A REVIEW OF THE CURRENT STRATEGY FOR CAPPING MINING SPOILS

C.G.WAYGOOD[1] and S.FERREIRA[2]

[1]Jones & Wagener, Consulting Engineers
Johannesburg, Gauteng, South Africa; E-mail: waygood@jaws.co.za
[2]Jones & Wagener, Consulting Engineers
Johannesburg, Gauteng, South Africa; E-mail: ferreira@jaws.co.za

ABSTRACT

The use of soil stripped ahead of mining is the current best practice for capping of mining spoils. The thickness used varies, being typically either the full depth of soil or a fixed depth based on the intended post mining land use. Soil is placed back on top of levelled spoils. There are mines where the soil thickness is extremely limited due to poor utilisation of soils, or thin soils in the pre-mining environment.

Long term studies have indicated that capping systems deteriorate with time and often don't perform as expected. As a result, costs for managing water makes from mined out areas are likely to be higher than may otherwise have been expected. Future maintenance requirements of capping systems have generally not been seriously addressed on most South African mines.

This paper is a desktop review with limited laboratory testing of potentially viable of alternative strategies for capping of opencast spoils from coal mines in the Witbank area. Options considered include the blending of spoils with soil and options to add ash where practical. The laboratory testing indicates that such measures have the potential to improve the performance of capping systems, while at the same time achieving possible cost savings. The objective is to encourage practitioners to reconsider the options and costs associated with capping of mining spoils.

1. INTRODUCTION

Over the past few decades, extensive attention has been given to the design of cover systems for mine spoils, but more particularly mine waste, tailings and leach pads. Progress has been made in the fields of soil cover modelling, the development of store and release systems and the use of capillary breaks to limit recharge through the covers amongst others. However, for largely practical reasons, the issue of cover systems placed on to rehabilitated spoils has received considerably less attention.

In the Witbank area of South Africa, the rehabilitation of opencast mine spoils is typically carried out as follows:

- Material is stripped ahead of mining. In some instances, the full depth of soils is stripped, but in many cases, only the volume required for the intended land capability post mining is stripped. Based on arable land usage as defined by the Chamber of Mines, 600mm of soil cover would generally be considered adequate.
- The stripped material is then placed over spoils after they have been levelled, typically as one mixed layer of soils and sub-soils.
- The area is then grassed with a mix of species.

The process often does not include soil testing to determine whether improvement measures are required for long term sustainability. In addition, future maintenance requirements are often not considered or adequately addressed. A further problem is that the thickness of the capping layer at some mines is extremely limited due to poor management and utilisation of soils, or thin soils in the pre-mining environment.

This paper shows how long term studies have indicated that capping systems deteriorate with time and often don't perform as expected, resulting in increased infiltration through the capping layer and consequently increased water make. This in turn results in higher than expected management costs for the water make, particularly where water treatment is required.

Limited laboratory testing was undertaken to evaluate alternative strategies for capping of opencast spoils from coal mines in the Witbank area. These included blending spoils material with the topsoil, as well as the addition of ash, where practical.

The primary objective of the paper is to indicate that alternative spoils rehabilitation strategies are available that both perform well and are potentially cost effective. Practitioners are therefore encouraged to reconsider the options and costs associated with capping of mining spoils.

2. PROBLEM STATEMENT

There are several potential problems associated with the current strategy, including the following:

- The objectives of capping are often not well defined, but are usually driven by land usage. In terms of final land use, Mentis (2006) has noted several problems on capping systems at various opencast mines associated with disturbed soils, depletion of organic carbon and nutrients and low soil pH. These factors have resulted in limited progression of vegetation to climax species and a more sustainable final land use.
- However, the focus of this paper is the issue of water management costs operationally and post mining, particularly where water treatment will be required at some point in the life of the mine. It is suggested that the thickness of the capping and the nature of the materials used will directly impact on the future water treatment costs.

In terms of water make, Rykaart *et al* (2006) published the findings in an international review of soil cover design and construction practices for mine waste closure at the International Conference on Acid Rock Drainage (ICARD) in 2006 which indicated several areas of concern around capping systems. These issues and others are discussed below.

- Covers seldom perform as well as originally envisaged. This is illustrated in Figure 1 overleaf, comparing the saturated hydraulic conductivity as specified at the design stage with those measured in the field.
- Data obtained on capping systems clearly indicates a deterioration in the performance of capping systems with time, resulting in increased infiltration. This is illustrated in Figure 2 overleaf, based on four case studies. Studies at Rum Jungle and other sites with long term data have indicated that the capping systems will be affected by factors such as physical processes (erosion, wet/dry cycling, settlement, cracking and others), chemical processes (such as dispersion and salinisation) and biological processes (root penetration, burrowing animals, extent of vegetation establishment and plant die back amongst others) (O’Kane, 2003). The reality is that the capping system will most likely deteriorate significantly in future, and water management systems will need to account for this.

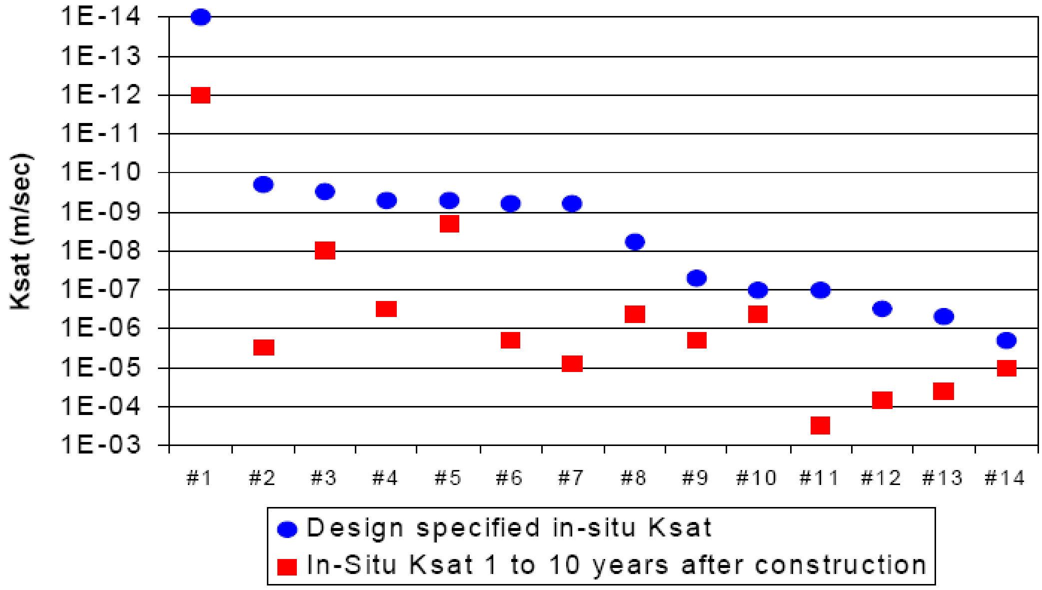

Figure 1. Comparison of designed and measured hydraulic conductivities (Rykaart et al)

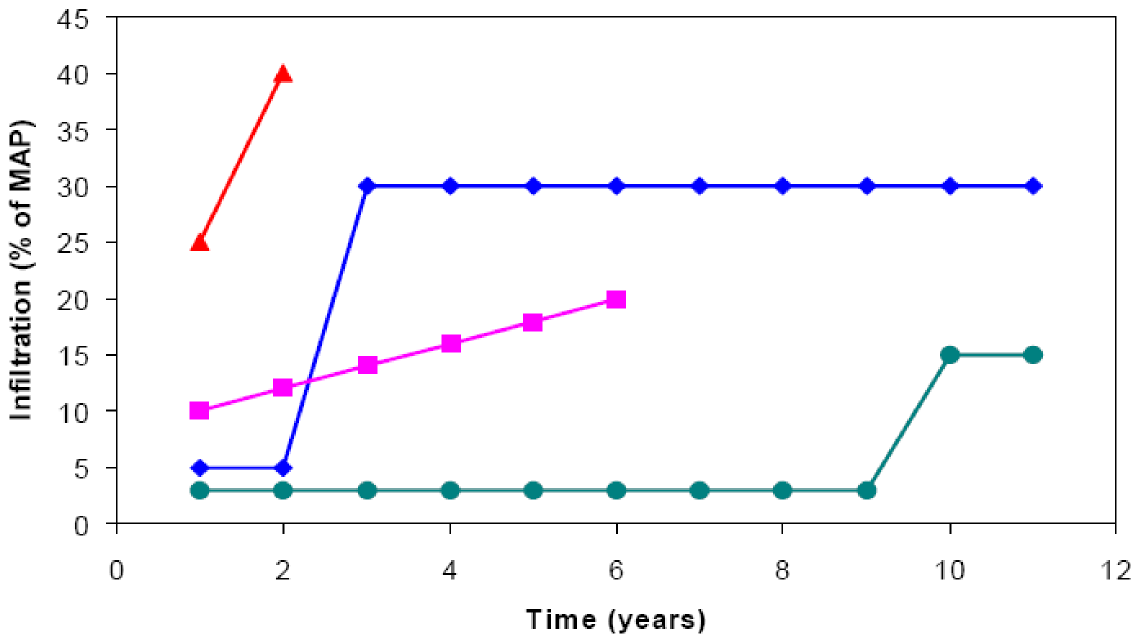

Figure 2. Long term monitoring data indicating the change in infiltration rates with time for four sites (Rykaart et al)

- Thirdly, the paper noted that "there appears to be a disconnect between … highly sophisticated design philosophies and the practicality of constructing covers that are expected to perform in accordance with the design, for undetermined time periods". A decision to utilise a certain simple cover of a particular thickness is not inherently wrong, provided it is a "decision" and not simply repetition of past practices without fully considering the long term implications.
- It is worth noting that, although most mines have commitments in their EMPR documents to maximise the freedraining areas, a detailed survey of mined out areas can indicate how difficult this can be on a micro level. Figure 3 overleaf, from a large opencast mine, is a detailed survey of a mined out area using infrared. Although the area in Figure 3 is generally freedraining, there are many small, localised non-freedraining areas (indicated in blue in the figure).

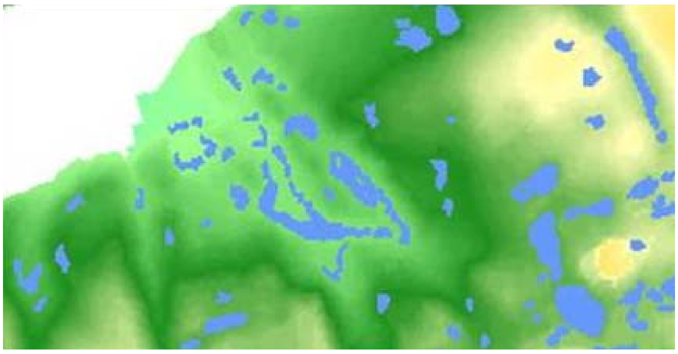

Figure 3. Plan showing a detailed survey of a rehabilitated area showing numerous localised non-freedraining areas

Within these ponding areas, seepage may be far greater than originally envisaged during closure planning.

- Lastly, a survey of soil thicknesses on various mines has indicated that it is not uncommon on some of the older mines for capping thicknesses to be of the order of 150mm to 300mm.

3. PRACTICAL CONSIDERATIONS

It is known that increasing the complexity of covers increases the construction costs significantly. Rykaard *et al* (2006) found that reclamation covers typically cost around R200 000/ha, simple covers around R300 000 to R400 000/ha and complex covers as much as R3 000 000/ha. If one considers a simple base case of a mine in the Witbank area, the benefit in reducing the infiltration rate can be very roughly estimated as illustrated in Table 1 below.

Table 1. Expected financial benefit of reducing infiltration rates based on 700mm of rainfall, all costs per ha, base date 2009

Assumed infiltration (%)	Expected water make per ha (m^3/day)	Capital costs of Water Treatment	Operating costs	Water treatment cost per ha
20	3.8	R 76,712	R 197,317	R 274,029
15	2.9	R 57,534	R 147,987	R 205,522
10	1.9	R 38,356	R 98,658	R 137,014
5	1.0	R 19,178	R 49,329	R 68,507

Note:

- Order of magnitude capital cost for water treatment based on R15million/Ml/day treatment and R5million/Ml/day sludge and brine costs
- Typical operating costs over 100years assuming no income for the water, discounted at 6% for future costs, R8/m^3 treatment cost

Clearly the actual costs will vary for each situation, and will change with time. However, the above figures are considered reasonably indicative for a typical mine. Note that infiltration rates of around 14% to 16% appear to be widely used in the Witbank area for modelling recharge through rehabilitated spoils, but the actual rate will vary significantly depending on the cover details, rainfall experienced, vegetal cover etc.

It would appear that, to be viable, costs to reduce infiltration by improving the capping of spoils should not increase the rehabilitation costs by the order of R50 000 to R100 000/ha unless a dramatic reduction can be achieved. This certainly excludes consideration of complex covers. Further, there are practical constraints to be considered in terms of the mining operations. For example it may not always be practical to blend materials and the cost to haul materials can quickly become prohibitive.

Nevertheless, based on the above, it was considered worthwhile to explore various options for the capping that may be viable in some instances, and then to discuss the practical constraints later.

4. THEORETICAL REVIEW OF THE IMPACT OF CAPPING THICKNESS ON PERCOLATION

As discussed, cover systems are expected to perform under both saturated and unsaturated conditions on most mines.

Saturated Conditions

In terms of saturated flow, Darcy's Law is still widely used, expressed here in its empirical and one-dimensional form.

$$Q = KA(h_1 - h_2)/L$$

where Q is the volume of water per unit time, K is the hydraulic conductivity, *h* represents the head difference, L the flow length and A the cross sectional flow area.

From a capping perspective, in a vertical flow situation, increasing the cover thickness (*L*) would appear to reduce the through flow. However, because the cap is located on a permeable material in most instances, h_1-h_2 is also equal to the thickness of the cap assuming a nominal head of water. Thus, once the cap is saturated, the rate of flow is directly proportional to *K* and independent of the cap thickness. However, the time to saturate the capping is significantly affected by the capping thickness, as may be expected.

Unsaturated Conditions

For unsaturated conditions and utilising vegetation to remove moisture from the cover system, the situation is far more complex, as might be expected. Bear & Verruijt (1996) and various others set out the complex equations and calculations relating to the capillarity and retention curves, motion and balance equations and boundary equations used to model flow behaviour. These equations are not repeated here. There are also numerous models available to assess the performance of capping systems, of which Vadose/W was preferred for the International Network for Acid Prevention (INAP) review of dry cover performance (O'Kane, 2003).

The most important aspects to be considered in terms of the store and release cover under unsaturated conditions are discussed below.

- The effect of vegetation. Although not measured in the laboratory testing, the significance of vegetation is apparent from Figure 4, indicating the difference that vegetation can make to the overall ingress of water. In terms of store and release, the natural rooting depths relative to the capping thickness and the maintenance of a healthy vegetation cover will be a significant factor in the ability of the store and release capping to control water ingress. Botanists indicate that most grasses and trees have 80% of roots within the upper 300mm of soil with 90% of biomass being within 600mm of surface, although this does not preclude vegetation from extracting water from deeper soils where practical. A typical depth used in modelling the extraction of water from covers by vegetation is around 1m, but in arid environments rooting depths in excess of several metres has been measured.

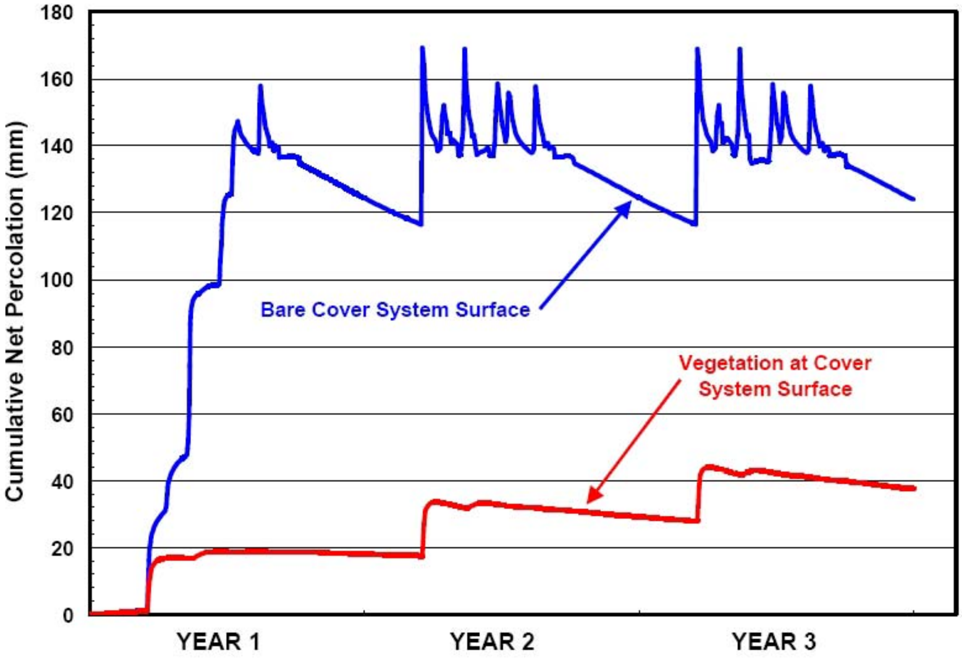

Figure 4. Affect of vegetation on the performance of capping systems as modelled (O'Kane, 2003)

- The function of the capping will be to retain water for long enough that the vegetation is able to extract the water. In this sense, the total field capacity of the soil (that is, the amount of water it can retain under the gravitational forces) and the volume of water that can be retained relative to the vegetation rooting depth will be a key consideration. This volume of water that can be retained and then evapo transpirated will be largely dependent on:
  - The thickness of the capping layer. The relationship between the capping thickness and percolation is dependant on such a range of factors that typically complex models are required to determine the rate, but Figure 5 overleaf indicates typical data obtained relating layer thickness to percolation.
  - The soil water characteristic curve. This is the measurement of moisture retention within the capping system. This is not a unique value, in that the soil will perform differently under different conditions of wetting or drying, overburden pressure, or location above the water table (where it exists). The typical field capacity of the material was estimated in the laboratory testing through measurement of the capillary moisture content, being the moisture content retained within the soil under the influence of gravity.
  - The homogeneity of the capping (changes in grading within the capping layers). This can be a complex relationship sometimes working for the capping and sometimes against. For example, capillary breaks may form due to finer material overlaying coarser material, but these can also limit root penetration. Segregation during placement by end tipping of material have been shown to provide a pathway of coarser material along which water can flow.

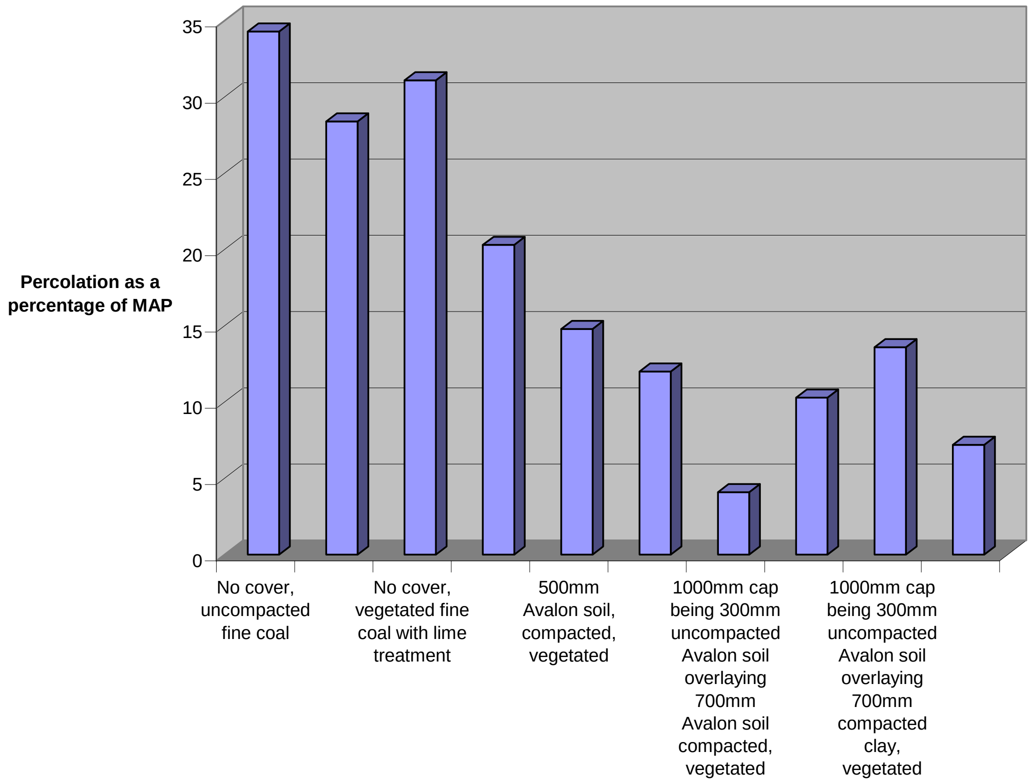

Figure 5. Reduction in infiltration related to the thickness of capping layers (Bezuidenhout,2004)

5. ALTERNATIVES CONSIDERED AND TESTING METHODOLOGY

The premise of this paper was based on the observation that:

- On many mines vegetation is able to grow on spoils, but that the infiltration through spoils remains high.
- On some mines that have been operating for many years, there appears to be a shortage of suitable capping material.

The assumption inherent in the options considered is that the capping thickness can potentially be increased with only some small change in overall saturated permeability and unsaturated properties. There are already sites where the capping soils and relatively inert spoils have been blended, and in Australia there are areas where relatively inert mine spoils forms a key part of the capping material on which vegetation will develop. The question is whether there are alternatives to a simple cover placed over spoils for strip mining operations in the Witbank area, particularly given the carbonaceous nature of the spoils material, and the highly variable nature of the spoils material.

Methodology

Samples of spoils, soils being used in rehabilitation and ash from a power station associated with one of the large mines in the Witbank area were collected. The following samples were analysed in terms of saturated permeability, and expected field capacity (for the unsaturated case):-

- Sample 1 – Soils currently used in rehabilitation.
- This represents the base case.
- Sample 2 – 50% soils mixed with 50% spoils.
- Of interest is the impact of this on the saturated and unsaturated permeability, with the opportunity, where soil thicknesses are limited, to obtain a thicker store and release capping. Only the permeability of the blended material was considered, not the pH.
- Sample 3 – 40% soils mixed with 40% spoils and 20% fly ash (by volume).
- The purpose of blending ash with the cover material would be to counter the acidity of the spoils material. This is a relevant option on several mines linked to Eskom power stations, particularly if the ash can be cost effectively transported to the rehabilitation area, possibly reducing the disposal requirements on the existing ash dams.

6. RESULTS

Due to time constraints, a full soil moisture retention curve for the mixed materials was not determined, but the capillary and non-capillary pore space was measured. The laboratory test results are given in Table 2.

Table 2. Laboratory test results

Sample No	Sample Contents	Max. Mod. AASHTO Dry Density (kg/m^3)	Optimum Moisture Content (%)	Pore Space (%)		Coefficient of Permeability (cm/s)
				Capillary	Non-Capillary	
1	Topsoil	2002	11.5	6.2	25.6	2.473×10^{-5}
2	50% Topsoil 50% Spoils	2123	11.6	6.1	25.7	3.204×10^{-7}
3	40% Topsoil 40% Spoils 20% Ash	1859	12.4	8.6	25.2	4.56×10^{-7}

It is interesting that:

- Mixing topsoil and spoils gave a lower hydraulic conductivity (the saturated hydraulic conductivity).
- Adding ash increased the capillary moisture content without significantly affecting the saturated conductivity.

From a capping perspective, sample 3 appears to have advantages in terms of capillary moisture content (able to retain more moisture) with the ash likely to offset some of the acidity risk associated with the spoils. However, detailed geochemical analysis of the blends has not been undertaken to date to determine the long term pH.

While it is known that a capping layer does not have to be fully saturated before percolation through the cap occurs, it is of some value to consider the amount of moisture required to saturate capping layers formed using these materials, for the following scenarios (assuming the soils were at field capacity at the start of a rainfall event):

- For a 300mm capping layer constructed of topsoil, the capping layer could retain some 60mm of infiltration before becoming totally saturated.
- If blended with an equal volume of spoils to form a 600mm combined capping, the layer could potentially retain some 120mm of infiltration before becoming totally saturated.
- If the layer thickness is increased by the addition of a further 150mm of ash to form a 750mm thick layer, the layer could potentially retain some 125mm of infiltration before becoming totally saturated.

7. DISCUSSION

The laboratory test results indicate some interesting facts:

- For this particular site, blending the topsoil with spoils reduces the saturated permeability by two orders of magnitude. However, the variability of the spoils is always significant, and the impact on hydraulic conductivity is likely to be variable. Nevertheless, this is a desirable consequence in terms of capping design.

- In terms of field capacity, the mix of ash and spoils with topsoil has the highest capillary moisture content, which should give benefits in terms of a store and release capping system, particularly with the added thickness of the layer.

Given that the costs to excavate and haul material for rehabilitation can typically be R15 to R20/m^3 depending on haul distance, it can be appreciated that an extra 0,5m of soil stripped can add R100 000/ha to the rehabilitation cost. Conversely, spoils are already present, and blending of the soil with spoil material can be a very cost effective way to increase the net water retention capacity in the capping layer. However, possible limitations in terms of the depth that can practically be mixed with readily available equipment, and that some counter may then be required for the acidity within the spoils must be borne in mind. Ploughing equipment capable of mixing soils to a depth of 1m has been developed, although large dozers are required to operate it. Alternatively, the methodology of dozing spoils flat before bringing in soils could be reconsidered to allow spoils and soil to be windrowed alongside each other before dozing and blading of material to form a mixed layer. It is likely that the above strategy would be most applicable to sites where the available soil depth is limited, probably sites where soil thicknesses are less than 0,5m. Given the costs associated with water management, site specific modelling of capping systems to evaluate the associated benefits is probably warranted.

Further, Mentis (2006) has shown that soil capping systems placed without consideration of the need for additional organic carbon, appropriate additions of nutrients, proper pasture management and detailed planning are often not successful in the longer term. Thus the potential additional costs to properly manage a thicker spoils/soil capping layer, compared to a thinner cap of soil only may not be that significant.

Mines will need to reconsider some of the current practices in terms of capping if they wish to minimise the capital and operational costs of water management. In many instances, the long term sustainability of vegetal cover will require thicker capping layers than present, which will also favour reduced percolation through the capping systems.

The possibility of having to recondition capping systems by bringing in additional material cannot be excluded on some of the older mines with thin capping systems, particularly where the water management requires treatment.

8. CONCLUDING REMARKS

It has been shown that in the long term, conventional capping systems on opencast spoils often do not perform as expected, resulting in a greater water make than initially envisaged. Where the availability of soils for capping is limited (by either the quantity available or haul costs), blending of soils with spoils can have the benefit of allowing a thicker capping layer of reduced permeability at a lower cost. The further addition of ash, where practical, can further increase the capping layer thickness while improving the moisture holding capacity of the capping and possibly countering acidity in the spoils material.

While the above remarks are based on limited laboratory testing, such measures are certainly worth considering where conditions are potentially favourable. The decision to implement such measures should, however, be based on thorough, site-specific testing of materials and modelling of alternative capping systems. In addition, the long term ability of the system to sustain adequate vegetal cover, together with long term maintenance requirements need to be considered.

As a final note, it is interesting to consider that all of the above assumes that infiltration of water into the spoils is a negative consequence due to the associated environmental issues and the high current cost to treat water. That is certainly the case for the present and the foreseeable future. However, it is not unlikely that at some point in time the value of water will be such that water treatment becomes a viable industry, at which point infiltration through capping systems may be considered in a completely different light!

9. REFERENCES

J. Bear and A. Verruijt. 1992 Modelling groundwater flow and pollution. Theory and applications of transport in porous media. *Isreal Institute of Technology, Haifa, Isreal.*

N. Bezuidenhout, JA Wates, JJG Vermaak and D Kgwale. 2004 The evaluation of soil covers used in the rehabilitation of coal mines. *Water Research Commission, South Africa.*

M. O'Kane. 2003 Evaluation of the Long-Term Performance of Dry Cover Systems. *International Network for Acid Prevention*

M. Rykaart, D. Kockley, M. Noel and M. Paul. 2006. Findings of international review of soil covers design and construction practices for mine waste closure. *International Conference on Acid Rock Drainage (ICARD). St. Louis MO.*

M.T Mentis. 2006. Restoring native grassland on land disturbed by coal mining on the Eastern Highveld of South Africa. *South African Journal of Science (May/June).*