A review of mine land rehabilitation outcomes: Culture, procurement and practice

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Abstract

Land rehabilitation transcends the mere establishment of vegetation across disturbed landscapes; it should be conceptualised as a specialised ecological reconstruction process. This process necessitates a long-term perspective on the success of land repurposing. It requires a continuum of inputs specified and managed by a dedicated and qualified custodian to ensure the sustained economic viability and ecological sustainability of the land.

Based on the authors' combined experience and field observations over more than five decades, they advocate for an urgent shift away from traditional land rehabilitation practices toward a paradigm centred on land capability reconstruction and active stewardship. The prevailing rehabilitation culture has overly simplified the process to a mere revegetation exercise, which is fundamentally incompatible with the comprehensive requirements for sustainable land capability. While the regulatory framework provides valuable guidance for obtaining a mine's social license to operate, a paradigm reset is essential. Mining companies must prioritise rehabilitation quality, set achievable sustainability goals, and establish clear pathways and milestones to meet relinquishment criteria.

Currently, the status quo view—a model reliant on outsourced contracting and agricultural approaches—is that mine rehabilitation is a one-time intervention rather than a complex, systemic, and long-term process. This perspective presents significant challenges, as the success of ecological interventions can only be accurately assessed over extended timeframes, often spanning decades. Shortsighted rehabilitation specifications, coupled with practitioners operating within agricultural decision frameworks, frequently overlook the necessity for integrated rehabilitation expertise and the scientific foundation essential for designing and implementing effective ecological outcomes. A lack of long-term monitoring information impedes the required adaptive management of rehabilitated systems and, therefore, delays the transition towards final land use. This short approach costs the mining industry millions annually, often without recognising the inadequacies in long-term liability mitigation and the substandard ecological success achieved. The disconnect between procurement processes, the qualifications of service providers, and the unclear pathways to relinquishment can impede successful rehabilitation outcomes, frequently undermining progress toward sustainability milestones. Unless there is a fundamental reset of the land rehabilitation culture, pursuing sustainability will remain an elusive and perhaps impossible objective. Consequently, mining companies may hesitate to fully commit to sustainable land rehabilitation practices, as the prospects for relinquishment and final closure remain uncertain at best.

Keywords

rehabilitation practice, closure outcomes, environmental procurement, unsuccessful relinquishment

Introduction

The extensive mining operations in South Africa began in the 1880s with the diamond and gold rush and have significantly shaped the country's economy. As a result, South Africa has become a global leader in mining, contributing notably to economic development, local, and international business services, and employment opportunities. However, these mining activities have historically prioritised immediate economic gains over environmental sustainability, leading to well-documented adverse impacts on land and water over the past 150 years.

The late 20th century marked a turning point, with increasing environmental awareness spurred by the Brundtland Report on sustainability (Bruntland, 1987). This shift prompted both governmental and industrial policy responses aimed at environmental responsibility, resulting in the establishment

of legal frameworks and guidelines focused on environmental protection and rehabilitation. The evolution of mine rehabilitation in South Africa thus reflects a transition from reactive measures to proactive sustainability strategies aimed at ecosystem restoration and community benefit.

The timeline of mine rehabilitation in South Africa can be summarised as follows:

- **2002:** The government prioritised environmental sustainability in the Constitution Article 24, leading to the Mineral and Petroleum Resources Development Act (MPRDA), which required mining companies to prepare Environmental Management Plans (EMPs) for rehabilitation. Relevant legislation includes the National Environmental Management Act (NEMA) of 1998, the National Environmental Management: Waste Act of 2008, and the National Water Act of 1998, all of which provide guidelines for environmental protection and rehabilitation in mining.
- **2004:** The Mining Charter was introduced under Article 2 of the MPRDA to accelerate Black Economic Empowerment and economic transformation within the mining sector. This Charter has undergone amendments in 2010 and 2018 to facilitate the participation of black-owned small, medium, and micro enterprises (SMMEs) in the mining economy, often through corporate social esponsibility (CSR) initiatives focused on environmental sustainability.
- **2007:** The Department of Mineral Resources and Energy (DMRE) developed rehabilitation guidelines in collaboration with stakeholders, emphasising best practices and sustainable outcomes. Earlier documents, such as the Chamber of Mines Guidelines for Coal Mines (1981) and Aide Memoire (1996), served as precursors to these guidelines.
- **2008:** Financial provisions were implemented, requiring mining companies to allocate financial resources for rehabilitation to ensure funds remain available for these efforts, even in cases of corporate insolvency.
- **2010s:** A heightened emphasis on sustainable development led to the integration of biodiversity conservation, community engagement, and post-mining land use planning into rehabilitation strategies, reflecting a more comprehensive approach to sustainability.
- **2020s:** Recent advancements in mine rehabilitation have focused on addressing historical mining legacies, internal improvement of compliance and self-governance, and enhancing stakeholder participation. Regulatory enforcement of quality rehabilitation is largely absent in South African mines. There is, however, a growing emphasis on innovative techniques and technologies in rehabilitation practices through university research programmes.

Globally recognised as a leader for its robust environmental legislation and regulatory frameworks, South Africa underscores the importance of integrating environmental considerations into mining operations. The government promotes sustainable practices and innovative approaches, yet incentives for sustainability outcomes remain limited. Achieving effective land rehabilitation and realising "walk-away" closure scenarios remain uncertain outcomes for the mining industry.

Understanding the scientific requirements and outcome standards necessary for these concepts, alongside the priorities of regulators, is crucial for empowering the mining sector to ensure the sustainability of post-mining landscapes.

Rehabilitation objectives

Internationally, the Land Rehabilitation Guideline (Tanner et al., 2007) outlines three primary schools of thought regarding rehabilitation objectives:

1. **Community commitments:** This approach focuses on delivering end-products that meet the needs of affected communities rather than merely restoring previous conditions.
2. **Restoration of previous land use capability**: Historically prominent in South Africa, this perspective recognises that mining often occurs on land with high agricultural potential.
3. **No net loss of biodiversity:** This principle is emphasised in guidelines sponsored by the International Council on Mining and Metals (ICMM) and the International Union for Conservation of Nature (IUCN) and in many corporate mining policies.

In South Africa, rehabilitation objectives typically incorporate elements from all three approaches. The obligations of mine permit holders are clearly outlined in the MPRDA and its accompanying regulations, which stipulate that "as far as reasonably practicable," the land affected by mining operations must be rehabilitated to its natural or predetermined state or to a land use conforming to sustainable development principles (Section 38 (1) (d) of MPRDA, 2002).

The MPRDA regulations require the submission of closure objectives as part of the draft Environmental Management Programme Report (EMPR), which must outline key objectives for mine closure to guide project design and management of environmental impacts. These objectives should specify future land use goals for the site and associated closure costs (Reg 61 (1) of the MPRDA Regulations, 2004). Applicants for mineral rights must also submit a closure plan, translating these objectives into an implementable strategy (Reg 62 of the MPRDA Regulations, 2004). Key components of this plan include closure objectives, summaries of regulatory requirements, results from environmental risk assessments, rehabilitation efforts, methods for decommissioning mining components, long-term management expectations, proposed closure costs, and records of consultations with interested parties.

From the mining industry's perspective, rehabilitation practices aim to rehabilitate impacted land to a sustainable condition. The question remains what this requires, and who is ultimately accountable. Recognising that complete restoration is often unattainable, this approach emphasises minimising the loss of land use capability and promoting net societal benefits. Historically, restoration of land capability has been the primary focus, enabling cost estimation for rehabilitation processes and facilitating feasible scopes of work. Common rehabilitation projects involve soil placement, water control measures, soil amelioration, and revegetation of commercial pastures, often accompanied by maintenance phases.

A significant complication in closure and sustainability decisions is that rehabilitation objectives must align with national and regional integrated development plans (IDPs), which necessitate municipal involvement. The committed end land use may not necessarily reflect local community desires. Ultimately, rehabilitation objectives approved in the EMP and Closure Plan are costed and executed by the mine, based on corporate commitments and the mine's understanding of sustainable post-mining land use. While Section 38 (1) of the MPRDA emphasises restoring the

mine area to its natural or predetermined state, it also stipulates that rehabilitation must be practicable and involves a public participation process to define the 'end use'.

Predicting viable land use at the end of a mine's life is challenging, leading to frequent amendments of the EMP during operations to review closure commitments. Most mines engage in low-cost revegetation to create stable, aesthetically pleasing surfaces that can benefit adjacent commercial or subsistence farmers. However, rehabilitated land often remains unmanaged, and insufficient soil amelioration, incomplete maintenance programmes, and variable land use hinder ecosystem reconstruction.

The notion that initial revegetation efforts will naturally develop into fully productive landscapes within the life-of-mine through succession processes, is proven wanting. Due to under-amelioration of soil carbon sources, most rehabilitated systems lack essential soil chemical and microbial properties necessary for sustaining productive land use. Thus, investment in the drivers of soil and ecological health must be reconsidered in rehabilitation specifications and cost structures to achieve quality outcomes. A key limitation of self-sustaining substrates is the lack of soil nutrient cycling. These cycles are dependent on soil organic matter and adequate soil moisture, which sustain microbial activity and regulate soil nutrition, i.e., the minimum requirements for healthy soils.

Mine rehabilitation best practices

To enhance the rehabilitation process, best practice guidelines and rehabilitation and closure toolboxes have been established globally by government agencies and mining companies. These frameworks assist in regulatory compliance, accelerate planning, and guide decision-making for land rehabilitation by establishing key performance indicators (KPIs) critical to a mine's rehabilitation strategy.

A summary of widely adopted best practices (Barter, 2024) includes:

- **Early and continuous engagement:** Actively involve stakeholders—including local communities, government agencies, and environmental organisations—in mine closure planning to incorporate their perspectives.
- **Comprehensive mine closure plans**: Develop scientifically grounded closure plans tailored to the unique environmental and social conditions of each site.
- **Sufficient financial provision:** Ensure financial resources for mine closure are adequate and reviewed regularly to cover rehabilitation costs, including ongoing monitoring and maintenance.
- **Progressive rehabilitation measures:** Implement rehabilitation strategies during the operational phase, such as soil stabilisation, revegetation, and water management, to minimise erosion, protect water quality, and foster natural ecosystem recovery.
- **Effective erosion control measures**: Use techniques like terracing, mulching, and sedimentation ponds to prevent erosion and safeguard water quality during and after closure.
- **Sustainable plant species:** Focus on native plant species for revegetation and employ innovative techniques like bioremediation and ecological engineering to restore ecological functionality.
- **Monitoring and evaluation:** Establish regular monitoring programmes to evaluate rehabilitation effectiveness and adjust activities based on findings.
- **Training and awareness programmes:** Provide comprehensive training for mine workers on rehabilitation best practices to ensure their commitment to the process.
- **Collaboration with research institutions:** Partner with research organisations to share knowledge of and innovate mine rehabilitation practices.

However, a critical shortcoming of these guidelines is the assumption that they will yield land capable of sustainable end uses within the lifespan and business cycles of the mine. Many practices focus on mere revegetation rather than the comprehensive restoration of ecosystems, which requires years of assessment to evaluate biodiversity recovery effectively. The end objectives of many rehabilitation commitments are also quite confusing as the aim of alignment with industry guidelines is simply to revegetate the land and not to deliver a reconstructed ecosystem with the minimum required criteria of structure, function, and composition. The notion of successfully returning biodiversity to a rehabilitated mine site can only be evaluated after many years, as the eventual survival of recreated habitat should be evaluated and not merely the initiation of the process. Adequate provisions for mine closure commitments depend on thorough land capability designs that inform potential end-use scenarios. This consideration should precede commitments about rehabilitation, biodiversity outcomes, and permit issuance.

From the mining operator's perspective, these elaborate unquantified or unclear rehabilitation KPIs are often considered impractical, unaffordable, and difficult to supervise. Furthermore, it is often challenging to identify the individual responsible for ensuring that the works are adequately scoped, professionally executed, scientifically quantified according to the correct sustainability metrics, and reported correctly to the company executive and the competent authority. The timeline over which these KPIs need to be evaluated also often creates an accountability vacuum as individuals move around or are rapidly reassigned throughout the mining industry, and corporate knowledge about the projects dwindles over time. The lack of continuity and incomplete process management often necessitate rework, which is not budgeted for. With the compounding effect of regulatory absence and lack of enforcement capability, rehabilitated land is reactively managed. Furthermore, the mining industry and the public need to understand that living (rehabilitating) systems cannot be managed according to fixed timelines and inflexible administrative processes, which render the thought process and the qualification of success virtually impossible.

The reactive management of rehabilitated land is exacerbated by regulatory inadequacies and enforcement challenges. There is a pressing need for a paradigm shift in land rehabilitation to emphasise sustainability and the associated costs, especially considering rapid resource depletion. A reset regarding the thought processes about land rehabilitation is urgently needed in the interest of sustainability and the actual cost of sustainability. Considering the rapid deterioration of natural resources, time is not on the side of the industry.

Review of mine rehabilitation quality criteria

Over the past 30 years, several methodologies for assessing mine rehabilitation efforts have evolved, yet published data on rehabilitation quality remains limited, primarily confined to academic studies and internal reports. While the extent of rehabilitation (in hectares) is documented in annual reports, qualitative assessments of rehabilitated land's conversion back to productive use are scarce.

Mine rehabilitation quality also means different things to different mining operations, when the simple execution of rehabilitation is regarded as being successful, the reintegration of rehabilitated land back into natural systems or reaching biodiversity targets may be the benchmark for others. The definition of rehabilitation quality varies widely among mining operations. For some, simply executing rehabilitation activities marks success, while others seek to reintegrate rehabilitated land into natural systems or meet specific biodiversity targets. Consequently, rehabilitation outcomes can differ significantly based on mining type, regulatory compliance, and specific practices employed.

The most prevalent quality criteria or relinquishment criteria are also selected based on edaphic and ecological bases rather than the productivity value of revegetated systems. Since the objectives of the monitoring programmes are not aligned, sustainability outcomes may be delayed. Key observations regarding rehabilitation quality criteria include:

1. **Variable regulatory and social adherence:** Companies often prioritise short-term environmental compliance over long-term land use integration, hindering the viability of end land uses.
2. **Variable ecological success rates:** Rehabilitation success is inconsistent; some sites recover ecosystems effectively, while others remain degraded. Critical factors include soil type, climate, and disturbance extent.
   - **Innovative practices:** Adoption of innovative techniques, like using native plants and bioremediation, is increasing. However, attention must focus on substrate design and landscape-level sustainability to avoid project delays.
   - **Soil and water quality:** Challenges persist in reconstructing soil profiles and restoring hydrological functions. Some rehabilitated areas show improvement, while others suffer from contamination and erosion.
   - **Biodiversity recovery:** Many sites struggle to restore premining biodiversity levels, especially where invasive species thrive. Clear definitions and timelines for biodiversity targets remain elusive, impacting the overall value of reinstatement efforts.
3. **Long-term monitoring:** Robust long-term monitoring programmes are lacking, which is essential for evaluating rehabilitation effectiveness and ensuring ecosystem resilience over time.

Despite increased awareness among mining organisations of their rehabilitation responsibilities, a comprehensive framework or database for assessing rehabilitation quality remains absent, leading to significant decision-support challenges in reintegrating and transitioning mined land back to productive use.

Land rehabilitation in action

The authors have collectively spent more than 50 years studying and assessing land rehabilitation quality across the South African mining industry, conducting rehabilitation implementation works and scientific assessments on all the types of mine waste facilities, mine impacted land, residue stockpiles and backfilled open pits. They argue that the in-field philosophy, methodology, and quality of mine rehabilitation have barely progressed since the advent of the industry in the late 1950s. Although there is evidence of intensive revegetation efforts since the 1990s, and despite excellent legislation, the plethora of guidelines and toolboxes, the rapid advancement in land rehabilitation knowledge and quality assessment frameworks, and amelioration and survey technology, simple revegetation programmes are still the benchmark for "sustainability" projects. In light of their on-site experience, they wish to reflect on what they observe regarding land rehabilitation decision-making throughout the industry and what the outcomes of the processes have delivered through the lens of run-of-the-mill mining operations. It is clear that operational pressures and priorities, procurement oversight and priorities, financial cycles, and compliance modes still largely dictate decisions about land rehabilitation implementation and specifications, even though environmental pressure has now become sustainability and stewardship pressure.

On-site rehabilitation observations: A non-linear process, multiphase process

Engaging with mine personnel about land rehabilitation outcomes often reveals several misconceptions based on the expectation that singular interventions with associated short-term maintenance constitute a successful rehabilitation activity. The following summary presents the ideas behind misconstrued rehabilitation decision-making that underlie the South African rehabilitation culture:

1. **Hectares levelled:** Success is measured by the number of hectares levelled, based on the expectations of the Department of Mineral Resources. This fosters a belief that flattening land completes rehabilitation, and this intervention will allow nature to take over, minimising costs.
2. **Landscaping and grass planting:** Some entities equate rehabilitation with merely spreading a mix of grass seeds, assuming they can disengage from the process afterward.
3. **Sufficiency of rehabilitation schedules:** Submitting a rehabilitation schedule is often seen as enough to appease regulators, with plans to execute rehabilitation in subsequent years.
4. **Timing misconceptions:** There is a belief that rehabilitation can begin after the December break, often leading to delays.
5. **Confusion surrounding land capability:** Rehabilitation is frequently misunderstood as synonymous with land capability.
6. **Assumptions about end-use:** There are expectations that rehabilitated land can be utilised as carbon offsets, natural sinks, fulfil biodiversity commitments, return to its original state, or support similar activities as before mining, such as farming.
7. **Yield expectations:** A misconception exists that rehabilitated land will produce the same commercial outputs as its premining capability.
8. **Short-term solutions:** The expectation for a "walk-away solution" within two years post-rehabilitation persists.
9. **Community transfer:** There is a belief that rehabilitated land will be handed over to communities for agricultural use.
10. **Natural rehabilitation:** Some assume that land will naturally rehabilitate without active vegetation establishment.

These misconceptions underscore significant confusion within mining operations regarding the drivers, expectations, timelines, and specialised focus necessary for effective land rehabilitation. Current specifications reflect a limited cost blueprint, often failing to support long-term rehabilitation success.

The authors argue that this culture of inaccurate costing—rooted in substandard specifications—arises from reliance on generic guidelines and closure cost estimates, which overlook the true long-term expenses associated with land rehabilitation.

Despite substantial investments in rehabilitation efforts in South Africa over the past 50 years, many rehabilitated mine sites continue to face significant challenges, such as:

- Evidence of substrate instability (geotechnical and surface instability);
- High erosion rates, gullies and spills across the rehabilitated land;
- Soil void and depleted of nutrients;
- Soil hard setting year-on-year;
- Poor vegetation cover and biomass year-on year;
- Limited species diversity, no progression of species diversity, low or no succession rates;
- Non-functional soil microbial activity;
- Rapid decrease in soil organic matter in rehabilitated soils;
- Precipitates of chemical compounds;
- Low/no water holding capability;
- Water ponding on surface;
- Water decant and seepage of different volume and qualities;
- Alien invasive plants rapidly increasing;
- Limited end land use reintegration;
- Lack of site security with either overgrazing, loitering or annual fire risks;
- Absence of designed surface water management infrastructure;
- Substantial contribution to poor air quality in the form of dust episodes or spontaneous combustion smog.

From a specifications and closure perspective, further challenges include:

- Lack of a project vision or plan;
- Absence of specific closure objectives;
- No documentation of initial site assessments and analysis reports;
- Missing water management and treatment programmes;
- Lack of monitoring data and accountability;
- No record of materials used in rehabilitation;
- Absence of a sustainability progress charter.

These challenges indicate that existing rehabilitation methodologies fail to meet sustainability criteria, prompting a critical need to examine why current processes do not achieve desired medium- to long-term outcomes. This leads to wasted resources and time, exposing mines to non-compliance and increased costs while stalling sustainability progress.

Mining NPV culture and rehabilitation implementation thought process

Mining operations and land rehabilitation do not share aligned KPIs, complicating effective rehabilitation execution. Mining managers must balance profitability with the necessity of environmental rehabilitation, which is often seen as a begrudged expense that could diminish profit margins. Different managerial approaches and incentive structures further complicate decision-making regarding rehabilitation. The mining manager needs to balance the operation's profitability on the one hand (as per the business plan and budget requirements), whilst on the other hand make provisions for environmental rehabilitation, which can potentially erode management's profit share. The project ownership and acumen of process and systems managers also differ in approach, and the different incentive mindsets will drive different decisions. However, the rehabilitation activity will always be acutely managed for a fixed-cost margin, or allowable cost per tonne mined, whilst environmental systems cannot be approached as a fixed-cost allowable in the same budget.

Mining companies may prioritise immediate financial returns over long-term liabilities, resulting in insufficient budgeting for rehabilitation efforts. Confusion and underestimation of mine rehabilitation operational costs and final liability costs can arise from several factors related to discounting practices and project value calculations. One of the origins of this culture is that financial models applied for mining projects consider operational rehabilitation cost as part of the net present value (NPV), where environmental cost is often planned and viewed as a once-off expense and may be underestimated before and during the mining operation as different cost scenarios.

Discounted rates may present a profitable project, but it is well known that rehabilitation costs escalate at a higher rate than the average inflation rate (linked to rises in agricultural and equipment costs), and risk-free rates increase the cost of capital and hence, increase the required shareholder returns from the project over time. Thus, rehabilitation costs are almost always underestimated due to the incorporation of inaccurate discount rates into NPV calculations. Furthermore, NPV calculations may not adequately account for uncertainties and risks associated with rehabilitation, such as regulation changes, environmental conditions, or unexpected remediation needs.

The requirement for financial provisions for rehabilitation has been implemented to mitigate this risk further. While financial provisions for rehabilitation have been mandated to mitigate these risks, many companies still employ inadequate financial strategies that do not fully capture rehabilitation costs. Closure costs included in liability provisions are frequently conflated with costs allowable for rehabilitation works. The closure cost allowed for in the liability provision is also often used in the cost allowable for rehabilitation works. Since rehabilitation is an operational cost, it should not be confused with the closure liability cost provision, and the works need to be carried out concurrently during operations, which has also become the exception at many mines. It is, therefore, evident that the cost available for land rehabilitation will always be subject to a minimum allowable to establish vegetation. Therefore, the aim of the specification will be completely different from a specification that needs to be implemented and maintained over 10 years.

As a result, funding for land rehabilitation is limited to the minimum funds necessary for establishing vegetation, leading to specifications that differ significantly from those needed for projects requiring long-term maintenance. This dynamic typically results in low-cost projects and ultimately yields subpar results. Since the lowest cost contractor would then come into contention, a seed cocktail and simplified amelioration programme would always focus on project completion in one growth season. They will deliver a sparse pasture cover – often not resilient to South African climate variation. This practice cannot deliver sustainably productive end-land-use.

This is the status quo interface between rehabilitation finance decisions and lack of clarity regarding the outcomes process summarised, and it will continue if the existing decision-making culture and project ownership (lack-of-ownership) model persist. To address these challenges, mining companies should adopt more accurate discounting methods, implement comprehensive lifecycle assessments, and ensure that financial provisions reflect the true scope of future liabilities.

Adopting a Land Custodian Model, whereby sustainability-accountability is managed by professional land management agencies, could facilitate the delivery of sustainable land covers

over time, aligning with the KPIs of sustainable mining strategies. This necessitates a re-evaluation of cost, implementation, liability management, and ownership models to ensure long-term rehabilitation outcomes.

Land rehabilitation procurement processes

Standard procurement processes typically appoint service providers based solely on competitive bids, significantly influencing the outcomes of rehabilitation efforts. While selecting cost-effective and competent contractors is crucial from a governance perspective, the assumption that a robust procurement process will yield optimal value for mining companies is fundamentally flawed.

The current procurement paradigm fails to foster savings or sustainable development for small, medium, and micro enterprises (SMMEs), exacerbating the opportunity costs associated with expedited environmental improvements and undermining the interests of mining operations. A constructive procurement approach, conducive to enhanced sustainability outcomes, would involve evaluating the total cost of ownership of rehabilitation projects over five years. This strategy entails appointing professional contractors as accountable partners and designating specialist contractors as custodians during the maintenance phase to ensure a well-monitored and maintained landscape, ultimately supporting effective and sustainable end land use projects.

Key insights for enhancing procurement policy in the context of long-term sustainability projects include:

- **Proactive planning:** Professional land rehabilitation contractors engage in advance planning, procure materials early to pass savings onto the mining company, and incorporate follow-up maintenance in service delivery.
- **Expert involvement:** The inclusion of rehabilitation specialists, such as engineers and scientists, within the contractor's delivery team is essential for problem-solving, monitoring, and rapid intervention, which are critical to the long-term success of rehabilitation projects.
- **Timely engagement:** The success of initial rehabilitation efforts is heavily contingent on seasonality – late contractor appointments can substantially diminish establishment success, often leading to project failure without accountability for sustainability outcomes. In many cases, late initiation of projects results in dismal failure of the project and procurement is not held accountable for sustainability project failures.
- **Economies of scale:** To achieve cost reductions and relay these benefits to clients, professional contracting firms require predictability in purchase orders to enable bulk procurement, particularly if a specification-based approach is adopted.
- **Equipment reliability:** For a professional contractor to deliver quality rehabilitation works, it is extremely important to work with reliable, precision-enabled equipment in a harsh environment, considering that the contractor is subjected to high capital layout and continuous maintenance costs. To provide a viable long-term service, longer term contracts (no less than 5 years) would contribute substantially to the mine and the contractor's cause.
- **Neighbour engagement:** While appointing local farmers for rehabilitation projects can foster goodwill, their primary focus on low-cost solutions and personal farming priorities often results in inadequate service delivery and diminished accountability. Although competent, a farmer's personal farming interests usually dictate the assignment of equipment and resources, and the mine's project will always be a second priority, whilst the mine has limited leverage to keep the farmer accountable.
- **Inexperienced contractor risks:** An emerging pattern of land rehabilitation failure is noticed where corporate social responsibility programmes under the auspices of the Mining Charter to empower local and often inexperienced doorstep companies. Mine procurement may often substitute a professional rehabilitation contractor for an inexperienced SMME landscaping company. The local community rehabilitation contractors have become part of the competitive landscape, often sub-contracting the local farmer or specialist contractor at a considerable cost to the mine, with low-cost delivery in mind. This process increases costs and subpar service quality due to reliance on subcontracting arrangements.
- **Rework implications:** Adopting a low-cost approach to land rehabilitation and specification-based projects invariably leads to rework over time, further inflating costs.

The misalignment of procurement processes, coupled with insufficient synergy among rehabilitation contractors, technical support, and effective equipment and material management, incurs substantial financial costs for mining companies. Moreover, the ecological benefits that could accrue during the time lost to ineffective rehabilitation efforts are critical and irreplaceable.

An alternative technical approach to successful land rehabilitation

Successful land rehabilitation begins with a vision of establishing a minimum viable ecosystem capable of delivering ecosystem services and functioning benignly within the landscape. The overarching objective remains compliance with the "best practicable" option as outlined in the Mineral and Petroleum Resources Development Act (MPRDA) Section 38.1, which mandates the return of land to a state consistent with sustainable development principles.

A three-step framework is proposed to facilitate a comprehensive understanding of rehabilitated land status, enabling mining companies to categorise their progress effectively. This framework can be readily communicated to regulators and local communities to manage expectations regarding land use readiness:

1. **Land rehabilitation initiation (0–5 years):** Establish the foundational elements of the rehabilitation process.
2. **Land maintenance (5–10 years):** Implement ongoing management strategies to foster ecological recovery and stability.
3. **Land relinquishment (10+ years):** Transition stewardship of the rehabilitated land to ensure long-term ecological integrity and land use viability.

Management of this phased approach should be entrusted to experienced land rehabilitation specialists and project managers, emphasising liability management and compliance.

The objective of this phased process is to oversee the reconstruction of natural processes towards the establishment of a selfsustaining resource base. This approach necessitates the development of a customised design document that delineates project architecture, including timelines, resource allocations, developmental criteria, and success metrics.

Essential components of the phased process include:

- **Soil management:** Ensuring the availability and quality of soil close to the final placement destination, considering adequate volume and appropriate characteristics.
- **Soil profiling:** Implementing precise soil profiling for sustainable surface preparation.
- **Organic content management:** Designing, costing, and modelling soil organic content accumulation to meet specifications.
- **Moisture and soil chemistry modelling:** Integrating soil moisture, alkalinity, acidity, and sodicity management into project specifications.
- **Professional practices:** Employing professional amelioration and biodiversity management strategies.
- **Ongoing management:** Conducting monthly land management practices, including weeding, fire management, and defoliation.
- **Specialised custodianship:** Designating specialised land custodians focused on end land use development.
- **Monitoring programmes:** Establishing frequent and detailed monitoring protocols to provide insights aligned with specific end land use objectives.

Adopting this alternative approach is strongly recommended to achieve viable end land use outcomes and ensure committed stewardship at optimal costs.

Land custodianship – assign the land rehabilitation process to someone who cares

Adopting a land custodianship model signifies a transformative approach to land rehabilitation, promoting sustainable management practices that emphasise long-term stewardship. This model integrates community involvement with specialist oversight and management by professional rehabilitation contractors, ultimately fostering enhanced ecological resilience, reduced management costs, and improved community relations. By engaging local communities, companies can ensure that rehabilitation initiatives align with local needs and ecological contexts, maximising effectiveness.

The long-term custodianship model offers several advantages over traditional short-term rehabilitation strategies:

1. **Long-term planning and integrated land use:** The custodianship model encourages comprehensive land use planning that prioritises the long-term viability of ecosystems and associated services. This proactive approach enables more sustainable land use decisions compared to reactive, short-term management strategies.
2. **Community engagement and stewardship:** Involving local communities fosters stewardship and shared responsibility for the land. This engagement often results in sustainable practices that reflect local ecological knowledge and cultural values, potentially reducing the need for costly oversight. Moreover, sustainable land use initiatives, such as ecotourism and sustainable agriculture, can create economic opportunities, providing ongoing revenue streams for communities.
3. **Ecosystem focus:** The custodianship model emphasises the long-term restoration and maintenance of ecosystems, fostering biodiversity and enhancing ecological resilience. Allowing natural processes to facilitate ecosystem recovery can improve biodiversity and ecosystem services (e.g., water filtration, carbon sequestration), leading to economic benefits that surpass initial rehabilitation costs. Healthy ecosystems exhibit greater resilience to disturbances, potentially mitigating the need for costly interventions in the future.
4. **Lower long-term liabilities:** Prioritising custodianship can result in lower long-term financial liabilities associated with land management. Sustainable practices diminish the necessity for intensive inputs and interventions over time, allowing organisations to anticipate and mitigate future environmental challenges. This proactive stance can reduce costs linked to unforeseen remediation efforts.
5. **Reduced intensive inputs:** Long-term custodianship requires less intensive management, as natural recovery processes can prevail. This approach enables the implementation of adaptive management strategies that evolve based on monitoring outcomes and changing conditions, ultimately reducing the necessity for costly interventions. In contrast, intensive management models often require ongoing inputs, such as labour and resources, to maintain rehabilitated areas.

Transitioning to a long-term land custodianship model emphasises sustainability, community involvement, and integrated planning, rendering it a more effective and cost-efficient alternative to short-term, intensive management approaches. This shift benefits not only environmental integrity but also enhances economic and social outcomes for local communities. By committing to sustainable land stewardship, companies may face fewer regulatory hurdles and associated costs, fostering a more stable operational environment.

Conclusion

This review elucidates the complexities surrounding mine land rehabilitation in South Africa, highlighting that, while existing policies and guidelines support rehabilitation efforts, challenges persist in their implementation. These challenges arise from ineffective specifications, unrealistic expectations regarding minimalistic rehabilitation interventions, procurement inefficiencies, and financial shortsightedness.

The authors argue that the current rehabilitation practices are disjointed and misdirected, as ongoing rehabilitation efforts will require substantial additional work to achieve satisfactory outcomes. A lack of monitoring data, optimisation of specifications, and insufficient resources, combined with unclear end objectives, render rehabilitated areas unsuitable for their intended commercial use as outlined in environmental management plans (EMPs) and closure plans.

The prevailing culture within mining companies, which emphasises immediate financial returns while viewing environmental rehabilitation as a costly burden, is unsustainable. This approach leads to the misalignment of key performance indicators (KPIs) between mining and rehabilitation, resulting in inadequate budgeting for long-term efforts and frequent underestimation of operational costs due to flawed financial practices. Although financial provisions for rehabilitation are mandated, many companies conflate closure costs with rehabilitation expenses, often restricting funding to basic vegetation establishment rather than comprehensive, sustainable solutions. The reliance on low-cost contractors further undermines the quality and effectiveness of rehabilitation efforts.

To address these issues, a paradigm shift towards a structured approach that formalises realistic three-phased timelines for the rehabilitation process is essential. For effective land rehabilitation,

contractors should aim to achieve specific outcomes over a 10–15-year period, ensuring that substrate must be 1) geotechnically stable, 2) devoid of pollutants or pathways for pollution, and 3) ecologically reconstructed to a degree that facilitates functional ecosystem services. Rehabilitation specifications that effectively support long-term soil carbon and moisture cycling are crucial components for selfsustaining and productive substrates. Rehabilitation specifications must emphasise and account for long-term soil carbon and moisture cycling, which are critical for creating selfsustaining and productive substrates. Only when substrates demonstrate ecological functionality—evidenced by active nutrient and moisture cycling—should considerations for productive land use be initiated. Furthermore, if long-term data fails to confirm landscape function across various seasons, the rehabilitated system should be deemed unstable, requiring continued management until stability is achieved.

Thus, the rehabilitation execution process must not be perceived merely as a transactional commercial endeavour where the lowest bidder is selected to achieve sustainability outcomes. Restoring natural systems requires specialised partnerships, and embracing a long-term land custodianship model could provide a more sustainable and effective framework for successful rehabilitation outcomes.

It is imperative for the mining industry to uphold its reputation by delivering sustainable end land use. Addressing existing inefficiencies in land rehabilitation approaches is essential to enhance overall effectiveness and accountability in the sector.

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