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Phytoremediation for mine closure: integrating community development into long-term mine water management

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Abstract

The attainment of environmental, social and governance (ESG) goals for the mining industry is a critical requirement due to the unique environmental and social challenges faced by the industry and often presents a challenge. Phytoremediation is a niche technology suitable as a sustainable long-term option for the management of mining-influenced water after closure to mitigate uncontrolled discharges and reduce 'into perpetuity' liabilities, while providing socio-economic opportunities through community involvement and development of sustainable community enterprises. The benefits phytotechnologies provide, including biodiversity enhancement and carbon sequestration, can be aligned to support ESG goals and values, thereby creating shared value for both mining company and community. This is particularly important in the South African context as the closure of mines often results in social disruption and unemployment.

A deliberate, planned strategy is required to ensure substantial relevant job creation, community investment and upliftment is realised when a phytoremediation project is implemented. This project involved the planting of indigenous trees for the management of mining-influenced water at several sites. It entailed the set-up and implementation of comprehensive social and technical systems for skills transfer that resulted in benefits to the local communities. Project systems and budgets were designed to include non-mechanised protocols for the planting process, maintenance and monitoring tree growth. The project was intentionally developed to be labour intensive and provide stimulus for the local economies through training and upskilling of local unskilled employment and involvement with local small businesses that worked jointly with the planting projects. The establishment of business opportunities allowed for the development of a partnership between the phytoremediation contractor and the community, ultimately transitioning into a fully-fledged supplier enterprise operated by the community with the ability to expand beyond the original project.

This paper demonstrates the socio-economic benefits realised and highlights pitfalls, challenges and successes experienced during implementation of the phytoremediation project at scale while maintaining the integrity of the long-term mine water liability mitigation requirements.

Keywords: *phytoremediation, community, mining-influenced water*

1 Introduction

The adoption of environmental, social and governance (ESG) principles in the mining sector enables and ensures transparent, sustainable mining. An integrated approach to ESG principles involves the company's commitments to environmental stewardship to minimise environmental impacts and footprints, social responsibility to support stakeholder inclusion and meaningful engagement, and robust governance practices (Purvis et al. 2019). Furthermore, South Africa's legal requirements (Government of South Africa 1998, 2002) pertaining to mine closure once mining activities cease, seek to mitigate long-term negative environmental impacts, ensure sustainable use of land, and protect the welfare of affected communities. It is essential, both legally and financially, for public mining companies to fulfil their closure obligations. Through the implementation of a post-closure rehabilitation project, the mining company must be able to measure,

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manage and address environmental impacts while enabling the social (people, communities and human rights) and economic aspects of the principles.

Nature-based solutions, such as passive water management systems, which include phytoremediation in the form of phytohydraulics, may present sustainable long-term options for the management of mining-influenced water. Phytohydraulics when integrated in the management of mining-influenced water 'into perpetuity' with other passive treatment systems provides beneficial hydraulic control on contaminated groundwater plumes emanating from tailings and discard facilities and around discharge locations in highly disturbed mining environments. The trees aid containment of such mining-influenced water to the contaminated source sites, thereby preventing movement of contaminants into surrounding clean receiving environments, thus protecting the downstream environments. A further benefit associated with the implementation of phytoremediation as a tool for long-term water management is the reduction of clean water ingress into mining-affected rehabilitated areas, thereby reducing the discharge volumes emanating from sites after closure. Concomitant advantages coupled to phytohydraulics include improvement in soil conditions and erosion control through soil stabilisation, carbon sequestration and biodiversity improvements if using indigenous tree species; factors which ultimately support company ESG goals and values. The application of phytoremediation also enables the transformation of environmental liabilities into socio-economic opportunities through intentional project design, thereby addressing social closure obligations.

Mines play a pivotal role in their local communities. They are often major employers and instrumental in the development of adjacent supply chains. However, when mine closures occur, the communities are frequently the most threatened due to this co-dependency. The Department of Mineral Resources and Energy (DMRE) published the Draft National Mine Closure Strategy in May 2021 (DMRE 2021), which emphasises collaborative regional mine closure and the development of post-mining alternative economies. It is intended to enable economic diversification, thereby alleviating long-term negative environmental impacts and creating sustainable economies that address societal challenges after closure. Social closure during mine closure can present substantial challenges, but if integrated with closure activities such as land rehabilitation and water management, existing liabilities can be transformed into assets or as a minimum, offset some of the closure costs, which benefit both the mines and communities, thereby leaving a positive legacy.

However, unlocking socio-economic benefits such as job creation and skills development, while managing environmental liabilities related to long-term water management issues, can be challenging and requires a paradigm shift in thinking. Phytoremediation is a rehabilitation strategy that uses vegetation to remove, stabilise and manage environmental contaminants and provide beneficial hydraulic control of mining-influenced water (Chowdhury et al. 2015, Dye et al.2017). Phytoremediation projects can address multiple environmental challenges simultaneously and cost effectively, and can be adopted at different stages of mining, i.e. before, during, and after mining, depending on the remedial objective. However, the execution of a phytoremediation project requires proactive, strategic approaches to deliver impactful socio-economic benefits to communities around mining activities.

This paper aims to demonstrate that strategically integrating community requirements by implementing a million trees as part of a long-term water management project can contribute to a positive mining legacy and address regulatory closure obligations and ESG commitments. It also provides insight into some of the challenges that were faced during the execution of the project and how the challenges were overcome.

2 Methodology

The project methodology from initiation to current status is described in the flow diagram (Figure 1).

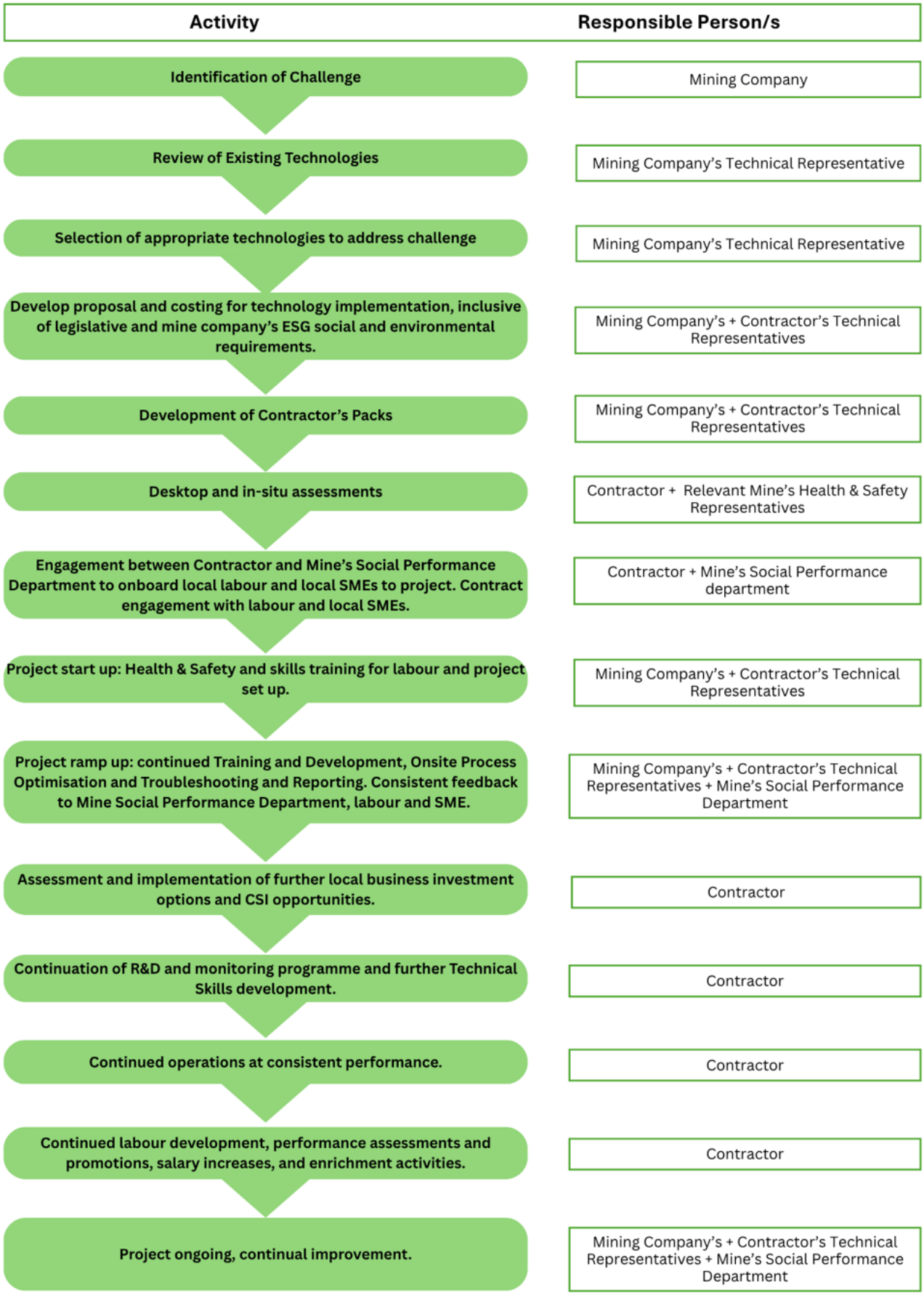

Figure 1 Project flow methodology

The decision to implement phytoremediation as part of the long-term water management challenge for some sites was taken in-house and was based on hydrogeological assessments, locations of discharge points, final volumes and water qualities as well as land availability around the discharge locations and ingress areas. The potential for community participation was included in the final decision to enable post-closure opportunities to be made available. The community members were not involved in the decision-making with respect to the implementation of phytoremediation as these were based on technical and scientific parameters. University students who formed part of the contractor team were included in discussions and decision-making to empower them for future projects.

The remainder of the flow process was managed by the contractor, with input from the mining technical and social departments, where required, and is discussed in more detail below.

3 The procurement process of phytoremediation

The objective of mining organisations is to extract valuable mineral resources economically and in a viable manner to create value, thus leading to the subcontracting of some projects to allow the mine to focus on its core mandate of mineral extraction. Environmental rehabilitation projects, such as phytoremediation projects, are commonly subcontracted through a procurement process. The mine procurement process ensures that the contractor awarded the project is technically competent, legally compliant, provides cost-effective services and operates in line with corporate policies.

The principles guiding the procurement process for most environmental projects are driven by the requirements of existing environmental management programs. The procurement of a phytoremediation project for long-term management of post-closure water liabilities generally focuses on acquiring technical expertise that requires highly qualified and trained personnel, and on improving project efficiency through the adoption of advanced equipment and machinery. This procurement approach unintentionally excludes communities with low or unrelated skills, thereby undermining the opportunity for balanced inclusion of low-skilled communities. This strains the relationships between the mine and the communities, resulting in dejected and angry communities excluded from economic activities they so hoped to be part of. The mine's social department team, in their advisory capacity, can participate in the design of aspects of the environmental management program to include social principles by embedding these in the procurement process, and particularly the procurement process for projects implemented during mine closure.

4 Job creation and skills development through phytoremediation

Communities in and around mining areas are the most threatened by the environmental impacts of mining during and after mining, but a much more significant risk is to their livelihoods, particularly after closure. Opportunities to alleviate the social pressures accompanying mine closure can be leveraged during closure activities such as rehabilitation and water management.

A phytoremediation project linked to long-term water management on mines in the closure phase presented an opportunity to integrate the social requirements of job creation and skills development, primarily to uplift community members out of the poverty cycle. The project included constructing and operating a nursery to produce the requisite number of trees of specific quality and resilience and planting these trees on mine-impacted sites. This phytoremediation project was implemented to partially address significant long-term water management challenges and substantial liabilities.

4.1 Job creation

Large-scale phytoremediation projects on mining sites can be designed to maximise job creation and can thus address some local socio-economic challenges. Specific protocols were developed to use manual labour for hand pitting and planting, and the subsequent maintenance of these sites in the early years. These activities not only created jobs but also had a positive effect on tree survivorship due to training of labour to ensure appropriate handling of saplings during the planting process.

The mine's social performance department played a pivotal role in ensuring the employment of manual labour from the relevant labour-sending areas, with a focus on unskilled labour for general worker positions. This was a deliberate strategy as unskilled labour constitutes a high percentage of the unemployed in the area; it allowed for poverty alleviation, and optimal skills development and transfer to the most vulnerable members of the community. Figure 2 depicts the labour breakdown for the project, with 86% of labour comprising unskilled workers trained to perform planting and maintenance. In addition, the team consisted of local supervisors (5%) who were upskilled from general workers, while the technical team that performed the training during the operations and ensured protocols were followed, made up the remainder of the staff.

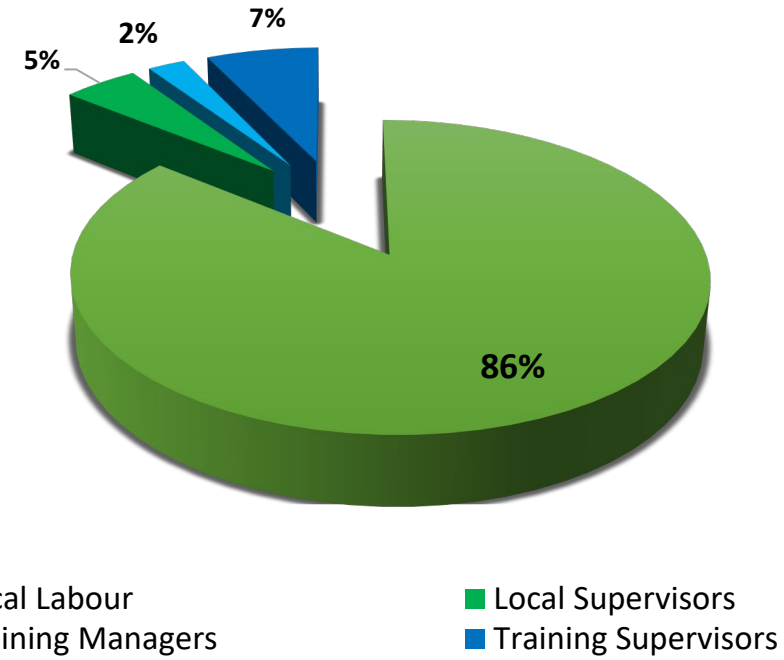

Figure 2 Labour breakdown for the planting teams employed for the phytoremediation project

The nursery construction was undertaken by a local building supplier who employed local labour. The local community were well versed in mining activities, and the general sentiment was that they welcomed the opportunity to learn how to construct and set up a tree nursery. The labourers were appropriately trained in the construction and set-up of a shade-house, water supply system and greenhouse tunnel. Upon completion of the construction and set-up of the nursery, recruitment of labour from the local community to operate the nursery was initiated. Over a period of 6 months, 9 general workers, unskilled in nursery operations, were recruited with the assistance of the mine's social performance department. Four highly skilled supervisors were added to the staff complement due to the size of the nursery to train the unskilled labour in the various aspects of nursery operations which were conducted daily and included germination, transplanting, bag-filling, watering, disease and pest control, and specialised infrastructure maintenance. The nursery is still operational after the phytoremediation project and is currently managing around 290,000 trees.

4.2 Skills development

The skills transfer process was conducted in phases to ensure that all labourers had equal opportunities beyond the initial training phase. Skills development focused on the 'why and how' to ensure proper understanding of the job. In an environment where the community is mostly unskilled or skilled in mining and engineering, learning how to grow, plant and care for trees created new opportunities. However, working with unskilled labour required experienced contractor supervisory staff, patience and consistency.

Further to this, post-graduate students at the University of the Witwatersrand were given an opportunity to advance their studies. and developed in the field of phytoremediation and other allied technical areas. The individuals (students at masters and honours levels) were trained and received support in various forms,

including student fees payments, part-time work, payment for external coursework, laptops, assistance with in-field training, data and sample collection, fuel, food and accommodation stipends, among others. Some of these students are continuing their studies as the research and development is ongoing, and others have graduated.

4.2.1 Health and safety first

Health and safety in mining-related activities is crucial because the industry involves heavy machinery, hazardous materials and physically demanding work conditions. The *Mine Health and Safety Act 1996* (Government of South Africa 1996) governs health and safety on all South African mines and is strictly enforced. The skills acquired in health and safety are critical to project success. The mine requires the completion of various training courses before any work on the mine site commences. Contractor and labour compliance is compulsory; however, attending courses and obtaining a certificate does not guarantee a person's understanding of health and safety and safe behaviour. Further to this, general housekeeping, maintaining a tidy environment, waste disposal, and respect for health and safety equipment are also important. A challenge is that some staff see health and safety as an impediment to reaching day-to-day targets.

Contractor supervisors and managers are required to exercise vigilance to ensure that inexperienced staff develop a critical understanding of why health and safety is important for their own wellbeing, their colleagues' wellbeing, and the environment as a whole. The contractor management and supervisory staff's extensive experience in health and safety across many industries, particularly the mining industry, proved significant in ensuring all staff obtained the health and safety skills required to perform their duties in the nursery and in the field in a safe and responsible manner.

4.2.2 Tree planting and tree maintenance skill transfer process

The skills transfer process for tree planting and maintenance for the project consisted of several stages:

- Stage 1: the first stage of the skills transfer process required all labourers to start at the general worker level. Basic training covered site preparation, amendment addition, planting, watering, and maintenance skills such as ring and hand weeding (Figure 3). Employees were monitored closely and evaluated regularly. In addition, employees in the health and safety positions were trained to fulfil these health and safety roles and to continue learning under trained supervisors.
- Stage 2: the second stage identified the best-performing workers to perform higher-level functions within the team, such as pitting and planting team leaders. These employees were chosen based on their leadership skills, ability to work with colleagues, work ethic and performance. All candidates were interviewed, and those considered best suited for the job were selected. During this period, the skills transfer process continued, and the labourers obtained further experience in activities.
- Stage 3: in the third stage, additional higher-level positions were introduced, such as administration, quality controllers, site assistants, tractor drivers, LDV (light delivery vehicle) drivers, and brush cutters. The aim was to advance competent individuals who would eventually move into supervisory or technical positions or be supported to create small businesses to meet specific supply requirements.
- Stage 4: the labour team was given the opportunity to complete a horticultural and landscaping course. This course enabled them to contextualise and extended the skills they had acquired over a 2-year period and to create opportunities beyond the phytoremediation work.

Figure 3 Hand planting of trees on the mine site

4.2.3 Mine indigenous tree nursery

At the nursery, the staff were trained in a similar staged approach to activities pertaining to the nursery operations. These activities included, among others, seed germination, transplanting of seedlings, watering, weeding, and disease and pest control. Specific training was provided for administration and communication, as well as health and safety training as required by the mine.

Staff were promoted based on performance and skills. The best-performing local staff were placed on a management plan for training to take over the nursery operation when it would function as an independent entity.

5 Cost benefits

The non-mechanised approach to planting trees proved more cost-effective than mechanised planting. Job creation was maximised by restricting mechanisation to necessary activities, such as ripping and discing. Higher planting rates for the specific size of tree used were achieved through hand planting, enabled by the development and implementation of streamlined, intelligent processes. Hand planting can also result in higher survivorship among trees often planted in hostile environments due to mining-related contamination. Lower mortality rates require less blanking (replacement trees), resulting in savings.

6 Local economic benefit through local business investment

The project not only focused on job creation for the local community and labour skills development, but also on investment in existing local businesses to meet all allied supply requirements. Local small, medium and micro enterprises were supported during project implementation to deliver required services. Figure 4 shows the breakdown of the investment in local business areas.

The supply of labour, labour transport, mobile toilets, potable water, refreshments, personal protective equipment, construction material for the nursery, soil amendments, and general equipment was sourced locally; thus, a significant economic investment was made into the local community.

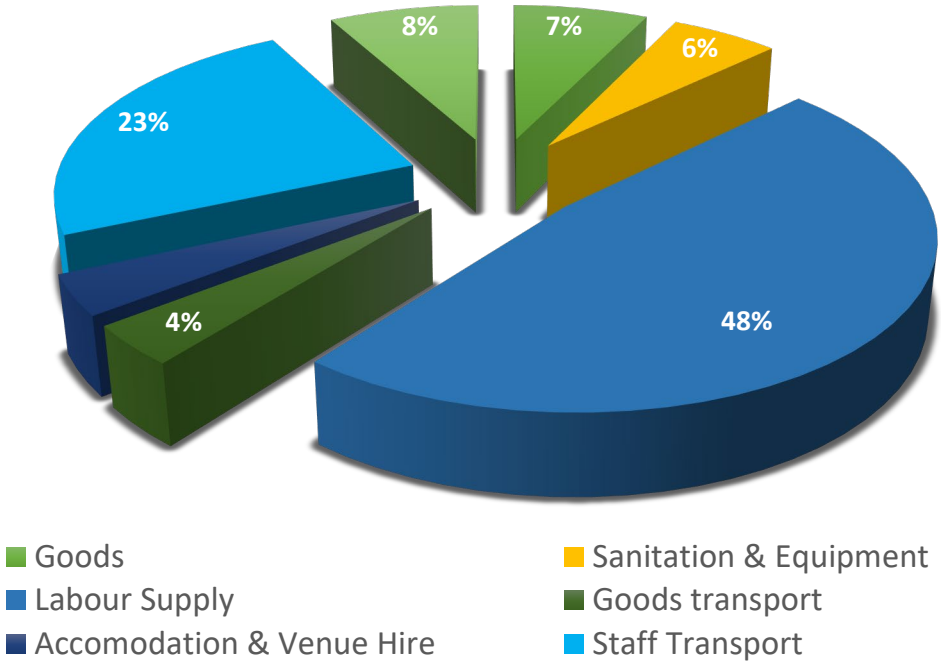

Figure 4 Project expenditure's contribution to local business sectors

7 Labour and community enrichment initiatives

The project afforded the contractor the opportunity to improve the lives of the labour force and the community in other ways, i.e. beyond the phytoremediation project and local business investment. This included skills transfers that could be used outside the project to potentially create small businesses within the local community, as well as several initiatives that were run concurrently with day-to-day project activities. Initiatives included grocery voucher awards and bonus incentives, which formed part of the process and gave impetus to maintain a certain planting rate during the planting season. Year-end functions were held, and Spring Day celebrations involved the donation of fruit and gifts, as well as fruit trees for their homes to provide fruit to nursery staff once established. Fruit was generally provided as a healthy supplement during the working day, and hot drinks and a snack were supplied at the start of the cold winter mornings. Further to that, vegetable seeds and compost were donated to an existing garden at a local school to benefit the elderly and children, as well as grocery and sanitary packs for destitute households.

Enrichment initiatives were offered, such as crochet skills to produce crocheted beanies for cold winter mornings, as well as items for resale, as shown in Figure 5. A horticulture and basic landscape design course was provided to 32 labourers to enable them to grow their own ornamental plants, vegetables and fruit – whether for their own use or to establish small enterprises to sell – and implement landscape design to the local community.

(a) (b)

Figure 5 (a) Crochet enrichment course; (b) Spring Day celebrations

Nursery staff were trained in all aspects of running a nursery to ensure that, when the nursery was handed over, operations would be sustainable and capable of supplying the region. A community initiative to assist small local businesses was established, and 3 specific businesses were supported: a gardening service, catering, and compost production. Figure 6 shows a local business operator with donated equipment.

Figure 6 Local business support with the donation of equipment

8 Challenges and achievements

The success of a project of this nature requires commitment and support from the mine, particularly since a project of this scale was new to the mining industry. Due to the novelty of this type of project in the mining industry, none of the social foundation work conducted by the mining company addressed the skills

requirements deemed appropriate for both the nursery and field planting implementation. The mine's relationship with the community is crucial for the success of any project involving local unskilled labour. Poor communication between the mine and the community can significantly impact project dynamics and lead to community unrest.

Training unskilled labour and labour with skills unrelated to the work at hand presents a particular challenge. These challenges not only pertain to understanding the mine health and safety rules and regulations but also to grasping the requirements of a job of this nature, namely, planting and maintaining trees in the field. Some of the teams trained during the project have already been employed by mines for rehabilitation and phytoremediation, not only in the coal mining industry but further afield in the gold mining sector.

Further challenges included people misunderstanding or not respecting the nature of living organisms, including that trees require care and careful handling to grow well. The labour team struggled to understand that if the tree was damaged or planted incorrectly, or if the amendments were applied in the wrong ratio, this would affect the tree in the future, even though it looked well in the present. A change of mindset was required and required considerable time and effort to establish.

The mine's relationship with the local business community determines the cost of supply and this can lead to a misconstrued view of what is fair to pay as overhead. Furthermore, the quality and consistency of service had to be managed to ensure the project's sustainability. In general, community expectations tend to go beyond what is reasonable or practicable. This issue could severely impact project costs if these baselines are not communicated to contractors at the project proposal stage. This challenge could be addressed by including such a discussion prior to project approval. The potential exploitation of contractors by suppliers should be addressed by the mine to avoid creating a culture of expectations beyond reason and thus fertile ground for conflict between mine and community or contractor and community.

The Draft National Mine Closure Strategy in May 2021 (DMRE 2021) advocates for socio-economic integration, with rehabilitation and long-term water management acting as catalysts to provide opportunities to achieve socio-economic mine closure. However, regulatory requirements that govern closure and current closure practices constrain socially integrated mine closure projects as legislation deals with mine closure obligations in isolation, where rehabilitation and water management are managed as separate environmental liabilities rather than as a holistic solution. Liabilities funds are generally held as guarantees or trusts, and are not easily accessible to finance rehabilitation until rehabilitation is complete and also do not cater for social projects. Mining companies therefore tend to view socially integrated mine closure projects as requiring substantial long-term financial investment with little benefit. However, as this paper demonstrates, a well-designed project can transform environmental liabilities into socio-economic opportunities and achieve alignment with corporate policies by integrating social and liability expenditure meaningfully and planning early in the mining life cycle. In the case of the phytoremediation project, the mining company used water liability funding that is held on balance sheet rather than as a trust or guarantee. With mindful planning, the phytoremediation project with its allocated budget was designed to be labour intensive with training that went beyond the planting program to ensure community members were able to work beyond the scope of the project.

Despite these and other challenges, the project resulted in the establishment of a fully functional nursery capable of producing 250,000 saplings per annum for the surrounding mining and municipal region. Over 300,000 trees were successfully planted, and a further 290,000 trees were produced at the mine nursery over 2 planting seasons, a first for a project of this nature.

9 Conclusion

Phytoremediation as a tool for water management was shown to enable a coordinated approach to addressing community requirements through job creation and skills development while addressing company liabilities. This project highlighted that the integration of environmental and socio-economic principles can create benefits that endure if planned carefully with long-term sustainability in mind.

Long-term water management is unlikely to be achieved without community support, as plantation maintenance is vital to the success of the 'into perpetuity' water liability mitigation, after closure. This project demonstrates that it is possible to include community members through appropriate upskilling and broader training to ensure post-project capacity to work in the rehabilitation space.

This venture is one of the first projects where the community is involved in a long-term technical water management solution. In parallel, this supports the National Mine Closure Strategy, whereby community development is integrated into long-term sustainability projects – supporting the broader post-mining transition and the requirements of South Africa's Just Transition Framework.

The focus is on further development of the local and greater community by collaboration with government and tertiary institutions to lever small and microbusinesses through the creation of a circular economy, beyond just employment.

This project went beyond the minimum legislative and mining company's requirements for local community investment. Due to the particular nature of the phytoremediation technology and this specific project's process, it is imperative that the mining company and their technical representatives be committed to the process from conceptualisation to process optimisation, and to ensure the continued sustainability of the program and the broader post-mining transition and Just Transition Framework objectives.

The long-term sustainability of the project is currently unknown as it has only been operating for a few years.

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