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Economical Viability of Rehabilitated Sugarcane Agriculture

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Abstract

Surface mining of heavy minerals is conducted on the east coast of South Africa. The resultant disturbed land is rehabilitated to sugarcane agriculture (its pre-mining land use) by capping the backfilled sand dunes with a layer of a sand-slimes mixture. The required composition and thickness of this layer was modeled with the predicted sugarcane yields as a primary output variable. Both the composition and thickness of the layer are significant in determining the water-holding capacity of the reconstituted soil, which in turn is a determining factor of the sugarcane yield. Sugarcane yield results obtained from the first harvest off rehabilitated land compare favorably with the predicted model results - and typical yield numbers from similar neighboring farming operations.

A business case model for rehabilitated farmland is used to determine the breakeven sugarcane yield for positive revenue to cash cost. Since cane yield is, to an extent, a function of the sand-slimes layer thickness, the resultant breakeven yield numbers are used to confirm the optimum layer thickness previously calculated and reported from a soil perspective.

It is furthermore shown that like most other sugarcane producers, the rehabilitated land is sensitive to the currently prevailing adverse economic conditions in the sugarcane industry.

1 Introduction

Exxaro KZN Sands commissioned the Hillendale heavy minerals mining operation located on the north coast of KwaZulu-Natal, South Africa, during April 2001. The relatively high fine fraction or slimes content of the run of mine allows hydraulic mining of the surface. The opencast mining depths vary from 10 to 40 m below the surface. Mining activities are planned to cease during 2010.

The run of mine reports to a primary wet plant as a slurry where it is split into heavy minerals concentrate, a coarse sand fraction and slimes. The heavy minerals concentrate is transported via truck to a processing complex; the sand is pumped back to the mining void where it is backfilled using cyclones, and the slime is pumped to a residue facility. The mining area and residue facility are designated to be rehabilitated to its pre-mining land use of sugarcane agriculture.

Previous work (Hattingh and Viljoen, 2006) has shown that soil water-holding capacity is a determining factor in the successful rehabilitation of dryland sugarcane agriculture, especially when rain becomes a limiting factor. The predicted sugarcane yield is highly dependent on the plant available water in the soil (Hattingh et al., 2007). The rehabilitation method at Hillendale therefore includes the establishment of a sand-slimes mixture as a cap over the shaped dune profiles. Variables which will influence the plant-available moisture in the cap include the sand to slimes ratio and the depth of the mixed layer.

As far as the completion criteria for rehabilitation is concerned, the Hillendale rehabilitation objective specifically refers to sustainability and economic viability. Sustainability in this specific context is measured in terms of yield and landform stability. The latter is influenced by erosion and, following the outcome of the study reported by Hattingh et al. (2007), work on verification of the estimated extent of this aspect is still in process. Regarding yield, previously reported modeling results (Hattingh and Viljoen, 2006; Hattingh et al., 2007) are compared with the first actual yield numbers obtained from sugarcane trials conducted on rehabilitated Hillendale land. Correlating predictive and actual sugarcane yield results, however, does not imply economically-viable sugarcane production. The second part of this paper therefore focuses on the required breakeven yield as calculated using a business model. The required breakeven yield number is compared to the predicted and actual yield numbers. Since the yield is strongly correlated to both rainfall and thickness of the sand-slimes layer, conclusions are drawn on the recommended layer thickness based on the mean and variation in annual precipitation of the area.

2 Model predictions and actual yield numbers

2.1 Modeling the composition and thickness of the sand-slimes mixture

Previous modeling work conducted specifically for Hillendale was reported by Hattingh and Viljoen (2006) and Hattingh et al. (2007). The primary purpose of this work, utilizing a combination of the RETC software (Van Genuchten, 1980) and soil water balance model (Annandale et al., 1999), was to determine the required sand-slimes structure and layer thickness for optimum water-holding capacity. Sugarcane yield is strongly depended on rainfall and the model results were therefore reported as a function of mean annual precipitation (MAP). Model input variables were given as characteristic statistical distributions allowing a Monte Carlo simulation of the data. Predicted yields are therefore interpreted as having a 95% confidence limit.

From the results of this exercise - referred to in short as the RETC-SWB model, the sand:slimes ratio was set at 75:25, leaving scope for variability in the sand-slimes mixing plant to range between 70 and 80% sand. This range proved to be the optimal sand-slimes ratio between the opposing attributes of maximum water-holding capacity (which increases with increasing percentage slimes), and the rheological properties of the mixture (increasing slimes contents) which imply increasing pumping costs.

The resultant predicted sugarcane yields, as a function of mean annual precipitation (MAP), are given in Figure 1 for mix layer thicknesses varying between 1 and 2.5 m (Hattingh et al., 2007). In the latter work, a 10 year historical rainfall dataset was used to generate a recharge dataset using ACCRU. The discontinuities in the graphs are suspected to be caused by variations in rainfall intensity. The predicted sugarcane yields from this graph should therefore not be seen as absolute, but as a realistic indication of the trend. The results from Figure 1 should be interpreted together with the typical rainfall data of the area, which varies from 550 to 2356 mm per year, with a mean of 1146 mm. From this work it was concluded that yields of 65 to 70 t/ha is obtainable for the median rainfall of 1100 mm for layer thicknesses from 1 to 2.5 m. This compares favorably with typical yield numbers of the area which ranges between 50 and 70 t/ha. However, “sustainability” implies an extent of resilience of the rehabilitated land to drought conditions. The issue therefore is to understand the required layer or cap thickness that will have sufficient water-holding capacity to provide dryland sugarcane agriculture yields that are equivalent to yields from adjacent farms during dry seasons.

2.2 Modeling the sugarcane yield

Whereas the RETC-SWB model was initially used to predict the effect of varying soil compositions and layer thicknesses on sugarcane yield, a second more appropriate model - CaneSim, which was specifically developed for sugarcane - was used to refine the sugarcane yield predictions. Although CaneSim does take different soils and soil conditions into account, the primary purpose of the CaneSim model (Singels at al., 1998) is to allow benchmarking of historical data against predicted yields to predict future expected yields. This functionality creates the possible opportunity that the CaneSim model could be used to indicate long-term sustainability of the rehabilitated land in terms of sugarcane agriculture, a helpful tool when setting closure standards. Although the RETC-SWB model has the capability to predict sugarcane yield, the CaneSim model is supported by the South African Sugar Association, and was developed by the Agronomy Department of the South African Sugar Research Institute (SASRI). The capability to predict yield is an important functionality for the purpose of proving sustainability.

Sugarcane is harvested every 12 to 18 months. The original seedcane is only replaced every four to six harvests (harvests subsequent to the first harvest from the same seedcane are referred to as ratoons). Hence, to prove sustainability of the rehabilitated land with actual yield data will require multiples of ten years. Predictive models, like CaneSim, have the potential to reduce this period markedly.

A comparison of the predicted sugarcane yield from the RETC-SWB and CaneSim models is given in Figure 2 over a range of sand-slimes compositions (Esprey, 2008). The CaneSim model predicts higher yields for soils with lower water-holding capacities (such as 90% sand). This can be interpreted as CaneSim overestimating the sugarcane yield for soils which are under strain, such as soils containing a small fines fraction and soils during dry years. However, which model is the more accurate can only be verified once more historical results are available from the rehabilitated land.

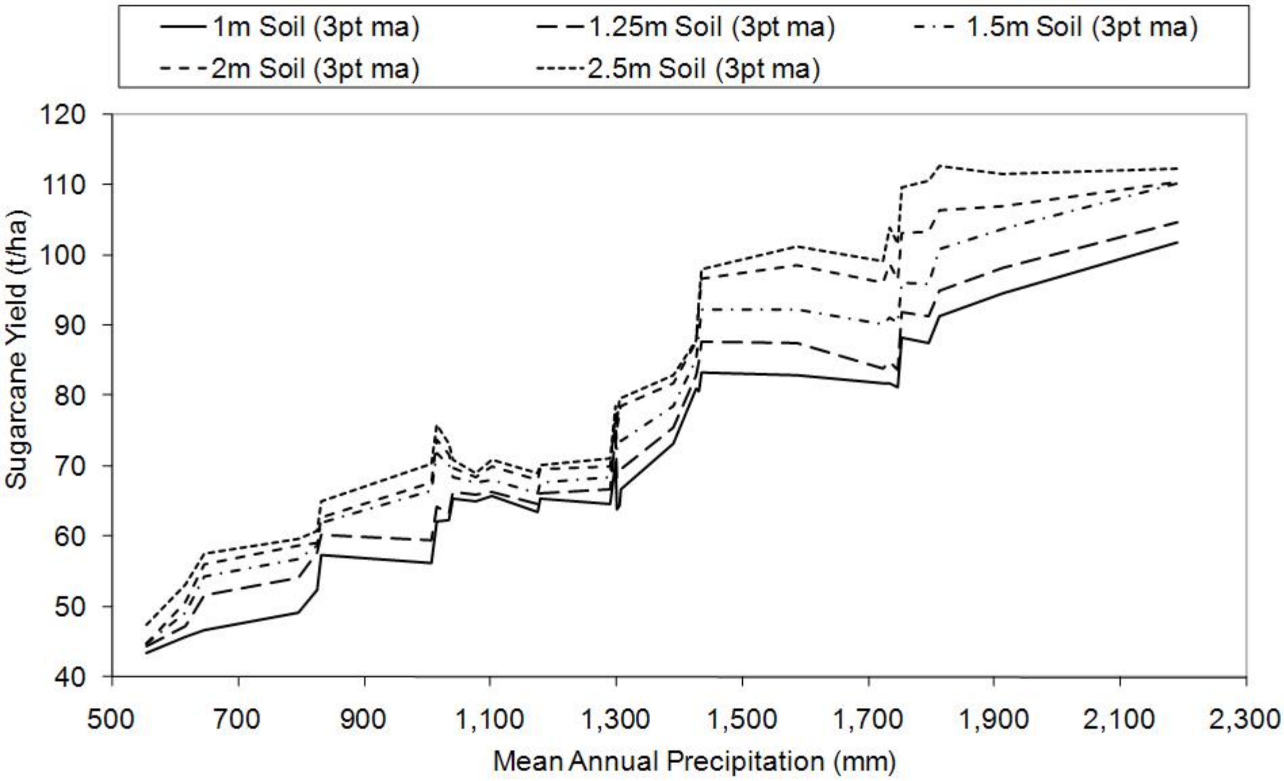

Figure 1 **Predicted sugarcane yields as generated by the RETC-SWB model (three-point moving averages) for varying depths of reconstituted soil, as a function of mean annual precipitation (Hattingh et al., 2007)**

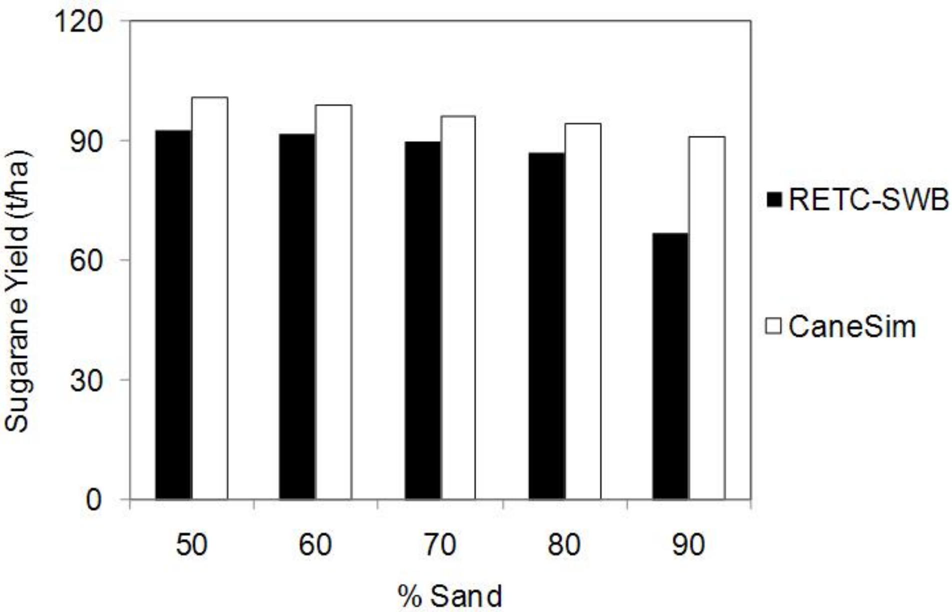

Figure 2 **Predicted sugarcane yields from the RETC-SWB and CaneSim models for a layer depth of 1.5 m as a function of the sand-slimes ratio**

2.3 Actual sugarcane yields

The first harvest from sugarcane grown on rehabilitated Hillendale land was obtained during February 2008. The seedcane for these trials were planted during February 2007 and given various fertilizer/soil amendment treatments. The trials are part of a larger Ph.D. study revolving around the structural, chemical and biological nature of the reconstituted soil, conducted by the University of Zululand, South Africa.

The rainfall for the period 1 February 2007 to 31 January 2008 was 1170 mm. From the long-term averages for this area, this rainfall is exceeded approximately 40% of the time, hence the growth period was slightly wetter than in an average year. The average temperature for this period was 21°C, with 7°C and 37°C being the minimum and maximum temperatures respectively.

The sugarcane was planted in two plots: a small plot with a mix depth of 0.5 m and a second larger plot with a mix depth of 1.8 m. The small plot (30 x 15 m) was divided into subplots with individual measurements of 3.85 x 4.6 m, allowing a 0.5 m spacing between neighboring subplots. Six of these subplots were planted with sugarcane - two treatments repeated three times, with the remaining plots receiving alternative treatments. The larger plot, with overall dimensions of 90 x 45 m, was divided into subplots of 10 x 8 m, leaving a 1 m space between neighboring subplots. Twenty of the subplots were planted with sugarcane - five treatments, each replicated four times. In both the small and large plots, seedcane was planted in rows spaced 1 m apart. Both plots are located on the top of a dune and are thus susceptible to wind and water erosion. The sugarcane received no irrigation. The actual yields were obtained from the trial plots by the random sampling of 1 m^2 subplots. In the case of the 0.5 m cap plots, three 1 m^2 samples were taken, while four 1 m^2 areas were sampled for the 1.8 m cap plots. The leaves were stripped from the stalks and a fresh stalk mass (as would be delivered to the mill) was determined. Converted to tons per hectare, this number is defined as the cane yield. The stalks were analyzed by the SASRI laboratories to determine the percentages sucrose, non-sucrose and fiber, which are the key indicators of cane quality. This sampling method is advocated by SASRI for research trials as well as for estimating the yield for large farming operations (Smit, 2008). The minimum and maximum cane yields are shown by the lower and upper limits of the vertical markers in Figure 3.

Substantial variation in the yields is apparent. The detailed study of the trials is still in progress; however preliminary indications are that this could be attributable to a combination of inhomogeneity introduced during the uneven deposition of the capping material, and the size of the sampling plots.

The significant issue, however, is that the experimentally-obtained yields are markedly higher than typical yields recorded on neighboring farms, which range between 50 and 70 t/ha (Groom, 2008). There are a number of possible reasons why this could be the case, but as rainfall was not a limiting factor, it is unlikely that this was due to water-holding capacities of the reconstituted soils compared to undisturbed land.

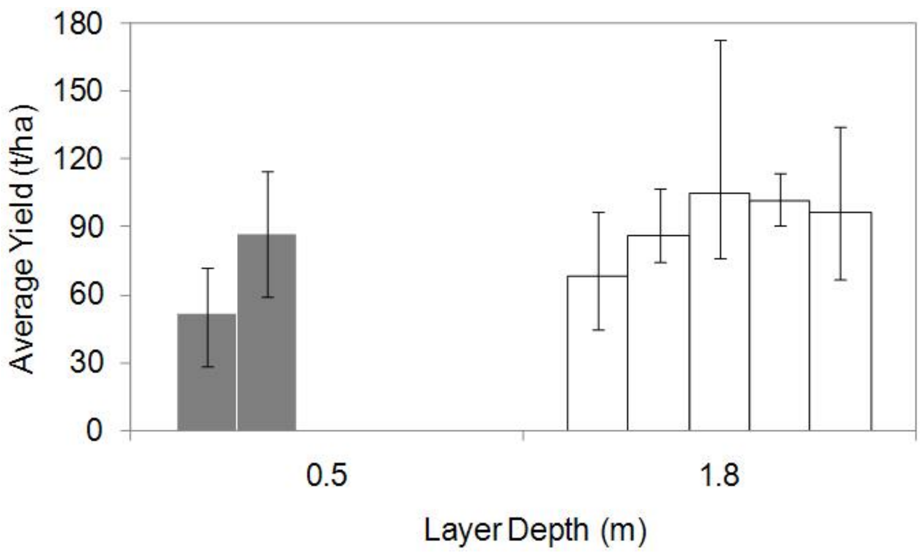

Figure 3 Average sugarcane yields of the trial plots for layer depths of 0.5 and 1.8 m (upper and lower ends of vertical lines indicate maximum and minimum yield numbers)

A comparison between predictions from the RETC-SWB and CaneSim models, and actual average yields for a sand:slimes ratio of 80:20 as a function of layer depth, is shown in Figure 4. In both models, the ratoon lengths were assumed to be 12 months with harvesting taking place during February, as was the case with the trial plots. Both models compare favorably with the actual measurements, and show a trend of lower yields at 0.5 m layer thickness and improved yields at 1.8 m layers. These preliminary results are furthermore interpreted to indicate that the variation in actual yield measurements exceeds the difference between predictions of the two models for an 80% sand reconstituted soil.

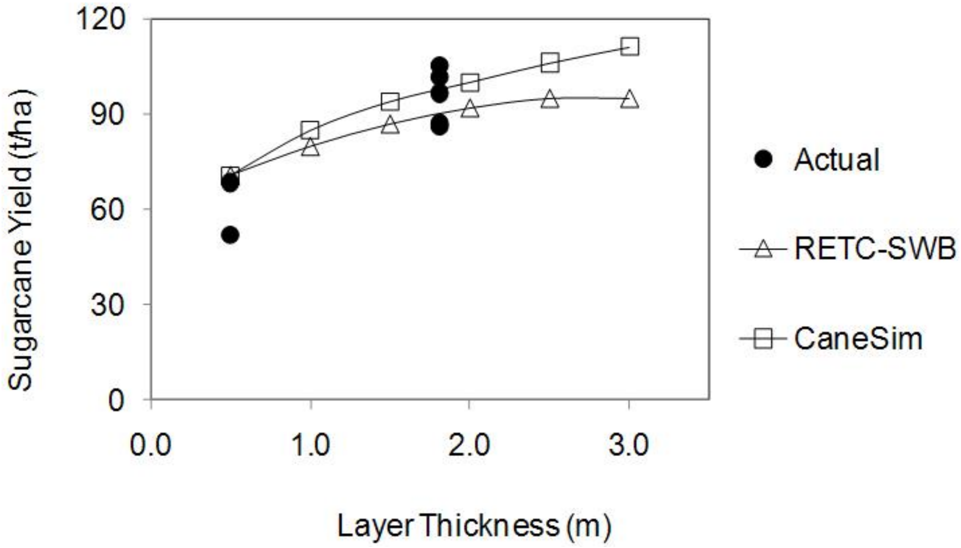

Figure 4 Predicted versus actual sugarcane yields of an 80:20 sand:slimes mixture at thicknesses of 0.5 and 1.8 m

3 Breakeven yield

From the above it appears that a profitable sugarcane yield can be generated by simply increasing the sand-slimes layer depth. The RETC-SWB work conducted during 2007 (Hattingh et al., 2007), however, showed that for all practical purposes the yields predicted from cap thicknesses beyond 1.8 m do not increase further. The ideal layer thickness therefore lies between 0.5 and 1.8 m. The recommendation from this work was that a layer of 1.25 m be considered, excluding a provision of 108 mm for erosion, as this would provide the most cost-effective outcome whilst providing an acceptable yield.

The chosen layer thickness will need to provide acceptable yields during periods of drought. The economic drivers dictating whether sugarcane remains a suitable crop in this area is, however, outside the control of the mine.

3.1 A business case for sugarcane agriculture

South African sugarcane producers are financially rewarded for both the quantity and quality of their sugarcane delivered to the mill. This reward is calculated as per the equation below (SASA, 2008):

$$Financial\ reward = sugarcane\ yield \times \%RV \times RV\ price \tag{1}$$

The %RV (recoverable value) is a measure of the relative value of the quality of the cane, taking into account the sucrose, non-sucrose and fiber content of the cane. Typical values for %RV are 10 to 12%. The average recoverable value of the 2007/08 harvest of the trial plots at Hillendale was 10.6%. The RV price is determined by the South African Sugar Association. Hence, both volume (sugarcane yield in t/ha) and the quality of the cane (%RV) determines the income of the sugarcane producer.

In an exercise subsequent to the work conducted by Hattingh et al. (2007), the breakeven cane yield, where the revenue to cash cost becomes positive, was calculated for RV of 10, 11 and 12%. This approach is based on the assumption that the rehabilitated farmland will be compared with neighboring farming operations, none of which is profitable in all climatic and economic conditions.

In compiling the business model, the following were assumed (all monetary numbers are in South African Rand, ZAR):

- As rehabilitation progresses, the farming area is increased over a period of six years, from 100 hectares to the full 350 hectares.
- The crop cycle is six years, i.e. replacement of the original seedcane commences after six years.
- The average monetary award per %RV over the six years is R 1950.
- Average planting costs, over the six years, are R 12,720 per hectare.
- Ratoon maintenance cost is, on average, R 4780 per hectare over the six years.
- Cutting, loading and hauling costs are, on average over six years, R 69 per ton of fresh and cleaned stalk sugarcane.
- Input costs are according to the needs of similar soil and dryland operational farms as published by SASRI (2008) and SACGA (2008) and adjusted for increased cost input numbers of 2008.
- Costs associated with rehabilitation monitoring are carried by the mine and not by the farming business.
- The mine initially finances the newly-developed farming operation with R 1,200,000 to enable purchasing of farming equipment and vehicles.
- Capital is advanced by the existing mining business, thus avoiding interest payments during the initial years.

An example business model is provided in Table 1 (Phatisa Equity, 2008). An average sugarcane yield of 60 t/ha is assumed over the six years, providing for yield variations over wetter and drier seasons. An average cane quality of 11% RV is assumed. Once the full area is established after six years, the business becomes cash positive. At prevailing input costs, it will, however, take a few more years to pay back the liabilities.

3.2 Sensitivity analysis on input costs and income

While the increase in input cost was estimated at 6.5% for the 2006/07 season (The Cane Grower, 2007), research conducted during April 2008 reported a weighted increase of 28.7% in operating cost of a large scale sugarcane farming operation from the previous season. Increases in fertilizer and fuel costs respectively contributed 14.3 and 4.5% (The Cane Grower, 2008). Seeing that the increase in input cost was already incorporated in the assessment summarized in Table 1, the sensitivity of the total profit to additional increases in input cost of 5, 10 and 15% over the full six years was calculated. In the analysis the income was kept fixed at R 1950 per %RV at a relative value of 11% and cane yield of 60 t/ha. The results of this sensitivity analysis are shown in Table 2. At input cost increases just above 5%, the farming operation is becoming cash negative.

3.3 Determining the optimum sand-slimes layer thickness

Provided that standard farming practices are followed and applied as a minimum, obtaining the average cane volumes and qualities, as given in Table 1, is feasible. The cane quality can be improved by the application of ripeners during normal rainfall seasons. It is, however, especially during dry years that the viability and sustainability of the rehabilitated land will be tested.

Table 1 Summary table showing production volumes, turnover and income statement

Production Volumes and Turnover	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Area planted	100	80	30	70	70	35
Area ratooned	0	90	160	200	250	315
Area harvested	0	90	160	200	250	315
Mature cane carried over to next season	0	10	20	10	30	35
Total area established	100	180	210	280	350	385
Sugarcane harvested	0	5400	9600	12,000	15,000	18,900
Sales volumes	0	594	1056	1320	1650	2079
Turnover	*0*	*1,158,300*	*2,059,200*	*2,574,000*	*3,217,500*	*4,054,050*
Income Statement						
Turnover	0	1,158,300	2,059,200	2,574,000	3,217,500	4,054,050
levies	0	14,850	26,400	33,000	41,250	51,975
Sales volumes	0	1,143,450	2,032,800	2,541,000	3,176,250	4,002,075
Cost of sales	1,272,000	1,820,400	1,808,800	2,674,400	3,120,400	3,255,000
planting	1,272,000	1,017,600	381,600	890,400	890,400	445,200
ratoon maintenance	0	430,200	764,800	956,000	1,195,000	1,505,700
cut, load and haul	0	372,600	662,400	828,000	1,035,000	1,304,100
Other direct costs	107,700	215,400	215,400	215,400	215,400	215,400
Gross profit	*-1,379,700*	*-892,350*	*8600*	*-348,800*	*-159,550*	*531,675*
Overheads	356,300	356,300	356,300	356,300	356,300	356,300
management fees	234,000	234,000	234,000	234,000	234,000	234,000
depreciation	122,300	122,300	122,300	122,300	122,300	122,300
Total Profit	**-1,736,000**	**-1,248,650**	**-347,700**	**-705,100**	**-515,850**	**175,375**

Table 2 Change in total profit with increased input costs (base case as per Table 1)

% Increase in Input Cost	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
0	-1,736,000	-1,248,650	-347,700	-705,100	-515,850	175,375
5	-1,799,600	-1,339,670	-438,140	-838,820	-671,870	12,625
10	-1,863,200	-1,430,690	-528,580	-972,540	-827,890	-150,125
15	-1,926,800	-1,521,710	-619,020	-1,106,260	-983,910	-312,875

The average annual increase in RV price for the 1995-2005 period was 4.3% (The Cane Grower, 2007). These increases are already reflected in the average RV price of R 1950 per %RV. The sensitivity of the total profit to additional increases in the RV price of 0.5, 1.0 and 1.5%, is shown in Table 3. It is evident that the profitability of the newly developed farmland under current economic conditions, is under pressure - as is the case with most other South African sugarcane producers: since the 2003/2004 season, sugarcane producers have, on average, come close to breakeven with total cost (SACaneGrowers, 2008) - a shortfall that has historically occurred during drought seasons. The current conditions are, however, stated to be due to prevailing economic conditions in the industry.

Table 3 Change in total profit with increased RV price (base case as per Table 1)

% Increase in RV Price	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
0	-1,736,000	-1,248,650	-347,700	-705,100	-515,850	175,375
0.5	-1,736,000	-1,242,859	-337,404	-692,230	-499,763	195,645
1.0	-1,736,000	-1,237,067	-327,108	-679,360	-483,675	215,916
1.5	-1,736,000	-1,231,276	-316,812	-666,490	-467,588	236,186

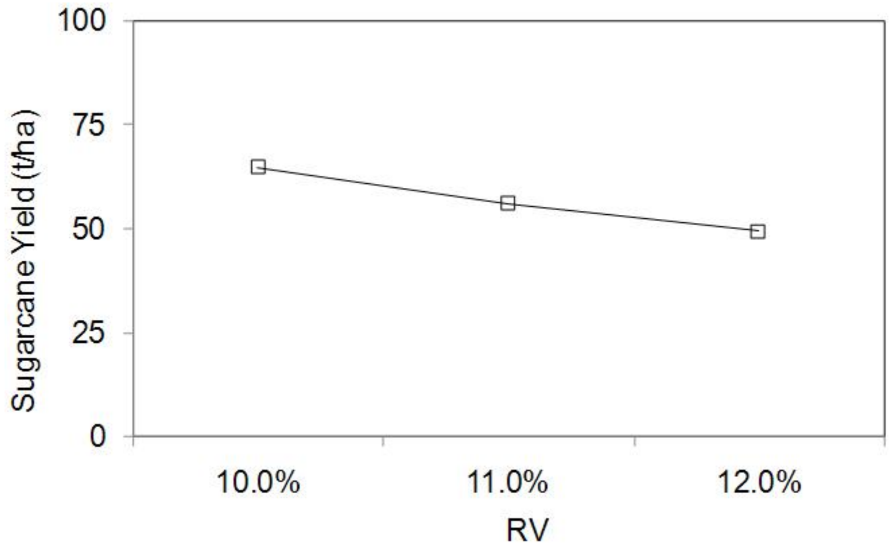

Figure 5 Breakeven sugarcane yield as a function of the relative cane value, RV

Bearing in mind that, although calculated for a confidence interval of 95%, the results from the modeling work shown in Figure 1 are based on a theoretical exercise and should be interpreted as indicative only. The following broad indicators are derived:

- From Figure 5, the indicative breakeven yield at an RV of 11% is 56 t/ha. From Figure 1 this can be obtained with average annual rainfalls ranging between 615 mm for a 2.5 m sand-slimes layer thickness, and 825 mm for a 1 m sand-slimes layer thickness. For a 1 m layer thickness, the minimum required rainfall is exceeded 85% of the time. For a 1.5 m layer thickness, the minimum required rainfall to ensure a yield of 56 t/h, is 700 mm per annum. This rainfall is exceeded 97% of the time.
- However, should the recoverable cane value drop to 10% the breakeven yield is 65 t/ha. To achieve this with a layer thickness of 1 m, the annual rainfall should be approximately 1025 mm or more. This rainfall is exceeded 58% of the time. To achieve a yield of 65 t/ha with a layer thickness of 1.5 m, the mean annual rainfall should be approximately 950 mm and exceeded 65% of the time. Increasing the layer thickness does not, in this case, appear to make a substantial improvement in the scenario. Between mean annual rainfalls of 1000 and 1300 mm, a plateau of cane yields between 65 and 70 t/ha occurs, before the predicted yield increases again with increasing rainfall (Figure 1), even if the model deficiencies are ignored and the graph is smoothed out.

A summary of layer thickness, cane yield, required mean annual precipitation and percentage of the time when this rainfall is exceeded, is given in Table 4. Lower quality cane (10% RV) requires annual rainfall that exceeds the mean annual rainfall less than 70% of the time. Good quality cane (12% RV) can achieve the breakeven yield at rainfalls which exceed the mean annual precipitation 90% of the time for a mix layer of 1 m and 98% of the time for a 1.5 m and thicker mix layers.

Taking into account that the recoverable value (%RV) for the 2007/08 season of the Hillendale harvest was 10.6% without the application of any ripeners, it is confirmed from an economic point of view that the thickness of the sand-slimes layer be set at 1.25 m (excluding provision required for erosion losses). For a 1.25 m mix layer depth, a yield of 65 t/ha is indicatively possible with a minimum annual rainfall of 1050 mm - a rainfall which is exceeded about 55% of the time. Similarly, an indicative yield of 50 t/ha is possible from a 1.25 m layer thickness for a minimum annual rainfall of 625 mm, which is exceeded 98% of the time. This is also in agreement with the recommendation by Hattingh et al. (2007) who based their recommendation on the water-holding capacity of the soil.

Within the context of the Hillendale rehabilitation, the expected resilience of the rehabilitated land is therefore stated as that which can break even under current economic conditions with regard to revenue to cash cost, more than 55% of the time.

4 Conclusions

With fluctuating input parameters, whether it is from climatic factors or economic factors, finalizing completion criteria for mine closure purposes is problematic. This paper has confirmed, from an economic point of view, the sand-slimes layer thickness required for optimal sugarcane production, previously determined by Hattingh et al. (2007) based on soil water-holding capacity analyses.

Business case calculations for sugarcane agriculture on the rehabilitated farmland have shown it to be marginally revenue to cash cost positive under the current adverse economic conditions, similar to other local sugarcane farming operations. The cyclic nature of the sugarcane industry implies that the economic viability of the rehabilitated farmland during the post-mining years is likely to differ from the current conditions. In addition, a range of various climatic conditions is certain to influence agricultural yields from the land over the next few years. However, when determining completion criteria, it is recommended that economic viability and sustainability of the rehabilitated land be proven by an approach similar to that demonstrated in this work. Actual sugarcane yield and quality numbers, as well as income and cost figures, should be fundamental to such argument.

Table 4 Summary of breakeven cane yield at given recoverable cane values (%RV), sand-slimes layer thicknesses, required mean annual rainfalls (MAR) and % of the time which these rainfalls are exceeded (%time)

%RV	Breakeven Yield, t/ha	Layer Depth, m	MAR	% Time
10	65	1.0	1025	58%
		1.5	950	65%
		2.0	925	68%
11	56	1.0	825	85%
		1.5	700	97%
		2.0	650	> 98%
12	50	1.0	800	90%
		1.5	625	> 98%
		2.0	575	> 98%

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