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Conceptual models of Witbank coalfield, South Africa

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Final Report

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Summary

This report presents the work undertaken as part of the EO MINERS WP3 - project task 3.1. “Site Specific Available Data Collection” and develops a conceptual site model (CSM) for the Witbank coalfield, South Africa and for Bank Colliery, South Africa which has been selected to demonstrate the automated time-lapse electrical resistivity monitoring (ALERT) system of a leachate plume.

The report presents the available information regarding known apparent environmental impacts. This information is derived from a literature review and from the findings of surveys conducted as part of work package WP1. Additionally the principal socio-economic impacts defined by WP1 have been presented. It goes on to consider the environmental factors that influence the transport of contaminants from the source to the exposed individuals or environmental receptors, through identified potential exposure pathways, describing the source- pathway-receptor interactions through two conceptual site models (CSMs), one for the Witbank Coal Mining region and the other for Bank Colliery. A CSM for the socio-economic impacts has also been attempted.

Examining the CSM results in the identification of data gaps and information needed for a full environmental assessment of mining in Witbank and provides the rational for EO selection.

Present and past coal mining in Witbank is associated with a number of environmental problems, including: acid mine drainage (AMD) derived from the oxidation of pyrite in the coal, specific contaminants including potentially harmful metals and arsenic (which occur in the mining environment and in dust associated with both the operation of the mines and the transport of the coal) and ground gases that are both naturally occurring and a consequence of self-combustion of the coal and waste dumps. A wide range of ecological and socio-economic impacts result from these impacts, including the impacts on land value and agriculture. Additional problems include ground subsidence due to pillar collapse, which has further consequences on the migration of AMD and self combustion.

The CSMs have been used to idenfity the key direct or indirect indicators of mining impacts and an assessment of the potential to monitor these using Earth Observatory (EO) assessments has been made. The majority of the indicators lend themselves to EO assessment in one form or another (Table 7).

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1. Introduction

1.1. PROJECT/ TASK

The aim of Task 3.1 is to develop an understanding of the risk paradigm within the context of the site/ area under consideration. This is best achieved through a conceptual model (section 11) of the potential impacts developed from a framework of understanding of the: physical context (geography, geology, hydrology and hydrology); mining activities; environment (natural environment, ecology, contaminant pathways); socio-economic factors (water supply, agriculture, economical dependencies) and societal aspects (housing infrastructure, development strategies). The latter benefits from the incorporation of the results from Work Package 1, which contributes to a socio-economic conceptual model (section 11).

The focus of this report is the Witbank coalfield, South Africa (section 2) with a focus on the area of Bank Colliery, which was selected to demonstrate the ALERT system (section 1.2).

1.2. PROPOSALS FOR THE INSTALLATION OF THE ALERT SYSTEM

At the time of the preparation of this report an Alert system (automated time-lapse electrical resistivity monitoring (Ogilvy, 2009)) was being installed at the Bank Colliery, in order to monitor the extent of a leachate plume associated with a discard dump immediately to the north of Bank Colliery. Situated in the eastern area of the Witbank coalfield, Bank Colliery is operational, but is scheduled for closure in 2016. It is situated in the order of 20 km to the south of Middleburg. The discard dump dates to 1948 and comprises an area of about 25 ha (JMAConsulting(Pty)Limited, 2008). Since 2002 co-disposal with slimes (the finer grained component of the colliery waste) has been carried out. The scale of this component of the earth observatory is such that it requires the derivation of a site-specific conceptual model (sections 8 and 10).

2. Regional Framework

South Africa has nineteen coal provinces, stretching from the border with Botswana in the north-west, through the Limpopo and Mpumalanga provinces and into KwaZulu-Natal in the east (Figure 1).

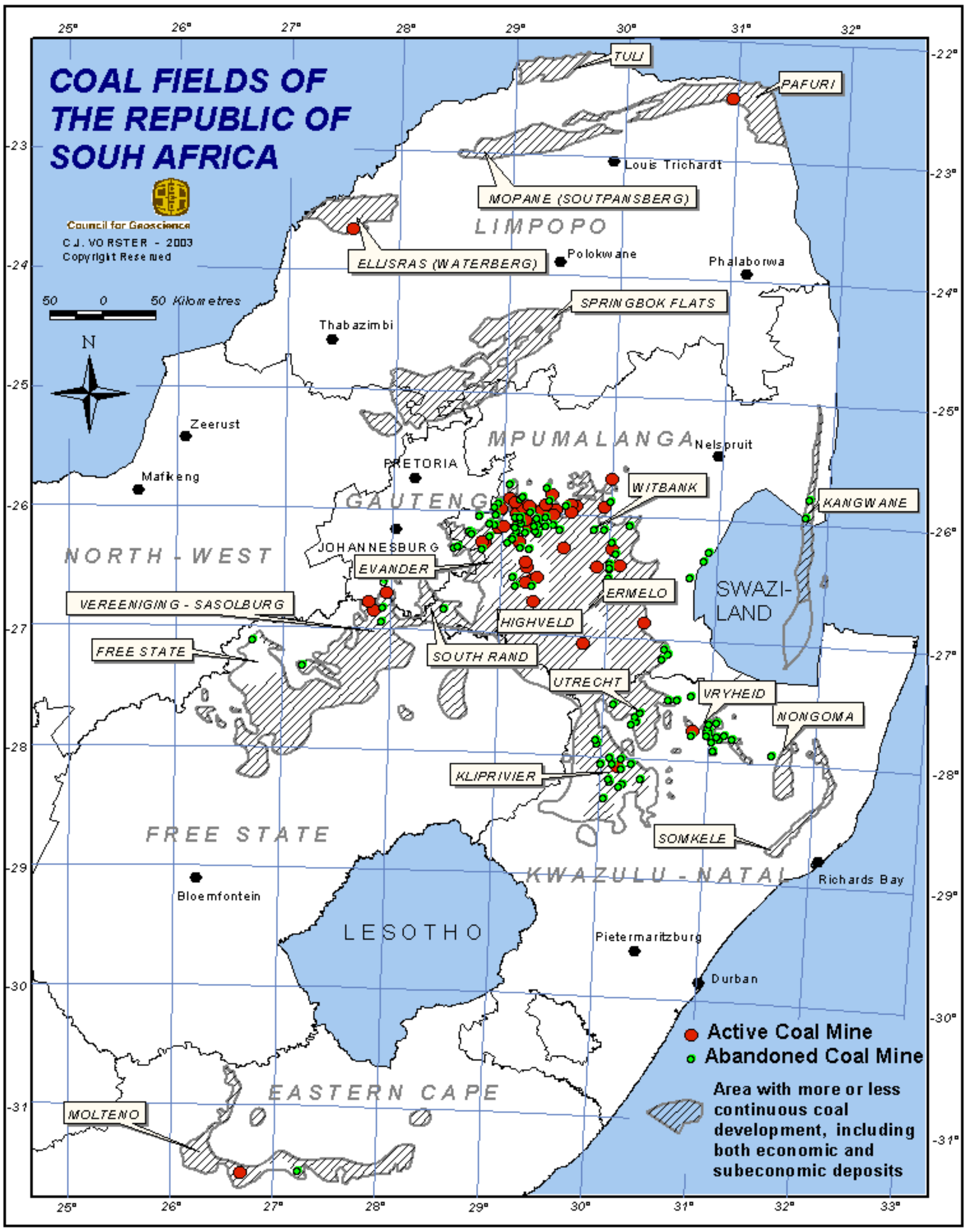

Figure 1: Coal deposits of South Africa (C.J. Vorster, 2003)

The coal provinces are subdivided into distinct coalfields. Current mining activity is largely focused in the Highveld, Ermelo and Witbank (eMalahleni) coalfields of the Mpumalanga province (Department of Mineral Resources (DMR); http://iis-db.stanford.edu/pubs/23082/WP_100_Eberhard_Future_of_South_African_Coal.pdf.) Together these coalfields produce 48% of the country's total power generation capacity (Hobbs et al., 2008). Of these, the Witbank coalfield is the most important centre of South Africa's current coal mining activity with about 55 collieries in operation (DWR, 2009). Local coal demand is dominated by the electricity sector, which was responsible for 61% of local coal sales in 2005. According to the Department of Mineral Resources, about 77% of the country's primary energy needs and 90% of its electricity production needs are met by coal. In 2005 South Africa burned 106 million tons of coal in the production of electricity, the majority being used at State-owned utility Eskom's thirteen coal fired power stations. Forecasts indicate that in order to meet rising electricity demand 47000 MW of additional generation capacity will be required between 2005 and 2025 (Creamer Media, 2007).

Rich coal deposits are found around Witbank. Many coal related and other industries are found near Witbank and (to the northeast) Middelburg in Mpumalanga Province in South Africa. Most notable are the Highveld Steel and Vanadium plant west of Witbank and the stainless steel plant at Middelburg. Several Eskom Power Stations (Kendal, Matla, Kriel, Duvha, Arnot, Hendrina and Komati) are supplied with coal from various mines. Energy content is a key consideration in the cost of coal. Higher calorific value (or high-grade) coal generally fetches higher prices and has a higher export demand. Lower calorific value (or low-grade) coal generally has a high ash content. Sulphur content is also important, due to the environmental restrictions on sulphur emissions in many part of the world (Department of Environmental Affairs [DEA], 2010). Power stations are generally fired with relatively low-grade coal, with thermal values ranging from 12 Mj/kg to 25 Mj/kg, whilst export quality coal generally starts at about 25 Mj/kg (http://www.miningmx.com/news/energy/913174.html).

The use of low-grade coal in coal-fired power stations requires large quantities of coal being used as fuel source resulting in relatively higher gaseous and particulate emissions. Large coal stockpiles, and significant amounts of ash generated for disposal, are also a source of fugitive particulate matter. Eskom generates approximately 95% of the electricity used in South Africa and relies on coal-fired power stations to produce approximately 90% of its electricity (http://www.eskom.co.za).

The Witbank coalfield incorporates five main coal seams numbered consecutively from oldest (No. 1 Seam). It contains a large and important resource of high yield export quality coal (especially in the No. 4 Seam). As a consequence, the Witbank coalfield is well served by infrastructure, including coal transportation facilities, such as the Richards Bay coal terminal rail network. It spans approximately 190 km from Springs in the southwest to Belfast in the northeast, with an average north to south extent of approximately 60 km (Hobbs et al., 2008). Important urban centres include Witbank, Middelburg and Ermelo. These areas already have high concentrations of people relying on them for survival. A number of smaller urban and peri-urban areas, contributing to the high population occur around the major centres (Mpumalanga Province, 1999).

In South Africa recent legislation (in particular the Minerals and Petroleum Resource Development Act [MPRDA], National Water Act [NWA] and the National Environmental Management Act [NEMA]) sets out the legal framework governing mineral exploration and exploitation related activities. Environmental Impact Assessments as well as Environmental Management Plans (EMPs) including a Closure Plan are prerequisites for applications for prospecting and mining permits. Table 1 (adapted from Ashton et al., 2001) provides a list of legislation that is relevant to mining activities and the control of environmental impacts. This should be read in conjunction with any output from Work Package 1.

Past legislation did not place emphasis on the rehabilitation of mining areas and mines simply ceased operation, i.e. became derelict and ownerless. In 1975 the Fanie Botha Accord placed the responsibility for the impacts from all pre-1976 derelict and ownerless mines on the State. The first act that placed the environmental liability and responsibility of sustainable land use into mine closure planning on the mine operator was the Minerals Act (Act 50 of 1991). After 1994 the new Constitution forced reform to much of the existing legislation. This resulted in the promulgation of new legislation (i.e. NWA (Act 36 of 1998), MPRDA (Act 28 of 2002) and NEMA (Act 107 of 1998). The MPRDA placed the liability of environmental and social impacts on the mine until a closure certificate has been issued by the Department of Mineral Resources (Hobbs et al., 2008).

Hobbs et al. (2008) pointed out there has been a change in emphasis from a holistic “one strategy for all” approach to a more diverse one with a varying level of guidance for different mining activities.

The South African Department of Water Affairs (DWA) is responsible for the management of water supply and use. The management of South Africa’s water resources is aimed at achieving equitable access to water resources and their sustainable and efficient use. South Africa has been divided into nineteen Water Management Areas (WMAs) and the water resources within each WMA are managed by a Catchment Management Agency through Catchment Management Strategies. The Witbank coalfield falls within the Olifants River Management Area. Irrigation boards are responsible for the day to day management of water allocations for irrigation.

Sector/ Area	Laws or Regulations
Environment	Environment Conservation Act No. 73, 1989
	National Environment Management Act (NEMA) No. 107, 1998
	Environmental Laws Rationalization Act No. 51, 1997
Water	National Water Act No. 36, 1998
	Water Services Act No. 108, 1997
Health	Atmospheric Pollution Prevention Act No. 45, 1965
	Air Quality Act, 2004 (Act No. 39, 2004)
	Occupational Health and Safety Act No. 85, 1993
	National Health Act No. 63, 1977
	Labour Relations Act No. 66, 1995
Minerals and Mining, Miners Health	Minerals Act No. 50, 1991
	Mine Health and Safety Act No. 29, 1996
	Mines and Works Act No. 27, 1956
	Nuclear Energy Act No. 46, 1999
	Mineral and Petroleum Resource Development Act (Act 28, 2002)

Table 1: Legislation that is relevant to mining activities and the control of environmental impacts (adapted from Ashton et al., 2001)

3. Geological Framework

The majority of Africa's coal reserves are hosted in rocks of the Karoo Supergroup (Cairncross, 2001; Figure 2), which underlies approximately 60% of South Africa. The largest proven reserves in South Africa occur in the northwest, north and northeast section of the Karoo Basin (Cairncross, B, 2001). The Karoo Supergroup is a thick sequence of sedimentary rocks deposited between 300 and 180 million years ago. The coal seams occur in a division of the Supergroup known as the Ecca Subgroup, consisting of sandstones and mudstones, together with coal seams, which were laid down by large river deltas that entered the ancient Karoo Sea. Although rocks of the Ecca Subgroup are widespread across the centre of the country, conditions suitable for the formation of coal did not occur everywhere and the coal deposits are limited to the main Karoo Basin in an arc extending from Welkom in Free State Province to Nongoma in ZwaKulu-Natal. There are also occurrences in several smaller outlying remnants of the Karoo Supergroup. The Karoo Basin is a typical foreland basin (Visser, 1986).

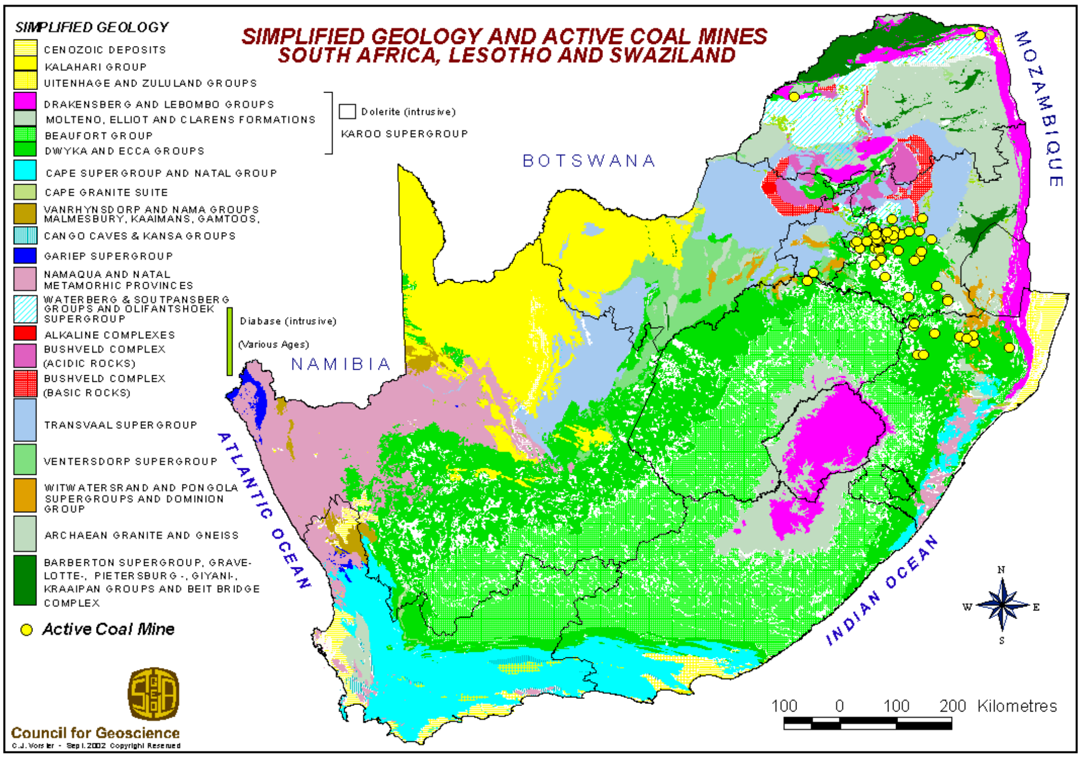

Figure 2: Simplified geological map and active coal mines of South Africa

The tectonic setting of the Karoo Basin has been described by Cairncross (2001) and Hobday (1987). The Permian to early Triassic coals were deposited on Gondwana, in the back arc of the Gondwanan orogenic belt, during a period of warming. Vegetation change reflected the changing climate with tundra vegetation giving way to swamps and deciduous Glossopteris forests. Coal quality and geometry were influenced by a number of factors including: variable subsidence and sedimentation rates in the foredeep; rift and epicratonic basin settings; local palaeotopography, and eustatically induced changes in base level. Palaeotopography and depositional environment were particularly important. The coal was deposited in a range of depositional environments from proximal conglomeratic alluvial fans through fluvial, delta-plain, lake margin, back barrier and blanket mires in sediment starved basins (Hobday, 1987). Most of the commercial seams are contained in fluvial and delta-plain sequences, with thick, dip – elongate, inter-channel seams and more extensive coals typically overlying abandoned delta lobes (Hobday, 1987). These coals are characterised by low sulphur, rare seat earths and close association with conglomeratic sediments that are largely glaciogene in origin (Hobday, 1987). Typically, basal diamictite and glacial outwash deposits grade into coarse fluvial and finer deltaic facies with thick, intervening lacustrine or epeiric basin shales succeeding the glaciogene facies (Dwyka Group). The Karoo Basin coal province is cratonic, bounding a major southern foredeep with only minor coals (Hobday, 1987).

A west to east increase in the rank and vitrinite content of South African coal exists, although the Limpopo coals are more generally of higher rank (Cairncross, 2001). The majority of the reserves are in the Permian Vryheid Formation of the Ecca Group. This document will focus on the Witbank coalfield, which together with the adjoining Ermelo and Highveld coalfields, contains an estimated 50% of the nation’s recoverable coal reserves. Witbank lies towards the northern extent of the Karoo Basin, where the sediment thins and the Vryheid Formation rests unconformably on the Transvaal Supergroup, the Waterberg Group and volcanic rocks associated with the Bushveld Igneous Complex (Figure 3). The northern margin of the Witbank coalfield marks the northern limit of the Permian Karoo Supergroup sediments that include the Ecca Group. Thus the coal seams situated on the northern margin of the coalfield are relatively shallow. Farther south in the basin the Karoo Supergroup is underlain by tillite, shale and siltstones of the Carboniferous Dwyka Formation (Table 2). The east-west trending Smithfield Ridge (Rooiberg Fesites) bounds the Witbank coalfield to the south, separating it from the adjacent Highveld Coalfield. The only major disturbances to the strata are the minor dolerite dykes and sills, which have displaced the coal seams and burnt and devolatised the coal seam in certain areas. There are six coal seams in the Vryheid Formation, which occur at a relatively shallow depth (<200 m) in the northern part of the basin (Cairncross, 2001).

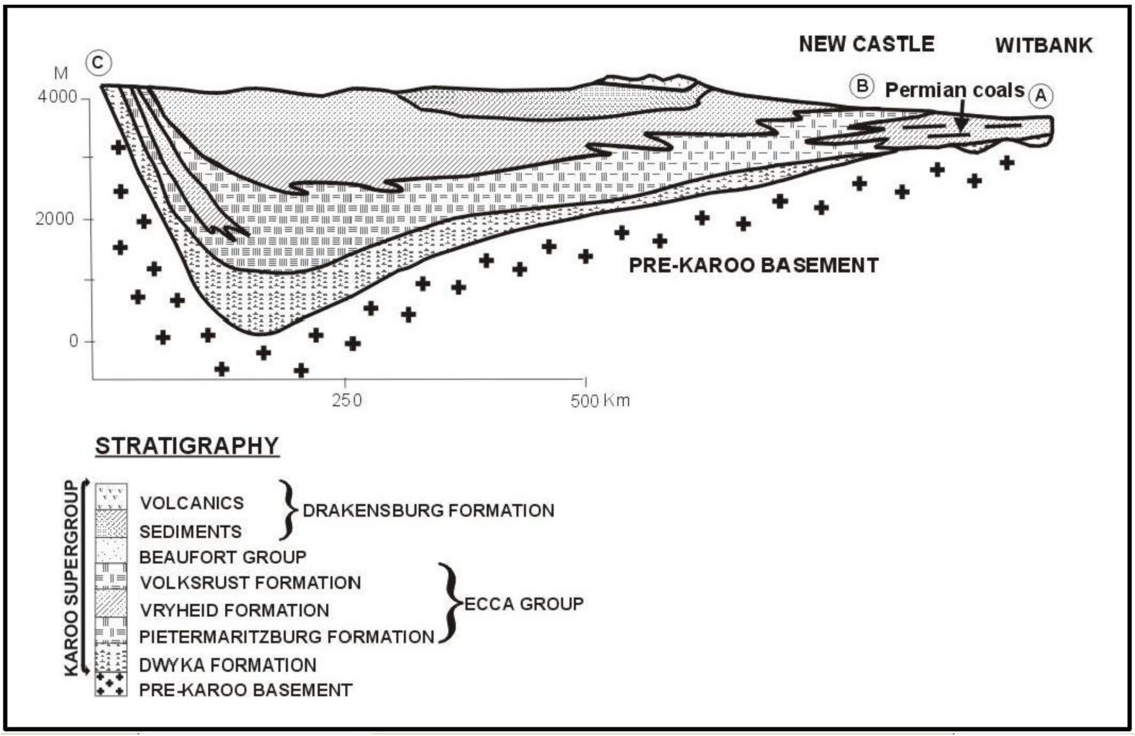

Figure 3 : Cross-section through the Karoo Basin illustrating the tectonic and stratigraphic position of the coal-bearing Vryheid Formation (after Cadle et al.,1990)

The strata of the Karoo Supergroup consist primarily of sandstone, carbonaceous siltstone, shale, minor conglomerates and coal seams. The sediments display coarsening upward sequences with some fining upward facies, indicative of deltaic and fluvial deposits respectively (Cairncross, 2001). Marine sediments commonly cap the organic deposits.

A regional three-dimensional (3-D) model of the Witbank coalfield (Grodner and Cairncross, 2003) shows a continuous, conformable basin fill sequence that represents a number of regressive sequences capped by coal, in turn overlain by transgressive marine sediments.

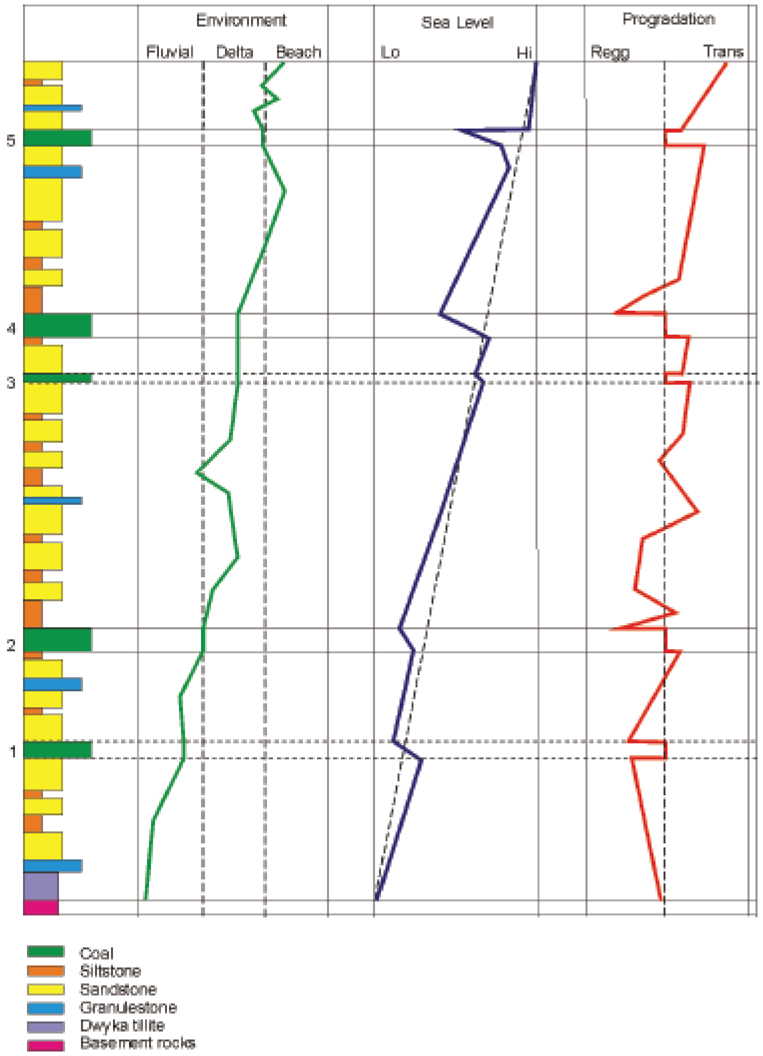

Figure 4: Graph of sea level change combined with graphs of sedimentary environment and amount of progradation in the basin (after Grodner, 2003)

The model demonstrates how the fluvial axes exhibit a strong northeast – southwest trend, following glacial valleys that were eroded as the glaciers retreated in a northward direction, prior to the deposition of the Vryheid Formation. The axes were superimposed one on top of another until more recent times when the glacial valleys had already been filled, thus they exert less influence on the later sequence. Grodner and Cairncross (2003) also noted that the distribution of coal was influenced by the influx of clastic material (prohibits coal formation) as well as by rises and falls in sea level.

Triassic			Beaufort Group	
Late Permian	Tatarian	Karoo Supergroup	Ecca Group	Volksrust Formation
	Kazanian			
	Ufimian			
Early Permian	Kungurian			
	Artinskian			Vryheid Formation
	Sakmarian			
	Asselian			
Carboniferous			Dwyka Group	

Table 2 : Stratigraphy of the Karoo Basin (derived from Cairncross, B, 2001)

Coal seams that are close to the surface tend to be highly weathered and coal recovery is not practical. The depth of weathering is reported to vary considerably. Bell et al. (2001) identified weathering of between 5 and 10 m in thickness. This has implications for the viability of opencast mining, which provided 53% of mine production in 2005, in conjunction with: board and pillar 37%, stoping 7% and longwall 3% (Hobbs et al., 2001). Despite the large number of coal mines in the Witbank coalfield, this coalfield has not reached its production peak (Prevost and Msibi, 2005).

4. Geographical Framework

4.1. CLIMATE

Climatic conditions vary between the east and west of South Africa (Figures 5, 6 and 7), largely due to the presence of the southerly flowing warm Agulhas ocean current of the Indian Ocean coastline (to the east) and the northward flowing cold Benguela current of the Atlantic Ocean (to the west).

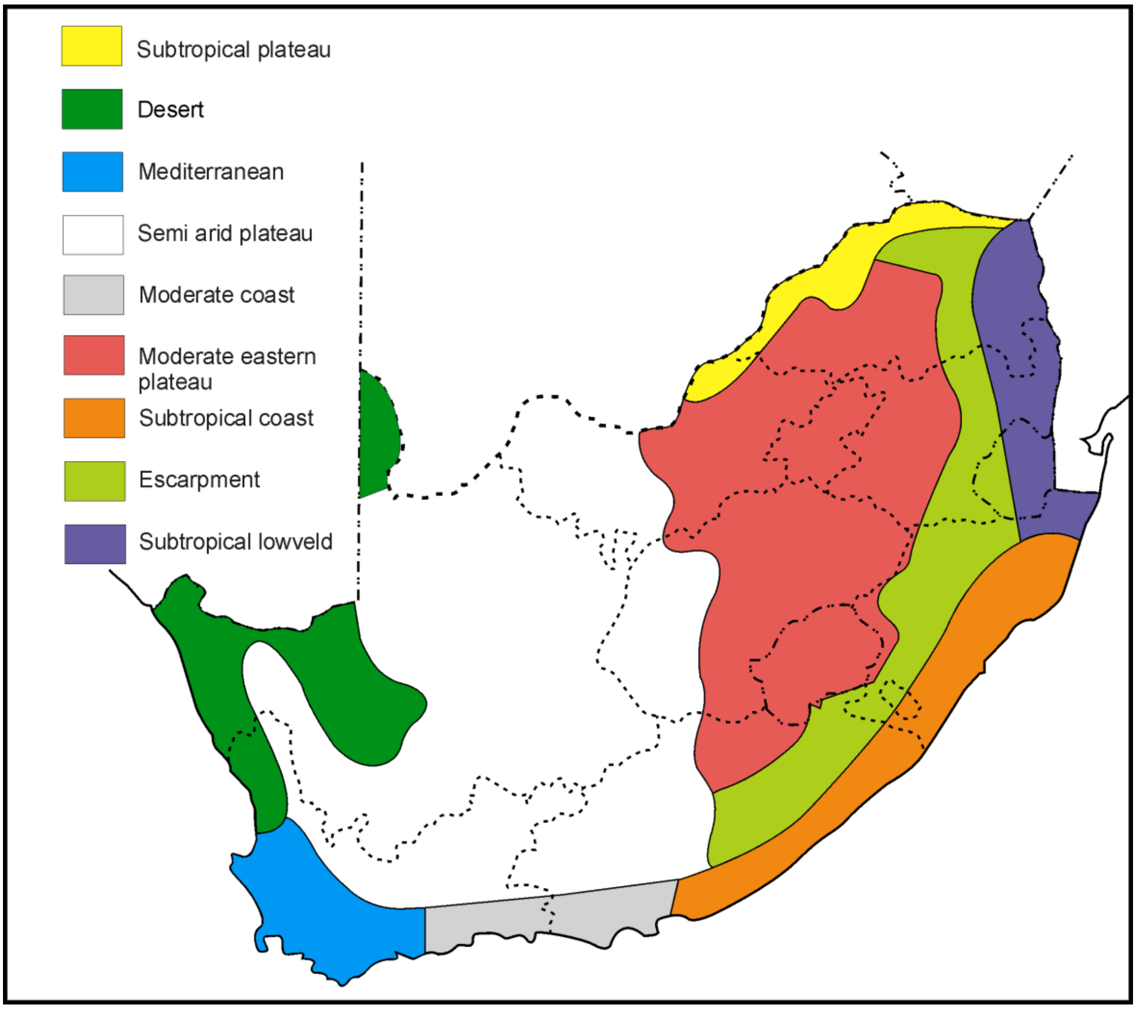

Figure 5 : Climate regions of South Africa

Climate is largely controlled by the movement of air masses associated with the Inter-Tropical Convergence Zone (ITCZ). During the summer, high land temperatures produce low pressures and moisture is brought to the Olifants river catchment through the inflow of maritime air masses from the Indian Ocean. During the winter, the sun moves north and the land cools, causing the development of a continental high pressure system. Moderate summers and cold winters characterize the climate of the area. Descending and out flowing air produces the regional dry season. Rainfall is therefore seasonal and occurs mainly during the summer (October to April). The annual rainfall over the Olifants river catchment is generally between 500 and 800 mm, but exceeds 1000 mm over parts of the Highveld (Figure 6; McCartney et al., 2004). The mean annual rainfall in the Upper Olifants catchment is 689 mm, whilst the mean annual evapotranspiration rates for the catchment is 1450 mm (McCartney et al., 2004).

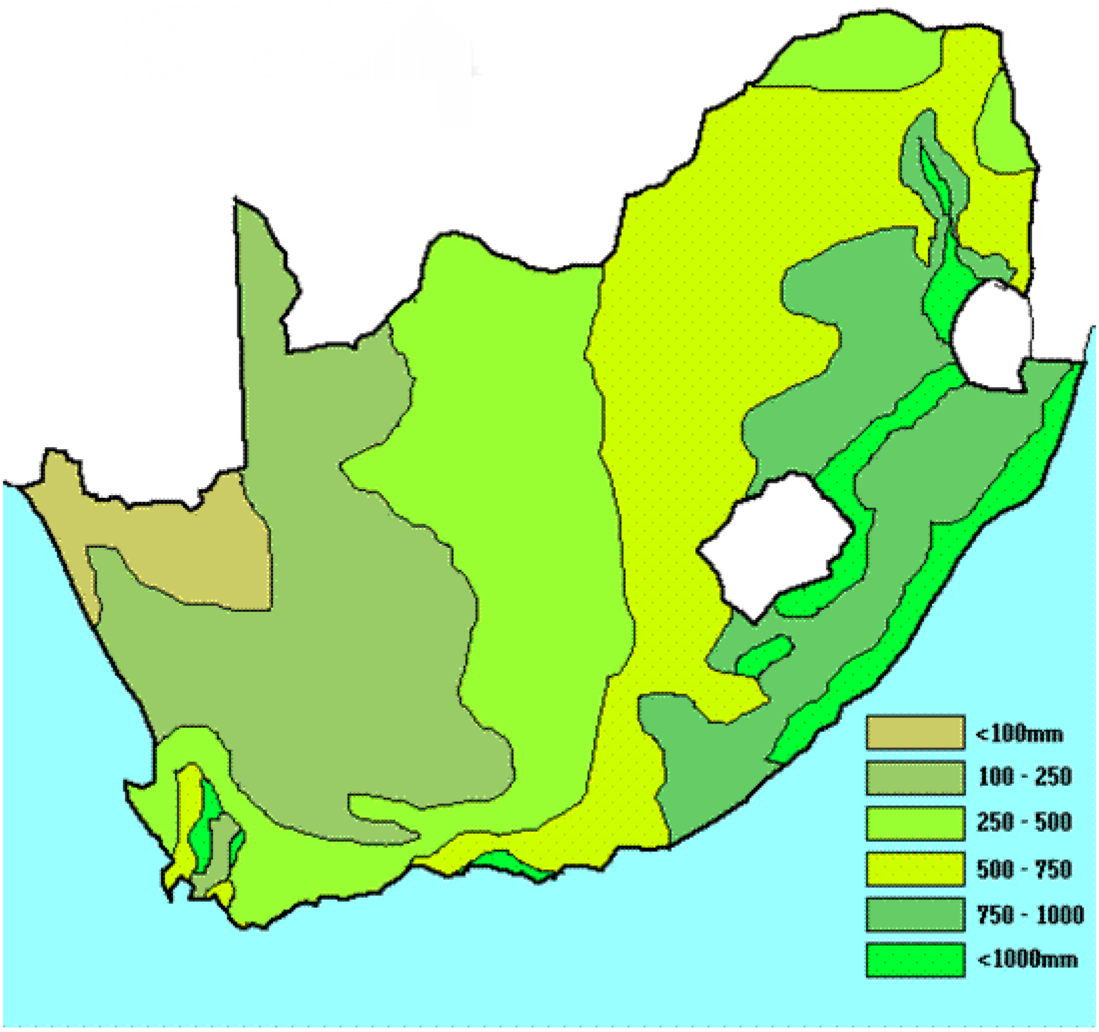

Figure 6 : Average rainfall map of South Africa (after McCartney et al., 2004)

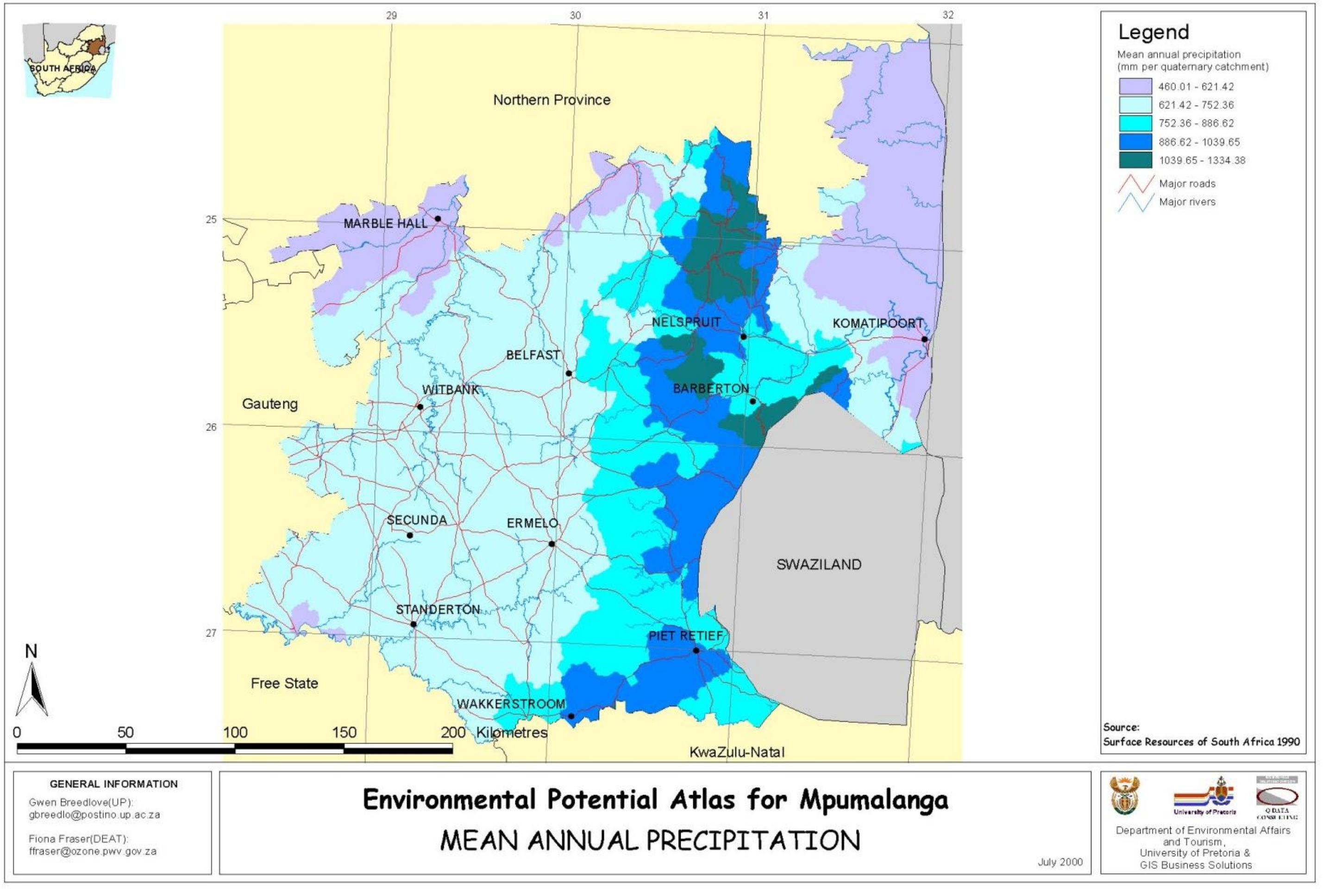

Figure 7 : Average rainfall of the Mpumalanga province

The predominant anticyclonic circulation over the Mpumalanga coalfield, particularly in winter, results in light winds clear skies and the development of surface temperature inversions at night that persist well into the morning (DEA, 2010). The mechanisms to disperse pollutants that are released at or near ground level into this stable atmosphere are typically weak. Pollutants tend therefore to accumulate near their source or to travel under the light near surface drainage winds. Relatively high ambient concentrations of contaminants may occur especially at night and in the morning when the surface inversions are strongest. This meteorology is particularly relevant to low-level industrial stacks, domestic fuel burning and motor vehicles. During the day, surface warming induces the break-up of the surface inversion and promotes convection, which enhances the dispersion of the night time pollution build-up. Convection may carry emissions from taller stacks down to ground level, which results in episodes of high ambient pollutant concentrations (DEA, 2010). Immediately above the surface inversion a strong nocturnal wind system provides an effective mechanism to transport pollutants from taller stacks away from their source. The low-level jet (LLJ) occurs over much of the Highveld Priority Area (HPA) at night and is stronger and more persistent in winter. Pollutants released in the HPA not only affect the HPA. Easterly airflow associated with a ridging Indian Ocean Anticyclone results in recirculation over the subcontinent (DEA, 2010). Convective summer showers and thundershowers wash pollutants out of the atmosphere on a relatively local scale (DEA, 2010).

4.2. VEGETATION

Mpumalanga falls mainly within the grassland biome. The escarpment and the Lowveld form a transition zone between this grassland area and the savannah biome. Long sweeps of undulating grasslands change abruptly into thickly forested ravines and thundering waterfalls of the escarpment, giving way to the subtropical wildlife of the Lowveld. The Witbank coalfield is situated mainly within the grassland biome, with some patches of savannah in the north. According to Daemane (2010) grasslands are amongst the most threatened and least conserved (only 1.3%) vegetation biomes in South Africa.

Grasslands have high species richness and a high turnover of biodiversity across the landscape. The South African grasslands are very old, complex and slowly-evolved systems with indigenous species diversity that is second only to the well-known fynbos biome. The grasslands also play a critical role in water production with South Africa's major river systems all originating in the biome. The term 'grassland' creates the impression that the biome consists only of grass species. In fact, only one in six plant species in the biome is a grass. The remainder includes bulbous plants such as arum lilies, orchids, red-hot pokers, aloes, watsonias, gladioli and ground orchids. There are also many other species, such as blue cranes and swallows, habitats and ecosystems that form an important part of the threatened biomes in South Africa. Thirty percent of the biome is irreversibly transformed and only 1.9% of the biome is formally conserved. Because the grasslands biome contains the economic heartland of South Africa and is home to most South Africans, it is under considerable development pressure. The life-sustaining biodiversity and ecosystem services (such as water production) of the grasslands are being eroded to such an extent that human wellbeing is threatened. As a result, the government has identified the grasslands biome as one of the priorities for conservation action.

According to the Adcock classification the majority of the area falls within the Bankveld, Themeda Veld or Turf Highveld and Sourish Mixed Bushveld veld types (Mpumalanga http://www.mpu.agric.za/Web/area/reports/r14.pdf).

4.3. DISTRIBUTION OF POPULATION

In 2000 the population of South Africa was 43.421 million with a relatively low growth rate [0.5%, (Ashton, et al., 2001; Figure 8)]. Important urban centres in the study area include Witbank, Middelburg and Ermelo (Figure 1). These areas already have high concentrations of people relying on them for survival. However, a number of smaller areas (urban and peri-urban) and therefore a high population occur around the major centres (Mpumalanga Province, 1999).

There is a tendency for people to move towards larger urban centres creating nucleated settlement patterns based on the assumption that employment is available. The result is increased urbanization, and hence the concentration of people, which gives rise to the growth of urban centres and the formation of nucleated settlement patterns (Mpumalanga Province, 1999).

Urban centres of Mpumalanga province are likely to record substantial population growth rates in the future, as a result of both natural growth and inter-provincial and intra-provincial job related migration. Mpumalanga province consists of both urban and rural settlements, each with their own characteristics and different housing typology. Urban settlements incorporate towns, cities and informal settlements, or peri-urban areas that develop on their edges. Rural settlements form part of areas in which people are directly dependent on their immediate environment for their daily requirements (Mpumalanga Province, 1999).

The road network plays a significant role in determining the settlement pattern. The N4 is a major corridor in Mpumalanga and the major settlements in the province are located on the corridor forming a linear settlement pattern. The increased importance of the Maputo corridor is having an impact on the urban areas located along the corridor (Mpumalanga Province, 1999).

In Mpumalanga, rural environments can be classified into two major groups, namely: the former homeland (densely populated) areas and the rural areas (Figure 9), which are less densely populated and where the livelihood of people primarily depends on agriculture. Around 61% of Mpumalanga's population resides in the rural environment. The less dense rural environment is also associated with concentrations of people close to mining, forestry and power station activities. In general, these centres are well served in terms of infrastructure and facilities.

The study area falls within the Nkangala District Municipality. The Nkangala area is considered to be the second largest in terms of its population as 39% of its population lives in urban areas. The most dominant urban areas are Witbank and Middelburg, with a strong resource base in coal, manufacturing and agriculture with related industrial centres. As a result, the Witbank and Middelburg areas have well established industrial clusters around them, which benefit from the good economies of scale in the area. Within the urban areas, the bulk infrastructure is generally good, with the exception of informal settlement areas. Large-scale urban informal settlements are found in Witbank and Middelburg and their growth rate is increasing rapidly due to the urbanization process (Mpumalanga Province, 2001).

The abundance of coal reserves in the area has led to the establishment of coal driven power stations. Small settlements have developed in response to mining or coal power station activities in the area. This has led to the formation of smaller centres with good infrastructure, but spatially segregated from any economic activity (Mpumalanga Province, 2001).

Witbank and Middelburg are located within good proximity to Gauteng, which lies to the west and is still the major urban and industrial centre of South Africa. Transport networks in the area are well established and encourage business activities in the core urban areas. Witbank and Middelburg urban centres perform a regional function. These centres are likely to experience economic growth and potential associated with the development of the N4.

The South African sector of the Olifants Basin (Figure 13) supports several large and medium sized towns as well as numerous smaller communities and subsistence farmers (Figures 8 and 10). The total population of the Olifants Basin is about 10.5 million with South Africans comprising 85% of the population. Urban areas only comprise about 1.25% of the Mpumalanga Province which is relatively small (Department of Agriculture, 2006).

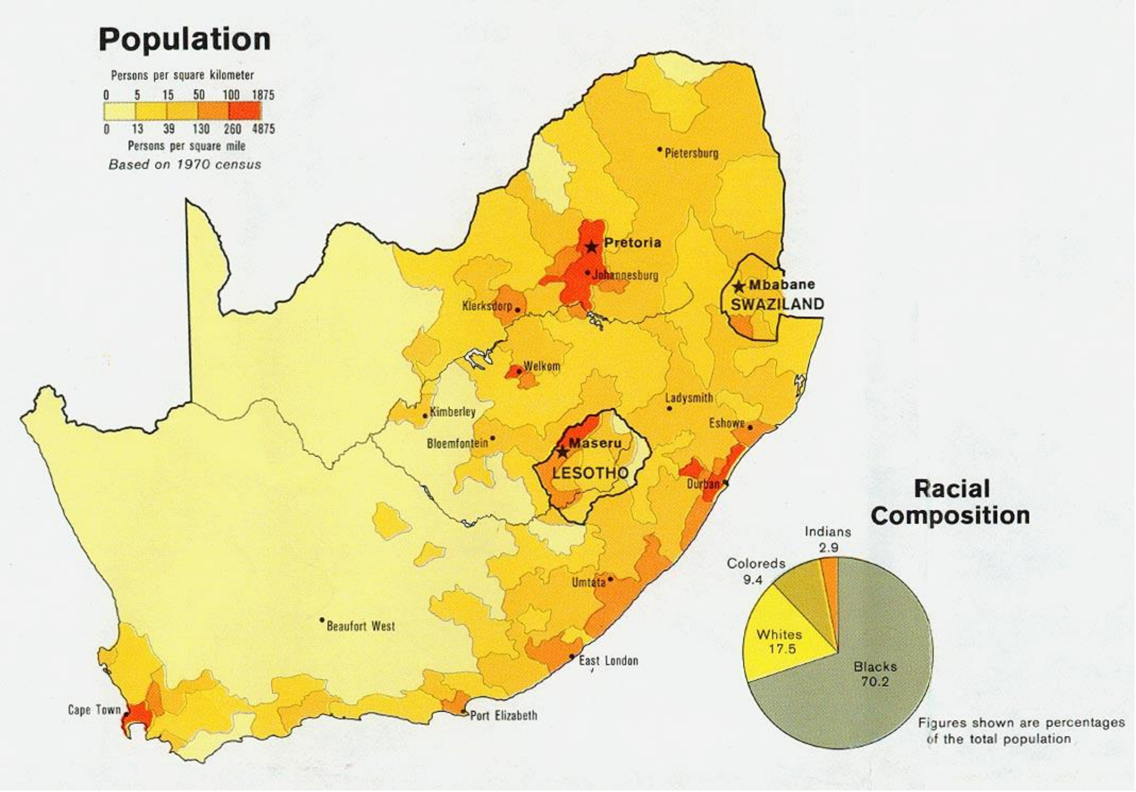

Figure 8 : Population density of South Africa. Source Wikipedia
http://en.wikipedia.org/wiki/File:South_Africa_2001_population_density_map.svg

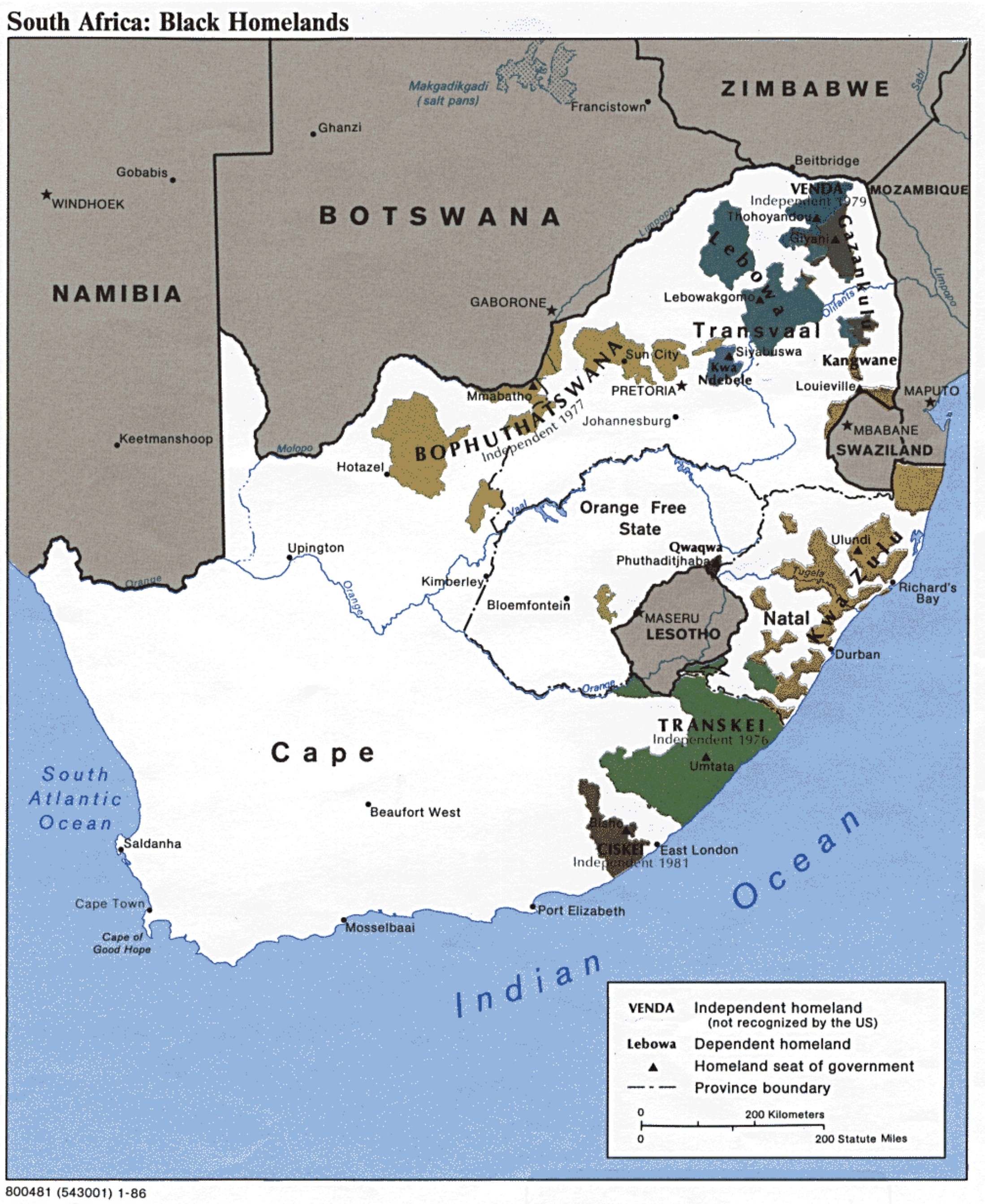

Figure 9: Former homelands of South Africa. Source Wikipedia
http://upload.wikimedia.org/wikipedia/commons/f/fa/Southafricanhomelandsmap.png

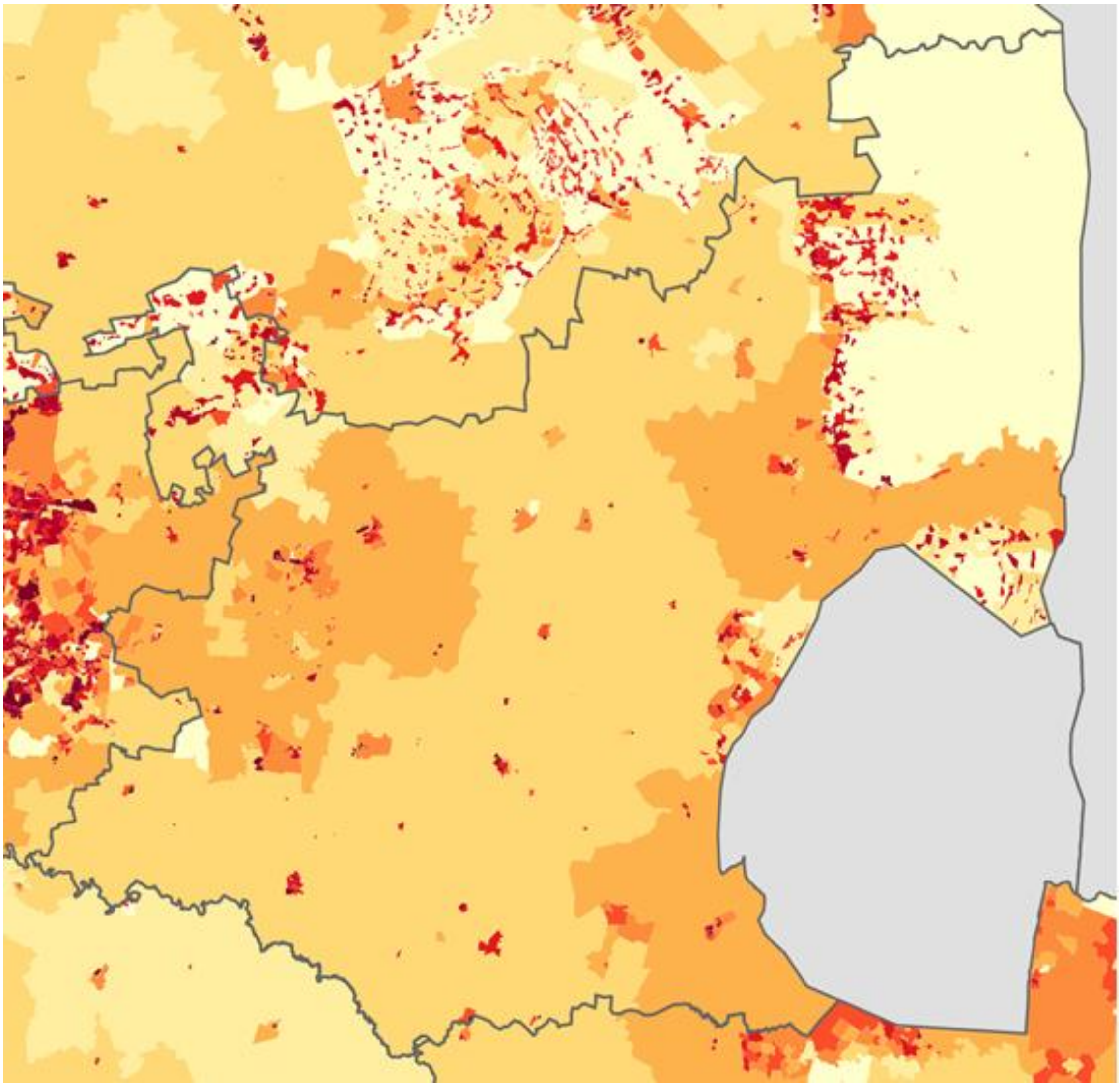

Figure 10 : Population density, Mpumalanga. Source Wikipedia
http://en.wikipedia.org/wiki/File:Mpumalanga_2001_population_density_map.svg

4.4. DISTRIBUTION OF CROPS

Agriculture is one of the largest economic sectors in Mpumalanga province, producing 15% of total output in South Africa (South Africa Yearbook, 2003). The growing demand for agricultural products is an important driver of the agricultural sector therefore emphasizing the importance of acceptable land use patterns that reflects the importance of agriculture in the Province. Mpumalanga is dominated by vast open areas of natural vegetation, which comprises 71% of the total land area in the Province. The extent of transformed and / or degraded land is changing due to mining activity in the Witbank and Highveld coalfields. Most of the converted natural land is under some form of cultivation (26%), including commercial plantations (towards the eastern side of the province), which comprise 8% of the total area of Mpumalanga (Department of Agriculture, 2006).

Agricultural production in Mpumalanga ranges widely from summer cereals and legumes in the Highveld region to subtropical and citrus fruit and sugar in the Lowveld. The main agricultural crops produced in the Highveld area include maize, wheat, tobacco, vegetables, beans, potatoes, sweet potatoes, sunflower seed, sorghum, dry beans, soy beans, and cotton. Mpumalanga is also well known for intensive and extensive beef production and the production of other animal produce such as sheep, chickens, eggs and pork. For much of the Highveld, dry land farming is utilized in agricultural production, with intensive irrigation activities in the Loskop dam area near Groblersdal (middle Olifants river catchment) and in the Lowveld area adjacent to the Crocodile and Komati rivers (Department of Agriculture, 2006). Agricultural activity in the Olifants Basin includes subsistence and commercial cultivation (of maize, lucerne, potatoes and sunflowers), game farming, livestock and dairy production. Minor areas of plantation forestry are also located in the wetter portion of the sub-catchment.

The southern part of the Nkangala is utilized for mixed farming activities, which involves cattle, dairy, sheep, wool, maize, potatoes, sweet potatoes and beans. The northern part of Nkangala is designated for cattle farming. The Groblersdal area is the location of the Loskop Dam Irrigation Scheme where citrus, sub-tropical and deciduous fruits are produced. In the eastern part of Nkangala, the topography changes from typical Highveld to mountainous landscape resulting in the rise of many rivers, which encourages activities such as fishing and forestry (Mpumalanga Province, 1999). The Nkangala area is dominated by extensive and dry land agriculture and limited potential for afforestation exists. Deforestation in the area has led to species' habitat loss and also made soil more susceptible to erosion agents (Mpumalanga Province, 1999).

Increased agricultural production is constrained by the limited water resources in some of the water-stressed catchments (Department of Agriculture, 2006). Water is a constraint for the expansion of current agricultural production as is the impact of agricultural activities such as irrigation on available water resources. Agricultural activities have also an impact on biodiversity due to the clearing and loss of vegetation, with the introduction of new cultivated land and irrigation schemes.

The 400 mm isohyet separates land that is suitable for growing crops to the east from land that is generally only suitable for grazing or crop cultivation on irrigated land to the west (Figure 11).

4.5. DISTRIBUTION OF SOILS

Soil formations reflect the influence of the parent material, climate and biological activity. Dominant soil types in the Olifants Basin are moderately deep sandy to sandy-clay loams in the south and west, grading to shallower, sandy or gravelly soils in the north and east. The deeper loam soils are important for agricultural activities and support extensive irrigation developments along many of the tributary rivers, especially downstream of the Losklop Dam.

The dominant soil types according to the South African Soil Classification (Macvicar and de Villiers (1991) are: Hutton (homogeneous red soil), Avalon (homogeneous yellow-brown soil with some iron accumulation in zones with periodic water saturation), Clovelley (homogeneous yellow-brown soil) and Glenco (homogeneous yellow-brown soil with some iron concretions/ ferricrete accumulation in zones with periodic water saturation) (Mpumalanga, 2010).

Further away from the main river channels, most of the land is given over to small and medium scale livestock farming. A few areas of black vertisols in the southern and western parts of the basin also support agriculture (Ashton et al., 2001). Minor areas of plantation forestry are also located in the wetter portion of the sub-catchment.

The generation of large quantities of mine wastewater at collieries and the need for cost effective and environmentally sustainable mine water disposal have generated interest in the use of low-quality mine water from collieries to irrigate agricultural crops (Idowu et al., 2008). Although this will boost the beneficiation of available water and release the increasing pressure on water resources, studies has shown that there is an associated increase in soil salinity. Although findings from studies undertaken to assess the impact of irrigation with mine water has shown that irrigation of certain crops would not affect the production thereof (Idowu et al., 2008), other studies have shown that there are critical flaws in the mine-water-irrigation concept in areas where certain criteria occur on site (Vermeulen and Usher, 2009).

4.5.1. Acidification of soils

Conflict arises between various land uses, which both utilise the natural resources and impact negatively on each other. The instances of such conflict can be noted where mining activities impact on agriculture through excessive air and water pollution and where agriculture and mining threatens the conservation of biodiversity, which again impacts on the tourism potential of the area (Mpumalanga Province, 1999).

Soil loss and land degradation have significant social, economic and environmental consequences that could lead to a reduction in the productive capacity of the land. Some of the human activities contributing to land degradation include unsuitable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper crop rotation, poor irrigation practices and mining (Mpumalanga Province, 2003).

In Mpumalanga, soil potentials are reduced through pollution, acidification, declining fertility, compaction and erosion (Mpumalanga Province, 1999). Soil erosion is increasing due to grazing pressure, cultivation on slopes under subsistence farming, the lack of appropriate soil conservation planning as well as the clearing of land for mining (Mpumalanga Province, 1999). Most parts of the province fall within a pH band of 6.5 – 7.3 and only 2% is considered to be alkaline (pH 7.3 – 8.4). The area of greatest acidity (pH<5.2) comprises approximately 8% of the province and is well correlated to the areas afforested (which enables leaching of bases by biomass) under commercial species (Mpumalanga Province, 2003) as well as areas affected by the deposition of acidic air pollutants generated from coal fired power stations and other industries. Increased acidity levels are seen in places like Witbank, Kendal, Bethal, Balfour, Standerton and Ermelo. Fossil fuel and biomass-burning are the main contributors to acid rainfall. Soils become progressively more acidic thus affecting biodiversity (Mpumalanga ISF, 1999).

Mpumalanga also generates the largest amount of hazardous waste in South Africa (Mpumalanga ISF, 1999), a third of national production. Much of the hazardous waste is produced by the industrial and mining sectors. It is important to note that less than 0.1% of this actually reaches a hazardous waste site.

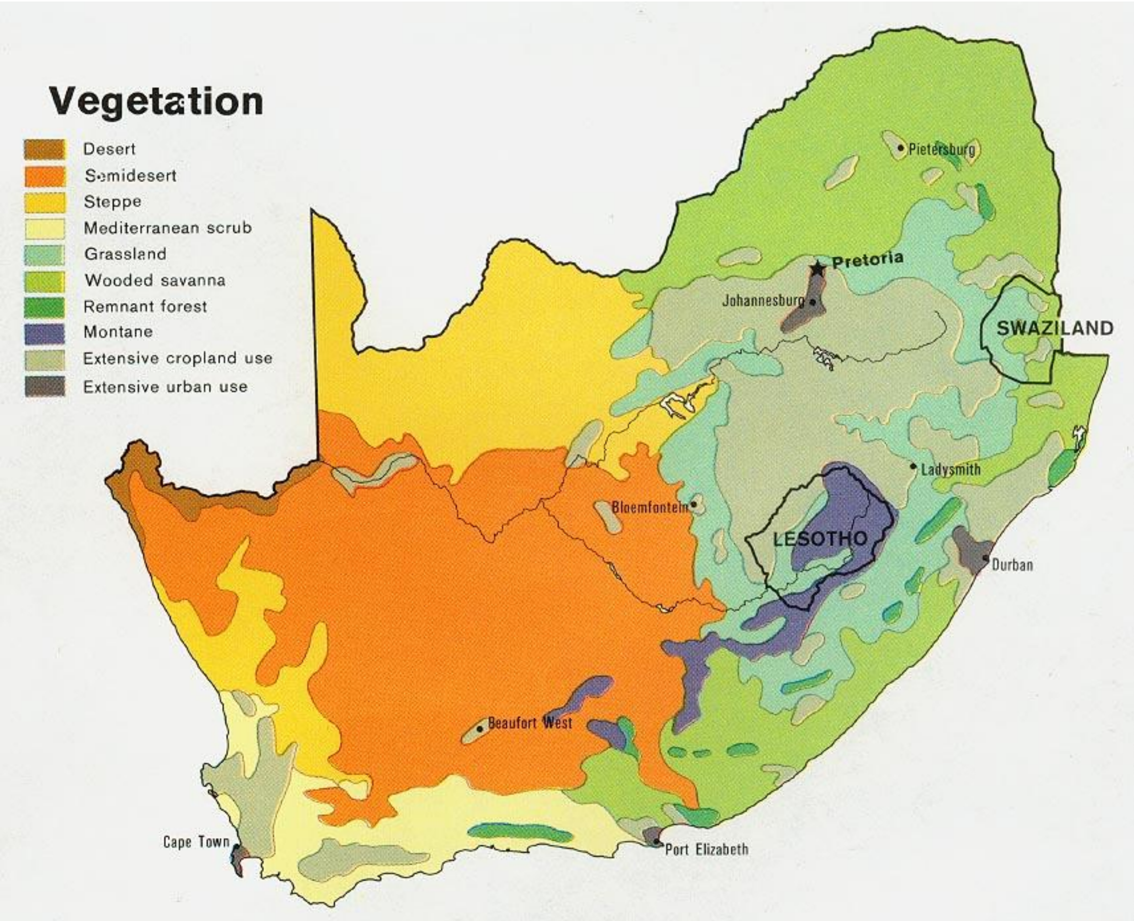

Figure 11 : Vegetation distribution in South Africa (Department of Agriculture, 2006)

4.6. WATER RESOURCES, DAMS AND RIVERS

The rolling hills of the Highveld are characterized by abundant seasonal wetlands, perennial and seasonal streams and many fresh to mildly saline pans. This diversity arises because of the unique nature of the groundwater aquifers.

The Karoo bedrock strata are generally massive, with very low porosity, except for that provided by occasional fractures. Overlying the bedrock is a weathered zone (regolith) in which the rocks are partially or completely decomposed, creating a porous mass. Near the surface of the regolith there is often an impermeable layer formed by precipitation of material (mainly iron and/or silica compounds). This structure gives rise to three different groundwater aquifers: the first is formed by fractures in the bedrock; the second by the deeper regolith, and the third by the zone above the plinthite layer (perched aquifer). Water is supplied to the aquifers by rainfall, and soaks into the ground to supply the aquifers. Water flowing laterally in the perched aquifer may emerge on surface to form wetlands high on the hill sides. Infiltrating rain and water seeping from these wetlands supplies the deeper weathered rock aquifer. The aquifers fill with water in the rainy season, and slowly discharge water into streams through the dry season, thus sustaining stream flow throughout the dry season. Fractures in the bedrock also provide some surface water by seepage, but this aquifer appears to be of lesser importance than the regolith aquifers because of its more limited storage capacity. Water quality differs in the different aquifers, being highest in the perched aquifer (<20 ppm dissolved solids), and lowest in the fractured rock aquifer, where the dissolved solid concentration is in the order of hundreds of parts per million (McCarthy and Pretorius, 2009).

Mpumalanga Province contributes to the source of four of Southern Africa's major river systems. Approximately 53% of Mpumalanga is drained by the Olifants River System (a major tributary of the Limpopo River, Figure 15), the Vaal River System, the Inkomati River System and the Pongola River System. The four basin states comprising the Limpopo Basin have jointly formed a Joint Permanent Technical Commission (JPTC) to deal with matters of common interest with respect to the Limpopo River and its tributaries (Ashton et al., 2001).

The Mpumalanga Lake District (see also section 7) has more than 270 fresh water lakes, including Lake Chrissie (Figure 12), which is the country's largest natural body of fresh water and is groundwater fed. The Lake District is part of the eastern escarpment where four river catchments meet (the Vaal, Komati, uMpuluzi and the Usutu). The value of this area is reflected in a conflict of interest (environmental and tourism versus mining) in the Mpumalanga Province.

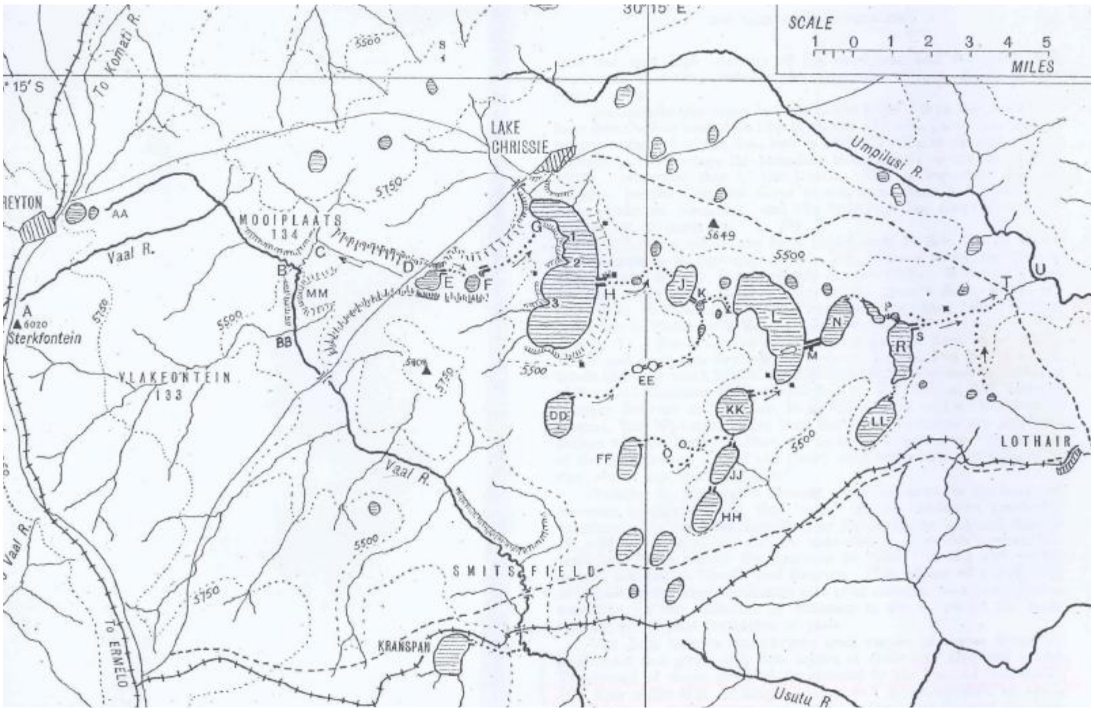

Figure 12 : Mpumalanga Lake District

Each of the African river basin states has its own water management system, dividing the basins into Water Management Units, or Water Management Areas (Figure 13). Ashton et al. (2001) reported that in South Africa the process of setting up formal Catchment Management Agencies for the nineteen Water Management Areas in the country has started.

The easterly flowing Olifants River is a major tributary of the Limpopo River (Figure 15) draining areas of four Southern African states, namely Botswana (to the west), Mozambique (to the east), Zimbabwe (to the north) and South Africa (eleven sub-catchments to the south). From its origin in the Bethal-Trichardt area to its confluence with the Wilge River, north of Witbank, the Olifants River flows in a north-north-easterly direction where it is joined by the Letaba river, immediately before entering into Mozambique. The Olifants river catchment comprises nine sub-catchments in South Africa with another in Mozambique and has a relatively dense network of tributary streams and rivers. Most of the tributaries in the lower reaches of the catchment only have seasonal or episodic flows (Ashton et al., 2001). The Olifants River was considered to be a strong-flowing perennial river, but now it is considered a weakly perennial river where flow frequently ceases during drought periods (Ashton et al., 2001). The South African portion of the catchment has some 201 water storage dams.

The southern area of the Olifants river catchment is underlain by the Karoo Supergroup rocks (sections 3 and 7), which hosts the coal deposits (Ashton et al., 2001). Beyond this, harder silicified sandstones and cherts, as well as syenitic and granitic outcrops, form elevated remnants. The upper Olifants River (Figure 16) is characterised by coal mining and thermal power generation plants, as well as critically important agricultural areas, towns and cities and light and heavy industries. The middle reaches contain extensive areas of irrigated agriculture as well as platinum, chrome and vanadium mining and smaller urban areas (Ashton et al., 2001). The lower reaches of the catchment contain several small mines as well as an important copper and phosphate mining complex around Phalaborwa.

Water demands by industry, mining and irrigation account for > 75% of the water used in the Olifants river catchment (Ashton et al., 2001). Three inter-basin transfer schemes convey water from the Vaal system in South Africa into the headwaters of the Olifants River to provide domestic water supplies as well as cooling water for several coal-fired thermal power stations (Ashton et al., 2001).

The Olifants River has a catchment area of about 54 750 km^2, a mean annual runoff of 2 400 x106 m^3 and is subject to intensive mining activities in most of its 9 sub-catchments. The major rivers contributing to the Olifants River are the following:

- The Rietspruit, the Steenkoolspruit and the Viskuile that confluences to form the main stem of the Olifants River south of Witbank.
- The Klein Olifants River is to the east of the tributaries above, and joins the river north west of Middelburg.
- The Wilge and Koffiespruit rivers drain the area to the west of the main stem and join the Olifants River north of Witbank.
- The Moses and Elands rivers drain the western part of the region.

The health of the upper Olifants River has deteriorated over the last decade. Lake Loskop receives water from the upper catchment of the Olifants and serves as a catchment sink. The potential pollution sources in the upper Olifants river catchment area include seepage of acid mine drainage from several abandoned and active coal mines, factories, smelters, sewage plants, etc. (Driescher, 2008; Mpumalanga Province, 2003).

The Wilge sub-catchment of the Olifants River joins the Olifants River immediately upstream of the Loskop Dam. This catchment is underlain by the Karoo Supergroup rocks surrounded by dolomite and limestone, which issue sufficient water to ensure that the river is perennial. There is limited mining and quarrying activity in this sub-catchment, thus mining-related impacts are minimal. However, there are minor discharges of treated domestic effluent from Bronkhorstspruit and Cullinan and there is a large water supply dam (Bronkhorstspruit Dam). Characteristic of the Wilge sub-catchment are the small wetlands that form on the uphill side of protruding dolerite formation (Ashton et al., 2001).

The Klein Olifants-Riet sub-catchment of the Olifants River exhibits similar hydrological features to the Wilge sub-catchment. It includes the coal mining towns of Witbank and Middleburg and receives additional water via inter-basin transfer from the Vaal, Usutu and Komati systems. All of the rivers and streams in the sub-catchment are perennial. The Little Olifants-Riet sub-catchment of the Olifants River is largely underlain by the Ecca Group and Dwyka Formation of the Karoo Supergroup. To the north the area is underlain by acid and intermediate intrusive formations of the Waterberg Group. Additionally, there are small areas of dolomite and limestone in the northern part of the sub-catchment (Ashton et al., 2001). Like the Wilge sub-catchment, the Little Olifants-Riet sub-catchment of the Olifants River is characterised by a large number of small wetlands that form on the uphill side of protruding dolerite dykes and sills that dip gently to the south (Ashton et al., 2001).

The mining industry is considered to be the major point source of pollution (Figure 14). As a result of these and other anthropogenic activities in the catchment over the past decade, the aquatic ecosystem has been degraded and increasingly contaminated by pollutants such as heavy metals. A number of settlements discharge untreated or partially treated domestic and industrial effluent into the Olifants river catchment (Ashton et al., 2001).

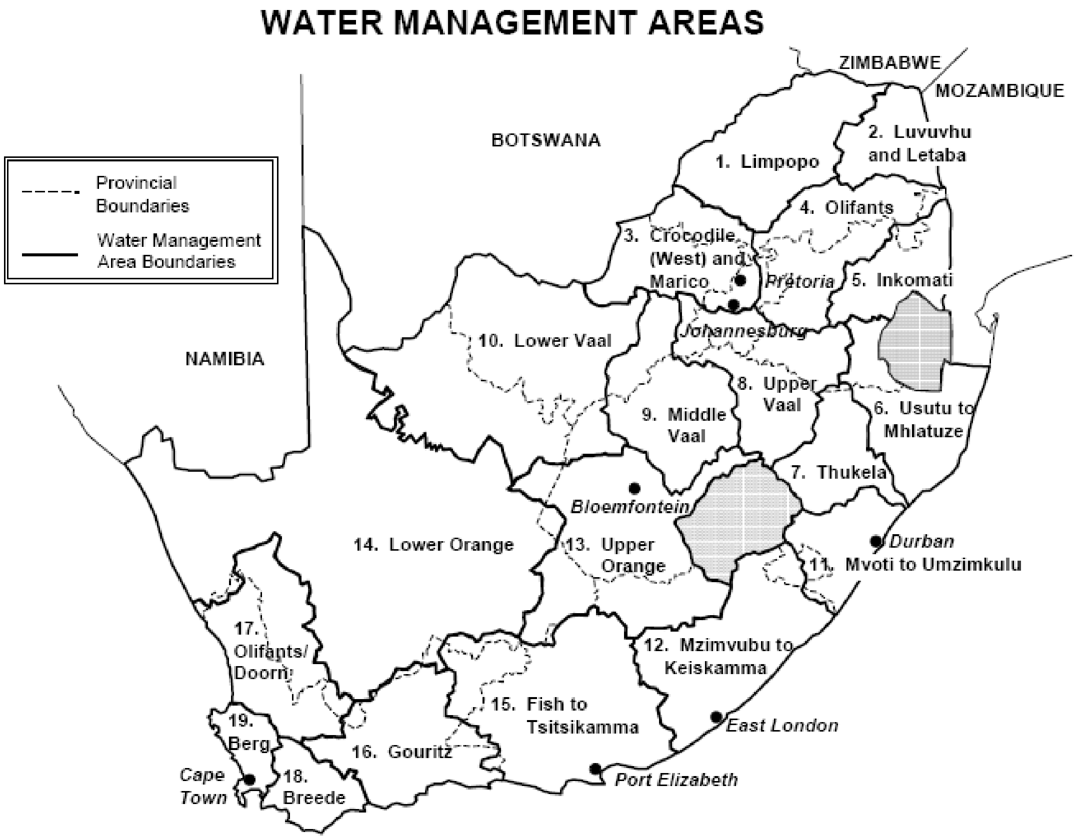

Figure 13 : Water management areas of South Africa. (After Ashton et al., 2001.)

Whilst the South African Department of Water Affairs (DWA) is responsible for the management of water supply each coal mine and thermal power station collaborates in the management of their water supplies and in the disposal of their wastes and effluents. The water quality of almost all of South Africa's river systems has worsened progressively as a result of increasing urbanization and industrialization; the adverse effects of poor water quality have been compounded by the operation of water storage reservoirs and abstraction of increased volumes of water for human uses (Ashton, 2007). The decline in the water quality of the Olifants river catchment has also been reported (Seymore et al., 1995; Du Preez et al, 1997; Driescher, 2008; de Villiers and Mkwelo, 2009).

The water demands by industry, mining and irrigation account for 75% of all water used (Ashton et al., 2001).

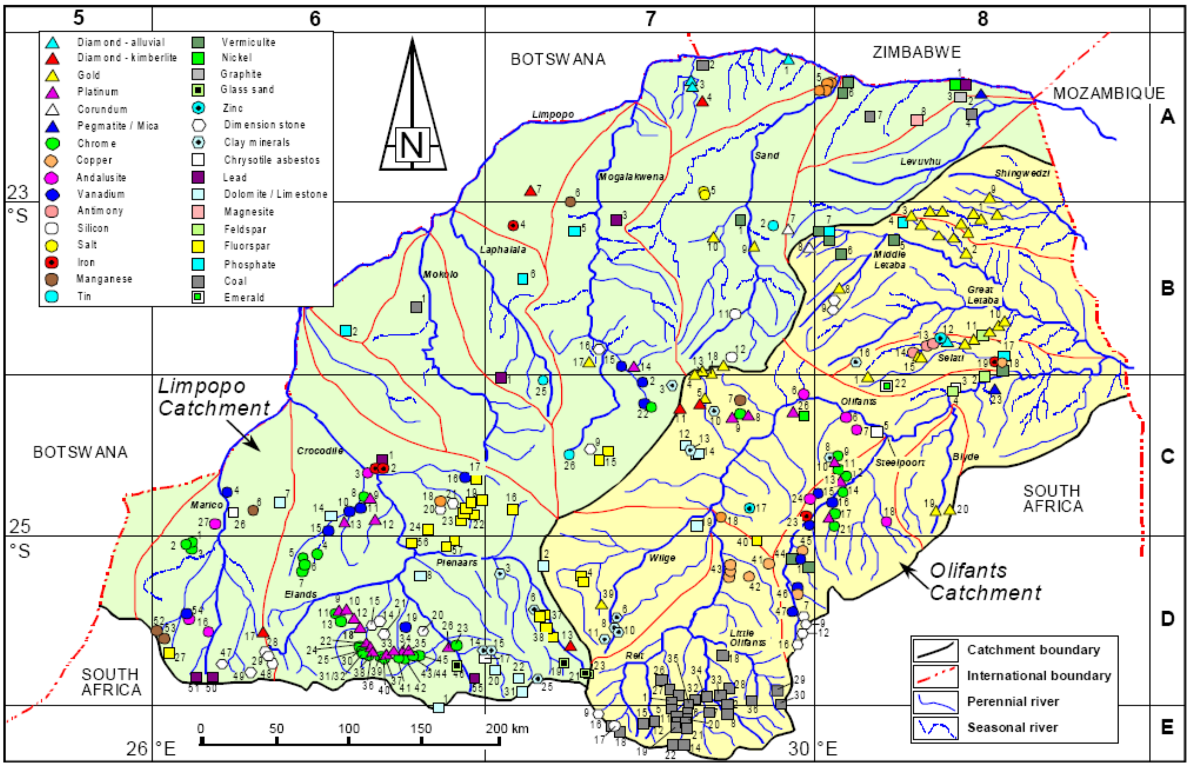

Figure 14 : Mining activities in the Limpopo and Olifants river catchments of South Africa. (After Ashton et al., 2001.)

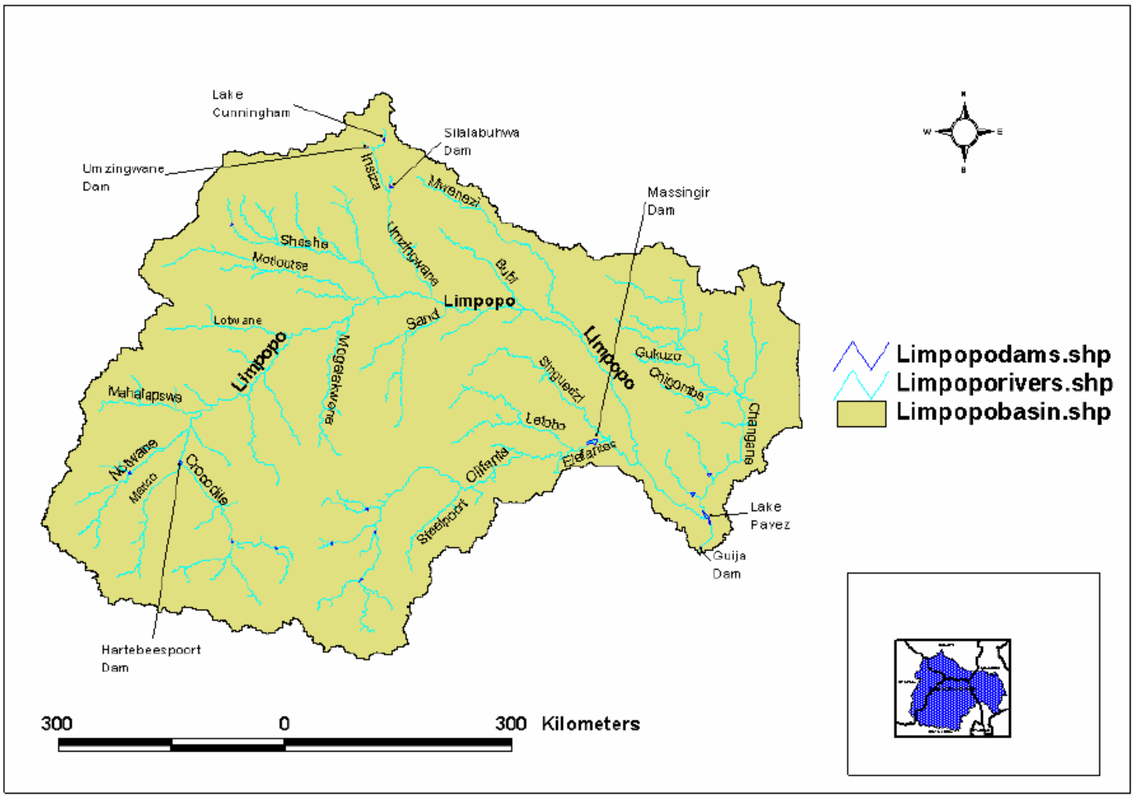

Figure 15: The Limpopo catchment

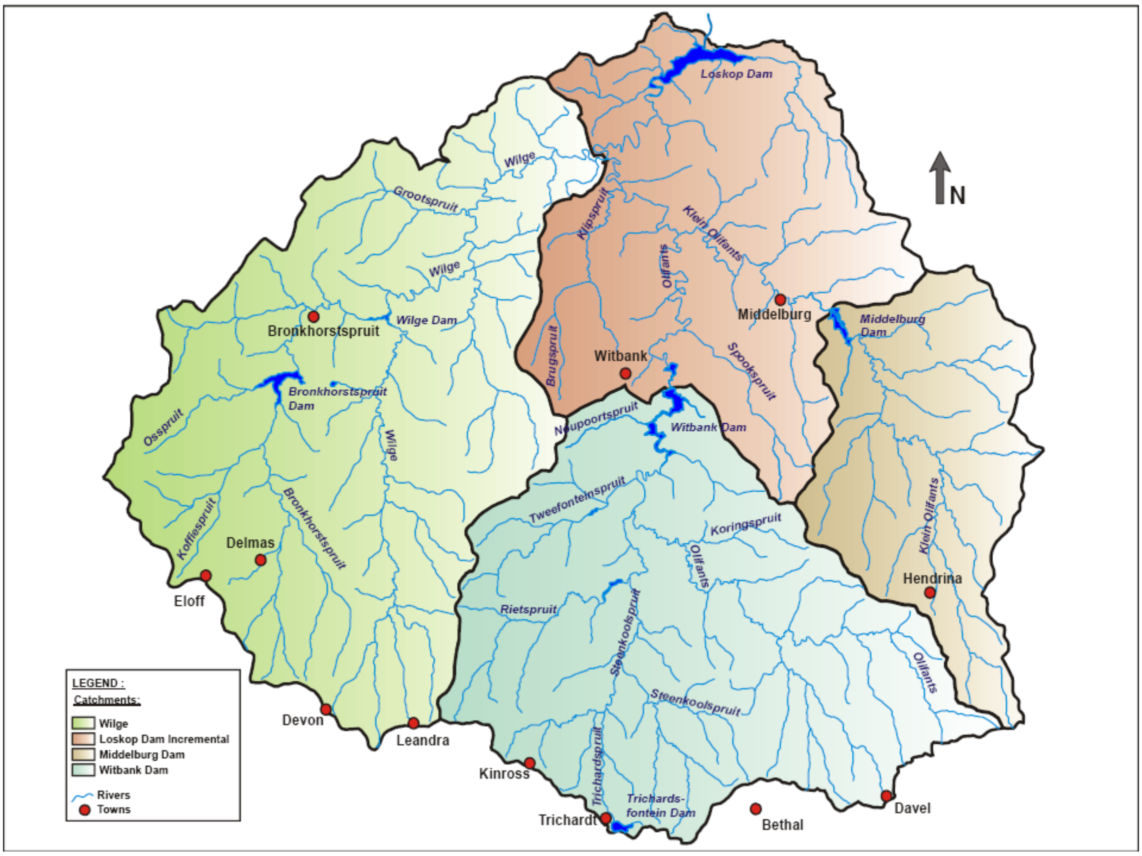

Figure 16 : Upper Olifants river catchment

4.7. TRANSPORT

The mining industry has been pivotal in the development of infrastructure and the establishment of manufacturing industries (Ashton et al., 2001). Five major national routes, viz. the N2, N3, N4/N12, N11 and N17, form provincial links across the coalfield (Figure 17). The development of transport infrastructure includes the extensive rail network transporting coal to the Richards Bay Coal Terminal. South Africa started coal export in the early 1970's with the majority of South African coal exports shipped through the Richards Bay Coal Terminal, situated in KwaZulu- Natal.

The mined coal goes through a series of processes (beneficiation) before being exported, such as washing (Limpitlaw et al., 2005) and separation to decrease the ash content and consequently increase the calorific value. These take place in preparation plants usually located close to the mines and coal is mainly transported by truck but also via conveyor belts in some areas. The coal is then transported by train to the ports from where it is shipped. Richards Bay is the main coal export port, with a capacity of about 70 million tonnes per annum. Other ports are Durban and Maputto

(Mozambique), with a smaller capacity of 2 million and 1.8 million tonnes per annum, respectively (Scott Wilson, 2006).

The coal transported to local thermal power stations are mainly transported by truck but also via train and conveyor belts. The increase in heavy truck traffic on the rural roads has had a substantial impact on the road surface integrity and also on the traffic volume.

The power utility, Eskom, had in recent years, been sourcing increasing quantities of coal through short-term contracts from mines that were not tied to its power stations; and trucking the coal had undermined the quality of road surfaces, particularly in the Mpumalanga province, where many of the group’s power stations were clustered (Creamer, 2010).

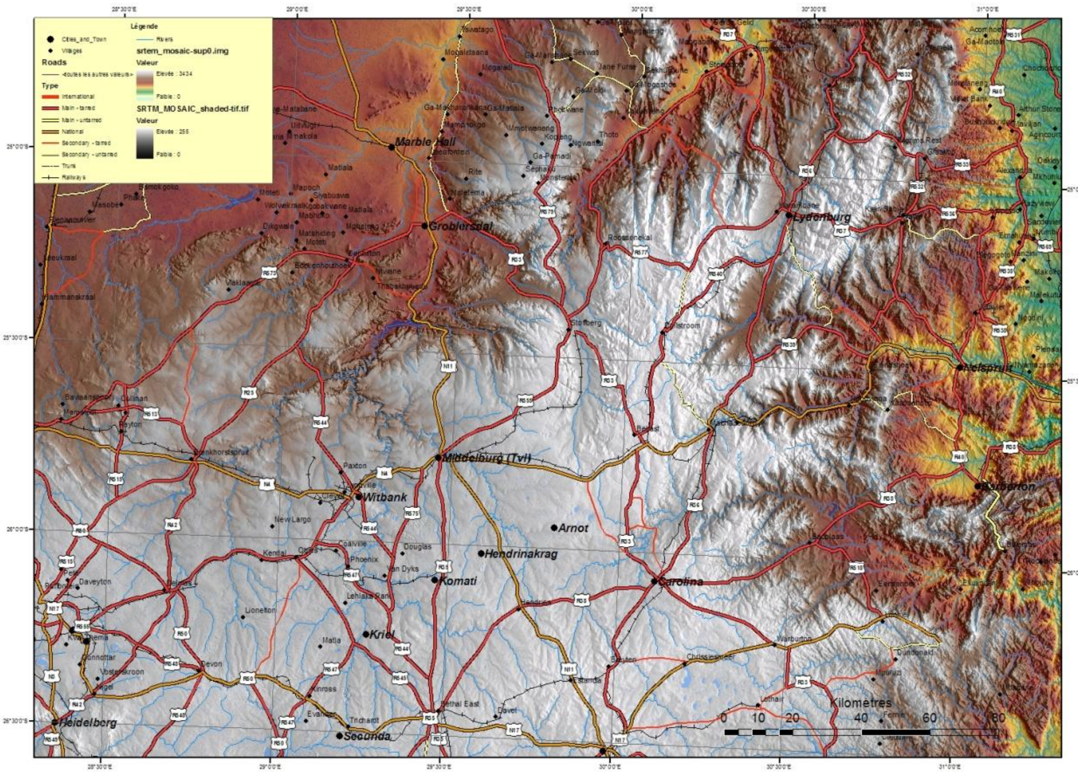

Figure 17: Road and railways of Mpumalanga

4.8. HISTORY AND CULTURAL FACTORS (INCLUDING ARCHAEOLOGICAL SITES)

There are a number of anthropological interests in Southern Africa, these include cave art and hominid finds, e.g. Cradle of Humankind (North West Province) and ancient kingdoms such as Mapungubwe in Limpopo Province, bordering Zimbabwe and Botswana. These areas fall outside the area of interest of the current project.

The Botshabelo Mission Station in Middelberg was originally a place of refuge for Christians in South Africa and grew into an important and rather influential centre where the Gospel was widely proclaimed among the black people. It became a place where both black and white people received education and training. The Botshabelo Mission Station also incorporates an Ndebele village, which comprises of an open-air museum established to successfully preserve the interesting tribal culture. This well known tribe is famous for its colourful huts, cultural garb and brilliant arts and crafts. The Ndebele people made the Cultural Heartland area famous with their colourful geometric art works that are known around the world.

The well known Loskop Dam Nature Reserve can be found deep in the Cultural Heartland of South Africa's Mpumalanga Province. The Loskop Dam is a 27 km long dam which makes it the largest dam in the Southern Hemisphere (http://www.sa-venues.com/attractionsmpl/mpumalanga_cultural.htm). The dam measures over 2 350 ha and is situated within the Loskop Dam Nature Reserve which is the receiving environment of most of the water pollution generated in the upper Olifants river catchment.

South African heritage resources are protected under the National Heritage Resources Act, No 25 of 1999 (NHRA). The Act follows the principle that heritage resources should be managed by the levels of government closest to the community. These local and provincial authorities will manage heritage resources as part of their planning process. The South African Heritage Resources Agency (SAHRA) is a statutory organisation established under the NHRA, as the national administrative body responsible for the protection of South Africa's cultural heritage. All archaeological remains, artificial features and structures older than 100 years and historic structures older than 60 years are protected by the relevant legislation, in this case the NHRA (Act No. 25 of 1999).

Cultural resources include all sites, structures and artefacts of importance, either individually or in groups, in the history, architecture and archaeology of human (cultural) development. Sites are classified as heritage if they fall under the following:

- The significance of the sites and artefacts are determined by means of their historical, social, aesthetic, technological and scientific value in relation to their uniqueness, condition of preservation and research potential. It must be kept in mind that the various aspects are not mutually exclusive, and that the evaluation of any site is done with reference to any number of these.

- Sites regarded as having low significance have already been recorded in full and require no further mitigation. Sites with medium to high significance require further mitigation.
- Archaeological sites: any area of land containing artefacts, ecofacts, features and structures in any combination of the above.
- Isolated occurrences: findings of artefacts or other remains located apart from archaeological sites. Although these are noted and samples are collected, it is not used in impact assessment and therefore do not feature in the report.
- Traditional cultural use: resources which are culturally important to people.

The heritage value of the area can be summarised as follows (van Schalkwyk, 2006; Delius, 2006):

4.8.1. Stone Age

Very little habitation of the Highveld area took place during Stone Age times. Tools dating to the Early Stone Age (ESA) period are mostly found in the vicinity of larger watercourses, e.g. the Vaal River, or in sheltered areas such as the Magaliesberg. During Middle Stone Age (MSA) times (c. 150 000 – 30 000 BP), people became more mobile, occupying areas formerly avoided. The MSA is a technological stage characterized by flakes and flake-blades with faceted platforms, produced from prepared cores, as distinct from the core tool-based ESA technology. Open sites were still preferred near watercourses. These people were adept at exploiting the huge herds of animals that passed through the area, on their seasonal migration.

Late Stone Age (LSA) people had even more advanced technology than the MSA people and therefore succeeded in occupying even more diverse habitats. Some sites are known to occur in the region. These vary from sealed (i.e. cave) sites, located to the north and south of the study area, to open sites in the Magaliesberg. For the first time there is the evidence of people's activities derived from material other than stone tools. Ostrich eggshell beads, ground bone arrowheads, small bored stones and wood fragments with incised markings are traditionally linked with the LSA. The LSA people have also left us with a rich legacy of rock art, which is an expression of their complex social and spiritual beliefs.

There are only a few places in Mpumalanga where Early Stone Age tools have been found and the area is not known as a site. Middle and Late Stone Age sites may occur along rivers and streams but none have been identified and their occurrence is difficult to predict.

4.8.2. Iron Age

Iron Age people started to settle in southern Africa c. AD 300, with one of the oldest known sites at Broederstroom south of Hartebeespoort Dam dating to AD 470. Having only had cereals (sorghum, millet) that need summer rainfall, Early Iron Age people did not move outside this rainfall zone, and neither did they occupy the central interior Highveld area. Because of their specific technology and economy, Iron Age people preferred to settle on the alluvial soils near rivers for agricultural purposes, firewood and water.

The occupation of the larger geographical area (including the study area) did not start much before the 1500's. By the 16th century things changed, with the climate becoming warmer and wetter, creating conditions that allowed Late Iron Age farmers to occupy areas previously unsuitable, for example the treeless plains of the Free State and the Mpumalanga Highveld. This wet period came to a sudden end sometime between 1800 and 1820 with a major drought lasting 3 to 5 years. The drought must have caused an agricultural collapse on a large, subcontinent scale. This was also a period of great military tension. Military pressure from Zululand spilled onto the Highveld by at least 1821. Various marauding groups of displaced Sotho-Tswana moved across the plateau in the 1820s. Mzilikazi raided the plateau extensively between 1825 and 1837. The Boers trekked into this area in the 1830s. And throughout this time settled communities of Tswana people also attacked each other.

As a result of this troubled period, Sotho-Tswana people concentrated into large towns for defensive purposes. Because of the lack of trees they built their settlements in stone. These stone-walled villages were almost always located near cultivatable soil and a source of water. Such sites are known to occur near Kriel (e.g. Pelser et al 2006) and in the Bornkhorstspruit area.

Farming activities have transformed the study area and there are no traces of Early Iron Age settlements. Typical late Iron Age features such as stone-walled settlements, potsherds, hut floors, middens and iron artefacts were not found in the study area due to disturbance by farming and mining activities. Scattered artefacts may be found along the river courses.

4.8.3. Historic period

White settlers moved into the area during the first half of the 19th century. They were largely self-sufficient, basing their survival on cattle/sheep farming and hunting. Few towns were established and it remained an undeveloped area until the discovery of coal and later gold. The establishment of the NZASM railway line in the 1880s, linking Pretoria with Lourenço Marques (Maputo) and the world at large, brought much infrastructural and administrative development to the area. This railway line also became the scene of many battles during the Anglo-Boer War and a concentration camp was established near the Balmoral station. During the Anglo-Boer War, a number of skirmishes occurred in the larger region, with one of the last and biggest battles fought that being at Bakenlaagte south of the town of Kriel on 30 October 1901. In line with the 'scorched earth' policy, most farmsteads were destroyed by the British during the latter part of the hostilities.

5. Mining History and Anthropogenic framework

5.1. EXPLOITATION

Coal mining occurred only sporadically in the area. However, with the discovery of the Witwatersrand goldfields, the need for a source of cheap energy became important, and coal mining developed on a large scale in various regions. By 1899, at least four collieries were operating in the Middelburg- Witbank district, supplying the gold mining industry.

Mining (excluding artisan mining) contributed 16% of South Africa's export revenue in 2003 (Hobbs, 2008) and contributed 8% of the South African GDP, accounting for 9% of employment and 38.6% of foreign earnings (Ashton et al., 2001). The coal is either worked in open cast mines, longwall mining or by partial extraction in underground workings, whereby pillars of coal are left in place to support the roof of the workings (Bell et al., 2000, 2001). This is referred to as the bord and pillar method of mining in the Witbank collieries.

Typical infrastructure requirements include: haul roads, ore dumps, ventilation shafts, surface facilities (offices, workshops, car parking and warehouses etc.); tailings and waste rock disposal areas; transport and service corridors; product processing and washing plants; stockpiles; chemicals and fuel storage, and accommodation.

The mining life cycle includes: prospecting, development, construction, operation, waste management, restoration and closure (Ashton et al., 2001). Ashton et al. (2001, p. xlvi) provide a good overview of the potential environmental impacts associated with each phase of mining activity. A further consideration is the unregulated artisan mining operations.

Systematic mining at Witbank commenced in 1896, when Samuel Stanford and the Neumann Group established the Witbank Colliery Limited company (www.shtetlinks.jewishgen.org/witbank/WHistory.htm). The first shaft was sunk on Witbank Farm, formerly known as Swartbosch, or more formally Leraatsfontein. The town of Witbank was laid out in 1903 by the Witbank Colliery Limited and the Colliery controlled the town until 1906. It was the provision of the railway line between Pretoria and Lourenço Marques (Maputo) that triggered substantial population growth.

Initially, all the mines were located in the shallow coal areas around Witbank. By 1889, at least four collieries were operating in the Middelburg-Witbank area, with the bulk of supply going to the newly discovered goldfields at Johannesburg. Coal production and export increased sharply since 1907 with the development of a rail-port system. In the 1970's increased demand for electricity resulted in increased coal production (Lang, 1995; Moolman, 2004). Increased demand resulted in new mining techniques being introduced, such as walking draglines. During the 1970's, wide-scale expansion in the coal mining industry has led to the development of mega mine complexes. Initial operations were large surface strip mines. Coal seams deepen to the south and much of the coal extraction in the southern mines is done through underground high recovery extraction methods.

Mining is South Africa's major industry sector. The country is heavily reliant on coal as a source of energy where more than 90% of generated electricity comes from coal-fired power stations (Scott Wilson, 2006). Almost 90% of saleable coal production in South Africa is from mines controlled by five of the country's largest mining groups – BHP Billiton Energy Coal South Africa, Anglo Coal, Sasol, Exxaro Resources, and Xstrata (DME, 2008).

South African coal was exported to 28 countries in 2006 of which 88% went to European nations, where Great Britain, Spain, France, the Netherlands, Italy, Germany, Denmark and Belgium were the largest customers. The Witbank coalfield remains the largest producer, followed by the Highveld coalfield (World Coal Institute, 2008. website - www.worldcoal.org).

5.2. METHODS OF WORKING

50% of coal produced in South Africa is from opencast mines with the remainder produced from underground (DME, 2008). There are three different methods used to extract coal: bord and pillar mining (or room and pillar), longwall mining and opencast mining. Shallow underground mining (up to 50 m below the surface), includes bord (room) and pillar (remnant pillars to support the overlying materials). Deeper mining methods include longwall mining and require proprietary infrastructure to ensure safe working (Ashton et al., 2001).

Collieries in the Witbank coalfield have historically used bord and pillar mining with typically low coal recovery ratios, leaving a significant amount of coal in pillars, and as floor and roof coal. Longwall mining methods were introduced in the late 1970s and 1980s, but their use was not extensive and bord and pillar mining continued to predominate. Where it is carried out (Coal seams 1 and 2) opencast mining is undertaken as strip mining by dragline. Further detail can be found in Directory D2/2010: Operating and developing mines in the Republic of South Africa: http://www.dmr.gov.za/Mineral_Information/New/D2-2010%20%20part%201.pdf

Bord and pillar: in this form of mining only a portion of the coal is extracted, the rest being left in place as pillars to support the overlying rocks. Towards the end of mining, pillars may be partially extracted (pillar robbing) to recover additional coal, but a considerable amount of coal is left in the ground. If sufficient support is left, the roof rocks can remain stable. The original pillar dimensions were in the order of 6 x 6 m with bord widths of 7 m. In some areas it is associated with stability problems, see below (Bell et al, 2000). The pillar and bord method of working has resulted in significant remnant reserves in the pillars of some of the abandoned mines (Lind, 2005). These reserves have considerable economic value for secondary mining and until recently (e.g. Analysis of Pillar Extraction Potential [A-PEP, (Lind, 2005)] South Africa had limited design methodology for decision making regarding safe and economic pillar extraction (Lind, 2005).

Longwall: in this form of mining, the coal is removed entirely and the roof allowed to collapse into the mined out void. The mining face is protected by supports which are moved forward as mining progresses. Collapse causes fracturing of the overlying rocks and can cause subsidence of the surface if mining is shallower than about 200 m depth. In such cases, fractures will extend through to surface.

Opencast: in this form of mining, the soil cover is scraped off and stockpiled, the rocks overlying the coal seam are blasted and removed to one side, and the coal is then extracted. Next, the broken rock is returned to the pit, the site is landscaped, the soil is returned and grass is planted.

Cairncross (2001) has observed that coalbed methane has, within the recent past, become the focus of attention for some of the more deeply buried South African coals.

5.3. PROCESSING

Most power stations do not wash their coal. However, as the reserves become depleted washing the coal to improve its quality is one way of improving its value. There are a number of conflicting interests associated with coal processing, including the issues of water resources, and the environmental impacts, including AMD (section 6.7) as a consequence of leaching of the waste. Coal beneficiation plant has improved as a consequence of new technologies, particularly with respect to separation and water recycling.

5.4. REMEDIATION AND RESTORATION TECHNIQUES

The interconnectedness of underground mine workings attributable to different mining companies increases the difficulties associated with the liabilities of the “polluter pays” principle. Costs associated with the long term maintenance of infrastructure in such aggressive (corrosive) conditions are high.

The environmental impact of Acid Mine Drainage (AMD) can be minimised at three basic levels (Akcil, 2006): primary prevention, secondary control (AMD migration prevention), or tertiary control (collection and treatment of effluent). The control of AMD migration can be achieved in a number of ways, e.g. diversion of surface water flowing towards the site of pollution, prevention of groundwater infiltration to a potentially polluting site, prevention of hydrological water seepage into the affected areas and controlled placement of AMD generating waste. Some natural wetlands can remove iron, manganese and other metals from AMD, but the geochemical and ecological impacts need to be considered. Methods used for treatment include neutralization (limestone, hydrated lime, soda ash, caustic soda, ammonia, calcium peroxide, kiln dust and fly ash), metal removal, desalination and natural degradation (Akcil, 2006).

Three water management schemes have been employed in the Witbank area in an attempt to manage the cumulative impact of AMD generated by the local mines on the Olifants river catchment (Hobbs, 2008). These schemes include: (i) the Brugspruit Water Pollution Control Works, which was led by DWAF and designed to treat 10 Ml/d from two waste streams (a northern one with high Total Dissolved Salts [TDS] and a southern one with low TDS) with soda ash added to the final effluent to provide additional buffering capacity; (ii) a controlled discharge scheme in the upper Olifants, which operates on a high flow release period with waste load allocations to participating industries and has generally met its aim of reducing sulphate concentrations in the Witbank Dam (to < 155 mg/l), although there remain problems during extended dry periods, and (iii) the newer Emalahleni Water Reclamation Plant. The latter is a collaborative project between Anglo Coal and BECSA and is treating mine water from Klienkopje, Greenside, Navigation and South Witbank Collieries. It is able to treat 25ML/d water through a process involving limestone neutralisation, ultra-filtration and reverse osmosis desalination, to potable standard and distributed to local water users in the eMalahleni Town (Oelofse, 2008; Mey et al., 2009).

The Brugspruit Water Pollution Control Works was reported to be no longer functioning because of a shortage of staff, theft of electrical cables providing power to the facility and lack of maintenance (Hobbs, 2008).

The potential use of lime-treated AMD for irrigation of agricultural crops has been investigated (Annandale, 2009). The use of saline mine water, including lime treated from Kromdraai (dominated by Ca and SO4) and Ca, Mg and SO4 enriched Kleinkipjé (Major) and Kleinkipjé (Tweefontein) water from the Mpumalanga Province, for crop irrigation has been investigated. This work confirmed that neutralized acid mine drainage can be successfully used for a variety of crops and that gypsiferous waters do not seem to have a deleterious effect on the soil environment because the gypsum precipitates in the soil. Irrigation with mine water needs to give due consideration to long term monitoring strategies that involve interest groups in the catchment and to ensure that any environmental impacts remain acceptable (Annandale, 2009).

There remain a number of research directions with respect to remediation (Oelofse, 2008), including: a study of the fate and pathway of heavy metals associated with AMD; establishing where intervention is most required; an epidemiological study of off-mine populations impacted by mining activities and the collection of reliable data on human-related impacts associated with mining activities; the extent of mine pollution impacts; the establishment of remediation priority areas; establishing where and how to minimise groundwater infiltration to mine workings; strategies to utilize the storage potential of abandoned underground mines.

6. Known impacts of mining

6.1. GENERAL

There are a number of know environmental impacts that have been alluded to in the preceding sections. These include the effects of AMD, the potential for self-combustion, subsidence, air pollution, disruption of natural drainage patterns and acid rain. Each of these issues is described below. In some cases, in particular that of dust monitoring, the impacts of coal mining are difficult to discriminate from the associated industries, including power generation, because the research focus has been on the impact rather than the source. In addition to the environmental impacts there are the socio-economic impacts associated with coal mining. A number of these impacts have been identified through the review of legislation and the surveys undertaken as part of Work Package 1 and are outlined in section 10. Where supporting data has been obtained these impacts are described below.

Demand for coal is increasing both locally and internationally due to the growing demand for electricity. This is resulting in coal mining expansion at a rapid rate across the Highveld grasslands, leading to increased pressure on grasslands biodiversity, including wet lands and water production. While the demand for coal continues to grow, a challenge for biodiversity management is to limit and manage the impact of mining activities on the grasslands biome. Ensuring that spatial biodiversity information informs decisions around mining is one way to work towards this. Other opportunities lie in the regulatory and market environment that influences coal mining. Opencast mining has a particularly devastating impact on biodiversity, effectively removing biodiversity values from the landscape. This includes negative impacts on wetlands, as coal resources often underlie wetlands and it has been observed that most rehabilitated opencast pits will decant.

The impact of a particular mining or minerals processing operations on the biophysical environment can take the form of physical and/ or chemical impacts. Where physical weathering predominates (within low rainfall regions of the Limpopo Basin), there are relatively low or localized impacts on the water resources, whereas those in the wetter regions of the basin where chemical weathering processes predominate tend to have far more extensive impacts (Ashton et al., 2001). Water quality changes are widely considered to be the most significant consequence of mining activities (Ashton et al., 2001). Typically, the following form sources of contamination: underground stopes, coal discard dumps and fines, restored opencast pits and plant areas (Ashton et al., 2001).

Whilst large scale operations are likely to have a proportionately greater impact on the environment, most large mining operations employ more effective and efficient environmental management programmes than their smaller counterparts (Ashton et al., 2001). Mining also creates demand for water, putting it in competition with other water users, particularly when the mining is responsible for any deterioration in water quality.

6.2. SUBSIDENCE (ROOF AND PILLAR COLLAPSE ISSUES)

Remnant pillars sustain the load of the overburden with stress concentrating on the corners of the pillars. This may result in spalling and ultimately in pillar failure. The failure of one pillar can bring about collapse in others as a consequence of the ongoing redistribution of load (Bell et al., 2000, 2001). Failure of a large number of pillars may result in regional subsidence troughs associated with tangential compressive strain and circumferential tension (Bell et al., 2000, 2001). The actual detail of the subsidence trough will reflect the detail with respect to the mine layout, topographical and geological setting and the depth of working. Historically pillars were frequently “robbed” on retreat, which also affects the nature of subsidence. Bell et al. (2000, 2001) described how stooping has been carried out in some mines to ensure long term stability. This comprises the removal of 85% of the original pillar, such that on backward retreat the hanging-wall collapses into the goaf.

Another consequence of the pillar and bord method of working is the potential for roof sag between the pillars. The roof strata are generally weak, incompetent shales. Collapse of weathered material can occur and in some instances this may develop to form crown-holes (Bell et al., 2000, 2001; Bullock and Bell, 1997).

The potential for pillar collapse is influenced by a number of factors, including pillar strength, distribution of discontinuities, pillar dimensions, room dimensions, depth of overburden and groundwater conditions.

In the Witbank coalfield shallow mining (<100 m) has lead to severe disturbance of the surface, such as cracks of up to 5 cm wide, and obvious subsidence After the original bord and pillar mine operations were abandoned the slow deterioration of the roof and pillars of the shallow mines resulted in collapse and subsidence. This comprises the removal of 85% of the original pillar, such that on backward retreat the hanging-wall collapses.

Coal strength at 11 collieries has been investigated (van der Merwe, 2003). From 900 coal strength tests carried out during 1993 to 1994 it was established that the strength of a coal specimen increases linearly with an increasing diameter to length ratio (width to height ratio for the pillar). Samples from different mines were ranked from weakest to strongest and samples from the Bank Colliery were found to fall midway in the range. The reason for the inter-site variation in strength was not established and actual strength values were not presented.

More recently the focus has been on applying advanced technologies (Altounyan, 2001), including advanced rock bolting with high bond strength and stiffness to resist roof movement. Advanced rock bolting relies on the understanding of the mode of roof failure (lateral shearing due to horizontal stresses), design of the support system from stress measurements and monitoring of the performance of the design. The latter is particularly important because when compared with the UK for equivalent shallow conditions relatively small vertical movements may be required before a fall can occur (Altounyan, 2001). As a consequence of this sensitivity a new telltale type (strain monitor) was required for the research in Guadehoop reported by Altounyan (2001).

The consequences of pillar collapse are far reaching and include: loss of agricultural land, adverse affects on land values, damage to infrastructure and property, potential for air entry to abandoned mines with the consequential potential for self combustion (see below) and disruption of groundwater levels and flow paths. Cracks developing in the overlying strata also become conduits for water flow into the mine workings (Bullock and Bell, 1997).

6.3. SPONTANEOUS COMBUSTION, ESPECIALLY ON RE-ENTRY TO FORMERLY CLOSED WORKINGS

One of the consequences of coal mining is the exposure of the coal to air and moisture resulting in the ignition of the coal through the processes of chemisorption, oxidation, and spontaneous combustion. The ignition of coal is a global concern and burning coal may cause significant environmental problems (Pone et al., 2007). Spontaneous combustion occurs in both abandoned mines and active mines, as well as in the mine spoil heaps, particularly the older ones, which have a higher proportion of remnant coal in them. Some of the coal heaps contain up to 20-30% remnant coal, making them virtually economic for reworking (Bell et al., 2001). The poor compaction of the old spoil heaps result in the easy access of air and water which contributes to the spontaneous combustion process. Despite the large tonnage of good coal dumped as waste in Witbank, it was neither economically viable nor technically feasible to rehabilitate the dumps. In many instances nearby communities are illegally reworking/mining on the older spoil heaps and digging in the abandoned shallow underground mines (Singer, 2010).

The environmental impact of spontaneous combustion of the coal seams in the Witbank coalfield was studied in order to determine if toxic elements and compounds are being mobilized in the environment (Pone et al., 2007). Gas temperatures of 34 to 630^{0}C were determined at coal-fire vents, where coal-fire gas minerals (CFGM) and gases were sampled. The CFGM, which formed by condensation and sublimation were dominated by sulphur compounds and salammoniac with associated heavy metals (arsenic, mercury, lead, zinc and copper). The gases included toluene, benzene, and xylene, which are known carcinogens. Halogenated compounds, including bromomethane, iodomethane and trichloromethane in low concentrations and dichloromethane and chloromethane in high concentrations were also detected, together with high concentrations of carbon monoxide, carbon dioxide and methane (Pone et al., 2007). The nature of the risks to human health and the environment (land, water and air quality and ecological impacts) of most of the compounds in the gas and CFGM by products are unknown and merit investigation in the Witbank coalfield (Pone et al., 2007). Sulphur dioxide (SO_2), are released as gas into the atmosphere during coal seam fires. The sulphur oxides react with ions in the fluid phase (e.g. water, rain, water particles in the atmosphere, etc.) and precipitate sulphur-bearing minerals during condensation. These solid sulphur compounds may, in part, be dissolved into the surface water and transported in streams and waterways (Pone et al, 2007).

From their experience at Middelburg Colliery, where the mine has been undergoing spontaneous combustion for over 50 years, Bell et al. (2001) noted that the potential for spontaneous combustion increases as a consequence of subsidence and the formation of tension gaps associated with pillar collapse in bord and pillar mines. This is a consequence of the increased air and water flow through the abandoned mines.

Past attempts at remediation of shallow underground mines have included: stooping, as described above, construction of earth filled cut-off trenches, injection of water into the workings and opencast mining of boundary pillars to provide a protective perimeter to the site. None of the attempts were very successful as burning has bypassed many of the trenches (Bullock and Bell, 1997). A suggestion to blast and collapse the shallow workings was met with concerns of potential increased access of air and water and was abandoned (Bullock and Bell, 1997).

6.4. CONTAMINANTS INCLUDING ACID MINE DRAINAGE AND LEACHATE

The accumulation of high levels of metals in fish species along the entire length of the Olifants river as well as high concentration of trace metals and nutrients in storage reservoirs has been reported (Driescher, 2008; Oberholzer et al., 2010). Specific areas of concern arising from the increase in dissolved solids (salinity) were outlined by Ashton et al. (2001). These include: reduced crop yields where irrigation water has been impacted by AMD; flocculation of clay particles in soils irrigated by high salinity water; adverse osmotic effects on aquatic plants and animals, due to alterations to the sodium: potassium ratios, and decreased rates of photosynthesis in aquatic plants. The impacts of increased suspended solid levels include: decreased light penetration to bottom sediments and consequential loss of benthic photosynthetic organisms; clogging of fish gills; coating of aquatic plant leaves, thereby precluding photosynthesis; deposition of sediment and smothering of micro and macro habitats for aquatic invertebrates, and contamination by adsorbed ions, which may result in toxicity.

Extensive coal mining has resulted in poor quality acidic water, which is, in part, attributable to a historic lack of policy to address AMD, especially at the mine closure stage (Hobbs, 2008). Although new legislation has been introduced (section 2), vulnerabilities remain, including the government's management of the liabilities associated with derelict and ownerless mines (Hobbs, 2008).

Water quality in the Loskop Dam is reported to have deteriorated over time and sulphate loads in the Witbank Dam are reported to have increased from 33 T/d in 1993 to 70 T/d in 1998 (Hobbs, 2008). The potential impacts of mining on the water environment can be subdivided according to mining operations (Oelofse, 2008), e.g. related to mining; seepage from mine residues, dewatering operations and rewatering (flooding of mine workings). In 2004 62 ML/d of polluted mine water was discharged from abandoned coal mines and in the order of 50 ML/d of AMD discharges into the Olifants river catchment (Oelofse, 2008).

Whilst the availability of data regarding water quality is limited, it should be noted that there is a Council for Scientific and Industrial Research/ South African University collaboratively funded multi-disciplinary catchment based study of the upper Olifants River and its tributaries: (http://www.engineeringnews.co.za/article/olifants-river-study-under-way-to-identify-potential-stressors-2010-03-15). This study will investigate the sources of different stressors to the river system, develop and refine appropriate water quality management and decision making processes and consider remediation measures for the rivers in the catchment. One of the key drivers for this work was a 14-ton fish die off in the Loskop Dam in 2007 and also with a significant decline in the number of crocodiles in the Loskop Dam (Ashton, 2010).

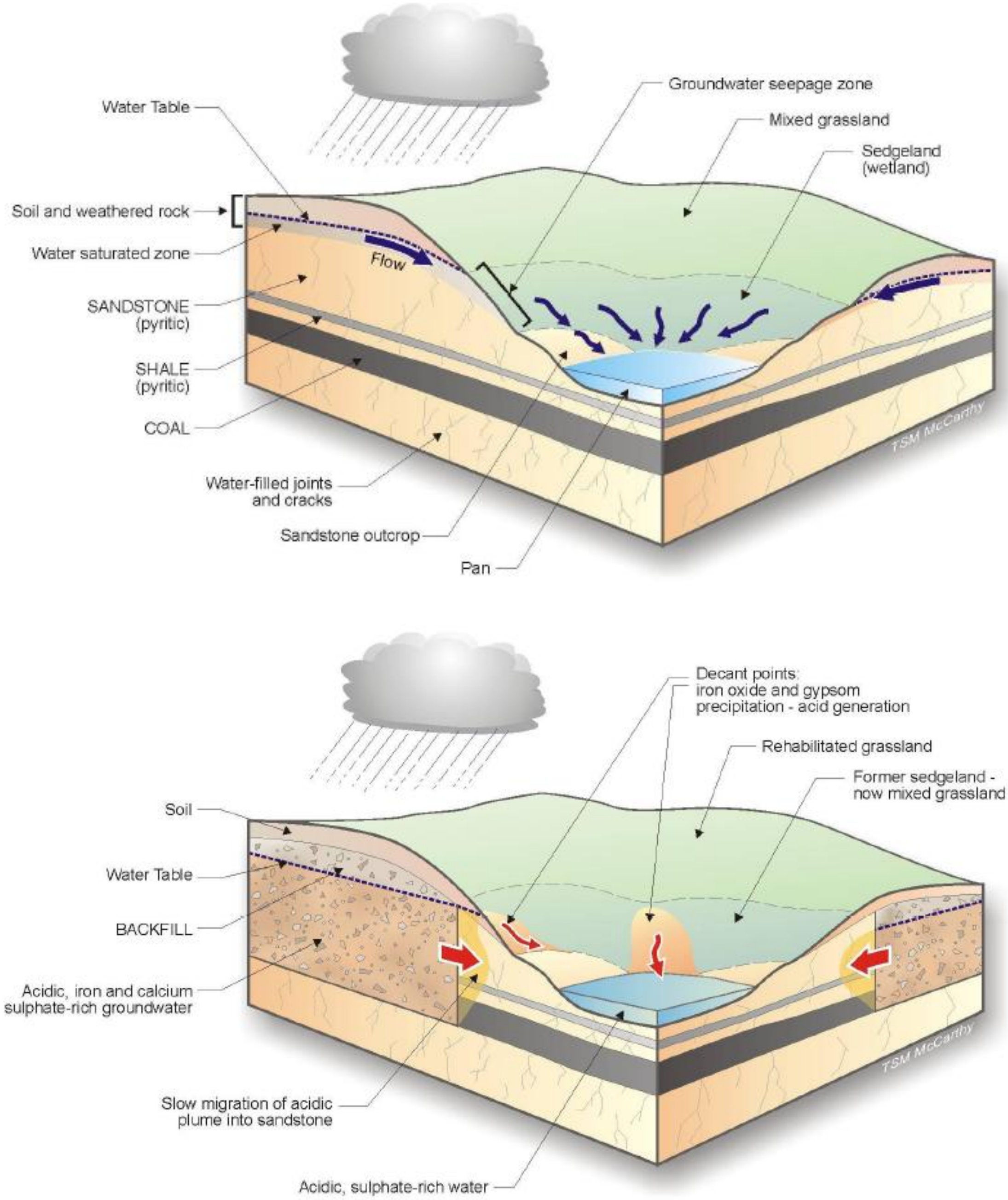

Figure 18 : Geology and hydrogeology of a pan (top) and hydrological functionning after mining and rehabilitation (bottom), after McCarthy et al, 2007

Leachate generation occurs as a consequence of the restoration of groundwater levels following mine abandonment as well as seepage from spoil heaps. Water comes into contact with exposed pyrite, thereby facilitating oxidation of the sulphide and the generation of low pH leachate (AMD), which has greater leaching potential, particularly with respect to metals and also the dissolution of feldspars and clay minerals, which releases aluminium to the water (Figure 18). AMD results in both acidification and salinization of aquifers and streams.

The breakdown of pyrite and other sulphides can be described by the sequence of equations presented by Ashton et al. (2001, p. liv, see below) and is facilitated by chemolithotrophic bacteria, e.g. Thiobacillus ferrooxidans, which have been found in water draining from the mine waste deposits, and in the seepage zone below the same deposits. This is of particular concern in the high-sulphur coalfields in the upper Olifants river catchment. The rates of AMD generation are influenced by: pH, temperature, oxygen content of the gas phase, oxygen concentration in water, degree of saturation with water, chemical activity of Fe^{3+}, surface area of the exposed metal sulphide, chemical activation energy required to initiate acid generation and bacterial activity (Akcil, 2006).

$$2FeS_2 + 2H2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4$$

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$$

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \text{ (bacterial catalysis)}$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

Long term monitoring of seven DWA monitoring stations in the Olifants river catchment showed that at four of the seven long-term monitoring stations river water sulphate levels exceeded 100 mg/l (threshold value for aquatic ecosystems) for most of the duration of the records since 2001 (De Villiers, 2009). At these stations river water sulphate levels also exceeded the 200 mg/l threshold value for human consumption between 27% and 45% of the duration of the records. The sulphate concentration at Witbank Dam ranged between 34 and 300 mg/l (median 165 mg/l), at Middelburg Dam between 32 and 1185 mg/l (median 162 mg/l) and at Loskop Dam between 5 and 190 mg/ l (median 68 mg/l) (De Villiers, 2009). The most pronounced historic increase in sulphate levels was found at Loskop Dam, where concentrations have increased by a factor of about 7 since the 1970s (de Villiers, 2009).Typical chemistry data for selected sampling scenarios are shown in Table 3.

Parameter	Sampling Sites				
	Deep Underground Mine	Shallow Underground Mine	Surface Flow (Close to Source)	Surface Flow (0.75 km from Source)	Surface Flow (1.5 km from Source)
pH	8.04	6.78	3.41	3.2	3.12
EC (mS/m)	164	228	120	212	219
Ca	186	561	60	139	144
Mg	89	107	38	83	91
Na	120	15	46	44	40
Cl	13	3	66	52	44
SO_4	910	1767	562	1460	1509
Al	-	<0.1	27	110	107
Co	-	0.04	0.92	1.63	1.58
Fe	-	21	2.7	5.6	11.8
Mn	-	3.2	25.5	37.5	36.7
Ni	-	0.1	0.39	1.13	0.94
Zn	-	0.36	0.74	2.05	1.95

Table 3: Selected water chemistry data for selected coal mine scenarios, from (Ashton,et al., 2001)

Despite the lack of systematic monitoring it was possible to evaluate river water quality on the basis of sulphate concentrations. These data demonstrate that the coal mining areas have had significant impacts on the sub-catchment's water quality. The chemical compositions of AMD from drill holes sunk at a number of collieries were published by Bell et al. (2001; Table 4).

Determinand (mg l^{-1})	Middleburg Colliery (2)	Middleburg Colliery (3)	Witbank Colliery (1)	Witbank Colliery (2)	Tavistock Colliery (1)	Tavistock Colliery (2)
TDS	3604	5778	3048	3354	5778	7158
EC (mS m^{-1})	340	355	389	403	355	368
pH	2.8	2.8	2.65	2.7	2.8	2.9
Nitrate NO_3 as N	0.1	0.19	0.29	0.29	0.21	0.28
Chloride	611	184	951	989	18	4.8
Sulphate	1440	3233	910	1306	3253	3840
Total hardness as $CaCO_3$	377	214	106	161	2461	1977
Calcium	84	509	42	40	509	462
Magnesium	31	289	14.9	14.8	289	200
Sodium	399	47	620	755	47	32
Iron	193	198	122	99	198	726
Manganese	9.3	49	5.9	3.9	49	30
Aluminium	84	32	81	87	32	38

Table 4 : Chemical composition of acid mine water from drillholes sunk at adjacent collieries (from Bell et al., 2001)

Pulles et al. (1996) identified that South African coal mines have been unable to cost-effectively eliminate the following sources of water pollution: acidic saline conditions with mobilized dissolved metals and nutrient enrichment.

The investigation of trace elements in coal has become increasingly important in the context of promoting clean coal technologies and the identification of coal beneficiation. Ruch (1998) established that Hg, Zr, Zn, Cd, As, Pb, Mn and Mo are concentrated in the mineral matter in the coal. In an investigation of the trace elements, their distribution and potential for density or froth separation, Bergh (2009) established that the majority of the trace elements (As, Hg, Mo, Pb, Se, Mo, Cu, Ni and Cd) in the No 4

Seam, Witbank, are associated with the pyrite content of the coal. Although, As and Hg occur in a second form that is associated with organic sulphur in the high vitrinite fractions of the coal. The elevated trace elements that were established included: Hg, As and Mo. As and Hg occur in association with organic sulphur in the high vitrinite fractions of the coal. The trace element values determined for the Highveld coals and high ash middlings product from the Number 4 Lower seam are comparable with values available in literature for South African coals, with the exception of Hg, Mn and Cr. Hg values reported here are lower, Cr and Mn higher (Wagner and Hlatshwayo, 2005). Compared to the cited global average values for fourteen trace elements the values obtained for the Highveld coals generally fall below or well below these average values, with the exception of Cr and Mn. Concentrations of Cd and Cu are lower compared to global average values, and As, Mo, Pb, Se, Sb, and Zn can be considered low to very low. Arsenic is ten times lower compared to typical USA concentrations. Values for Co and Ni are similar to global averages, with V and Hg being very slightly higher. Higher concentrations of most elements related to the higher ash content of the middlings samples were reported. Compared to global averages the chalcophile elements determined in the Highveld coals are all depleted and the siderophile elements are enriched or comparable to global averages (Wagner and Hlatshwayo, 2005). Risk-based health studies in the USA on coals with similar or higher Hg and significantly higher As contents have not reported negative health effects, and therefore it could be assumed that the mobilization of these trace elements from the five Highveld coals are unlikely to cause human health problems (Wagner and Hlatshwayo, 2005). Opperman (2002) reported on the difficulty of floating the Witbank coal, the requirement for substantial quantities of reagent to enhance the hydrophobic nature of the coal and the development of new flotation equipment for the Goedehoop Colliery.

A contaminant that is generally associated with coal mining and combustion is selenium (Se) (Lemly, 2004). Selenium is a naturally occurring trace element that can be released in the waste materials from certain mining, agricultural, petrochemical, and industrial manufacturing operations. Once in the aquatic environment, it can attain toxic levels that result in poisoning of fish and wildlife because of bioaccumulation in food chains (Lemly, 2004). Enrichment factors of Se in coal to Se in surrounding soil and mineral layers can exceed 65 and can be leached from freshly mined coal. Although South African coal contain on average, 0.2–1.2 ppm Se, these levels are considered as low concentrations when compared with other coal occurrences (Yudovich and Ketris, 2006). Selenium was not found to be a significant contaminant in the context of the No 4 Seam, Witbank (Bergh, 2009). Due to the very low Se concentrations determined in the Highveld coal, it is considered unlikely that there would be a local environmental concern (Wagner and Hlatshwayo, 2005).

The following activities also impact on water resources in the sub-catchments: landfills and solid waste disposal sites; disposal of liquid (domestic, light and heavy industrial) effluent; seepage from power station ash dumps; disposal or seepage of high salinity power station cooling water; moderate volumes of runoff from towns and other urbanized areas; diffuse impact of agricultural return flows from irrigation areas, and litter and domestic garbage (Ashton et al., 2001). Treated sewage effluents result in eutrophication of receiving waters. More recently public attention was drawn to the large scale fish and crocodile deaths in the Loskop Dam as well as in the lower Olifants

River (Kruger National Park; Steyn, 2008; Ashton, 2010). The cumulative effects of the anthropogenic impacts on the river over the past century have resulted in the observed stress in the ecosystem (Oberholzer, 2010). Additional effects include: seepages from power station ash dumps and industrial inputs, such as those from metallurgical plants (e.g. the Highveld Steel plant) and various foundry operations (Ashton et al., 2001). The increased salt concentrations tend to diminish the presence of suspended sediments by auto-flocculation of the sediments (Ashton et al., 2001). There is a potential for AMD, raw sewage and power station ash leachates to counter each other (Ashton et al., 2001). Petrik (2003) carried out experimental work to demonstrate the potential benefits of the co-disposal of high pH leachate derived from fly ash tips with that of AMD.

6.5. SOIL EROSION AND SEDIMENTATION

Mine construction is associated with widespread soil disturbance, landscape scarring, loss of agricultural land, accelerated erosion and consequential ecological changes (both aqueous where water courses are impacted by transported sediment and terrestrial). The effects may be latent for several years after rehabilitation is complete (Limpitlaw et al., 2005), with soil loss only becoming evident in time-scales in the order of 10s of years. Added to this the capillary rise of salts can further blight agricultural land (Limpitlaw et al., 2005).

It should be noted that land degradation also results from overcrowding and insecure ownership in the smaller communal farming areas (Ashton et al., 2001).

6.6. AIR POLLUTION

6.6.1. General

The Highveld area in South Africa is also associated with poor air quality and elevated concentrations of criteria pollutants occur due to the concentration of industrial and non-industrial sources (Held *et al*, 1996; DEAT, 2006). The Minister of Environmental Affairs and Tourism (now the Department of Environmental Affairs) therefore declared the Highveld Priority Area (HPA) on 23 November 2007. The areas of eastern Gauteng and western Mpumalanga were declared the second priority area, in the context of Section 18(1) of the National Environmental Management: Air Quality Act 2004 (Act No. 39 of 2004) (AQA). The area is considered to exceed ambient air quality standards and cause a significant negative impact on air quality and human health. It is therefore necessary to declare the area an air pollution ‘hot spot’ and recommend appropriate air quality management initiatives to address the problems. These will be handled by National Government.

Air quality is impacted by: industrial emissions, domestic fuel burning, biomass burning, mining, and transportation. The total annual emissions of fine particulate matter (PM10) on the HPA is estimated at 279 630 tons, of which approximately half is attributed to dust entrainment on mine haul roads (DEA, 2010). The emission of PM_{10} from the primary metallurgical industry accounts for 17% of the total emission, with 12% of the total from power generation.

By contrast, power generation contributes 73% of the total estimated NOx emission of 978 781 tons per annum and 82% of the total estimated SO_2 emission of 1 622 233 tons per annum (DEA, 2010). There are 11 power stations in the HPA in Mpumalanga, with an additional station planned. Their emissions are released well above the stable surface layer through tall stacks. The night time surface temperature inversion prevents the plumes from reaching ground level, with dispersion occurring above the inversion. During the day, particularly in summer, convection can bring the plumes to ground level when high concentrations may occur (fumigation). Modelled exceedances of the ambient 1-hour and 24-hour SO_2 standards from power generation emissions occur across the central HPA, i.e. the southern parts of the Emalahleni LM and the northern parts of the Govan Mbeki LM, and close to the individual power plants at Kendal, Hendrina, Komati and Arnot (DEA, 2010).

Metal manufacturers in Emalahleni and Steve Tshwete municipalities, together with hydrocarbon processes (i.e. Sasol) in Govan Mbeki are included in the industrial sources, which are by far the largest contributors of emissions in the HPA, accounting for 89% of PM_{10}, 90% of NO_x and 99% of SO_2.

Major industrial source contributors were grouped into the following categories:

1. Power Generation

2. Coal Mining

3. Primary Metallurgical Operations

4. Secondary Metallurgical Operations

5. Brick Manufacturers

6. Petrochemical Industry

7. Mpumalanga Industrial Sources (excluding the above)

Monitoring data confirm that areas of concern are in the vicinity of Kendal, Witbank, Middelburg, Secunda, Ermelo, Standerton, Balfour, and Komati where exceedances of ambient SO_2 and PM_{10} air quality standards occur (DEA, 2010). The effects of poor dispersion conditions in the winter are evident throughout the monitoring record for all pollutants, resulting in greater frequency of exceedances of the standards. PM_{10} displays this seasonal trend most strikingly, showing a sharp contrast between wintertime peaks and summer minimum values at monitoring sites.

Mortality outcomes calculated for South African urban areas estimate that outdoor air pollution caused 3.7% of total mortality from cardiopulmonary disease in adults aged 30 years and older, 5.1% of mortality attributable to cancers of the trachea, bronchus, and lung in adults, and 1.1% of mortality from acute respiratory infections in children under 5 years of age (Norman et al, 2007a).

Exposure to indoor air pollution was associated with a number of health outcomes, including chronic obstructive pulmonary disease (COPD), lung cancer, nasopharyngeal cancer, tuberculosis, cataracts, asthma, birth defects, and acute lower respiratory infections (ALRI) among children younger than 5 years (Norman et al, 2007b). Exceedance of ambient air quality standards present situations where potential impacts on human health can occur. Ambient monitoring and dispersion modelling have identified eight areas on the HPA where ambient concentrations of PM_{10}, SO_2 or NO_2 exceed the ambient standards. Exposure may be high where this exceedance coincides with populated areas and the risks to human health may be significant (DEA, 2010). It is important to note that all residential areas where wood and coal are combusted experience high concentrations of particulates and CO, particularly those that are densely populated. Here, exposure can be particularly high. Due to the relatively local scale of their air pollution problem, they may not fall directly into one of the identified hotspot areas (DEA, 2010).

The state of ambient air quality in the HPA is described using ambient monitoring data, dispersion modelling and the findings of research projects on the Highveld. The monitoring stations provide data at specific sites and while their spatial representativeness is limited, they are accredited and the ambient concentrations are considered accurate (DEA, 2010). Stakeholders conducting monitoring in the HPA include Eskom, Sasol and monitoring stations recently installed by the DEA and MDEDET.

National ambient air quality standards were developed for South Africa by the DEA and published in 2009 (DEAT, 2009). Seven criteria pollutants are regulated. Transitional compliance periods with higher limit values have been included for PM10 and benzene.

The standards include a limit value, averaging period, permissible frequency of exceedance and date at which compliance is expected. Regarding the permissible frequency of exceedance, it refers to the number of times the limit value can be exceeded without being recorded as an exceedance of the standard, e.g. the SO_2 24-hour limit value of 125 $\mu g/m^3$

Concentrations of SO_2 and PM_{10} at the DEA monitoring station in the KwaGuqa Township were plotted against wind direction to determine the relationship between significant source sectors in the surrounding areas. The results show major contributions from the northwesterly direction, with secondary sources in the southeasterly and south southwesterly directions. This is consistent with the large industrial area, Ferrobank, in the northwest, and various mining operations to the south. It is apparent across seasons that PM_{10} sources exist in all vectors and no clear contributors can be isolated. This is indicative of the generally high particulate loading on the HPA. The state of air quality in the Emalahleni Hotspot results from a combination of emissions from power generation, steel manufacturing and residential fuel burning (DEA, 2010). The input of industries in the area dominates the source contribution, showing clearly that residential fuel burning, motor vehicles and coal mining are far less significant in considering the total air quality loading for all pollutants (DEA, 2010). In terms of PM_{10}, residential fuel burning does contribute a sizeable percentage to ambient concentrations.

6.6.2. Coal mining impacts on air quality

The use of coal for energy production results in both the primary environmental impacts associated with the mining and removal of coal for use in coal fired power stations in Mpumalanga, as well as the secondary impacts resulting from the burning of this coal for energy production.

Coal intensive activities contribute to large-scale water and air pollution, including significant carbon dioxide emissions, which contribute to the greenhouse gas emissions. The generation of electricity through coal-fired power stations produces pollutants such as particulates, sulphur dioxide and nitrogen oxides. Emissions from coal-fired power stations are a serious concern for Mpumalanga as they cause impaired air quality in areas close to and away from the emission source and much of the demand for electricity in the country thus generates ambient air quality impacts that are felt largely in Mpumalanga and the surrounding areas. None of the currently operating power stations have flue gas desulphurisation technology installed. There are various means of removing SO_2 from flue gases. Eskom has committed to installing flue gas desulphurisation at the planned new Kusile power station. This will be the first coal-fired power station in South Africa to have this technology installed.

Opencast mining is widely employed for the economic extraction of coal deposits close to surface in the Mpumalanga coalfield. The key atmospheric pollutant emitted from these operations is PM (particulate matter). There are various sources of PM emissions including, but not limited to, the following:

- The use of vehicles on unpaved and paved roads;
- Remobilisation of material deposited on road surfaces;
- Blasting;
- Overburden Stripping;
- Ore and overburden handling;
- Crushing and screening of ore;
- Wind entrainment from stockpiles, and
- Spontaneous combustion (section 6.6.3.).

The primary contributor to PM is from unpaved mine haul roads. When a vehicle travels on an unpaved road, the force of the wheels on the road surface causes pulverization and release of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed (US EPA, 1995).

The rate of PM entrainment is largely dependent on the characteristics of the wearing course material, the mass and number of vehicles travelling and, to an extent, the speed at which these vehicles travel on the roads. Mines apply various means of reducing haul road-related PM emissions through the application of palliative measures. These include:

- Application of chemical palliatives;
- Applying vehicle speed constraints;
- Providing a tightly-bound wearing course material;
- Armouring the surface (placing a thin layer of higher quality wearing course on the existing material or turning this into the top 50mm of material);
- Good maintenance practices; and/or
- Regular light watering of the road.

6.6.3. Coal combustion impacts on air quality

The export contracts require low ash material (<9% ash), consequently during the 1980s the South African industry started to wash the products in large quantities. The discard was dumped, and many dumps started burning due to spontaneous combustion. By the mid-1980s, Lloyd et al. (2000) reported that the ambient SO_2 levels in present-day Mpumalanga had reached noxious levels in some regions. The primary source was shown to be the burning dumps, not power stations in the area. As a result, methods for constructing dumps were developed, which markedly reduced the chance of spontaneous combustion (DEA, 2010).

In addition to power generation, coal combustion in stoves and coal heated boilers in hospitals and factories contributes to low-level coal-related atmospheric pollution (EIA, 2004). Such use of coal for domestic and industrial purposes also adds to the environmental impacts associated with commercial energy production from coal-fired power stations in the province. Other environmental impacts associated with energy production include air pollution from synthetic fuel production and vehicle emissions, pollution and health impacts associated with the use of leaded petrol, and oil and fuel spills and leaks can contaminate surface and groundwater.

Domestic coal and wood combustion within informal settlements and rural areas has been identified through various studies to be, potentially, one of the greatest sources of airborne particulates and gaseous emissions to be inhaled in high concentration (i.e. before dispersion and fallout processes can ameliorate impact) (DEA, 2010). Fuel used for domestic energy generation typically comprises coal, wood, paraffin and LPG, with animal dung and other waste materials used to a smaller extent. Electricity is used where available, but factors such as cultural traditions also play a role in the continuing use of other fuels. Combustion of coal and wood, and in some areas paraffin, remain the prevalent energy source for space heating and winter cooking in the townships and informal settlements of the HPA. Although many households are electrified, coal, and to a lesser extent wood, continues to be used due to the cost associated with electricity as a heating energy carrier (DEA, 2010). Domestic coal burning is a significant source of low-level fine particulate (PM2.5 and PM10) and contributes significantly to SO_2, CO, TOC and benzene emissions. Greenhouse gas emissions are also produced, including, but not limited to, CO_2, CH_4 and N_2O. Pollutants from the combustion of wood (including veld fires) include respirable particulates, NO_2, CO, polycyclic aromatic hydrocarbons, particulate benzo(a)pyrene and formaldehyde (DEA, 2010). Particulate emissions from wood burning within South Africa contain about 50% elemental carbon and about 50% condensed hydrocarbons (Terblanche et al., 1992).

Due to the nature of household energy usage, residential fuel burning has a characteristic diurnal and seasonal signature. Periods of elevated residential fuel burning are in the early morning and evening, when space heating and cooking takes place. An increase in residential fuel burning may be expected as the demand for space heating and cooking increases with colder winters, but coal consumption levels do not reflect this and the winter consumption of wood and paraffin differ marginally. A wide array of factors affect the extent of household fuel combustion, including population density and growth, the availability of electricity, household income, the degree of urbanisation, and the percentage of informal (unserviced) households (DEA, 2010).

6.6.4. Ground Gases

Ground gases may include: methane, carbon dioxide, carbon monoxide, hydrogen sulphide. Whilst the latter three are toxic to human health and pose a particular risk to the artisans, methane is explosive. The explosive limits of methane are 5 – 15% v/v. Faouconnier (1992) analysed barometric data associated with known occurrences of explosions in South African mines and established that whilst diurnal fluctuations do not have a major influence on the accumulation of gas in underground workings, pressure drops associated with cyclonic weather systems are a major contributor to gas explosions in mines. Most coal-mine explosions in South Africa occur in the coalfields of Natal and the Mpumalanga (Eastern Transvaal; Faouconnier, 1992).

Although the presence of toxins harmful to human health has been recorded for coal-fire gas in China and the USA, there is little known about the topic and the risks to human health in South Africa (Prone et al., 2007). High concentrations of known carcinogens such as toluene, benzene and xylene were found in gas collected in the Witbank coalfield (Prone et al., 2007). High concentrations of carbon monoxide, carbon dioxide, and methane were also detected. Prone et al. (2007) concluded that the health consequences of exposure to the hazardous elements represent a serious risk and an environmental impact assessment of the extent of the impact is much needed.

6.7. ACID RAIN

Coal combustion releases sulphur to the atmosphere, which combines with oxygen to form sulphur dioxide with the potential to fall as acid rain and run-off from mining can contaminate groundwater, while waste coal may spontaneously ignite (EIA, 2004).

Acid deposition over the Highveld area has been investigated for over two decades, prompted by a growth in anthropogenic emissions and related concerns about potential degradation of soil and water resources (Scorgie and Kornelius, 2009). Long-term trends in acid deposition, and the likelihood and timing of critical load exceedances were discussed. SO_2 can be formed in the atmosphere through the reaction of hydrogen sulphide and ozone (thermal gas-phase photo-oxidation). Substantial H_2S emissions occur on the Highveld, with large industrial sources on the Mpumalanga Highveld alone accounting for over 70 ktpa. The contribution of combustion processes to acid deposition, and the relative impact of such deposition on water quality compared to other pollutant sources are also of interest. The total annual S deposition maximum occurs over the central Highveld (between Witbank, Secunda and Bethal). Deposition rate peaks of >35 kg/ha/year are predicted to occur in the vicinity of large point sources including coal-fired power stations, petrochemical plants and large steelworks (Scorgie and Kornelius). Annual total S deposition rates exceed 3 kg/ha/year over much of the Highveld, with a peak of over 35 kg/ha/year over the central Highveld (between Witbank, Secunda and Bethal). Emissions and trends in S deposition predicted for central Highveld catchments are consequently projected for the 1980 to 2020 period.

Dryland agriculture in the HPA involves clearing of veld and ploughing in preparation of fields for planting is extensive with amongst others, maize, sorghum, groundnuts and sunflowers being farmed. The contribution of dust generated by agricultural activities to the ambient dust loading in the HPA are not quantified in this baseline assessment as these activities are of relatively short duration (DEA, 2010).

6.8. ALTERED PATTERNS OF STREAM FLOW AS A CONSEQUENCE OF MINE DE-WATERING

In the Little Olifants-Riet sub-catchment of the Olifants River disruption to the interconnected wetlands occurs as a consequence of mining activities, including blasting, ground clearance and stripping of overburden. This has disrupted the hydrology and attenuating capacity of the dolerites, causing increased summer flows and lower winter flows.

Another consideration with respect to the disruption of groundwater flow paths is the potential for undermining streams and water courses.

A large number of dams and weirs have been constructed in the various streams and rivers in the upper Olifants river catchment. These dams are mainly used for agricultural purposes such as stock watering and irrigation. These structures can cause the inundation of wetlands upstream of the dam wall. In addition, the dam outlets are not always sufficient during flood periods and may break, leading to erosion. The cumulative impact of the dams on the hydrology of the catchment is large, especially during low-flow periods (Palmer *et al* 2002). The most important impacts of dams and weirs on the natural hydrological system, which are both directly and indirectly related to mining, are (Myburgh 1999):

- Changes in the water temperature;
- Changes in the chemical properties of the river;
- Changes in the habitat complexity;
- Changes in the composition and functioning of the biotic populations;
- Changes in flooding frequency;
- Changes in the extent of flooding;
- Changes in the movement of sediment and organic material;
- Changes in nutrient cycling;
- Restricting the movement of various aquatic fauna species, both up-stream and down-stream of the dam, and
- Addition of salt loading to the system in the long term.

Artificial wetlands are any type of wetland constructed by man and mostly include dams and weirs. In this case the dams are included in a separate layer and the artificial wetlands only include those wetlands that are obviously anthropogenic, but do not include dams (Ewart-Smith et al., 2006). Some of the wetlands may however be a result of a dam or weir, upstream or downstream of the wetland. Less than 0.2% of the wetlands in the catchment are indicated as artificial wetlands, although it is suspected that a much larger percentage of the wetlands may be artificial.

6.9. SOCIETAL IMPACTS

A list of socio-economic impacts derived from Work Package 1 is presented in Table 6. Some of these impacts overlap with environmental ones, particularly those pertaining to water supply and quality. Amongst the societal impacts listed noise has received particular attention in the context of road traffic (section 6.9.1), but has been poorly covered beyond this, e.g. with respect to blasting, which was identified as an environmental impact by Work Package 1.

Although the different sets of provincial noise regulations are to be replaced by the thoroughly revised new National Noise Regulations, the Mpumalanga Noise

Regulations still stand (Environment Conservation Act, Act 73 of 1989). These define an intruding noise as ‘disturbing’ if it causes the ambient noise level to rise by 7 dBA or more. Poor enforcement of legislation inevitably results in noise pollution. There does not appear to be any published literature on this.

A road traffic noise prediction model was developed, in accordance with the procedures specified in SANS 10210 (SANS, 1996), which established that although the noise emissions from railway operations are characterised by the occurrence of noisy single events and these emissions can be distinguished over relatively large distances, the noise caused by rail traffic is generally perceived as being less disturbing than that of road traffic. For this reason railway noise was not included in the estimation of the future ambient noise levels.

7. Hydrological, Hydrogeological and Hydrogeochemical Framework

As mining and other industries in the region expand, water demand has grown and Hobbs (2008) reports an average 3.5% per annum increase in water demand between 2000 and 2006. Much of the supply comes from dams. The relatively low rainfall and high demand for water make it a valuable resource. The bedrock geology is largely of low storage potential and groundwater aquifers are limited.

The regional topography and river pattern suggests an easterly hydraulic gradient across the region. Clearly this will vary to reflect the local hydrogeology.

Surface runoff in the upper Olifants river catchment is regulated by several large dams, including: Bronkhorstspruit, Witbank and Middleburg and farther downstream the Loskop Dam (Figure 16). Typically river flows in South Africa range from 20% of mean annual rainfall in the wettest areas to zero in the deserts, with an average 10% of the mean annual rainfall (Ashton et al., 2001). Flow data is sparse. However, the DWA maintains a comprehensive system of flow and 35 water quality monitoring points on all of the tributary rivers within its area of jurisdiction. Water quality and flow data for the Olifants river catchment are available from the National Chemical Monitoring Programme (de Villiers, 2009). There is also a National Toxicity Monitoring Programme that is still under development (de Villiers, 2009). Both programmes fall under The Directorate Water Quality Management of DWA (de Villiers, 2009).

Subsidence associated with the Middelburg Mine of the Witbank coalfield has had an impact on the hydrology in a number of ways, including reduced surface runoff, increased groundwater recharge and deterioration of water quality (Bell et al., 2000, 2001). Ground instability and the associated tension gaps, crown holes and lower ground density provide potential surface water recharge points; a consequence of this is that surface water runoff can be reduced by up to 50% (Bell et al., 2001). Additionally, subsidence has resulted in local flooding. This pushes water farther into the mined void and increases the potential for acid mine water generation.

Many of the mines are interconnected. This can be problematic where mines are under different ownership. Upon mine closure this results in groundwater flow between the mines. Understanding the inter-mine flow is important in the context of predicting long term mine discharges. Applied to seven mines in the Witbank coalfield, Havenga (2005) have shown that inter-mine flow can be modelled. Groundwater modelling of this type requires a good conceptual model, including hydraulic properties and knowledge of the geometric configurations of the mines.

Groundwater use in the province is relatively small compared to water use supplied from surface water resources. Groundwater is an important source of fresh water, which can be influenced by any changes in surface land use which range from changes in infiltration rates, from hardening of surfaces to contamination of groundwater from leachate generated at waste sites (Mpumalanga Province, 1999). Groundwater is often contaminated by industrial, residential and agricultural activities, with landfill sites and mining activities rating as the most problematic (Mpumalanga Province, 1999).

Four distinct aquifers are present in the Olifants river basin. They are:

- Weathered Rock Aquifers;
- Structural or Fractured Aquifers;
- Dolomitic or Karst Aquifers, and
- Alluvial Aquifers.

Each aquifer type has a unique range of storage capacities and yield potentials as outlined below.

7.1.1. Weathered Rock Aquifers

The Ecca sediments are weathered to depths of between 5 and 12 m below the surface although may be as thin as 0.2 m or as thick as 50 m in certain areas (Hodgson & Krantz, 1998; Department of Water Affairs, 1991). The upper aquifer is associated with this weathered zone and water is often found within a few metres below surface. Solid unweathered rock or structural aquifers tend to form the lower boundary of this aquifer. This aquifer is the most extensively exploited aquifer and is recharged by rainfall. The percentage recharge to this aquifer is estimated to be in the order of 1 to 3% of the annual rainfall, based on work in other parts of the country by Kirchner et al., (1991) and Bredenkamp et al. (1995). Observed flow in the catchment confirmed isolated occurrences of recharge values as high as 15% of the annual rainfall (Hodgson and Krantz, 1998). It should, however, be emphasised that in a weathered system, such as the Ecca sediments, highly variable recharge values can be found from one area to the next. This is attributed to the localised impact of mining and the composition of the weathered sediments, which range from coarse-grained sand to fine clay.

The aquifer tends to be rather low yielding (range 100 to 2 000 $\ell \cdot h^{-1}$), because of its limited thickness, giving a typical flow of approximately one litre per second. However, when existing in conjunction with a structural aquifer, yields of up to five litres per second may occur from a borehole penetrating both the weathered aquifer and a deeper aquifer beneath (RSA Department of Water Affairs, 1991). The good quality of this groundwater can be attributed to the many years of dynamic groundwater flow through the weathered sediments. Leachable salts in this zone have been washed from the system and it is only the slow decomposition of clay particles, which presently releases some salt into the water (Hodgson and Krantz, 1998).

7.1.2. Fractured Aquifers

The fractured Ecca aquifers are comprised of un-weathered Ecca sandstones and shales, where fractures are the principal controls on groundwater movement. The pores within the Ecca sediments are too well-cemented to allow any significant flow of water. All groundwater movement therefore occurs along secondary structures, such as fractures and joints in the sediments. These structures are better developed in competent rocks, such as sandstone, hence the better water-yielding properties of these rocks.

Water storage and transmission occurs in what is known as secondary porosity in structural aquifers; secondary porosity being that porosity attributable to fractures, cracks and joints in the rock and not actually to the rock itself. With depth more of these cracks are closed due to the weight exerted by the overlying formations. At depths below 30 m, water-bearing fractures with significant yields tend to be rarer, being spaced 100 m or more apart (Hodgson & Krantz, 1998). These fractures may be identified as linear features on air photographs or indeed may often be readily observed in the field. Highly variable yields are found in these aquifers. Initially yields may be high, but then show a marked decrease with continued pumping due to the limited storage in some of the cracks. In general, there is insufficient yield from these aquifers for intense irrigation (Hodgson & Krantz, 1998). Of all the un-weathered sediments in the Ecca, the coal seams often have the highest hydraulic conductivity.

7.1.3. Dolomitic or Karst Aquifers

The groundwater in dolomitic aquifers are found mostly in the underground cavities that are formed at depth in calcium rich rocks as a result of the dissolution of materials such as solid dolomite by carbonic and sulphuric acid present in the groundwater. Yields from successfully placed boreholes tend to be high, ranging from five to forty litres per second. This aquifer type is present in three main areas of the Olifants basin. First, along the western foothills of the Drakensberg Mountains from Pilgrim's Rest in the south to Maseseleng in the north. The other two areas are around Delmas and Marble Hall (RSA Department of Water Affairs, 1991).

7.1.4. Alluvial Aquifers

Alluvial aquifers consist of unconsolidated material ranging from clayey silts to coarse gravels and boulders that occur along watercourses, in old dried up valleys and in existing or historic floodplains. Borehole yields are generally high, with 30% giving in excess of ten litres per second (DWAF, 1995c).

7.1.5. Recharge

Groundwater recharge in the basin is estimated to be 3% to 6% of the mean annual precipitation, which in turn is estimated to be between 500 to 1700 mm per year. Specific exceptions are that more than 60% of the basin receives less than 700 mm precipitation per year. On the other hand recharge of up to 8% of precipitation is suspected in the north western fringes of the catchment. The range of mean annual precipitation quoted here shows that quite often recharge occurs only locally and is certainly not spatially homogenous. Total recharge for the basin per year is estimated at approximately 1800 million cubic meters (RSA Department of Water Affairs, 1991).

As a consequence of the processes listed above most of this recharge occurs during, or shortly after, heavy rain and it is suspected that the majority of water reaching the water table does so via macro pores (cracks, fissures, etc) in the soil rather than through the actual soil body.

7.1.6. Artificial Groundwater Recharge

There are a number of methods of artificially enhancing groundwater recharge, some of which are:

- Inefficient irrigation - either through over irrigating or by having a leaky distribution system;
- Leaky reservoir - groundwater recharge induced by creating reservoirs of water over a relatively permeable unsaturated zone lying on top of a suitable aquifer;
- Reversed pumping - injecting clean and treated water into an aquifer via boreholes.

In all cases artificial recharge should only be thought of as a tool to tap excess surface runoff - something that is not always readily available when the needs of the whole region and the downstream recipients are considered. This means that in the Olifants river basin artificial recharge may only be conducted during the height of the rainy season or from surface water reservoirs.

7.1.7. Quality

Groundwater quality is intrinsically linked to the chemical properties of the aquifer's geology through which it flows. As a result its quality varies from one aquifer to another, and even within aquifers. However, artificial pollution of groundwater by man-induced means is increasingly common. Further, given among other things, the slow speed that groundwater moves through the ground resulting in a very long residence time, once an aquifer is polluted it may take many generations before that aquifer can again produce unpolluted water (Aston , 2000).

In the upper weathered aquifer the groundwater can be considered to be of excellent quality when existing in its natural state. The material that it flows through has long since been flushed of its leachable minerals and hence provides a nearly inert conduit for the water. The presence of local surface pollution would of course severely adversely affect this relatively unprotected aquifer as it occurs near the surface and often has little soil cover. Deeper in the fractured aquifers one finds a higher salt load due to the longer residence time and the less leached rocks that the water comes into contact with. When the groundwater has come into contact with granitic rocks there often are naturally occurring high levels of fluoride.

7.1.8. Groundwater - Surface Water Interaction

The general impression from the literature is that, throughout, the Olifants River is a gaining one (the discharge increases along its length) and, with the exceptions of the alluvial aquifers near rivers, the predominant groundwater movement is from the ground to the rivers.

Where relatively unpolluted groundwater is drawn towards the streams it may be exploited as a source of localised water supply. Additionally, although a river may be polluted, the groundwater nearby need not be, as it may not be receiving water from the river.

7.1.9. Pans

There are several small, but ecologically important wetlands in the Olifants river catchment. According to the National Water Act (No 36 of 1998) a wetland is defined as, "*land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil*." This definition includes all naturally occurring wetlands and pans, but excludes rivers, lakes and artificial wetlands, except for the transition zone from the river/lake and the terrestrial ecosystem. Wetlands in dry regions are commonly referred to as endorheic pans. A high density of pans occurs in the Mpumalanga Province. In some instances pans are referred to as lakes. The Mpumalanga Lake District lies in the order of 120 km to the southwest of Witbank and 30 km to the northeast of Ermelo, on the eastern escarpment where four large drainage basins (Komati, Umpuluzi, Usutu and Vaal) meet. The lakes comprise a number of enclosed "pans", the deeper ones, exemplified by Lake Chrissie, which is the country's largest natural body of fresh water and is groundwater fed and permanently flooded (Exigent Engineering Consultants, 2006).

Various studies have indicated that there is a relationship between wetland distribution and the underlying geology and soils (Marneweck et al., 2001, Merot et al 2003, Devito et al 1996). The geology of a site influences several of the topographical characteristics of the site, as well as erosion processes, groundwater and vegetation type. According to Palmer et al (2002) most of the wetlands in the upper Olifants river catchment occur on sediments from the Vryheid Formation (Cairncross and McCarthy, 2008), with a few on the Waterberg Group, Dwyka Formation and the least on the Rooiberg Group, Bushveld Complex. Wetlands are also strongly associated with dolerite intrusions (Snyman 1998, Vegter 1995). Pans mostly occur on shales and unconsolidated surface sands in areas without integrated drainage and with an average slope of less than one degree. Pans of this type are more characteristic of arid areas than of the humid area in which they are situated (Russell, 2008). They are sometimes difficult to define (Allan et al 1995, Morant 1983). Endorheic pans are typically circular to oval shallow depressions without an outflow. Pans are seldom more than three meters deep, although systems up to 20 m deep have been defined as pans. Some systems in Mpumalanga that are large, deep and permanently wet can be defined either as pans or as lakes. In addition, pans have been viewed as a lake type in the past (Allan et al, 1995).

The formation of pans is complex and can be influenced by climate, geology, surface disturbance by animals, lack of integrated drainage systems and wind. Although pans are mostly scattered across the landscape, without any obvious pattern, some pans occur linearly, in the location of ancient rivers (Allan et al 1995). A number of the pans exhibit north-south elongation and appear to be associated with faulting and fracturing in the bedrock (Russell, 2008). They are generally in the order of 1-2 km in diameter, but vary considerably (Russell, 2008) and are fed by both rainwater and groundwater, but have no surface connection to the drainage network. A number of the pans are associated with the presence of mounds, or lunettes on their downwind side, suggesting that deflation plays a role in their propagation (Russell, 2008). It has been postulated that they are associated with former drainage channels and the dunes are associated with deflation of the fluvial channel with inner dunes associated with deflation of the pan floor (Russell, 2008). Alternative theories regarding their formation include: tectonic subsidence, biologic factors such as grazing and sediment removal, leaching of material, burning of near surface coal, the effects of differential compaction of strata, but none of these have been proven (Cairncross and McCarthy, 2008). There are also different theories on the propagation once pans have formed (Russel, 2008). Wind deflation is regarded as one of the most important mechanisms.

Locally, perched aquifers are developed from which springs exude on the ground above the pans. The presence of a ferricrete layer can act as an aquitard which inhibits the water movement vertically through the subsurface. Such perched aquifers occur at around 1760m above sea level (Russell, 2008). Seepage of water then occurs with much of the area immediately surrounding the pan being a seasonal wetland.

Sampling of the major pans at the end of the wet and dry season and showed that the water chemistry was dominated by Na-Cl-HCO_3, with pH in the range 7.0 to 10.5 and 100 mg/l – 10g/l Total Dissolved Solids (the higher concentrations being associated with more saline bodies, subject to seasonal desiccation ; Russell, 2008. Spring waters associated with the lakes had pH in the range 6.0 to 8.0 and Total Dissolved Solid concentrations in the range 20 – 200 mg/l. The chemistry is influenced by the ratio of the surface area to the catchment area and is subject to strong seasonal variation as a consequence of evaporation, such that removal of species, e.g. carbonate, calcium, magnesium and potassium, through mineral precipitation occurs. On the capillary fringes of the pans, evaporite deposits were found during the dry season as a result of capillary evaporation of interstitial waters below the pan floor. Thenardite (Na_2SO_4), halite and other sodium carbonate minerals were identified in the precipitates (Russell, 2008).

The pans receive water in a number of different ways. Rain falling directly onto a pan surface adds water. Each pan is surrounded by its own watershed, and some of the rainwater falling within this catchment forms surface run-off and flows directly into the pan, whilst the remainder percolates into the ground to become groundwater. This groundwater regime forms an important part of pan hydrology. The sandstone around and below the pans consists of massive, low porosity rock, with few, widely spaced joints. They have very little storage capacity for water, and transmit water very slowly. Nevertheless, some groundwater migrates through the joint system into the pans, but this source is probably the least important. Most of the groundwater collects in the weathered rock and soil overlying the bedrock (McCarthy et al., 2008). Typically the soil profiles in the region contain a horizon rich in iron oxide (ferricrete) that provides a local barrier to downward flow of groundwater. The thickness of the regolith layer is greatest on the higher ground surrounding the pans, and becomes thinner on the slopes towards the pan, where it may disappear completely, giving way to rock outcrop. Spaces between the regolith grains become filled with groundwater, which saturates the material below the water table. Because of thinning of the regolith down slope, the zone of saturation eventually impinges on the land surface, and forms a seepage line. This process gives rise to the hill-slope wetlands that surround the pans. Seeped water flows slowly across these wetlands into the pan (McCarthy et al., 2008).

Opencast mining in Mpumalanga is considered a threat to the natural hydrological functioning of the pans (McCarthy et al., 2008; Russell, 2008). Water flows readily into and through the mass of broken rock in the backfill and decants to ground and surface water. It is considered that the AMD would filter into the pans through seepage of the groundwater impacted on by the open pit which has been back-filled with the broken, pyrite-bearing waste rock (McCarthy et al., 2008). As pans act as closed basins water is only removed through evaporation, resulting in metals transported into the pan as constituents of AMD largely concentrating in the pans making the pans toxic pools. Although the pans have the capacity to buffer AMD pH, the buffering capacity might eventually be exhausted (Russell, 2008).

There is an additional concern that the negative features in the landscape might be used for overburden, or that overburden stockpiles might form positive features subject to infiltration and AMD generation. Any lowering of groundwater to facilitate mining might also impact on the hydrological functioning of the pans. Additionally, any air pollution generated as particulate matter through mining and power generation has the potential to settle on plants and inhibit photosynthesis in plant species (Russell, 2008).

8. Ecological Framework

Wetlands play an important role in the maintenance of biodiversity. Several species from various taxa are dependent on wetlands for breeding and feeding purposes. Although the species diversity in an individual wetland may be low, the overall species diversity in the wetlands of the region may be very high. Several Red Data species also depend on wetlands for survival, such as the Blue Crane and Nile Crocodile (Kotze et al 2005, Venter 2003). According to Palmer et al. (2002) the wetlands in the upper Olifants river catchment has high plant species diversity. In their study they recorded 354 indigenous and 59 exotic plant species. Red Data plant species have been recorded in the wetlands of the upper Olifants river catchment.

There are several small, but ecologically important wetlands in the Olifants river catchment.

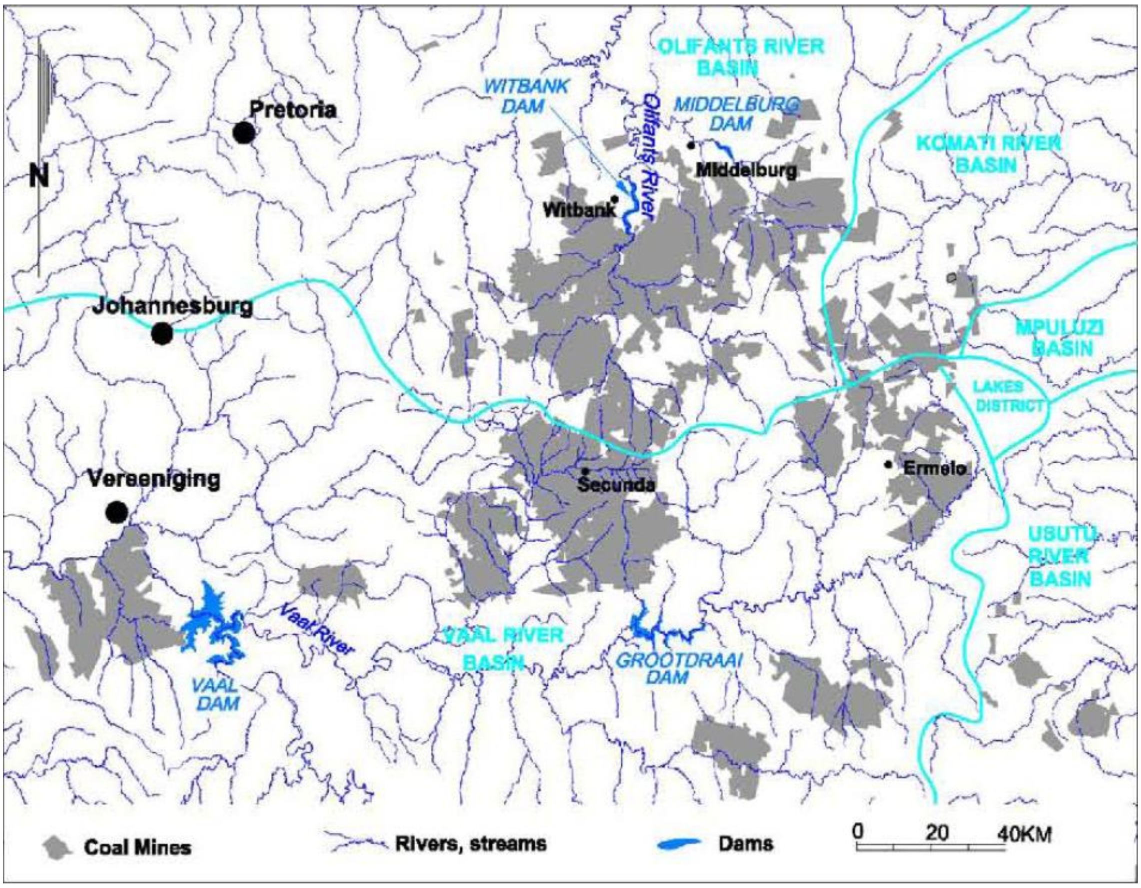

Figure 19 : Distribution of coal mines in the Highveld region in relation to river catchments, after McCarthy and Pretorius, 2009

The importance of wetlands for waterfowl habitat was identified and the conservation of wetlands forms part of the Ramsar Convention (Convention on Wetlands of International Importance especially as Waterfowl Habitat). Various Red Data bird species and bird species of concern, including the Blue Crane, Wattled Crane, Flamingoes (Greater and Lesser) and Grass Owl, are also dependant on wetlands for breeding and/or feeding activities (Cowan 1995, South Africa Tourism 2006). Metals can enter the wetland system in particulate form or in a dissolved state as fall out from the air. The natural removal of metals takes place through precipitation, absorption and plant uptake with metals associated with mine water often precipitating out. The precipitation of metals are influenced by the pH and redox potential present at a particular moment. The reduction or transformation of sulphate in wetlands is an important process in the wetland biochemistry. This process requires the presence of sulphate reducing bacteria. The bacteria occur in sediment and micro zones in plant litter. The process requires an environment with low oxidation potential (-120mV) and the presence of organic matter. Once the sulphate has been reduced other processes are required to immobilise or remove the sulphur compounds from the system (Palmer et al 2002, Kotze 2000, Kotze et al 2000, Brady & Weil 1999).

Scientifically intriguing and biologically valuable as it is, the area is also considered economically important for the coal mining industry, and several opencast mines are proposed, leading to concern that groundwater could be severely polluted and the natural hydrological functioning of the pan systems destroyed (http://wetlands.sanbi.org; http://wetlands.sanbi.org/wfwet/gumboot_article.php?id=99).Further, the AMDcan displace fresh groundwater in the surrounding area and result in acidic and saline soils, making conditions unsuitable for plant growth. Studies at backfilled opencast coal mines to the west of the Lake District showed that the mines have filled with water five to ten years after closure, resulting in polluted water emerging onto the surface. In the case of the Mpumalanga Lake District any pollution entering the pans will be trapped there, accumulating over time and eventually destroying all aquatic life (McCarthy et al. 2008). The pans would become virtually sterile, toxic pools. There is at present no way to completely stop the production of AMD.

Early work on polychlorinated byphenyls (PCBs) and chlorinated hydrocarbon pesticide residues in water, fish and sediment from the Olifants River (Grobler et al., 1994) was based on sampling of water, sediment and fish from the Olifants River, upstream of Witbank, and analysis for 10 chlorinated pesticides and two PCB during 1990. No PCBs, or chlorinated pesticides were detected in the water phase and the concentrations in the sediment were too low to confirm by mass spectrometry (at the time of sampling). Low concentrations of residues of DDT were determined in the fish. A comparable study of trace metals in these compartments (Grobler et al., 1994) established that metal concentrations generally reflected natural geological background levels. More specifically, arsenic, cadmium, mercury and lead were not detected in the compartments that were investigated.

The National River Health Programme is a programme that assesses the health of a river system. The health of the river systems are published in reports and are available to the public (CSIR 2001, http://www.csir.co.za/rhp/index.html).

In South Africa, the Department of Water Affairs and Forestry (DWAF) has found the Total Effluent Milleuhygiene TEM approach, developed in the Netherlands, the most appropriate for ecological hazard assessment, and has adopted a similar approach to manage complex industrial wastewater discharges (DWAF, 2003). The South African approach is called the Direct Estimation of Ecological Effect Potential (DEEEP).

South Africa has implemented a National Biomonitoring Programme for Aquatic Ecosystems (Taylor, 2007). It has been suggested that the Biological Diatom Index provides a good basis for monitoring general water quality and for integrated reflection on past water quality.

Tools used to assess the health of the rivers are:

- South African Scoring System (SASS) 5;
- The Fish Assemblage Integrity Index (FAII);
- The Riparian Vegetation Index (RVI); and

- The Index of Habitat Integrity (IHI).

SASS 5 uses the specific habitat requirements of invertebrates, including snails, crabs, worms, insect larvae, mussels and beetles, to assess the overall condition of a river system. Most invertebrate species are short-lived, the changes in river condition are therefore, displayed accurately by the species composition. The SASS 5 results are expressed as an index score and as an average score per taxon (CSIR 2001).

The FAII is an index using fish as an indicator of river health. Fish are long-lived and are therefore, indicators of long-term changes in the river health. The index categorise fish populations according to their intolerance to changes in habitat and pollution. The results are expressed as a ratio of the observed conditions to the expected conditions without human impact. The system is currently being utilised, but is also being refined to ensure greater accuracy (CSIR 2001). Heath and Claassen (1999) conducted a study on the feasibility of using fish as indicators of pollution. Impacts on the systems are often reflected by the aquatic organisms present in the system. Fish tend to accumulate pollution in their tissues. The accumulation of pollution in the fish tissues do however vary between fish species and the different tissue types within a fish.

The RVI focuses on the health of the riparian zones of rivers. Various impacts including the collection of firewood, changes in the flow regime and grazing or cultivation practices in the riparian zone can change the characteristics of the zone. A number of criteria are used to assess the riparian vegetation including vegetation removal, cultivation, construction, inundation, erosion, sedimentation and alien vegetation. The health of the riparian zone is then expressed as a percentage of change from the natural conditions (CSIR 2001).

The greater the diversity of available habitat in and around streams, the greater the species diversity that can be expected in a river system. Different habitat types that can be expected include pools, rapids, sandbanks, stones in the riverbed and riparian vegetation. The IHI is an index that assesses the available habitat in a river or stream, and the impacts of human activities such as water abstraction, flow regulation, and bed and channel modification. The index includes the status of both the riparian and in-stream habitats (CSIR 2001).

9. Bank Colliery Discard Dump

The Bank Colliery Dump was selected as the site for installing the ALERT system (section 1.2).

The following is largely derived from JMAConsulting(Pty) Limited (2008) and comprises a site specific study to set the context of the monitoring of the associated leachate plume. The Bank 5 Discard Dump comprises an area of approximately 25 ha and reaches a height of ~ 30 m (Figure 20).

Figure 20 : Bank 5 colliery dump. Source Google

It comprises colliery waste, including slimes and drains in a northerly direction to a paddock area. Prior to 2002 the slimes were disposed of directly into the underground workings associated with the No 2 Coal Seam (via two boreholes to the north of the dump). Plans presented by JMAConsulting (Pty) Limited, 2008 indicate that whilst there are no underground workings immediately beneath the dump the mine workings are in very close proximity to the north-east of the dump, suggesting the potential for groundwater mixing with the leachate from the dump. The mine workings are reported to be in the order of 25 m deep (JMAConsulting (Pty) Limited, 2008).

Surface water drainage flows in a northerly direction. Bank Spruit (1.5 km to the east of the site), Blesboklaagte Spruit (immediately to the north of the paddock area) and its north-easterly flowing tributary (in the order of 1.5 km to the north-west of the dump) are the main water courses that drain the area to the Bankfontein Dam.

The geology comprises basement rhyolites of the Rooiberg Group, overlain by tillite of the Dwyka Formation, which, in turn, are overlain by the sedimentary sequence of the Ecca Group (section 3). The coal seams, particularly the lower ones (No. 1 and No.2) follow the palaeo (pre Karoo) topography. The area has been intruded by Karoo dolerites. Of particular note is the Ogies Dyke, which is about 15 m in thickness and lies immediately to the south of the Dump. JMAConsulting (Pty) Limited, 2008 reported that the No. 2 coal seam ranges from an elevation of almost 1560 m above mean seal level (amsl) in the southeastern part of the area towards a saddle westward (1530 – 1540 m amsl) and north and south of the saddle the seam dips to elevations of 1500 to 1510 m amsl. The No. 5 coal seam ranges from an elevation of nearly 1600 m amsl in the southeastern part of the area, towards a saddle to the west (1590 to 1595 m amsl) and north and south of the saddle the seam dips to elevations of 1560 to 1580 m amsl. The No. 5 coal seam is absent (possibly weathered away) in the south-eastern and north-eastern part of the site. It is also reported (Jeff Davies, personal communication, 2010) that enhanced groundwater flow may also occur in baked and fractured Karoo sediments adjacent to the dolerite dykes.

A geohydrological study of the impact of the Bank 5 coal discard dump was commissioned in 2007 by Anglo Coal. This work was undertaken by JMA Consulting (Pty) Limited (JMAConsulting (Pty) Limited, 2008). This included the drilling of 8 boreholes to the northeast of the discard dump, groundwater level monitoring and chemical analyses of groundwater samples (pH, total dissolved salts and sulphate concentrations), numerical flow modelling and plume transport modelling. JMAConsulting (Pty) Limited (2008) reported that the sedimentary strata of the Karoo Supergroup comprise fracture rock with a low permeability and low yielding boreholes (< 1 l/s). Three types of aquifer can be defined in the Bank area: shallow perched aquifer (water perched by clays in the soil overburden, 2-7 m in thickness), shallow weathered zone of the Karoo aquifer (up to 40 m and averaging 19 m), and deeper fracture flow in the Karoo aquifer. The groundwater is generally unconfined in the weathered layers, becoming increasingly confined with depth. The lateral extent of the shallow aquifer is limited by structural members, such as the dolerite dykes and other geological discontinuities. Hydraulic aquifer boundaries occur where streams form constant head influx, or discharge boundaries, or where groundwater divides act as no flow boundaries. Calculated groundwater flow ranges between 1 and 4 m per day (JMAConsulting (Pty) Limited, 2008).

Groundwater levels, with the exception of one borehole, were found to be in the order of 0 – 10 m below ground level, which is in keeping with the natural background water levels. The groundwater level in the anomalous borehole (B-4) was nearly 28 m below ground level. The results of the groundwater chemistry indicate that pH and sulphate are particularly elevated in boreholes immediately to the east and northeast of the dump (boreholes 12 [pH 3 – 4, sulphate 5000 to 11500 mg/l] and 22 [sulphate 2000 to 6000 mg/l]). Elevated total dissolved salts were also determined in a borehole to the north-north-east of the dump (borehole B-8). This water is not used for domestic purposes. The contamination was defined by a plume that was subsequently modelled using groundwater and transport modelling (JMAConsulting (Pty) Limited, 2008). Groundwater flow directions emulate the surface topography, flowing (1-4 m/yr) in the shallow weathered zone in a north-easterly direction away from the dump. JMAConsulting (Pty) Limited (2008) suggest that the main mechanism for potential contaminant migration is convection.

JMAConsulting (Pty) Limited (2008) undertook geochemical sampling and testing of the Bank Discard Dump. This comprised eight samples (two from the old discard, two from the slimes, and three from the new discard and sediment from the paddock). The mineralogy of the dump material was analyzed by XRD and the percentages of quartz, kaolinite, mica, gypsum, anhydrite, amorphous phases, jarosite, alunite, pyrite, haematite, enstatite, rudite and anatase were determined. Pyrite was found to be higher in the more recent discard material. The amorphous phases (secondary Al, Fe containing hydroxides/ hydroxysulphates) were more concentrated in the more weathered materials. A measure of the potential for AMD generation, the ABA (acid-base accounting) and the neutralization potential (NP) was made for each of the samples. Each was shown to have the potential for acid generation. Very high sulphate values (10 000 – 15 000 mg/l) were present in the seepage from the Bank 5 Dump.

The results of the modelling work have been used to inform recommendations for mitigation measures. The potential installation of the ALERT system offers a means of verifying the model outputs in the report (JMAConsulting (Pty) Limited, 2008).

Dr Richard Ogilvy and Mr Philip Meldrum (British Geological Survey) visited the site in June 2010. In addition to the information provided by JMAConsulting (Pty) Limited (2008), they established that the dump is well compacted and stable. As a consequence this dump is not prone to self combustion. At the time of the visit the site was being remediated with soil in preparation for a grass capping. This will be aesthetically more pleasing and it offers the potential to minimise the surface exposure of efflorescent minerals and dust generation from the dump. One of the key concerns that was identified in the context of the installation of the ALERT system was that of equipment security and the consequential difficulty with power supply.

10. Findings from Work Package 1

The aim of work package 1 was to identify the needs from industry, regulatory bodies and stakeholders (society and NGOs) to evaluate the indicators and parameters to be taken into account in the assessment of the environmental, socio-economic and societal footprints of the extractive industry at each stage of a project (from exploration to closure).The main direct environmental and societal impacts in the Witbank area of mining have been due to land degradation and water pollution. Associated with this are employment and population displacement problems (Hobbs, 2008). Informal settlements are established because of the lure of potential employment, which creates an added demand on services and infrastructure both in the short and the long-term, thus requiring consideration of industry generation post-reclamation (Limpitlaw et al., 2005). Health hazards arise from the dust, noise, working conditions and water quality. Sediment is a significant ecological problem and many wetlands and rivers are believed to be clogged with coal dust. Water pollution sources include operating, closed and abandoned mines with AMD and related metal contamination forming the most important problems.

Many of these and additional socio-economic impacts were identified from the surveys carried out for work package 1 and are incorporated in Tables 10.1 and 10.2.

10.1. ENVIRONMENTAL IMPACTS

Cause	Issue
Blasting	Damage to homes and infrastructure (sewage and water pipes)
	Noise
Dust	Air and Water quality
Inadequate provision of infrastructure	Failure of infrastructure: damage to roads, overflowing of sewers
Dewatering	Groundwater drawdown
	Sinkholes and subsidence
Poor regulation and management of contaminated water (especially AMD) discharges	Water quality. Regional scale assessment of impacts in the Vaal, Usutu and Komati catchments required. Damage to the Olifants River and its tributaries. Transboundary impact.
	Impact on agricultural land
Poor planning regulation/ balancing of interests	Damage to wetlands
Demands for rapid issue of water licenses, some activity unlicensed.	Water quality
Volumes of traffic	Road damage
Low levels of enforcement of legislation	Poor regulation, no suspension of mining rights in the interim during decision making, recourse to court delayed until all other avenues exhausted.
Minerals and Petroleum Resources Development Act (MPRDA) favours mining interests over local community and environmental interests.	Imbalance in the prioritisation of environmental vs mining interests
Department of Mineral Resource avoidance of issuing closure certificates to avoid taking State responsibility; mining company avoidance of carrying out the proposed remedial works	Non-closure of mines
Environmental decisions made by the Department of Mineral Resources, rather than the Department of Environmental Affairs and there are weak provisions for consultation with other departments. Multilayered decision making.	Environmental interests not fully represented in decision making
Illegal mining – outside licensed areas	Wetland impacted
Mine impacts from all stages of mine life	Environmental impact assessment required for each stage of mine development
Non-coal industrial impacts	Additional contaminant stresses

Table 5: environmental impacts, issues raised

10.2. SOCIO-ECONOMIC IMPACTS

Cause	Issue
Ease of access, 2-3 yr duration of coal mines, easy/ quick profit mentality	Coal is undervalued and environmental impacts are not paid for. Sustainability is not fully analysed
Loss of agricultural land, impact on downstream irrigation water quality	Impact on local economy and on food security
Mining	Impact on community health and safety (TB, sinus problems, upper respiratory disease, HIV[mining companies only pay for care of the worker, not their family]). Asthma and ear problems in babies, high level of respiratory problems in the aged. Smog on roads (N12 especially)
Poor communication	Lack of public participation and locals not employed in the mines
Compensation only paid to landowners/ tenants for loss of land to the mining footprint rather than mining impact footprint.	Long-term loss of value of agricultural land
Labour migration. Not all labourers from the redundant farms are employed by the mines, especially for open cast mines.	Farmers relocating to townships. Local unemployment.
	Unregulated populations settling near mines lured by potential for employment
Lowering of groundwater levels and deterioration of water quality	Water supply and quality
Poor enforcement	Illegal mining outside of lease area; Consequential deaths due to combustion of coal in illegally mined areas
Broader issues of poor environmental regulation	Illegal dumping of household waste and construction material
Poor enforcement of water use licenses	Unreasonable use of water resources
Insufficient expertise in environmental impacts, environmental health practitioners	Inadequate environmental health and environment management. In some clinics/ hospitals even trained staff lack motivation.
Legislature linked to companies that have mined in Mpumalanga	Lack of trust in decision makers
Poor ventilation of the mine workings	TB
Limited mine company resource input to the community. Reductions in compensation. Mining company withdrawal of promised support	Poor/ no care provision for family of HIV affected labour. Donations for food parcels withdrawn by new Anglo management

Table 6 : socio-economic impacts, issues raised

11. Conceptual Models

Three models have been generated: site-specific environmental, regional environmental and regional socio-economic, following the source – pathway – receptor paradigm (Figures 21 to 24, respectively). These models represent a range of scale of mining impacts and it is intended that they should form the basis for establishing the key indicators of mining impacts, which can be assessed in terms of their suitability for Earth Observation (Tables 7 and 8).

11.1. RECEPTORS

11.1.1. Bank Dump

The key receptors associated with the Bank Dump are: mine workers; farm properties/ small settlements, surface water quality and stream load, groundwater quality, soil and the atmosphere.

11.1.2. Regional-scale: Witbank coalfield

The key regional receptors associated with the Witbank coalfield are:

Human: mine workers and residents, including farm properties/ small settlements and regionally-based human receptors.

Surface water quantity and quality (including ecological impacts), including: rivers, reservoirs and lakes (including the Lake District).

Groundwater quantity and quality (including ecological impacts) and availability to down dip users.

Atmosphere: dust, which can cause acid rain and smogs.

Agricultural land: loss of land (direct loss to mining and indirect loss as a consequence of induced ground instability) and contamination by efflorescent salts, dust and acid rain.

11.1.3. Socio-economic impacts

The key receptors associated with the socio-economic impacts of the mining have been summarised as: employees; residents; land value; agriculture; food security (as a consequence of loss of agricultural land); environment (surface water, groundwater and air); ecological and aesthetic.

11.2. SOURCES

11.2.1. Bank Dump

The main source of contamination is the dump itself. There are however, a number of secondary sources, including: contaminated groundwater from the coal workings, efflorescent salts and dust derived from the dump.

11.2.2. Regional-scale: Witbank coalfield

The key contaminant of concern associated with the Witbank coalfield, which comprises both surface and underground workings, is the sulphate derived from the oxidation of pyrite in the coal. This is encountered in the dumps, tailings, groundwater (AMD), dust and efflorescent salts (precipitation and remobilisation from the soil). Further sources of contaminants include associated metal (including arsenic) leaching and ground gases. Ground gases are both naturally occurring and a consequence of the self-combustion that results from oxidation of workings and dumps.

11.2.3. Socio-economic impacts

Surface working sources: dust, sulphate-rich leachates, dust, blasting techniques; underground working sources: AMD, dewatering, self-combustion, poor ventilation; and social/ working conditions: poor ventilation, poor housing, poor food, poor infrastructure.

11.3. PATHWAYS

11.3.1. Bank Dump

Pathways associated with the Bank Dump include: Aeolian pathways, groundwater pathways, surface seepages, soil storage and release (efflorescent minerals), surface water run-off. The sources, pathways and receptors have been combined in Figure 21.

11.3.2. Regional-scale: Witbank coalfield

Pathways associated with the Witbank coalfield include: Aeolian pathways, groundwater pathways, surface seepages, soil storage and release (efflorescent minerals) and surface water run-off. The sources, pathways and receptors have been combined in Figure 22.

11.3.3. Socio-economic impacts

Pathways associated with the socio-economic impacts include: airborne; direct contact; groundwater; surface water; business and political (associated with insufficient funds for remediation, poor regulation), and economic (loss of value to land). The sources, pathways and receptors have been combined in Figure 23.

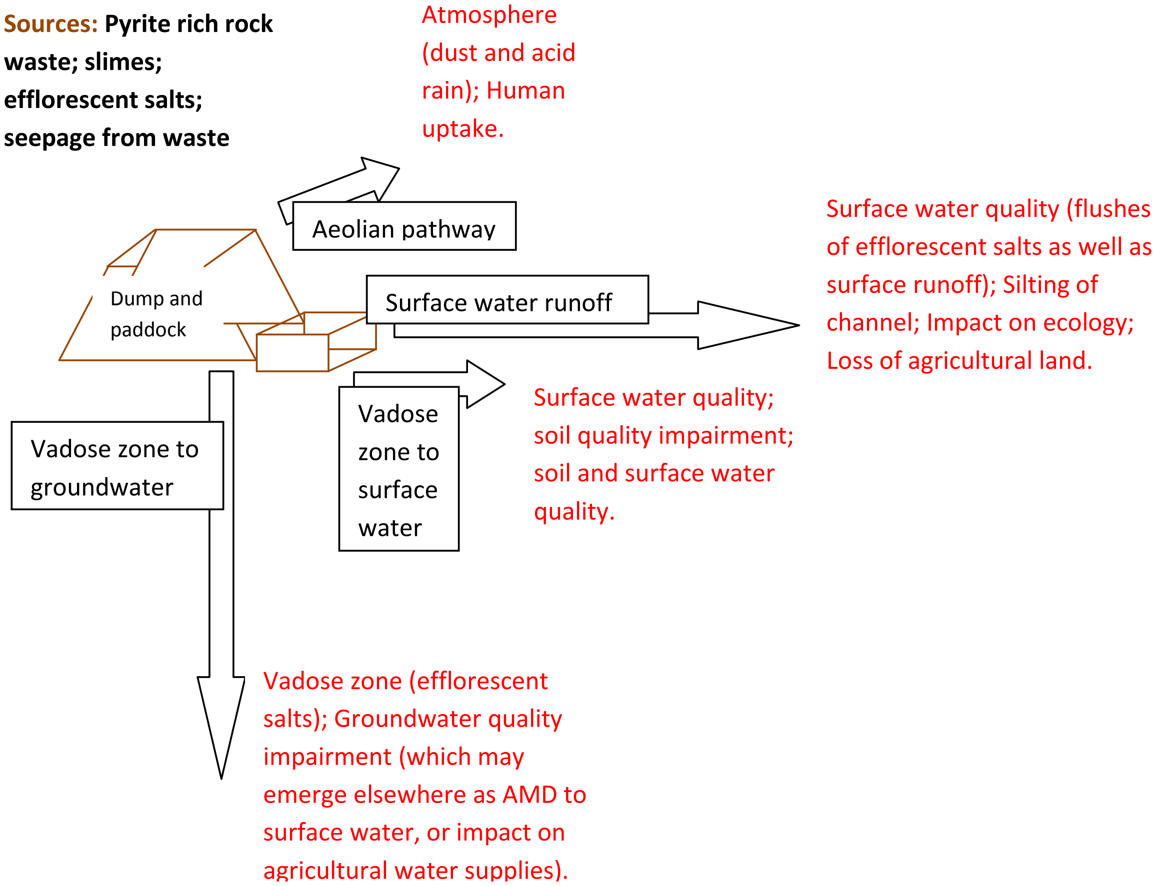

Figure 21 : Environmental Conceptual Model: Bank Dump

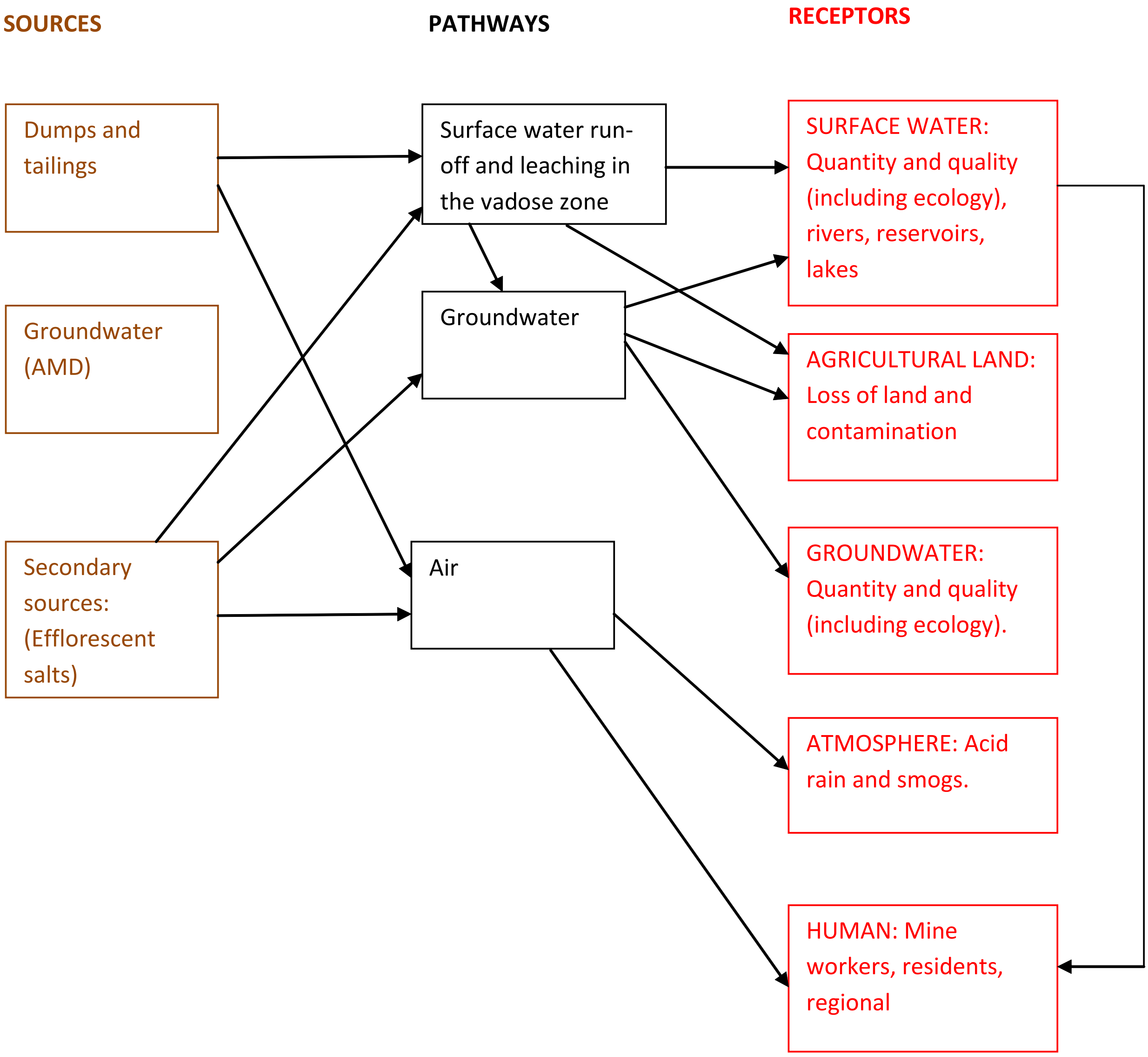

Figure 22 : Regional Environmental Conceptual Model, Witbank coalfield

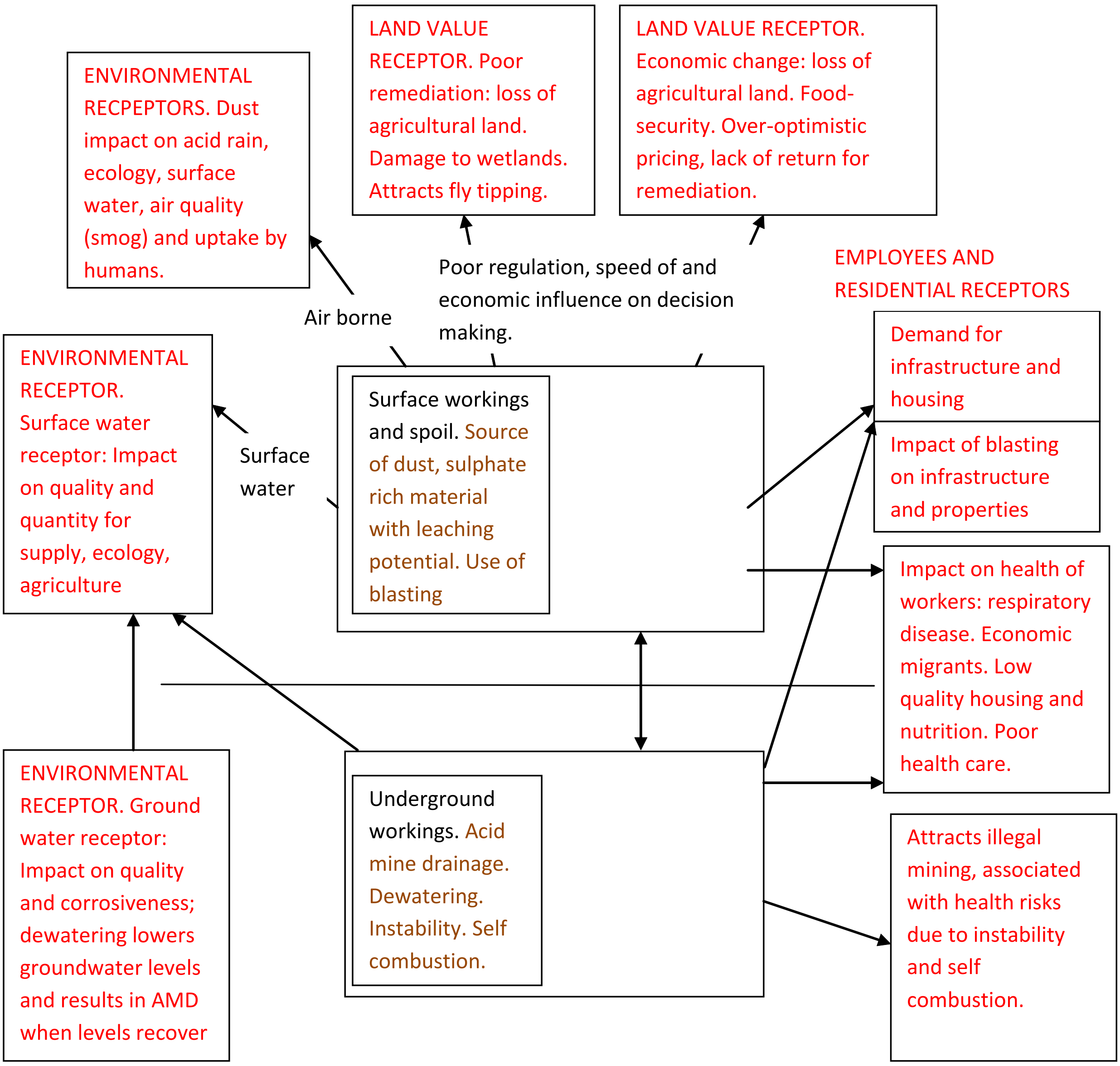

Figure 23: Regional socio-economic Conceptual Model

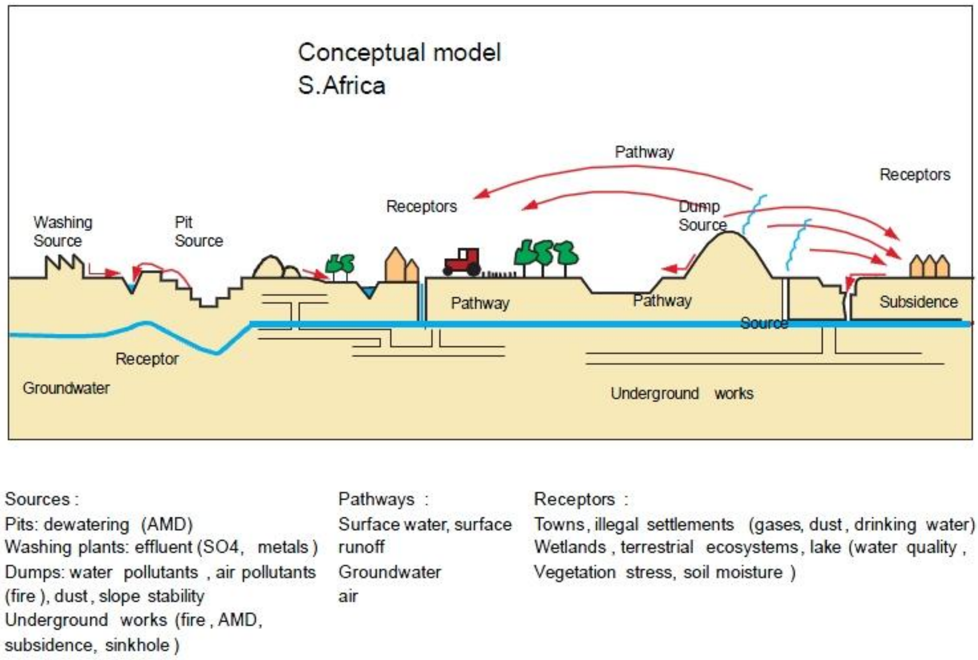

Figure 24: Schematic diagram of sources, pathways and receptors

11.4. POTENTIAL FOR REMOTE SENSING ASSESSMENTS

Table 7 summaries the main environmental issues associated with past and present coal mining in South Africa. For each environmental pressure the table provides one or more indicators/ parameters to measure the presence/extent/changes of the underlined issue and the potential for remote sensing assessment.

Table 8 summarises the main socio-economic issues associated with past and present coal mining in South Africa. For each environmental pressure the table provides one or more indicators/ parameters to measure the presence/extent/changes of the underlined issue and the potential for remote sensing assessment. The potential for remote sensing assessment excludes in-situ data, and those remote sensing data listed are suggested appropriate sensors and do not constitute an exhaustive list of all available sensors.

Causes	Environmental Issues	Indicators	Parameters	Potential for remote sensing assessment
AMD	**Ground and Surface Water Quality and Quantity**	DIRECT • Ecological impacts • Lowering of groundwater levels/ reduced stream flow INDIRECT • Acid mine drainage potential • AMD source proximity to water receptors • Cessation of pumping • Subsidence	1. Distribution of sulphate salts 2. Surface drainage map 3. Groundwater table depth and flow direction 4. Topographic maps 5. Maps of abandoned mines 6. Maps of licensed dewatering activities	1. YES – Hyperspectral airborne data, or multispectral satellite e.g. ASTER or Hyperion 2. YES – SRTM, LiDAR or elevation derived from stereo airborne photography or multispectral satellite imagery such as ASTER 3. YES – ground network required unless regional scale when GRACE satellite data could be utilised 4. YES – Any suitable scale elevation model and optical imagery such as SRTM/LiDAR and ASTER, SPOT, GeoEye 5. YES – Hyperspectral or thermal airborne data. 6. NO
Sediment loading		DIRECT • Sediment load in watercourses INDIRECT • Erosion potential of dumps • Sediment load source proximity to water receptors	1. Water turbidity 2. Topographic maps 3. Slope gradient 4. Surface drainage map	1. YES – hyperspectral airborne data or optical satellite data such as ASTER 2. YES – Any suitable scale elevation model and optical imagery such as SRTM/LiDAR and ASTER, SPOT, GeoEye 3. YES – SRTM, LiDAR or elevation derived from stereo airborne photography or satellite imagery such as ASTER 4. YES – SRTM, LiDAR or elevation derived from stereo airborne photography or satellite imagery such as ASTER

Table 7: Environmental Indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

Causes	Environmental Issues	Indicators	Parameters	Potential for remote sensing assessment
Windblown coal dust, gaseous emissions	**Atmospheric pollution** **Risk of explosion due to ground gases**	DIRECT • Air-suspended particulated matter • Gaseous emission • Vegetation burns/ stress • Accelerated building stone weathering INDIRECT • Proximity of blast zones • Proximity to unmetalled haulage routes • Distribution of spoil heaps • Location of coal washing plant •	1. Atmospheric dust and gases 2. Air quality 3. Cloud formation? 4. Vegetation stress	1. YES – Hyperspectral airborne data, if the particulates are of a suitable size / concentration and the concentration of gases can be distinguished from background levels (not all gases can be measured from remote sensing) 2. Airborne monitoring of air quality is possible from airborne hyperspectral imagers but it is dependent on many factors such as wind speeds. 3. YES – hyperspectral airborne and satellite e.g. MODIS 4. YES - Hyperspectral airborne data, multispectral satellite e.g. ASTER
Dewatering AMD Land degredation / loss	**Ecological diversity**	DIRECT • Reduced numbers of species • Reduced populations of species INDIRECT • Water quality and quantity • Water temperature • Ground contamination (direct or by dust	1. Species monitoring 2. Extent of surface waters (stream maps) 3. Temperature of surface waters 4. Habitat mapping and monitoring	1. YES – Hyperspectral airborne data – although direct measurements would be more accurate 2. YES – hyperspectral airborne and high spatial resolution IR satellite 3. YES – airborne thermal 4. YES – Hyperspectral airborne and high spatial resolution multispectral satellite

Table 8 (continued): Environmental Indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

Causes	Environmental Issues	Indicators	Parameters	Potential for remote sensing assessment
Mining AMD	**Land degradation/land loss**	DIRECT • Land use monitoring INDIRECT • Waste volume • Recultivation success in reclaimed areas	1. Vegetation stress 2. Land use mapping 3. Waste mapping 4. Deposit characteristics – coal to overburden ratio	1.YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 2.YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 3.YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 4.YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion; dependant on vegetation cover
Mining Ground gases AMD	**Vegetation stress**	• Vegetation stress • Health and extent of vegetation types	1. Vegetation monitoring 2. Habitat mapping	1. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 2. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion
Self-combustion of pyrite	**Coal fires**	• Coal fires in active/ closed opencast/ mines • Coal fires in spoil heaps	1. Temperature 2. Gas emissions	1.YES – airborne thermal and satellite thermal e.g. ASTER, Landsat 2.YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion
Dewatering	**Groundwater drawdown**	• Water table • Draining of vadose zone- soil desiccation • Subsidence	1. Water table monitoring 2. Soil moisture content 3. Ground levels	1. YES – ground network 2. YES – satellite e.g. SMOS, CHRIS/PROBA 3. YES – Airborne LiDAR, and stereo aerial photogrammetry, satellite InSAR

Underground mining	**Sinkholes**	DIRECT • Subsidence INDIRECT • Rock mass classifications	• Ground levels	• Yes : Airborne LiDAR, and stereo aerial photogrammetry, satellite InSAR
Overburden instability	**Landslide**	• Subsidence, slope instability	1. Slope Monitoring 2. Moisture content	1. LiDAR or elevation derived from stereo airborne photography or scale-dependent satellite imagery such as ASTER 2. Yes – satellite e.g. SMOS, CHRIS/PROBA
Tailings instability	**Slope failure**	• Subsidence, slope instability	1. Slope 2. Moisture content	1. LiDAR or elevation derived from stereo airborne photography or scale-dependent satellite imagery such as ASTER 2. Yes – satellite e.g. SMOS, CHRIS/PROBA

Table 9 (continued): Environmental Indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

Causes	Socio-economic Issues	Indicators	Parameters	Potential for remote sensing assessment
AMD	**Ground and Surface Water Quality and Quantity – Unreasonable use of water resources**	DIRECT • Ecological impacts • Lowering of groundwater levels/ reduced stream flow	1. Distribution of sulphate salts 2. Surface drainage map 3. Groundwater table depth and flow direction 4. Topographic maps 5. Maps of abandoned mines	1. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 2. YES – SRTM, LiDAR or multispectral satellite e.g.ASTER 3. Yes : ground network 4. YES – Any suitable scale elevation model such as SRTM/LiDAR and optical imagery such as ASTER, SPOT, GeoEye 5. YES – Hyperspectral or thermal airborne data.
		INDIRECT • Acid mine drainage potential • AMD source proximity to water receptors • Cessation of pumping • Subsidence		
Sediment loading		DIRECT • Sediment load in watercourses •	1. Water turbidity 2. Topographic maps 3. Slope gradient 4. Surface drainage map	1. YES – hyperspectral airborne data or optical satellite data such as ASTER YES – Any suitable scale elevation model and optical imagery such as SRTM/LiDAR and ASTER, SPOT, GeoEye 2. YES – SRTM, LiDAR or elevation derived from stereo airborne photography or satellite imagery such as ASTER 3. YES – SRTM, LiDAR or ASTER
		INDIRECT • Erosion potential of dumps • Sediment load source proximity to water receptors		

Table 10: Socio-economic indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

Causes	Socio-economic Issues	Indicators	Parameters	Potential for remote sensing assessment
Windblown coal dust, gaseous emissions	**Atmospheric pollution – impacts on the health of residents/ workers**	DIRECT • Air-suspended particulated matter • Gaseous emission • Vegetation burns/ stress • Accelerated building stone weathering INDIRECT • Proximity of blast zones • Proximity to unmetalled haulage routes • Distribution of spoil heaps • Location of coal washing plant • Health of workers • Health of population	1. Atmospheric dust and gases 2. Air quality 3. Cloud formation? 4. Vegetation stress 5. Poor ventilation of mine workings	1. Hyperspectral airborne data, if the particulates are of a suitable size / concentration and the concentration of gases can be distinguished from background levels (not all gases can be measured from remote sensing). 2. Airborne monitoring of air quality is possible from airborne hyperspectral imagers but it is dependent on many factors such as wind speeds 3. YES – hyperspectral airborne and multispectral satellite e.g. MODIS 4. Hyperspectral airborne data, multispectral satellites such as ASTER 5. N/A with remote sensing
Population migration	**Economic vulnerability**	DIRECT • Density/ size of settlements • Mining company investment in the community INDIRECT • Extent of built environment	1. Population monitoring 2. Land use monitoring 3. Monitoring the quality of sprawl development	1. YES – size of urban areas can be monitored using airborne photography and hyperspectral or multispectral satellite e.g. SPOT or active satellite e.g. TerraSAR-X 2. YES – Hyperspectral airborne data, and higher resolution satellite data such as ASTER 3. YES – size of urban areas can be monitored using airborne photography and hyperspectral or multispectral satellite e.g. SPOT or active satellite e.g. TerraSAR-X; direct measurements will provide more accurate information

Table 11 (continued): Socio-economic indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

Causes	Socio-economic Issues	Indicators	Parameters	Potential for remote sensing assessment
Mining AMD	**Land degradation/ land loss – Food Security**	DIRECT • Land use monitoring INDIRECT • Waste volume • Recultivation success in reclaimed areas	1. Agricultural vegetation stress 2. Land use mapping 3. Monitoring remediation 4. Waste mapping 5. Deposit characteristics – coal to overburden ratio	1. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 2. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 3. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion supplemented by in situ observations 4. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion 5. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion if the deposits are exposed on the surface
Mining Ground gases AMD	**Health vulnerability – workers and residents**	• Health of the population • Mining company investment in health issues • Working conditions	• Health statistics	• Direct
Mining/ Poor regulation	**Illegal mining**	• Health and Safety • Land value • Combustion • Sinkholes • Groundwater quality	• Land use monitoring and comparison with maps of licensed mining operations	• YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion although direct measurements would be more accurate

Table 12 (continued): Socio-economic indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

Causes	Socio-economic Issues	Indicators	Parameters	Potential for remote sensing assessment
Self-combustion of pyrite	**Coal fires – particular risk in the context of illegal mining**	• Coal fires in active/ closed opencast/ mines • Coal fires in spoil heaps	1. Temperature 2. Gas emissions	1. YES – airborne thermal and satellites with thermal bands e.g. ASTER, Landsat 2. YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion, although direct measurements are more accurate
Mining Blasting Subsidence	**Infrastructure damage**	• Leaking pipes • Damaged roads	1. Topography – subsidence in urban areas 2. Traffic monitoring	1. Radar Interferometry 2. Direct observation is more timely although airborne photography / imagery can be utilised
Industry and services	**Non-coal impacts due to associated industry**	• Environmental • Demands on water resources • Benefits of employment	• Land use monitoring	• YES – Hyperspectral airborne data, multispectral satellite e.g. ASTER or Hyperion

Table 13 (continued): Socio-economic indicators and their potential for EO assessment. The remote sensing datasets listed in the assessment column is a theoretical list of possible remote sensing types that will be refined during the project.

12. Additional sources of information

1. Coaltech 2020, is a joint research programme that includes the major coal companies, universities, the CSIR, the National Union of Mineworkers and the State to address the specific needs of the coal mining industry in South Africa with a particular focus on technological development.

2. Council for Scientific and Industrial Research/ South African University collaboratively funded multi-disciplinary catchment based study of the upper Olifants River and its tributaries that is being led by Dr Paul Oberholster :(http://www.engineeringnews.co.za/article/olifants-river-study-under-way-to-identify-potential-stressors-2010-03-15).

3. (Ashton et al., 2001) present tables of the mining operations in each of the catchments. Table 5.5 details the operations in the Riet and Little Olifants sub-catchments. The details for Bank (Code number E7-2) suggest that it is a medium size concern with a medium to high impact.

4. Mpumalanga Groundwater MasterPlan, DWAF)

5. Information on mining related research in South Africa can be accessed via: http://www.google.co.uk/url?url=http://www.pmg.org.za/files/docs/110621wrc.doc&rct=j&sa=U&ei=53OETtILgpvUBY7DwO8P&ved=0CA8QFjAA&q=MOLWANTA+JB+ET+AL+2010+Monitoring+evaluation+and+verificatio+of+long+term+performance+of+the+passive+water+treatment+plant+at+Vryheid+Coronation+cOLLIERY+Report+1623/1/10&usg=AFQjCNFO39MUe1a-7joxyViir7qKuY1bZw

and

http://www.wrc.org.za/Pages/KH_DocumentsList.aspx?dt=1&su=28&ct=7&ms=4;17;

where a series of research reports can be located.

13. Missing data

a) Regional

i) Details of the planning regime and data held, e.g. abandoned mine records, planning applications for new or secondary mining

- Monitoring of acid mine drainage (ph, colour, chemical composition)
- Mining Wastes typology
- Mining installations footprint
- Air plume (coal burning, stacks)
- Dust emissions, geographical dispersion, and deposition
- Rehabilitation progress during mine operation and post closure
- Subsidence/sink holes evolution/ wastes stability
- Traffic routes
- Discharge of solids in the water surface network
- Distinguish the different emissions (industry / mining)
- Information on sinkholes, roads, populated areas
- Mining permits and applications
- Municipality Spatial Development plans

ii) Ecological information – sources, monitoring data

- Monitoring of swamps and humid areas
- Forest characteristics and changes (conifers, broad leaved trees ratio for example), health of the different species
- Monitoring of the encroachment of protected areas
- Surface water network evolution
- Groundwater depth monitoring
- Eutrophication of lakes Wetlands/ pans delineation from satellite images

- Delineation of original river beds, pre-pan development, in order to determine the zone of impact of mining on the water resources from satellite images
- Tributaries of the Olifants river where export quality agriculture occurs downstream
- Information on sinkholes, roads, populated areas
- Nature reserves and other sensitive areas
- Decant points/ current and potential
- Mining permits and applications
- Agriculture activities (food security/no of farm workers etc)
- Municipality Spatial Development plans
- Position of sinkholes, etc.
- Geology
- Markets

iii) Geographical information: distribution of rivers, people

- Agriculture typology
- Land use changes
- Artisanal mining development
- Flooding
- Groundwater supply and minerals water protection
- Housing, illegal development =impact on local communities
- Wetlands/ pans delineation from satellite images
- Delineation of original river beds, pre-pan development, in order to determine the zone of impact of mining on the water resources from satellite images
- Tributaries of the Olifants River where export quality agriculture occurs downstream
- Decant points/ current and potential
- Agriculture activities (food security/no of farm workers etc)

- Markets

b) Site specific

i) Operational working plans

ii) Mine waste management plans/ Tailings lagoons, design, stability

iii) Remediation plans

iv) Coal handling and storage procedures

v) Shaft locations

vi) Geotechnical data – rock types, strength, fracture patterns (for consideration of subsidence)

vii) Any monitoring requirement and outputs

viii) Detail of any dewatering

14. Additional Potential work for an Earth Observatory

The following suggestions arise from consideration of the conceptual models. Many may be precluded on technical or cost grounds.

- Remote sensing of collapsed mines i.e. associated subsidence features/ hollows/depressions. This could include radar interferometry

- Use of thermal imagery with a potential for identifying areas of combustion.

- Monitoring of power station emissions might be considered in the context of the potential for acid rain generation.

- It is evident from the photographs of the Bank Dump that the climatic conditions are such that the increased salinity arising from mining activity gives rise to efflorescent salts, the extent of which could be monitored within the context of the Earth Observatory.

- Where evidence of eutrophication can be determined from algal growth in water courses, it may be possible to monitor this in the context of the Earth Observatory.

- Similarly, areas where the ecology of surface waters has been depleted (vegetation die-back) may be evident in the context of the Earth Observatory.

- It may also be feasible to monitor specific, more sensitive water bodies, e.g. the lake district and wetland springs.

- AMD is commonly associated with iron brown staining (derived from the mobilisation of iron), which lends itself to monitoring. Alternatively, or in conjunction with this, it might be possible to monitor stream sediment loads.

- The extent of agricultural land, land dereliction and population migration (based on location of settlements) lend themselves to monitoring in the context of the Earth Observatory.

- Infrastructure monitoring in mine impacted areas?

- Consideration could be given to further monitoring of the Bank Dump plume in order to calibrate the ALERT system to provide quantitative data with respect to contaminant concentrations.

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