EVALUATING THE IMPACT OF RECENT REHABILITATION GUIDELINES ON OPENCAST COAL MINE REHABILITATION IN MPUMALANGA

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

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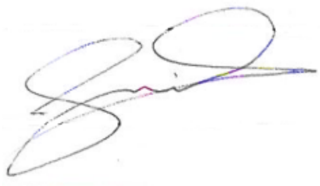
DECLARATION

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



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ABSTRACT

Mine rehabilitation and closure in South Africa are challenged by continuous changes to environmental and financial provision legislation as the “what to” do to sufficiently reduce the impacts of mining. These are met with much resistance from mining houses. Opinions of industry professionals suggested ways to achieve successful mine closure of which most were aimed at the mechanisms of “how to” achieve it. Encompassing “how to” guidelines for rehabilitation have been in existence since 2007 and since 1981 for opencast coal mining in South Africa.

A case study was conducted on 15 opencast coal mines in Mpumalanga, South Africa to determine the relationship between guideline compliance and rehabilitation success. A qualitative assessment, based on questionnaires and multi-criteria decision analysis, was performed to compare guideline compliance for the various mines. Mines were subsequently ranked from least to best compliant. Overall rehabilitation success depends on the success of the first building blocks of rehabilitation implementation namely landform and soil reconstruction. An analytic geometry mathematical model was developed with key dimensions and areas of mine features used as input to quantitatively assess rehabilitation success of landform and soil reconstruction. The success results of each mine were plotted against their compliance ratings to produce linear trendlines for landform development, soil reconstruction and as a combination of both. The sensitivity of input variables was analysed for 22 scenarios. Trendline slopes of all the scenarios were convincingly positive indicating that better compliance yields increased rehabilitation success.

It was concluded that the current status of rehabilitation could have been vastly different if the long existing “how to” do rehabilitation guidelines were followed. The benefits of applying the guidelines to existing and new mining areas are not only limited to increased rehabilitation success; it will also shape the nature and probably reduce the aggressiveness of future changes to legislation.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation/Acronym	Explanation
Guidelines	Guidelines for the Rehabilitation of Mined Land
EMP	Environmental Management Plan
MPRDA	Mineral and Petroleum Resources Development Act (Act 28 of 2002)
NEMA	National Environment Management Act (Act 107 of 1998)
EIA	Environmental Impact Assessment
Soil shaping	Landform recreation
The Guidelines' four categories of success criteria as the general building blocks of the rehabilitation objectives	
LSC	Landform and soil cover
Veg	Vegetation
WQ	Surface and ground water qualities
RLR	Residual and latent risks
P	Primary theme
S	Secondary theme
Questionnaire definitions	
RPs	rehabilitation practitioners
MPs	mining engineers/planner
Guidelines compliance ranking section	
MCDA	Multi-criteria decision analysis
AHP	Analytical hierarchy process

1 INTRODUCTION

The aim of environmental legislation in South Africa, related to mining, is to provide a basis of what needs to be done to sufficiently reduce the impacts and hence allow for successful ownership transfer of mined areas. The heart of rehabilitation and closure requirements are set out in three acts namely: The Constitution (Act 108 of 1996); The Mineral and Petroleum Development Act (Act 28 of 2002); and The National Environmental Management Act (Act 107 of 1198). In addition to these acts, the National Water Act also makes specific reference to closure related measures that requires approval by the Department of Water and Sanitation before a closure certificate can be issued. These acts require the necessary permissions to be obtained to mine that are underpinned by the identification of consequential impacts and development of the associated remediation or prevention management systems and mechanisms. While the legislative and competent authorities sit with the Department of Environmental Affairs and the Department of Mineral Resources respectively, they are not the only authorities liable to be involved in rehabilitation and closure.

The first statutory requirement to rehabilitate areas affected by mining activities was the Minerals Act, promulgated in 1991. The need for mine rehabilitation was however considered prior to this but as a self-motivated action by mining companies (Limpitlaw, *et al*., 1997). This need resulted in the development of rehabilitation guidelines by the Chamber of Mines as far back as 1981. Not long after the promulgation of the Mineral and Petroleum Act, the same set of guidelines were updated by the Coaltech Research Association and the Chamber of Mines and is now known as the Guidelines for the Rehabilitation of Mined Land (Guidelines). The guidelines of 1981 were refined with up-to-date knowledge and expanded to cover rehabilitation from the mine planning phase to post-closure for surface and underground mines. The aim of the Guidelines was to provide assistance on how to practically achieve the rehabilitation objectives set out by legislation.

As knowledge of mining impacts, failed rehabilitation attempts and residual risks become evident and widely known, it is understandable that there was and still is pressure from society and industries to stop and remediate these impacts. The government, on the other hand, has a constitutional obligation to provide the people with an environment that is not harmful to health and well-being. They are also becoming more wary of the uncertain liabilities as custodian recipients of mined land post-closure. Because of this, there is a need to force the mining sector to leave a sustainable environmental legacy with at least the same value as it had before and hence the rapid changes in legislation.

Mine rehabilitation and closure in South Africa are however challenged by periodic changes to environmental and financial provision legislation. The changes are becoming more stringent and the rate of change is also increasing. Some of these changes, for example the promulgation of Government Notice R1147, places an onerous task on the mining sector to firstly interpret new regulations and then to comply within short timeframe constraints. The rapid changes are further riddled with contradictions and often regulated by authorities operating outside of their competence regime while the number of government departments involved in mine closure also creates its own set of problems. The highly dynamic legislation regime is, not surprisingly, met with much resistance by mining houses (Gore & Pienaar, 2018; Milaras *et al*., 2014; Department of Environmental Affairs and Tourism, 2004).

The environmental impacts of mining and rehabilitation efforts and outcomes were reviewed and are described in more detail in the literature review. The impact potential of surface mining is second only to urbanisation (Thompson, 2005). Altered landscapes, changed land use, reduced land capability and air and water pollution are all current consequences of mining. Mine rehabilitation in general aims to address these impacts sufficiently to re-establish ecological value, leave a post-closure scenario that is acceptable to society and aid land transfer to government or third parties. Rehabilitation efforts of specifically opencast coal mines around the world, including South Africa, have however been largely unsuccessful as shown later in the study. While many mine-sites exist that have officially been accepted as rehabilitated, the post-mining land capability was found to be unacceptably low, environmental pollution unacceptably high and the longevity of the overall efforts have failed. Poor rehabilitation approach and practices related to post-mining landform development and soil reconstruction were cited (later in this report) as the predominant causes of unsuccessful rehabilitation.

Recent opinions of industry professionals suggested ways to achieve successful mine closure of which most were aimed at the practical mechanisms of how to achieve it with very little focus on additional changes to legislation that may be required (Milaras, *et al*., 2014). This is surprising as encompassing guidelines for practical rehabilitation implementation, the Guidelines, have been in existence since 2007 and since 1981 for opencast coal mining in South Africa. The current rehabilitation legislation cycle is summarised on a high level by the author in Figure 1.

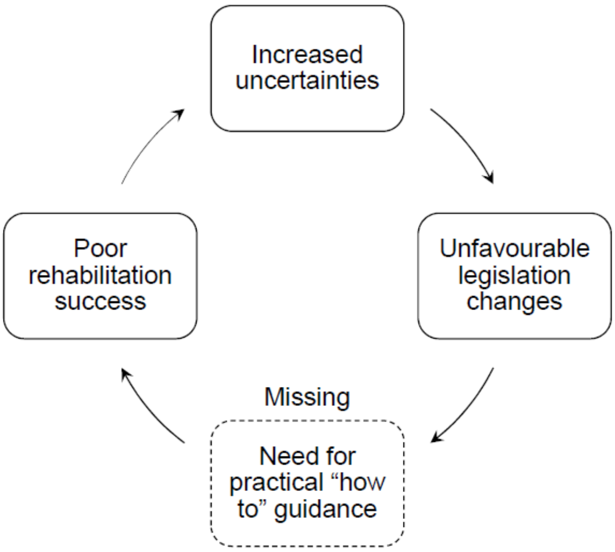


Figure 1 High level summary schematic by the author of the current rehabilitation legislation cycle

The author is a participant observer and actively involved in mine closure, specifically in opencast coal mining. Work related discussions with approximately 15 rehabilitation practitioners and mining engineers regarding their current topsoil management practices, rehabilitation of final voids and how rehabilitation costs were determined to inform mine planning and feasibility, revealed the following:

- Topsoil placement is guided by the depth stated in the Environmental Management Plan (EMP). No mention was made to achieve and be able to demonstrate the required land use as stated in the EMP;
- A general perception was that there was not enough topsoil on the mine to achieve the required placement depth;
- Final voids and ramps will be backfilled with the box cut material. In most cases it was noted that the box cut material was not enough, was located too far from

where it was required or had been used to backfill other areas. In one instance a mine developed a materials balance and post mining landform to use as part of concurrent rehabilitation, but it was not followed;

- A response by most of the mining engineers was the requirement to backfill to pre-mining landform elevations;
- The approach to determine and consider rehabilitation costs as part of mine planning varied as follows:
  - No allowance was made during planning but there was acknowledgement that it was necessary;
  - A standard cost per hectare was allowed for, although in general it could not be stated how the cost was determined; and
  - Rehabilitation costs are understood to be made up of the backfill of the final void and ramps while concurrent rehabilitation is considered to be an operational cost. The box cut volume and haul distance to the final location is used to determine rehabilitation costs and was added to the unit cost for run-of-mine coal mining.
- The discussions consistently concluded that the mines are left with voids that cannot be rehabilitated as well as having topsoil deficits.

Adhering to any rehabilitation guidelines were hardly ever mentioned and their practices suggest that guidelines were not being used extensively. In some cases, senior management was not even aware of the Guidelines. The lack of a consistent and accurate approach to consider site specific rehabilitation costs would suggest that mine planners did not consider rehabilitation in sufficient detail as is recommended in the Guidelines.

It is concluded that all stakeholders were aware and recognises that historical and current rehabilitation efforts are not yielding the necessary results. Authorities try to overcome this by continuously changing legislation while industry professionals suggest that there is a need to focus on the practical aspects of rehabilitation which is exactly the aim of the Guidelines. This poses the question whether the Guidelines, as it is, adds any value to rehabilitation success.

1.1 Study Rationale and research objectives

The bulk of the information contained in the Guidelines consists of attainable technologies or science. The information is not new and straight forward. If it doesn't add value, the lack of value-adding guidelines can be the cause of substandard rehabilitation practices. This consequently sets the scene for ongoing changes in legislation as authorities and mining houses alike are struggling to find a set of practical implementation rules that will result in the desired outcomes. The aim of the research is therefore:

> "To assess whether the degree of compliance to the Guidelines for the Rehabilitation of Mined Land adds any value to rehabilitation success or failure which ultimately determines the nature of legislation."

Therefore, the key questions are:

1. What is the status of current rehabilitation practices and does it provide enough detail to assess comparative guideline compliance between different mines; and
2. How do rehabilitation outcomes differ for mines that follow or don't follow rehabilitation guidelines?

From the key question the following two objectives were formulated to assess the research aim:

1. Evaluate the extent to which the Guidelines are being followed; and
2. Determine if there is any relationship between rehabilitation success and the extent to which the Guidelines are being followed.

1.2 Layout of Report

Section 2 outlines the literature review that consists of primarily of five sections. The first three are presented as standalone sections as follows:

- An explanation of the opencast coal mining methodology is provided as a basis to assess rehabilitation success. Impacts of opencast coal mining is reviewed and the significance of the study area is explained.

- The current status of rehabilitation outcomes is reviewed and synthesized to identify the shortcomings of rehabilitation;
- Changes to rehabilitation and closure legislation are discussed and leads into a sub-section explaining the need for rehabilitation guidelines. The Guidelines are reviewed, and specific sections are discussed in more detail to provide context to inform the research.

They each provide a background to substantiate the chosen methodology and overall hypothesis. The fourth section summarizes the Guidelines and provide a view of the validity thereof. The fifth section offers a conclusion of the literature review.

Section 2.5 explains the research methodology and how the set objectives were achieved. It specifically elaborates on how the case studies of opencast coal mines were performed to compare guideline compliance and determine the relationship between guideline compliance and rehabilitation success. The sensitivity analysis methodology is also discussed.

Section 4 shows the success results of each mine in terms of landform development, soil reconstruction, a combination of both and how they were plotted against their compliance ratings to produce linear trendlines for each of the three situations. The sensitivity analysis results of input variables for 22 scenarios are also shown. The results are interpreted and discussed throughout the section.

Section 5 and 6 concludes the research findings and suggests further research.

2 LITERATURE REVIEW

To achieve the aim and objectives of the research study an understanding of four main categories were required. A literature review was done to consider each of the categories, firstly to establish the process and impacts of opencast coal mining. The current status of rehabilitation and the focus areas of rehabilitation shortcomings were then reviewed as the second category. The third category includes an overview of the legislative framework that defines the processes that are to be followed in order to establish what the objectives are that need to be achieved as part of rehabilitation. Context around the content and purpose the Guidelines are then provided as the practical implementation tool on how to achieve the rehabilitation objectives. The final category compared the current status of rehabilitation and focus areas of rehabilitation shortcomings with the focus areas of the Guidelines to review whether it addresses the issues of today and can still be considered as relevant.

2.1 Opencast coal mining and impacts

2.1.1 The future and building blocks of opencast mining

In this section the future of global coal mining, coal mining in South Africa and specifically opencast coal mining were reviewed. The opencast coal mining process that is typically followed in Mpumalanga was also reviewed to demonstrate how similar mining techniques are used to form a basis to compare the individual case studies in a consistent manner. A section is specifically dedicated to providing context of the various steps of opencast mining. It is fundamental to demonstrate this understanding as it is forming the core of the mathematical model that was developed to determine rehabilitation volume requirements.

Rutledge estimated the global total coal production based on curve fits of production history. The total future production was concluded to be 690 Gt of which 90% would have been mined out by 2070 (Rutledge, 2011). More recent studies based on current proven coal reserves shows sufficient quantities to meet global demand for the next 134 years (BP, 2018) and goes to 150 years as estimated by the World Coal Association (World Coal Association, 2019).

The 19 coal fields of South Africa are shown on Figure 2 of which 10 are actively producing coal. In 2017, the 25 active coal mines were owned by seven mining companies (superimposed as red dots in the same figure). The Witbank and Highveld coalfields contains 21 of the active collieries and is owned by six of the seven mining companies (Minerals Council South Africa, 2017).

The Witbank, Highveld and Waterberg coalfields contains approximately 70% of the total coal compliment of South Africa. The Witbank and Highveld areas are considered to be reaching the end of its recoverable coal reserves with an estimated 9 billion tonnes in each as at 2005 (Jeffrey, 2005; Chabedi & Zvarivadza, 2016). Based on the average run of mine production between 1982 to 2000 for Witbank (2320.3 Mt) and Highveld (972.49 Mt) (Jeffrey, 2005) it is estimated that coal mining will continue to 2036 and 2079 for these areas respectively.

The Waterberg coalfield is characterised by multiple coal zones and seams that are for the most part, deeper than 250 meters below the surface. The relatively shallower coal (up to 110 meters deep and 60 meters thick) between the Daarby and Eenzaamheid faults poses various challenges of its own (Chabedi & Zvarivadza, 2016) and is unlikely to follow conventional mining techniques. Coal mining in Waterberg is relatively new with the only notable colliery being Grootegeluk mine, situated in the shallower coal areas, that can be described as a hybrid between open pit and strip mining. Chabedi and Zvarivadza (2016) investigated the feasibility to mine the deeper coal of the Waterberg by underground mining methods and identified two zones that could potentially be mined by longwall mining in a feasible manner. It is noted that coal mining in the Waterberg coalfield has a unique set of challenges due to the depth and thickness of the coal seams. The impact on the current land capability of the area will be significantly less should underground mining methods be applied compared to surface mining methods which is unlikely to happen in the foreseeable future with current technology.

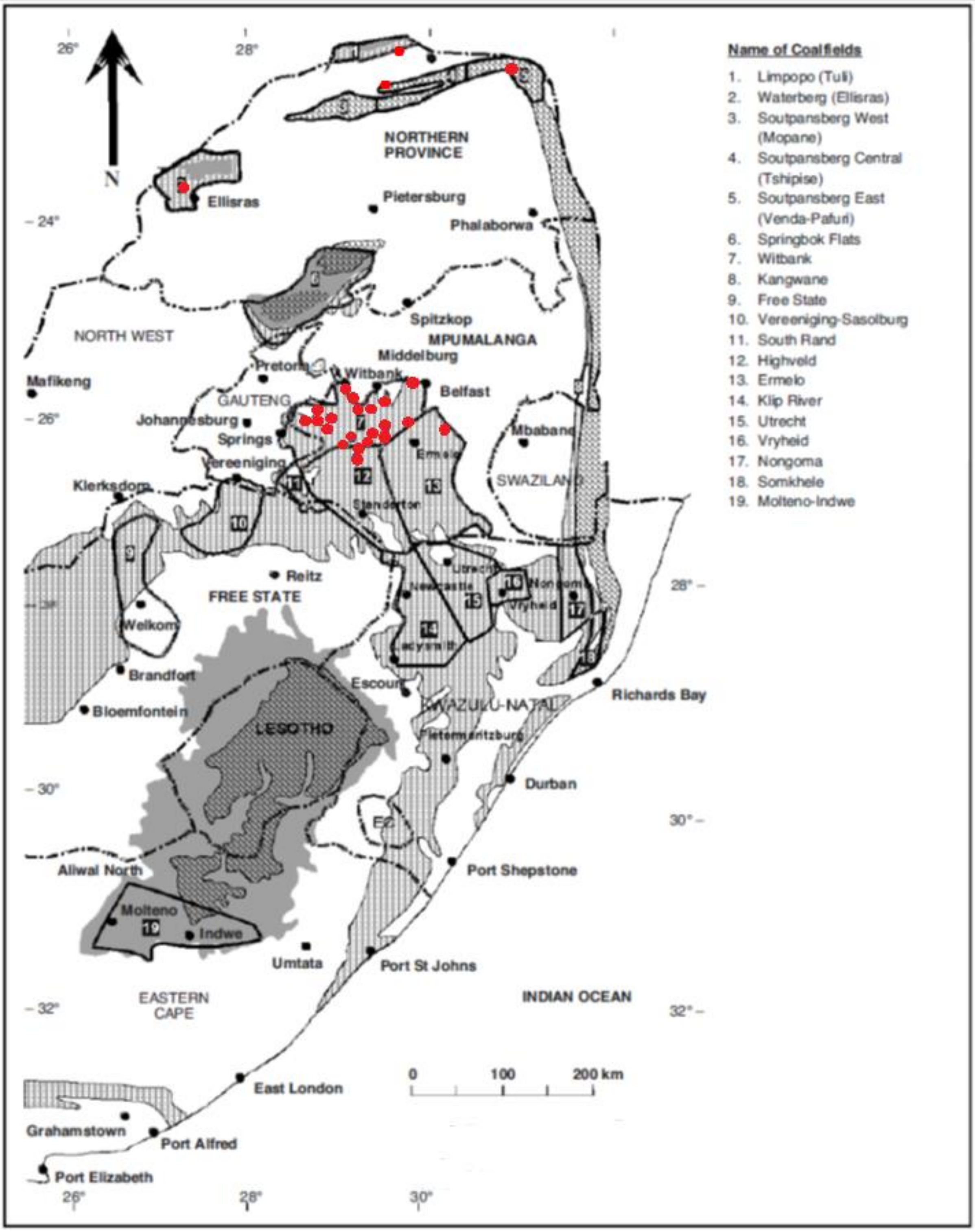


Figure 2: Coal fields of South Africa (Jeffrey, 2005) superimposed with active collieries (red dots) in 2017

The northern boundary of the Witbank coalfields stretches roughly from Springs, Emalahleni, Middelburg to Belfast. The southern boundary is approximately 50km further south and is defined by the pre-Karoo felsite contact known as the Smithfield ridge. Directly south lies the Highveld coalfield that is located between Nigel in the west and Davel in the east and stretches approximately 90km north to south. The Witbank and Highveld coalfields are the two largest producing coal fields in South Africa (XMP Consulting CC, 2010) with surface areas covering 568 000ha and 700 000ha respectively (Hancox & Gotz, 2014).

The Witbank and Highveld coalfields consist predominantly of five coal seams named 1,2,3,4 and 5 Seam in order from deep to shallow (Figure 3). The coal seams in the Highveld coalfield are between 0 m and 300 m deep while the Witbank coalfield is shallower. In general, the 2 and 4 seams are most abundant and mined for export and domestic thermal coal respectively. The 1 seam is occasionally mined for export steam coal and the 5 seam for coking and metallurgical coal where sufficient quantities and qualities are present. The 3 seam varies from high to low quality in thin and sometimes discontinuous layers that makes extraction uneconomical (Jeffrey, 2005).

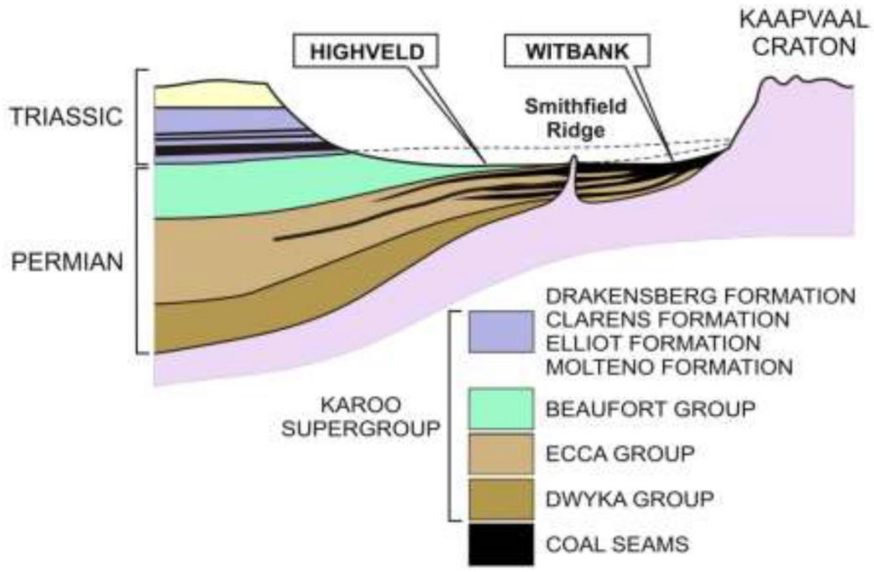


Figure 3: Schematic cross-section of the Witbank and Highveld coalfields (Hancox & Gotz, 2014)

The area has been mined for over 100 years with three mining methods namely bord and pillar, longwall and opencast mining (McCarthy & Pretorius, 2009). Bord and pillar was historically used until longwall mining was introduced during the later stages of the 1970’s and throughout the 1980’s. This method was however not utilised extensively (Banks, Palumbo-Roe, van Tonder, Davies, Fleming & Chevrel, 2011) and strip mining became the mining method of choice since the 1970's (Limpitlaw, *et al*.,1997). Just over half of the national production is now done with surface mining methods (Universal Coal, 2017) that includes the mining of many of the remaining pillars previously mined by the bord and pillar method.

According to the Surface Strip Coal Mining Handbook by the South African Colliery Managers Association (Mining Handbook) most of the shallow coal seams in south Africa can be exploited by opencast mining (Thompson, 2005) and is most commonly used in the study area. The method is described in the Mining Handbook under the headings of surface preparation, drilling and blasting, overburden removal, loading and haulage of the mined deposit and rehabilitation and is summarised in the following paragraphs. Reference is also made to Figure 4 that depicts the sequence of typical strip mining. As the name suggests, mining is sequentially done in strips or cuts. In Figure 4 the direction of mining is from A to N while the sequence of surface preparation to a rehabilitated landform is in the opposite direction.

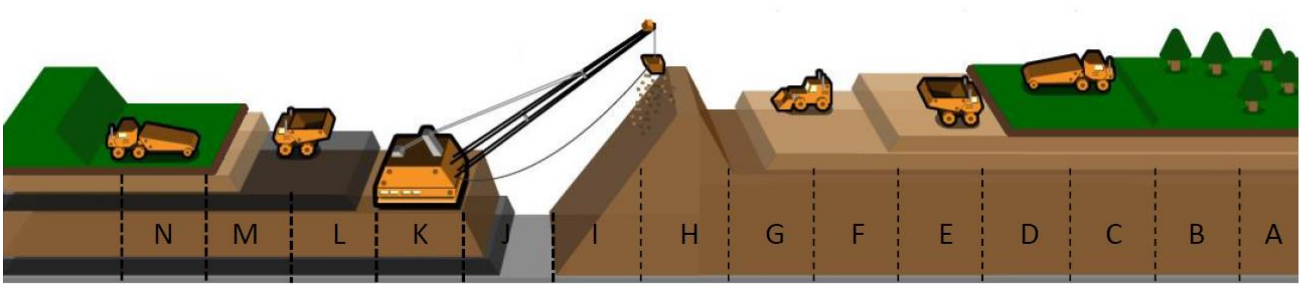


Figure 4: Strip mining method sequence by (Herigemblong, 2018) with strip information added

Virgin areas need to be cleared from infrastructure and vegetation to prepare the surface for mining. It is required by law to re-use the topsoil as growth medium and stripping needs to be done in such a way as to accommodate this. The definition for topsoil can vary but is generally considered to be the upper soil layers to the depth of root penetration of pre-mined vegetation. The predominant soil layers are defined as horizons namely A, B and C. Each of the horizons have distinct properties such as organic material content, clay content and relative presence or absence of biological activity (Soil Science Society of America, nd).

Once the topsoil has been removed access is provided to remove the overburden in order to expose the coal. Overburden removal includes free-digging or drilling and blasting and is removed by dragline or by load and haul with truck and shovel methods. This is also considered as one of most important aspects of opencast mining and requires rigorous planning to achieve the required production rates as cost effectively as possible. Figure 4 shows overburden removal by means of a dragline that is stationed at strip K and moves overburden from strips M-L to I-H. The exposed coal is usually loaded into haul trucks with a type of loading shovel which is determined by the mining method, coal geology and other production and equipment constraints.

Rehabilitation is considered to start at the placement of the removed overburden (strip H) and suggests that placement at the final backfill location is the most cost-effective. Additional backfilling steps may be required to promote surface stabilisation, compaction, water quality maintenance or spoil sealing purposes. Shaping of the backfilled spoils is then required to achieve a profile that suits the post-mining land capability. Amelioration actions like ripping, fertilising, mulching and adding lime may be required to prepare the landform to receive topsoil. This is followed by the placement of topsoil and eventually revegetation (strip A and B). A final note in the Handbook states that closure will be achieved when the criteria as defined in the environmental management program report, have been met in order to minimise the impact on health, safety and the environment.

Thompson (2005) describes the key driver in any mining operation as to extract the mineral deposit as cost effectively as possible which is largely determined by the mining method that is chosen for the specific mineral deposit. Following the mining method selection decision, the next step is to determine the most suitable position for the box-cut and cut direction. The capital layout to start any opencast mine is significant, the location of the box-cut is therefore vital to allow for production to start as soon as possible for cash flow and economic reasons. In general, this is achieved by locating the box-cut at the shallowest end of the coal seam with a parallel cut orientation to the strike coal seam proceeding in a down-dip direction. The box-cut is therefore relatively small which also contributes to a smaller volume and footprint of waste material to be stockpiled. This approach (1) as well as the other three primary

(2,3,4) box-cut positions are indicated in Figure 5.

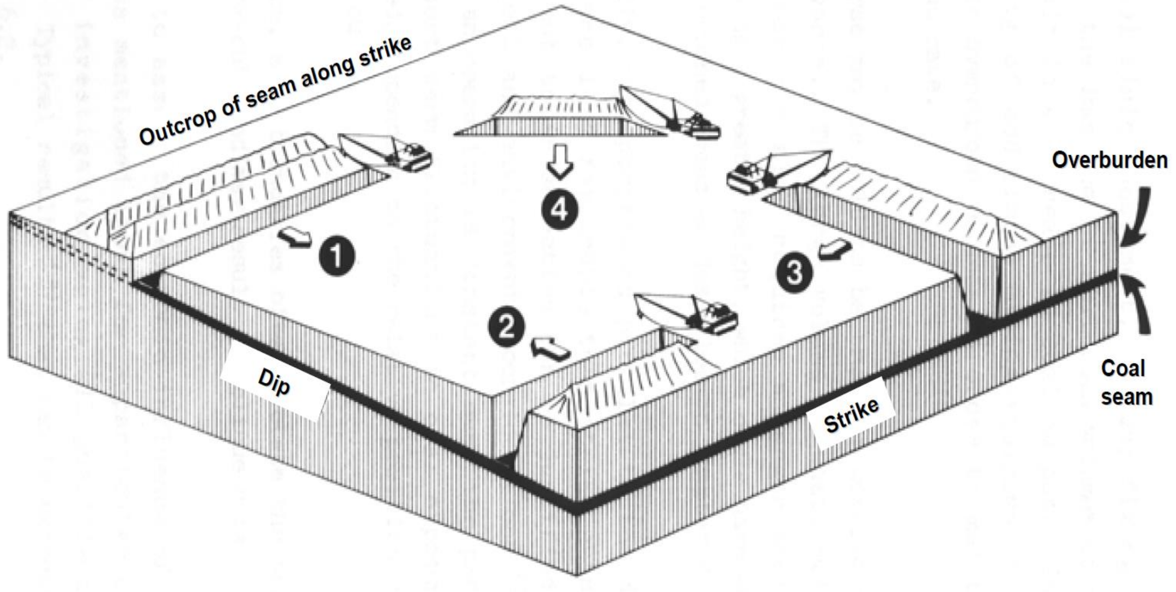


Figure 5: Primary box-cut orientations for strip mining operations (Walton & Atkinson, 1978)

Box-cut positions are informed by various factors such as cash flow requirements, mining rights boundaries, required rate of production, plant availability over the life of mine and geotechnical considerations. All four approaches have their advantages and disadvantages however any of them could be the optimal choice given the site-specific conditions of the mineral deposit. The handbook provides typical cash flows (Figure 6), based on the work done by Atkinson (SME, 1992), for various box-cut positions over the life of mine of a coal deposit that is also typical Highveld and Witbank coalfields. The strike cut with a down-dip advance is shown to recover the capital layout cost the quickest as well as having the highest total return on the investment.

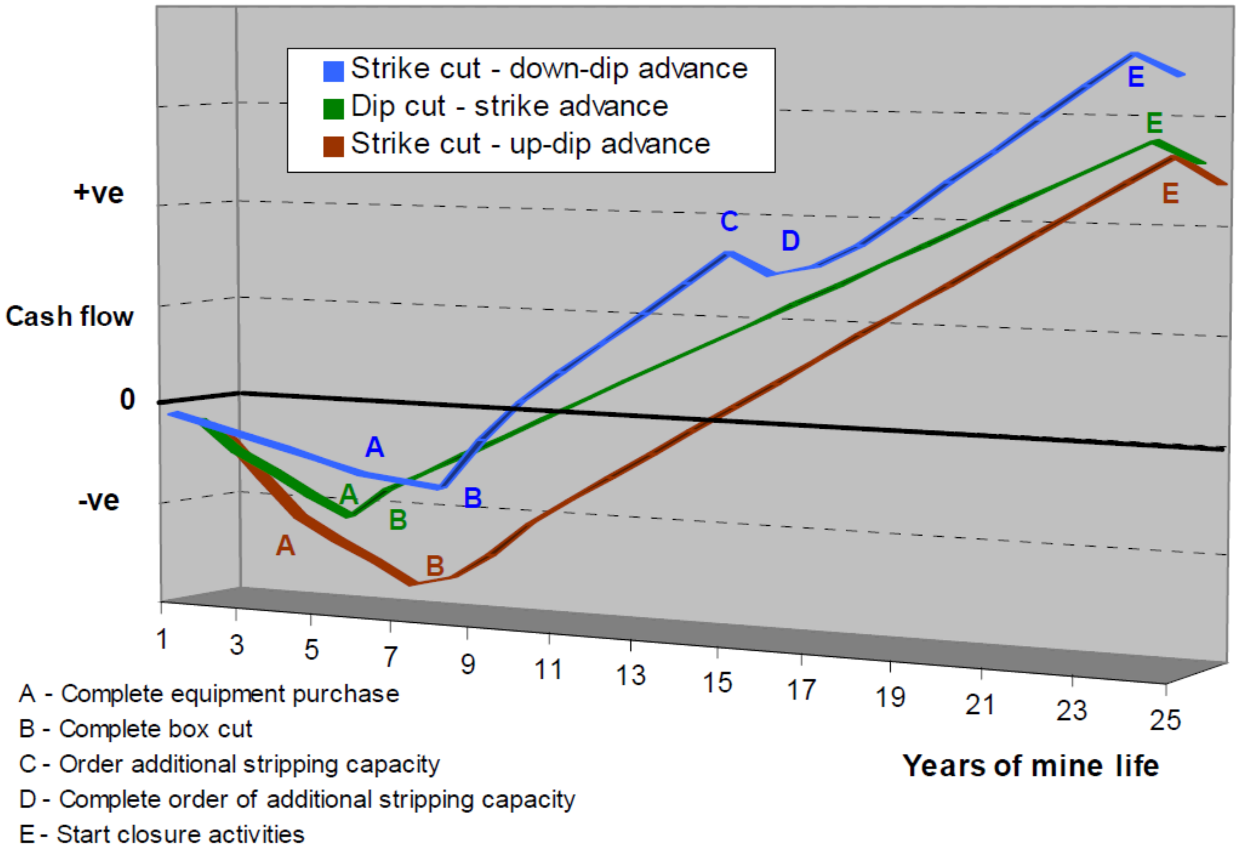


Figure 6: Typical cash flow comparisons for various box-cut orientations (SME, 1992)

Given the general geometric properties of the coal seams in Mpumalanga and the apparent economic benefits, box-cut position one has traditionally been the approach of choice. The Handbook concludes that even if site specific anomalies are considered, there is hardly ever a more attractive approach than the strike cut with a down-dip advance.

It is concluded that global coal reserves are enough to meet the foreseen demand for more than 100 years. The remaining reserves in South Africa are enough to supply coal for at least another 60 years based on current production rates should the demand continue. It was shown how the coal seams of both the Witbank and Highveld coalfields are fairly similar and are being mined with the same mining techniques such as by dragline, truck and shovel or a combination of both. In addition to this, the start approach of the strike cut with a down-dip advance was shown to be the preferred method. As a result, the mined-out topography consists of the same key features and hence requires the same overall rehabilitation approach.

2.1.2 Impacts of opencast mining on the environment

In this section the impacts of opencast mining are discussed and categorised as either landform change or environmental pollution. While changes to the landform are evident from the onset of mining, some impacts related to landform change presents itself after mining like the reductions in land capability. Environmental pollution also starts at the onset of mining but is typically observed at later stages during mining and persists well after mining. The importance of the Mpumalanga province is further discussed focussing on the agriculture, specific impacts and the overlap of mining footprints and agricultural hotspots.

Opencast mining has various environmental, social and economic effects and impacts (Goswami, 2015). Apart from urbanisation, the disturbance potential from surface mines is unmatched by any other human activity (Thompson, 2005). In the late 1970's the impacts of surface coal mining were described as the complete alteration of land which is transformed into a new landscape with very different soil characteristics (Schafer, *et al*., 1979; Haigh, 1978). A more recent study describes the impacts from coal mining as coal mine accidents, land subsidence, damage to the water environment, mining waste disposal and air pollution. These fall within either of two categories namely environmental pollution or landscape change (Bian, *et al.*, 2010). While both are evident at underground and surface mining operations the latter have higher impacts in both categories.

Direct impacts due to mining are discussed in the following paragraphs. High concentrations of trace metals and nutrients have been reported in water reservoirs along the Olifants river while high levels of metals have been measured in fish species (Driescher, 2008). Crops irrigated with water that was contaminated with acid mine drainage showed reduced yields. Adverse osmotic effects and decreased rates of photosynthesis in aquatic plants were measured (Ashton, *et al*., 2001). Soil losses on rehabilitated land and subsequent downstream sedimentation is caused by high levels of erosion. This is sometimes not immediately evident and can take 10 to 15 years to manifest. The placement of thin soil covers can also be a mechanism for salt migration via capillary action into vegetation which is further exacerbated by erosion (Limpitlaw *et al*., 2005).

Soil compaction is one of the main problems of rehabilitated soils and leads to poor root development and plant growth in general (Nell & Steenekamp, 1998). This can be attributed to the use of heavy/mining equipment and poor practices for soil placement. Soil with a bulk density of more than 1600 kg/m^3 tends to restrict root growth (Mckenzie, *et al*., 2004). Another impact of high-density soil is the reduction in topsoil volume to cover rehabilitated areas. Heavy mine equipment can densify soil to over 2000 kg/m^3 reducing the available soil volume by up to 20% (Mckenzie, *et al*., 2004). Poor topsoil management practices further reduce soil volumes through contamination and sterilisation of excessively high stockpiles.

Coal mining has adverse effects on the eco-system as a whole. Goswami confirms the previously mentioned impacts and summarises coal mining as being associated with the destruction of habitats, degradation of natural resources, posing a threat to biodiversity and adversely altering microbial communities (Goswami, 2015). More recently, Weyer, *et al*. (2017) summarised the effects following coal extraction should successful rehabilitation not be achieved, as soil erosion, loss of valuable soil resources, soil and water contamination, soil compaction, ponding surfaces, cracking, spontaneous combustion and subsidence. Society recognised these impacts very early on and a public demand to mitigate and remediate it led to the enactment of legislation (Doyle, 1976).

Mpumalanga is the centre of the maize triangle of South Africa and coal mining has severe impacts on land and water availability required for farming (Bench Marks Foundation, 2014). The province also has almost half of the high capability arable land area in the country (Bureau for Food and Agricultural Policy, 2015). The Bench Marks Foundation compiled a report that focuses on the impacts of mining on food security and communities in the Nkangala District that includes Emalahleni and Middelburg within the Witbank coalfield. The report highlights that water, land and air are the primary negatively affected components by mining (Bench Marks Foundation, 2014) and provides various statistics and figures to support this conclusion. The Centre for Environmental Rights confirms this and summarises the impact on the environment as air and water pollution, destruction of arable land and loss of biodiversity (Centre for Environmental Rights, 2016).

To demonstrate the significance of the impacts on water, land and air it is stated that one of the top tier coal mining companies in the area strips 6 million and 125 million cubic metres of topsoil and overburden respectively, uses 6 560 tonnes of explosives and disturbs 339 ha of land that will need rehabilitation in an average year (Bench Marks Foundation, 2014). It is noted by the author that while the impacts on land and air may be apparent from this, the impact on the unseen geohydrology and hence boreholes are sometimes less known by the general public. Apart from the effect of blasting on geological structures, the water table in the mining area is also drawn down to make mining possible over the life of the mine.

The Bench Marks Report (2014) also refers to statistics from the Bureau of Food and Agriculture Production that indicates that 326 022 ha of farmlands are located on current mining areas and another 439 577 ha on prospecting areas. Should mining also happen on the prospecting areas a total of 765 599 ha of cultivated land will be lost. Figure 7 provides a graphic representation of the significant overlap of farm boundaries and coal resources and reserves.

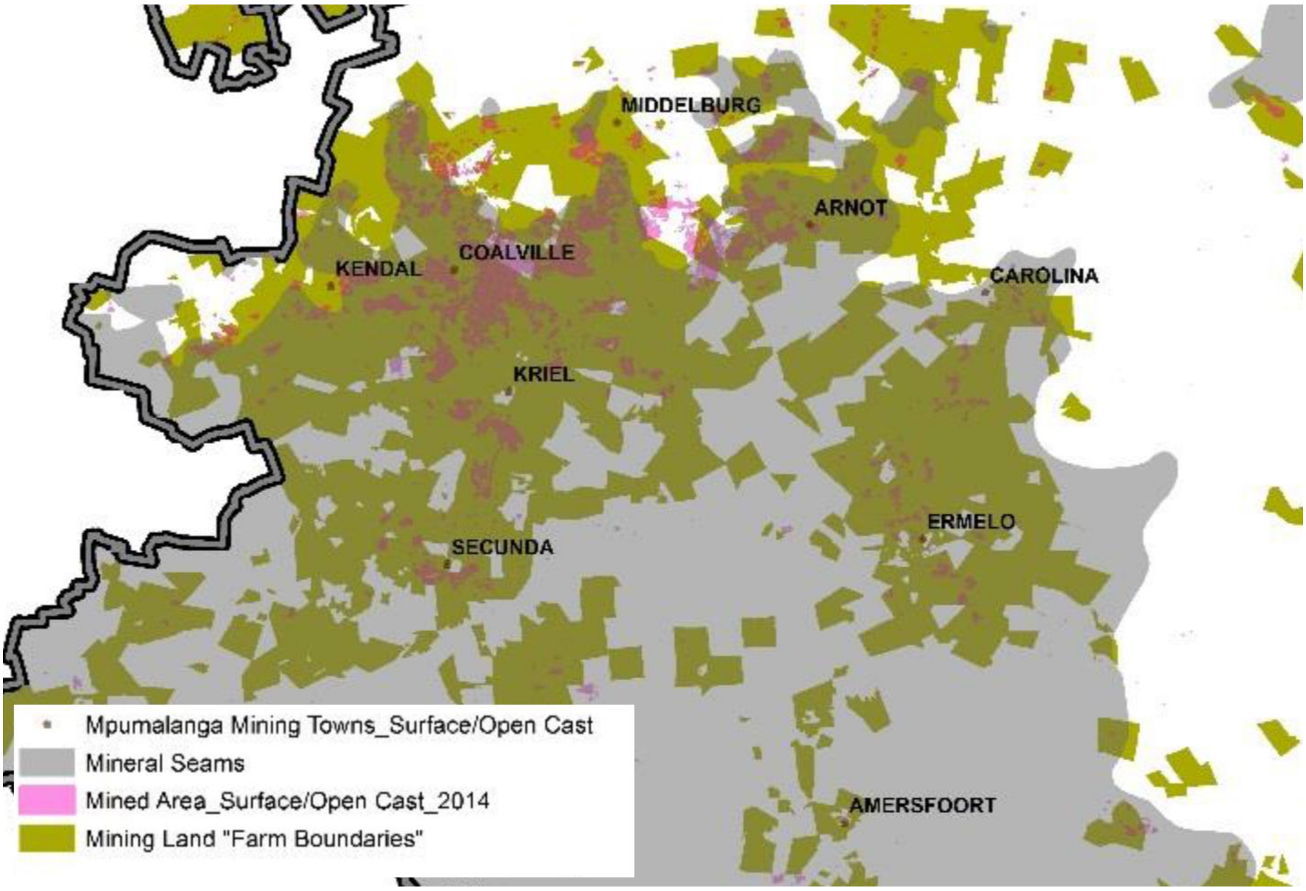


Figure 7: Mining land cover and mineral potential: Mpumalanga (Bureau for Food and Agricultural Policy, 2015)

The Highveld and Witbank coalfields are mainly located in the agricultural hotspot of Mpumalanga. The list of impacts of surface coal mining is extensive and literature shows that the same basic environmental issues are still as relevant today as it was in the 1970s. This is something that can be expected as the building blocks of surface mining methods, such as opencast mining, are still the same. What is surprising is the apparent increasing emphasis on the remediation of impacts of surface coal mining in Mpumalanga. This suggests that either these impacts cannot be mitigated or remediated to an acceptable standard and are getting worse or that mining companies do not have the corporate will to do so. Given the importance of the province and extent of mining in the area, it is expected that there should be a strong focus on the impacts from mining and in turn one would also expect to see rehabilitation efforts with associated diligence.

In summary of this section, it was shown that the impacts of opencast coal mining are severe and were categorised as either landform change or environmental pollution. The key impacts that were highlighted throughout consisted of:

- Alterations of the landform leading to excessive erosion, loss of land capability and changes in the surface water drainage regime;
- Detrimental changes in soil structure that reduces its growth potential and long term-sustainability;
- Air pollution specifically during the operational phase. This impact should be eliminated after closure unless vegetation is not established;
- Destruction of habitats and ecological value; and
- Detrimental impacts on the groundwater regime.

2.2 Status of opencast coal mine rehabilitation

A brief overview of rehabilitation and suggested success criteria was reviewed in this section. It was followed by a review of literature to determine the status of rehabilitation efforts and outcomes.

Mine rehabilitation aims to address these impacts sufficiently to leave a post-closure scenario that in general has a similar value to the pre-mining condition and is not harmful to society or the environment. There is no one universal definition for rehabilitation and is typically described by terms other than “rehabilitation” as reclamation, restoration, ecological restoration, revegetation, reforestation, remediation or closure. These are also mostly used interchangeably (Weyer, *et al*., 2017). Collectively these terms suggest a return to what the pre-mining land-use was with a strong nuance of re-establishing ecological value. Given this and since opencast coal mining is rarely done over well-developed infrastructure or established settlements it is concluded that rehabilitation in general aims to re-establish a natural or ecological environment. This is confirmed by the Australian Government, Department of Industry Innovation & Science and Department of Foreign Affairs & Trade (2016) who suggests five categories of rehabilitation implementation as Landform design and construction; Soil profile reconstruction; Species selection; Vegetation establishment; and Fauna recolonization. It is noted by the author that the suggested categories can only be implemented in the provided sequence, thus the one cannot be done before the previous category.

Australian Government *et al*. (2016) has also conceptualised five stages of rehabilitation planning. The very first stage is to define rehabilitation objectives and success criteria. In addition to this the Guidelines define four categories of success criteria for rehabilitation objectives that must be adhered to in order to address the overarching two categories of opencast coal mining impacts of environmental pollution and landscape changes. In order of chronological development, they relate to post-mining landform and soil cover, vegetation, surface and ground water qualities and management of residual and latent risks.

A search was conducted on academic search engines to determine the status of rehabilitation efforts. There is a considerable amount of literature that studied secondary drivers to specific rehabilitation outcomes such as why specific species of vegetation did not establish well when seeded with other specific species. The focus of the search however considered the primary efforts, outcomes or shortcomings of rehabilitation such as whether overall vegetation vigour was achieved. Search results were considered for the study area but were also extended to include national and global studies to increase the sample size under consideration. The search was done for combinations of the following key words: successful, opencast/surface coal mining, impacts, opencast/surface coal mining rehabilitation/reclamation, coal mining rehabilitation/reclamation success/outcomes.

Seventeen search results were identified that conformed to the above search qualifications. The results included nine global, seven South African and one South African/Australian cases. The focus area and findings and/or purpose of each case are briefly discussed in chronological order of study.

Case 1: Large areas in South Wales that are officially recognised as rehabilitated are in a very poor condition. Problems include poor soil structure, poor vegetation cover, increased surface water run-off, erosion and gulley formation. These problems are ascribed to low quality engineering and poor care and maintenance which were then exaggerated by natural processes (Haigh, 1992).

Case 2: High compaction and acidity in soils are generally responsible for poor vegetation cover on rehabilitated land in South Africa. The importance of a scientific approach to soil characterisation and appropriate remediation techniques are key to overcome this (Limpitlaw, *et al*., 1997).

Case 3: Nell and Steenekamp (1998) studied 1634 profile pits on rehabilitated soils of nine opencast mines in Mpumalanga. Bulk densities of 3016 samples representing 1040 soil horizons were tested and found elevated soil bulk densities in nearly all of them. They concluded that emphasis should be placed on the importance of detailed studies of soils and appropriate soil stripping and placement methods to achieve suitable compaction levels.

Case 4: Javurek (1999) describes the challenges of rehabilitated lands in England. The most widely used rehabilitation approach includes site preparation, soil remediation and monitoring and maintenance which is aligned with other approaches such as that of the Guidelines and Weyer, *et al*. (2017). Following this approach, the challenges were high bulk soil densities that inhibited root development, increased runoff, increased soil acidity, death or slow growth of seedlings due to poor planting techniques and lack of a sufficient care and maintenance program.

Case 5: Holl (2002) studied long term vegetation recovery on coal surface mines in the eastern USA, that was rehabilitated more than 35 years ago. The study showed that a number of indigenous species had not yet recolonised. Holl concluded that the outcome was aligned with conflicting objectives of short- term and long-term rehabilitation goals. This typically included the use of fast-growing non-native plants to kerb short-term erosion that inhibited the development of indigenous species.

Case 6: Nicolau (2003) examined the trends of topography design and construction of opencast mining rehabilitation. In this case it was stated that rehabilitation failed because of inadequate design and construction that resulted in the inability to sustain functional ecosystems. This further increased runoff with serious consequences to downstream receptors.

Case 7: The shortcomings of opencast rehabilitation activities in north-west Bohemia implemented during the last 50 years were analysed. The aim was to develop a small-scale approach to remediate the various shortcomings of the study areas and to define general rehabilitation methodological principles. The assessment and consequent guidelines identified two primary focus areas in need of attention namely landform design and landscape functionality (Sklenicka, *et al*., 2004).

Case 8: A study focussed on opencast coal mines in India concluded that the fertility status of soil had a shelf life and deteriorated over the duration of stockpiling. This in turn requires increased biological reclamation efforts of the soil during replacement (Ghose, 2004).

Case 9: Tongway and Hindley (2005) states that widespread degradation of Australian landscapes was caused due to a lack of knowledge and understanding of climate, soil and vegetation. They developed a land functionality analysis method that was extended to rehabilitation monitoring with a specific aim to link vegetation with soil and habitat development to aid management decisions.

Case 10: The long-term success of surface rehabilitation and pollution amelioration at collieries in South Africa depend on the nature of post-mining land uses. Management of soil resources, promotion of biodiversity and management of post-closure latent risks are key to achieve the required land capability. Insufficient post-closure land use practices have resulted in the degradation of rehabilitated areas. An integrated approach to closure planning is required where all stakeholders take responsibility for long-term sustainability (Limpitlaw, *et al*., 2005).

Case 11: Ecological succession trajectories of rehabilitation efforts in Mediterranean-dry Spain were studied to identify the key drivers of vegetation establishment. They included controlled catchment and runoff, avoiding soils with poor chemical properties and appropriate vegetation species selection (Moreno-de las Heras, *et al*., 2008).

Case 12: The presence of acid mine drainage in streams and rivers are increasing because of coal and gold mining around the world as well as in South Africa

(Ochieng, *et al*., 2010). This can be attributed not only to operational mismanagement but also due to poor rehabilitation and insufficient treatment approaches.

Case 13: The Mvula Trust conducted a study on the environmental consequences of coal mining in South Africa related to air pollution, water quality issues, biodiversity effects and climate change. The study also included the social consequences related to community needs and engagement of mining companies with the needs and issues of coal miners. Much of the focus of the study was on the Mpumalanga province that is known to be an agricultural hotspot. They found that rehabilitation efforts were not fit for agricultural use and acid mine drainage in rivers prevailed. They concluded that the effects of opencast coal mining were not easy to predict. Government is therefore reluctant to issue closure certificates due to the known scale of impacts and uncertainty of residual and latent risks (Munnik, *et al*., 2010).

Case 14: Banks, *et al*. (2011) developed a conceptual source-pathway-receptor model for the Witbank coal mining region that also confirmed the presence of acid mine drainage.

Case 15: Another study on opencast coal mines in India showed that residual and latent impacts were starting to manifest and concluded that the monitoring of these were essential for successful management and remediation thereof (Saini, *et al*., 2015).

Case 16: Water pollution, soil degradation, air pollution and specifically the destruction of high potential arable land and related high costs to rehabilitate and rectify the consequences are highlighted by the Bureau for Food and Agriculture (Bureau for Food and Agricultural Policy, 2015). They continue to show that agriculture and coal mining are in competition for the same land. Coal mining yields higher financial returns but will cease while agriculture is sustainable. It is finally concluded that coal mining results in low potential land capability and that residual and latent risks cannot not yet be fully quantified.

Case 17: Weyer, *et al*. (2017) evaluated the maturity of upfront planning for South African and Australian opencast coal mines. The performance indicators of the study focused on geology, soils, topography, hydrology, vegetation, climate and land use and showed that rehabilitation planning is vulnerable to adequate but not resilient. They concluded that greater detail and analysis should inform upfront rehabilitation planning to reduce uncertainty and risk towards rehabilitation success.

It is noted by the author how the focus areas of each study relate to the rehabilitation success criteria defined by the Guidelines. It is further noted how the focus shifts over time from post-mining landform and soil cover construction to vegetation establishment, surface and ground water qualities and management of residual and latent risks. This shift is directly linked to the chronological presentation of the associated impacts and aligned with our order of understanding of rehabilitation. The focus areas and timing of each study are further discussed in Section 2.4.

Not a single study was found that described successful opencast coal mining rehabilitation. There are however various studies that identify and look at individual aspects as indicators of rehabilitation success similar to those of Nell and Steenekamp (1998), Holl (2002) and Weyer *et al*. (2017). The number of very recent studies of mining impacts and rehabilitation shortcoming seems to be far greater than studies that attempt to find or show indicators of rehabilitation success. This suggests that we are still trying to fully understand the problems associated with opencast coal mining and rehabilitation. It is therefore not surprising that no study of overall success could be found and concluded that opencast coal mine rehabilitation is, so far, rather unsuccessful.

2.3 Legislation and rehabilitation guidelines

2.3.1 The changing nature of legislation

In this section, the legislative framework was briefly reviewed including the governing authorities and acts with their associated purposes. It was shown that the legal system is dynamic, and changes can be expected. It was however found that these changes are becoming more frequent with unrealistic compliance deadlines all of which are not in favour of the mining sector.

The Minerals Act, 1991 (Act 50 of 1991) provided statutory requirements to protect the environment and to rehabilitate areas that were affected by mining activities (Swart, 2003). Prior to this, rehabilitation in the coal industry has primarily been self-motivated (Limpitlaw, *et al*., 1997).

The Guidelines (Coaltech Research Association & The Chamber of Mines, 2007) reflect on the legal compliance framework as at October 2006 and shows that the crux of rehabilitation and closure requirements were set out in the following three acts namely:

- The Constitution (Act 108 of 1996) is the overarching piece of legislation that protects the right of the people to have an environment that is not harmful to health and well-being;
- The Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002) that specifically oversees the mining industry; and
- The National Environment Management Act (NEMA) (Act 107 of 1998) governs environmental authorisation that must be obtained for specific activities that may have negative impacts on the environment.

The following legislation are also mentioned by the Guidelines as having a significant impact on rehabilitation activities:

- The National Water Act (NWA) and in particular GN R 704;
- The National Forests Act;
- The National Heritage Resources Act; and
- The Conservation of Agricultural Resources Act.

The MPRDA and NEMA are considered to be the core of the legal requirements. They require that permission to mine must be obtained and that site-specific management systems be developed that are in compliance with further aspects of the two acts. More specifically the MPRDA requires that a mine must submit an Environmental Management Plan (EMP) prior to the commencement of mining and should update and maintain the continuous approval thereof throughout the life of the mine. The EMP builds on the Environmental Impact Assessment (EIA) and identifies the environmental impacts and mitigation measures including rehabilitation objectives and criteria that need to be achieved (Department of Environmental Affairs and Tourism, 2004). While the three acts still apply today, the Guidelines recognise that the South African legal system is dynamic and takes account of the fact that it will change over time. Anticipated changes at the time related to biodiversity and the likelihood that certain combinations of soil structures may be redefined as too important to be disturbed by mining activities (Coaltech Research Association & The Chamber of Mines, 2007).

Other significant changes affecting rehabilitation is that of financial provision for the management, rehabilitation and remediation of environmental impacts as a result of mining which used to be governed by the MPRDA and now falls under NEMA. Changes in environmental legislation related to mining resulted in the need and consequent changes to the financial provision regulations. These were promulgated in November 2015 and published under Government Notice GN1147.

At the time the legislative authority and competent authority remained with the Departments of Environmental Affairs and Mineral Resources respectively (PwC, 2016). These two authorities are not the only ones liable to be involved in environmental closure and this also generates a set of problems (Milaras, *et al*., 2014). The regulations were met with much resistance and were viewed as "unnecessarily onerous regulations riddled with legislative uncertainties and a myriad of contradictions" (Gore & Pienaar, 2018, p.4).

Another set of proposed changes was published by the Environmental Minister on 10 February 2017 (Gore & Pienaar, 2018). Measures, requirements and standards that mines in Africa have to comply with are increasing and changing continuously to the extent that Winds of Change Media held a dedicated conference in 2018 to shed light on the current African and South African legal frameworks and interpretations thereof (Winds of Change Media, 2018).

These changes aim to sufficiently reduce the impacts of mining. The major current focus is on financial provision to identify impacts and quantify the associated rehabilitation costs as a mechanism to hold the polluter accountable and to ensure that enough money is available to do the actual rehabilitation. These changes are again a way to establish “what” needs to happen, what is seemingly not addressed as part of these changes are the “how” to do it all.

2.3.2 Background of the Guidelines

The Guidelines for the Rehabilitation of Mined Land of 2007 aims to provide guidance to practically achieve rehabilitation objectives. It is an expansion of the guideline for the rehabilitation of land disturbed by surface coal mining of 1981 published by the Chamber of Mines. It was further augmented by the Australian mine rehabilitation and mine closure and completion guidelines and other South African and international best practice guidelines that have been developed for a range of mining methods (Coaltech Research Association & The Chamber of Mines, 2007).

Another significant effort to improve rehabilitation guidelines was the Mine Closure Toolbox developed by Anglo American first published in 2007 and revised in 2013. Much of the content was based on work that was already done as part of the development of the Guidelines. The toolbox was however met with varied reactions and has not been widely adopted in the industry (Aken, 2017) hence it will not be considered further as part of this research.

The Surface Strip Coal Mining Handbook (Mining Handbook) (Thompson, 2005) is founded on the review and evaluation of more than 220 scientific papers and references by practicing mining engineers. It is primarily focused on the planning and feasible extraction of resources specifically to inform engineers in opencast coal mining but has a dedicated module to guide rehabilitation and closure. Guidance for landform re-creation and topsoil management from the Guidelines and Mining Handbook are very similar. A notable difference however, is the approach of the mining handbook that still aims to re-establish the exact pre-mining landform, drainage patterns and land use compared to the Guidelines that has progressed beyond that and now aims to re-establish pre-mining conditions that are proportionally equal and similar in functionality.

Very little work was done to advance physical rehabilitation practices in South Africa or to keep the guidelines relevant and updated (Aken, 2017). This is recognised by the Chamber of Mines, Coaltech Research and the Land and Rehabilitation Society of South Africa who are in the process of updating the Guidelines as a joint venture. These guidelines are however the most recognised and advanced guidance for opencast mine rehabilitation at the moment. It was therefore selected as the basis to assess the extent to which mines are using guidelines and/or best practices to aid with practical implementation to achieve their rehabilitation objectives.

2.3.3 Overview of the Guidelines

The following sections include a review of the Guidelines by Coaltech Research Association & The Chamber of Mines (2007) as well as summaries of specific sections to provide context that informs the research. It is noted that everything in Section 2.3.3 is referenced from the Guidelines unless shown otherwise.

2.3.3.1 Aim of the Guidelines

The following section provides a brief overview of how rehabilitation is interpreted by the Guidelines, how the development of closure objectives should be approached and the suggested general success criteria to achieve the objectives.

South Africa has established a legal framework as a basis of what to do to minimise environmental impacts from mining activities. The aim of the Guidelines of 2007 is to provide a basis on how to achieve this. The principle of mine rehabilitation is probably understood in the same way on a high level, but site-specific objectives and criteria can vary considerably. Geographic location, climate, level of development of the host country, social and cultural beliefs and where in history mining started will be stimuli for the development of different schools of thought, objectives and approaches. For this reason, it can be expected that a universally accepted definition for rehabilitation is unlikely to exist. Even if it did, it would probably not stay the same with scientific advancements and changes in social expectations as well as changes due to modern requirements. The Guidelines recognises this and, for the purpose of the guideline to provide a basis for “how to do it”, provides a definition for rehabilitation as:

> “putting the land impacted by the mining activity back to a sustainable and usable condition”.

It also elaborates on the definitions and describes effective rehabilitation as an action that will be sustainable in the long-term future under normal land management practices. Rehabilitation objectives may contradict each other such as when the objective to provide for the wishes of the local community and to be aligned with the national and regional integrated management plans are not compatible. The objectives that, according to the Guidelines, must be adhered to, are to provide for a sustainable post-mining land use and to be aligned with the EMP and Closure Plan objectives and commitments. These must be developed and agreed on through an appropriate Public Participation Process before permission to mine is granted.

The Guidelines further defines closure as the state of rehabilitation that has achieved the set objectives, is in a state of stable performance and whereby the regulator and related third-party stakeholders are satisfied that long-term risks are within an acceptable and manageable range. The development of success criteria that are acceptable to government and third-party stakeholders is a key part to eventually get a closure certificate. The Guidelines specify four general categories of success criteria that must be adhered to as follow:

- Compliance to surface and groundwater qualities;
- A stable and suitable post-mining landform with the ability to underpin the end land-use;
- Suitable and sustainable vegetation with appropriate vigour that underpin the end land-use; and
- Management of residual and latent risks.

2.3.3.2 Overview of the content and layout of the Guidelines

The Guidelines aim to include the whole process from planning, permitting and financing, physical rehabilitation, development of monitoring criteria and completion and final closure. The layout of the guidelines consists of 16 key sections that can be categorised as front-end loading work (Section 1), physical rehabilitation aspects (Section 2 to 12), rehabilitation management and preparation to final closure (Section 13 and 14) and supplementary context (Section 15 and 16). The focus of the Guidelines is therefore primarily to guide the physical aspects and management of rehabilitation, this is evident from the proportional volume of the Guidelines dedicated to it. This is in essence to satisfy the four general success criteria with a specific focus on the first criterion as mentioned in Section 2.3.3.1.

2.3.3.3 Planning, authorisation and financing

The front-end loading work includes rehabilitation planning, legal authorisation and financing. Since the Guidelines focus on the "how to", the first section provides a broad overview of the required planning and authorisation activities and how these are interconnected. It paves the way for what the rehabilitation commitments will be and how they are developed to aid with suitable and thorough rehabilitation planning. The Guidelines correctly recognise that good planning right from conceptualisation is critical and provides more details on planning, authorisation and financing as an appendix. Appendices are also included with detailed explanations of the processes involved in legal authorisations and financing as well as a flow-chart showing the steps towards obtaining authorisation to mine.

2.3.3.4 Rehabilitation implementation (Physical rehabilitation sections)

The next category includes sections that are largely related to physical rehabilitation planning or activities and is briefly discussed in the following paragraphs.

<u>Land preparation for mining</u>

Land preparation for mining describes how the construction planning phase of a mine should already aim to minimise negative environmental impacts by keeping footprints of infrastructure and material stockpiles to a minimum. Placement of contaminated material should also be done to minimise potential future contact with the undisturbed environment while placement and storage of materials for rehabilitation purposes should be managed to maximise the efficient re-use of it. Location of future stockpiles, especially that of topsoil, should be carefully considered and be clearly identifiable for their future use. Re-handling of topsoil, contamination with subsoil or waste and topsoil wrongly identified all contributes to significant losses that can severely jeopardise successful achievement of rehabilitation objectives and commitments. In essence, *land preparation for mining* directs the mining engineer to plan everything with closure in mind.

Soil Stripping

Soil stripping and replacement are processes that account for significant soil losses where a site-specific management plan is not developed and followed. The Guidelines further notes that sufficient availability of soil materials is vital for successful rehabilitation and provide seven key points to guide efficient soil stripping. A soil survey and report need to inform the compilation of the Environmental Impact Assessment prior to mining. The report includes information of the characteristics and details of the soil horizons usually to a depth that is sufficient to include all the usable soils or soils that can be of value for rehabilitation. A biologist should assess the soils as growth medium and providers of seeds for native plant species and should also contribute when determining the horizons to be stripped for the use of rehabilitation. Details of the physical and chemical data from the soil report, combined with input from the biologist should be compiled into a detailed soil plan that will form the basis of the development of a soil stripping and soil use guide.

The stripping guide should be simple and clear enough to provide specific direction of where, how much, when and which horizons should be stripped and should also include placement details. The advantage of this approach is that a clear understanding of the available usable soils is developed that can and should inform placement locations, depths and other requirements to achieve functional and sustainable rehabilitation objectives and commitments. An ideal stripping approach is suggested as three lifts where the upper layer of the A horizon which contains the seedbank, the remainder of A horizon and the usable non-plinthic B Horizon be stripped separately. The Guidelines notes that standard practice in South Africa is mostly to strip and place the A and non-plinthic B together. The disadvantage of this is that the fertile materials are diluted and hence requires much more fertilisation and seeding to achieve similar vegetation vigour. The risk of this stripping method is the contamination of the plinthic B horizon due to over-stripping and consequent detrimental impacts on the new mixture of A and B horizon soil as growth medium. One of the features of Plinthite is the changes of physical characteristics through exposure to the atmosphere. Plinthite irreversibly hardens when exposed to repeated wetting and drying and exposure to heat from the sun resulting in poor root penetration (Kelley, *et al*., n.d.). It is mentioned that stripping should be done a suitable distance ahead of mining and be supervised to ensure soils are not over- or under-stripped. The result of under-stripping is leaving usable soil which will be lost as part of mining. A specific remark is made regarding hard setting due to over-stripping, which is confirmed by Kelley, *et al*. (n.d.). Most South African soils are prone to compaction especially when soils are moist. It recommends that moisture content be carefully considered, and that stripping be done during months with the lowest rainfall. Direct placement is also promoted to avoid further compaction and loss of the seedbed during stockpiling. The use of appropriate equipment to strip and place topsoil is the last key aspect of soil stripping. While specific equipment is not mentioned as appropriate or not, it is again concluded that the compaction caused by the equipment is the single biggest limitation for land capability re-establishment.

Soil stockpiling

Soil stockpiling is not preferred but the Guidelines recognise that direct placement is not always possible and provides a few key points to guide effective stockpiling. An observation from typical practice is made that stockpile locations are mostly informed by the shortest distance from where stripping or excavation is taking place. Topsoil is then often stored next to or as part of other waste and in many cases must be moved to another location prior to applying it for final rehabilitation. Re-handling and waterlogging of soils damage the soil structure and makes it susceptible to higher compaction with the same effort compared to its lesser disturbed state. Volume losses and potential contamination from nearby stockpiles are also inevitable when soils are moved and is exacerbated when soils are mistakenly used as construction materials for infrastructure development. Emphasis is placed on the appropriate selection of stockpile locations to mitigate the abovementioned adverse effects.

Another point is made regarding the risk of compaction, this time during the development of the stockpile. Dumping of soils in one lift is preferred to stockpile soils loosely. This preference will likely expand stockpile footprints to the extent that layered dumping is required. In the event where higher stockpiles is unavoidable, the Guidelines recommend to deliberately keep the access roads to the top of the stockpile to a minimum and to ensure vehicle follow the same tracks. The key points regarding soil stockpiling is concluded with a motivation to compile a detailed management and monitoring programme to ensure a vegetation layer is established naturally or artificially to reduce erosion. The programme should also include measures to reduce usage for alternative purposes, contamination, waterlogging and ensure awareness of the purpose of the stockpiles.

Infrastructure removal

Infrastructure removal of offices, workshops, processing plants, accommodation, etc are required at the end of mining. Emphasis is placed on the importance of selecting infrastructure that can remain on the mine site. While this reduces the closure liability, the next land user is likely to overestimate the value and practicality of these facilities resulting in defunct structures that can become a safety risk. The Guideline recognises that infrastructure removal and the remaining footprints need to be followed up by landform profiling, topsoil placement and vegetation to achieve contaminant-free, free draining and a functional land use. While these areas place an additional burden on landform planning and soil requirements, they are usually significantly smaller than the opencast mining footprint area and it will not be considered further for the purposes of the study.

Landform changes resulting from high extraction mining, the associated environmental impacts and their remediation

Landform changes resulting from high extraction mining, associated environmental impacts and respective remediation methods are discussed in a short chapter and is specifically aimed at long wall mining and pillar extraction which are both underground mining methods. Of the five environmental impacts that are mentioned, three are related to landform functionality and capability and are similar to the impacts that can be expected from strip mining namely: surface ponding, disturbance of water courses and increased groundwater make via increased surface water recharge. The remaining impacts are damage to infrastructure and surface cracking. Surface cracking could be an impact of opencast mining too but is usually significantly less than its impact on underground mines. Details of the impacts and related remediation measures of underground mining will not be elaborated on any further for the purposes of this study.

Landform re-creation (spoil shaping)

Landform re-creation (spoil shaping) is described as the process to achieve the post-mining topography as agreed on. Actual costs to re-create this are highlighted as one of the main reasons why the agreed topography may not always be achieved especially in the case of open-pit mining that results in an overburden stockpile and a void. Early planning is emphasized to ensure box-cut and concurrent overburden are placed appropriately and as aligned with the final landform as possible. The norm, during the compilation of the Guidelines, was to re-create landforms that were free draining with slopes that minimise the potential risk for excessive erosion. An ideal approach is suggested that the final landform be re-created as close to the agreed landform as possible while blending with the surrounding topography. It is argued that while the ideal approach will likely result in an outcome that is closer to the agreed rehabilitation objectives, the criteria for free draining compliance and erosion mitigation are just as relevant for the ideal approach. Unforeseen changes in the ore body and uncertainties regarding bulking factors are highlighted as difficulties to develop an accurate post-mining landform that is aligned with the agreed outcomes. Six sections are dedicated to guide landform design and will be discussed in the following paragraphs.

Develop a conceptual post-mining landform to guide landform re-creation from the planning phase. The final topography will be a function of the pre-mining topography, mining method, re-creation strategy and objectives and outcomes to be achieved that was developed during the permitting phase. It is noted that the landform design must take account of the following during the planning phase:

- Volumes of ore that will be mined and hence taken out of the landform re-creation process;
- Volumes of waste that will be moved and related bulking factors that will vary based on the local geology. Although it is not noted, a further predicament to material volume prediction in opencast mining is firstly the initial swell during blasting and secondly the compaction during placement that occurs immediately and also over time as settlement takes place. Swell, as part of blasting, can be predicted and measured to a fairly high accuracy, however compaction measurement is usually far more difficult. That said, both can only really be established once mining has commenced and will have to be checked with the initial factors used prior to mining;
- Re-creation of a surface water drainage regime that meet the needs of the objectives; and
- Integrating operational surface water drainage measures with the required post-closure measures where possible.

The post-mining landform also needs to be designed to achieve the required land capability commitments that are primarily dictated by the topography and soils. Higher capability classes, as is mostly required in the study area, necessitates moderate slopes to allow for acceptable erosion rates. Erodibility of soils is informed by numerous factors such as climate erosivity and soil type and it is therefore impractical to specify generic slope guidelines for land capabilities. Various mining companies have however set “best practice” slope standards of 1:5 or 1:7 and 1:10 or 1:14 to achieve grazing and arable land capabilities respectively. Further guidance is provided to avoid excessive long and steep slopes as well as very flat slopes.

Guidance for landform designs for box-cut spoils, voids and overburden dumps are provided in the case where it is not practical or economical for these to be incorporated into the post-mining landform as described earlier and needs to be rehabilitated where they are. The overarching principles to re-create suitable slopes related to the required land capability, erosion mitigation and being free draining remains the same.

Excessive slopes lengths will be encountered occasionally and requires measures that have not been addressed in the landform re-creation section. The Guidelines indicates that erosion mitigation measures on rehabilitated land requires the assessor to look at the site-specific conditions on a case-by-case basis related to slopes lengths, soil properties, rainfall season and expected timing of vegetation establishment (if not yet established). The unpredictability of the location and extent of differential settlement is further identified as a key consideration to adapt the design criteria of these measures appropriately during concurrent rehabilitation.

Monitoring of waste and soil movement should be done on a regular basis to reconcile volumes and assess compliance against the post-mining landform design in terms of elevations, waste placement, spoil placement as well as spoil placement specifications. Survey results should be used to calculate bulking factors and considered with the outcome of the compliance assessment to adjust the landform design as may be required. It is reasoned that this is a sound and practical approach given that the ease of effort to adjust the landform design to take account of areas not complying, where possible, far outweighs the effort of re-handling the material to be within the design specifications. This however does not free the mine from following some design as practical adjustments will have its limitations. The impact on the post-mining landform design due to changes in the mine plan should further be assessed and incorporated into the design where required.

Soil replacement

A complete section is dedicated *to soil replacement that should happen* after the post-mining landform has been created. The issue of ongoing settlement is mentioned as a key contributor to soil replacement considerations and the timing of exactly when soil replacement should happen seems to be unresolved, however, a process that allows for direct placement is preferred. Compaction is highlighted as “the greatest single problem that limits the effectiveness of rehabilitation in South Africa today” and it is stated that practically all of the 40 000 hectares of rehabilitated surface coal mine land have bulk densities in excess of that required to allow effective root penetration depth (Nell & Steenekamp, 1998). The Guidelines attempt to provide mitigation measures for this and are discussed in the following paragraphs.

Soils with specific properties and therefore functionality, should be replaced appropriately to marry the eventual moisture conditions with the physical characteristics of the soils. Differential settlement is elaborated on and explains how unintended localised depression or ponding areas can develop over time. Drivers for this could be wetting and drying as well as the re-establishment of the post-mining water table. Being "differential" points to that the location and degree of the resultant impacts are uncertain. It is suggested that settlement be measured, and an appropriate soil volume is kept aside for care and maintenance of such areas. Storage of 5% to 10% of the total stripped soil volume is recommended as a starting point or where it is difficult to determine the requirements.

Compaction is the product of inappropriate methods of placement and inappropriate time of placement. Methods that includes heavy machinery and machinery that increase traffic over rehabilitated areas intensify compaction. The Guidelines note that other constraints of machinery that is mostly being used in South Africa is the thickness of soil that can be placed at a time, placement volume control and spreading requirements prior to vegetation establishment. Truck and shovel and dozers with tracks are suggested as the preferred methods for placement and spreading of soil of the readily available technologies in South Africa. Replacing soils in the order in which they naturally occurred is ideal from a chemical and biotic point of view and a well-established concept internationally but increases handling and traffic as each layer must be constructed individually. Time of placement refers specifically to the season at which the moisture content of the soil is as low as possible and moisture content changes are consequently minimised. Compactability is maximised at different moisture contents per soil type but is usually less susceptible to compaction at low moisture contents. The suggestion, as a general rule, is therefore made to strip and place soils during the dry season.

Soil amelioration

Notwithstanding the guidelines provided for soil replacement additional effort is required for chemical and physical amelioration of the placed soil. Of the technologies available in 2007, deep ripping is suggested as a method successfully used in agricultural industry. According to the Guidelines the dynamics found on rehabilitated mine land is somewhat different and usually requires ripping to depths in excess of one meter at unnaturally high densities to allow for root penetration. A dozer fitted with one or two tines is the preferred tool to create an optimal breakout pattern with maximised disturbance. Moisture content again plays a significant role to achieve this. A disadvantage of this method is the upwards migration of rocks to surface and the cross contamination of subsoils and soils with higher growth-medium potential. Hand removal of rocks is suggested where higher land capabilities like row-cropping needs to be achieved. Depending on the required land capability, additional tillage may be required after ripping unless soil replacement was largely successful and natural vegetation is allowed to re-establish.

It can be expected that rehabilitation work to this point would have had a significant impact on the soil fertility of the resultant soil layer. Primary growth medium soils are usually mixed with each other and diluted with subsoils which are conversely to the betterment of subsoils as growth medium because fertile soils and organic material are introduce into previously inert soils. A fertile growth medium must be established to allow for any chance of successful vegetation establishment. The Guidelines note that additional fertilisation is required and should ideally be made up of site-specific requirements to avoid under- or over-fertilisation. The timing of initial fertilisation to add mobile and immobile nutrients needs to be accounted for during the appropriate stage of soil placement and/or vegetation. Secondary fertilisation as part of maintenance needs to be applied over a period of several years until the necessary fertility cycles are re-established.

Dealing with problem areas

A section is dedicated on how to deal with problem areas. These are typically areas that require an alternative rehabilitation approach to deal with issues such as a lack of suitable topsoil, soils with high acidity or metal toxicities and other contaminated areas. It is advised to develop a site-specific approach with the aid of expert assistance.

Revegetation and biodiversity re-establishment

Revegetation and biodiversity re-establishment seem to be opposing objectives as the industry has a propensity to see revegetation primarily as a mechanism for erosion control rather than to include a long-term view to satisfy biodiversity requirements. Revegetation is typically done with grass-seed mixes that establish quickly. This practice can be beneficial to achieve some land capabilities but can be to the detriment where other biodiversity objectives needs to be accomplished. Biodiversity objectives, species selection based on practical considerations, vegetation establishment methods during appropriate climate conditions and vegetation maintenance are emphasized. It is further recognised that revegetation and biodiversity objectives can become specialised and considerations should be given to make use of appropriate specialists.

Rehabilitation monitoring and maintenance

Monitoring is a key component to ensure that ongoing rehabilitation efforts and results are aligned with the planned rehabilitation approach and objectives. According to the Guidelines the two primary categories of monitoring are the aspects of physical rehabilitation and progress with re-establishment of the agreed-on ecosystem. It is highlighted by the author that soil stripping, overburden management, concurrent backfilling, levelling and soil replacement are again highlighted as the key aspects of physical rehabilitation that requires careful monitoring.

The concurrent levelling should be monitored at regular and appropriate intervals depending on the rate of mining to ensure compliance to surface water drainage and the post-mining land-use objective. Compliant reshaped areas should be signed-off by the surveyor and preferably by a rehabilitation specialist prior to the placement of topsoil. A soil balance should be kept and updated regularly. This should not only include stripping, placement and stockpile volumes but also assess compliance to the soil stripping guide and placement procedures. The Guidelines acknowledge that soil losses are unavoidable and recommend that immediate interventions be developed if losses of more than 10% are encountered. Replaced soil physical and fertility assessments should be done to inform maintenance and as feedback to recalibrate soil placement procedures if required.

The remaining aspects that are suggested to be monitored include erosion, surface water drainage systems, surface water quality, groundwater quality and vegetation performance. These are all aspects that follow on the physical development of the landform and topsoil placement and can only be measured after a period of time to determine their respective performances. Corrective measures are provided for each as an ongoing action that can last several years until the required objectives have been achieved. It is noted that the suggested monitoring aspects of the Guidelines are well aligned with the Australian Leading Practice Sustainable Development Program for the Mining industry's categories for rehabilitation implementation (Australian *et al*., 2016).

<u>Rehabilitation management and preparation to final closure</u>

A key environmental risk of mining is rehabilitation failure. The development of an EMP is a prerequisite to mining and identifies the key risks, related management protocols and policies and ongoing monitoring regime. Another risk is that opencast mining typically exceeds the length of employment of most employees and the lack of knowledge transfer of rehabilitation risks, progress and monitoring from one generation to another is a risk by itself. This requires the development of an environmental risk register that needs to be continuously updated with the EMP to a level of detail sufficient to facilitate succession. It is further recommended that the management system be reviewed on a regular basis to assess its efficiency and if it translates to the successful achievement of the rehabilitation objectives.

The typical long life of a mine goes with reduced certainty of eventual closure objectives. Social needs which is also a driver of these objectives will inevitably change over time. The Guidelines recommend that the principle of minimum loss of land capability as the main objective of rehabilitation should be followed if uncertainty exists. The closure plan should therefore be reviewed every two years and annually during the last seven years of mining to ensure compliance to the set objectives and possible changes that may have been introduced.

Supplementary context

The final sections briefly elaborate on the definition of final closure related to land rehabilitation activities and the legal compliance frameworks. Both have been discussed as part of other sections such as sections 2.3.3.1 and 2.3.

2.3.3.5 Guidelines summary

Rehabilitation is defined as putting land impacted by mining activities back to a sustainable and usable condition. The Guidelines provides a practical basis on "how to" achieve the rehabilitation objectives. Four success criteria categories are recognised as the general building blocks of the rehabilitation objectives which must be adhered to. In order of chronological development, they relate to post-mining landform and soil cover, vegetation, surface and ground water qualities and management of residual and latent risks.

It further emphasises that sufficient rehabilitation planning from as early as mine conceptualisation is critical from a legal perspective as well as to maximise the probability of achieving the rehabilitation objectives. The key aspects of rehabilitation are summarised as follows:

- Development of a soil survey report which includes information of the characteristics and details of soil horizons to a depth that is sufficient to identify all usable soils that can be of value for rehabilitation;
- Soil properties from the soil report with input from the biologist should be compiled into a detailed soil plan;
- This should be used to develop a soil stripping guide indicating specific details of stripping areas, depths, soil horizons, time of stripping and should also include placement details;

- The importance of appropriate soil horizon management is emphasised. Cross-contamination, over- and under-stripping and high moisture content leads to irreversible changes in soil properties, volume shortages and hard-setting. Compaction due to heavy and inappropriate equipment is further highlighted as the single biggest limitation for land capability re-establishment;
- Direct soil placement should be prioritised as it minimises negative impacts on the soil such as re-handling and waterlogging which makes the soil susceptible to higher compaction with the same effort compared to its lesser disturbed state. This also implies that concurrent levelling/reshaping should be prioritised to allow direct placement.
- A topsoil stockpile and management program should be developed to effectively establish stockpiles at the appropriate locations and should also include measures to reduce usage for alternative purposes, contamination, waterlogging and ensure employee awareness of the purpose of the stockpiles;
- Landform changes from opencast mining and associated environmental impacts include surface ponding, disturbance of water courses and increased groundwater make via increased surface water recharge. This implies that concurrent rehabilitation alleviates these impacts and should be prioritised as mitigation measure to curb these impacts;
- The development of a conceptual post-mining landform design to guide landform re-creation from the planning phase. The landform design should take cognisance of the materials balance to allow for an overall free-draining landform and re-creation of slope requirements as per the required post-mining land capabilities; and
- Measuring and monitoring of waste and soil movement should be done on a regular basis to reconcile volumes and compliance to the landform design and soil management guide. The survey results should also be used to calculate bulking factors and be considered with the outcome of compliance to the landform design to make the necessary design adjustments as may be required. The active involvement of the surveyor is therefore critical to achieve the required overall landform.

Opencast coal mine rehabilitation is typically 10% of overall mining costs. Rehabilitation related materials movement can be as much as 70% to 80% of that cost. The re-establishment of a functional topsoil layer is a very sensitive practice and unlikely to be successful if not managed appropriately. This is further pronounced by the degradation of the soil's fitness as growth medium and cover by increased handling and stockpiling.

It is concluded that the inter-dependence of the development of a material balanced landform design, site specific soil management, monitoring, waste and soil volume reconciliation and continuous updates of the rehabilitation plan are key to achieve the very first rehabilitation criterion on which the rest are founded. The importance of achieving this first criterion is confirmed by the rehabilitation guidelines of Australia that recognises landform design and construction and reconstruction of the soil profile as the first two steps of the five rehabilitation implementation techniques (Australian *et al*., 2016). Thompson also confirms this by stating that spoil backfilling, shaping, topsoil placement and revegetation, are considered to be the major components of rehabilitation (Thompson, 2005). The sections on rehabilitation monitoring, maintenance, management and preparation for final closure rounds the Guidelines off by integrating aspects to address the remainder of the success criteria. The Guidelines therefore aim to provide a set of practical implementation "how to" rules to achieve the four general success criteria with a very specific focus on the first criterion.

2.4 Relevance of the Guidelines

Milaras, *et al*. (2014) conducted a study to determine the professional thinking and practice of mine closure in South Africa. Some of the key aspects on how successful mine closure could be achieved offered by the majority of the respondents included the following:

- Ensuring integration of mine closure objectives with operational mine planning and including concurrent rehabilitation;

- Short, medium- and long-term risks and cost trade-offs should be considered. An example is provided of continuous rehabilitation and dump development strategies to reduce double handling as a long-term cost saving mechanism;
- Various specific successes included: topsoil recovery prior to mining; endangered plant recovery; control of alien species; rigorous topsoil management and placement; preference given to the establishment of indigenous species; establishment of a free draining topography, sustainable dump rehabilitation and development of artificial wetlands.

They concluded that rehabilitation success appeared to be driven by top management buy in, meticulous monitoring and research, detailed closure planning and concurrent rehabilitation.

The Guidelines recognise four categories of success criteria as the general building blocks of the rehabilitation objectives that require adherence. These relate to post-mining landform and soil cover (LSC), vegetation (Veg), surface and ground water qualities (WQ) and management of residual and latent risks (RLR). Seventeen studies were reviewed to assess the status of rehabilitation success globally and in South Africa (Section 2.2). They were further assessed whether the themes of the studies related to or address any of the four success criteria defined by the Guidelines. The studies typically had more than one theme, where applicable the themes were also categorised as primary (P) and secondary (S) themes. The findings are summarised in Table 1.

Table 1 Summary of themes from the rehabilitation efforts and outcome studies

Author(s), date of study and case reference number from Section 2.2 Status of opencast coal mine rehabilitation	**Relates to or address the Guideline's success criteria**			
	LSC	Veg	WQ	RLR
Case 1: Haigh (1992)	P	P		
Case 2: Limpitlaw, *et al*. (1997)	P	S		
Case 3: Nell & Steenekamp (1998)	P			
Case 4: Javurek (1999)	P	P		P
Case 5: Holl (2002)		P		
Case 6: Nicolau (2003)	P	S		
Case 7: Sklenicka *et al*. (2004)	P	S		
Case 8: Ghose (2004)	P	S		
Case 9: Tongway & Hindley (2005)	S	P	S	S
Case 10: Limpitlaw *et al*. (2005)	S	P	S	P
Case 11: Moreno-de las Heras *et al*. (2008)	S	P		
Case 12: Ochieng *et al*. (2010)			P	
Case 13: Munnik *et al*. (2010)		S	P	P
Case 14: Banks *et al*. (2011)			P	S
Case 15: Saini *et al*. (2015)	S	S	S	P
Case 16: Bureau for Food and Agricultural Policy (2015)	S	S	S	P
Case 17: Weyer *et al*. (2017)	S	S	S	P

Each of the reviews had a primary and sometimes a secondary theme that linked with the four success criteria of the Guidelines. The suggested key points for rehabilitation success by Milaras *et al*. (2014) can also be linked to these criteria. It is concluded that the Guidelines were well aligned with the current status of opencast coal mining impacts and rehabilitation requirements. The movement of the primary themes of the reviews from left to right over time of assessment confirms the chronological order of the manifestation of the impacts of the criteria. It also shows the evolution of our understanding of rehabilitation. The focus on some of the themes can only be seen after the publication of the Guidelines. The above suggests that the Guidelines were still as applicable today as it was when published in 2007 or in other words, the Guidelines had the foresight to address issues before others as the date and primary themes of some of case studies suggest.

2.5 Literature review conclusions

Opencast mining in the Highveld and Witbank coalfield has led to significant environmental impacts that affect the whole ecology. Current rehabilitation results have generally been described as a failure with a significant reduction in land capability. Apparent current rehabilitation practices are also such that no other result can reasonably be expected. The key word search to determine the status of rehabilitation efforts and outcomes did not yield any results demonstrating successful rehabilitation of opencast coal mines. This was alarming since coal have been mined extensively for almost two centuries notwithstanding the numerous regulations that have been promulgated globally and are supported by the development of various rehabilitation guidelines and best practices. It was shown that changes to environmental and financial provision legislation in South Africa were increasing and not in the favour of mining companies. These legal frameworks in South Africa provide the “what to” do to minimise the environmental impacts of mining activities to an acceptable level. Industry professionals are of the opinion that the focus toward successful mine rehabilitation and closure should be directed to aspects that details the “how to” do it.

The Guidelines were initially compiled in 1981, and republished in 2007, as the “how to” guide to achieve successful rehabilitation and closure. It is also the most widely recognised and advanced guideline for opencast mining rehabilitation to date. The practical aspects and four success criteria of the Guidelines were compared against the primary themes of studies related to the efforts and outcomes of rehabilitation. It was concluded that the Guidelines could be seen to be as relevant today as publication in 2007.

A closure certificate can only be issued once the predetermined rehabilitation objectives have been achieved through four categories of success criteria. In order of chronological appearance, they relate to post-mining landform and soil cover, vegetation, surface and ground water qualities and management of residual and latent risks. The success of the criteria builds on the success of the previous criterion. It is argued that if 100% success could be achieved in the first three criteria, residual and latent risks would be minimised to such an extent that it only relates to our shortcomings of scientific and engineering knowledge.

The purpose of the Guideline is to guide the practical implementation of rehabilitation with a specific focus on achieving the first criterion of post-mining landform and soil cover success. It is concluded that the Guidelines seems to offer much more value than found in current rehabilitation results and that the outcomes of rehabilitation of opencast coal mines could be very different if they were used. If so then compliance to the Guidelines could favourably shape the nature of legislation in future.

3 METHODOLOGY

3.1 Introduction to the methodology

The hypothesis of this research is that there is a relationship between Guidelines compliance and rehabilitation success. The relationship could indicate that the Guidelines do not add value in which case the aim of the research would not be reached. If the relationship indicates a positive contribution, increased compliance by the mining sector will yield better rehabilitation outcomes and could thereby shape the nature of changes in legislation in their favour of the mining sector from the current situation. The existence and nature of such a relationship can be determined as described by the two key questions that inform the two objectives of the study. Firstly, a method had to be devised that could determine the extent to which mines were following the Guidelines and secondly a method that could determine rehabilitation performance of the same mines.

As shown in the literature review the Mpumalanga province in South Africa is one of the largest agricultural hotspots and contains almost half of the high capability arable land in South Africa. Mpumalanga also holds the largest producing coal fields in the country. Long-term food security has been and still is severely compromised while pressure on mining houses to re-establish the same land capability on mined land is growing. The province still has several opencast operations that extract coal from the same coalfields utilising the same mining techniques. This provided an ideal opportunity to conduct case studies of mines with similar environments to ensure consistency to the research approach.

A research methodology framework was developed as part of the methodology approach and design (Section 3.2) as shown in Figure 8.

A. Questionnaires

- Assess rehabilitation practices within landform and soil profile development

B. Determine Guidelines compliance rank

- Assess guidelines compliance
- Rank mines from least to best compliance

C. Evaluate rehabilitation success

- Determine landform rehabilitation success
- Determine reconstructed soil profile success

D. Determine relationship

- Plot rehabilitation success against compliance ranks
- Develope trendlines, the slope indicates relationship between Guidelines compliance and rehabilitation success

E. Sensitivity analysis of results

- Sensitivity analysis

Figure 8: Research methodology framework

The following paragraphs introduce the sub-sections of Figure 8 and are elaborated on in more detail in Chapter 2.5. Guidelines compliance was determined by means of questionnaires related to conformance of the key requirements of the Guidelines (A). Mines could consequently be ranked from least compliant to most compliant (B). Opencast coal mine rehabilitation follows four general sequential steps where the success of the previous step is a prerequisite for possible success of the next step. Measurements of a variety of aspects could be gathered from historical aerial images that were typically provided by Google Earth Pro. A geometric analytical mathematical model was developed that reconstructs three-dimensional key features of the topography of the mines from the Google Earth Pro measurements to determine rehabilitation related material movement volume requirements. This and other measurements were used to assess rehabilitation performance of the first step of rehabilitation that includes landform development and soil reconstruction as an indication of overall rehabilitation success potential (C). Rehabilitation performance was then plotted against the compliance ranking of each mine to develop a linear trendline that indicated the relationship of Guidelines compliance and rehabilitation success (D). A sensitivity analysis was finally done to assess the output uncertainty against the probable range of input parameters.

3.2 Methodology approach and design

The aim of the research was to assess whether the degree of Guideline compliance adds any value to rehabilitation success or failure, or simplified as "How does the compliance to the Guidelines influence rehabilitation success?" This also addressed a bigger issue to determine whether there was evidence to re-emphasise the importance of the basic fundamentals of physical rehabilitation practices as part of the dynamic nature of ongoing changes in legislation. The following two objectives were formulated to achieve the aim of the research:

1. To evaluate the extent to which the Guidelines were being followed; and
2. To determine whether there was any relationship between rehabilitation success and the extent to which the Guidelines were followed.

According to Rowley (2002) and Yin (2002) the way to choose the most appropriate research methodology is by considering three aspects of the research as follows:

- What the type of research questions are;
- The control the investigator has over the actual behavioural events; and
- Whether the research considers present or historical phenomena.

The responses to the three considerations for this study were:

- The type of research question was "how";
- The investigator was a third-party assessing practices and results with no influence on how these are approached by various organisations; and
- The research considered current practices and results.

Given these answers, case studies would be the most appropriate research methodology to use (Yin, 2002). Case studies are specifically useful to investigate real world phenomena. Another benefit of case studies are that they could be approached in a qualitative and quantitative manner or as a combination of the two that allows the use of various sources (Rowley, 2002).

The simplified question of “How does compliance to the Guidelines influence rehabilitation success?” consists of two components, namely how well the Guidelines are being followed and what the related rehabilitation success is for a specific case study. Baxter and Jack (2008) states that multiple case studies allow for the analyses within and across each case to understand similarities or differences between them. They further state that the approach renders robust and reliable information. By making use of multiple case studies, a comparative relationship can be drawn to determine the nature of influence the Guidelines have on rehabilitation.

It was previously concluded that the success of rehabilitation criteria builds on the success of the previous criterion. A second conclusion was made that the purpose of the Guidelines was to guide the practical implementation of rehabilitation with a specific focus on achieving the first criterion of post-mining landform and soil cover success. Therefore, for the purpose of the research study and to set the boundaries of the case studies, compliance to the Guidelines and rehabilitation success focused specifically on the aspects related to achieve the first success criterion as an enabler for overall successful rehabilitation.

The basic nature of the research question was to answer “how” which was structured as two objectives. It was shown that case studies were the most appropriate research methodology to address the said objectives. A specific focus area was identified to determine research boundaries and led to the formulation of an overall research framework is previously shown in Figure 8.

3.3 Objective 1 methodology

Questionnaires were developed to gather information to determine the degree to which the Guidelines were being followed for the respective mining areas. In addition to which the questionnaire also aimed to gather information to evaluate the related rehabilitation practices as context to determine the main objective. The aim was to get feedback from all six active mining companies and as many of the 21 active collieries in the study area as possible. Participants were requested to identify and complete a questionnaire for every opencast area they were personally involved in. The questionnaires focused on topsoil stripping and placement approaches, equipment selection and the development and construction of post-mining landforms.

Individual questionnaires were developed for rehabilitation practitioners (RPs) and mining engineers/planner (MPs) as both parties should play an integral role to follow the rehabilitation guidelines. Each questionnaire consisted of nine multiple choice questions and a tenth question to identify the mining area to which the answers apply. The aim of the structure of each questionnaire was to ask three questions related to landform aspects and soil aspects respectively. It was aimed to structure the questions in such a way to reflect on as many of the nine points in the Summary of the Guidelines section. Three questions were included to provide supplementary information, specifically knowledge of the topsoil depth required and the post-mining land-use that needed to be achieved.

An effort was made to structure the questions in such a way to give the impression of general data gathering. The purpose was to avoid participant bias to answers as a means to show overall good performance of the mine. It is noted that the questionnaires were anonymous and, on the condition, that the details of the mining area would not be mentioned to maximise responses. Mining areas were therefore referred to as alphabetical letters. The implication of this is that no aerial images or anything that could lead to the identification of the mining areas could be shown. Ethical clearance (Protocol Number: H18/02/02) was obtained to gather information via questionnaires.

The responses were assessed for RPs and MPs and reduced to a single collection that could be used for further analysis. Incomplete responses and responses that could not be linked to specific mining areas were discarded.

The extent to which the Guidelines were followed was calculated as the distribution of applied rehabilitation practices per question and expressed as a percentage. A reflection was also given on the applied rehabilitation practices in three sections with related questions as follows:

- Questions related to topsoil stripping and placement;
- Questions related to topsoil thickness, land use requirements, perceptions the availability of sufficient topsoil and plant used to place topsoil; and
- Questions related to landform development and design.

3.4 Objective 2 methodology

To determine if there are any relationship to rehabilitation success and extent to which the Guidelines are being followed, nine of the 24 questionnaires were discarded for the purpose of the second objective for the following reasons:

- Most of the discarded areas had not yet been mined or were in the initial phases of mining and considered to be too small to be used for measurements. Only mines with visual evidence that steady state mining have been achieved were assessed;
- Details from Google Earth Pro (2018) were insufficient; and
- Infrastructural development had taken place on rehabilitated areas.

Rehabilitation success was assessed for the remaining 15 areas in their current status. They were also ranked in terms of how well the guidelines were followed as a basis of comparison against rehabilitation success to determine whether any relationship exist. The measure of rehabilitation success was assessed in terms of the individual parts of the first rehabilitation criterion namely post-mining landform and soil cover reconstruction. For the purpose of the research the various aspects of the two criteria were collectively defined land functionality and land capability, respectively.

3.4.1 Measuring of rehabilitation success for land functionality

Land functionality was assessed in terms of the ability to free drain clean surface water on current and potential future levelled areas. Google Earth Pro (2018) was used to view the historical imagery and related acquisition dates of the images to understand the mining footprint, duration of mining and rehabilitation schedule over time.

The ability to free-drain surface water was determined as the percentage free-draining areas for levelled and potential future levelled areas at final voids. Recent images during the wet season was used to visually identify and measure ponding areas on levelled areas. This conservative approach ensured that the measured areas were not over exaggerated as the visible ponding area could not be larger than the non-free-draining catchment area. Industry practise have shown that ponding areas could normally be rectified by making provision for a free-draining route by cut and using the same material to fill the remainder of the low-lying area. Significant ponding areas with no apparent free-draining route that could be rectified by the above approach were identified as isolated voids. It was therefore and further assumed that unlevelled areas (excluding the final voids and other isolated voids) could be shaped and levelled to be free draining in future as part of concurrent rehabilitation and was not used further in the assessment. The measure of rehabilitation success for land functionality was therefore reduced to the percentage of final voids and isolated voids that could be made to free drain.

To assess the percentage of the areas comprised by the current pit (final void) and isolated voids that could be filled and/or shaped to be free-draining an analytical geometry mathematical model was developed in Excel (Microsoft, 2016) to simulate the post-mining landform development of final voids. The rehabilitation approach of final voids aimed to move the minimum material by means of balanced cut and fill until the required slopes had been achieved. Low lying areas that resulted in ponding were then filled until the sub-catchment was able to drain to the surrounding catchments. The volume of isolated voids within the area of consideration were backfilled if excess fill material was available following the backfilling of the final voids. If fully backfilled, these areas were considered to be free-draining and could then receive topsoil. The resultant negative impacts from unrehabilitated final voids were in general more than that of isolated voids and therefore took preference to material allocation.

The current void dimensions, ramp lengths and daylight elevations, stockpiles, key elevations of the macro topography and other relevant features were measured with Google Earth Pro (2018) as shown in Figure 9. For the purpose of the study there was no need to establish exact measurements but rather comparative measurements. The root mean square error of vertical measurements in Google Earth Pro (2018) were computed at 1.7m and less for horizontal measurements (Mohammed, Ghazi, & Mustafa, 2013). Given the average distance of 1 577m between elevation extraction points and average elevation difference between the two points of 9m, the discrepancy was considered to be sufficiently accurate.

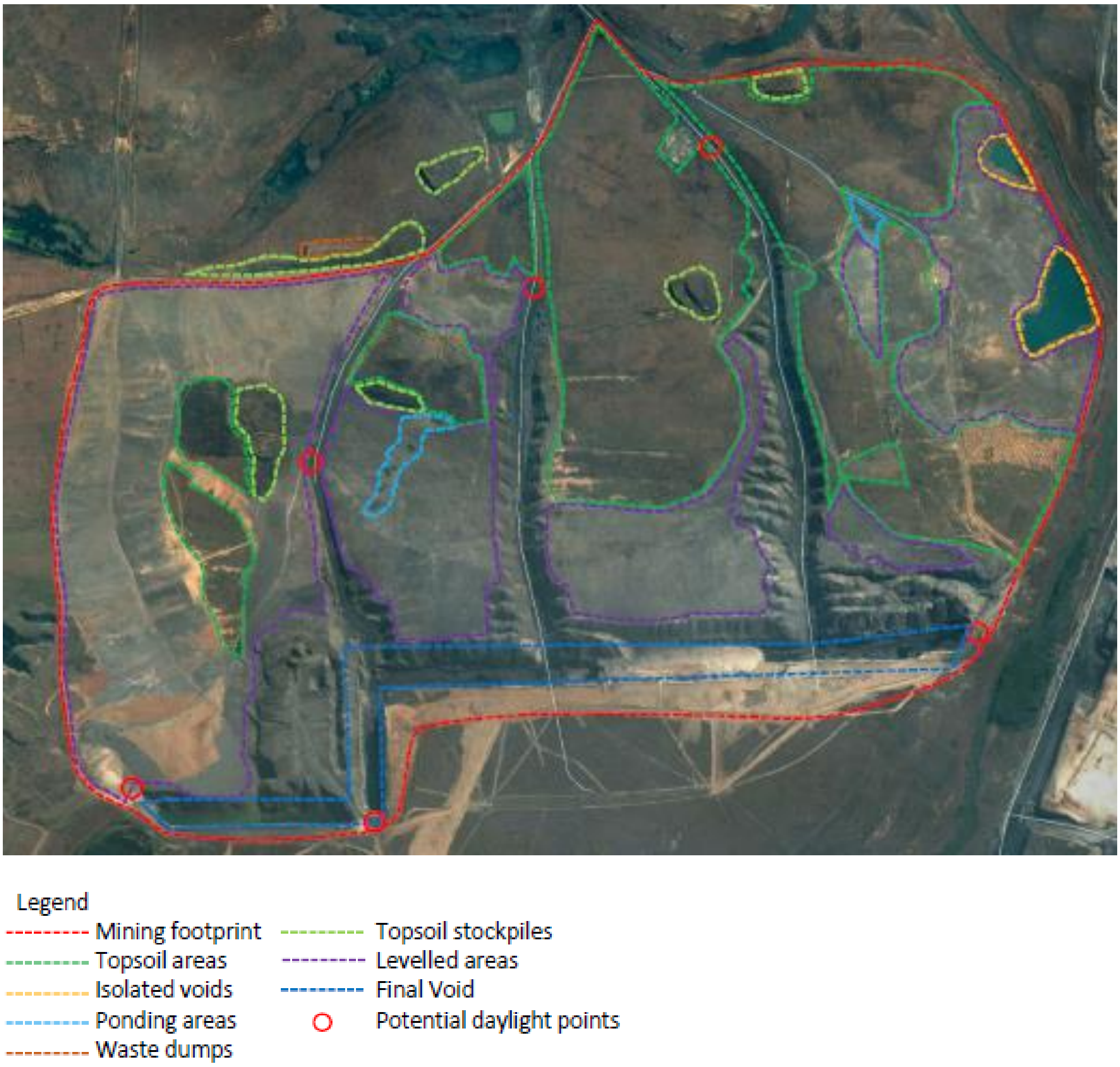


Figure 9: Google Earth Pro (2018) typical measurements

The measurements were then used as input to reconstruct a simplified mathematical geometrical model for further analysis (Figure 10,Figure 11 and Figure 12). Each mining area was sub-divided into smaller areas were representative of the simplified area and then analysed collectively.

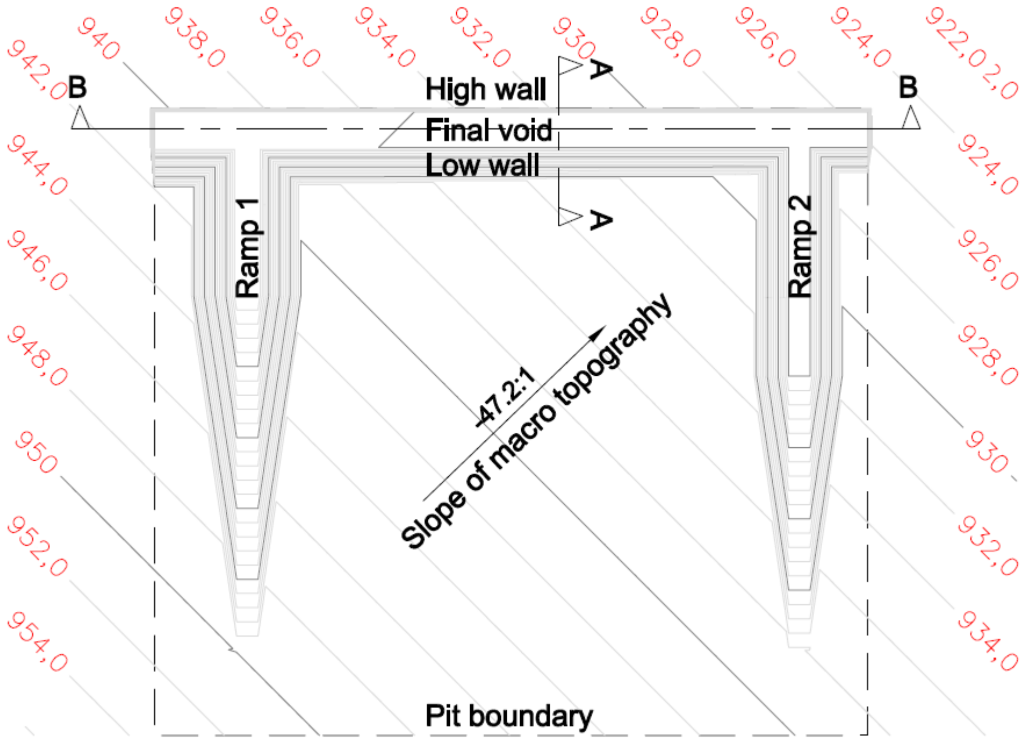


Figure 10: Typical reconstructed geometric model of an opencast pit layout

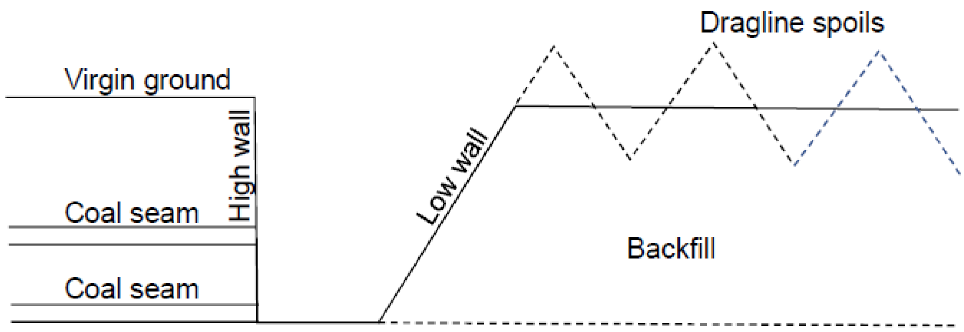


Figure 11: Typical section through final void (A-A)

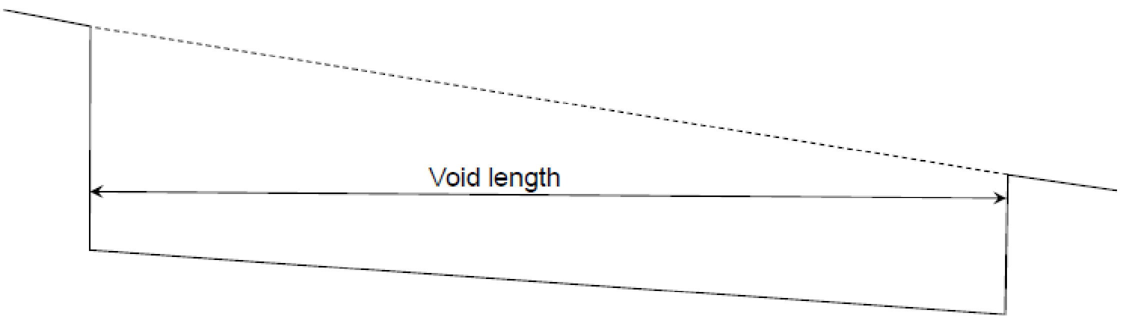


Figure 12: Typical section through final void (B-B)

Low wall shaping was done first since it consisted of unconsolidated material and could be moved by dozers to fill the bulk of the void (Figure 13). The required shaping of the high wall was thereby reduced as the virgin area to be shaped typically requires blasting. Final voids, in most cases, extend right to the mining rights boundary or other constraints and consequently did not allow shaping on the high wall side. In such cases the high wall had been filled from the crest until the required slope has been achieved (Figure 14). The remaining areas that were still below the lowest available surface drainage daylight point were filled with material from the available waste dumps to create a free-draining drainage route with a slope of 1:300 (Figure 15). In the event that the shaped final void could not be made free-draining with the available backfill volume, the percentage of the final void that could be made free-draining was determined by reducing the void length.

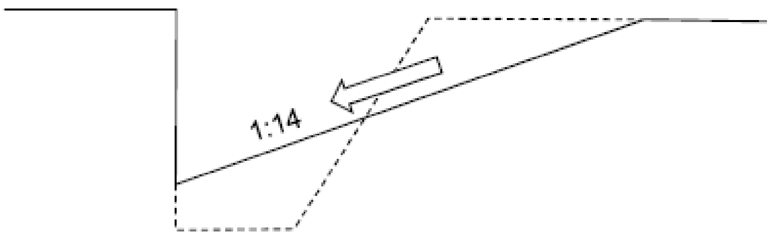


Figure 13: Low wall shaping

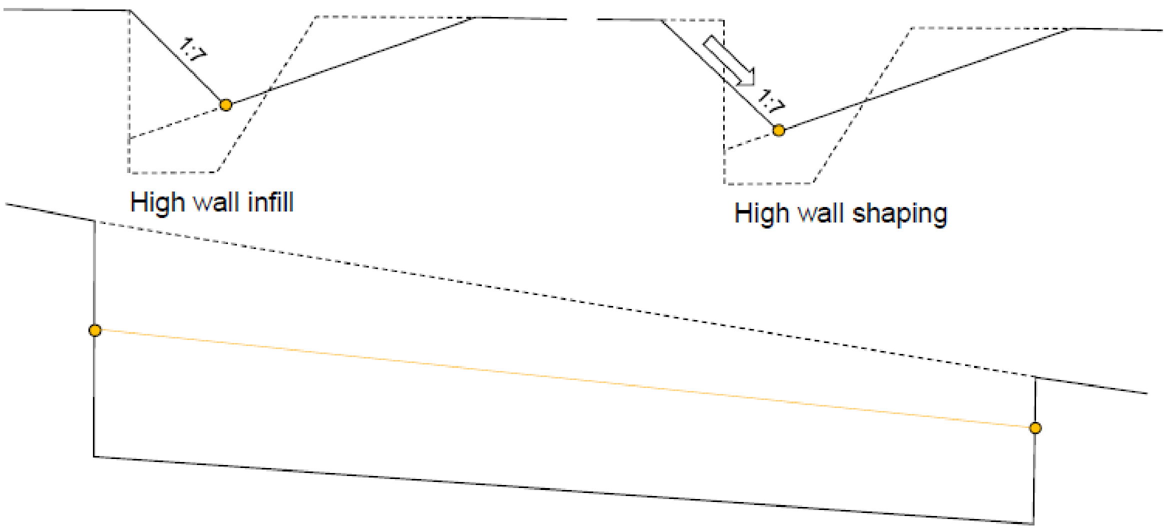


Figure 14: Typical high wall infill/shaping sections (A-A and B-B)

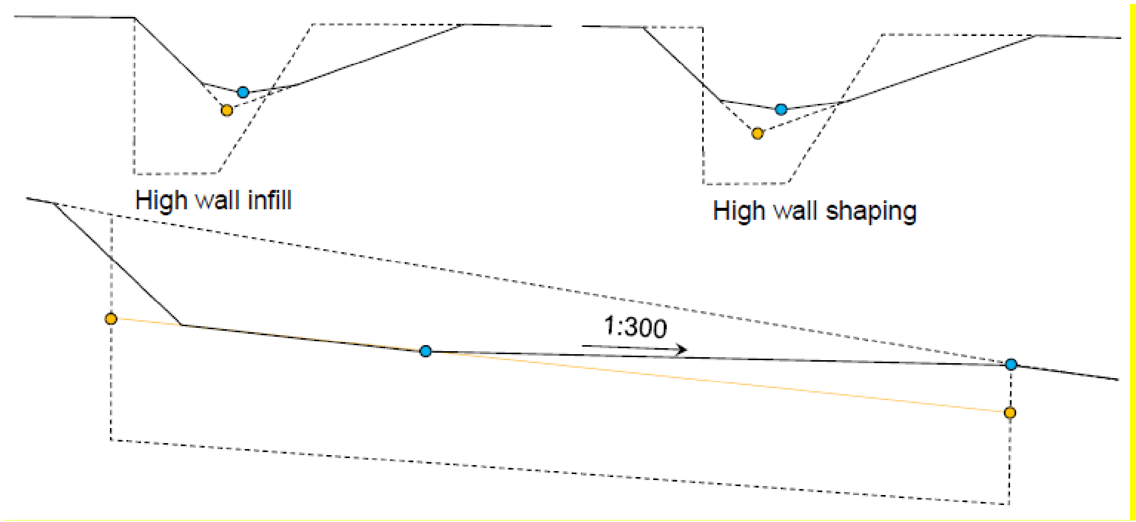


Figure 15: Typical fill to free-drain sections (A-A and B-B)

Only isolated topsoil or waste dumps within the footprint and in the vicinity of the footprint was considered to be available for future rehabilitation of the particular opencast areas. Stockpile volumes were calculated with airspace models in AutoCAD Civil3D (2017) based on the Google Earth Pro (2018) aerial images for topsoil dumps, waste dumps and isolated voids. Footprints, toe lines, crest lines and other key features were traced while the height/depths were estimated from the horizontal length of the side slopes (X) assuming a natural angle of repose of 1:1.5

(empirically determined from the average of similar dumps and voids found in the study area) as Figure 16.

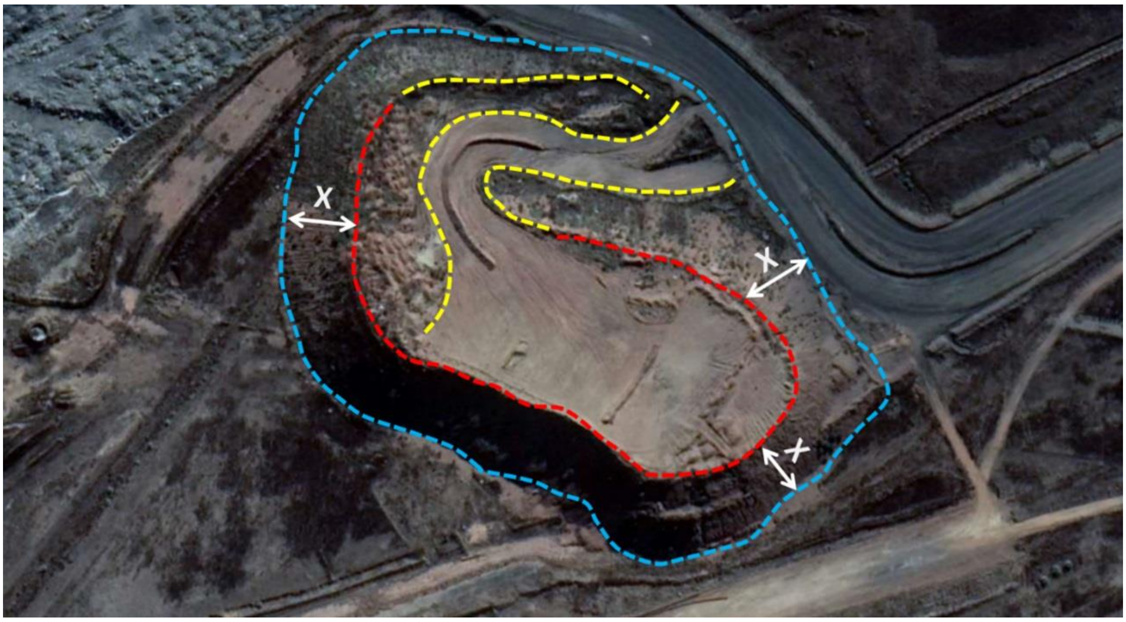


Figure 16: Volume calculation of dumps or voids (Google Earth Pro, 2018)

All three of the land functionality related questions in the questionnaires contribute to the likelihood that a functional and free-draining post-mining landform would be created and were mutually inclusive. Early development of a landform design, design compliance, setting-out and consolidation of rehabilitation efforts allowed for:

- Correct slopes to support the required post-mining landform;
- Correct backfill stockpile development and management;
- Following of the correct elevations as part of concurrent backfilling;
- Staying aligned with the materials balance to rehabilitate the final void; and
- Achieving overall free-draining topography.

The overall approach to determine the measure of rehabilitation success for land functionality was synthesized and expressed as the percentage of final voids and isolated voids that could be made free draining.

3.4.2 Measuring rehabilitation success for land capability

Landform capability success was assessed in terms of the extent to which the required depth of topsoil could be applied on the overall opencast footprint area. Google Earth Pro (2018) was used to measure areas that had already received topsoil. The resultant area of the final voids and isolated voids that could be made to free drain (as per the land functionality assessment), the remaining disturbed areas and waste dump footprints outside the mining footprint were considered to be available to receive topsoil. The total available topsoil volume from stockpiles were divided by the required topsoil placement thickness as per the questionnaires to determine the area that could be covered for each mine. Topsoil stockpile volumes were determined as described in the previous Section 3.4.1.

All three of the land functionality related questions in the questionnaires contributed to the likelihood that the required land capability could be achieved were also mutually inclusive. The assessment of rehabilitation success for land capability was determined by topsoil placement depth of future areas. The findings of Nell and Steenekamp (1998) and other literature indicate that that replaced soil properties were equally poor and therefore had no bearing on rehabilitation success. The approach to determine the measure of rehabilitation success for land capability was expressed as the percentage of the total disturbed areas that collectively had and could receive topsoil.

3.4.3 General limitation to determine rehabilitation success

Specific limitations have been mentioned in their related sections. General limitations of the methodology to determine rehabilitation success include the following:

- It was assumed that the strike cut with a down-dip advance was applied in all areas. It was therefore reasoned that the final void at the end of life of mine would not be shallower and similar in length than the current void. As a conservative approach the depth of the final void was accepted to be the depth of the current void. Given this and that rehabilitation success for land functionality was a function of the rehabilitation of voids and available backfill material on dumps which was unlikely to change after steady state mining had been achieved, rehabilitation success for land functionality would largely remain unchanged to the end of life of mine;
- It was also assumed that direct placement of topsoil was in progress as soon as steady state mining had been achieved. The disturbed areas without topsoil (excluding final voids) would therefore remain the same as the rate of topsoil

stripping and placement remains constant. This also means that topsoil stockpiles will not grow and was assumed to remain available until needed; and

- From the previous point it was further taken that the area of voids that could receive topsoil would remain static for the current period and to the end of life of mine scenario.

3.4.4 Summary of rehabilitation success assessment methodology

The measure of rehabilitation success was assessed in terms of the individual parts of the first rehabilitation criterion per definition of landform functionality and landform capability as follows:

- Land functionality success was expressed as the percentage of final voids and isolated voids that could be made free draining; and
- Land capability success was expressed as the percentage of the total disturbed areas that collectively had and could receive topsoil.

3.4.5 Guidelines compliance ranking

To determine if any relationship existed between the extent the Guidelines had been followed and rehabilitation success a comparative compliance rank had to be assigned to each. The level to which the Guidelines were followed was based on specific answers from questionnaires and measured calculations. Multi-Criteria Decision Analysis (MCDA) is useful to structure decision problems and evaluating and prioritising alternative decisions (Malczewski, 2006). The process accommodates qualitative and quantitative information that can also be weighted according to their relative importance or influence. MCDA was therefore selected to calculate a compliance performance score for each mine. Performance ratings were established for each criterion and respective criteria weights were determined with the Analytical Hierarchy Process (AHP). The results were used to inform a MCDA to evaluate the performance score of each mine. The performance scores were used to rank each mine from least to most compliant with the Guidelines.

The performance ratings for compliance of land functionality and land capability aspects and criteria weights were used to inform the compliance evaluation. Three specific questions from each were selected as compliance criteria as shown in Table

2 and Table 3. Performance ratings were assigned to each answer that demonstrated the mine's level of compliance to the Guidelines for each of the compliance criteria. Performance was initially assessed as Followed, Partially followed or Not followed with ratings of three, two and one respectively. To provide more qualitative granularity to the assessment the rating scores were consequently expanded to range from nine to one as shown in Figure 17. It is noted that the initial distribution performance ratings were considered in the sensitivity analysis. Performance ratings were assigned by a qualitative assessment of the possible questionnaire answers per question to demonstrate the measure of compliance to the key points in the summary of the Guidelines.

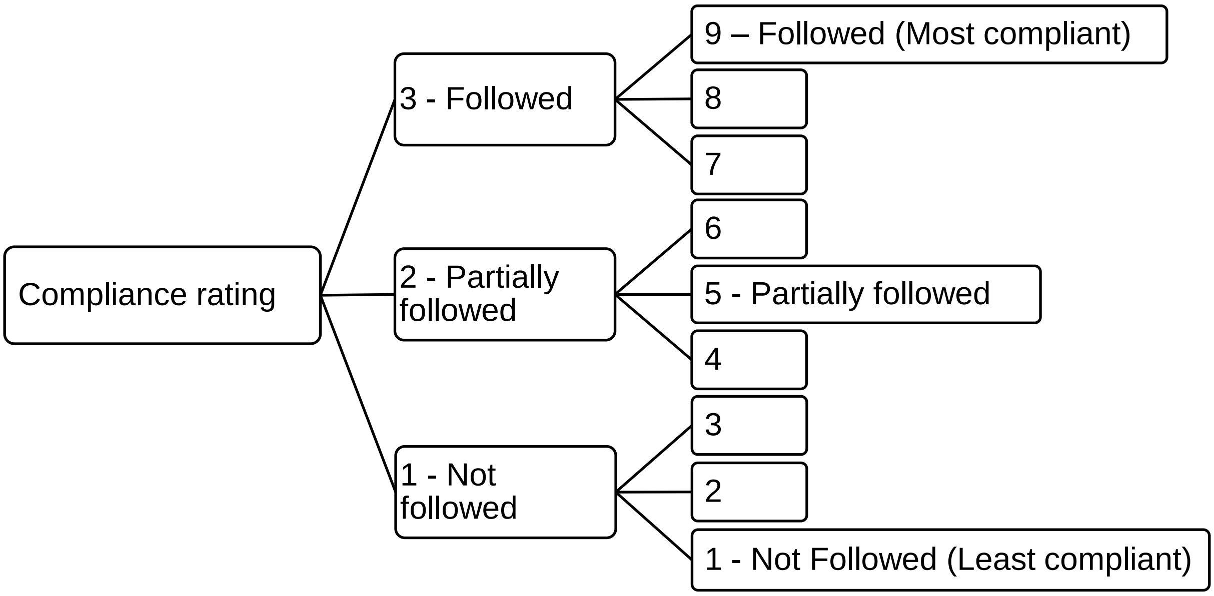


Figure 17: Guidelines compliance performance ratings

A fourth criterion was added for both land capability and land capability compliance in terms of concurrent levelling and direct topsoil placement to align with the Guidelines requirement to prioritise concurrent rehabilitation. Progress of concurrent levelling as part of land functionality was determined as the ratio between levelled areas and total disturbed area. The ratio of levelled areas to the total disturbed area would increase over time. This is attributed to the increase of the total mining footprint that was concurrently levelled while the rate of disturbance would remain in the same order of magnitude. The ratio of concurrent levelled area to the total disturbed areas was therefore divided by the number of years of active mining and multiplied by 10 as a factor to get an indication of how well concurrent rehabilitation was prioritised by the mine. The ratio of the area of placed topsoil to concurrent levelled areas was used to evaluate the measure of direct topsoil placement prioritisation. Criterion numbers have been assigned for easy reference where applicable.

Table 2: Land capability compliance criteria and ratings

Criterion number	Description	Source	Performance ratings
CS1	Successful soil stripping depth	Question 1: How is topsoil stripping done at your colliery?	a. 2 b. 5 c. 9
CS2	Successful soil stripping and placement methodology	Question 2: Are soil types indicated on a soil map and stripped accordingly and done so at a specific moisture content at your colliery?	a. 2 b. 6 c. 9
CS3	Use of appropriate equipment	Question 6: Do you have a dedicated fleet of plant (e.g. small dozers) to place and spread topsoil or is general mining equipment being used?	a. 9 b. 4
CS4	Direct placement of topsoil	Relationship between areas that have received topsoil and total levelled area.	Measured percentage

A measure of conditional scoring was applied for CL2 and CL3 as follows:

- CL2 a. was considered as Followed (9) unless the surveyor was not involved. The active involvement of the surveyor is critical to achieve the required landform and it is argued the required landform can at best be partially achieved with results in a performance rating of 6;
- CL2 b. was rated as 5 and 4 if the landform was acquired during the early and later stages of mining respectively. This was based on the perceived importance of landform implementation by the mine; and
- CL3 b. was rated as 5 and 4 if the landform design was Followed or Partially Followed respectively. This was also based on the perceived importance of landform implementation by the mine.

Table 3: Land functionality compliance criteria and ratings

Criterion number	**Description**	**Source**	**Performance Ratings**
CL1	Involvement of surveyor	Question 7: Does the surveyor guide material placement elevations on areas where backfilling/roll over or levelling is taking place?	a. 9 b. 1
CL2	Compliance to post-mining landform	Question 8: Please select the statement that best describes the actions at your colliery (related to the use of landform designs)?	a. 9/6 b. 5/4
CL3	Time of development of post-mining landform	Question 9: When did you acquire the post-mining landform design?	a. 9 b. 5/4
CL4	Concurrent levelling	Relationship between levelled area and total disturbed area.	Calculated factor

A qualitative pairwise comparison of relative importance was done for each of the four criteria for landform functionality and landform capability respectively. The importance of the criteria was based on the Guidelines with scores ranging from three to one for high to low importance respectively. The MCDA method was used to determine the performance score of each mine. The performance results for land functionality and land capability aspects with their respective criteria weights were used to develop weighted normalised matrices. A combined weighted normalised matrix was also developed to establish the average performance score for each mine. Mines were then ranked from least to most compliant for land functionality, land capability and a combination of the two.

3.4.6 Relationship analysis

The compliance rank of each mine was plotted on the X-axis and the percentage of rehabilitation success on the Y-axis for land functionality, land capability and as a combination. Linear trendlines were then generated for each of the three graphs for both base cases. The direction and slope of the trendlines indicated the relationship of Guideline compliance and rehabilitation results as follows:

- Positive slopes indicate that better compliance yields better results
- Flat slopes indicate no relationship between compliance and results
- Negative slopes indicate that better compliance yields worse results.

3.5 Sensitivity analysis

A sensitivity analysis was conducted where output uncertainty was scrutinised against the probable range of individual input values. Sensitivity analysis are particularly useful to determine the most influential input variables to output behaviour and to validate the research efforts (Ioos & Lemaitre, 2014).

Land functionality success was based on measures that could vary to future measurements at the end of life of mine. Base cases were developed for final void rehabilitation by means of high wall infill and high wall shaping that included the following inputs to key variables:

- The measured width of final voids at dragline operations vary considerably during mining. The void width for dragline operations was taken as approximately one strip width of 50m to reflect a more likely event that would be encountered at the end of the life of mine. The final void width of truck and shovel operations were taken as measured;
- The void depth was used as measured; and
- Low wall shaping was done to a slope of 1:14 and high wall shaping/infill to 1:7.

Variation to the key variables were considered individually as alternative inputs to the two base cases to assess the range of land functionality success as the following scenarios:

- Scenario 1: The width of final voids was taken as measured;
- Scenario 2: Void depths were increased and decreased with 15% respectively;
- Scenario 3: Void depths were increased and decreased with 15% respectively;
- Scenario 4: A slope combination of 1:7 on the low wall and 1:3 on the highwall to reduce cut and fill volumes; and
- Scenario 5: A slope combination of 1:3 on the high wall to reduce highwall shaping and 1:14 on the low wall to reduce additional fill to free-drain the remaining ponding areas.

The variability of land capability success was also determined for each of the scenarios of land functionality as the percentage of voids that could be made to free-drain varied.

The sensitivity to Guideline compliance was assessed by changes to the following as initially assessed in the two base cases:

- Scenario 6: Reducing the compliance scores to 3, 2 and 1 for Followed, Partially Followed or Not Followed with conditional scoring;
- Scenario 7: Reducing the compliance scores to 3, 2 and 1 for Followed, Partially Followed or Not Followed without conditional scoring;

- Scenario 8: Changing the importance ratings as input to the AHP to be equal for all four criteria;
- Scenario 9: Reducing the compliance scores to 3, 2 and 1 with conditional scoring and changing the importance ratings as input to the AHP to be equal for all four criteria; and
- Scenario 10: Reducing the compliance scores to 3, 2 and 1 without conditional scoring and changing the importance ratings as input to the AHP to be equal for all four criteria.

Trendlines were developed for each of the scenarios described in the sensitivity analysis to determine the sensitivity of the overall methodology and whether there were any limitations.

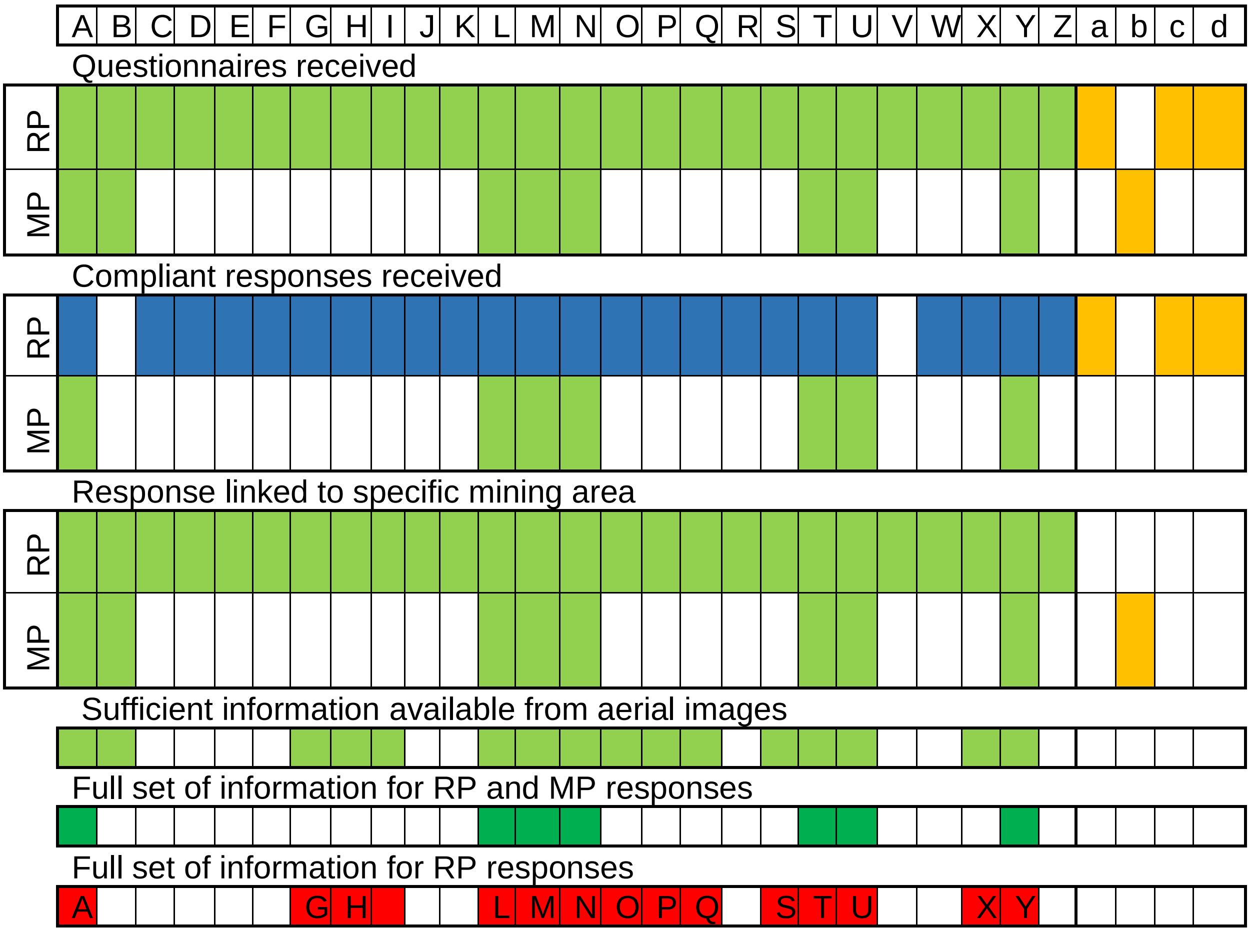
4 RESULTS AND DISCUSSION

4.1 Objective 1 results

Only one of the seven mining companies did not respond to the questionnaires, however the specific company only owned one of the active collieries. Table 4 illustrates the questionnaire response selection process. The alphabetical letters in the top row indicate the source colliery (mine reference number) of the response. Blocks without any fill indicate a lack of information for the specific aspect while the colours are for reference purposes only. A total of 38 completed questionnaires were received of which 29 were completed by RPs and 9 by MPs. Three and one of the questionnaires were completed by heads of departments for RPs and MPs respectively (shown in lower case letters). These could not be linked to specific mining areas and multiple answers were selected for the same question in many cases. The questionnaires from heads of departments were therefore discarded. Responses could positively be linked to 11 of the 21 collieries with a relatively equal representation of collieries to mining companies.

The aim was to get information from both parties per mining area not only to maximise the information to inform the evaluations but also to cross analyse the veracity of the answers to similar questions. Two of the responses from RPs contained multiple answers for the same question and were discarded. The responses of the remaining 24 questionnaires from RPs and seven from MPs could be linked to mining areas. If both questionnaires were used for the same mining area the sample size would be reduced to seven which were considered to be insufficient. The feedback of the RPs was therefore selected to inform the research study. The 24 responses of RPs that could be linked to mining areas and were filled in completely and correctly (indicated in blue) were used to evaluate the extent to which the Guidelines were being followed. Fifteen of the 24 responses could be linked to mining areas with sufficient aerial images (indicated in red) and were used for the second objective.

Table 4 Questionnaire response selection process



The questionnaire structure and questions are shown in the following tables in this section. The distribution of current practices of the 24 mining areas are reflected on and evaluated where applicable.

The majority of mining areas strip topsoil according to a stripping plan with guidance from a suitable experienced person (Table 5). Half of the mining areas do topsoil stripping without a soil map while the other half do but do not consider the moisture content during stripping (Table 6). It is concluded that a soil stripping is generally done to the correct depth. A concern is the lack of soil type consideration without using a soil map. Another concern was that those who do have a soil map do not consider moisture content and no evidence was found that moisture content was considered at all during soil stripping at any of the 24 mining areas.

Table 5: Question 1. Soil stripping method

1. How is topsoil stripping done at your colliery?	**Distribution**
Stripping to a constant predetermined depth	**29%**
Stripping kept to specific layers as visually determined by excavator operator	**17%**
Stripping is according to a soil stripping plan and guided on site by a soil scientist or suitable experienced person	**54%**

Table 6: Question 2. Are soil types indicated on a map and moisture content considered during stripping

2. Are soil types indicated on a soil map and stripped accordingly and done so at a specific moisture content at your colliery?	**Distribution**
No	**50%**
Topsoil is stripped according to a soil map, but moisture content is not assessed	**50%**
Topsoil is stripped according to a soil map at the specified moisture content	**0%**
Not sure	**0%**

Two thirds of the required post-mining land-uses are shown as grazing and correspond well to the 79% of mining areas that requires placement depths of 300mm to 500mm as is suggested by the Guidelines for this land use. The small percentage of arable requirements as per the respective EMPs is surprising given the large overlap of mining areas and high potential agricultural land. Wetland re-establishment on the mined footprint is required at 17% of the mining areas (Table 7 and Table 9). Both latter mentioned post-mining land-uses requires very careful efforts to be successful. The large percentage of perceived topsoil insufficiencies (Table 8) and mining equipment being used for topsoil placement (Table 10) suggests that topsoil management practices are poor and soil compaction can be expected at most of the mining areas.

Table 7: Question 3. Required depth of topsoil

3. What depth of topsoil is placed for rehabilitation at your colliery?	Distribution
±300mm	**58%**
±500mm	**21%**
±750mm	**4%**
±1000mm	**17%**

Table 8: Question 4. Availability of sufficient topsoil

4. Do you believe there is enough topsoil on at your colliery to sufficiently cover the required areas to the required depth?	Distribution
Yes	**25%**
No	**75%**

Table 9: Question 5. Required post-mining land-use

5. Which one of the following best describes the post-mining land use/s to be achieved at your colliery as per your EMP commitments?	Distribution
Mostly Arable	**4%**
Mostly Grazing	**67%**
Equal areas Arable and Grazing	**13%**
Mostly Arable with wetland re-establishment on mined footprint	**4%**
Mostly Grazing with wetland re-establishment on mined footprint	**0%**
Equal areas Arable and Grazing with wetland re-establishment on mined footprint	**13%**
Don't know	**0%**

Table 10: Question 6. Topsoil placement equipment

6. Do you have a dedicated fleet of plant (e.g. small dozers) to place and spread topsoil or is general mining equipment being used?	Distribution
Dedicated fleet	**38%**
Mining equipment	**63%**

Most of the mining areas indicated to follow a landform design that was acquired at the early stages of mining. This would be a good example of best practice if done with the aid of the surveyor. A post-mining landform developed during the later stages can very likely provide a solution that complies to the land-use requirements although flexibility and opportunity for optimisation of the most costly part of opencast rehabilitation decreases. The chances of rehabilitation success decrease even further if the latter is only partially followed. The key however is that no matter how early a well-designed landform is obtained, the absence of involvement of the surveyor nullifies its existence. The various combinations of results of Table 11, Table 12 and Table 13 can lead to very good or very poor practices and a wide range of post-mining landform success is expected to be found in the 24 mining areas.

Table 11: Question 7. Surveyor involvement with rehabilitation

7. Does the surveyor guide material placement elevations on areas where backfilling/roll over or levelling is taking place?	**Distribution**
Yes	**79%**
No	**21%**
Not sure	**0%**

Table 12: Question 8. Degree of following a landform design

8. Please select the statement that best describes the actions at your colliery?	**Distribution**
We have a post-mining landform design that we follow as part of rehabilitation.	**63%**
We have a post-mining landform design but don't follow it or only follow it partially as part of rehabilitation.	**38%**
We backfill and rehabilitated to the original ground levels.	**0%**
We will develop/design the appropriate rehabilitation/landform design towards the end of the life of the pit.	**0%**
No landform design work was or will be done.	**0%**

Table 13: Question 9. Time of acquiring a landform design

9. When did you acquire the post-mining landform design?	**Distribution**
Before mining stared of just after the start of mining	**58%**
During the later stages of mining	**42%**
Will be developed at the end of mining to close the final voids.	**0%**

It is concluded that the questionnaire results could suggest good overall rehabilitation practices if the favourable answers relate to a smaller percentage of the 24 mining areas. The variability in the results and poor key practices such as the lack to use dedicated soil maps, lack of moisture content consideration, use of heavy equipment, partial following of landform design and absence of surveyor input are rather an indication of variable and deficient overall rehabilitation practices that will inevitably lead to loss of land capability. Therefore, the extent to which the Guidelines are being followed varies significantly between the 24 case studies. This allows for an ideal distribution to plot rehabilitation success against and hence the development of the required trendlines.

4.2 Objective 2 results

The 15 responses of RPs that could be linked to mining areas, were filled in completely and correctly with sufficient aerial images were used to determine whether there was any relationship to rehabilitation success and extent to which the Guidelines were followed. These mines were indicated in red in Table 4.

4.2.1 Rehabilitation success

Rehabilitation success was determined for land functionality and land capability for two base cases and 10 alternative scenarios for each to determine the sensitivity of the overall methodology. The measure of rehabilitation success was assessed in terms of the individual parts of the first rehabilitation criterion per definition of landform functionality and landform capability as the percentage of final voids and isolated voids that could be made free-draining and as the percentage of the total disturbed areas that collectively had and could receive topsoil respectively. Table 14 show the input variables to the geometric analytic mathematical model while Table 15 shows the output.

Table 14 Analytical geometric mathematical model input information

Scenario		QTY	Unit
Void floor width	(Probability)	Min	
Void depth	(Probability)	Likely	
LW shaping slope	(Slope)	14	1:?
High wall shaping/infill	(Shaping/Infill)	Infill	
HW shaping slope	(Slope)	7	1:?
HW infill slope	(Slope)	7	1:?
Topsoil depth	(Depth)	1	m
Measured areas			
Total measured area		389.5	ha
Total measured topsoil area		15.6	ha
Total measured fugitive areas to be levelled and/or topsoiled		-	ha

Total measured pre-strip areas	-	ha
Total measured final void area to be levelled	34.7	ha
Waste dump footprints outside total measured area	14.4	ha
Total measured levelled areas	66.9	ha
Total measured ponding areas	3.3	ha
Actual length of final void	1,684.0	m
Isolated voids area within measure area	-	ha
Total topsoil stockpile volume	2,700,228	m^3
Pit/void input		
High wall infill/shaping	Infill	
Pit length for consideration	1,684.00	m
Ave pit length slope	240.57	1:?
Void floor width	50.00	m
Depth of final void	46.4	m
Compaction, swell, bulk & blasting parameters		
Compaction Factor at LW Shaping	1	Factor
Compaction factor at HW Shaping	1	Factor
High wall blasting swell factor	1	Factor
Rehabilitation parameters		
Low wall shaping slope	14	1:?
High wall shaping slope	7	1:?
High wall infill slope	7	1:?
Natural angle of repose	1.5	1:?
Topsoil thickness required	1	m

Table 15 Analytical geometric mathematical model output information

Material difference to free-drain final void	QTY	Unit
High wall shaping option	4,713,410	m^3
High wall infill option	2,504,715	m^3
Remaining topsoil		
High wall shaping option	0	m^3
High wall Infill option	0	m^3
Functionality – On already levelled areas		
Total ponding area	3.3	ha
Total levelled area	66.9	ha
Percentage free draining of total levelled	**95%**	
Total measured levelled areas	66.9	ha
Total measured area	389.5	ha

Percentage levelled of total measured area	**17%**	
Functionality – At final void		
Dumps available for backfill volume	4,713,410	m^3
Fugitive voids to be filled volume	0	m^3
High Wall Shaping option		
Fill to free-drain volume – HW shaping	-	m^3
Material difference to free-drain void	4,713,410	m^3
Material difference to backfill isolated voids	4,713,410	m^3
Can final void be made to free drain?	Yes	
Can isolated void be made to free drain?	Yes	
Total length of void	1,684	m
Total length of void that can be made free draining	1,684	m
Non-free-draining area	-	ha
Percentage free draining of voids	**100%**	
High Wall Infill option		
High wall infill required	2,208,694	m^3
Fill to free-drain volume – HW Infill	-	m^3
Material difference to free-drain void	2,504,715	m^3
Material difference to backfill isolated voids	2,504,715	m^3
Can final void be made to free drain?	Yes	
Can isolated void be made to free drain?	Yes	
Total length of void	1,684	m
Total length of void that can be made free draining	1,684	m
Non-Free-draining area	-	ha
Percentage free draining of voids	**100%**	
Capability – On already levelled areas		
Areas with topsoil	15.6	ha
Total levelled area	66.9	ha
Levelled areas without topsoil	51.21	ha
Percentage of topsoil place on levelled areas	**23%**	
Capability – At Final Void **High Wall Shaping Option**		
Total disturbed area requiring topsoil	416.4	ha
Total area that can receive topsoil	416.4	ha
Area that can receive topsoil	285.7	ha
Percentage of opencast area that can receive topsoil	**69%**	
High Wall Infill Option		
Total area requiring topsoil	403.9	ha

Total area that can receive topsoil	403.9	ha
Area that can receive topsoil	285.7	ha
Percentage of opencast area that can receive topsoil	**71%**	

Each mining area was subjected to the above analysis. Rehabilitation success results for the base case for are shown in Table 16.

Table 16 Rehabilitation success for base case

Base case – HW infill

Mine reference number	L	A	M	U	X	I	T	Y	G	N	H	P	Q	S	O
% to get topsoil	71%	47%	31%	44%	100%	79%	92%	44%	56%	30%	56%	44%	62%	50%	88%
% free draining of voids	100%	51%	100%	100%	100%	49%	6%	100%	22%	100%	13%	2%	0%	10%	0%
Combined percentage	85%	49%	65%	72%	100%	64%	49%	72%	39%	65%	34%	23%	31%	30%	44%

Base case – HW shaping

Mine reference number	L	A	M	U	X	I	T	Y	G	N	H	P	Q	S	O
% to get topsoil	69%	46%	30%	42%	100%	74%	92%	41%	55%	29%	55%	44%	62%	50%	88%
+ % free draining of voids	100%	100%	100%	100%	100%	63%	6%	100%	24%	100%	13%	2%	0%	13%	0%
Combined percentage	84%	73%	65%	71%	100%	69%	49%	70%	39%	64%	34%	23%	31%	32%	44%

4.2.2 Guidelines compliance ranking

The compliance ratings were assigned by a qualitative assessment of compliance to the key points in the summary of the Guidelines. A summary of compliance performance results (base case) of the four criteria for the respective land capability and land functionality aspects were summarised in Table 17. This was used as input data into the MCDA, after the related weights were determined by the AHP.

Table 17: Land capability and land functionality aspects compliance performance results

	Mine reference														
	L	**A**	**M**	**U**	**X**	**I**	**T**	**Y**	**G**	**N**	**H**	**P**	**Q**	**S**	**O**
Land capability performance ratings															
1	5	9	5	9	9	9	2	5	9	5	9	2	2	2	2
2	2	6	2	6	6	2	6	2	2	2	2	6	6	6	6
3	4	4	4	4	9	4	9	4	4	4	4	9	9	9	9
4	0.2	0.7	0.6	0.5	0.4	0.4	0.7	0.8	0.7	0.3	0.7	0.8	0.6	0.7	0.9
Land functionality performance ratings															
1	9	9	9	9	9	9	9	9	9	9	9	1	1	1	1
2	9	5	9	9	9	4	4	9	4	9	4	6	6	6	6
3	9	9	9	9	5	4	4	9	4	9	4	5	5	5	5
4	0.1	0.3	0.3	1.1	0.9	0.2	0.5	0.6	0.3	0.2	0.2	0.2	0.2	0.2	0.4

The importance of compliance criteria was qualitatively assessed to establish their relative hierarchy from highest to lowest importance as surveyor involvement, measure of following a post-mining landform, time of acquiring the post-mining landform and prioritisation of concurrent levelling design for landform functionality. Similarly, the criteria for land capability were compaction (use of appropriate equipment), stripping and placement methodology including moisture content considerations and prioritisation of topsoil placement. The assigned importance ratings were compiled as inputs into an AHP matrix, normalised to establish the criteria weights and tested for consistency (Table 18).

Table 18: Analytical Hierarchy Process results

Land capability

CS	1	2	3	4	Criteria Weight
1	1	0.5	0.33	2	0.168
2	2	1	0.33	2	0.231
3	3	3	1	3	0.484
4	0.5	0.5	0.33	1	0.117

Consistency assessment	
λ Max	4.12
Consistency Index	0.04
Random Index	0.90
Consistency Ratio	0.05
Consistency Ratio less than 0.10	Yes

Land functionality

CL	1	2	3	4	Criteria Weights
1	1	3	3	3	0.484
2	0.33	1	2	2	0.231
3	0.33	0.5	1	2	0.168
4	0.33	0.5	0.5	1	0.117

Consistency assessment	
λ Max	4.12
Consistency Index	0.04
Random Index	0.90
Consistency Ratio	0.05
Consistency Ratio less than 0.10	Yes

Table 19 shows the outcome of the MCDA as the compliance ranking for the two base cases. It is was found that compliance ranking was not necessarily the same for land and soil capability. Mines A, G, H and I shows consistent compliance over the two categories while mines L, O, P and Q on varied on average by 9.5 ranking places. This could suggest that rehabilitation practitioners have better skill sets and experience in either of landform recreation (and/or supported by surveyors) or soil reconstruction. It is the experience and opinion of the author that better landform recreation results are achieved when the surveyor is actively involved with the rehabilitation practitioner.

Table 19: Base case compliance rankings

Ranking	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Soil capability performance score	0.416	0.421	0.461	0.489	0.515	0.545	0.547	0.679	0.699	0.827	0.837	0.841	0.850	0.870	0.931
Mine ref number	L	N	M	Y	I	H	G	U	A	Q	S	T	P	O	X
Land functionality performance score	0.326	0.327	0.328	0.347	0.687	0.688	0.695	0.711	0.812	0.899	0.902	0.907	0.915	0.952	1.000
Mine ref number	S	Q	P	O	H	I	G	T	A	L	X	N	M	Y	U

Combined performance score	0.577	0.581	0.589	0.602	0.608	0.616	0.621	0.657	0.664	0.688	0.721	0.756	0.776	0.839	0.916
Mine ref number	Q	S	P	I	O	H	G	L	N	M	Y	A	T	U	X

4.2.3 Relationship analysis results

Rehabilitation success for each mine were then plotted against the mine's compliance rank relative to the other mines (Table 19). A linear trendline was developed that indicated the relationship of Guidelines compliance and rehabilitation success. The resultant relationship to rehabilitation success and extent to which the Guidelines were followed for both of the base cases for land capability, land functionality and as combined are shown in Figure 18, Figure 19 and Figure 20.

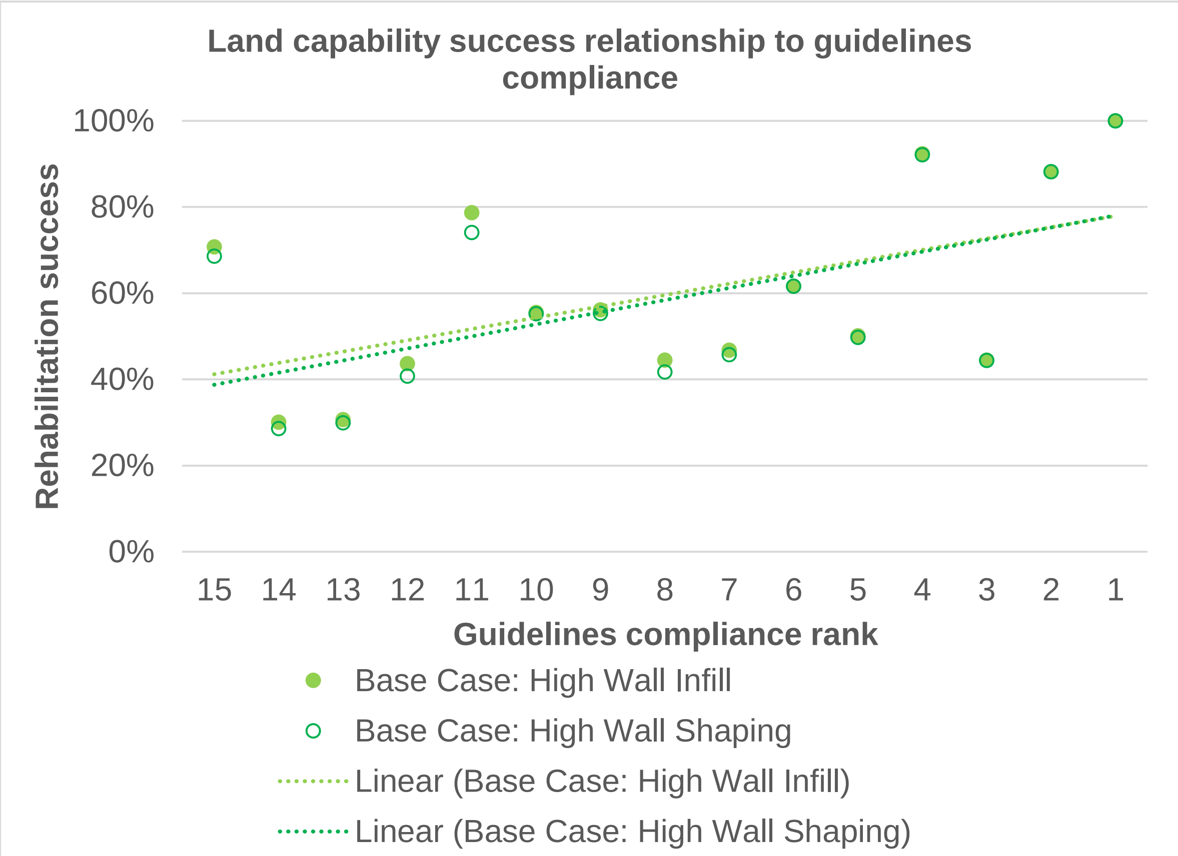


Figure 18: Relationship of Guidelines compliance rank to rehabilitation success: Land capability

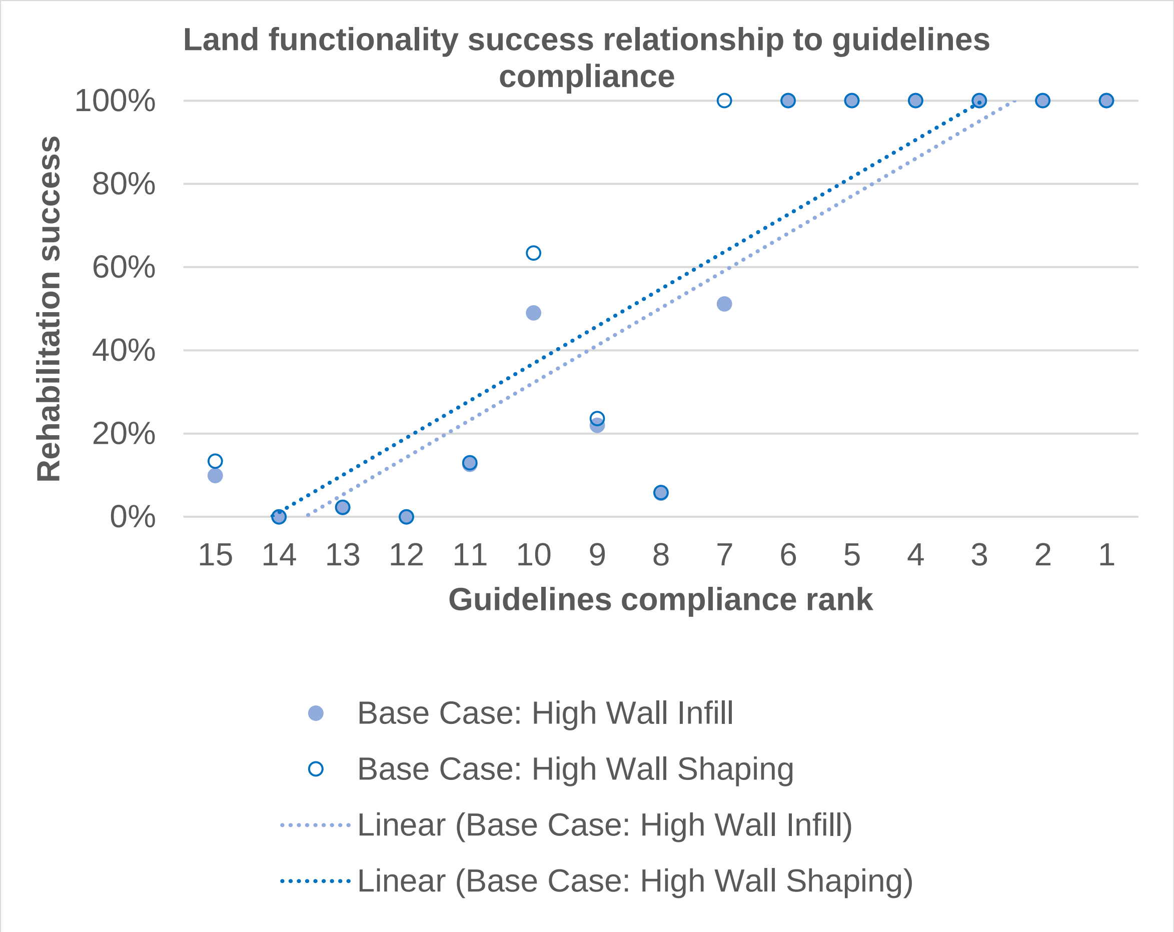


Figure 19: Relationship of Guidelines compliance rank to rehabilitation success: Land Functionality

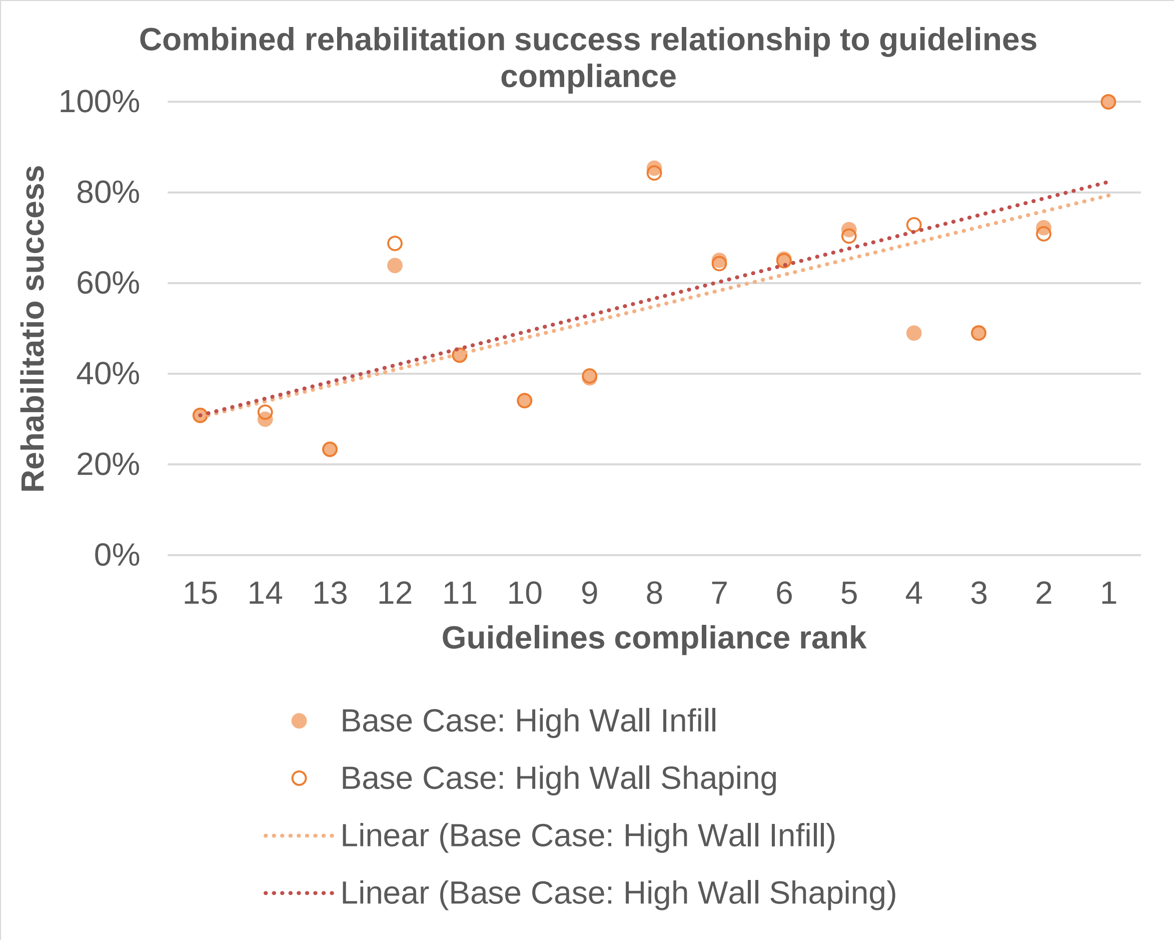


Figure 20: Relationship of Guidelines compliance rank to rehabilitation success: Combined

The relationship results show a positive trend for Figure **18** and Figure **19**. This indicates that mines with rehabilitation practices that were closer to what the Guidelines suggest, yield higher measures of rehabilitation success to those who practices did not comply for landform recreation and soil reconstruction. The combined results (Figure **20**) arrived at the same conclusion despite of the likelihood that rehabilitation practitioners are better skilled or supported in either landform recreation or soil reconstruction as noted in the results discussion of Table **19**.

4.3 Sensitivity analysis

A sensitivity analysis was conducted where output uncertainty was scrutinised against the probable range of individual input values. The slope direction remained positive for all the individual scenarios for land capability, land functionality and as a combination. Therefore, all the scenarios suggested that better guideline compliance yields higher rehabilitation success. Table 20 shows the slope variations found in the analysis.

Table 20: Trendline slope sensitivity analysis

High wall infill	**Base case**	**Scenarios**			**Slope difference from base case**	
		Min	**Mean**	**Max**		
Land capability	0.026	0.019	0.025	0.026	-0.7%	0.0%
Land functionality	0.090	0.088	0.090	0.091	-0.2%	0.2%
Combined	0.035	0.011	0.028	0.035	-2.4%	0.0%
High wall shaping						
Land capability	0.028	0.020	0.026	0.028	-0.8%	0.0%
Land functionality	0.090	0.084	0.088	0.090	-0.5%	0.1%
Combined	0.037	0.014	0.029	0.037	-2.3%	0.1%

Figure 21 and Figure 22 show the combined trend lines of the base case and ten scenarios for the high wall infill and shaping approach respectively.

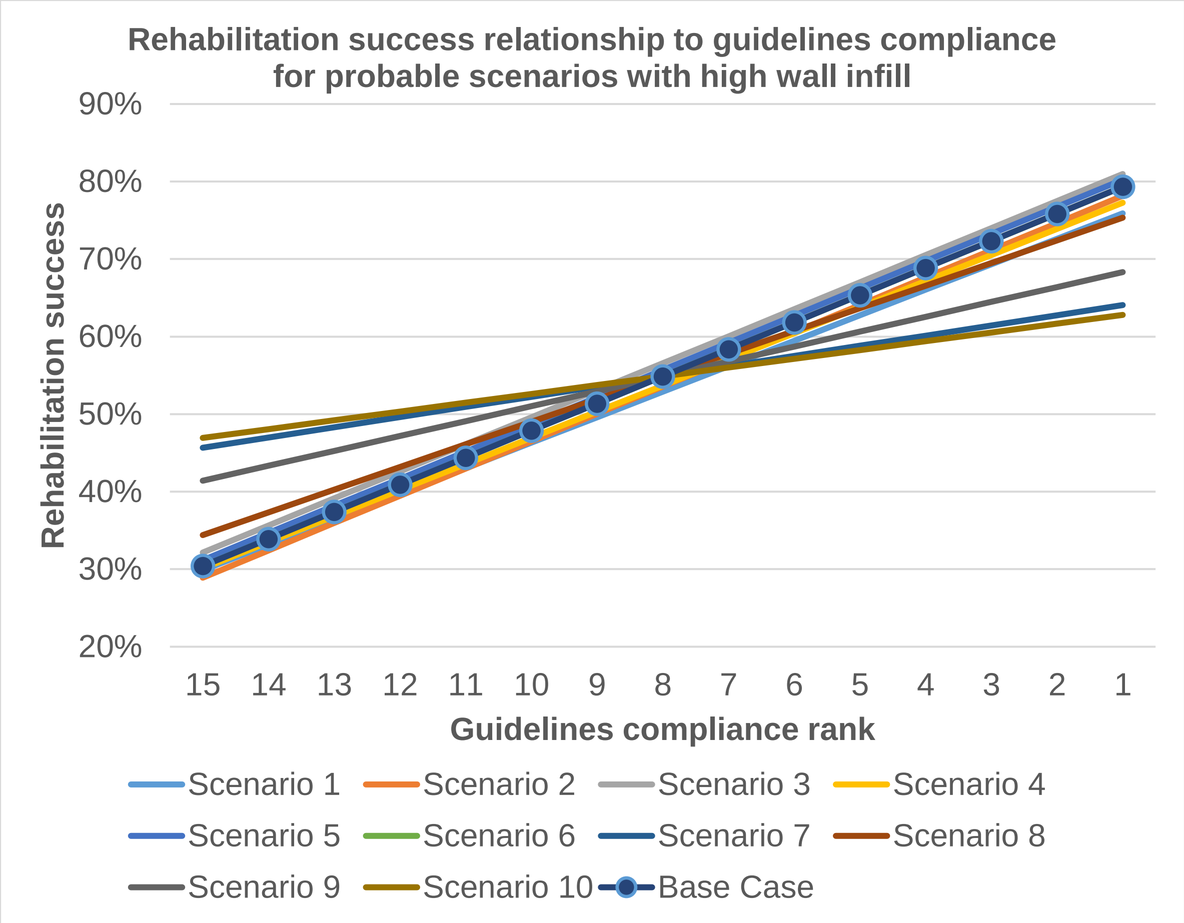


Figure 21: Trendline sensitivity for high wall infill scenarios

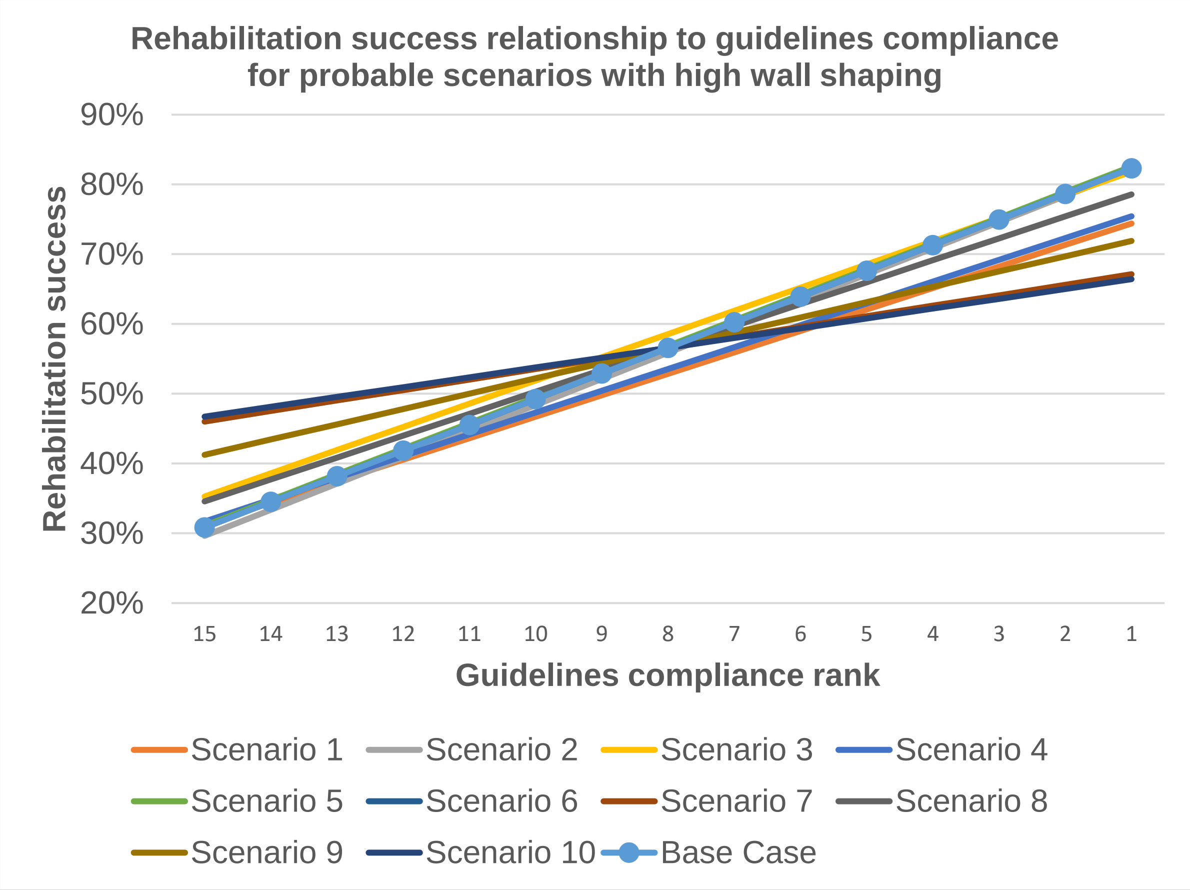


Figure 22: Trendline sensitivity for high wall shaping scenarios

Scenarios one to five considered variations to measured input parameters and slope criteria. Scenarios six to ten considered variations to guidelines compliance scores. Trendlines slopes and the associated coefficient of determination (R-value) were calculated for high wall infill and shaping options. The trendline behaviours are shown in Figure 23 and Figure 24.

The highest trendlines sensitivities were observed for Scenarios 8, and 10 for land capability. The scenarios included combinations of reduced sensitivity to compliance scores and assigned equal importance ratings to all aspects to inform the MCDA and AHP respectively. The decline in slope of the three scenarios is largely due to reduced R-values for all three scenarios. Areas that have received topsoil and can receive topsoil could largely be determined with good accuracy by means of simple measurements. Building on this and the research finding of better guidelines compliance yields higher rehabilitation, the reduced R-values implies that the importance ratings of aspect related to land capability rehabilitation were appropriately assigned in the AHP.

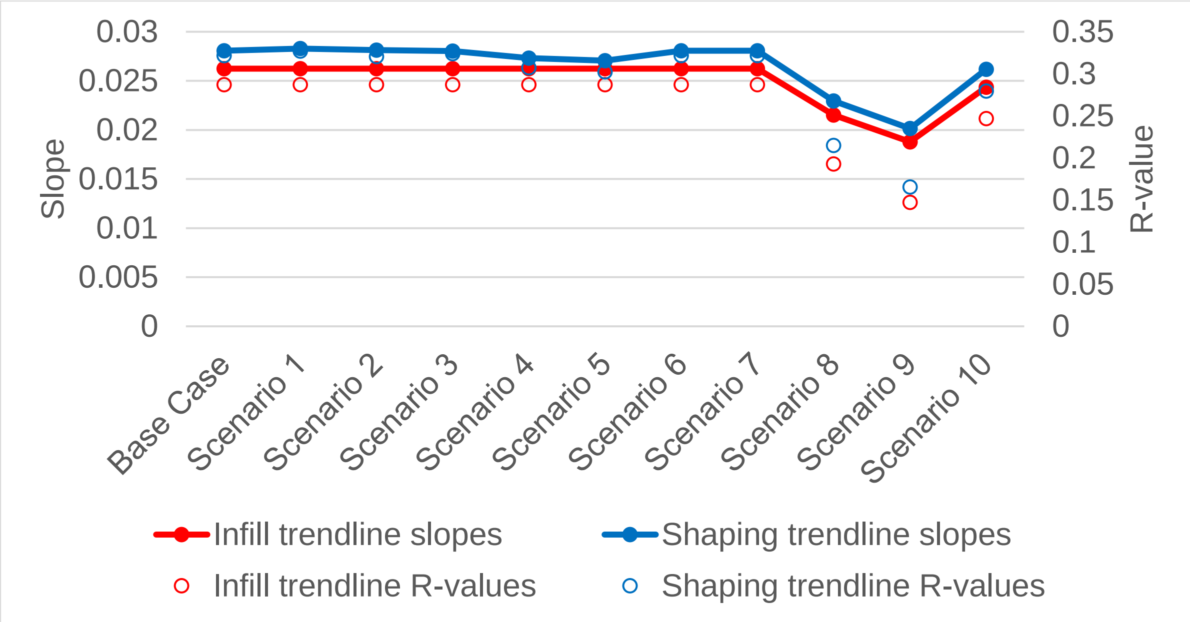


Figure 23: Trendline slope behaviour for land capability scenarios

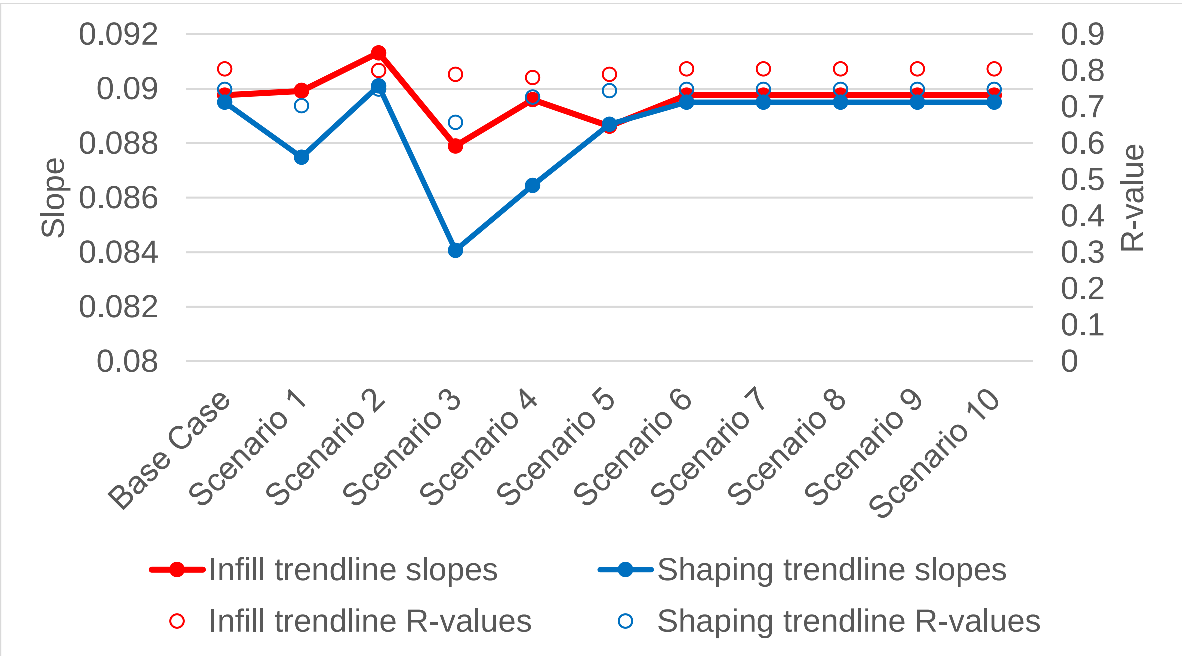


Figure 24: Trendline slope behaviour for land functionality scenarios

Higher sensitivity was observed for Scenarios 1, 3 and 4 for land functionality. Scenario 1 considered the final void width as measured. As stated in the methodology, the final width at the end of the life of mine is likely to be smaller than that of an operational mine due to the mining of multiple seams. Scenario 2 considered a 15% increase in void depth from what was measured. Both these scenarios were based on a larger void volume. The required material to rehabilitate the voids would logically be more and hence showed a reduced ability to be made to free-drain with the same available backfill volume as measured. Scenario 4 considered steeper slopes than the base case. While this resulted in reduced material shaping volumes that would be preferred by mines, the resultant volume to free-drain low lying areas will increase. The R-values remains consistent throughout indicating that the overall results of the methodology are sensitive to the characteristics of the three scenarios and should be determined with the proper care.

5 CONCLUSION

Status of opencast coal mine rehabilitation

Coal has been mined in the Highveld and Witbank coalfields for more than 100 years. Based on current demand and available reserves, global coal mining will continue for at least another 120 years and 60 years in South Africa. A large portion of this will be mined by opencast methods that goes hand in hand with impacts generally categorised as landform change and environmental pollution.

Mine rehabilitation aims to reduce the impacts of mining sufficiently to leave a post-mining landscape that has value for the next user and has acceptable levels of residual risk. In the literature review, 17 case studies were found related to opencast coal mine rehabilitation. The studies showed rehabilitation results varied significantly with no concrete examples of overall success. Specific attention was given to understand the shortcomings that was identified. The case studies were considered for the study area, but the search was also extended to include national and global studies. Not only was this method used to increase the sample size under consideration but also to get a thorough understanding of what the general themes of the case study focus areas were. It was found that the progression of the themes over time coincides with the order in which mining activity impacts are discovered.

South Africa has established a legal framework as a basis of what to do to sufficiently reduce environmental impacts from mining. The government has however become increasingly aware and wary of the consequent unknown liabilities as custodian recipients of mined land post-closure. The response from the various authorities have been to create mechanisms to force the mining sector to leave sustainable environmental legacies by means of rapid and ongoing changes in legislation. Authorities will each have a set of regulations and requirements hence the quantity of regulations and requirements increases with the number of authorities that are involved. It is the opinion of the author that more authorities or sub-authorities will be established in South Africa as the complexities towards the issuing of actual mine closure certificates are recognized. Should progress not be made with rehabilitation, the cycle of establishing more authorities and consequent legislation will continue while legislation will run the risk of becoming impossible to manage within a constructive and overarching framework.

Contrary to the reaction by authorities, a study of the opinions of industry professionals (in 2014) concluded with ways to allow for better rehabilitation outcomes which focused largely on the practical aspects of rehabilitation planning and implementation with almost no mention of change requirements to legislation. It is significant to note that the aim of the Guidelines (published seven years earlier and 33 years in the case of opencast coal mining guidelines) were to provide the practical basis for rehabilitation. The Guidelines identified four general success criteria that had to be met in order to achieve rehabilitation objectives which relate to post-mining landform and soil cover, vegetation, surface and ground water qualities and management of residual and latent risks. Incidentally the general themes of the rehabilitation shortcomings identified in the 17 studies could be categorised into the four success criteria identified by the Guidelines.

Aim of the research project

The aim of the research was to assess whether the degree of Guideline compliance adds any value to rehabilitation success which will influence the nature and frequency of changes to legislation. Questionnaires were developed with the aim to understand current rehabilitation practices and the related compliance to the Guidelines. No limitation was set on the stage of mining/rehabilitation and feedback was received from opencast areas that have not started to operate to areas where rehabilitation was considered to be completed (although small unrehabilitated areas were still identified). The measure of rehabilitation success was determined for the same mines. It is noted that rehabilitation success was measured for the first two steps of rehabilitation namely landform development and soil reconstruction only. The premise of this was that the subsequent steps of rehabilitation cannot be achieved if the first two steps were unsuccessful and that the first two steps cannot be feasibly repeated if the first attempt failed.

Aspects that could have an impact on the results of the research project

The land capability assessment assumed that topsoil on stockpiles and placed topsoil had the properties to function as per the EMP requirements. If this assumption was found to be false, it could reduce individual rehabilitation performance scores of the assessed mines. Although it was not tested in this study it could however strengthen the research hypothesis since the soil properties will likely be better had the Guidelines been followed.

The implications of material type identification inconsistencies from the aerial images will increase topsoil but decrease backfill material and vice versa. The consequence is that more topsoil may be available for placement but with reduced landform area to receive topsoil. Again, this statement is true vice versa. The average ratio of topsoil to backfill material was 1:2 suggesting that the gain and loss of each be negligent. The minimum and maximum ratio is however 0.03 and 3.53 which could result in a different rehabilitation performance outcome. Ground truthing of material identification could therefore add value to the study.

Base case measurements and sensitivity analysis

For the base case assessment, all dimensions were measured as is from the aerial images. It is recognised that the dimensions of active voids and ramps could change before final rehabilitation while mined-out areas can be measured more accurately. Mined-out area dimensions could therefore be confirmed by means of actual measurements; however, the dimensions of future final voids can only be estimated. Ground truthing in this instance would therefore yield accurate dimensions for mined-out areas but not for active areas. This uncertainty was addressed in the sensitivity analysis to consider plus and minus variations to measured values. Rehabilitation options with various slope configurations were also analysed for sensitivity. Lastly the sensitivity analyses tested the Guidelines compliance qualitative assessment rating assignment for subjectivity. A total of 22 scenarios were analysed for sensitivity in addition to the base case scenarios.

Final result

Guidelines compliance and rehabilitation success were plotted on a graph to determine the relationship between them by means of a linear trendline. It was found, without exception of any of the scenarios, that higher measures of rehabilitation success were associated with better Guidelines compliance. Whether compliance was intentional or not it was shown that the first two fundamental steps, and therefore the following steps, for opencast coal mine rehabilitation had a better chance of success if the value of the Guidelines were unlocked through compliance.

Value and shortcomings of the Guidelines

The Guidelines have been developed by the mining industry for the mining industry and it could therefore be argued that the proposed approaches would have been verified to be realistic and pragmatic. In addition to the collective engineering and scientific knowledge and practical experience of the contributors that is shared in the Guidelines, the various “how to” aspects were synthesized into simple and practical annexures that can be used as they are by anyone in the industry. The contributors do however acknowledge that the Guidelines were based on existing knowledge and may include gaps or omissions. This is followed by an open invitation to the general public to contribute to the Guidelines as knowledge gaps are filled and technology advances.

The Guidelines were the next generation from the guidelines for opencast mining in 1981 that tried to simplify mine rehabilitation in one generic guideline. This proved to be difficult as some examples exist where the Guidelines refers the user to specialist advice for case-by-case situations or anomalies. These are however few of these and they do not take away from the fundamental approach that is provided in the Guidelines. Mine rehabilitation is an integrated and very complex process and it can hence be expected that a one size fits all guideline is unlikely to exist. This was confirmed by the most recent rehabilitation guidelines (published late in 2019) by the same corporate authors that focused specifically on surface coal mines. It is their intention to develop guidelines that focus on specific mining methods and/or commodities in future.

Detailed explanations and a framework of the legislative processes involved in legal authorisations and financing are provided in the Guidelines. While this can be very valuable for the uninformed, it will inevitably become outdated. Keeping aligned with the purpose of the Guidelines to provide the “how to” practicalities of rehabilitation, the detailed references to specific legislation can potentially be changed to make the reader aware of the high level legislative requirements with references to where the most up to date information can be found.

Final conclusion

In conclusion, the research study has shown that mines in the Highveld and Witbank coalfields whose rehabilitation approaches were better aligned with the "how to" Guidelines achieved better rehabilitation outcomes than those who had less alignment. The direct causes of rehabilitation failures have been studied and is well known, the 17 case studies that were assessed stretched over a period 25 years. The Guidelines described various practical steps to be followed on how to plan and implement rehabilitation that is directly underpinned by the learnings of the failures of the case studies. Yet rehabilitation practitioners and mining engineers confirmed the sporadic and inconsequent rehabilitation approaches that is currently being applied. A disconnect to an integrated rehabilitation approach exists that is reflected in the current rehabilitation approach responses and rehabilitation results. The outcomes of this is the consequent and mostly reactive changes to legislation by authorities.

The research study further showed that the existing rehabilitation legislation cycle (Figure 1) is not sustainable as too much legislation can start to yield diminishing returns. When better rehabilitation results are achieved, the liabilities and uncertainties are reduced. This enables the authorities to get a better understanding of the remaining liabilities they need to take account of and take potential ownership of. It is finally concluded that the application of the Guidelines will help re-align the cycle (Figure 25) towards a sustainable and effective legislation regime.

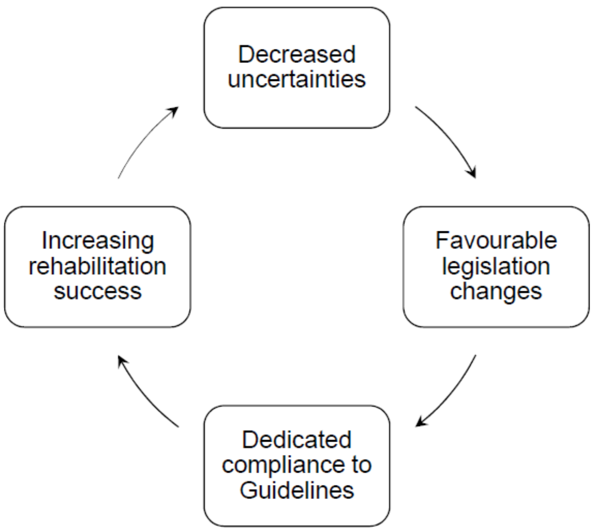


Figure 25 Rehabilitation legislation with dedicated Guidelines compliance

6 RECOMMENDATIONS FOR FURTHER RESEARCH

This research developed a methodology, with certain limitations, to determine the relationship between Guideline compliance and rehabilitation success. The methodology can be refined by considering other aspects as follow:

- Guidelines compliance was qualitatively determined and largely based on feedback from one person per mining area. It is suggested to triangulate compliance by means of quantitative measurements;
- Reconstruction soil cover success was assumed to be equally poor throughout based on literature. Topsoil management practices could however be rectified, and it is possible that different results have already been achieved recently. Site specific soil assessments would increase confidence in the overall methodology if included;
- Site specific topographical survey would refine material availability volumes measurements and volume requirements;
- Topsoil is in general easily identifiable from aerial images. On site stockpile identification will however increase the confidence of the methodology;
- A result of changing legislation is to avoid waste/discard dump development on virgin areas. In-pit disposal is becoming a favourite alternative and can significantly affect the overall materials balance. It is suggested to extend the sensitivity analysis to include in-pit disposal of discard.

It is also recommended to expand the research to specifically other commodities mined by opencast or even underground methods.

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APPENDIX A: ETHICAL CLEARANCE CERTIFICATE

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Barnard

CLEARANCE CERTIFICATE **PROTOCOL NUMBER: H18/02/02**

PROJECT TITLE	Evaluating the impact of recent rehabilitation guidelines on open cast coal mine rehabilitation in Mpumalanga
INVESTIGATOR(S)	Mr P Barnard
SCHOOL/DEPARTMENT	School of Mining/
DATE CONSIDERED	16 February 2018
DECISION OF THE COMMITTEE	Approved Permission letters are required before data collection can commence
EXPIRY DATE	10 June 2021

DATE 11 June 2018 **CHAIRPERSON** ______________ (Professor J Knight)

cc: Supervisor : Mrs I Watson

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

____
Signature

07/07/2020
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES