# Surface-strip coal mine land rehabilitation planning in South Africa and Australia: maturity and opportunities for improvement


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## Highlights

- A maturity model for surface-strip coal mine land rehabilitation planning is presented
- The model was applied to mine rehabilitation guidelines and approval reports
- Guidelines and approval reports are vulnerable to adequate, but not yet resilient
- Legislation may be contributing to immaturity for some aspects of planning
- Upfront planning and analysis in dynamic mining environments are discussed

## Abstract

At the mine approval phase, there is logically a focus on mine start-up and operational requirements, however, insufficient attention is given to rehabilitation planning aspects. To evaluate how rehabilitation planning is addressed upfront, we proposed a maturity model, which consists of three maturity performance indicators measured for seven environmental domain evaluative criteria. The maturity model, was applied to mine rehabilitation guidelines and mine approval consultant rehabilitation reports in South Africa and Australia, Queensland and New South Wales. We found that these documents were vulnerable to adequate, but not yet resilient, i.e. rehabilitation information was gathered, but seldom analysed, with limited integration and rehabilitation risk determination. Legislation, as well as the temporary and dynamic nature of mining, may inadvertently be contributing to immaturity. We conclude by discussing ways forward and the need to determine upfront, a site's total rehabilitation failure risk, as an aid to improving rehabilitation planning.

## Keywords

mine closure and rehabilitation; mineral legislation; risk assessment; environmental planning; multi-discipline; integrated modelling; maturity models; cumulative impacts

## Introduction

It is estimated that >50% of the Earth's land surface has been cleared by humans (Hooke R.L. et al., 2012). In Southern Africa, 16% of native vegetation was cleared by 2006 (Mucina and Rutherford, 2006). Australia, by 2004, suffered a similar 12% clearance of native vegetation (Thackway et al., 2010). In both these countries mining has claimed large tracts of high potential agricultural land, resulting in competition between agriculture and mining. This is especially true for coal mining, due to its geological formations, which extend over large areas. South Africa has 1.5% high potential arable soils, with half occurring in the province of Mpumalanga. At current mining rates, approximately 12% of this will be lost, while a further 13.6% is under prospecting rights (Bureau for Food and Agricultural Policy, 2012). Lechner et al. (2016a) for Queensland, Australia, reported approximately 61% of good quality strategic cropping land coinciding with coal mining exploration permits.

Land use degradation from coal mining is likely to continue into the foreseeable future with South Africa and Australia playing pivotal roles in coal supply, despite increasing market competition from alternative energy sources (Hancox and Gotz, 2014). Coal accounts for some 40% of global electricity production, is abundant, widely distributed across the globe, affordable and it is estimated that there are enough reserves for approximately 115 years at current production (World Energy Council, 2013). In 2011, South Africa ranked ninth and Australia fourth, in terms of countries, with largest proven recoverable coal reserves (World Energy Council, 2013). Given the ongoing threat to high productivity potential agricultural land and impacts on biodiversity, the science and practice of land rehabilitation is critical for meeting global and country environmental sustainability objectives and achieving future food security.

Our paper's geographical focus is on the Southern Hemisphere countries of South Africa and Australia, specifically Queensland and New South Wales. These countries and jurisdictions were chosen as they share similarities in climate, geology and vegetation. Also, many of the large mining companies are present in both countries and Australia provides an international bench-mark for comparison with South Africa.

Surface-strip coal mining can disturb landscapes extensively, typically affecting ten times more land than that affected by underground coal mining (Tongway and Ludwig, 2011). Surface mines have a disturbance potential that is unmatched by any other human activity, except for urban development. Surface-strip coal mining may involve the use of walking draglines which can excavate pits 2 km long, 50 m wide and 50 m high, thus potentially disturbing 5 million $m^3$ of soil per pit (Thompson, 2005).

Following coal extraction, disturbed lands require rehabilitation. Failure to rehabilitate mined land effectively may result in the occurrence of negative rehabilitation risks such as soil erosion and loss of valuable soil resources, soil and water contamination, soil compaction, ponding, surface cracking, spontaneous combustion and subsidence, which could lead ultimately to site rehabilitation failure (Australian Government et al., 2016b; Gauteng Department of Agriculture Environment and Conservation, 2008; Limpitlaw et al., 2005; Rethman, 2006). Site rehabilitation failure may include weed infestation and unproductive land with the substrate unable to support sustainable end landuses such as grazing and cropping. Withdrawal of social license may also result from poor rehabilitation performance, as well as company reputational damage and heightened community opposition to new and expansion mining applications and public campaigning for stronger regulatory controls, with added costs to mining companies. Mined landscapes are highly-disturbed (Erskine and Fletcher, 2013). Doley et al. (2012) state within the post-mining context, the inability to achieve true restoration, in terms of the 'pure restoration' definition, is due primarily to the radical differences between the physiochemical and biological characteristics of the original vs. rehabilitated mine environments. Rehabilitation may only be achieved in-part through a multi-disciplinary approach and restoration in its pure definition is seldom achievable.

Rehabilitation falls within mine closure planning, exerting an influence throughout the mine life-cycle (Australian Government et al., 2016a). The rehabilitation process is conceptualised as five stages of planning and implementation by Australian Government et al. (2016b): Stage 1. Defining rehabilitation objectives and targets; Stage 2. Conducting rehabilitation planning; Stage 3. Implementing rehabilitation techniques, which is split into five categories, i) Landform design and construction; ii) Reconstruction of the soil profile; iii) Selection of suitable species; iv) Establishment of vegetation and v) Fauna recolonization; Stage 4. Setting completion criteria; and Stage 5. Undertaking rehabilitation management and monitoring.

Sustainable development principles are of importance for rehabilitation planning. Sustainable development was first defined by the World Commission on Environment and Development as, 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). The 1992 and 2002 World Summits on Sustainable Development were further key milestones. Sustainable development principles have evolved with applicability to mine closure and rehabilitation in South Africa and Australia (Australian Government et al., 2011, 2016a, b; Australian Government and Department of Industry Tourism and Resources, 2006; International Council on Mining and Metals, 2003, 2008; International Institute for Environment and Development and World Business Council for Sustainable Development, 2002; Minerals Council of Australia, 2005). Sustainable development principles are not static, are often not universally agreed upon and have different compliance standards depending on local policy and legislation requirements. Sustainable development as applied to the Australian context means that, investments in minerals projects should be financially profitable, technically appropriate, environmentally sound and socially responsible (Australian Government et al., 2011, 2016a). In South Africa sustainable development is defined as, the integration of social, economic and environmental factors into planning, implementation and decision making so as to ensure that mineral and petroleum resources development serves present and future generations (Department of Minerals and Energy, 2002).

Mine rehabilitation legislation in both South Africa and Australia has developed in response to the sustainable development movement. In South Africa, prior to 1956, no mine closure and rehabilitation legislation existed (Limpitlaw et al., 2005). The first voluntary rehabilitation guideline document was compiled in 1981 (Chamber of Mines of South Africa, 1981). At this time rehabilitation was approved simultaneously with mining applications by the Department of Water Affairs & Forestry and the Government Mining Engineer (Wells, 1986).

Legislation promulgated thereafter included: Minerals Act, Act No. 50 of 1991; Environmental Impact Assessment Regulations of 1997 in terms of the Environmental

Conservation Act, Act No. 73 of 1989; National Environmental Management Act, Act No. 107 of 1998, National Water Act, Act No. 36 of 1998; Minerals and Petroleum Resources Development Act, Act No. 28 of 2002 and its 2004 Regulations (GNR No. 527); and National Environmental Management: Waste Act, Act No. 59 of 2008 (Supplementary material, Table 2). The Environmental Impact Assessment Regulations has had four amendments, the most recent in 2017. More recently the 2015, Financial Provisions Regulations were promulgated (Department of Environmental Affairs, 2015). These operate in conjunction with the Environmental Impact Assessment Regulations of 2014 and their 2017 amendments (Department of Environmental Affairs, 2017).

In Queensland, Australia was one of the first states to introduce Environmental Impact Assessment procedures, with the State Development and Public Works Organisation Act, 1971 (Elliott and Thomas, 2009). The Mineral Resources Act, 1989; Environmental Protection Act, 1994; Integrated Planning Act, 1997; and the Environmental Protection Regulations, 2008, followed (Supplementary material, Table 2). Currently, mined land rehabilitation is regulated by Sections 125 (1) (l) (i) (E); 264; 268; and 318Z of the Environmental Protection Act, 1994 (Department of Environment and Heritage Protection, 2014; State of Queensland Australia, 1994).

In New South Wales, the Environmental Planning and Assessment Act, 1979 was the first protective environmental legislation promulgated (Elliott and Thomas, 2009). The Mining Act, 1992 and the Protection of the Environmental Operations Act followed (Supplementary material, Table 2).

Despite the good intentions of guiding policy and legislation, sustainability objectives are rarely achieved, with rehabilitation failures often evident. A worst-case failure example is negative mine legacies. It is acknowledged that many of these mines are historic and the mining activity most certainly was initiated and likely ceased before environmental or sustainable development legislation so there was much less emphasis on stakeholder interests and long-term environmental impacts. Negative mine legacies are indeed a grave reminder of what can result from inadequate environmental responsibility. Negative mine legacies include approximately 6,000 abandoned mines in South Africa and more than 50,000 in Australia, with 15,380 situated in Queensland and 410 in New South Wales (Auditor-General South Africa, 2009; Department of Mineral Resources, 2009; Unger et al., 2012). Unger et al. (2012) note inconsistency and the ambiguity in the category definitions describing mine characteristics for the Australian data sets. Further, only a percentage of these are surface-strip coal mines and mine site size varies. Therefore, mine numbers may be over representative. The contingent liability to rehabilitate the 15,000 abandoned mines in Queensland is estimated in excess of $1B AUD (Queensland Government, 2012). It is estimated that it would cost almost $3B AUD to rehabilitate the 6,000 abandoned mines in South Africa (Auditor-General South Africa, 2009). The long-term treatment of acid mine drainage and the construction and operating fees of plants was excluded in the cost calculation for South Africa. In addition, reputational costs, which are difficult to quantify and end land-use specification have likely too not been included in either calculation.

End land-use rehabilitation costs vary considerably, with ‘native ecosystems’ costing almost double that for ‘permanent pasture’ establishment (Department of Environment and Heritage Protection, 2017). Lechner et al. (2016b), using spatial data and the Queensland financial assurance calculator, estimated the rehabilitation financial liability for operating surface coal mines in the Fitzroy Basin, Australia, to be more than $4.349 and $5.461B AUD, with some rehabilitation liabilities omitted due to the spatial data method applied. Financial assurance is a type of financial security provided to the Queensland Government by the holder of an environmental authority. It covers any costs or expenses incurred to prevent or minimise environmental harm or rehabilitate or restore the environment, should the holder fail to meet their environmental obligations in the environmental authority. To facilitate financial assurance calculation the Queensland Department of Environment and Heritage Protection developed financial assurance calculators to help streamline the assessment of the environmental authority financial assurance requirement (Department of Environment and Heritage Protection, 2017). These rehabilitation costs, although seemingly exorbitant, in comparison to the profits derived from mining are minimal. To put rehabilitation liabilities in context, Australia's exports of black coal from 2007 to 2008, were valued at $24.4B AUD (Geoscience Australia and Australian Bureau of Agricultural and Resource Economics, 2010).

An attribute of negative mine legacies, is incomplete remediation, with responsibility by default relegated to governments and communities (Unger et al., 2015). Unger et al. (2015) note that incomplete remediation may be due to premature cessation of operations, inadequate regulatory requirements, insufficient funds, or inadequate community engagement to agree upon and meet closure expectations. A deeper cause may however be due to the lack of legislation and sustainable responsibility being applied to these early mines. Mine planning most likely would not have taken environmental considerations seriously and critical rehabilitation risks and their interactions may not have been adequately considered.

While it is recognised in good practice guidance that early upfront rehabilitation planning reduces the potential risk of rehabilitation failure, this practice seldom occurs (Lechner et al., 2017; Limpitlaw and Mitchell, 2013; Mc Cullough, 2016; Minerals Policy Institute, 2016). Authorities emphasise developing the necessary skills, equipment and technical knowledge over time during progressive rehabilitation actions so as to achieve successful rehabilitation (Australian Government et al., 2016b). In project planning, it is accepted that the earlier planning is initiated and the greater the analysis and attention to detail, the higher the project success rate, with minimal failures, associated costs and damage to the environment (Australian Government et al., 2016b; Ireland, 2008). There is the added potential for rehabilitation failures to compound exponentially during the mine life-cycle, making later rectification difficult and expensive.

The aim of this paper is to review rehabilitation maturity in mine rehabilitation guidelines and mine approval consultant rehabilitation reports, with comparison between all South Africa's coal bearing Provinces and Australia, specifically the states of Queensland and New South Wales. We first define rehabilitation and the rehabilitation end-product. We then develop a maturity model with objectives for mature upfront surface-strip coal mine rehabilitation planning, integration and rehabilitation risk determination. Using the maturity model, we systematically review mine approval consultant rehabilitation reports and the mine rehabilitation guidelines likely used by these consultants to prepare these. We evaluate these documents on whether they address the maturity model's objectives. We then explore legislation as a driver of immaturity. We discuss the nature of mining operations and whether it is possible to include a high level of detail and analysis upfront in planning for mining projects, which are temporal and dynamic and when progressive rehabilitation methods are favoured. We conclude by suggesting ways forward and the need to develop a tool to determine a site's rehabilitation failure risk, thereby identifying opportunities for improvement in upfront rehabilitation planning. This paper focuses on environmental issues pertaining to rehabilitation however, we acknowledge that there are also associated socio-economic and management issues that need to be addressed.

## Method

*Defining rehabilitation and the rehabilitation end-product*

The first step to developing a rehabilitation maturity model is to define rehabilitation and what the rehabilitation end-product should look like. These definitions are necessary for clarity and as they provide an indication of what the rehabilitation maturity model should strive to include as a bench-mark for the evaluation of rehabilitation planning documents, to lead towards an improved rehabilitation end-product.

Several terms exist which are synonymous with mined land rehabilitation. These are used interchangeably and are seldom defined by rehabilitation professionals. They include: ecological restoration, restoration, rehabilitation, reclamation, revegetation, reforestation, remediation and closure. This lack of clarity can be problematic, as the failure to define the rehabilitation end-product can create legal disputes at closure, when rehabilitation outcomes show disparity to the expectations of regulatory authorities, mining companies and local communities.

The authors offer their definition for rehabilitation, which they see as comprising of three sequential phases, from remediation, to revegetation/ reforestation to a final stage of reclamation (Table 1). This definition attempts to attain a balance between theory definitions such as ‘ecological restoration’ and ‘restoration’ and practice based definitions used in the mining industry, including ‘reclamation’, ‘rehabilitation’ and ‘remediation’. These have been adapted from work by others (Australian Government et al., 2016b; Australian Government and Department of Industry Tourism and Resources, 2006; Chamber of Mines of South Africa and Coaltech Research Association, 2007; Clewell and Aronson, 2013; Howell et al., 2012; Principles and Standards Reference Group and Society for Ecological Restoration Australasia, 2016; Society for Ecological Restoration International Science & Policy Working Group, 2004).

**Table 1.**

Mined land rehabilitation author definitions.

| Term | Definition |
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| **Rehabilitation** | Encompasses three phases: Phase 1, Remediation, Phase 2 Revegetation/ Reforestation and Phase 3: Reclamation, which may be present singularly or in combination, within portions or the whole of disturbed mine sites. These form a trajectory towards an improved ecosystem from least to moderate ecological value. They are phases of 'succession', along time-lines, leading to 'rehabilitation'. The re-establishment of pre-existing biotic integrity in terms of species composition and community structure is excluded. Final rehabilitation includes repaired ecosystem processes, productivity and services with indigenous vegetation of a moderate ecological value. Detailed scientific restoration ecology principles do not apply, rehabilitation is practice based. |
| **Phase 1: Remediation** | Involves eliminating or reducing contaminants from a place where they are not wanted. Geohydrological changes due to mining activity primarily dictate remediation requirements. |
| **Phase 2: Revegetation/ Reforestation** | Includes the establishment of one or several quick growing stabilising indigenous or non-indigenous plants species. This may include: commercial cropping or pastures; native grasslands; timber plantations; or native forests. |

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| **Phase 3: Reclamation** | The land is returned to a useful purpose, which may include: non-indigenous plantings (commercial cropping, pastures or timber plantations) or indigenous vegetation of low to moderate ecological value. Non-indigenous plantings are permissible as they act as ‘nurse’ species, making the site favourable for later indigenous species introduction. Reclamation also includes the process of making favourable the ‘soil foundation’ for plant establishment. Public safety and aesthetics are included. Reclamation allows for the ‘rehabilitation’ end-product to be attained. |

*Rehabilitation maturity model*

Our rehabilitation maturity model includes objectives for mature upfront surface-strip coal mine rehabilitation planning, integration and risk determination with indicators of what is the ideal mature rehabilitation state and the steps required to attain this (Table 2). Specifically, it serves as a bench-mark for the evaluation of maturity in rehabilitation planning documents.

The model is based on the Culture Ladder by Hudson (2007) developed for Health, Safety and Environment in the oil and gas industry and as adapted by Unger et al. (2015) for the evaluation of abandoned mine rehabilitation programs. The Hudson Ladder defines a pathway from less to more advanced cultures, with five 'categories of advancement' including: pathological, reactive, calculative, proactive to generative. The adaption by Unger et al. (2015) also uses five 'categories of advancement' but terms these 'performance indicators', which include vulnerable, reactive, compliant, proactive and resilient. The Hudson Ladder uses an instrument of measurement for characterisations which define how an organisation's culture is currently best defined and provides advanced targets toward which it can evolve (Hudson et al., 2002). Information is presented in table format with a vertical column of 'dimensions' and horizontal rows of 'categories of advancement'. Descriptions of behaviour are provided for each of the levels of 'categories of advancement' across all 'dimensions'.

Our rehabilitation maturity model uses seven environmental domain evaluative criteria: geology, soils, topography, hydrology, climate, vegetation and landuse. These evaluative criteria are foundation rehabilitation factors that influence the potential for rehabilitation failures as well as opportunities, they determine the long-term viability of land for sufficient ecosystem restoration and are important for building a landscape from the bottom-up. They have their origin in the ecological concept of environmental and anthropogenic determinants of vegetation distribution and therefore may too dictate what can be achieved during rehabilitation by offering trends for vegetation establishment and suitable species choices (Greve et al., 2011; Mucina and Rutherford, 2006). The environmental domain evaluative criteria are representative of the multi-disciplines that are involved during the mine rehabilitation process. They include key factors that should be considered as a minimum for any operation, to assist with closure planning and to identify which elements need to be monitored or investigated during the mine life-cycle (Australian Government et al., 2016a).

Each environmental domain evaluative criteria was measured for their maturity using only three of the five performance indicators as described by Unger et al. (2015): vulnerable, compliant and resilient, with compliant reworded to adequate. The remaining two intermediate performance indicators of reactive and proactive were omitted. These adaptations were made for simplification and so as to apply the maturity model by Unger et al. (2015) to our maturity model’s specific needs. There is significant quantity of information in our three performance indicators and having five would make the model impractical. In our model, ‘vulnerable’ implies inadequate consideration, with no data gathered at all, e.g. in the topography environmental domain evaluative criteria category, this would imply not including or requesting the consideration of elevation or aspect issues among other; 'adequate’ implies suitable consideration, with data as required gathered, e.g. includes/ requests specific information on: upland or lowland elevation; and north, south, east or west facing slopes; and ‘resilient’ implies full consideration, in addition to complying with the criteria for adequate, showing full maturity where data gathered has been used for ‘intelligent’ rehabilitation planning, e.g. elevation and aspect topographic information has been used/ requested to inform rehabilitation planning decisions; integration has been undertaken/ requested to indicate potential rehabilitation failure and risk; and rehabilitation failure risk has been determined/ requested.

The key undertakings required to attain resilience include rehabilitation planning, integration and risk determination. Planning refers to whether data has informed rehabilitation decisions. While, integration is based on the ‘integrated modelling’ concept, whereby different components of the natural and other systems are modelled in a linked way, ideally with representation of feedbacks, loops, responses, thresholds and other features of system behaviour (Argent, 2004; Hamilton et al., 2015). Integration in the context of our maturity model, is therefore important within and across the environmental domain evaluative criteria, to go beyond linear relationships with a focus on linked network relationships, their analysis and potential contribution to rehabilitation failure risk. Risk is defined as, the overall process of risk identification, analysis and evaluation by Standards Australia/ Standards New Zealand (2009). Where risk identification is the process of finding, recognising and describing risks, including their sources and events; risk analysis is the process to comprehend the nature of risk and to determine the level of risk; and risk evaluation is the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/ or its magnitude is acceptable or tolerable. Risk treatment, the process to modify a risk is also included, i.e. controls of prevention and mitigation. Our maturity model’s resilient status therefore aims to ensure that these risk parameters are adequately met.

**Table 2.**

Rehabilitation maturity model for evaluation of mine rehabilitation guidelines and mine approval consultant rehabilitation reports with emphasis on a) rehabilitation planning, integration and risk determination and b) regulatory approval requirements (Adaptation of (Hudson, 2007; Unger et al., 2015)).

| **Performance Indicators** | **Vulnerable (1)**[1] | **Adequate (2)** | **Resilient (3)** |
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| **Environmental Domain Evaluative Criteria** | inadequate consideration, with no data gathered at all | suitable consideration, with data gathered | full consideration, in addition to Adequate (2), with rehabilitation planning, integration and risk determination |
| **Geology** | Does not include/ request geological information on substrates for new landforms.<br><br>Does not include/ request geological characterisation of wastes.<br><br>Does not include/ request consideration of acid rock drainage and toxicity development potential. | Includes/ requests specific information on unstable geological formations.<br><br>Includes/ requests specific information on physical behaviour, chemical reactivity and geochemical characterisation of mine waste material under the conditions in which it is stored, the constituent elements present and their likely future speciation and mobility. | Geological information has been used/ requested to inform rehabilitation planning decisions.<br><br>Integration has been undertaken/ requested within the geology domain to indicate potential rehabilitation failure and risk, e.g. are there any ore bodies, such as nickel that could cause toxicity, when combined with other geological conditions? Integration has also been undertaken/ requested with linkage to other domains, e.g. high water table (hydrology domain), high rainfall area (climate domain), increases potential for acid rock drainage. |

[1] A score of (1) is awarded for vulnerable, (2) for adequate and (3) for resilient. Intermediate scores are awarded for when documents do not fall definitively within these three main performance indicators. A score of (1.5) is awarded for falling between vulnerable and adequate and (2.5) for falling between adequate and resilient.

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| | | Includes/ requests specific information on presence of sulphide minerals, water and exposure to atmosphere; and on salinity and metal toxicities. | Rehabilitation failure risk has been determined/ requested, involving identification, analysis, evaluation and treatment of risk, e.g. the potential risk of acid rock drainage has been identified; analysis has included determining the level of risk based on the integration of parameters from the geology, hydrology and climate domains; evaluation has included comparison to known acid rock drainage severity parameters; and treatment has included among other considering lowering of the water table and capping of the site to prevent atmospheric exposure and exposure to high rainfall conditions. |
| **Soils** | Does not include/ request soil information for new landforms.<br><br>Does not include/ request baseline soils data for topsoil and subsoil in the context of future use of soils.<br><br>Does not include/ request consideration of: soil chemical, physical and biological properties. | Includes/ requests specific information on soil chemical properties of: pH; salinity; sodicity; exchangeable cations and anions; electrical conductivity of saturation extract; and plant nutrient availability.<br><br>Includes/ requests specific information on soil physical properties of: texture; aggregation; soil cohesion; bulk density; topsoil depth; permeability; erodibility; water retention; infiltration and dispersive ability; rockiness; and known problem soils. | Soil information has been used/ requested to inform rehabilitation planning decisions.<br>Integration has been undertaken/ requested within the soil domain to indicate potential rehabilitation failure and risk, e.g. which soil parameter combinations (texture/ particle size, bulk density, top soil depth, water retention capacity, known problem soils, and organic carbon content) may contribute to soil compaction? Integration is also undertaken/ requested with linkage to other domains, e.g. for compaction risk to increase are other parameters also present e.g. flat slopes (topography domain), highwater table (hydrology domain) and high rainfall (climate domain)?<br><br>Rehabilitation failure risk has been determined/ requested involving identification, analysis, evaluation and treatment of risk, e.g. the potential risk of compaction has been identified; analysis has included determining the level of risk based on the integration of parameters from the soil, topography, |

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| | | Includes/ requests specific information on soil biological properties of: litter cover; organic carbon content; nitrogen fixation; Mycorrhizal fungi; and soil seedbanks. | hydrology and climate domains; evaluation has included comparison to known compaction severity parameters; and treatment has included among other considering slope alterations and implementation of controls of soil handling methods and machinery use. |
| **Topography** | Does not include/ request topographical information as a baseline for geomorphic design of landforms.<br><br>No inclusion or request for consideration of elevation and aspect.<br><br>No inclusion or request for consideration of slope categories. | Includes/ requests specific information to aid the design of landforms.<br><br>Includes/ requests specific information on: upland or lowland elevation; and north, south, east or west facing slopes<br><br>Includes/ requests specific information on slope stability, drainage, length, shape and roughness. | Topographical information has been used/ requested to inform rehabilitation planning decisions.<br><br>Integration has been undertaken/ requested within the topography domain to indicate potential rehabilitation failure and risk, e.g. which topographic parameter combinations (slope drainage, length, shape and roughness) may contribute to slope instability? Integration is also undertaken/ requested with linkage to other domains, e.g. for slope instability risk to increase are other parameters also present e.g. faults/ fissures (geology domain); coarse sandy textured soils, low cohesion soils, shallow soil depth, and low litter cover and organic carbon content (soil domain); high surface runoff intensity and high velocity of flow (hydrology domain); low vegetation cover (vegetation domain); and high rainfall area (climate domain)?<br><br>Rehabilitation failure risk has been determined/ requested involving identification, analysis, evaluation and treatment of risk, e.g. the potential risk of slope instability has been identified; analysis has included determining the level of risk based on the integration of topography, soil, hydrology, climate and vegetation domain parameters; evaluation has |

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| | | | included comparison to known slope stability severity parameters; and treatment has included among other considering altering slope angle, length, shape etc. |
| **Hydrology** | Does not include/ request hydrological information in a manner which could inform new landform design.<br><br>No inclusion or request for consideration of ground or surface water information.<br><br>No inclusion or request for consideration of wetlands and 1:100 year floodlines nor water regimes. | Includes/ requests specific information on: groundwater table depth; underground streams; aquifers; boreholes; and on: surface water runoff intensity, velocity of flow, depth, frequency, water quantity and quality.<br><br>Includes/ requests specific information on: wetlands and 1:100 year floodline inundation, frequency, duration, depth and depth to groundwater in the growing season;<br><br>Includes/ requests specific information on: presence of water reducing dams and vegetation, potential for irrigation from natural water and decant sources. | Hydrological information has been used/ requested to inform rehabilitation planning decisions.<br><br>Integration has been undertaken/ requested within the hydrology domain to indicate potential rehabilitation failure and risk, e.g. which hydrological parameter combinations (high water table, low runoff intensity and low flow velocity) may contribute to water retention? Integration is also undertaken/ requested with linkage to other domains, e.g. for water retention risk to increase are other parameters also present e.g. high clay content soils (soil domain), wet south gentle concave slopes (topography domain) and high rainfall (climate domain)?<br><br>Rehabilitation failure risk has been determined/ requested involving identification, analysis, evaluation and treatment of risk, e.g. the potential risk of water retention has been identified; analysis has included determining the level of risk based on the integration of parameters from the hydrology, soil, topography and climate domains; evaluation has included comparison to known water retention severity parameters; and treatment has included considering slope alterations and soil amendments among other. |
| **Vegetation** | Does not include/ request vegetation information in a | Includes/ requests information to inform vegetation establishment. | Vegetation information has been used/ requested to inform rehabilitation planning decisions. |

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| | manner which can be used to inform re-vegetation.<br><br>No inclusion of past vegetation types, resilience nor succession status.<br><br>No inclusion of: vegetation biodiversity potential for linkage etc., suitable plant species and propagative material, nor of potential threats to vegetation establishment, i.e. alien vegetation presence and influence of fauna and humans. | Includes/ requests specific information on: past vegetation types; frequency and magnitude of natural disturbances, i.e. site resilience; succession status; biodiversity potential; potential nurse and vegetation establishment species; and availability of seed and vegetative plant propagation material.<br><br>Includes/ requests specific information on: resistance ability to invasion from alien plant species, proximity to alien vegetation seed banks; extreme fire events/ fire regimes; and anthropogenic perturbations, i.e. restricted or open access types allowing human/ animal impacts. | Integration has been undertaken/ requested within the vegetation domain to indicate potential rehabilitation failure and risk, e.g. which vegetation parameter combinations (poor species selection and planting of climax vegetation in a pioneer environment) may contribute to vegetation failure? Integration is also undertaken/ requested with linkage to other domains, e.g. for vegetation failure risk to increase are other parameters also present e.g. negative soil states (soil domain), steep slopes (topography domain) shallow water table (hydrology domain) and low infrequent rainfall (climate domain)?<br><br>Rehabilitation failure risk has been determined/ requested involving identification, analysis, evaluation and treatment of risk, e.g. the potential risk of vegetation failure has been identified; analysis has included determining the level of risk based on the integration of vegetation, soil, hydrology, climate and topography domain parameters; evaluation has included comparison to known vegetation failure severity parameters; and treatment has included considering soil amendments, use of decant for irrigation and correct choice of species among other. |
| **Climate** | Does not include/ request climate information.<br><br>No inclusion or request for consideration of precipitation nor temperature. | Includes/ requests specific information in a manner which provides partial insight into influencing factors on rehabilitation. | Climate information has been used/ requested to inform rehabilitation planning decisions.<br><br>Integration has been undertaken/ requested within the climate domain to indicate potential rehabilitation failure and risk, e.g. which climate parameter combinations (low rainfall |

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| No inclusion or request for consideration of humidity, evaporation, wind factor, micro-climates and season length | Includes/ requests specific information on: mean annual precipitation, seasonality, annual deviation, intensity and frequency; and mean annual temperature and winter and summer maximums. | and hot temperatures) may contribute to surface cracking? Integration is also undertaken/ requested with linkage to other domains, e.g. for surface cracking risk to increase are other parameters also present e.g. problem soils (soil domain), low water table (hydrology domain) and minimal vegetation cover (vegetation domain)? |
| | Includes/ requests specific information on: high, medium or low humidity and evaporation; strong/ constant/ weak/ seldom wind factors; microclimates including valleys (sheltered/ cooler), hillslopes and plateaus (exposed/ hot and dry); extremes of climates i.e. droughts, frost, snow; and season length. | Rehabilitation failure risk has been determined/ requested involving identification, analysis, evaluation and treatment of risk, e.g. the potential risk of surface cracking has been identified; analysis has included determining the level of risk based on the integration of parameters from the climate, soil, hydrology and vegetation domains; evaluation has included comparison to known surface cracking parameters; and treatment has included considering soil amendments among other. |

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| **Landuse** | Does not include/ request landuse information.<br><br>No inclusion or request for consideration of historical and existing landuse.<br><br>No consideration has been undertaken of opportunities, threats and needs for future landuse establishment. | Landuse information included, but only superficially.<br><br>Includes/ requests specific information on: historical, existing and potential landuses.<br><br>Include a mechanism for regular review of landuse suitability and an analysis of requirements to progressively attain end landuse goals and objectives. | Landuse information has been used/ requested to inform rehabilitation planning decisions from the outset. Limitations on land use are clearly understood. Opportunities for beneficial landuses identified early and studies planned for during operations.<br><br>Integration has been undertaken/ requested within the landuse domain to indicate potential rehabilitation failure and risk, e.g. what past site landuses have occurred that could restrict future landuse options? Integration is also undertaken/ requested with linkage to other domains, e.g. for agricultural crop cultivation to be successful you require good soil fertility (soil domain), high rainfall (climate domain), gentle slopes (topography domain) and water available for irrigation (hydrology domain).<br><br>Rehabilitation failure risk has been determined/ requested involving identification, analysis, evaluation and treatment of risk, e.g. agricultural crop production may fail; analysis has included determining the level of risk based on the integration of parameters form the landuse, soil, climate, topography and hydrology domains; evaluation has included comparison to known agricultural crop failure severity parameters; and treatment has included considering soil amendments, irrigation from decant and slope treatments among other. |

*The systematic review process and study limitations*

Using our rehabilitation maturity model (Table 2) we systematically reviewed surface-strip coal mine related rehabilitation documents. These documents consisted of mine approval and after mine approval consultant rehabilitation reports and mine rehabilitation guidelines from South Africa and Australia, Queensland and New South Wales (Supplementary material, Table 1).

Fourteen mine approval consultant rehabilitation reports were reviewed: seven from South Africa and seven from Australia, four of these being from Queensland and three from New South Wales. Six after mine approval consultant rehabilitation reports were reviewed from Australia, one from Queensland and five from New South Wales. Equivalent reports in this category, from South Africa could not be found for review. Ten mine rehabilitation guidelines were reviewed: five from South Africa, comprising of two leading practice guidelines, one company and two technical guidelines and five from Australia comprising of one technical and four leading practice guidelines.

The mine approval phase was the primary focus, as this period can substantially influence rehabilitation success or failure outcomes. After mine approval consultant rehabilitation reports were included for comparison and to determine if maturity improves progressively. Rehabilitation guidelines are of importance as they influence the content of mine approval consultant rehabilitation reports.

Documents were acquired via an internet web-search, hence only documents in the public domain were used. Mine approval and after mine approval consultant rehabilitation reports were found difficult to attain online, due to mining company confidentiality constraints. Mostly only reports forming part of the public participation process were found uploaded. Therefore, assessed reports may be under-representative, with potential errors in results possible. An added challenge is that the format and content of these reports varied widely among consultants and jurisdictions, making document comparison difficult. Although mine rehabilitation guidelines were easily attainable online, a potential error could be that the sample size of 10 is small, as few guidelines have been prepared to date, that could be reviewed, due to their wider application. However, even with this small sample size, valuable observation could be drawn.

Documents were qualitatively scored, in a single round, per category, by the corresponding first author, who has over 20 years of consulting environmental impact assessment experience. Scoring was done by only one author to ensure consistency in scoring across the performance indicators. A score was awarded depending on which maturity performance indicator each environmental domain evaluative criteria fell within. A score of (1) was awarded for vulnerable, (2) for adequate and (3) for resilient. A score of (1.5) was awarded for falling between vulnerable and adequate and (2.5) for falling between adequate and resilient. These intermediate scores were awarded for when the documents did not fall definitively within the three main performance indicators and to increase the scoring range. Average scores were calculated for all document categories across each environmental domain evaluative criterion. A comparative analysis of the various document types was conducted using Microsoft Office™ Excel 2016 Radar Charts (Fig. 1-5).

## Results and discussion

Mine approval consultant rehabilitation reports for South Africa and Australia, (Queensland and New South Wales), showed low levels of maturity, falling between vulnerable and adequate, but not yet resilient. The average score for South Africa (1.74) was slightly higher than that of Australia (1.60) (Fig. 1 and Supplementary material, Table 1). The highest scoring environmental domain evaluative criteria taken from the average scores for all these reports from South Africa showed a focus on geology, soils and hydrology, suggesting attention to contamination prevention/ remediation. This was followed by a focus on end landuse. Reports for Australia focused mostly only on contamination prevention. These observations appear to correlate to our rehabilitation definition in Table 1, showing that there is firstly a focus on Phase 1: Remediation followed thereafter by Phase 2: Revegetation/ Reforestation. The highest score was attained for the New Vaal Colliery (2.14), in South Africa, for its suite of mine approval consultant rehabilitation reports which consisted of an Environmental Impact Assessment and Environmental Management Programme report. This included financial provisions, specialist studies, a risk assessment and a preliminary closure plan. Here, the preliminary closure plan is one of the few documents found that attempts rehabilitation planning, integration and risk determination, although further detail and analysis could still be provided. The second highest score was attained for the Cavel Ridge mine (1.93) in Australia, Queensland, for its Environmental Impact Statement and Environmental Management Plan report, with specialist studies.

Scores were higher for when the full suite of documents were included in the evaluation. Environmental Impact Assessment/ Environmental Impact Statement, Environmental Management Programme/ Environmental Management Plan and their specialist study reports contained the most detail, whereas stand-alone documents were found lacking in detail. Despite the value of all these documents, their focus is toward the assessment of impacts from mining on the environment and not on the rehabilitation risks that are imposed by the environmental domain. Rehabilitation when described in these documents is management, objective and target based. There is little attention paid to rehabilitation planning, integration and risk determination.

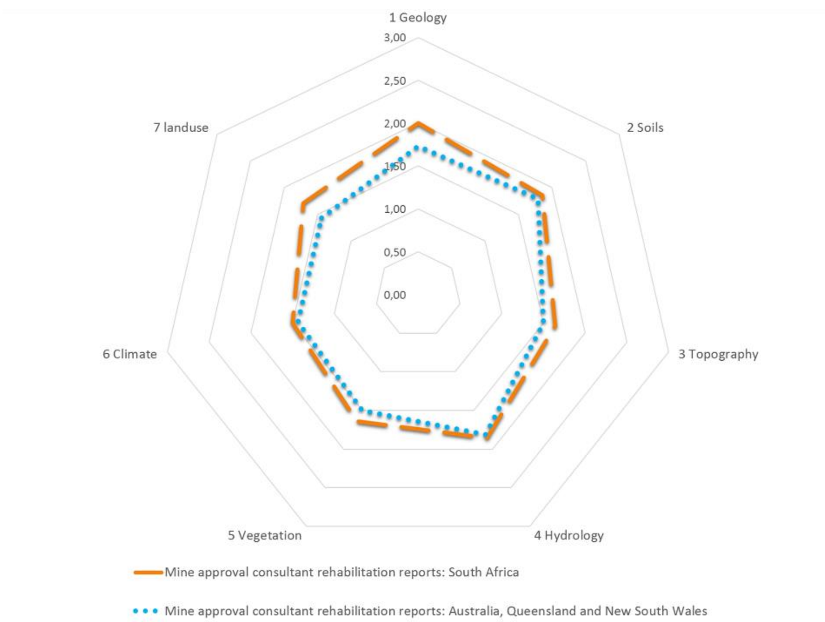


**Fig. 1.** Radar chart of maturity model rankings, of mine approval consultant rehabilitation reports for South Africa (7) and Australia (7), Queensland and New South Wales, showing averaging categorical scores.

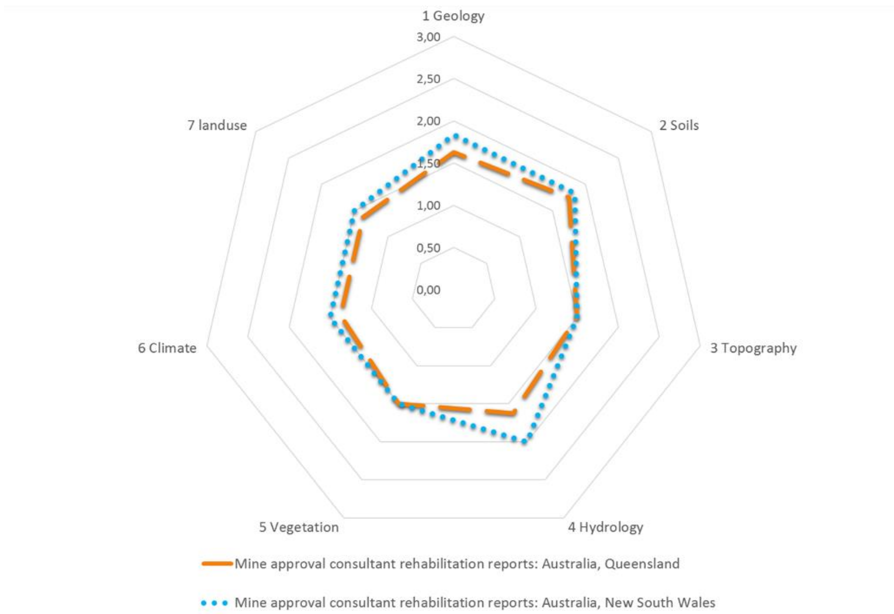


**Fig. 2.** Radar chart of maturity model rankings, of mine approval consultant rehabilitation reports for Australia, Queensland (4) and New South Wales (3), showing averaging categorical scores.

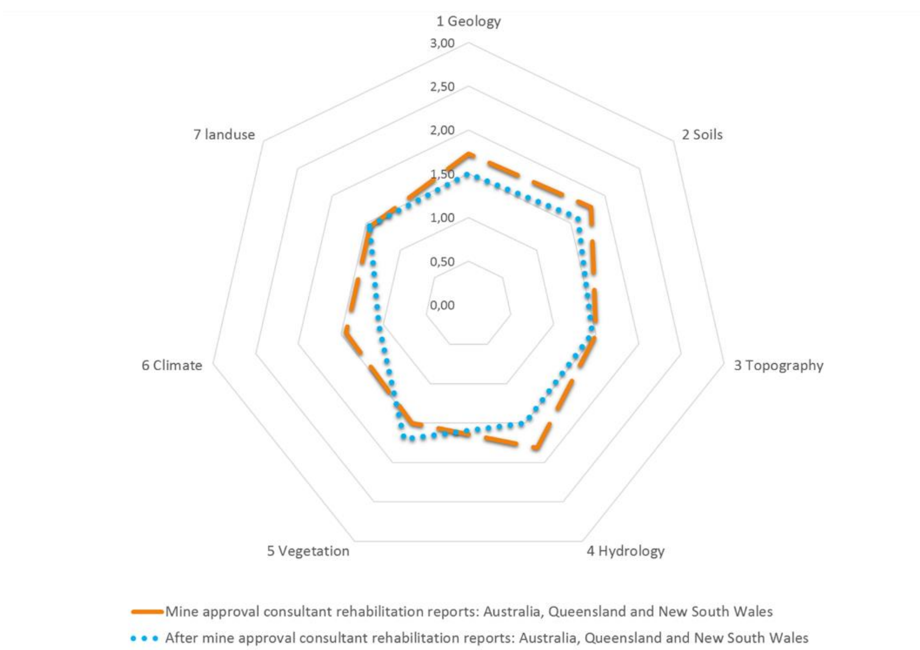


**Fig. 3.** Radar chart of maturity model rankings, of comparison of mine approval (7) and after mine approval (6) consultant rehabilitation reports for Australia, Queensland and New South Wales, showing averaging categorical scores.

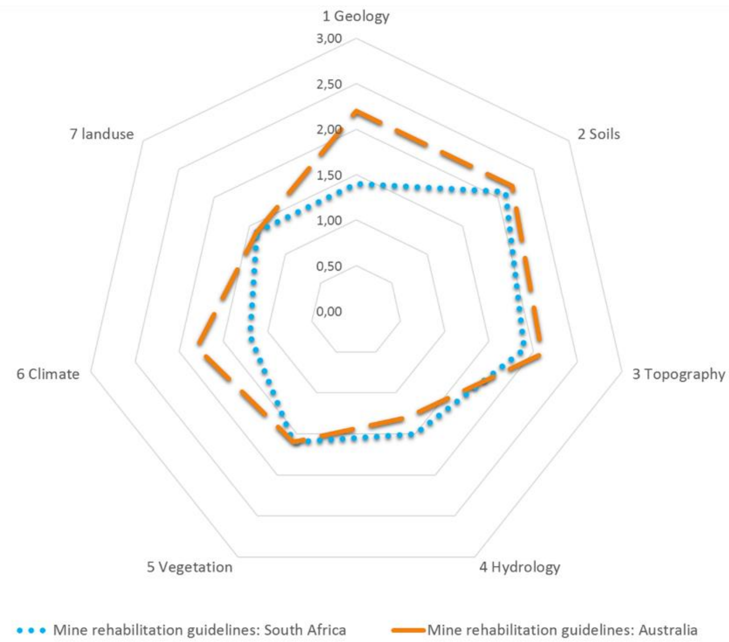


**Fig. 4.** Radar chart of maturity model rankings, of mine rehabilitation guidelines for South Africa (5) and Australia (5), showing averaging categorical scores.

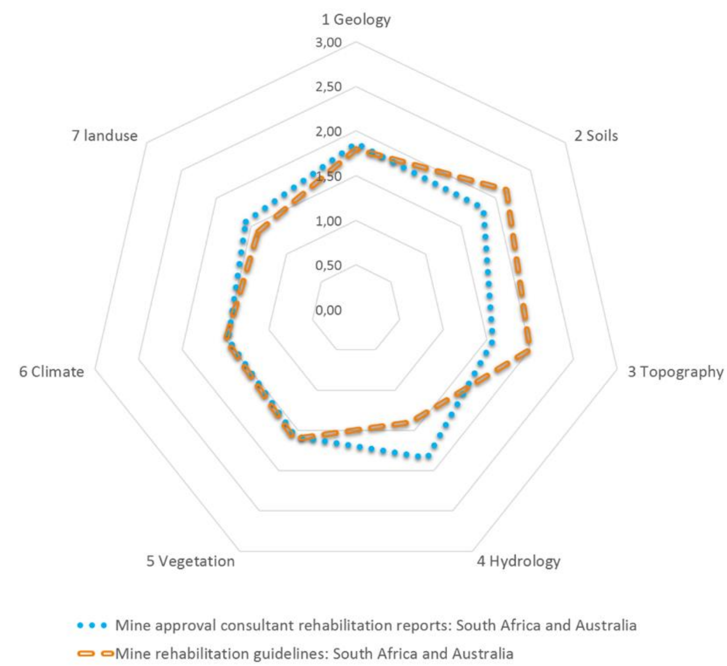


**Fig. 5.** Radar chart of maturity model rankings, of comparison of mine approval consultant rehabilitation reports (14) and rehabilitation guidelines (10) for South Africa and Australia, showing averaging categorical scores.

A comparative assessment was made between Queensland and New South Wales, Australia for mine approval consultant rehabilitation reports (Fig. 2 and Supplementary material, Table 1). New South Wales' (1.67) average score was higher than that of Queensland (1.54). The Queensland reports focused on contamination prevention, followed by landform and substrate establishment, whereas the New South Wales reports focused on mostly contamination prevention.

A further comparison was made between mine approval and after mine approval consultant rehabilitation reports for Queensland and New South Wales, Australia (Fig. 3 and Supplementary material, Table 1), i.e. progressive rehabilitation management documents, as produced after mine approval has been granted, to ascertain if rehabilitation planning improves following mine approval, during the operational phase. Mine approval documents tended to focus on contamination prevention, whilst after mine approval documents were mainly concerned with landform and substrate establishment. The average score for the mine approval documents (1.60) was higher than that of the average score for the after mine approval documents (1.46). This was surprising, as it was theorised that by progressive rehabilitation, the after mine approval rehabilitation reports would become more detailed over time. The low scoring could be due to documents having a management, objective and target based approach, with attention on criteria and indicators and again not so much on rehabilitation planning, integration and risk determination.

Mine rehabilitation guidelines showed similar low levels of maturity, falling between vulnerable and adequate, but not yet resilient (Fig. 4 and Supplementary material, Table 1). The average score for Australia (1.80) was higher than that for South Africa (1.59).

The South African guidelines focused on landform and substrate establishment, containing detail on soils, topography and vegetation, whilst the Australian guidelines focused firstly on contamination prevention and only then on landform and substrate establishment. The highest scoring document was an Australian technical guideline (Department of Minerals and Energy, 1995), which scored 2.14. This document contains useful detailed technical data sheets; however; the focus is more on mining than on rehabilitation. This was followed by a South African leading practice guideline which scored 1.86, the high score may be attributed to the inclusion of detailed appendices and that this document was prepared voluntary and not in response to legislation (Chamber of Mines of South Africa, 1981). Two Australian leading practice guidelines were ranked after these, with scores of 1.79 each (Australian Government and Department of Industry Tourism and Resources, 2006; Minerals Council of Australia, 1998). These early leading practice guidelines attained high scores, despite being dated and that more recent versions have since been produced to include Chamber of Mines of South Africa and Coaltech Research Association (2007), which scored 1.57 and Australian Government et al. (2016b), which scored 1.71. Detail in leading practice guidelines appears to have declined, inadvertently legislation driven, which is discussed further in a subsequent section and possibly in response to the increasing use of progressive rehabilitation and that detail is only expected to be added during the mine operational and closure phases and not at the planning phase. Liability may also be a contributory factor, with regulators being reluctant to stipulate prescriptive detail, fearing legal accountability, should failures arise from information misuse.

It is unknown what terms of reference were used in the updating of guidelines in South Africa and Australia nor what the focus issues were. Revised or new guidelines appear to be the modernisation of earlier versions or adaptations of existing jurisdiction guidelines, with local content or company specifics simply added e.g. Anglo Coal Environmental Rehabilitation Improvement Group (2009) is based on Chamber of Mines of South Africa and Coaltech Research Association (2007). Another example of this includes Chamber of Mines of South Africa and Coaltech Research Association (2007), which is based on Chamber of Mines of South Africa (1981).

Resilient maturity was rarely observed in mine rehabilitation guidelines. Guidelines emphasised management actions, such as how to create a landform or establish vegetation, with little focus on rehabilitation risk determination and on understanding how the environmental domain integrates to determine rehabilitation opportunities or failure outcomes.

The reviewed guidelines differed in their mining type focus. Only three guidelines were found to be coal mining specific. The remaining seven guidelines have application to other mining types, including metalliferous mining, as well as to coal, over several geographical areas. This wide focus could be to satisfy government, state and private sector mine industry bodies with diverse membership and needs. Such an approach can prove problematic, as issues relevant to specific mining types may be overlooked, leading to poor rehabilitation planning decisions and ultimately rehabilitation failure. The format of rehabilitation guidelines differed too. Guidelines were found to be formatted mostly according to mine life-cycle phases. Occasionally guidelines followed an environmental domain structure. Structuring guidelines toward mine life-cycle phases, may be beneficial for general mining decisions, however an environmental domain structure may be more suited for rehabilitation decisions, as this allows similar information to be grouped to aid rehabilitation planning, integration and risk determination.

An additional web-search was undertaken, to include other mining countries, to attempt to acquire an example of a resilient or near resilient rehabilitation guideline, that could be used as a bench-mark of what a resilient guideline should look like. A detailed guideline by Newton and Claassen (2003), for the rehabilitation of disturbed lands in California, United States of America was found and this scored 2.21. The guideline is not mining specific, but has value in its attention to environmental domain criteria and their integration to form rehabilitation failure risks, such as soil erosion, compaction etc.

A final comparative assessment was made between mine approval consultant rehabilitation reports and mine rehabilitation guidelines for South Africa and Australia (Fig. 5 and Supplementary material, Table 1). Mine approval consultant rehabilitation reports were found to focus on contamination prevention, whilst mine rehabilitation guidelines focused more on landform and substrate establishment. The focus toward contamination prevention in consultant reports could be attributed to geohydrological legal liability issues, particularly those liked to acid mine drainage. Mine rehabilitation guidelines (1.69) scored very close to mine approval consultant rehabilitation reports (1.67), both however fall between vulnerable and adequate and are not yet resilient. This lack of resilience, apart from reflecting poor rehabilitation planning and integration also reflects the lack of inclusion of risk in rehabilitation planning.

## Legislation as a driver of immaturity

Although there have been some improvements in some jurisdictions, legislation in South Africa and Australia, Queensland and New South Wales, may inadvertently be driving immaturity in rehabilitation documents.

In South Africa, rehabilitation, from 1997 to 2015, was specified within a stand-alone Mine Rehabilitation Plan, as appended to a Basic Assessment or Scoping and Environmental Impact Assessment, Environmental Management Programme, Closure Plan or Environmental Risk Assessment (Supplementary material, Table 2). Alternatively, rehabilitation specifications were included as sub-sections within all or some of these reports. These documents formed part of the mine approval process (Department of Environmental Affairs, 2014). Broad document content, including rehabilitation requirements was stipulated in the Environmental Impact Assessment and Minerals and Petroleum Resources Development Act Regulations (Department of Environmental Affairs, 2014; Department of Minerals and Energy, 2004). Only as mines moved into their operational and closure phases was greater detail requested (Department of Minerals and Energy, 2004).

To address this oversight, as well as insufficient financial provisions and the need to integrate Environmental Impact Assessment, waste, water and mineral legislation, the 2015 Financial Provisions Regulations were promulgated (Department of Environmental Affairs, 2015). These regulations require that an Annual Rehabilitation Plan; Final Rehabilitation, Decommissioning and Mine Closure Plan; Environmental Risk Assessment; and Financial Provisions be included within the Environmental Management Programme and hence the upfront mining application approval process (Supplementary material, Table 2). Provision is made for the annual updating and auditing of the Annual Rehabilitation Plan, allowing for continual improvement. The Final Rehabilitation, Decommissioning and Mine Closure Plan, Environmental Risk Assessment and Financial Provisions are required to be updated progressively and finalised at closure. Few mine applications have been submitted in terms of the 2015 regulations, hence limiting our assessment thereof. Based on a review of those that we could acquire, document content was found to be broad, with detail only increasing marginally during the operational and closure phases. The 2015 Financial Provisions Regulations, however provide a mechanism for promoting improved rehabilitation planning and enforcement. Risk assessment techniques, mitigation and controls are also emphasised.

In Australia, a similar situation exists, where the legislative process in Queensland includes the preparation of an Environmental Impact Statement to attain an Environmental Authority, which includes a Mine Rehabilitation Plan. The Mine Rehabilitation Plan later transitions into a Progressive Rehabilitation report during the operational phase and a Final Rehabilitation report, with residual risk calculations and a risk assessment at closure. Prior to construction commencement, a Plan of Operations is required detailing how the applicant intends meeting Environmental Authority conditions including rehabilitation and financial assurances (Supplementary material, Table 2). There is overlap between the Mine Rehabilitation Plan and the Plan of Operations. At closure, application is made for the surrender of the Environmental Authority.

In New South Wales, once the Environmental Impact Statement has been submitted and the Environmental Authority issued, prior to construction, a Mining Operations Plan must be prepared (Supplementary material, Table 2). This includes cost estimates for rehabilitation, an Environmental Risk Assessment, risks specific to rehabilitation and adaptive management responses.

Requirements for Plan of Operations and Mining Operations Plans stipulate more detail than that required for approval documentation in both states, whilst Mining Operations Plans call for more detail than Plan of Operations. There is no legislative requirement for a closure plan in either state, in contrast to Western Australia, which requires this (Government of Western Australia et al., 2015).

In both South Africa and Australia, Queensland and New South Wales, detail is not prescribed for mine approval. Only after mine approval, during the operational and closure phases, with progressive rehabilitation, are detailed rehabilitation methodologies prescribed. Mine rehabilitation guidelines and thereafter mine approval consultant rehabilitation reports are formatted based on legislation, therefore if legislation prescriptions are broad these documents too will be broad. Legislation may therefore inadvertently be contributing to immaturity in these rehabilitation documents.

## The temporal and dynamic nature of mining and progressive rehabilitation

Mining is a temporary activity, spanning between 15 to 50 years. It is also dynamic, and constantly adapting in response to environmental, socio-economic and political circumstances (Laurence, 2006, 2011). This temporal-dynamic nature makes it difficult to plan for rehabilitation at the mine approval phase, with progressive rehabilitation favoured, after mine approval. Monitoring from progressive rehabilitation provides knowledge of what constitutes closure risk and whether management actions will be successful (Mc Cullough, 2016). Successful rehabilitation requires continuous improvement, as afforded by progressive rehabilitation and is reliant on the site personnel developing the skills, equipment and necessary technical knowledge to carry out rehabilitation, which may not be available at the time of mine approval planning (Australian Government et al., 2016b).

Given the temporal-dynamic nature of mining and the benefits of progressive rehabilitation mine authorities, owners and their consultants are understandably reluctant to include detailed planning and analysis during the mine approval phase. The lack of detail and analysis as evident in rehabilitation legislation, mine rehabilitation guidelines and mine approval consultant rehabilitation reports confirms this.

Whilst this reticence is acknowledged, the authors believe that greater detail than what currently exists would be beneficial upfront, to attain as a minimum adequate maturity and to prepare for resilient rehabilitation planning. The development of a model is advocated to achieve resilience; the model could act as an interface between mine rehabilitation guidelines and mine approval consultant rehabilitation reports and guide subsequent progressive rehabilitation and adaptive management decisions, which could lead to better rehabilitation outcomes.

## Research directions

Further research is required to investigate the integration of the environmental domain evaluative criteria defined in our paper, with other important causal driver criteria such as: mine management actions which may worsen or improve impacts to the environmental domain criteria; controls that could prevent or mitigate impacts; and the type and nature of rehabilitation risk-events that may arise from and be affected by these factors, which could increase rehabilitation risk and ultimately rehabilitation failure. An understanding of these issues could lead towards the development of the advocated model, which should have capabilities for resilient rehabilitation planning; quantitative multi-discipline integration and for rehabilitation risk determination, to determine a site's rehabilitation risk and its ultimate potential for rehabilitation failure. Suitable tools, techniques and methods, based on risk assessment and integrated environmental modelling principles require further investigation to achieve this objective. It is hypothesised that such a model, which would require testing, could be able to identify critical upfront rehabilitation information and planning needs, so that risks and opportunities may be detected early for minimisation or maximisation as required. This would aid current mine approval rehabilitation planning and enhance progressive rehabilitation and adaptive management decisions leading toward improved rehabilitation outcomes.

## Conclusions

Our paper has presented a rehabilitation maturity model which describes the characteristics of mature upfront surface-strip coal mine rehabilitation planning, integration and risk determination. The maturity model addressed seven environmental domain evaluative criteria, deemed critical for the rehabilitation of surface-strip coal mines, from the bottom-up. A systematic review using the maturity model revealed that mine rehabilitation guidelines and mine approval consultant rehabilitation reports in South Africa and Australia, Queensland and New South Wales fall between vulnerable and adequate, but are not yet resilient. Legislation is likely driving immaturity, although reforms in some jurisdictions are addressing recognised areas of ambiguity or weakness. Despite the temporal-dynamic nature of mining and the value of progressive rehabilitation, greater detail and analysis than what is currently occurring should be included in upfront rehabilitation planning if companies are to reduce uncertainty and therefore risk in their rehabilitation success. The alternative of companies having larger rehabilitation liabilities toward the end of the mine's life needs to be avoided to achieve sustainable post-rehabilitation outcomes. Our maturity model provides a point of reference for the improvement of mine rehabilitation guidelines and mine approval consultant rehabilitation reports, allowing for the development of evidence based policy, regulations and plans to be developed.

## Acknowledgements

Contributions are gratefully acknowledged from David Mulligan, Tim O'Connor, Peter Kuyler, James Lake, Phil Tanner and Janice Tooley. The anonymous reviewers are thanked for their valuable contributions to improving the quality of the paper. The University of Pretoria and the Coaltech Research Association are thanked for funding the research.

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## Supplementary material

**Table S1.** Summary scoring of maturity for mine rehabilitation guidelines and mine approval consultant rehabilitation reports, for South Africa and Australia, Queensland and New South Wales, using our maturity model's scoring technique[2].

| Document description | Geology | Soils | Topography | Hydrology | Vegetation | Climate | Landuse | Average score |
|---|---|---|---|---|---|---|---|---|
| **Mine approval consultant rehabilitation reports: South Africa** | | | | | | | | |
| Arnot Mooifontein Opencast Expansion Project, Golder Associates, Exxaro Arnot Coal. Date accessed 20170712<br>Rehabilitation Plan, 2011<br>Minerals and Petroleum Resources Development Act, 2002<br>http://www.golder.com/modules.php?name=Documents&op=viewlive&sp_id=1030<br><br>Strength: The report focuses mostly on vegetation and landuse.<br>Weakness: Mainly goals and objectives are provided. Not detailed.<br>Comment: The Environmental Impact Assessment and Environmental Management Programme reports could not be found on the web. | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 | 1.5 | 2.0 | 1.64 |

[2] A score of (1) is awarded for vulnerable, (2) for adequate and (3) for resilient. Intermediate scores are awarded for when documents do not fall definitively within these three main performance indicators. A score of (1.5) is awarded for falling between vulnerable and adequate and (2.5) for falling between adequate and resilient.

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|---|---|---|---|---|---|---|---|---|
| Specialist studies associated with these reports are likely to contain detail. | | | | | | | | |
| Kleinkopje Colliery, Pit 2A Extension, Shangoni Management Services (Pty) Ltd., Anglo Operations (Pty) Ltd. Date accessed 20170712<br>Final Decommissioning, Rehabilitation and Closure Plan, Annual Rehabilitation Plan & Geohydrology Specialist Study, 2016<br>2015 Financial Provisions Regulations<br>http://www.shangoni.co.za/wp-content/uploads/ANG-KLE-16-05-03_Dec_Rehab_Closure_Plan_Final.pdf<br>http://www.shangoni.co.za/wp-content/uploads/ANG-KLE-16-05-03_Ann_B_Rehab_Plan_Final.pdf<br>http://www.shangoni.co.za/wp-content/uploads/ANG-KLE-16-05-03_Geohydrology.pdf<br><br>Strength: Specialist studies included are detailed, particularly the Geohydrological Risk Assessment and the Landform Study<br>which use modelling software to perform integration.<br>Weakness: Final Decommissioning, Rehabilitation and Closure Plan and Annual Rehabilitation Plan reports generally lack detail and analysis.<br>Comment: The Environmental Impact Assessment and Environmental Management Programme reports could not be found on the web. | 2.5 | 1.5 | 2.5 | 2.5 | 1.5 | 1.5 | 1.5 | 1.93 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Specialist studies associated with these reports are likely to contain detail. | | | | | | | | |
| New Vaal Colliery, Shangoni Management Services (Pty) Ltd. & Golder Associates, Anglo Operations (Pty) Ltd. Date accessed 20170712<br>Environmental Impact Assessment and Environmental Management Programme, Financial Provisions, Specialist Studies,<br>Risk Assessment and Preliminary Mine Closure Plan, 2017<br>Minerals Act, 1991 & Minerals and Petroleum Resources Development Act, 2002<br>http://www.shangoni.co.za/new-vaal-colliery-emp-amendment<br><br>Strength: The Preliminary Closure Plan by Golder Associates contains useful summaries on how biophysical aspects could affect closure.<br>The landuse analysis section is very detailed. The Groundwater specialist study uses an integrative model.<br>Weakness: The Preliminary Closure Plan could be more analytical.<br>Comment: Not all specialist studies could be found on the web. The Preliminary Closure Plan is very well written. | 2.5 | 2.5 | 2.0 | 2.5 | 1.5 | 1.5 | 2.5 | 2.14 |
| Wolvekrans, Jones and Wagener, South 32 Coal South Africa (Pty) Ltd. Date accessed 20170713. | 1.5 | 2.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.64 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Environmental Impact Assessment, Environmental Management Programme, Specialist Studies & Conceptual Design Report Predicative Rehabilitation Designs, 2016<br>Minerals and Petroleum Resources Development Act, 2002<br>http://www.jaws.co.za/uploads/PPDocs/E812-05_REP-01_r1_th_MvZ_EIR_EMPr_20161025.pdf<br><br>Strength: Detail is contained in specialist reports.<br>Weakness: Minimal integrated analysis of data has been undertaken.<br>Comment: Not all the specialist studies could be found on the web. | | | | | | | | |
| Vlakfontein Coal Mine Phase 2, SRK Consulting, African Exploration and<br>Mining Finance Corporation SOC Ltd. Date accessed 20150704, no longer available on the web.<br>Environmental Management Programme Amendment, 2014.<br>Minerals and Petroleum Resources Development Act, 2002.<br>http://www.srk.co.za/en/files/File/South-Africa/publicDocuments1/Vlakfontien/<br><br>Strength: Detailed specialist studies are provided, particularly for soils and vegetation. | 2.0 | 2.0 | 1.0 | 2.0 | 2.0 | 1.5 | 1.5 | 1.71 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Weakness: Analysis is focused on impacts and not on rehabilitation risk. Rehabilitation discussions are intertwined throughout the report. | | | | | | | | |
| Klipspruit Extension: Weltevreden, Digby Wells Environmental, South 32 Coal South Africa (Pty) Ltd. Date accessed 20170714.<br>Environmental Impact Assessment and Environmental Management Programme, 2015. Minerals and Petroleum Resources Development Act, 2002.<br>http://www.digbywellsdocs.com/PublicDocuments/?downloads=bhp3595-south32-sa-coal-holdings-eia-and-emp-klipspruit-extension-weltevreden<br><br>Weakness: This document on its own lacks detail and analysis.<br>Comment: Specialist studies could not be sourced on the web. These may l contain detail but may lack analysis.<br>Generally Environmental Impact Assessment and Environmental Management Programme reports tend to focus on impacts<br>and not on rehabilitation risks. | 2.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.57 |
| Palmietkuilken Mining Project, Digby Wells Environmental, Canyon Resources (Pty) Ltd. Date accessed 20170714. | 2.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.57 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Environmental Impact Assessment and Environmental Management Plan, 2017. Minerals and Petroleum Resources Development Act, 2002. http://www.digbywellsdocs.com/PublicDocuments/?downloads=cnc4065-anglo-operations-limited-draft-eia-and-emp<br><br>Weakness: This document lacks detail and analysis. Comment: Specialist studies could not be sourced on the web. These may contain detail but may lack analysis. Generally Environmental Impact Assessment and Environmental Management Programme reports tend to focus on development impacts and not on rehabilitation risks. | | | | | | | | |
| **Average score, mine approval consultant rehabilitation reports: South Africa** | 2.00 | 1.86 | 1.64 | 1.86 | 1.64 | 1.50 | 1,71 | 1.74 |

**Mine approval consultant rehabilitation reports: Australia, Queensland**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Cavel Ridge, BHP Billiton. Date accessed 20170712. Environmental Impact Statement, Environmental Management Plan, Specialist Studies, 2009. http://www.bhp.com/environment/regulatory-information | 2.5 | 2.5 | 1.5 | 2.0 | 1.5 | 2.0 | 1.5 | 1.93 |

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|---|---|---|---|---|---|---|---|---|
| Strength: Documents are easily accessible on the web.<br>Transparency is evident.<br>Weakness: The focus is on impacts from mining on the environment, more so than rehabilitation risk as imposed by environmental domain criteria.<br>Comment: A detailed composite Environmental Impact Statement report. | | | | | | | | |
| Isaac Plains East, Hansen Bailey, Date accessed 20170713.<br>Environmental Impact Statement: Rehabilitation and Mine Closure Plan, 2016.<br>http://hansenbailey.com.au/hb-publications-ipe-epbc.html<br><br>Strength: Documents are easily accessible on the web.<br>Transparency is evident.<br>Weakness: The focus is on impacts from mining on the environment, more so than rehabilitation risk as imposed by environmental domain criteria.<br>Comment: Documentations is broad and management and objective focused. | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Baralaba North Coal Mine, Date accessed 20170713.<br>Rehabilitation Management Plan, 2014. | 1.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.0 | 1.0 | 1.29 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| http://baralabacoal.com.au/bar/assets/File/Rehabilitataion%20Management%20Plan.pdf<br><br>Weakness: Mainly management actions, objectives and criteria based report. Monitoring measures are also prescribed.<br>Comment: Other documents were not available on the web.<br>The Rehabilitation Management Plan dictates what should be done, but does not analyse rehabilitation risk, nor integrate risks from the environmental domain. | | | | | | | | |
| Carmichael Coal Mine, EMM, Adani Mining Pty Ltd. Date accessed 20170713.<br>Closure and Rehabilitation Strategy, 2013.<br>http://eisdocs.dsdip.qld.gov.au/Carmichael%20Coal%20Mine%20and%20Rail/SEIS/Appendices/Appendix%20R/Appendix-R1-Mine-Closure-and-Rehabilitation-Strategy.pdf<br><br>Weakness: The Closure and Rehabilitation Strategy is management, objective and monitoring based.<br>Comment: Not detailed and specific to rehabilitation planning, integration and risk determination. Documents were difficult to source on the web. | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.0 | 1.5 | 1.43 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Average score, mine approval consultant rehabilitation reports: Australia, Queensland** | 1.63 | 1.75 | 1.50 | 1.63 | 1.50 | 1.38 | 1.38 | 1.54 |

**Mine approval consultant rehabilitation reports: Australia, New South Wales**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mt Arthur Coal - Modification, BHP Billiton. Date accessed 20170712.<br>Environmental Authority with Specialist Studies, 2010 and Rehabilitation Strategies, 2010, 2012 and 2017.<br>http://www.bhp.com/environment/regulatory-information<br><br>Strength: Documents are easily accessible on the company website and<br>are comprehensive. Transparency is evident.<br>Weakness: The Environmental Authority and Specialist Studies including the Rehabilitation Strategy documents are not detailed in terms of rehabilitation planning and risk.<br>Documents are mainly focused on providing management actions and objectives.<br>Comment: Environmental Authority Specialist Studies provide greater detail,<br>However, rehabilitation planning, integration and risk determination is lacking. The focus is on impacts from mining on hydrology, vegetation etc. | 2.0 | 2.0 | 1.5 | 2.0 | 1.5 | 1.5 | 1.5 | 1.71 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| and not on the rehabilitation risks imposed by the environmental domain. | | | | | | | | |
| Duralie Coal Mine, Duralie Coal, Date accessed 20170713.<br>Environmental Authority with Specialist Studies, including Rehabilitation Strategies, 2010 and 2014. http://www.duraliecoal.com.au/page/environment/duralie-environmental-assessment-documents/<br><br>Strength: Documents are easily accessible on the company website and are comprehensive. Transparency evident.<br>Weakness: The Environmental Authority and Specialist Studies including the Rehabilitation Strategy documents are not detailed in terms of rehabilitation planning and risk.<br>Documents are mainly focused on providing management actions and objectives.<br>Comment: Initial approval was granted in 1997, extensions were approved in 2010 and 2014 and amendments were approved in 2011, 2012.<br>Environmental Authority Specialist Studies provide greater detail,<br>However, rehabilitation planning, integration and risk determination is lacking. The focus is on impacts from mining on hydrology, vegetation etc. and not on the rehabilitation risks imposed by the environmental domain. | 2.0 | 2.0 | 1.5 | 2.0 | 1.5 | 1.5 | 1.5 | 1.71 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Drayton South Coal, Anglo Coal, Date accessed 20170713.<br>Environmental Impact Statement, 2015.<br>http://hansenbailey.com.au/documents/drayton/Main_Report.pdf<br><br>Weakness: Document is focused in impacts from mining on the environment and not the risks of rehabilitation as from the environmental domain.<br>Comment: Minimal detail is provided on mine rehabilitation. | 1.5 | 1.5 | 1.5 | 2.0 | 1.5 | 1.5 | 1.5 | 1.57 |
| **Average score, mine approval consultant rehabilitation reports:<br>Australia, New South Wales** | 1.83 | 1.83 | 1.50 | 2.00 | 1.50 | 1.50 | 1.50 | 1.67 |
| **Average score, mine approval consultant rehabilitation reports:<br>Australia, Queensland and New South Wales** | 1.73 | 1.79 | 1.50 | 1.81 | 1.50 | 1.44 | 1.44 | 1.60 |
| **After mine approval consultant rehabilitation reports: Australia, Queensland** | | | | | | | | |
| Baralaba North Coal Mine, Date accessed 20170713.<br>Rehabilitation Monitoring Program, 2013.<br>http://bar.rdacms.com.au/index.cfm/baralaba-projects/baralaba-north/baralaba-north-continued-operations-project1/?keywords=rehabilitation | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.0 | 1.5 | 1.43 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Strength: Success criteria include: safe, non-polluting, stable and self-sustaining. Some useful monitoring methods are described, particularly for soils.<br>Weakness: Target based not integrated risk analysis based.<br>Comment: This report relates to key indicators that should be monitored in the post-mining landscape to evaluate whether the post-mining landscape is meeting success criteria.<br>It is not focused on rehabilitation planning, integration and risk determination. | | | | | | | | |

**After mine approval consultant rehabilitation reports: Australia, New South Wales**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mt Arthur Coal - Modification, BHP Billiton. Date accessed 20170712<br>Mine Operation Plan, 2015, Biodiversity and Rehabilitation Management Plan, 2012 & 2015 and various monitoring,<br>auditing and adaptive management reports.<br>http://www.bhp.com/environment/regulatory-information<br><br>Strength: Documents are easily accessible on the company website and are comprehensive. Transparency is evident.<br>Weakness: The Mine Operation Plan is management based focusing on goals and objectives. It also has a strong focus on closure more so than rehabilitation. | 2.5 | 2.5 | 1.5 | 2.5 | 2.5 | 1.5 | 1.5 | 2.07 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Comment: Adaptive management reports call for greater detail and analysis to prevent or adapt to rehabilitation failure, particularly as related to soils and soils testing.<br>The Mine Operation Plan/ Rehabilitation Management Plan attempts to analyse data, leading towards a resilient status.<br>Rehabilitation planning, integration and risk determination could however still be improved. | | | | | | | | |
| Duralie Coal Mine, Duralie Coal, Date accessed 20170713.<br>Rehabilitation Management Plan, 2012 and 2015.<br>http://www.duraliecoal.com.au/page/environment/duralie-environmental-assessment-documents/<br><br>Strength: Documents are easily accessible on the company website and comprehensive.<br>Transparency is evident.<br>Weakness: Management actions based with goals and objectives.<br>Comment: Very little has been provided for rehabilitation planning, integration and analysis.<br>There is more focus on specifications for rehabilitation with an emphasis on soils and vegetation. | 1.0 | 1.5 | 1.0 | 1.0 | 1.5 | 1,0 | 1.0 | 1.14 |
| Drayton, Anglo Coal, Date accessed 20170713.<br>Mine Closure Plan, 2009, Rehabilitation and Offset Management Plan, 2011 and 2013. | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.0 | 1.5 | 1.43 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| http://www.angloamerican.com.au/~/media/Files/A/Anglo-American-Australia-V2/Attachments/environment/Rehabilitation%20and%20Offset%20Management%20Plan.pdf http://www.angloamerican.com.au/~/media/Files/A/Anglo-American-Australia-V2/Attachments/environment/drayton-mine-closure-plan.pdf<br><br>Weakness: Prepared after mine approval. Forms part of mine Environmental Management System. Comment: Mine closure Plan lacks rehabilitation detail. It is mainly management and objective focused.<br>Rehabilitation and Offset Management Plans are mostly in the format of a specification document.<br>The Mine Operation Plan could not be sourced, this could contain greater detail. | | | | | | | | |
| Sunnyside Coal Mine, Namoi Mining Pty Ltd, Ecological Australia. Date accessed 20170713. Rehabilitation and Landscape Management Plan, including Mine Closure Plan, 2011. https://www.whitehavencoal.com.au/environment/docs/rehablitation-and-landscape-management-plan.pdf<br><br>Weakness: Prepared after mine approval. Forms part of mine Environmental Management System. Documents are difficult to acquire on the web. | 1.0 | 1.5 | 1.5 | 1.0 | 1.5 | 1.0 | 1.5 | 1.29 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Comment: The Rehabilitation and Landscape Management Plan is mainly management based with objectives, targets and actions prescribed. | | | | | | | | |
| Maules Creek Coal Mine, Aston Coal 2 Pty Ltd., ICRA MC Pty Ltd. and J Power Australia Pty Ltd. Date accessed 20170713. Mine Operations Plan, 2017. https://www.whitehavencoal.com.au/environment/docs/maules-creek-mining-operations-plan.pdf<br><br>Strength: A strong focus on vegetation establishment.<br>Weakness: Prepared after mine approval. Forms part of mine Environmental Management System. Documents difficult to acquire on the web.<br>Comment: Mainly management actions and objectives. Minimal focus on rehabilitation planning, integration or risk determination. | 1.5 | 1.5 | 1.5 | 1.5 | 2.5 | 1.0 | 1.5 | 1.57 |
| **Average score, after mine approval consultant rehabilitation reports: Australia, New South Wales** | 1.50 | 1.70 | 1.40 | 1.50 | 1.90 | 1.10 | 1.40 | 1.50 |
| | | | | | | | | |
| **Average score, after mine approval consultant rehabilitation reports: Australia, Queensland and New South Wales** | 1.50 | 1.60 | 1.45 | 1.50 | 1.70 | 1.05 | 1.45 | 1.46 |

**Mine rehabilitation guidelines: South Africa**

**Leading practice**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Chamber of Mines of South Africa, 1981)<br><br>Strength: Water resource contamination prevention, landform and vegetation focus. Detailed appendices<br>Weakness: Techniques may be dated and legislation has changed.<br>Comment: First self-regulatory guideline for the coal industry. | 1.50 | 2.50 | 2.00 | 2.50 | 1.50 | 1.50 | 1.50 | 1.86 |
| (Chamber of Mines of South Africa and Coaltech Research Association, 2007)<br><br>Strength: Landform and vegetation establishment focus. Moderate detailed appendices.<br>Weakness: Techniques may be dated and legislation has changed. Broad and generic.<br>Comment: Minerals industry guideline. | 1.00 | 2.50 | 2.50 | 1.00 | 1.50 | 1.00 | 1.50 | 1.57 |

**Company**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Anglo Coal Environmental Rehabilitation Improvement Group, 2009)<br><br>Strength: Landform and vegetation establishment focus. | 1.00 | 2.50 | 2.00 | 1.00 | 2.50 | 1.00 | 1.50 | 1.64 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Weakness: Contains management actions specific to Anglo coal.<br>Comment: Anglo Coal in-house document. | | | | | | | | |

**Technical**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Thompson, 2005)<br><br>Strength: Detailed descriptions of coal mining methods.<br>Weakness: Limited focus on rehabilitation.<br>Comment: Mining engineering focus. | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.00 | 1.00 | 1.36 |
| (Gauteng Department of Agriculture Environment and Conservation, 2008)<br><br>Strength: Very detailed document<br>Weakness: Analysis is for impacts not rehabilitation risk.<br>Comment: Minerals industry focus. | 2.00 | 1.50 | 1.50 | 1.50 | 1.00 | 1.50 | 1.50 | 1.50 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Average score, mine rehabilitation guidelines: South Africa** | 1.40 | 2.10 | 1.90 | 1.50 | 1.60 | 1.20 | 1.40 | 1.59 |

**Mine rehabilitation guidelines: Australia**

**Leading practice**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Minerals Council of Australia, 1998) | 2.50 | 2.50 | 2.50 | 1.00 | 2.00 | 1.00 | 1.00 | 1.79 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Strength: Landform, soils and vegetation focus. Moderate detailed appendices.<br>Weakness: Information is intertwined throughout. Broad and generic.<br>Comment: Minerals industry focused. | | | | | | | | |
| (Australian Government and Department of Industry Tourism and Resources, 2006)<br><br>Strength: Landforms, soils and vegetation focus, described in life-cycle phases.<br>Weakness: Information is intertwined throughout. No appendices. Broad and generic.<br>Comment: Minerals industry focused. | 2.50 | 2.50 | 1.50 | 1.50 | 1.50 | 2.00 | 1.00 | 1.79 |
| (Australian Government et al., 2016b)<br>Strength: Landforms, soils and vegetation focus, described in life-cycle phases.<br>Weakness: Information is intertwined throughout. No appendices. Broad and generic.<br>Comment: Minerals industry focused. | 1.50 | 2.50 | 2.50 | 1.00 | 1.50 | 2.00 | 1.00 | 1.71 |
| (Government of Western Australia et al., 2015)<br><br>Strength: Recent guideline. Risk assessment focus.<br>Weakness: Closure focus, rehabilitation a component of closure.<br>Comment: Minerals industry. Closure. | 2.00 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.57 |

**Technical**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Department of Minerals and Energy, 1995) | 2.50 | 2.00 | 2.50 | 1.50 | 1.50 | 2.50 | 2.50 | 2.14 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Strength: Detailed technical sheets provided.<br>Weakness: Limited focus on rehabilitation, more on mining.<br>Comment: Minerals industry technical guideline. | | | | | | | | |
| **Average score. mine rehabilitation guidelines: Australia** | 2.20 | 2.20 | 2.10 | 1.30 | 1.60 | 1.80 | 1.40 | 1.80 |
| **Summary score, mine approval consultant rehabilitation reports: South Africa and Australia** | 1.86 | 1.82 | 1.57 | 1.83 | 1.57 | 1.47 | 1.58 | 1.67 |
| **Summary score, mine rehabilitation guidelines: South Africa and Australia** | 1.80 | 2.15 | 2.00 | 1.40 | 1.60 | 1.50 | 1.40 | 1.69 |
| **Mine rehabilitation guidelines:** Near resilient maturity example from other mining countries | | | | | | | | |
| (Newton and Claassen, 2003) | 2.00 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 1.00 | 2.21 |

**Table S2:** Mine rehabilitation legislation and document types: South Africa and Australia, Queensland and New South Wales.

| | South Africa | | Australia | |
|---|---|---|---|---|
| **Mine life-cycle phase** | **< 2015 Financial Provisions Regulations** | **> 2015 Financial Provisions Regulations** | **Queensland** | **New South Wales** |
| **Approval** | Basic Assessment or Scoping and Environmental Impact Assessment.<br>Environmental Management Programme.<br>Closure Plan & Environmental Risk Assessment.<br>(Rehabilitation specified in body of the above reports)<br>**OR**<br>Mine Rehabilitation Plan.<br>(As a stand-alone appendix attached to the above reports). | Basic Assessment or Scoping and Environmental Impact Assessment.<br>Environmental Management Programme.<br><br>The following documents form part of the Environmental Management Programme:<br>Annual Rehabilitation Plan; Final Rehabilitation, Decommissioning and Mine Closure Plan;<br>Environmental Risk Assessment; and Financial Provisions. | Environmental Authority.<br>Environmental Impact Statement. Environmental Management Plan no longer required.<br>(Rehabilitation specified in body of Environmental Impact Statement **OR a**s a stand-alone Mine Rehabilitation Plan appended to Environmental Impact Statement).<br><br>Mine Rehabilitation Plan (At start, later transitions into Progressive Rehabilitation Report/ Final Rehabilitation Report) | Environmental Authority.<br>Environmental Impact Statement (Rehabilitation specified in body of Environmental Impact Statement **OR** as a stand-alone Mine Rehabilitation Plan appended to Environmental Impact Statement)<br><br>Mine Rehabilitation Plan (At start, later transitions into Mining Operation Plan) |
| **Operation** | Rehabilitation specification reports. (Often a condition of approval and required prior to start of operation). | Annual Rehabilitation Plan (Update annually).<br>Final Rehabilitation, Decommissioning and Mine Closure Plan, Environmental Risk | Progressive Rehabilitation Report (Updated progressively for surrender of a part of a site or for surrender of the Environmental Authority) | Mining Operation Plan ('Hybrid' Mine Rehabilitation Plan and Closure Plan, required prior to operation start-up, |

| | | | | |
|---|---|---|---|---|
| | Mine Rehabilitation Monitoring and Adaptive Rehabilitation Response reports (Update progressively, in-house). | Assessment and Financial Provisions (Update progressively). | Plan of Operations (Includes rehabilitation program, financial assurance, needed prior to operation start, after Environmental Authority, updated every 5 years or if changes occur) | after Environmental Authority is granted, valid for 5 years, public document, includes rehabilitation cost estimates, Environmental Risk Assessment, risks of rehabilitation and adaptive management responses. Soon to be renamed Rehabilitation Management Plan. |
| **Closure** | | Final Rehabilitation, Decommissioning and Mine Closure Plan, Environmental Risk Assessment and Financial Provisions (Finalise at end). | Final Rehabilitation Report (updated for surrender of parts or a whole pf the site, for progressive or final rehabilitation, for surrender of the Environmental Authority)<br>Risk Assessment<br>Residual Risk Calculation | |
| **Legislation** | National Environmental Management Act, Act No. 107 of 1998; 2014 EIA Regulations; National Environmental Management: Waste Act, Act No. 59 of 2008; National Water Act, Act No. 36 of 1998; and | National Environmental Management Act, Act No. 107 of 1998; 2014 EIA Regulations, with 2017 amendments; National Environmental Management: Waste Act, Act No. 59 of 2008; 2015 Regulations regarding the planning and management of | Minerals Resources Act, 1989; Environmental Protection Act, 1994; Environmental Protection Regulations, 2008; and State Development and Public Works Organisation Act 1971. | Environmental Planning and Assessment Act, 1979; Mining Act. 1992; and Protection of the Environment Operations Act, 1997 |

| | | | |
|---|---|---|---|
| Minerals and Petroleum Resources Development Act, Act No. 28 of 2002 and its 2004 Regulations.<br><br>All are National legislation.<br><br>Assessing Authority was the National Department of Environmental Affairs and in some cases the Provincial Department. | residue stockpiles and deposits; National Water Act, Act No. 36 of 1998; Minerals and Petroleum Resources Development Act, Act No. 28 of 2002; and 2015 Financial Provisions Regulations.<br><br>All are National legislation.<br><br>Assessing Authority is the National Department of Mineral Resources and in some cases the Provincial Department. | All are Queensland state legislation.<br><br>Commonwealth Environmental Protection and Biodiversity Act, 1999 is applied, when the project has national environmental significance. | All are New South Wales state legislation.<br><br>Commonwealth Environmental Protection and Biodiversity Act, 1999, is applied, when the project has national environmental significance. |