Treatment Costs in Relation to Supply

"Full cost pricing" - in first world countries – is considered a fundamental pillar of sustainable water use. Other principles vital to sustainable water use conveyed in De Villiers and De Wit (2010) are:

- Public education,
- Demand management,
- Linking water conservation to development and construction approvals,
- Reduction of water system leakage,
- Creation and implementation of bylaws promulgating the fitment of low-flow water fixtures in all new buildings, and
- Water re-use, effluent treatment and storm water capture.

In South Africa (considered a developing country), the challenge of establishing these principles to achieve "full cost pricing" presents, arguably, an enormous challenge.

The minimum amount that needs to be spent to ensure that the country's future water yield will at least match current values, and to reduce the cost of pollution to the environment is estimated on the order of R100 billion (De Villiers and De Wit, 2010). The re-establishment of functionality of municipal water treatment plants through huge financial injections is motivated by the need to reduce pollution of surface and groundwater resources as well as to address South Africa's future water outlook scenarios. Currently, 14% (1 899 of 13 227 Mm^3/a) of the total "Local reliable yield" derives from “Return flows” (Table 19). Return flows constitute water which is used, treated and which gets re-used, or released back into the environment (i.e. these amounts are also included in “Requirements”). Mining and industry contribute 54 Mm^3/a, irrigation 675 Mm^3/a and the bulk is derived from urban water recycling which contributes 970 Mm^3/a to return flows.

Table 19. Detailed breakdown of current water yield and availability in South Africa. All values in 10^6 m^3/a. (De Villiers and De Wit, 2010).

Water Management area	Reliable local yield				Trans	Local requirements							Trans	Balance	
	Surface	Ground	Return	Total	In	Irrigation	Urban	Rural	Mining	Power	Afforestation	Total	Out	NWRS	Revised
Limpopo	160	98	23	281	18	238	34	28	14	7	1	322	0	-23	-123 (a)
Luvuvhu and Letaba	244	43	23	310	0	248	10	31	1	0	43	333	13	-36	
Crocodile (West) and Marico	203	140	367	710	519	445	547	37	127	28	0	1184	10	41	
Olifants	410	99	100	609	172	557	89	44	94	181	3	968	8	-194	
Inkomati	816	9	72	897	0	593	63	26	24	0	138	844	311	-258	-280
Usutu to Mhlathuze	1019	39	52	1110	40	432	50	40	91	0	104	717	114	319	294
Thukela	666	15	56	737	0	204	52	31	46	1	0	334	506	-103	
Upper Vaal	599	32	499	1130	1311	114	635	43	173	80	0	1045	1379	17	
Middle Vaal	-67	54	63	50	829	159	93	32	85	0	0	369	502	8	
Lower Vaal	54	125	55	234	548	525	68	44	6	0	0	643	0	31	
Mvoti to Umzimkulu	433	6	84	523	34	207	408	44	74	0	65	798	0	-241	
Mzimvubu to Keiskamma	778	21	57	856	0	193	99	39	0	0	46	377	0	480	
Upper Orange	4311	65	71	4447	2	780	126	60	2	0	0	968	3149	332	
Lower Orange	-1083	25	96	-962	2035	977	25	17	9	0	0	1028	54	-9	
Fish to Tsitsikamma	260	35	122	417	575	763	112	16	0	0	7	898	0	95	
Gouritz	191	64	20	275	0	254	52	11	6	0	14	337	1	-63	
Olifants/Doorn	266	45	24	335	3	356	7	6	3	0	1	373	0	-35	
Breede	687	109	70	866	1	577	39	11	0	0	6	633	196	38	

Water Management area	**Reliable local yield**				**Trans**	**Local requirements**							**Trans**	**Balance**	
	Surface	**Ground**	**Return**	**Total**	**In**	**Irrigation**	**Urban**	**Rural**	**Mining**	**Power**	**Afforestation**	**Total**	**Out**	**NWRS**	**Revised**
Berg	403	57	45	505	194	301	389	14	0	0	0	704	0	-5	
TOTAL	10240	1088	1893	13227		7920	2897	574	755	297	428	12871	170	186	39 (b)

Detailed breakdown of current water yield and availability in South Africa, as given in the most recent National Water Resource Strategy (NWRS) assessment.

All values in 10^{3} m^3/a

(a) Revised balance based onb revised groundwater yield and requirement values

(b) Adjusted as a result of changes in (a)

De Villiers and De Wit (2010) suggest that water treatment processes to treat acid mine drainage and mine water decant are significantly more sophisticated than conventional or desalination plants. They also incur higher operating costs (owing to shorter life-time and more frequent replacement of consumables e.g. filters and ion exchange resins) as a result of the high acidity of these waters. Despite the extent of sophistication of the chemical treatment required, the capital cost of treatment plants for mine water is estimated to be equivalent to or even lower than that of desalination plants (Table 20).

The capital redemption cost in desalination plants is almost equivalent to operational plus maintenance costs; this is approximately 2 to 7 times that total production costs of conventional plants (this is, however, dependant on location and chemical properties of water being treated) (Table 20). The basis for estimated costs of water derived from treatment of mine decant is a pricing model which assumes that operational and maintenance costs will be covered by income derived from recovered mineral resources – that is, that production cost is equal to capital redemption cost only.

By considering treatment options proposed at Anglo Coal and Western Utilities Corporation (Table 20; De Villiers and De Wit, 2010), a capital cost of R 1500 million and R 200 million respectively is required to operate a treatment plant with a capacity of 150Ml/d and 20Ml/d. However, no capital redemption costs or production costs have been estimated.

Table 20. Estimated costs of different water treatment options (Capital redemption cost is calculated assuming a 25 year plant life, and 12% annual interest rate) (after De Villiers and De Wit, 2010).

Treatment options	Capacity		Capital Cost		Capital Redemption	Operate and Maintenance	Production Cost
	Ml/d	**Mm^3/a**	**R million**	**R/l/d cap**	**R/kl**	**R/kl**	**R/kl**
Conventional							
Rand Water (6 plants)	5260	1920	?	-	?	Estimated R100 billion needed for outstanding maintenance tot existing infrastructure	2.53
City of Cape Town	various	-	?	-	?		1.05 – 1.25 (water only)
Amatola Water (rural)	various	-	?	-	?		3.39
Desalination							
Groundwater							
Seawater	5	1.8	16.5 - 24.5	3-5	1.1-1.7	1.3-3.2	2.40-4.90
	5	1.8	40 - 63	8-13	2.8-4.4	3.0-4.0	5.80-8.40
	50	18	338 - 530	7-11	2.4 - 3.7	2.6 - 3.3	5.00 - 7.00
e.g. Sedgefield-seawater	1.5	0.5	16	10.7	3.8	~3.0	~6.76
Mine Decant							
Western Utilities Corp	150	55	1 500	10	?	= mineral recovered?	?
Anglo Coal	20	7	200	10	?	= mineral recovered?	?

Unquantified External Costs

A critical factor that has to be considered is that the amounts of water used by the different sectors are much smaller than the amounts of water contaminated as the result of these uses.

Contamination of water as a result of its sector-specific use is a critical matter. De Villiers and De Wit (2010) cite the example of the generation of electricity at coal-fired power stations. This action requires 297 Mm3/a - only 2.3% of total water requirements (Table 19), however, the acid mine drainage generated from coal mining impacts (Table 21) on 1 038 Mm^3/a of total yield – over 3 times the amount of water used by power stations and 8% of total current national water yield.

In addition, the effects from acid mine drainage will persist for many years to come with a final cumulative impact on water yield (and quality) which will exceed the *actual* amount of water used during electricity generation, by at least a factor of 100 (De Villiers and De Wit, 2010).

Table 21. Predicted impact of climate change, coal and gold mining on future water quality and local yield (Mm3/a) in South Africa's Water Management Areas (De Villiers and De Wit, 2010).

	NWRS 2025 base		**-5% Climate**		**Mining**		**Climate Mining**		**Origin of impact**
Water Management Area	**Yield**	**Balance**	**Yield**	**Balance**	**Impact**	**Balance**	**Yield**	**Balance**	
Limpopo	**281**	**-48**	**267**	**-62**	**-83**	**-131**	**184**	**-145**	Coal in Mokolo catchment; 40% of SA reserves
Luvuvhu and Letaba	404	42	384	22	-27	15	321	-5	Coal in Matuale catchment
Crocodile (West) and Marico	846	125	804	83	-336	-397	282	-439	Gold-AMD in Upper Crocodile
					-186				Pt mining dewatering in Apies/Pienaar
Olifants	630	-242	599	-274	-238	-480	361	-512	Coal mining in Upper Olifants
Inkomati	1028	-197	977	-248	-118	-315	859	-366	Coal mining in Upper Inkomate
Usutu to Mhlathuze	1113	311	1057	255	-5	273	1019	217	Coal in Mfolozi catchment
					-33				Coal mine decant - Mkuze
Thukela	742	-111	705	-148	398	-645	171	-682	Coal mining in Upper Thukela
					-136				Coal mining in Buffalo catchment
Upper Vaal	1229	-42	1168	-103	-184	-783	427	-844	Upstream of Vaal Dam: coal, gold, Sasol, iron
					-557				Downstream of Vaal Dam: gold
Middle Vaal	55	9	52	6	-142	-280	-237	-275	Gold in Vaal catchment
					-147				Gold in Sand-Vet catchment
Lower Vaal	127	57	121	51	0	57	121	51	
Mvoti to Umzimkulu	555	-423	527	-451	0	-423	527	-451	
Mzimvubu to Keiskamma	872	459	828	415	0	459	828	415	
Upper Orange	4734	88	4497	-149	0	88	4497	-149	
Lower Orange	-956	-7	-1004	-55	0	-7	-1004	-55	
Fish to Tsitsikamma	456	71	433	48	0	71	433	48	

Water Management Area	NWRS 2025 base		-5% Climate		Mining		Climate Mining		Origin of impact
	Yield	Balance	Yield	Balance	Impact	Balance	Yield	Balance	
Gouritz	278	-76	264	-90	0	-76	264	-90	
Olifants/Doorn	335	-32	318	-49	0	-32	318	-49	
Breede	869	36	826	-7	0	36	826	-7	
Berg	568	-67	540	-95	0	-67	540	-95	
TOTAL	14166	-234	13458	-942	-2590	-2824	10738	-3532	

Predicted impact of climate chagne, coal and gold mining on future water quality and local yield (Mm^3/a) in South Africa's Water Management Areas, based on evidence for water quality degradation at existing and abondoned mines.
The total yield impaced on by coal mining adds up to 1308 (Mm3/a) (calculated from the sum of "impact" amounts in the "mining" column with coal as the "origin of impact"

It is suggested that South Africa will have a water deficit of 4 424 Mm^3/a by 2025, 2 590 Mm^3/a of this resulting from the impact of acid mine drainage on yield (De Villiers and De Wit, 2010).

To counter this deficit, two situations are suggested

a) Construction of specialised water treatment plants to clean a total minimum volume of 2 590 Mm^3/a of mine water, and
b) Construction of desalination plants to produce 1 834 Mm^3/a of potable water (i.e. 4 424 - 2 590 Mm^3/a).

The capital cost required (if equivalent to that of a seawater desalination plant at R530 million per 18 Mm^3/a capacity), will be (taken from Table 20):

a) More than R76 billion for specialised water treatment plants and
b) R54 billion for desalination plants.

If capital expenditure is equivalent to operational and maintenance costs (Table 20), total minimum water production cost of R260 billion is calculated (when treatment plants are assigned a 25 year lifespan). By adding the estimated R100 billion required for outstanding maintenance work on existing infrastructure to this, the sum of R360 billion is calculated in order to secure South Africa’s water within 15 years time.

Loss of the ecosystem services (e.g. the maintenance of water supply and water quality carried out by healthy ecosystems) and the destruction of ecological integrity of river catchments are considered the prime reasons for these massive costs. The loss in ecosystem services is amplified and financial costs associated with this loss becomes magnified when water treatment plants become dysfunctional – the Olifants River catchment is considered as an example of wetland degradation and destruction in the coalfields of Mpumalanga.

9 Environmental Conditions Associated with Coal Deposits and Coal Mining

Academic and public environmental awareness has increased considerably over recent years with the realisation of the extensive impact coal mining has on the surrounding natural environment. Coal mining is notorious for pollution – which can take a number of different forms depending on the geological environment, mining method used and state of the mine (abandoned or active) (Bell *et al.,* 2001). Given the extensive number of collieries in the Witbank Coalfield and its long mining history, and even though a number of deposits have been exhausted and mines closed, pollution continues to be a serious dilemma in the coalfields of South Africa. Figure 29 shows likely stages of environmental pollution in the production of coal.

9.1 Subsidence and collapse of ground

Pillars in room and pillar mines are robbed (extracted by mining) – often over an extensive area in a mine - in order to increase the amount of coal recovered from a mine. Because the pillars support the overhead load (attributed to overburden), removing pillars causes increased compressional stress on any remaining pillars and strata immediately above the workings. Pillars may then fail and/or sagging of the roof beds occur (Wardell and Wood, 1965; Bell *et al.*, 2001). As voids migrate and the room areas collapse, crownholes form on surface. The subsidence may lead to extensive surface fracturing above the mine workings. Similarly, discontinuous subsidence may form from multiple pillar failure (Bell *et al.*, 2001).

9.2 Disturbance of groundwater reservoirs and disruption of natural water paths

The disturbance of groundwater reservoirs is articulated by McCarthy and Pretorious (2009), a summary of their explanations appears below:

Additional void spaces are created by longwall mining allowing an increase in inflow of water into the void and an increase in seepage. The water is typically of low quality and is most likely not usable for agricultural or domestic uses when tapped from a borehole.

Additional voids are created in the fractured rock aquifer by room and pillar mining – but as long as no collapse occurs within the workings the regolith aquifer (the weathered zone overlying the bedrock) remains intact. Enhanced recharge into the old workings from rainwater occurs as extensive fracturing of ground surface and the appearance of crownholes increases permeability – up to half of the rain which falls may infiltrate the ground over the mined area (Bell *et al.*, 2001).

Opencast mining creates a massive aquifer in the mine void and destroys the groundwater aquifers (Bell *et al.*, 2001).

Other disruptions include the development of springs in areas where subsurface structural integrity has been compromised and water from the workings entering local streams. The polluted water may decimate flora over the area where seepage occurs (Bell *et al.*, 2001).

9.3 Underground fires

Room and pillar mines run the risk of underground fires and collapsing ground. After mines were closed, the coal-bearing pillars may catch fire and causing the collapse of the overhead roof rocks. Ultimately the ground conditions on surface deteriorate as the surface becomes unusable (McCarthy and Pretorious, 2009), simultaneously noxious sulphur- and nitrogen oxides emissions enter the atmosphere (Bell *et al.*, 2001).

9.4 Spontaneous combustion

A measurable rise in temperature results from the percolation of air through the remaining coal in mines, stockpiles and dumps. If the heat is not dissipated the temperature of the coal will continue to increase and facilitate an increase in the rate of oxidation of the coal (Stracher *et al.*, 2004). If conditions are favourable, this self-heating of coal will result in spontaneous combustion.

The temperature of self-heating (SHT) is the lowest temperature that will produce a sustained exothermic reaction (Banerjee, 1985) – i.e. it is the minimum temperature at which the materials burn spontaneously. Oxidation is accelerated if the SHT temperature is reached before thermal equilibrium is achieved - resulting in a rapid increase in temperature, even higher rates of oxidation and ultimately combustion occurs generating smoke and gaseous products (Pone *et al.*, 2007). Factors that play a vital role in the process of spontaneous combustion were identified by Glasser and Bradshaw (1990) as:

1. *The reaction between the coal and the gaseous reactants causing self-heating.*
2. *The transport of the gaseous reactant into the bed.*
3. *The rate of heat energy dissipation from the bed.*

Pone and others (2007) affirm that

1. *Opencast mining exacerbates the process of self-heating because coal seams are exposed to the uncontrollable influences of climate.*
2. *The heterogeneous character of coal seams and waste dumps contribute significantly to the realization of these three factors.*

Bell and others (2001) describe that the rate of air flow is reduced in partially collapsed workings, which prevents heat from being conducted away from hotspots with the result that fires (caused by spontaneously combusted coal) are persistently present in the Witbank coalfield. A sulphurous stream emitted from a crownhole is illustrated in Figure 31 (after Bell *et al.*, 2001) and the authors affirm that the spontaneous combustion of coal occurs readily under existing conditions.

Figure 28. A sulphurous stream emitted from a crownhole (Bell *et al* ,2001)

9.5 Acid rain

Acidification of the environment through the emission of acidifying compounds into the environment contributes to the formation of acid rain (Hordijk and Kroeze, 1997). Compounds most prevalent in the process are sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and carbon dioxide (CO_2). Following their release, these compounds are transported as gases over a distance – where the total distance transported depends on atmospheric lifetime of the compounds, altitude of emission (e.g. from a stack) and prevailing meteorology. Precursors of acid rain have both natural (e.g. decaying vegetation and volcanoes) and anthropogenic (e.g. the combustion of fossil fuels) sources. Hordijk and Kroeze (1997) state that anthropogenic emissions exceed natural emissions in many regions of the world.

Acidification of the environment occurs through wet and dry deposition of acidic compounds. Dry deposition takes place when acidic compounds become incorporated into dust or smoke and return to the earth's surface where they adhere to surfaces of buildings, trees and plant life etc. Dry deposits may be rinsed off (e.g. by rain) increasing the acidity of runoff. In contrast, wet deposition is the increase in the acidity of rain water which then falls to the earth. Environmental effects include:

- Increased acidity of groundwaters
- Direct damage to plants and animals (by enhanced levels of SO_2, NO_x, NH_3 and O_3 [ozone]),
- Damage to buildings (from acidic rainfall) – including those of cultural heritage.

Complex chemical and photochemical processes may occur during atmospheric transport of SO_2 , NO_x and NH_3 (these processes are not discussed here as they fall out of the scope of the study). Sulphur dioxide is returned to the earth's surface as sulphur dioxide (SO_2) or more commonly H_2SO_4 (sulphuric acid); ammonia may reach the earth's surface as NH_3 (ammonia) or NH_4 (ammonium) and nitrogen oxides (NO_x) as NO_2 (nitrogen dioxide) or deposited as NO (nitric oxide).

When contemplating the anthropogenic influence on acid rain, Hordijk and Kroeze (1997) put forward that the sulphur content of fossil fuels determines the amount of

SO_2 emitted into the atmosphere and the formation of NO_x is indicated by the combustion temperature of the fuel.

9.6 Acid Rock Drainage

Acid Rock Drainage (ARD) results from the oxidation of iron bearing sulphides (most commonly pyrite and marcasite [FeS_2]) to form sulphuric acid (Murad and Rojik, 2004). Oxygen is available for the oxidation of iron sulphides from water used during mining as well as the exposure of the minerals to the atmosphere (Pinetown *et al.*, 2007). The terms Acid Mine Drainage (AMD) and Acid Rock Drainage (ARD) are not synonymous, strictly speaking. AMD refers to the chemical interactions that are accepted to have been caused by mining activities whereas ARD may occur in the natural environment in the absence of anthropogenic influence. AMD will be considered in greater detail for the purpose of this study and is examined in greater depth in *section 9.7* - ***Acid Mine Drainage*** .

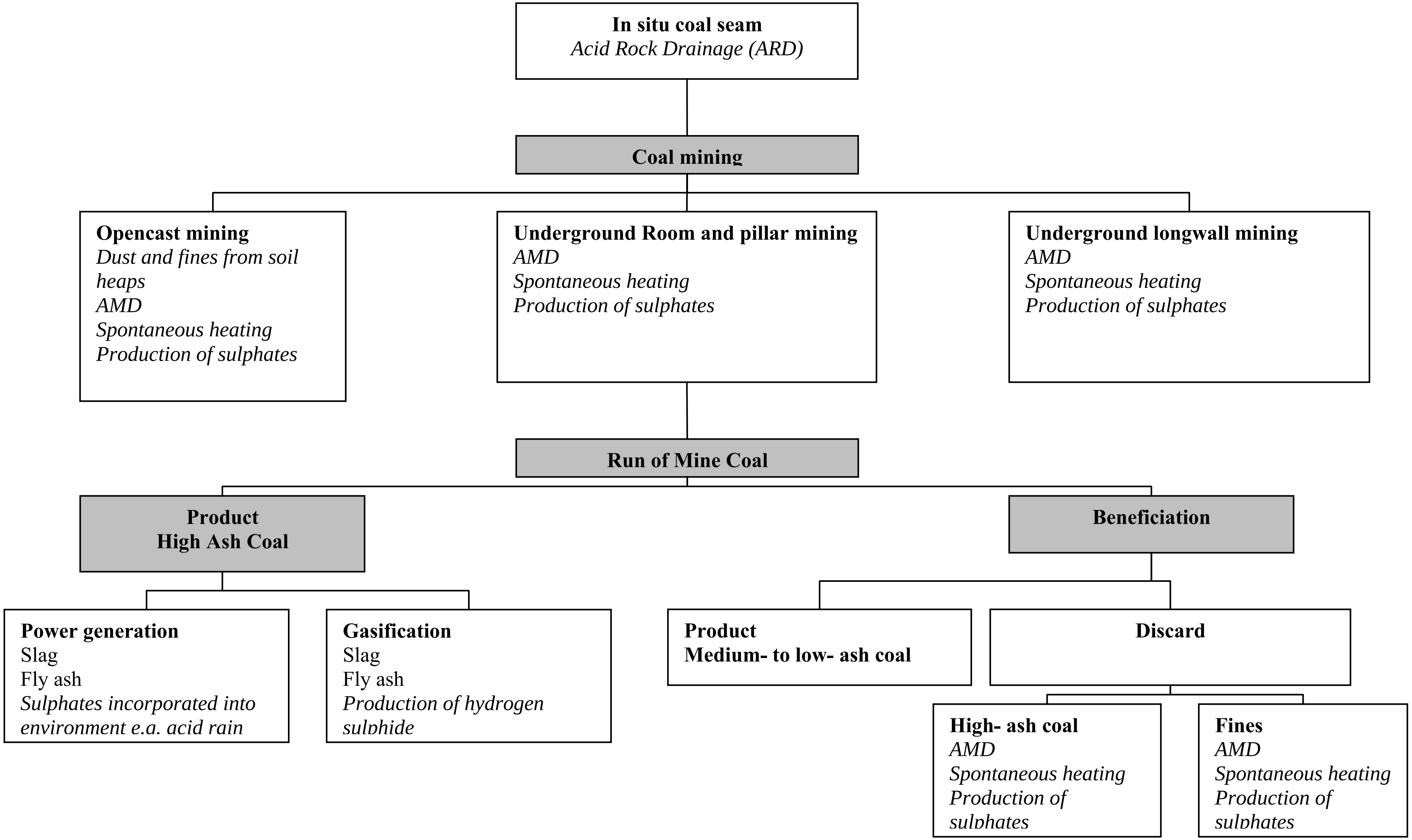


Figure 29. Schematic representation of likely stages of environmental pollution in the production of coal (AMD – Acid Mine Drainage) (modified after Chelin, 2000).

9.7 Acid Mine Drainage

In recent times, public awareness regarding the potential environmental hazards which result from mining activities has increased (Gray, 1997). Both coal and metal mines produce pollution (Whitehead and Jeffrey, 1995) and certain types of mining are more prone to produce Acid Mine Drainage (AMD) than others (Gray, 1997).

AMD results from the oxidation of sulphide minerals and the subsequent migration of the oxidation products (sulphuric acid, hydroxides and iron oxides) into solution (Pinetown *et al.*, 2007 and Cravotta *et al.*, 1999). The general oxidation reactions which produce a sulphate and iron oxide are shown in equation 1 and equation 2 respectively.

$$2\ FeS_2 + 7\ O_2 + 2\ H_2O \rightarrow 2\ FeSO_4 + 2\ H_2SO_4 \qquad \text{Equation 1}$$

$$4\ FeS_2 + 15\ O_2 + 10\ H_2O \rightarrow 4\ FeOOH + 8\ H_2SO_4 \qquad \text{Equation 2}$$

(Murad and Rojik, 2004)

Vermuelen and Usher (2005) state that in South African coal mines, pyrite is the most important sulphide and in some instances the most abundant component in mineral matter of South African according to Pinetown and others (2007). Coals and shales of marine origin tend contain higher concentrations of sulphides than their freshwater counterparts (Gray, 1997).

Acidophilic bacteria, namely *Thiobaccillus Ferrooxidans*, are said to accelerate and extend these reactions (Sawyer *et al.*, 1994; De Beer, 2005 and Chelin, 2000). Silverman (1967) report the increased oxidation rate to be as large as up to 10^6 times.

The generation of AMD is exacerbated as sulphide rich materials and sediments are exposed to water (used during mining operations) and the atmosphere (Bologo *et al.*, 2009 and Pinetown *et al*, 2007).

The minerals pyrite and marcasite are largely responsible for acid mine drainage problems in coal mines (Pone *et al.*, 2007)

A detailed discussion is given by Pone and others (2007) on the spontaneous combustion of coal in the Witbank coalfield of South Africa. The sulphur content of the coals varied between 0.15 and 8 wt%; minerals formed on coal-seam surfaces and gases escaping from vents, were examined to were analysed to verify the presence of chemical compounds. X-ray diffraction (XRD) studies of coal fire gas mineral (CFGM) by-products confirmed the presence of a number of sulphide-bearing minerals including barite ($BaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), iron sulphate ($FeSO_4$), letovicite ($(NH_4)_3H(SO_4)_2$) and mascagnite ($(NH_4)2SO_4$).

The highly negative Net Neutralising Potential (NNP) observed suggest the Number 5 and Number 4 coal seams, as well as the unit between the Number 4 and 2 seams are potentially acid generating (Pone *et al.*, 2007).

Resultant waters are considered strongly acidic (as their pH value may be as low as 2) and highly saline as they bear a complex variety of heavy metal ion and other concentrated constituents (manganese, sulphate, iron and aluminium) in solution (Bologo, 2009).

Pinetown and others (2007) state that significant environmental hazards associated with coal mining are created once interactions between such minerals and the immediate environment take place – particularly as AMD affected waters may potentially infiltrate aquifers and contaminate groundwater. Vermeulen and Usher (2005) explain that the local geology and depth of mining will contribute to pollution of aquifers and rivers as geohydrological flow paths (either man-made or natural) ultimately decant and/or seep into the adjacent strata and environment. It is essential to treat AMD waters as they carry potentially toxic metals (e.g., Al, Cu, Zn and Cd) (Rose and Elliot 2000, Johnson, 1986; Chapman *et al.*, 1983). The adverse effects of AMD can ensue unless action is taken to prevent sulphide oxidation – both *during* mining and once mining has *ceased* (Murad and Rojik, 2004).

The rate of acid generation is dependent on:

- Availability of chemical activation energy (in order to initiate reaction);

- Temperature (generally, the higher the temperature – the greater the rate of acid generation);
- Extent of exposed surface area of sulphide-bearing body (the larger the exposed surface area - the greater the rate of acid generation);
- Presence of acidophilic bacteria (greater the presence, the greater the rate of acid generation);
- The presence of bacteria will initiate a sub-set of factors which contribute to the rate of acid generation. These include the availability of biological activation energy, density of the bacterial colony and rate of growth of colony;
- pH conditions (the lower the pH the greater the rate of acid generation);
- Availability of oxygen (in gaseous and liquid phases) ;
- Extent of water saturation (the greater the water saturation, the greater the rate of acid generation); and
- Chemical activity of ferric iron (Fe III) (the greater the rate of activity - the greater the rate of acid generation.

Vermuelen and Usher (2005) list the general sequence of reactions that generate sulphate by AMD in four (4) main steps. These steps are explained by De Beer (2005) namely

1) the oxidation and weathering of sulphides in pyrite by oxygen and water such that dissolved iron, sulphate and hydrogen ions are liberated (i.e. pH decreases);
2) the conversion of ferrous iron to ferric iron in the presence of oxygen;
3) the hydrolysis of iron which further liberates hydrogen (i.e. acidity and as such the pH continues to decrease); and
4) the oxidation of additional pyrite by ferric iron (in the absence of atmospheric oxygen).

$$\mathbf{4FeS_{2(s)} + 14O_{2(g)} + 4H_2O_{(l)} \rightarrow 4Fe^{2+}{}_{(aq)} + 8SO_4^{2+}{}_{(aq)} + 8H^+{}_{(aq)}} \qquad \text{Equation 3}$$

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

$$\mathbf{4Fe^{3+}{}_{(aq)} + 12H_2O_{(l)} \rightarrow 4Fe(OH)_{3(s)} + 12H^+{}_{(aq)}} \qquad \text{Equation 5}$$

$$\mathbf{2FeS + 14Fe^{3+}{}_{(aq)} + 8H_2O_{(l)} \rightarrow 15Fe^{2+}{}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 16H^+{}_{(aq)}} \qquad \text{Equation 6}$$

(De Beer, 2005)

The greatest potential source for AMD is that of Mine Residue Deposits (MRD's) owing to the significant exposed surface area and residence time.

The Mineral and Petroleum Resources Development Act, 2002 (MPRDA) defines:

- "**residue deposit**" as any residue stockpile… and a
- "**residue stockpile**" as any debris, discard, tailings, slimes, screening, slurry, waste rock, foundry sand, beneficiation plant waste, ash or any other product derived from or incidental to a mining operation and which is stockpiled, stored or accumulated for potential re-use, or which is disposed of, by the holder of a mining right, mining permit or production right;

While the Department of Water Affairs (DWA) Best Practice Guideline (BPG) makes use of the term 'Mine Residue Deposit' (MRD). For the purpose of this minor-dissertation, the term MRD be used and is considered to include all the items described as a 'residue stockpile'.

Other sources of AMD include drainage from underground workings and surface runoff from faces of open pit mine and pit workings (Chelin, 2000).

10 Water quality of the Olifants River Catchment

In this chapter, it will be shown that although the geology of the catchment area is relatively uniform and the main industrial activity is coal mining, the river water chemistry is diverse. In order to apply proper management practices, it is of critical importance that the processes that control the surface water chemistry be well-understood.

10.1 Surface Water in South Africa: General Characteristics

The relationship between climatic factors, weathering and water chemistry is illustrated in Figure 30. In South Africa the natural water chemistry is typically controlled by chemical weathering of the bedrocks – which contribute, in particular, calcium (Ca), magnesium (Mg), silicon (Si) and bicarbonate ($H CO_3^-$).

Vogel (2000) states that a high variation in rainfall exists in the arid to semi-arid South African climate. Because annual evaporation exceeds rainfall, where Weaver and others (1999) state that only 8.6 % of the annual rainfall is available as surface water, Miller (2000) identifies that South Africa is situated in a negative run-off zone. Surface waters in South Africa are generally highly saline as a result of these climatic conditions (Figure 30). Typically, South African surface waters hold high concentrations of calcium, magnesium and sodium, chloride and bicarbonate (reflected as total alkalinity).

Day and others (1998) state that natural waters tend to be chemically similar in geographic regions. Characteristically the groundwater in the [study] region is highly mineralised chloride-sulphide water with the dominant geological features being Karoo sediments. Day and others (1998) also recognise that rivers in the region have waters in which calcium, magnesium and sodium cations are approximately co-dominant but the major anion is bicarbonate – and subsequently this is presented in their categorisation of rivers.

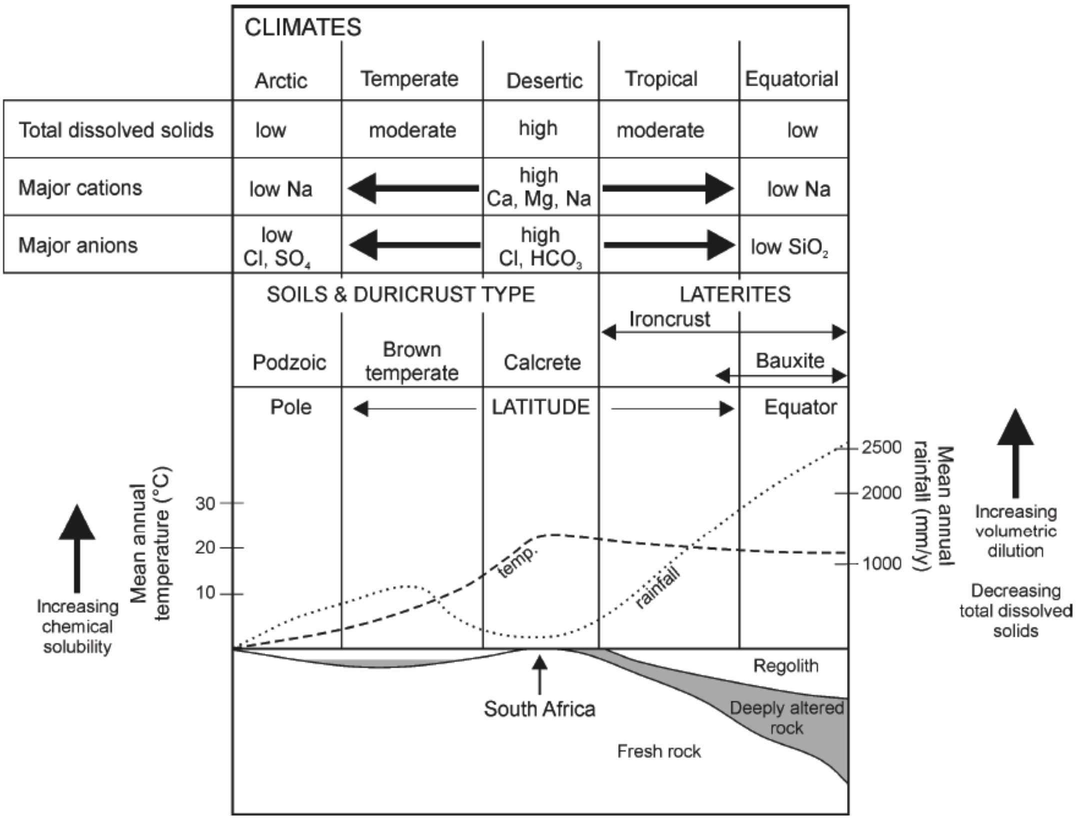


Figure 30. Showing the relationship between climatic factors, weathering and water chemistry (Huizenga, 2004 adapted from Plant *et al.*, 2001).

The occurrence of the above-mentioned ion species increase the propensity of development of acid mine drainage. Acid mine drainage is discussed in detail in *section 9.7 Acid Mine Drainage.*

10.2 Evaluation of water quality data in the Olifants River Catchment

Inorganic water chemistry data were commercially obtained from the Council for Scientific and Industrial Research (CSIR) (Environmentek) as: "Water Quality on Disc, version 1.0". The CD contains water quality data for the 2068 monitoring sites in South Africa spread over the different primary catchment areas. Water samples are routinely collected as part of the National Water Quality Monitoring Programme and chemically analysed at the Institute for Water Quality Studies. The water quality data on the disc includes pH, total alkalinity (measured as CaCO3 in mg/L) and the concentrations of the following major chemical species: sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), ammonium (NH_4^+), silicon (Si), fluoride (Fl^-), orthophosphate (PO_4^{3-}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and total dissolved solids (TDS) (all in mg/L).

For the current study, five monitoring stations in the area of interest were selected. These stations are representative of the variety of different water chemistries typical in the area. All of the monitoring stations fall within Mpumalanga's Olifants Water Management Area (WMA) and the Upper Olifants River Catchment. Monitoring stations and the numbers of analyses used are indicated in Table 22 (a). The water quality gathered historically will be assessed and compared to current water quality.

Table 22. (a) Number of analyses for each sample site for specified period.

Monitoring station	Monitoring period	Number of analyses
Klipspruit at Zaaihoek (B1 H004 Q01)	1976 - 1999	580
Middelburg Dam on Little Olifants River (B1 H015 Q01)	1983 -1999	699
Koringspruit at Vaalkranz (B1 H020 Q01)	1990 - 1999	423
Tweefonteinspruit at Tweefontein (B1 H031 Q01)	1990 – 1996	68
Blesbokspruit at Blesbok (B1 H032 Q01)	1998 - 1999	43

10.3 Methodology

As mentioned in *section 10.2 Evaluation of water quality data in the Olifants River Catchment,* water chemistry data were commercially obtained from the Council for Scientific and Industrial Research (CSIR) (Environmentek) as: "Water Quality on Disc, version 1.0". The water quality data on the disc includes pH, total alkalinity (measured as CaCO3 in mg/L) and the concentrations of the following major chemical species: sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), ammonium (NH_4^+), silicon (Si), fluoride (Fl^-), orthophosphate (PO_4^{3-}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) and total dissolved solids (TDS) (all in mg/L). Appendix A shows data for the selected sampling stations as well as the dates for which they were monitored. Heavy element concentrations [e.g. magnesium (Mg), iron (Fe), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn) and lead (Pb)] were determined from samples collected in 2010. The following sample stations were used for evaluation as they are representative of the variety of different water chemistries typical in the area:

- Klipspruit at Zaaihoek (B1Q004H01)
- Middelburg Dam on Little Olifants River (B1H015Q01)
- Koringspruit at Vaalkranz (B1H020Q01)
- Tweefonteinspruit at Tweefontein (B1H031Q01)
- Blesbokspruit at Blesbok (B1H032Q01)

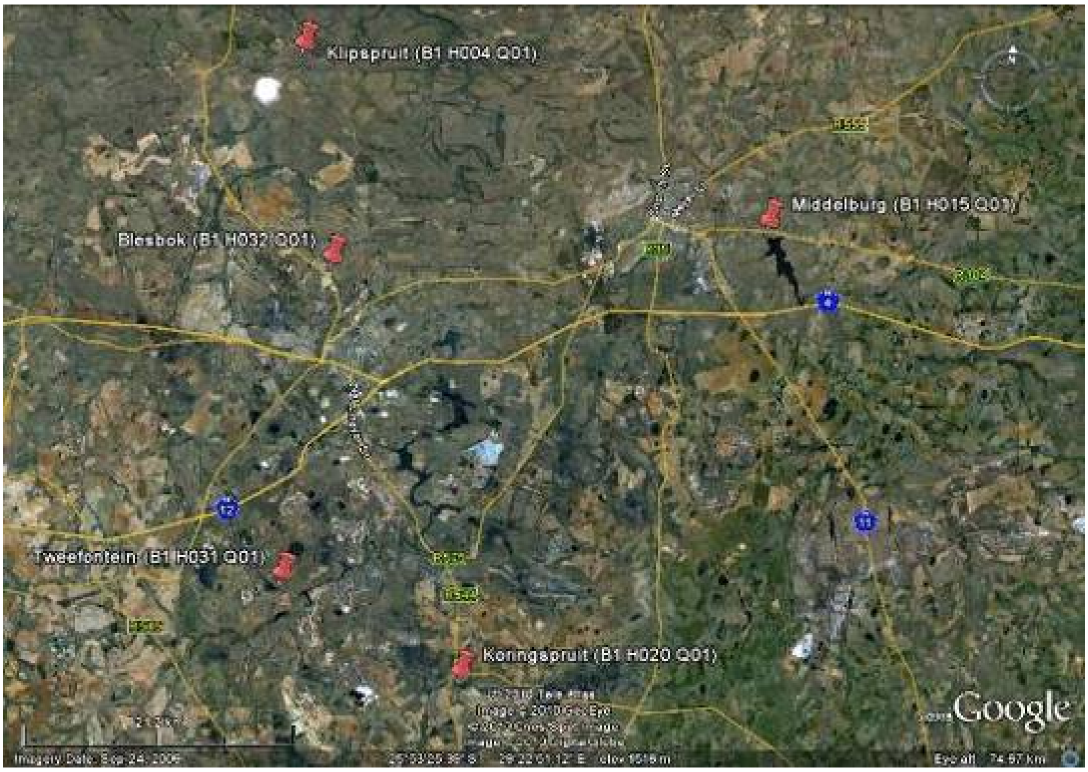


Figure 31. The location of the five selected stations (Google Earth, 2009).

Sample Collection and Analysis

The objective of sample collection and analysis was to test the hypothesis of the current study; the objective was not to augment existing data. The focus of the sample collection and analysis was on surface water as historic data was available. Historic data for groundwater conditions were unavailable to the author for use in this minor dissertation. In addition, physical parameters were analysed rather than chemical parameters owing to limited access to laboratory facilities and study funding.

A field excursion was conducted to collect samples during the dry, winter month of August. Water samples were collected using 100ml translucent, screw-top, polyethylene sample collection bottles (the bottles were prepared by rinsing thrice with distilled water). Water samples were taken from the centre of streams. The bottle was filled with water from the stream, the cap securely screwed on before shaking the bottle for approximately 5seconds then discarding the water - This was repeated three times taking care as not to disturb the sediments before or during the collection. The fourth cycle when the bottle was filled, the sample was retained and numbered. The samples were stored in a refrigerator before being transport to the laboratory for Inductively Coupled Plasma Mass-Spectrometry (ICPM-S) analysis. Three drops of ultra pure nitric acid was added to several of the samples (individualised in the sections which follow). Water samples were analysed using ICPM-S at Eco-Analytica Laboratories, Potchefstroom, South Africa. Appendix B shows the results of the ICPM-S analysis.

Readings of water parameters were taken *in situ* using a Hanna Instruments 9828 Multiparameter System. The instrument measures pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP) and dissolved oxygen (DO). The multi-sensor probe was lowered into the centre of the stream, taking care as not to disturb the sediments before or during the reading whilst ensuring that the multi-sensor probe was completely submerged. The multi-sensor probe was cleaned using distilled water between each successive sample and returned to its calibration solution filled housing case when not in use. *In situ* readings (presented in Appendix C) were taken at the spot where water samples were collected and their Global Positioning System (GPS) co-ordinates were recorded (presented in Appendix D). Table 22 (b) shows the results of water quality for selected sampling stations.

Table 22. (b) Water quality results for selected sample stations

Station	**Temper-ature (°C)**	**pH**	**Electrical Conduc-Tivity (µs/cm)**	**Oxidation - Reduction Potential**	**Dissolved Oxygen Content (ppm)**	**Total Dissolved Solids (ppm)**
Klipspruit at Zaaihoek (B1 H004 Q01)	13	3.44	8.91	6.78	0	446
Middelburg Dam on Little Olifants River (B1 H015 Q01)	15	8.46	13.84	0.38	0	691.2
Koringspruit at Vaalkranz (B1 H020 Q01)	14.2	7.46	922.8	-0.56	0	460.2
Tweefonteinspruit at Tweefontein (B1 H031 Q01)	N/A	N/A	N/A	N/A	N/A	N/A
Blesbokspruit at Blesbok (B1 H032 Q01)	13.27	3.21	12.46	50.46	0	629.8

a) Klipspruit at Zaaihoek (B1 H004 Q01)

Readings taken from the stream (Figure 32) show an average temperature of 13°C, pH of 3.44, electrical conductivity (EC) of 8.91 µs/cm, oxidation-reduction potential (ORP) of 6.78, dissolved oxygen content of 0ppm and total dissolved solid (TDS) content of 446ppm (Appendix C). White, microcrystalline precipitate found in places along banks (attached to gravel). No bedrock outcroppings or precipitate on rocks were observed, though cobble to boulder sized debris is present nearby (Figure 33).

Figure 32. Showing Klipspruit and a portion of the stream sampled (field of view 3m).

Figure 33. Showing rock debris from road construction in vicinity of Klipspruit.

b) Middelburg Dam on Little Olifants River (B1 H015 Q01)

Algae is present in the river; readings taken (Figure 34) show an average temperature of 15°C, pH of 8.46, EC of 13.84 µs/cm, ORP of 0.38, DO content of 0ppm and TDS content of 691.20ppm (Appendix C). Grey-coloured, microcrystalline precipitate occurred scarcely and was formed on soils near the water's edge. Sandstone outcrops were fairly common on the western bank of the portion of the river sampled (Figure 33).

Figure 34. Showing Little Olifants River and a portion of the river sampled (width of stream 5m from bank to bank).

Figure 35. Rock outcrop along western bank of Little Olifants River near sampling sites.

c) Koringspruit at Vaalkranz (B1 H020 Q01)

Readings taken for Koringspruit (Figure 36) show an average temperature of 14.20°C, pH of 7.46, EC of 922.80 µs/cm, ORP of -0.56, DO content of 0ppm and TDS content of 460.20ppm (Appendix C). Outcrops were absent and soils were exposed as vegetation is scarce (Figure 36). A very thin layer of white-coloured, microcrystalline precipitate was found on gravel (though scarcely so) in close proximity to the water's edge.

Figure 36. Showing portion of the stream sampled (width of stream 7m from bank to bank).

d) Tweefonteinspruit at Tweefontein (B1 H031 Q01)

Tweefonteinspruit was completely dry in all readily accessible points and grassy vegetation prevented any exposure of outcropping bedrock. Subsequently no samples were collected.

e) Blesbokspruit at Blesbok (B1 H032 Q01)

Access to the stream discovered near to human settlement and algae is present in the stream. Readings taken from the stream (Figure 37) show an average temperature of 13.27°C, pH of 3.21, EC of 12.46 µs/cm, ORP of 50.46, DO content of 0ppm and TDS content of 629.80ppm (Appendix C). Outcrops absent and a fair amount of rubble and litter in the area; white-coloured, microcrystalline precipitate found in patches at the water's edge.

Figure 37. Showing Blesbokspruit and a portion of the stream sampled (width of stream 7m bank to bank).

10.4 Stiff diagrams

Concentration of solutes and the proportion of ionic species in relation to one another are represented in ion concentration diagrams. Specifically, the pattern of anions and cations in water can be shown using *Stiff diagrams* (Stiff, 1951).

Regional groundwater monitoring systems commonly makes use of the Stiff plotting technique, proposed and described by Stiff (1951). Horizontal lines extend right and left from a vertical line at zero to form the graph and positive ions (cations) are plotted to the left while negative ions (anions) are plotted to the right (Stiff, 1951). Ion concentrations are plotted in milliequivalents per litre (meq/L) in such a way that the concentration of ionic species increases with increasing distance from the vertical axis. An irregular, polygonal shape is produced; one of the distinct features of Stiff plotting is the inclination of the pattern to maintain its characteristic shape – even as the sample becomes more and more dilute. The pattern thus reveals both the total salt concentration as well as the chemical composition of the water (Stiff, 1951).

Stiff diagrams are regarded as a straightforward, practical means of characterising and comparing groundwaters (Stiff, 1951) because the diagrams allow a speedy inspection of water chemistry by considering

- The shape of the diagram (which shows the concentrations of the different species relative to each other) and
- The width of the diagram (which shows absolute concentrations of the different species).

Stiff diagrams have been utilised in the current study due to the ease with which they can be created and read and are done in accordance with the methodology in Huizenga (2004).

Piper and expanded Durov diagrams may also be used as they allow for the classification and inference of hydrogeochmeial processes occurring in the groundwater system, subsequently, the use of these methods are highlighted in literature e.g. DWAF (2008) ‘Minimum requirements for water monitoring and waste management facilities’.

Table 23. Average world river composition (from Huizenga, 2004; Meybeck, 1985), recalculated into mmol/l and meq/l. Normal range in unpolluted fresh water and potential sources are indicated (Appelo and Postma, 1993).

Species	**World river composition**			**Normal range**	**Source**
	mg/L	**mmol/L**	**meq/L**	**(mg/L)**	
Na^+	8.5	0.37	0.37	2 – 46	Feldspar, rock-salt, zeolite, atmosphere
K^+	1.5	0.04	0.04	0.5 – 8	Feldspar, mica
Ca^{2+}	15.0	0.37	0.75	2 – 200	Carbonate, gypsum, feldspar, pyroxene, amphibole
Mg^{2+}	3.9	0.16	0.32	1 – 50	Dolomite, serpentine, pyroxene, amphibole, olivine, mica
NH_4^+	0.02	0.00	0.00	-	-
SiO_2	10.4	0.17	0.69	1 – 60	Silicate minerals
F^-	-	-	-	-	Fluorite
PO_4^{3-}	0.01	0.00	0.00	0 – 2	Organic matter, phosphate minerals (apatite)
Cl^-	10.5	0.30	0.30	2 – 70	Rock-salt, atmosphere
HCO_3^-	53	0.87	0.87	0 – 300	Carbonate minerals, organic matter
SO_4^{2-}	12.3	0.13	0.26	1 – 500	Atmosphere, gypsum, sulphide minerals
NO_3^{2-}	0.1	0.00	0.00	0.1 - 2	Atmosphere, organic matter

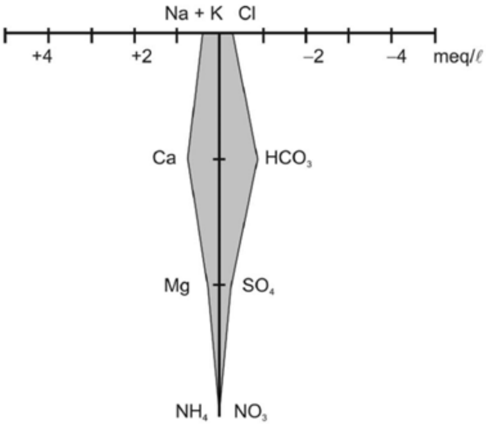
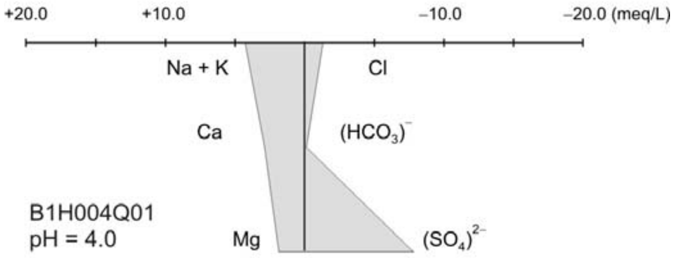


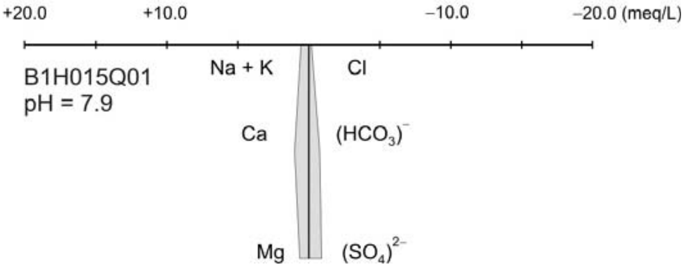
Figure 38. Stiff diagram for average world river composition (Huizenga, 2004).

Stiff diagrams for the five monitoring stations are shown in Figure 39 (a) to (e).

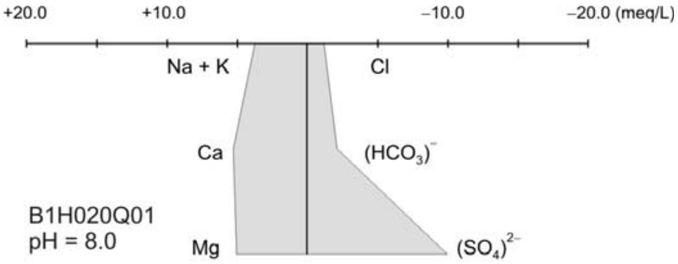
a) Klipspruit at Zaaihoek (B1Q004H01)



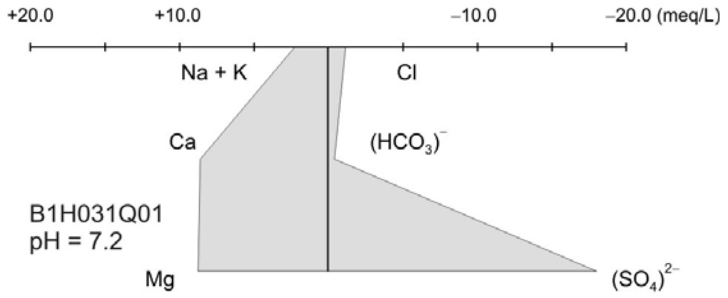
b) Middelburg Dam on Little Olifants River (B1H015Q01)



c) Koringspruit at Vaalkranz (B1H020Q01)



d) Tweefonteinspruit at Tweefontein (B1H031Q01)



e) Blesbokspruit at Blesbok (B1H032Q01)

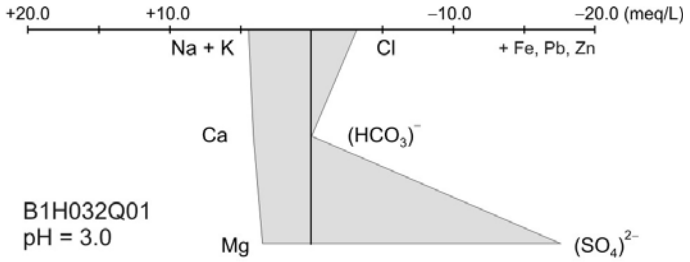


Figure 39. (a) to (e) Stiff diagrams for the sample stations.

Six components were compared at each site i.e. sodium + potassium, calcium, magnesium, chloride + iron + lead + zinc, alkalinity and sulphate.

Literature (e.g. Zaporozec, 1972) suggests alternate groupings of components, i.e. sodium + potassium; alkalinity + carbonate; chloride, fluoride + nitrates but this format was not possible owing to different constituents being considered.

Groundwater with similar major ion ratios shows the same geometry / shape in their Stiff diagrams as shown by stations B1H004Q01 and B1H032Q01 ; B1H020Q01 and B1H031Q01 respectfully.

At stations B1H004Q01, B1H031Q01 and B1H032Q01 sulphates dominate over chloride-iron-lead-zinc and bicarbonate; while at station B1H020Q01 there is a greater concentration of sulphates and bicarbonate than over chloride-iron-lead-zinc.

Stations B1H004Q01 and B1H032Q01 have a dominance of sodium which exceeds its calcium and magnesium content. This contrasts with B1H031Q01 and B1H020Q01 where calcium and magnesium are the dominant cations.

The Stiff diagram for B1H015Q01 has a unique shape compared to the other stations. The Stiff diagram much more closely resembles the Stiff diagram for the average world composition (Figure 38). The diagram is markedly narrower than the other stations, indicating lower absolute concentrations of ions. The comparison of data from station B1H015Q01 to the average world composition provides enlightenment to the state of the water from the sample station and it's potential role in the hydrogeological cycle. The resulting concepts and discussion are out of the scope of this study, but are recognised as having potential value in future studies.

The concentration of bicarbonate (i.e. total alkalinity) is higher than that of sulphate and chloride-iron-lead-zinc anions, while the concentration of calcium is higher than that of sodium + potassium and magnesium cations.

10.5 Discussion

The data utilised in the current study focuses on physical parameters as an indication of water quality. pH was viewed as a dominant factor in the study and while alternatives for evaluation are possible (e.g. using a time series plot of pH to establish trends) Stiff diagrams where selected for use. The similarities and contrasts in shape of the Stiff diagrams allow for quick comparison of data. The diagrams identify waters with unique signatures and clearly show the dominant constituents at each site (Grobbelaar *et al.*, 2004).

South African rivers should possess a pH of 8 (Huizenga, pers. comm., 2011), and when keeping in mind the characteristic shape of the Stiff diagram for "clean" water (i.e. unpolluted water) (Figure 38) the monitoring stations considered in the current study show the following:

The most noticeable chemical characteristics for station B1H004Q01 are the intermediate sulphate concentration and low pH value as well as low concentrations of chloride, sodium and magnesium. This indicates that **dilution** has taken place at station B1H004Q01.

The most noticeable chemical characteristics for station B1H020Q01 are the sulphate concentration and pH value of 8.0 combined with higher calcium and magnesium content. An increase in concentration of dissolved calcium and magnesium results from neutralisation by dolomite and is accompanied by an increase in pH while sulphate concentration does not change. This indicates that **dilution** as well as **neutralisation** has taken place at station B1H020Q01.

The most noticeable chemical characteristics for station B1H031Q01 are the high concentrations of calcium and magnesium and near-neutral pH. As for station B1H020Q01, an increase in concentration of dissolved calcium and magnesium results from neutralisation by dolomite and is accompanied by an increase in pH while sulphate concentration does not change. This indicates that **neutralisation** has taken place at station B1H031Q01.

The most noticeable chemical characteristics for station B1H032Q01 are the low pH value, sulphate concentration and intermediate concentrations of calcium and magnesium which indicate that **neutralisation** has taken place at station B1H032Q01. In contrast to all the other stations, station B1H015Q01 has low concentrations of all cations and anions combined with near-ideal pH. These chemical characteristics reveal station B1H015Q01 is **unaffected by pollution**.

The relationship between the cations and anions illustrated by Stiff diagrams is the same for stations B1H004Q01 and B1H032Q01; B1H020Q01 and B1H031Q01 respectfully. Station B1H015Q01 shows unique chemical traits compared to all the other stations.

Absolute concentration of ions generally decreases south to north (Figure 40) and is attributed to:

- Neutralisation (by underlying dolomite) and

- Dilution (through the addition of water to the system from sources such as other rivers) or
- A combination of the two processes

However, no inferences are made to the nature or location of the main source of pollution as it is outside the scope of the study.

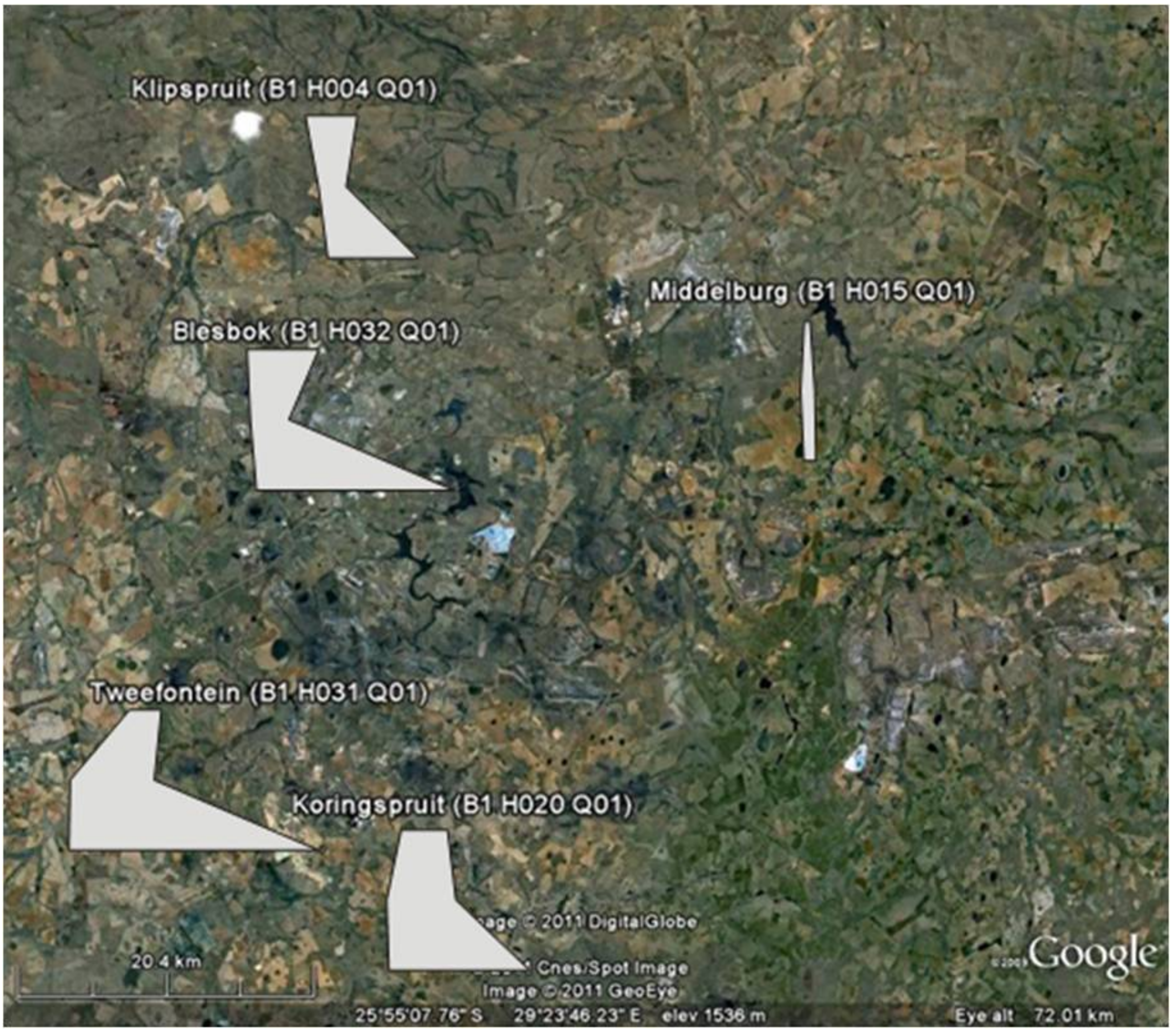


Figure 40. Map of the area showing Stiff diagrams (Google Earth, 2009).

The low pH values and high sulphate concentrations associated with those values are considered typical characteristics for the acid mine drainage (e.g. Huizenga, 2004; Banks *et al.*, 1997 and Bell, 1998) (discussed in *section 9.7 Acid Mine Drainage)* and sustain the concerned opinion regarding the extreme vulnerability of the region's water resources to degradation (Bologo *et al.*, 2009 and Pinetown *et al*, 2007; Gray, 1997; South Africa, 1996 and Whitehead and Jeffrey, 1995).

The parameters considered in the water quality objectives (discussed in *section 8.1 Water Quality*) do not make provision for interactive or dynamic processes such as dilution or neutralisation or a combination of the two when considering the overall and total health of the water resource. The objectives are broadly categorised (Table 24) with the result that *waters affected by acid mine drainage may not be recognised as such*.

Table 24. Comparison of water quality objectives for domestic, industrial and agricultural use of water (DWAF, 19961,2,3).

Water Quality Parameter	**Target Water Quality Range – Domestic Use**	**Target Water Quality Range - Industrial**	**Target Water Quality Range – Agricultural (Irrigation)**
chloride	0 – 100 mg/L	0 - 20 mg/L	0 – 100 mg/L
fluoride	0 - 1.0 mg/L	Not specified	0 - 2.0 mg/L
Nitrate + nitrite	0 – 6 mg/L	Not specified	Not specified
Phosphate	0 - 0.5 mg/L	Not specified	Not specified
Sodium	0 – 100 mg/L	Not specified	0 – 70 mg/L
Sulphate	0 – 200 mg/L	0 - 30 mg/L	Not specified
Total dissolved solids	0 – 450 mg/L	0 - 100 mg/L	0 - 40 mg/L
pH	6.0 - 9.0	7.0 - 8.0	6.5 - 8.4

11 Conclusion

It was hypothesised that the guidelines, policies and regulations in place at this point in time, are sufficiently aiding the coal mining industry in successfully retarding pollution of groundwater resources, and that the geology of the area may indeed be capable of masking pollution because (*in addition* to acid mine drainage) water chemistry may be influenced by water-rock interaction (geohydrology) and dilution (geochemistry). The study has shown that pollution of groundwater resources has not been retarded and that water chemistry is indeed influenced by geohydrology and geochemistry.

Water pollution is attributed to mine water contamination from mining of the Witbank Coalfields. The pollution has resulted in low pH, high sodium, high chloride and high sulphate concentrations present at monitoring stations on the Klipspruit, Koringspruit, Tweefonteinspruit and Blesbokspruit which fall in the Olifants Water Management Area. Through the processes of dilution, neutralisation and a combination of the two, waters affected by acid mine drainage are not always recognised as such.

In order to achieve effective, meaningful and sustainable management of water resources in the Olifants River Catchment, fundamental processes (e.g. dilution) affecting polluted water resources need to be properly understood and incorporated into relevant literature. Comparing data from the current study against historical, monitoring data of selected monitoring stations within the Olifants Water Management Area, it was shown that water quality has not necessarily improved over time.

Just as the South African Code For The Reporting Of Exploration Results, Mineral Resources And Mineral Reserves (SAMREC) Code embodies the principles of materiality, transparency and competency; so too do the National Water Act (Act 36 of 1998) and National Environmental Act (Act 107 of 1998) and Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) strive to maintain a framework of accountability as well as value addition to national assets.

The protection and management of natural resources is vital to achieve sustainability. Adequate management is achieved through the implementation of current best practices and legislation. Benefits to the mining industry and society as a whole are vast and may still be achieved in a supportive but strict regulatory environment.

12 Opportunities for future research

This study has considered the general role and influence of management practices as well as mineral- and environmental legislation on the Olifants River Catchment.

Several focal points from a complex and broad subject have been presented here and have led to a several new questions which may be considered for further investigation:

1. Dolomite is the source material for neutralisation – considering the extensive amount of mining that has already taken place,
    a. What is the volume of water that has already been neutralised?
    b. How much dolomite is left to continue neutralising contaminated waters?
2. What are the individual contributions (per colliery) to polluted groundwaters?
    a. Can pollution be attributed historically to specific collieries?
    b. Can pollution be predicted per colliery? If so, what options exist for hazard mitigation?
3. Do mining companies have sufficient access to knowledge and support regarding methods / techniques to prevent the formation of acid mine drainage (and subsequently decrease pollution of water resources)
4. Should the State adopt a more aggressive stance regarding "the polluter pays" principle?
5. Legislation is continuously being revised with the aim of improved environmental protection, however, are policy makers sufficiently prepared to address the multifaceted considerations of such dynamic economic-social-environmental interactions?
6. Conservation of assets can be achieved in a number of ways - the critical issue is to find the balance where value and reward are equitable.
    a. What are the most beneficial investments into society that mining companies can make in their respective mining regions?
    b. Should mines be forced to make investments into society? If so, to what extent?
7. What are the potential long-term impacts on the mining industry (traditionally a capital-intensive industry) if profits are taken from operations and shareholders

and redirected into community and environmental projects, instead of being channelled into further mineral resource exploration projects and / or the expansion of existing mining operations?

13 References

Andrews-Speed, P. and Rogers, C.D. (1999). Mining taxation issues for the future. *Resources Policy*, **25**, 221-227.

Anglo American. (2009). Anglo American Public Limited Company Fact Book 2008/2009. p82.

Appelo, C.A.J. and Postma, D. (1993). Geochemistry, groundwater and pollution. Rotterdam: A.A. Balkema Publishers. 649pp.

ASTM (American Society for Testing Materials). (1981). D388 - 12 Standard Classification of Coals by Rank. 7pp.

Banerjee, S.C., 1985. Spontaneous Combustion of Coal and Mine Fires. Balkema, Rotterdam, p. 18.

Banks, D., Younger, P.L., Arnesen, R-T., Iversen, E.R. and Banks, S.B. (1997). Mine water chemistry: the good, the bad and the ugly. Environmental Geology, 32, 157-174.

Bell, F.G. (1998). Environmental Geology: Principles and Practice. Blackwell Science Ltd Oxford England. p262 -264.

Bell, F.G., Bullock, S.E.T., Ha¨lbich, T.F.J. and Lindsay, P. (2001). Environmental impacts associated with an abandoned mine in the Witbank Coalfield, South Africa. International Journal of Coal Geology, 45**,** 195–216.

Boggs, S. (2006). Principles of Sedimentology and Stratigraphy, Fourth Edition. London: Prentice Hall. 662 pp.

Bologo, G., Maree, J.P. and Zvinowanda, C.M. (2009). Treatment of acid mine drainage using magnesium oxide. International Mine Water Conference, 19th – 23rd October 2009, Pretoria, South Africa, p371 – 380.

Bowen, R. (1980). Groundwater. Applied Science Publishers Ltd, England. p79-86.

Bredell, J.H. (1987). South African Coal Resources explained and analysed: Report Geological Survey of South Africa, 0154. 39pp.

British Geological Survey (BGS). (2007). Mineral Profile: Coal. Keyworth, Nottingham: British Geological Survey, 28pp.

Brundtland Commission, (1987). Our Common Future. United Nations World Commission on Environment and Development (WCED), 1987 March 20. Oxford: Oxford University Press. p24-25.

Cadle, A.B., Cairncross, B., Christie, A.D.M and Roberts, D.L. (1993). The Karoo Basin of South Africa: type basin for coal-bearing deposits of southern Africa. *International Journal of Coal Geology*, **23**, 117-157.

Cairncross, B., (1990). Tectono-sedimentary settings and controls of the Karoo Basin Permian coals, South Africa. *International Journal of Coal Geology*, **16**, 175–178.

Callaghan, C.C. (2009). Beneficiation in South Africa (with image credits to De Beers Group; Anglogold and Mintek). MSc. Lecture at the University of Pretoria, South Africa, October 2009 (unpublished). p15-23.

Catuneanu, O., Hancox, P.J. and Rubidge, B.S. (1998). Reciprocal flexural behaviour and contrasting stratigraphies: a new basin development model for the Karoo retroarc foreland system, South Africa, *Basin Research*, **10**. 417-439.

Chapman, B.M., Jones, D.R., Jung, R.F., (1983). Processes controlling metal ion attenuation in acid mine drainage streams. *Geochim. Cosmochim. Acta*, **47**, 1957-1973.

Chelin, M.A. (2000). An assessment of water management issues facing the coal mining industry of the Witbank and Middelburg Dam catchments. Pretoria; UP. (Dissertation – M.Sc.) 138pp.

Coaltech. (2010). Guidelines on small-scale coal mining in South Africa. 32pp (accessed from http://coaltech.csir.co.za/smallscale/Small-scaleCoal.pdf ; last accessed February 03, 2010).

CSIR (Council for Scientific and Industrial Research). (2010). State of Rivers Report: Crocodile Sabie/Sand and Olifants Rivers (accessed from http://www.csir.co.za/rhp/state_of_rivers/crocsabieolif_01_toc.html ; last accessed May 19, 2010)

Cravotta, C.A. III, K.B.C. Brady, A.W. Rose, and J.B. Douds. (1999). Frequency distribution of the pH of coal-mine drainage in Pennsylvania - Mineralogy and chemistry. *In* D.W. Morganwalp and H. Buxton (ed.) U.S. Geological Survey Toxic Substances Hydrology Program—Proc. Technical Meeting, Charleston, SC. 8–12 Mar. 1999. Water- Resources Investigations Rep. 99-4018A. USGS, Reston, VA, 313–324.

Day, J. A., Dallas, H. F. and Wackernagel A. (1998). Delineation of management regions for South African rivers based on water chemistry. *Aquatic Ecosystem Health and Management* **1**, 183-197.

De Beer, M. (2005). Treatment of acid mine drainage and acid effluents. Potchefstroom; NWU. (Dissertation – M.Sc.). 81pp.

De Villiers, S and De Wit, M. (2010). H_2O-CO_2-Energy equations for South Africa: Present status, future scenarios and proposed solutions. AEON (Africa Earth Observatory Network) Rondebosch, Cape Town. 48pp.

DACE (Department of Agriculture, Conservation and Environment). (1999) Draft Mpumalanga State of the Environment Report. 136pp.

DACE (Department of Agriculture, Conservation and Environment).). (2003) Mpumalanga State of the Environment (SOE) Report. 178pp.

DEAT (Department of Environmental Affairs and Tourism). (1996). South African Water Quality Guidelines (second edition) Volume 1: Domestic Use. 214pp.

DEAT (Department of Environmental Affairs and Tourism). (1999). National State of the Environment Report (NSoER) on Internet for South Africa (accessed from http://www.ngo.grida.no/soesa/nsoer/issues/water/index.htm; last accessed February 03, 2010).

DEAT (Department of Environmental Affairs and Tourism). (2007). Best Practice Guideline A2: Water management for mine residue deposits. 87pp.

DWAF (Department of Water Affairs and Forestry). (1996)[1]. South African Water Quality Guidelines (second edition). Volume 1: Domestic Use. Holmes, S. (ed). 214pp.

DWAF (Department of Water Affairs and Forestry). (1996)[2]. South African Water Quality Guidelines (second edition), Volume 3: Industrial Use. Holmes, S. (ed). 122pp.

DWAF (Department of Water Affairs and Forestry). (1996)[3]. South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Irrigation. Holmes, S. (ed). 194pp.

DWAF (Department of Water Affairs and Forestry). (2002). National Water Resource Strategy - Proposed First Edition. 40pp

DWAF (Department of Water Affairs and Forestry). (2004) Olifants Water Management Area (WMA) Internal Strategic Perspective (ISP) Version 1, PWMA 04/000/00/0304. 58pp.

DWAF (Department of Water Affairs and Forestry). (2007). Best Practice Guideline A2: Water Management For Mine Residue Deposits. 87pp.

DWAF (Department of Water Affairs and Forestry). (2008). Minimum requirements for water monitoring and waste management facilities. 68pp.

DME (Department of Minerals and Energy). (2008). South African Minerals Industry (SAMI) 2007/2008. p iv, 1-5.

DME (Department of Minerals and Energy). (2010). Coal. 3pp (accessed from http://www.dme.gov.za/energy/coal.stm ; last accessed February 03, 2010)

Eriksson, P.G., Altermann, A. and Hartzer, F.J. (2006). The Transvaal Supergroup and its precursors. In: Johnson, M.R. Anhaeusser, C.R. and Thomas R.J. (Eds.) *The Geology of South Africa.* Geological Society of South Africa, Johannesburg / Council for Geoscience, Pretoria, p244.

Falcon, R.M.S. (1986). A brief review of the origin, formation and distribution of coal in Southern Africa. In Anhausser, C.R. and Maske, S. (Eds). *Mineral Deposits of Southern Africa - Volume II.* Geological Society of South Africa, Johannesburg. p1879-1898.

Gaigher, J. L. (1980). The mineral matter in some South African coal. M.Sc thesis (unpublished), University of Pretoria, South Africa, 60 pp.

Geldenhuis, S.J.J. and Harpley, D.P. (1989). *Waste Disposal , Groundwater Quality And Rehabilitation – A South African Perspective.* Groundwater and Mining: Proceedings of the 5th Biennial Symposium of the Groundwater Division, Geological Society of South Africa; Randburg, South Africa, July 21 – August 04, 1989. p249-256.

Glasser, D. and Bradshaw, S.M. (1990). Spontaneous combustion in beds of coal. In: Cheremisin Off, N. (Ed.), Handbook of Heat and Mass Transfer: 4 Advances in Reactor Design and Combustion Science, Chapter 26, NJ Gulf, p. 1071.

Google Earth (version 5.1.3533.1731) [software]. (2009). Google Incorporated, Mountain View, California, USA. Available from http://www.google.com/earth/download-earth/html.

Gray, N. F. (1997). Environmental impact and remediation of acid mine drainage: a management problem. *Environmental Geology*, **30**, (1-2), 62 -71.

Grobbelaar, R., Usher, L_M., Cruywagen, E., de Necker, E. and Hodgson, F.D.I. (2004). Long-term impact of intermine flow from collieries in the Mpumalanga Coalfields. Water Research Commission report number 1056/1/04. p9.

Grodner, M. And Cairncross, B. (2003). A regional scale 3D model of the Witbank Coalfield, Northern Karoo Basin, South Africa. *South African Journal of Geology*, **106**, 249 – 264.

Hohls, B.C., Silberbauer, M.J., Kühn, A.L., Kempster, P.L. and van Ginkel, C.E. (2002). *National Water Resource Quality Status Report: Inorganic Chemical Water Quality of Surface Water Resources in SA –- The Big Picture.* Report No. N/0000/REQ0801. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa. 96pp.

Hordijk, L and Kroeze, C. (1997). Integrated assessment models for acid rain. *European Journal of Operational Research*, **102**, 405-417.

Huizenga, J.M. (2004). Natural and anthropogenic influences on water quality: an example from rivers draining the Johannesburg Granite Dome. Johannesburg: UJ. (Mini-Dissertation – MSc.). 83pp.

Huizenga, J.M. (2011). Personal communication, unpublished.

Ikaneng, M. (2008). Coal. In Department of Minerals and Energy: Directorate of Mineral Economics: South African Minerals Industry (SAMI) 2007/2008. p42-47.

Jordaan, J. (1986). Highveld coalfield, 1985-1994. *Irr.* Anhaeusser, C. R., and Maske, S. (Eds), *Mineral Deposits of Southern Africa,* I. Geol. Soc. S. Afr., 1020 pp

Johnson, C.A. (1986). The regulation of trace element concentrations in river and estuarine waters contaminated with acid mine drainage: The adsorption of Cu and Zn on amorphous Fe oxyhydroxides. *Geochim. Cosmochim. Acta*, **50**, 2433 - 2438.

Johnson, M.R., van Vuuren, C.J., Visser, J.N.J, Cole, D.I., de V Wickens, H. Christie, A.D.M. and Roberts, D.L. (1997). The foreland Karoo Basin. In: Selley, R.C. (Ed.) *Sedimentary Basins of Africa.* Elsevier, Amsterdam, p269-317.

Johnson, M.R., van Vuuren, C.J., Visser, J.N.J, Cole, D.I., de V Wickens, H. Christie, A.D.M., Roberts, D.L. and Brandl, G. (2006). Sedimentary rocks of the Karoo Supergroup. In: Johnson, M.R. Anhaeusser, C.R. and Thomas R.J. (Eds.) *The Geology of South Africa.* Geological Society of South Africa, Johannesburg / Council for Geoscience, Pretoria, p461 – 499.

Lang, J., (1995). Coal Mining in the Life of South Africa: Power Base. Jonathan Ball Publishers, Johannesburg, p231.

Lurie, J., (1987). South African Geology for Mining, Metallurgy, Hydrological and Civil Engineering, Revised Lexicon Edition, Lexicon Publishers, 342pp.

Loos, M.A., Cleghorn, C. and Mödinger, H. (2000). Occurrence of bacteria causing acid mine drainage in the outer layers of coal waste dumps in relation t abiotic ecological determinants and soil covers used for dump rehabilitation. Water Research Commission report number 454/1/2000. 157pp.

Lusher, J.A. and Ramsden, H.T. (2000). Water Pollution. In: Fuggle, R.F and Rabie, M.A., (Editors), in *Environmental Management in South Africa*, (third impression). Juta and Co. Ltd., Cape Town, 456-492.

McCarthy, T.S. and Rubidge, B. (2005). The story of Earth and life. Struik Pulishers, Cape Town, 333pp.

McCarthy, T.S. and Pretorious, K. (2009). Coal mining on the Highveld and its implications for future water quality in the Vaal River System. The International Mine Water Conference 2009 October 19-23, Pretoria, South Africa. p56-65.

Meybeck, M**.** (1985). How to establish and use world budgets of river material. In : *Physical and Chemical Weathering in Geochemical Cycles*, Lerman, A and Meybeck, M (eds). NATO Advanced Study Institute Series vol. 251. Dortrecht: Kluwer Academic Publishers. p247-272.

Miller, G.T. (2000). Living in the environment. Principles, connections and solutions 12th edition. Belmont: Wadsworth Publishing Company. 758pp.

Mining Mirror. (2009). Seizing the window of opportunity. p26-31.

Mining Weekly (2010). Growth in China and India to shift global thermal coal trade. (accessed from http://www.miningweekly.com/article/growing-demand-from-china-and-india-to-shift-thermal-coal-trade-2010-10-19; last accessed February 21, 2011).

Moolman, C., (2004). The spontaneous combustion challenges in mining old coal pillar workings from surface. Final Proceedings of the International Conference on Spontaneous Combustion. Fossil Fuel Foundation and SABS, Johannesburg, South Africa, p11–18.

Murad, E. and Rojik, P. (2004). Jarosite, schwertmannite, goethite, ferrihydrite and lepidocrocite: the legacy of coal and sulphide ore mining. In *Supersoil 2004: 3rd Australian New Zealand Soils Conference*, 5-9 December 2004, University of Sydney, Australia. p1-8.

Perman, R., Ma, Y., McGilvery and Common, M. (1999). Natural Resource and Environmental Economics, Second Edition. Pearson Education Limited, England. p16-20 and 184-186.

Pinetown, K.L., Ward, C.R. and van der Westhuizen, W.A. (2007). Quantitative evaluation of minerals in coal deposits in the Witbank and Highveld Coalfields, and the potential impact on acid mine drainage. *International Journal of Coal Geology,* **70,** 166-183.

Pinheiro, H.J. (2009). MSc. lecture notes: Coal - Origin, Formation and Utilization. (Unpublished). 81pp.

Plant, J., Smith, D., Smith, B. and Williams, L. (2001). Environmental geochemistry at the global scale. *Applied Geochemistry*, **16**, 1291 – 1308.

Pone, J.D.N., Hein, K.A.A., Stracher, G.B., Annegarn, H.J., Finkleman, R.B., Blake, D.R., McCormack, J.K. and Schroeder, P. (2007). The spontaneous combustion of coal and its by-products in the Witbank and Sasolburg Coalfields of South Africa. *International Journal of Coal Geology,* **72,** 124-140.

Pulles, W., Howie, D., Otto, D. and Easton, J. (1995). A Manual on Mine Water Treatment and Management Practices in South Africa, Water Research Commission Report No. TI80/96. 8-19pp.

Pringle, C. (2010). South Africa to undertake coal resource study. Mining Weekly Online (accessed from http://www.miningweekly.com/print-version/south-africa-to-undertake-coal-resource ; last accessed January 28, 2010).

Roberts, M., (2005). South Africa's mineral production and sales 1985–2004. Department of Minerals and Energy Report R50/2005, Pretoria, Republic of South Africa. 20 pp.

Rose, S. and Elliot, W.C. (2000).The effects of pH regulation upon the release of sulphate from ferric precipitates formed in acid mine drainage. *Applied Geochemistry*, **15**, 27 – 34.

SAMREC (The South African Mineral Resource Committee). (2000). South African Code For Reporting Of Mineral Resources And Mineral Reserves (The SAMREC Code). 38pp.

SARW (Southern Africa Resource Watch), Open Society Institute of Southern Africa, Third World Network Africa (TNW Africa), Tax Justice Network Africa, Action Aid International, Christian Aid. (2009). Breaking the Curse: How Transparent Taxation and Fair Taxes can Turn Africa’s Mineral Wealth into Development. Open Society Institute of Southern Africa, Johannesburg; Third World Network Africa, Accra; Tax Justice Network Africa, Nairobi; Action Aid International, Johannesburg; Christian Aid, London. 81pp.

Sawyer, C.N., McCarty, P.L. and Parkin, G.F. (1994). Chemistry for environmental engineering. 4th edition, McGraw-Hill International Editions, 592pp

Silverman, M.P. (1967). Mechanism of Bacterial Pyrite Oxidation. *Journal of bacteriology*, **94** (4), 1046-l05l.

Singh, A.K., Mondal, G.C., Tewary, B.K. and Sinah, A. (2009). Major Ion chemistry, solute acquisition processes and quality assessment of mine water in Damodar Valley Coalfields, India. International Mine Water Conference, 19th – 23rd October 2009, Pretoria, South Africa, p267-276.

Smith, D.A.M., and Whittaker, R.R.L.G., (1986). The Coalfields of southern Africa: an introduction. In: Anhaeusser, C.R., Maske, S. (Eds.), *Mineral Deposits of Southern Africa*. I. Geological Society of South Africa, Johannesburg, 1875–1878.

Smith, R,M,H. (1990). A review of the stratigraphy and sedimentary environments of the Karoo Basin of South Africa. *Journal of African Earth Science*, **16**, 143-169.

Smith, R,M,H., Eriksson, P.G. and Botha, W.J. (1993). A review of the stratigraphy and sedimentary environments of the Karoo-aged basins of southern Africa. *Journal of African Earth Science*, **16**, 143-169.

Snyman, C.P. (1998). Coal. In *The Mineral Resources of South Africa* (M.G.C. Wilson and C.R. Anhausser, eds). Handbook 16, Council for Geoscience, Pretoria, p136-203

South Africa. (1996). Constitution of the Republic of South Africa as adopted by the Constitutional Assembly on 8 May 1996 and amended on 11 October 1996. (B34B-96.) (ISBN: 0-260-20716-7).

South Africa. (1998). National Environmental Management Act 107 of 1998. Pretoria: Government Printer.

South Africa. (1998). National Water Act 36 of 1998. Pretoria: Government Printer.

South Africa. (1999). Regulations on use of water for mining and related activities aimed at the protection of water resources. Government gazette, 408:704. 4 Jun. (Regulation gazette no. 20119).

South Africa. (2002). Mineral and Petroleum Resources Development Act 28 of 2002. Pretoria: Government Printer.

Statistics South Africa (Stats SA). (2007). Mid-year population estimates 2007. Statistical release, P0302, 9pp.

Stenzel, G.J. (2009). Water and Rehabilitation Issues affecting coal mining. South African Colliery Managers Association Northern Regional Meeting, Mpumalanga, South Africa, October 2009. 42pp.

Stiff, H.A. Jr. (1951). The interpretation of chemical water analysis by means of patterns. In: *Journal of Petroleum Technology,* **3** (10), 376-379.

Stracher, G.B., Taylor, T.P., Nolter, M., Vice, D.H., Blake, D.R. and Cerpovicz, P. (2004). Centralia mine fire collecting extravaganza with National Geographic. Geological Society of America Abstracts with Programs **36** (5), 42.

Tankard, A.J., Jackson, M.P.A., Erikson, K.A., Hobday, D.K., Hunter, D.R. and Minter, W.E.L. (1982). Crustal Evolution of Southern Africa. 3.8 Billion Years of Earth History, Springer-Verlag, New-York, USA, 523pp.

Tilton, J.E. (1994). Mining Waste and the Polluter-Pays Principle in the United States. In Eggert, R.G. (*editor*), *Mining and the Environment: International Perspectives on Public Policy*. Resources for the Future, Washington DC, , 172pp.

UNCTAD (United Nations Conference on Trade and Development). (2007). World Investment Report 2007: Transnational Corporations, Extractive Industries and Development. 323pp.

Veevers, J.J., Cole, D.I and Cowan, E.J. (1994). Southern Africa: Karoo Basin and Cape Fold Belt. In Veevers, J.J. and Powell, C.McA. (Eds), *Permian-Triassic Pangean Basins and Foldbelts Along the Panthalassan Margin of Gondwanaland*. Mem. Geol. Soc. Amer., **184**, 223-229.

Vermeulen, P. D. and Usher, B. H. (2005). Sulphate generation in South African underground and opencast collieries. *Environmental Geology,* **49,** 552–569.

Vogel , C. (2000). Climate and climate change: causes and consequences. In Fox, R. and Rowntree, K (eds). The geography of South Africa in a changing world. USA: Oxford University Press. p284-303.

Vorster, C.J. (Coordinator) (2003). Mineral Resource Map showing Coalfields in the Republic of South Africa. Council for Geoscience, Pretoria, South Africa. (One sheet).

Wagner, N.J. and Hlatshwayo, B. (2005). The occurrence of potentially hazardous trace elements in five Highveld coals, South Africa. International Journal of Coal Geology, 63, 3-4, 228-246.

Wardell, K., and Wood, J.C. (1965). Ground instability problems arising from the presence of shallow old mine workings. Proc. Midlands Soc. Soil Mech. Found. England: Birmingham., vol. 7, p7–30.

Wates, J. (1993). *Inadequate or a lack of policy with regard to the effect of mining on the water environment*; Workshop to prioritise mining related water research and technology transfer needs. Situation assessment report no. 06, Wates, Meiring and Barnard, Mpumalanga South Africa, October 22, 1993. 17pp.

Weaver, A., Le Roux, W. and Pretorius, P. (Eds). (1999). State of the environment in South Africa 1999 – an overview. (accessed from http://www.ngo.griba.no/soesa/ ; last accessed February 10, 2011).

Whitehead, P. and Jeffrey, H. (1995). Heavy metals from acid mine drainage - impacts and modelling strategies. In *Man's Influence on Freshwater Ecosystems and Water Use.* International Association of Hydrological Sciences Publication no. 230, 55 – 66.

WCA (World Coal Association). (2010). World Coal Statistics 2009. (accessed from http://www.worldcoal.org/resources/coal-statistics/; last accessed February 21, 2011).

WCA (World Coal Association). (2011). Investing in Energy Infrastructure. Ecoal, January 2011(accessed from http://www.worldcoal.org/resources/ecoal/ecoal-current-issue/investing-in-energy-infrastructure/ ; last accessed February 21, 2011).

WCI (World Coal Institute). (2008). WCI Case study: South Africa, Emalahleni Water Reclamation Project. (accessed from http://www.worldcoal.org/bin/pdf/original_pdf_file/anglo_coal_water_treatment_case_study%2809_06_2009%29.pdf ; last accessed January 07, 2011). 2pp.

Zaporozec, A. (1972). Graphical interpretation of water quality data. Gourndwater, 10 (2), 25pp

WRG (2030 Water Resources Group). (2009). Charting our water - Economic frameworks to inform decision-making. 198pp (accessed from http://www.2030waterresourcesgroup.com/water_full/Charting_Our_Water_Future_Final.pdf ; last accessed February 04, 2010).

14 Appendices

Appendix A. Water data from disk: Averages per year for each year of monitoring period

a) Klipspruit at Zaaihoek (B1 H004 Q01)

Year	PH	CA	MG	K	NA	TAL	CL	F	SI	SO4	TDS
1976	3.28	55.50	24.00	6.10	94.70	0.40	88.80	0.92	4.98	353.15	670.50
1977	3.18	39.00	14.40	5.43	86.00	0.90	74.50	0.81	3.62	262.00	495.00
1978	3.50	49.20	16.70	4.74	63.60	0.00	53.80	0.82	5.88	260.00	472.00
1979	3.07	55.50	20.90	7.82	104.20	0.00	80.30	0.85	4.68	313.00	593.00
1980	3.35	37.50	15.10	5.66	93.40	0.00	64.10	0.88	6.17	302.00	535.00
1981	3.21	48.95	17.95	7.63	109.65	0.00	72.50	0.66	6.38	325.50	597.00
1982	3.40	53.30	21.45	8.54	127.05	0.00	79.65	0.90	4.37	381.20	689.00
1983	3.71	60.25	26.05	10.24	149.40	1.00	96.95	0.76	4.53	424.25	792.00
1984	4.03	50.70	19.90	8.59	104.75	0.45	70.65	0.86	2.99	317.85	590.50
1985	4.10	63.20	25.60	9.25	153.10	0.00	93.60	1.10	4.86	458.80	842.00
1986	4.20	67.55	27.65	10.60	184.95	2.00	103.00	1.07	3.50	548.45	972.00
1987	4.10	41.50	18.60	5.51	68.50	0.00	44.10	0.81	4.74	290.90	461.00
1988	3.59	42.30	18.90	5.92	84.50	0.00	54.30	0.77	4.44	296.10	511.00
1989	4.21	58.40	26.40	6.76	122.10	1.40	64.80	1.04	4.78	388.00	683.00
1990	3.26	43.75	19.85	5.79	94.50	0.00	42.90	0.91	6.29	391.80	615.50
1991	3.56	48.20	21.10	5.00	86.00	0.00	37.30	0.70	4.61	383.90	589.00
1992	3.99	58.80	25.70	7.76	120.40	2.00	54.00	0.80	4.11	464.45	739.50
1993	6.10	41.75	17.80	5.65	63.10	9.55	32.80	0.41	4.33	255.60	437.50
1994	6.12	40.75	17.80	7.13	64.80	10.15	33.65	0.54	2.55	248.25	436.00
1995	6.92	52.60	24.40	9.48	81.80	20.70	47.10	0.48	2.75	314.00	575.00
1996	4.24	68.30	24.65	5.79	64.55	10.15	20.35	0.38	6.40	391.05	589.00
1997	3.81	68.45	27.90	6.78	72.40	8.75	23.55	0.12	5.44	437.90	663.00
1998	3.79	87.90	26.50	9.01	132.40	3.30	41.70	0.04	4.30	534.20	857.00
1999	3.92	76.55	24.50	9.15	148.80	0.00	49.85	0.05	3.57	543.55	903.00
Average	**4.03**	**54.58**	**21.83**	**7.26**	**103.11**	**2.95**	**59.34**	**0.69**	**4.59**	**370.25**	**637.81**

b) Middelburg Dam on Little Olifants River (B1 H015 Q01)

	PH	CA	MG	K	NA	TAL	CL	F	SI	SO4	TDS
1983	7.46	33.96	19.76	7.57	22.40	63.78	11.94	0.43	0.83	128.00	303.00
1984	6.93	31.27	18.16	6.58	15.38	46.64	8.30	0.35	1.31	117.95	256.50
1985	7.44	36.79	21.90	7.62	19.74	57.87	14.97	0.37	1.28	152.22	325.00
1986	7.59	38.68	23.25	7.75	21.24	57.27	13.43	0.37	1.61	154.25	329.38
1987	7.13	37.68	23.32	7.32	20.25	52.44	14.12	0.42	1.43	156.39	324.20
1988	7.03	28.33	17.65	5.48	16.55	48.79	14.08	0.42	1.22	104.97	247.80
1989	7.87	34.23	21.97	5.98	19.60	60.58	14.51	0.38	1.68	137.73	308.78
1990	7.81	44.13	26.00	6.13	18.71	53.80	14.86	0.36	1.49	180.41	357.29
1991	7.74	40.38	23.35	5.70	16.93	52.22	13.62	0.36	1.67	162.91	297.78
1992	7.82	51.61	30.69	7.17	21.49	71.48	12.29	0.41	1.09	211.07	422.06
1993	7.78	52.52	32.81	7.54	24.02	70.08	12.48	0.48	1.03	225.19	440.85
1994	8.05	50.78	32.59	7.86	23.55	72.78	12.85	0.49	1.55	215.38	432.64
1995	8.07	58.61	39.02	8.51	28.43	80.84	16.36	0.51	0.98	263.80	514.08
1996	7.92	30.40	19.31	7.26	16.43	60.21	13.02	0.34	2.37	122.07	283.35
1997	8.05	40.02	26.03	7.08	20.05	69.33	12.47	0.30	0.94	166.94	357.91
1998	8.06	32.97	21.10	6.41	18.86	64.68	13.73	0.34	0.86	131.75	304.44
1999	8.03	37.48	24.99	6.02	20.72	65.29	14.30	0.35	1.82	157.82	341.94
Average	**7.69**	**39.99**	**24.82**	**6.94**	**20.26**	**61.65**	**13.37**	**0.39**	**1.36**	**164.05**	**343.94**

c) Koringspruit at Vaalkranz (B1 H020 Q01)

Year	PH	CA	MG	K	NA	TAL	CL	F	SI	SO4	TDS
1991	7.90	67.00	39.60	9.94	86.00	103.40	49.90	0.89	3.18	323.00	726.00
1992	6.85	163.65	89.90	20.49	109.70	43.25	54.40	0.64	6.68	776.90	1466.00
1993	7.72	85.85	52.90	8.01	78.95	83.60	49.55	0.75	3.90	415.15	813.00
1994	8.10	90.20	55.80	7.60	66.40	162.80	42.60	0.74	2.42	362.90	851.00
1995	7.88	76.90	47.40	8.93	70.30	79.30	38.30	0.58	4.08	392.00	730.00
1996	8.06	75.50	49.60	6.59	67.60	146.80	34.10	0.66	2.89	291.10	758.00
1997	8.18	78.55	50.35	7.29	75.70	177.75	38.90	0.64	2.81	295.15	780.50
1998	8.09	96.50	65.90	6.37	77.70	180.60	34.70	0.56	2.84	384.90	911.00
1999	7.91	215.40	126.90	11.80	98.30	79.30	61.60	0.32	4.91	1051.70	1681.00
Averag	**7.85**	**105.5**	**64.26**	**9.67**	**81.18**	**117.42**	**44.89**	**0.64**	**3.75**	**476.98**	**968.5**

d) Tweefonteinspruit at Tweefontein (B1 H031 Q01)

YEAR	PH	CA	MG	K	NA	TAL	CL	F	SI	SO4	TDS
1990	7.23	162.40	97.63	8.29	41.35	23.38	41.02	0.78	5.44	804.35	1184.47
1991	7.33	173.23	107.01	8.84	45.12	24.81	44.84	0.83	2.04	860.98	1271.44
1995	5.72	318.73	192.32	18.03	97.77	22.65	65.58	0.27	5.69	1649.12	2371.50
1996	7.16	125.77	86.28	6.41	37.31	39.23	27.58	0.34	3.30	649.00	980.83
Average	**6.86**	**195.03**	**120.81**	**10.40**	**55.39**	**27.51**	**44.76**	**0.56**	**4.12**	**990.86**	**1452.06**

e) Blesbokspruit at Blesbok (B1 H032 Q01)

YEAR	PH	CA	MG	K	NA	TAL	CL	F	SI	SO4	TDS
1998	3.00	108.82	55.75	4.60	107.87	0.00	125.68	0.00	18.93	1112.07	1522.91
1999	3.34	73.97	38.88	3.22	92.71	7.05	104.74	0.02	18.92	707.88	1037.13
Average	**3.17**	**91.39**	**47.32**	**3.91**	**100.29**	**3.53**	**115.21**	**0.01**	**18.92**	**909.98**	**1280.02**

Appendix B ICP M-S Results

a) Klipspruit at Zaaihoek (B1 H004 Q01)

	KLIPSPRUIT					
Sample Number	1	2	3	4	5	Average
	ppm	ppm	ppm	ppm	ppm	
Li 7	0.021	0.022	0.02	0.021	0.021	0.021
Be 9	0.003	0.0027	0.0028	0.0027	0.0028	0.0028
B 11	0.3	0.28	0.27	0.27	0.26	0.276
Na 23	100	110	100	100	100	102
Mg 24	38	39	37	38	38	38
Al 27	4.1	3.8	3.9	3.7	4.1	3.92
Si 29	0.25	0.25	0.25	0.26	0.26	0.254
K 39	9.1	9.2	8.8	9.1	9.1	9.06
Ca 43	43	44	43	44	44	43.6
Sc 45	0.00097	0.00088	0.00087	0.00078	0.00091	0.000882
Ti 47	0.00027	0.00026	0.0002	0.00021	0.0002	0.000228
V 51	0.0034	0.0027	0.003	0.0029	0.003	0.003
Cr 53	0.0098	0.01	0.0096	0.0085	0.008	0.00918
Mn 55	2.1	2.1	2.1	2.1	2.1	2.1
Fe 57	1.3	0.71	0.96	0.79	1.1	0.972
Co 59	0.075	0.079	0.076	0.079	0.079	0.0776
Ni 60	0.13	0.13	0.13	0.13	0.13	0.13
Cu 63	0.043	0.097	0.084	0.077	0.089	0.078
Zn 66	0.33	0.34	0.3	0.31	0.29	0.314
Ga 69	0.00048	0.00042	0.00041	0.00046	0.00044	0.000442
Ge 72	4.40E-04	3.60E-04	3.60E-04	4.00E-04	4.50E-04	0.000402
As 75	0.0019	0.0016	0.0015	0.0013	0.0016	0.00158
Se 82	0.035	0.023	0.029	0.025	0.027	0.0278
Br 79	0.063	0.059	0.057	0.059	0.063	0.0602
Rb 85	0.015	0.016	0.015	0.015	0.016	0.0154
Sr 88	0.12	0.12	0.12	0.12	0.12	0.12
Y 89	0.067	0.066	0.068	0.065	0.069	0.067
Zr 90	0.00026	0.00006	0.000072	0.00018	0.00017	0.000148
Nb 93	<2.000E-5	<2.000E-5	<2.000E-5	<2.000E-5	<2.000E-5	#DIV/0!
Mo 95	0.000024	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	0.000024
Ru 101	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Rh 103	<1.600E-5	<1.600E-5	<1.600E-5	<1.600E-5	<1.600E-5	#DIV/0!
Pd 105	0.00014	0.00021	0.00012	0.00016	0.00013	0.000152
Ag 107	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Cd 111	0.00047	0.00041	0.00034	0.00041	<3.400E-4	0.000408
In 115	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	#DIV/0!
Sn 118	0.000024	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	0.000024
Sb 121	0.00013	<3.800E-5	0.000048	<3.800E-5	<3.800E-5	0.000089
Te 125	<5.900E-5	<5.900E-5	<5.900E-5	<5.900E-5	<5.900E-5	#DIV/0!
I 127	0.007	0.0059	0.0058	0.0061	0.0059	0.00614
Cs 133	0.0063	0.0064	0.0064	0.0063	0.0064	0.00636
Ba 137	0.039	0.04	0.042	0.04	0.038	0.0398
Ce 140	0.1	0.099	0.1	0.098	0.1	0.0994
Hf 178	0.000023	0.000018	<1.700E-5	<1.700E-5	<1.700E-5	2.05E-05
Ta 181	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
W 182	<1.400E-5	<1.400E-5	0.000016	<1.400E-5	<1.400E-5	0.000016
Re 185	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Os 189	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
Ir 193	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Pt 195	0.000025	0.000062	0.000024	<2.100E-5	<2.100E-5	0.000037
Au 197	0.0001	0.000072	0.000072	0.000069	<4.700E-5	7.83E-05
Hg 202	0.0017	0.0017	0.0011	0.0016	0.0012	0.00146
Tl 205	0.0005	0.0005	0.00049	0.00061	0.00068	0.000556
Pb 208	0.008	0.0029	0.005	0.0043	0.0029	0.00462
Bi 209	<2.300E-5	<2.300E-5	<2.300E-5	<2.300E-5	<2.300E-5	#DIV/0!
U 238	0.017	0.011	0.013	0.011	0.015	0.0134

b) Middelburg Dam on Little Olifants River (B1 H015 Q01)

	MIDDELBURG					
Sample Number	1	2	3	4	5	Average
	ppm	ppm	ppm	ppm	ppm	
Li 7	0.0059	0.0075	0.008	0.0079	0.0082	0.0075
Be 9	<3.600E-4	<3.600E-4	<3.600E-4	<3.600E-4	<3.600E-4	#DIV/0!
B 11	0.15	0.21	0.21	0.21	0.21	0.198
Na 23	42	61	62	66	62	58.6
Mg 24	23	200	210	210	210	170.6
Al 27	0.097	0.076	0.1	0.019	0.41	0.1404
Si 29	0.22	0.22	0.22	0.23	0.22	0.222
K 39	8.2	15	15	16	15	13.84
Ca 43	30	110	110	110	110	94
Sc 45	0.00055	0.00051	0.00061	0.00068	0.00054	0.000578
Ti 47	0.00016	0.00013	0.00016	0.00016	0.00021	0.000164
V 51	0.0039	0.0028	0.0031	0.0028	0.0033	0.00318
Cr 53	0.0072	0.0077	0.0079	0.0075	0.0088	0.00782
Mn 55	0.65	0.0088	0.024	0.011	0.033	0.14536
Fe 57	0.7	1	1.2	1.1	1.8	1.16
Co 59	9.70E-04	6.80E-04	5.40E-04	6.40E-04	7.30E-04	0.000712
Ni 60	0.0061	0.0068	0.0081	0.0082	0.0079	0.00742
Cu 63	0.15	0.05	0.076	0.041	0.033	0.07
Zn 66	0.12	0.043	0.23	0.035	0.029	0.0914
Ga 69	0.00075	0.00088	0.00095	0.001	0.001	0.000916
Ge 72	2.80E-04	3.40E-04	3.90E-04	4.50E-04	4.50E-04	0.000382
As 75	0.0015	0.0011	0.0017	0.0018	0.0018	0.00158
Se 82	0.023	0.018	0.02	0.022	0.02	0.0206
Br 79	0.1	0.074	0.073	0.076	0.076	0.0798
Rb 85	0.0039	0.012	0.013	0.013	0.013	0.01098
Sr 88	0.13	0.75	0.76	0.78	0.77	0.638
Y 89	0.00017	0.000059	0.00011	0.000033	0.0001	9.44E-05
Zr 90	0.00013	0.000031	0.00011	0.000043	0.00029	0.000121
Nb 93	<2.000E-5	<2.000E-5	<2.000E-5	<2.000E-5	<2.000E-5	#DIV/0!
Mo 95	0.000018	0.00006	0.000033	0.000049	0.000031	3.82E-05
Ru 101	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Rh 103	<1.600E-5	<1.600E-5	<1.600E-5	0.000017	<1.600E-5	0.000017
Pd 105	0.000025	0.0001	0.000097	0.000099	0.000093	8.28E-05
Ag 107	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Cd 111	0.00036	<3.400E-4	<3.400E-4	<3.400E-4	<3.400E-4	0.00036
In 115	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	#DIV/0!
Sn 118	0.000021	<1.800E-5	0.000039	<1.800E-5	<1.800E-5	0.00003
Sb 121	0.000048	0.000056	0.000056	0.000043	<3.800E-5	5.08E-05
Te 125	<5.900E-5	<5.900E-5	<5.900E-5	<5.900E-5	<5.900E-5	#DIV/0!
I 127	0.011	0.011	0.011	0.012	0.012	0.0114
Cs 133	0.000038	0.00013	0.00011	0.00011	0.00012	0.000102
Ba 137	0.08	0.092	0.09	0.092	0.091	0.089
Ce 140	0.00049	0.000076	0.00028	0.000085	0.0003	0.000246
Hf 178	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	#DIV/0!
Ta 181	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
W 182	<1.400E-5	<1.400E-5	<1.400E-5	<1.400E-5	<1.400E-5	#DIV/0!
Re 185	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Os 189	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
Ir 193	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Pt 195	<2.100E-5	<2.100E-5	0.00023	<2.100E-5	0.00031	0.00027
Au 197	0.000078	0.000078	<4.700E-5	0.00012	0.000059	8.38E-05
Hg 202	0.0012	0.0014	0.001	0.0014	0.0013	0.00126
Tl 205	0.00053	0.00051	0.00047	0.0029	0.00045	0.000972
Pb 208	0.0056	0.0013	0.0058	0.0014	0.0031	0.00344
Bi 209	<2.300E-5	<2.300E-5	<2.300E-5	<2.300E-5	<2.300E-5	#DIV/0!
U 238	0.013	0.01	0.19	0.01	0.012	0.047

c) Koringspruit at Vaalkranz (B1 H020 Q01)

	KORINGSPRUIT			
Sample Number	1	2	3	Average
	ppm	ppm	ppm	
Li 7	0.0051	0.0051	0.0049	0.005033
Be 9	<3.600E-4	<3.600E-4	<3.600E-4	#DIV/0!
B 11	0.17	0.17	0.17	0.17
Na 23	74	75	73	74
Mg 24	100	100	100	100
Al 27	0.34	0.065	0.21	0.205
Si 29	0.24	0.25	0.24	0.243333
K 39	8.6	8.6	8.4	8.533333
Ca 43	76	77	76	76.33333
Sc 45	0.00085	0.0008	0.00079	0.000813
Ti 47	0.00024	0.00023	0.00017	0.000213
V 51	0.083	0.0034	0.0038	0.030067
Cr 53	0.0092	0.0084	0.0077	0.008433
Mn 55	0.11	0.01	0.1	0.073333
Fe 57	3.7	0.84	0.98	1.84
Co 59	0.0011	5.90E-04	0.0012	0.000963
Ni 60	0.01	0.0084	0.011	0.0098
Cu 63	0.13	0.028	0.12	0.092667
Zn 66	0.084	0.025	0.11	0.073
Ga 69	0.0014	0.0014	0.0014	0.0014
Ge 72	3.80E-04	2.60E-04	3.40E-04	0.000327
As 75	0.0014	0.0013	0.0014	0.001367
Se 82	0.024	0.024	0.026	0.024667
Br 79	0.15	0.15	0.15	0.15
Rb 85	0.0034	0.0031	0.0035	0.003333
Sr 88	0.48	0.48	0.47	0.476667
Y 89	0.0007	0.000076	0.00022	0.000332
Zr 90	0.0002	0.0018	0.00022	0.00074
Nb 93	<2.000E-5	<2.000E-5	<2.000E-5	#DIV/0!
Mo 95	0.00005	0.000067	0.000045	0.000054
Ru 101	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Rh 103	<1.600E-5	<1.600E-5	<1.600E-5	#DIV/0!
Pd 105	0.000062	0.000069	0.000069	6.67E-05
Ag 107	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Cd 111	<3.400E-4	<3.400E-4	<3.400E-4	#DIV/0!
				#DIV/0!
In 115	<1.700E-5	<1.700E-5	<1.700E-5	#DIV/0!
Sn 118	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Sb 121	0.000048	0.0001	0.0001	8.27E-05
Te 125	<5.900E-5	<5.900E-5	<5.900E-5	#DIV/0!
I 127	0.019	0.018	0.02	0.019
Cs 133	0.000037	0.00023	0.000033	0.0001
Ba 137	0.15	0.14	0.15	0.146667
Ce 140	0.0016	0.00013	0.00049	0.00074
Hf 178	<1.700E-5	0.000054	<1.700E-5	0.000054
Ta 181	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
W 182	<1.400E-5	<1.400E-5	<1.400E-5	#DIV/0!
Re 185	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Os 189	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
Ir 193	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Pt 195	0.000024	<2.100E-5	0.00012	0.000072
Au 197	0.000069	0.000091	0.000066	7.53E-05
Hg 202	0.0014	0.0011	0.0013	0.001267
Tl 205	0.00045	0.0005	0.00053	0.000493
Pb 208	0.0071	0.00087	0.0064	0.00479
Bi 209	<2.300E-5	<2.300E-5	<2.300E-5	#DIV/0!
U 238	0.014	0.01	0.017	0.013667

d) Blesbokspruit at Blesbok (B1 H032 Q01)

	BLESBOK					
Sample Number	1	2	3	4	5	Average
	ppm	ppm	ppm	ppm	ppm	
Li 7	0.15	0.15	0.14	0.1	0.12	0.132
Be 9	0.019	0.02	0.019	0.013	0.017	0.0176
B 11	0.35	0.32	0.3	0.28	0.27	0.304
Na 23	75	77	75	73	73	74.6
Mg 24	87	89	87	75	79	83.4
Al 27	27	27	27	17	22	24
Si 29	0.42	0.42	0.42	0.39	0.41	0.412
K 39	9.9	10	9.8	9.6	9.6	9.78
Ca 43	73	74	73	63	67	70
Sc 45	0.0022	0.0023	0.0022	0.0019	0.0021	0.00214
Ti 47	0.00043	0.00042	0.00031	0.00034	0.00039	0.000378
V 51	0.0055	0.0042	0.0038	0.0035	0.0041	0.00422
Cr 53	0.018	0.013	0.013	0.012	0.012	0.0136
Mn 55	6.1	6.2	6	4.7	5.3	5.66
Fe 57	12	3.7	12	1	12	8.14
Co 59	0.25	0.26	0.25	0.18	0.21	0.23
Ni 60	0.53	0.54	0.53	0.38	0.44	0.484
Cu 63	0.053	0.031	0.039	0.076	0.1	0.0598
Zn 66	0.5	0.48	0.49	0.38	0.4	0.45
Ga 69	0.00058	0.00056	0.00053	0.0006	0.00062	0.000578
Ge 72	0.0012	8.70E-04	0.0012	5.80E-04	0.001	0.00097
As 75	0.0045	0.0032	0.0035	0.0027	0.0041	0.0036
Se 82	0.034	0.03	0.031	0.028	0.023	0.0292
Br 79	0.063	0.061	0.064	0.061	0.065	0.0628
Rb 85	0.031	0.032	0.031	0.025	0.027	0.0292
Sr 88	0.21	0.21	0.21	0.19	0.2	0.204
Y 89	0.19	0.19	0.19	0.13	0.15	0.17
Zr 90	0.000056	0.000044	0.00017	0.000036	0.000073	7.58E-05
Nb 93	<2.000E-5	<2.000E-5	<2.000E-5	<2.000E-5	<2.000E-5	#DIV/0!
Mo 95	0.000026	0.000031	0.000031	0.000024	<1.800E-5	0.000028
Ru 101	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Rh 103	<1.600E-5	<1.600E-5	<1.600E-5	<1.600E-5	<1.600E-5	#DIV/0!
Pd 105	0.0004	0.00044	0.00036	0.00026	0.00037	0.000366
Ag 107	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Cd 111	0.00047	0.00036	<3.400E-4	0.00052	<3.400E-4	0.00045
In 115	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	<1.700E-5	#DIV/0!
Sn 118	0.000026	0.000021	0.000018	<1.800E-5	0.000054	2.98E-05
Sb 121	<3.800E-5	0.000046	0.000043	<3.800E-5	0.000041	4.33E-05
Te 125	<5.900E-5	<5.900E-5	<5.900E-5	<5.900E-5	<5.900E-5	#DIV/0!
I 127	0.02	0.019	0.02	0.015	0.017	0.0182
Cs 133	0.0053	0.0057	0.0054	0.0042	0.0045	0.00502
Ba 137	0.049	0.048	0.049	0.053	0.053	0.0504
Ce 140	0.3	0.3	0.3	0.2	0.25	0.27
Hf 178	0.000039	0.000035	0.000035	0.000019	0.000035	3.26E-05
Ta 181	0.000015	0.00002	0.000015	<1.300E-5	0.000015	1.63E-05
W 182	0.00002	0.000018	0.000025	0.000017	0.000021	2.02E-05
Re 185	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	<1.500E-5	#DIV/0!
Os 189	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	<1.300E-5	#DIV/0!
Ir 193	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	<1.800E-5	#DIV/0!
Pt 195	<2.100E-5	<2.100E-5	<2.100E-5	<2.100E-5	0.00061	0.00061
Au 197	0.000056	<4.700E-5	0.000063	<4.700E-5	0.0018	0.00064
Hg 202	0.00089	0.0012	0.0013	0.00099	0.0017	0.001216
Tl 205	0.0012	0.0011	0.0011	0.00075	0.00089	0.001008
Pb 208	0.0064	0.0027	0.0059	0.0075	0.0066	0.00582
Bi 209	<2.300E-5	<2.300E-5	<2.300E-5	<2.300E-5	<2.300E-5	#DIV/0!
U 238	0.019	0.013	0.015	0.013	0.018	0.0156

Appendix C. Water Readings *in situ*

a) Klipspruit at Zaaihoek (B1 H004 Q01)

Klipspruit at Zaaihoek (B1 H004 Q01)						
Sample number	**EC (µs/cm)**	**TDS (ppm)**	**ORP (mV)**	**DO (ppm)**	**pH**	**Temp.(°C)**
001	8.9	445	0.8	0	3.43	13.00
002	8.93	446	7.8	0	3.48	12.98
003	8.89	446	9.1	0	3.46	12.97
004	8.92	446	7.9	0	3.43	13.04
005	8.92	447	8.3	0	3.41	13.05
Average	**8.91**	**446.00**	**6.78**	**0.00**	**3.44**	**13.01**

b) Middelburg Dam on Little Olifants River (B1 H015 Q01)

Middelburg Dam on Little Olifants River (B1 H015 Q01)						
Sample number	**EC (µs/cm)**	**TDS (ppm)**	**ORP (mV)**	**DO (ppm)**	**pH**	**Temp.(°C)**
001	13.87	692	4.5	0	8.27	14.59
002	13.84	692	5.7	0	8.45	16.60
003	13.83	691	3.1	0	8.44	14.65
004	13.82	691	-4.4	0	8.56	14.64
005	13.85	690	-7	0	8.58	14.64
Average	**13.84**	**691.20**	**0.38**	**0.00**	**8.46**	**15.02**

c) Koringspruit at Vaalkranz (B1 H020 Q01)

Koringspruit at Vaalkranz (B1 H020 Q01)						
Sample number	**EC (µs/cm)**	**TDS (ppm)**	**ORP (mV)**	**DO (ppm)**	**pH**	**Temp.(°C)**
001	943	470	-7.3	0	6.62	14.22
002	921	459	0.8	0	7.04	14.13
003	920	458	-3	0	7.77	14.25
004	916	457	-6.1	0	7.88	14.21
005	914	457	-9.7	0	7.99	14.18
Average	**922.80**	**460.20**	**-5.06**	**0.00**	**7.46**	**14.20**

d) Tweefonteinspruit at Tweefontein (B1 H031 Q01)

Tweefonteinspruit at Tweefontein (B1 H031 Q01)						
Sample number	**EC (µs/cm)**	**TDS (ppm)**	**ORP (mV)**	**DO (ppm)**	**pH**	**Temp.(°C)**
001	-	-	-	-	-	-
002	-	-	-	-	-	-
003	-	-	-	-	-	-
004	-	-	-	-	-	-
005	-	-	-	-	-	-
Average	**-**	**-**	**-**	**-**	**-**	**-**

e) Blesbokspruit at Blesbok (B1 H032 Q01)

Blesbokspruit at Blesbok (B1 H032 Q01)						
Sample number	**EC (µs/cm)**	**TDS (ppm)**	**ORP (mV)**	**DO (ppm)**	**pH**	**Temp.(°C)**
001	11.02	555	9.6	0	3.41	13.66
002	11.3	565	19.5	0	3.39	13.36
003	11.4	570	26.2	0	3.39	13.13
004	14.4	727	95.9	0	2.92	12.96
005	14.66	732	101.1	0	2.93	13.26

Average	**12.56**	**629.80**	**50.46**	**0**	**3.21**	**13.27**

f) Water used for rinsing multi-sensor probe

Rinsing water						
Sample number	**EC (µs/cm)**	**TDS (ppm)**	**ORP (mV)**	**DO (ppm)**	**pH**	**Temp.(°C)**
001	164	82	-12.3	0	6.59	15.26
002	160	80	-8.8	0	6.83	15.33
003	161	80	-11.7	0	6.99	15.35
004	161	81	-14.2	0	7.13	15.41
005	160	80	-16.2	0	7.25	15.45

Average	**161.20**	**80.60**	**-12.64**	**0.00**	**6.96**	**15.36**

Appendix D. GPS Waypoint Co-ordinates for Sampling Sites

Grid Lat/Lon hddd°mm'ss.s"
Datum WGS 84

Header	**Description**	**Type**	**Position**
Waypoint	001_klipspruit	User Waypoint	S25 40 48.1 E29 10 03.5
Waypoint	002_klipspruit	User Waypoint	S25 40 48.3 E29 10 03.9
Waypoint	003_klipspruit	User Waypoint	S25 40 48.5 E29 10 03.9
Waypoint	004_klipspruit	User Waypoint	S25 40 48.6 E29 10 04.1
Waypoint	005_klipspruit	User Waypoint	S25 40 48.6 E29 10 04.3
Waypoint	001_klipspruit_ppt	User Waypoint	S25 40 48.2 E29 10 03.8
Waypoint	002_klipspruit_ppt	User Waypoint	S25 40 48.5 E29 10 03.8
Waypoint	003_klipspruit_ppt	User Waypoint	S25 40 48.7 E29 10 03.9
Waypoint	001_middelburg	User Waypoint	S25 46 12.3 E29 31 45.2
Waypoint	002_middelburg	User Waypoint	S25 46 12.2 E29 31 43.9
Waypoint	003_middelburg	User Waypoint	S25 46 13.1 E29 31 44.1
Waypoint	004_middelburg	User Waypoint	S25 46 14.4 E29 31 43.5
Waypoint	005_middelburg	User Waypoint	S25 46 15.3 E29 31 43.0
Waypoint	001_middelburg_ppt	User Waypoint	S25 46 12.2 E29 31 43.5
Waypoint	002_middelburg_ppt	User Waypoint	S25 46 14.8 E29 31 43.5
Waypoint	003_middelburg_ppt	User Waypoint	S25 46 15.2 E29 31 43.3
Waypoint	001_koring	User Waypoint	S26 06 26.8 E29 19 22.9
Waypoint	002_koring	User Waypoint	S26 06 27.4 E29 19 22.1
Waypoint	003_koring	User Waypoint	S26 06 27.8 E29 19 21.7
Waypoint	004_koring	User Waypoint	S26 06 28.9 E29 19 21.2
Waypoint	005_koring	User Waypoint	S26 06 29.5 E29 19 21.1
Waypoint	001_koringspruit_ppt	User Waypoint	S26 06 27.3 E29 19 22.3
Waypoint	002_koringspruit_ppt	User Waypoint	S26 06 27.7 E29 19 21.9
Waypoint	003_koringspruit_ppt	User Waypoint	S26 06 27.8 E29 19 21.6
Waypoint	001_tweefontein_dry	User Waypoint	S26 00 44.9 E29 12 50.5
Waypoint	001_blesbok	User Waypoint	S25 49 12.8 E29 12 28.6
Waypoint	002_blesbok	User Waypoint	S25 49 13.2 E29 12 28.6
Waypoint	003_blesbok	User Waypoint	S25 49 13.8 E29 12 28.6
Waypoint	004_blesbok	User Waypoint	S25 49 14.2 E29 12 28.7
Waypoint	005_blesbok	User Waypoint	S25 49 14.7 E29 12 28.7
Waypoint	001_blesbok_ppt	User Waypoint	S25 49 13.1 E29 12 28.4
Waypoint	002_blesbok_ppt	User Waypoint	S25 49 13.8 E29 12 28.7
Waypoint	003_blesbok_ppt	User Waypoint	S25 49 14.4 E29 12 28.6