Soil reconstitution as a key driver for successful rehabilitation at Hillendale Mine

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Introduction

Hillendale Mine is operated by Exxaro KZN Sands, and is situated on the north coast of KwaZulu-Natal in South Africa near the towns of Empangeni and Richards Bay, some 200 km north of Durban. During the mining operation the heavy minerals rutile, ilmenite, zircon and leucoxene are extracted for further beneficiation at a processing complex near the town of Empangeni. The deposit contains approximately 25% slimes (defined as the sub-45 micron fraction), and is mined using hydraulic monitoring. Run of mine is gravity fed down launders to pump stations, which deliver the material to a primary wet plant. Slimes is separated from the run of mine prior to the heavy minerals being separated from the sand. Sand tails containing approximately 2–5% slimes is pumped to the mining void. The slimes is thickened to a density of approximately 1.2, and most of the resultant material is pumped to a sub-aerial deposition site (residue dam).

The area is characterized by an annual rainfall of approximately 1300 mm, which is relatively high by South African standards. From an agricultural perspective the soils are deep and well weathered. Dryland agriculture has been practised on an extensive scale in the area for the past 70 years. Sugar cane in particular is cultivated on and around the mine area. In terms of environmental approvals, the post-mining land use and objectives are defined as economically viable and sustainable sugar cane cultivation in the mined areas.

During mining the soil profile is destroyed. In this paper the establishment of a reconstituted soil profile is discussed, with specific reference to the methodology that is being followed to achieve the homogeneous blending of sand and slimes.

Defining the rehabilitation strategy and soil specification

Strategically Exxaro KZN Sands divided rehabilitation into four aspects, comprising physical rehabilitation (restoration of soil structure), vegetative rehabilitation (restoration of vegetative cover), ecological rehabilitation (restoration of sustainable ecological communities), and sustainability (sustainable man/environment interface) (Hattingh and Viljoen, 2006). It is believed that the key to successful rehabilitation lies in achieving a substrate (soil) suitable for the establishment of the target vegetation. During the development of the rehabilitation strategy the key factor in the establishment of a suitable soil profile was shown to be the soil water retention of this material. Since dryland agriculture is practised, this aspect becomes critically important in ensuring that the post-mining land use is sustainable (Hattingh et al., in prep.).

From a financial perspective, a closure certificate being issued implies that the state takes over financial liability for the rehabilitated land. This has significant implications for the state—the default position will be that all possible latent and residual impacts must be identified and known prior to a closure certificate being issued. From the mine’s perspective this precautionary approach by the state implies that post-operational costs cannot be quantified exactly, and our approach is therefore to mitigate the risk of a long post-closure care and maintenance phase by means of addressing all potential latent defects during the operational rehabilitation phase. The financial viability of the soil reconstitution process itself is therefore not measured against other rehabilitation methods, but against the risk of not achieving closure.

During a series of technical workshops comprising experts in the various disciplines in the rehabilitation of the soil profile were identified. These aspects include the re-establishment of a functional soil profile, soil physical characteristics, soil chemistry, soil biota, salinization potential, erodibility and soil weathering.

The natural soils in the Hillendale area have been classified in terms of the South African soil classification system (MacVicar and co-workers, 1991) and consist of Hutton (orthic topsoils on red apedal subsoils) and Clovelly (orthic top soils on yellow apedal subsoils) soil forms. The topsoils consistently comprise medium to fine grained sand overlying heavier textured sandy clay loam to clayey subsoils. The topsoil structure consists of a single grain structure, whereas subsoils are apedal. These soils are typically deeply weathered and do not show secondary structures.

During the mining process a layer of topsoil (300 mm) is stripped off, and the balance of the material down to the footwall is processed. Sand with 2–5% slimes (defined as the sub-45 micron fraction) is returned as backfill in order to re-establish the dune to approximate the previous landform. From an agricultural perspective this material is not suitable for the dryland cultivation of sugar cane. A capping of more suitable material therefore has to be provided. The most significant difference between the pre-mining soil form and the backfill material is the percentage slimes, consequently a mixture of the sand and slimes is required as a capping over the backfilled sand. The required thickness of the cap is a function of specifically plant growth requirements, erodibility, weathering and runoff (Hattingh, et al.; in prep.). The percentage slimes required in the cap is a function of mainly soil water requirements (Hattingh and Viljoen, 2006). The conservative indications to date show that the reconstituted soil profile should consist of a homogeneously blended mixture of 70%–80% sand and 30%–20% slimes up to a maximum of 2 metres thick. This will be sufficient to ensure growth during dry periods.
From work done to date the soil chemical requirements do not warrant specific attention beyond amelioration in the initial stages. The University of Zululand, situated adjacent to Hillendale Mine, is actively involved in research on this topic using a number of paddocks specifically established for this purpose.

Developing a methodology to blend sand and slimes

Dry mixing versus wet mixing
Dry mixing is a mechanical process and can be achieved in a number of different ways. Test work has shown that, although it is costly, mechanical mixing is possible to a certain extent. The most significant shortcoming of the dry mixing of sand and slimes is that a homogeneous mix is not achieved, and the end result consists of slimes aggregations of varying size in a sandy matrix. This process involves the mixing of the two materials, with either of the two or both still wet. Wet mixing is more problematic in the sense that although homogenization is possible, the method itself or the manner in which it is executed may lead to segregation of the deposited product. Several mixing methods were tested and are described below.

Inversion and mixing
A slimes layer was deposited in a relatively flat area over backfilled sand to a thickness of up to 1.5 metres. The material was left to dry for 12 months. The thickness of the residual material was approximately 1 metre. This was inverted and mixed by means of a back-actor to a depth of approximately 2 metres. The result resembled clay balls in a sandy matrix. Due to the coarseness of the mixing method clay balls of up to 200 mm resulted. The near-surface balls degraded fairly rapidly into smaller units within weeks of being mixed. Due to the nature of this process the cost of inversion is fairly high, and it is reliant on sufficient backfill area being available to facilitate the drying of slimes.

Dune coating and reworking
The slopes of fresh backfill at Hillendale Mine are coated with a thin layer of slimes in order to minimize dust from the operations. Once this layer is dry, it can be pushed down slope by bulldozer, resulting in a mixture of slimes and sand. The resultant texture consists of relatively small slimes aggregations (up to 50 mm) in a sandy matrix. These slimes balls break up relatively rapidly, but the mixture is not homogeneous.

Deep tilling with slimes addition
A specialized plough was developed in South Africa, with the ability to till to depths up to 1 metre. Feeder pipes capable of injecting wet slimes into the soil during tilling were fitted to the plough, and field trials were conducted. The resultant mixture took a relatively long time to dry, and the mixture was not homogeneous.

Irrigation
Industrial sprayers were used to spray a wet sand and slimes mixture over the backfill. Although this method showed promise, it is very cumbersome and labour and equipment intensive. Segregation of slimes and sand did, however, not occur, and this method has the advantage that it can be applied in relatively inaccessible terrain.

Bulk mixing
The most significant breakthrough was achieved with bulk mixing. In essence this consists of the mixing of dry sand with wet slimes. The mixture is applied in layers, which are allowed to dry to a degree before the next application. The probability of segregation occurring is a function of the physical properties of the mixture. This specific aspect is discussed in more detail in the next section.

Managing segregation during the bulk mixing of slimes and sand
It is believed that segregation during deposition is a function of the rheology of the mixture, specifically shear stress. This is the subject of ongoing work at present, but the indications are that segregation will not occur in our situation and given our specific intentions about slope length and gradient if a shear stress of more than 60 Pa is achieved. Laboratory and pilot-scale testwork are underway to tighten this range. However, due to the non-newtonian

### Table I

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<tr>
<td>Soil profile</td>
<td>Soil chemistry</td>
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<td>Horizons</td>
<td>pH</td>
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<td>Cation exchange capacity</td>
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<td>Ca:Mg:K ratio</td>
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<td>Trace elements— Cl, Co, B, Fe, Mn, Z, Mo, Si</td>
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<td>Soil structure, strength and texture</td>
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<td>Organic carbon content</td>
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<td>Salinity and salinization</td>
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<td>Leaching profile</td>
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<td>Impact of flocculant addition</td>
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<td>Impact of gypsum as ameliorant</td>
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<tr>
<td>Plant physiological constraints</td>
<td>Weathering and runoff</td>
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<tr>
<td>Root depth</td>
<td>Release of metals</td>
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<td>Root extension</td>
<td>% Contribution of mined area to total runoff</td>
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flow behaviour of the sand slimes mixture, scaling up of the results is risky. Figure 1 depicts the calculated density versus yield stress data for a 70:30 (by mass %) mixture of sand and Hillendale slimes. From this the target density to achieve a yield stress of 50 Pa can be calculated to be approximately 1.56. These results have been confirmed by laboratory measurements (solid symbols in Figure 1). From a practical perspective, and given the implications of segregation (post-closure maintenance and costs due to managing isolated slimes pockets), there is a target yield stress of 100 Pa based on the pump characteristics of Hillendale Mine’s positive displacement pumps as well as achievable densities. Pumping studies completed to date have shown that a mixture with a yield stress of 120 Pa can be pumped successfully.

In Figure 2 the relationship between the density of slimes and sand mixtures are shown. Various sand solid combinations were assessed against different slimes densities. From this figure it is clear that, in order to achieve for example 50 Pa yield stress in the mixture, and for a thickener underflow density of 1.24, the percentage solids in the sand blended with slimes should be between 90 and 92%. To date the limited pilot plant data supports the theoretical data.

**Establishing a pilot plant with bulk mixing ability**

In order to test the success of bulk mixing on a larger scale than laboratory bench work, a pilot plant with a throughput capacity of 50 tons per hour was established. The facility consists of a conveyor belt feeding dry sand into a mixing sump together with slimes pumped from a slimes thickener. Sand is sourced from the rebuilt sand dune and contains ±8 to 10% moisture. The quantities of sand and slime going into the mixing plant are controlled by a belt scale for the sand and mass and flow meter on the slimes line. The facility was commissioned in 2005. To date a number of paddocks were filled with up to two metres of a 70:30 sand:slimes mixture. Segregation occurred only when...
process control measures were inefficient, showing that large-scale deposition of the blended material is possible. Drying times were relatively fast compared to pure slimes. Field trials aimed at determining the optimum mixture for sugar cane growth is currently in progress on these paddocks.

Key production issues in the process of being finalized include controlling the composition of the mixture and ensuring sufficient drying time between the deposition of layers. Further laboratory work is also ongoing with the aim of optimising the design envelope for the full-scale plant. The intention is to have a 400 ton per hour plant operational by the end of the first quarter of 2008.

While successful implementation of a large-scale bulk mixing and deposition plant will not guarantee the issuing of a mine closure certificate by the state, failure to implement a viable rehabilitation method will results in no certificate being issued. The capital and operational cost impacts of the bulk mixing plant are therefore weighed up against the cost of post closure rehabilitation or in perpetuity responsibility for the mining area. The benefits of progressive rehabilitation outweigh the alternatives by far.

Conclusions
The homogeneous blending of sand and slimes is essential for the successful rehabilitation of Hillendale Mine. Although such blending is problematic from a physical point of view, Exxaro KZN Sands have achieved this by means of a bulk mixing facility blending dewatered sand with thickened slimes. Segregation of the blended material must be managed carefully, but field trials have shown that this is possible. All work done to date has shown that the establishment of a homogeneously mixed cap of sand and slimes of a given range of proportions over the backfilled sand will provide a suitable substrate for the establishment of dryland sugar cane.

References

HATTINGH, R.P., VILJOEN, C., JOVANOVIC, N., LINSTROM, C., KRANTZ, R., and KOTZE, H. Reconstituted soils: a probabilistic approach to resolve aspects relating to the sustainability and economic viability of the rehabilitation of mined lands (In prep.)