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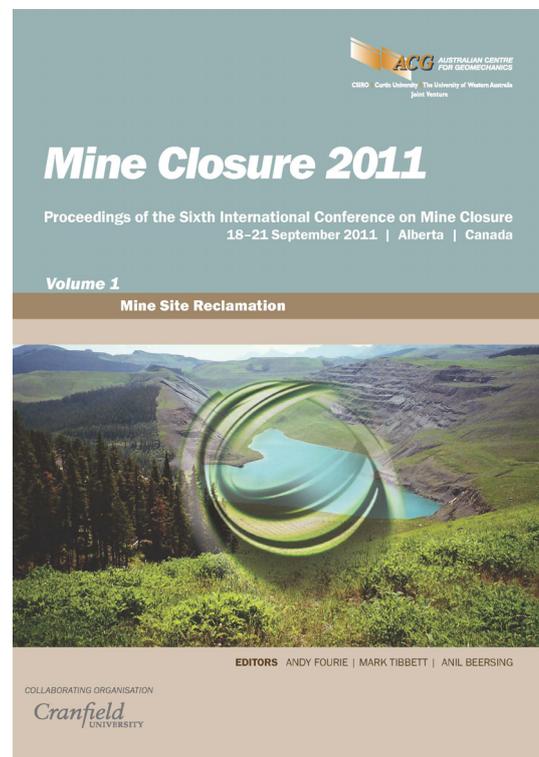
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Investigation into the current closure practices of platinum tailings storage facilities – the South African context

J.C.J. Boshoff *SRK Consulting, South Africa*

J.N. Hamman *SRK Consulting, South Africa*

Abstract

The largest reserves of platinum ore are found in the Bushveld Complex of South Africa, which presents a unique opportunity to study the status of mine closure in this context, specifically the closure of platinum tailings storage facilities.

The challenge for most of the platinum tailings storage facilities are that the facilities are still seen as a resource and could be re-mined as process technology improves. Therefore, expenditure towards closure during the operational phase is not viewed as advantageous. However, the re-mining of historic and existing facilities also presents the opportunity to develop the resulting new tailings facilities to the latest standards and internationally accepted practices for mine closure.

This paper investigates the current legislation applicable to the design and closure strategies of platinum tailings storage facilities in the South African context. An overview is given of challenges faced and the successful implementation of rehabilitation techniques in recent years. These include slope vegetation and dust suppression.

The paper also deals with the future challenges that the platinum industry could face in terms of closure. These challenges include dealing with ultra fine material and the increase of salts in the tailings as contaminated return water is reused.

1 Introduction

The mining sector is subject to increasingly stringent mining and environmental regulation. Particularly in South Africa, emphasis is on waste management and rehabilitation of the earth's surface that was disturbed during prospecting and mining activities. The platinum sector is no different with the conditions of the Bushveld complex creating its own unique challenges.

Tailings storage facilities (TSF) must form part of the closure strategy of mines in terms of current legislation. This is because tailings dams can be considered a long-term liability for mine closure – but the cost of long-term liability is often underestimated in the planning process. This paper serves to review the current conditions and practices for the platinum TSF in South Africa. Its purpose is to discuss the current closure aspects for platinum TSF and raise consideration for the future in the TSF closure approach.

The current applicable legislation and standards for platinum TSF is discussed as reference. There is an indication that the South African government intends to streamline the legislation process in the coming years with the aim of improving it. As part of contextualising the platinum TSF of South Africa, the construction legislation is followed by the construction methodology and then followed by the actions taken to limit the environmental impacts during the life cycle of these platinum TSFs.

The challenges faced by the client, designer and operator in developing the closure strategy for the platinum TSF are discussed as part of the long term view on the integrity of the TSF and it's possible environmental impact.

2 Current legislation and standards applicable to platinum TSFs in South Africa

This section provides a brief overview of the legislative requirements and guidelines that influence the construction, management, regulation and closure of platinum TSF in South Africa.

The regulation and closure of platinum TSFs in South Africa is currently directly affected by:

- The Constitution of South Africa, 1996.
- *National Environmental Management Act*, 1998 (Act No. 107 of 1998).
- *Mineral and Petroleum Resources Development Act*, 2002 (Act No. 28 of 2002).
- *Minerals Act*, 1991 (Act No. 50 of 1991).
- *National Water Act*, 1998 (Act No.36 of 1998).
- *Mine Health and Safety Act*, 1996 (Act No.29 of 1996).
- *Atmospheric Pollution Prevention Act*, 1965.

In Section 24(a) of the Constitution it is stated that everyone has the right to an environment that is not harmful to his or her health and well-being. The Constitution supersedes all other legislation.

The *National Environmental Management Act* (NEMA) provides the framework and principles for sustainable development and environmental care.

This *Mineral and Petroleum Resources Development Act* (MPRDA) was promulgated in May 2004 and provides a holistic cradle-to-grave approach for mining. The act provides for an environmental impact assessment (EIA) and environmental management programme (EMP) as requirement by the applicant to identify, mitigate and manage the environmental impacts emanating from prospecting or mining activities. The regulations pertaining to the EMP make provision *inter alia* for mine closure and future land use objectives and the proposed closure cost estimates (Swart, 2003). The current understanding is that the MPRDA would supersede the *Minerals Act* of 1991, although care should be taken since certain parts of the *Minerals Act* might fall outside the scope of the new MPRDA. It is therefore advisable to take cognisance of both these Acts.

The water management aspects of the TSF are regulated under the *National Water Act*, which was amended in 1999 by *National Water Amendment Act* No. 45. In terms of the *National Water Act*, all water uses including a TSF requires a water use licence. Water use licences contain a standard condition requiring the development of a Rehabilitation Strategy and Implementation Programme (RSIP) for concurrent rehabilitation over the life of mine with the intention of minimising impacts on the water resource post closure.

The design and management of the platinum TSF is further guided by three sets of guidelines and is discussed below.

The principle design and management document for platinum TSFs in South Africa is the Code of Practice for Mine Residue Deposits, issued by the South African National Standards (SANS) 10286:1998 that was approved in September 1998 by the South African Bureau of Standards (SABS). This document has been the backbone of TSF designs in South Africa since then. The standard advises all parties involved with the TSF life cycle what their objective principles and minimum requirements of care should be, which includes the design, operations and closure phases. The standard does not address the environmental issues or health and safety concerns of TSFs, but places more focus on the need for management throughout the life cycle of a tailings facility (Engels and Dixon-Hardy, 2010).

In May 2001, the then Department of Minerals and Energy: Mine Health and Safety Inspectorate published a guideline for the compilation of a mandatory code of practice on mine residue deposits. The purpose of the Code of Practice, to which this guideline relates, is the protection of the health and safety of any person working at the mine and any other person that might be affected by the mine residue deposit (Department of Minerals and Energy, 2000). There are some mines and platinum TSFs that are not compliant with the

guidelines and the relevant documentation is still being prepared but this is an ongoing process to cater for the backlog to address some of the older mines, which have been in operation for more than 50 years (Caldwell, 2010).

The Department of Water Affairs (DWA) developed a series of Best Practice Guidelines for Water Resource Protection in the South African Mining Industry. These guidelines address the environmental issues, specifically water issues, associated with mining operations. The three guidelines mainly applicable to platinum TSFs are:

- Best Practice Guideline No. A2: Water Management for Mine Residue Deposits (DWA, 2007).
- Best Practice Guideline No. A4: Pollution control dams (DWA, 2006).
- Best Practice Guideline No. G5: Water Management Aspects for Mine Closure (DWA, 2008).

One of the most significant potential post-closure impacts is the deterioration of the quality of the water resources and therefore the best practice guidelines noted above are applicable to post closure management with specific emphasis on the identification and management of water related closure risks and liabilities.

Clause 12 of SANS 10286 covers the last phase of the tailings dam life cycle from a management view. It refers to the aims, principles and minimum requirements for decommissioning, closure and aftercare of the TSF. The decommissioning starts with the cessation of the deposition of residue on the area of the facility and ends when all the measures for achieving the prescribed closure aims are in place. Aftercare starts at this point and continues thereafter with no defined endpoint. Responsibilities for aftercare could be transferred to third parties during this period through, *inter alia*, the granting of a closure certificate (SANS 10286:1998).

The process of mine closure and the issuing of a closure certificate in terms of the MPRDA are regulated by the Department of Mineral Resources. The holder of a prospecting right, mining right, retention permit or mining permit remains responsible for any environmental liability, pollution or ecological degradation, and the management thereof, until the Minister has issued a closure certificate to the holder concerned.

The MPRDA specifies that the holder must apply for a closure certificate upon:

- The lapsing, abandonment or cancellation of the right or permit in question.
- Cessation of the prospecting or mining operation.
- The relinquishment of any portion of the prospecting of the land to which a right, permit or permission relate.
- Completion of the prescribed closure plan to which a right, permit or permission relate.

It is important to remember that a closure certificate generally applies to the whole mine and is not necessarily given to the TSF individually. Very few of the platinum mines with TSFs that are in a dormant state have received closure certificates in South Africa. This means that an estimated 25,000 ha of land forms part of the footprint of platinum TSFs that still have to receive a closure certificate (Van Wyk, 1994). This estimated footprint is expected to have increased significantly since this statistic was published.

3 Platinum mining activities of the Bushveld Complex

The reserves of platinum-group metals (PGM) are concentrated in a distinct, narrow but extensive stratum known as the Merensky Reef, the U.G.2 chromitite layer and the Platreef. These layers are located within the gigantic layer known as the Bushveld Complex, which underlies an area of about 40,000 km² spanning the North West, Limpopo and Gauteng Provinces. The layer has a distinctive eastern and western region; a smaller region is located to the northern side of the complex and can be seen in Figure 1. These regions known as the eastern, western limb and the smaller northern limb are where the platinum mining activities takes place.

These three layers in the Bushveld Complex each have their own distinctive associated mineralogy. The Merensky Reef normally consists of a coarse-grained pyroxenite and is very narrow, varying in width from 0.15 to 0.40 m. The top and bottom contacts of the reef are usually marked by thin chromitite layers a few

millimetres thick. The greater part of the platinum group metals associate as complex sulphides within base-metal sulphides (Hochreiter et al., 1985).

The U.G.2 ore has a much lower content of nickel and copper sulphides, and contains much more chromite (60–90%) than the Merensky ore. The U.G.2 reef lies anywhere between 20 and 330 m below the Merensky reef and varies in thickness between 0.15 to 2.50 m (Jones, 2000).

The Platreef can be considered as metallurgically similar to Merensky ore, although somewhat enriched in palladium. The Platreef is in the form of a tabular body at the base of the northern (Potgietersrus) limb.

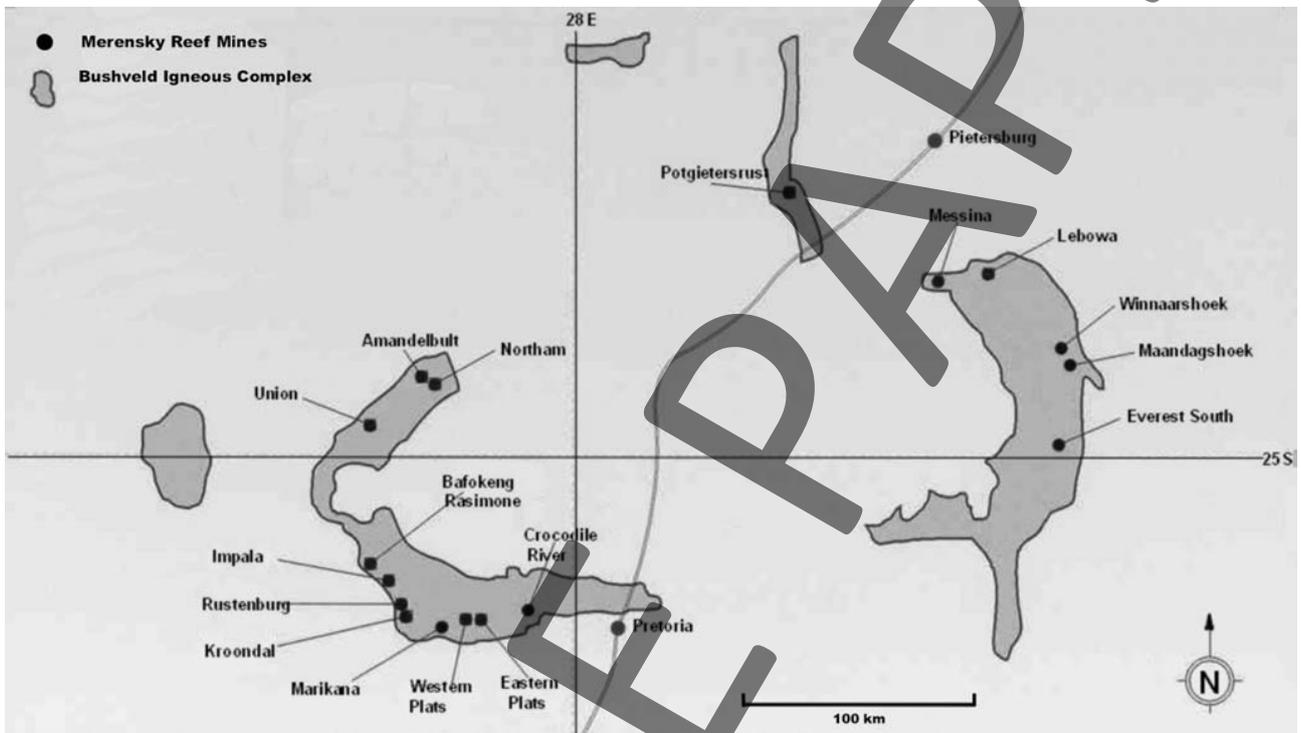


Figure 1 General layout of the Bushveld Complex

4 Current TSF construction methodology

In the South African platinum industry, the upstream method is the most commonly used tailings dam construction method for the containment of tailings in the platinum TSF. Due to the relatively flat or slightly undulating nature of the topography where the Bushveld complex exists the impoundment walls are of a ring dyke nature. Dependent on the availability of resources, the starter walls are generally constructed from the in situ clayey materials or selected borrow materials to a designed height. The height varies dependant on the topography and the rate of rise of the tailings but can on average be 6 m high at the lowest point of the TSF. The top level of the starter wall is maintained along the footprint edge until it ties in with the natural ground level. The containment wall then continues as a one meter high wall for the remainder of the TSF footprint. When the tailings level rises above the starter wall the upstream method is implemented and the coarser fraction from the deposited tailings is used for the building of the outer containment wall.

The basin area is limited to the land available and the production during the life of the mine. In South Africa the footprint of the TSFs for the big three mining companies can vary between 50 and 150 ha. The preparation of the basin usually consists of the removal and stockpiling of a thin top layer of in situ soil (known as the topsoil) and the in situ clay below the topsoil layer is left intact to act as a low permeability layer. A drainage system is also incorporated into the containment wall and in the basin to a degree to intercept, collect and remove seepage water from the facility. The drainage collects in solution trenches and usually drains to a return water dam. Seepage in the basin of the platinum TSF is mostly limited by a low permeability clay layer that occurs naturally in the platinum areas and originates from the weathering of

Norite rock (a dark-coloured igneous rock from the Bushveld Complex, consisting of about 50 per cent calcium feldspar and 50 per cent calcium-iron pyroxene).

Platinum tailings slurry is conventionally discharged from the top of the dam's crest by means of spigotting and to a lesser extent, cycloning. With the spigotting method a beach is created where the coarser fraction settles closer to the outside perimeter, due to natural segregation, and this then becomes the foundation for future embankment raises. A typical section of an upstream platinum tailings dam is indicated in Figure 2. The final height of the TSF is on average between 20 to 40 m but can be as high as 100 m in exceptional circumstances. The stability of the upstream tailings containment walls is improved by keeping the phreatic surface away from the outer walls by means of a drainage network that is installed during the construction phase and extended and maintained during the operational phase. The effectiveness of these drains is monitored by measuring the flow of the drains. The position of the phreatic surface is estimated from measurements that are taken from installed piezometers along the perimeter of the containment wall.

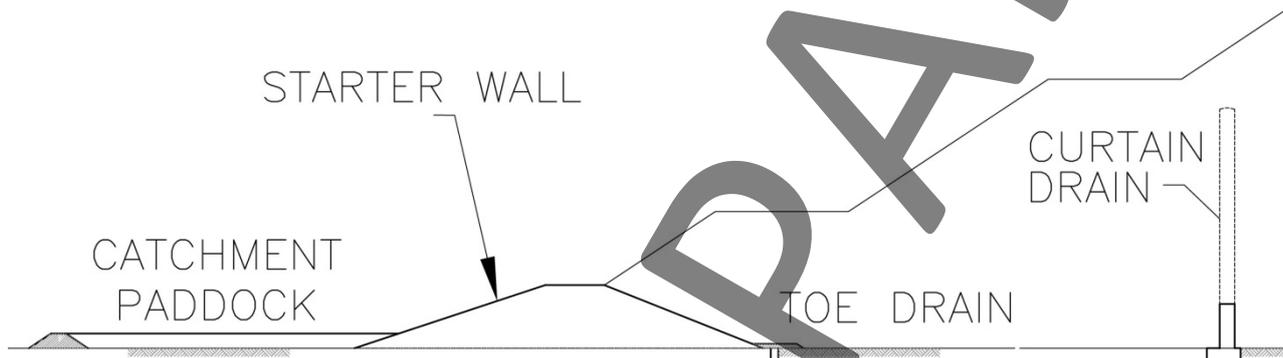


Figure 2 Typical section of an upstream raised embankment

During normal operations a pool of supernatant water will exist on the top of the tailings dam. The norm is to minimise the amount of water in the pool to assist with stability and minimise the potential of overtopping. The decant water drawn from a TSF usually requires a storage facility and therefore a return water dam is constructed and is located as close as possible to the footprint of the TSF. The return water dam is designed to contain a one in 50 year storm event, as required by legislation, and it is designed to collect all drainage and surface seepage water. The water is returned to the plant for re-use in the operations and also used for irrigation on the TSF (dust suppression and vegetation establishment).

An approach for managing the potential environmental impacts that can occur at any stage during the mine's life stages, namely exploration, construction, operation and closure aftercare has been developed (Holtom, 2010). These approaches as it relates to the TSF are briefly discussed below.

During the conceptual and design phase of the TSF, subterranean investigation is used as a method to assess the soil bearing capacity and suitable footprint for the storage facility. The impact of these subterranean investigations is limited as far as is reasonably possible to minimise the impact on the surrounding environment. Contamination from the plant and equipment used is considered and mitigation measures are put in place to limit the possible impact. The positioning of the TSF is optimised to minimise the impact on the groundwater and the surrounding environment.

During the construction phase the topsoil of the TSF footprint is removed and stockpiled for re-use; this requirement is guided by legislation. If any fauna or flora are identified as being at risk or threatened, measures are taken to protect or relocate if needed.

The operational phase is where most of the significant impacts could occur of all the phases in the TSF life cycle. Stability and environmental challenges during this phase requires active monitoring and maintenance of the tailings dams to limit the impact the TSF have on the environment and surrounding communities.

The TSF is generally constructed with an overall slope of one in three which is considered a relatively steep slope for closure purposes. Step-ins are constructed at certain levels to assist with the stability of the slopes and the bunds on each step-in are capped with a layer of waste rock to protect against erosion as illustrated in Figure 3.



Figure 3 View of the step-in and capping for protection on the sides of the platinum tailings dam

As the containment walls develop and increase in height, the lower slopes between the benches are vegetated by adding growth ameliorants which could be composts or fertilisers and a seed cocktail for vegetation establishment. If seedling protection is required, straw mulch is also included in the re-vegetation strategy. Because the acid producing sulphides are removed from the ore during floatation, the establishment of vegetation on platinum tailings is less problematic compared to some of the other metal groups like gold tailings. Some typical vegetation that was successfully established on platinum tailings dams is shown in Figure 4 below. Grassing on the slopes is done by preparing the slopes with a mulch layer. The mulch is left for at least a month and then vegetation takes place by hand planting seedlings or hydro seeding. With proper irrigation and maintenance certain grass and tree species have flourished on platinum tailings dams.



Figure 4 Typical vegetation that is established on platinum TSF

It must however be emphasised that irrigation is mainly used for vegetation establishment on the TSF and is therefore not sustainable for the long term due to the reduction in surplus water. On some of the older TSFs, it has been observed that an organic layer becomes established within the upper tailings horizon. This generally allows nutrient cycling between the growth medium and the vegetation that it supports, which assist in the vegetation's sustainability. At this point irrigation is no longer necessary.

The top of the tailings dam has a large exposed tailings surface area that is prone to dust generation while the facility is operational. The dust surveyed from Platinum TSFs consisted of three particle ranges, namely Respirable ($<7\ \mu\text{m}$), Thoracic ($7\text{--}10\ \mu\text{m}$) and Inhalable ($>10\ \mu\text{m}$). The average percentage was 9.72, 2.95 and

87.28% respectively. However, the risk of toxic consequences due to the elemental content of the dust was extremely low (Laubscher et al., 2009).

The generation of dust is limited by keeping a centralised pool on the top of the tailings dam along with maintaining a quick deposition cycle which will maintain a large wet beach area. The installation of wind barriers along the perimeter of the crest of the dam also assists with minimising wind blown dust down the slopes of the tailings dam. The wind barriers are usually constructed by planting wooden poles and tying shade cloth along the line of poles, see Figure 5. Dust suppression is further achieved on the drying surface between the perimeter of the crest and the decanting pool at the centre of the dam through the installation of an irrigation system that keeps the surface moist see Figure 5.

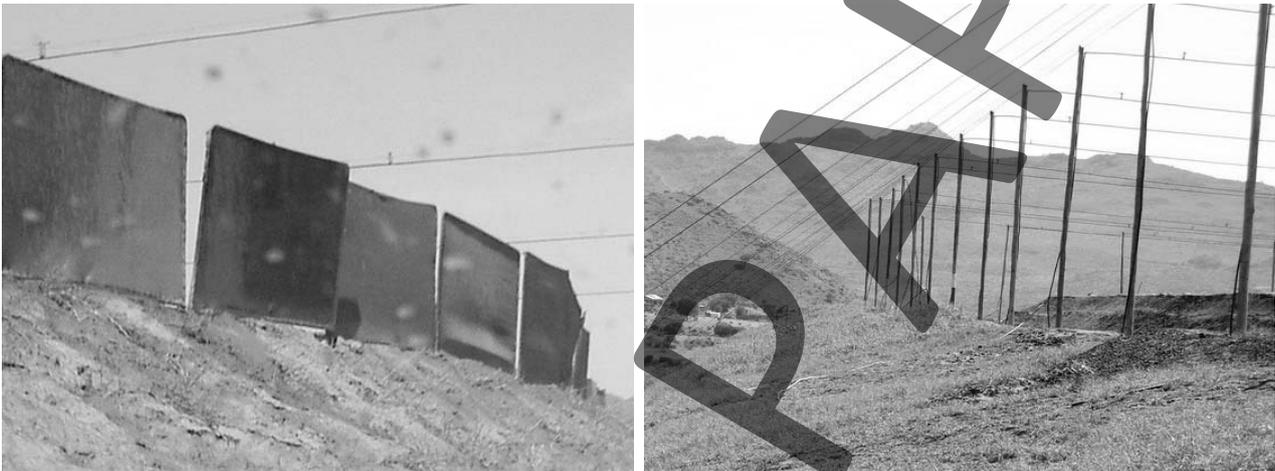


Figure 5 View of the wind barrier and the dust suppression system on the TSF

5 Main challenges towards TSF closure

The intent, from an engineering point of view, is to design and maintain the TSF using the best possible engineered standards through the entire lifecycle of the dam. The objective includes maintaining the overall stability of the dam, the prevention of erosion on the slopes of the dam and the minimisation of dust from exposed surfaces.

The challenges faced regarding the integrity of the TSF is that with the improvement of technology a finer grind material is produced with an 85% material passing the 0.075 mm sieve. The technological improvement also makes it financially viable for the re-mining of dormant platinum TSF and recovery of the chrome fraction from the tailings. This finer grind and the removal of the coarser chrome fraction changes the strength characteristics of the tailings deposited on the TSF and can influence the stability of the dam and make it more susceptible to erosion. The finer grind is more prone to the creation of layering and blinding of the drainage network in the TSF and therefore increases the risk of the phreatic surface migrating horizontally to the outer wall thereby impacting on the stability of the TSF slopes.

Platinum tailings are highly erodible when high rainfall events take place. Therefore it is required that the slopes are vegetated or clad and that the overall slope angle is less steep to reduce runoff velocity. The challenge is to have vegetation established as soon as reasonably possible and to keep the vegetation irrigated. The tailings generally have limited ability to retain water and therefore it is difficult to sustain the vegetation without irrigation for the first few years after establishment. This is especially visible on the northern slopes of the platinum tailings dams that are exposed to the scorching sun in the summer.

The main contributors to environmental concern from tailings dams are dust and seepage. Although dust generated from tailings dams has an extremely low risk of toxic consequences due to the elemental content of the dust, the dust is still visible and a discomfort for the surrounding population within 5 km of the TSF (Laubscher et al., 2009). The mineralogy of the tailings deposited is relatively geochemically inert as the majority of sulphides from the ore are removed from the tailings during the production of concentrate. There are however sufficient residual sulphides which upon oxidation and subsequent in situ neutralisation, release sulphates in concentrations typically dictated by gypsum solubility, with gypsum formation occurring

through the in situ neutralisation process. This is manifested as seepage with a sulphate, calcium and magnesium concentration elevated above levels which would be safe for most domestic uses. Although mineralogically the tailings are inert, there are often blasting residues associated with the tailings that pass through the concentrator and are deposited on the TSF. These residues are the salts of ammonia and nitrate which are present in elevated concentrations in the pool water. There is some nitrate and ammonia loss as the pool water seeps through the tailings; however, it is common that the concentrations of these salts are elevated in seepage at the toe of the TSF.

If the dust becomes excessive, the authority can impose restrictions that require the establishment of mitigation measures to prevent the mining operation from being halted. SANS 1929:2005 stipulates dust deposition rates that are permitted for residential and industrial regions, and a series of levels above which interventions or mitigation are required as listed in the table below.

Table 1 Dust fall Standards SANS 1929:2005

Classification	Dust Fall (mg/m²/day) – Averaged Over 30 Days	Permitted Frequency of Exceeding the Levels
Target – long-term average	300	Long-term average (annual)
Action – residential	600	Three within any year, no two sequential months
Action – industrial	1,200	Three within any year, no two sequential months
Alert threshold	2,400	None, first time exceeded, triggers remediation and reporting to authorities

The exceedance of the residential dust fallout average of 600 mg/m²/day can easily happen especially during the dry windy months in the second half of the year in South Africa. Therefore the available suppression systems, including wind barriers, irrigation and limiting the dry beach on top of the dam are implemented.

The management of rainfall on the top surface of the dam during post closure is a concern. The general practice currently is for the surface to remain sloped towards the centrally located intake structure with a combination of a paddock system and the establishment of vegetation on the surface. The potential risk is that the intake structure can become non-functional due to clogging or collapse of the decanting pipeline. Paddocks on the surface could have standing water in them and cause the established vegetation to drown; this leaves the area exposed and prone to dust generation. The ideal could be to investigate a deposition method that allows for the top surface to be dome shaped since reshaping the surface could be too expensive.

Flatter slopes on the tailings dams are ideal for closure as these slopes improve long term stability, decreasing erodibility and facilitating better vegetation establishment. As the available ground lease areas in South Africa become more limited, the area available for the TSF footprint is becoming scarcer which limits the extent of the TSF footprint.

Seepage and subsequent impacts on groundwater quality during operation and post closure generally pose a high risk, especially in areas where groundwater is a sole source of supply. Modelling of the groundwater pollution plume through all stages of the life cycle is critical to minimise the risk at closure and to provide adequate financial provision for appropriate mitigation measures post closure.

6 Future of mine closure

Mine closure is becoming a prominent issue debated by mining companies, communities and the government. Mining companies must consider the safety, environmental and social risks where significant liabilities can arise if treated incorrectly. The rehabilitation of tailings can be a time consuming and expensive component of mine closure. For mining communities mine closure can have severe implications due to the threat of economic and social collapse. For the government the abandoned mines potentially bring environmental responsibility and significant clean-up costs. Each of the three parties is directly impacted by

parties' respective engagement and requires dialogue and cooperation that can reduce costs and enhance results for all parties involved.

Technology is constantly improving and this is also the case for TSFs. Though not a new technology, paste and thickened tailings as a deposition method has experienced a growth in the last few years and through development the technology has become a viable contender for conventional deposition methods.

The thickened tailings deposition method reduces the dependency on drainage systems and has no need for a decanting facility. Usually a stable and consolidated surface is obtained quicker than conventional tailings deposition which allows for quicker access and progressive rehabilitation. Analyses to date indicate a considerable improvement in operating cost and a substantial reduction in closure cost compared with facilities based on conventional slurry densities (Jewell and Fourie, 2006), since progressive re-vegetation could be possible while the TSF is operational.

A consideration that will in future affect the integrity and operations of TSFs' is that of ore grade. As higher grade ore is gradually depleting, mines are forced to process the lower grade ore. The direct result of this is increased production which will increase the volume of tailings being delivered to the TSF. The challenge in the future will be to find a balance between the footprint available and the increase of TSF volumes required.

Dust generation is becoming more problematic with the respirable dust particles increasing as the grind becomes finer (currently at 9.8% on average). In future a more comprehensive investigation into dust suppression will become a necessity as the dust particles become an increased health risk, and limitations on water usage for dust suppression becomes more stringent. Dust risks are further exacerbated by the development of communities in close proximity to the TSFs as there is often an influx of job seekers at mining projects.

Water availability in South Africa is a contentious subject, but the overall feeling is that it will become scarce in future, which will increase the cost of water and encourage consideration for recycling of water. The recycling of water will most likely increase the salt content of the process water which will have to be considered in future as part of the environmental and integrity impact of the TSF.

The increase in salts concentration in seepage can have a considerable influence on the minimum requirements for the construction and closure of TSF. This will also influence the approach on seepage monitoring and treatment.

The authorities of South Africa have been transforming over the past ten years regarding mining and environmental legislation with the understanding that the objective is for the departments to be guided by a single set of legislation as guidance for mine closure. Active participation and discussion of all the affected parties will still be required in future as the process refines itself.

The challenge for the future in platinum tailings facilities is to adopt a view of partial closure, even if full closure is not attainable at this stage. Adopting this view could change the perception from a future consideration to an active consideration that will encourage the mines, the communities and government to participate in closure today and not only in the future.

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