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UTILISATION OF MINE WASTES IN PLANT BASED ALTERNATIVE COVER TRIALS

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SUMMARY: Evapotranspiration (ET) landfill covers have been proposed as an alternative to traditional barrier covers, with aims to improve long-term environmental performance. Trial of these systems is underway in south-east Australia utilizing mine waste for the cover substrate and a selection of native vegetation. Preliminary planting trials have seen the successful establishment of vegetation on the material, while compaction trials have enabled in situ dry bulk density to be related to the method of placement. The designed ET cover profiles will be assessed with four full scale test sections, including two lysimeters for the direct collection of percolation and two sections open to the normal fluxes of landfill gas, heat and water vapour present in the landfill environment in order to observe their effects on the establishing vegetation cover.

1. INTRODUCTION TO ALTERNATIVE LANDFILL CAPPING

The primary objective of a landfill cover is to prevent the ingress of water into the waste layer, and as a result, minimise the production of leachate and landfill gas which threaten to contaminate the surrounding environment. Traditionally, these covers have been constructed of compacted clay and/or geomembrane and have relied on resistive principals to achieve hydraulic control. Several short comings of these traditional barrier landfill covers have resulted in a growing interest to evaluate innovative alternative landfill cover designs such as the evapotranspiration (ET) landfill cover (Madalinski *et al.,* 2003).

ET landfill covers consist of one or more layers of fine grained soil and a layer of deep rooted vegetation (US EPA, 2000). They utilise what has been described by engineers as the “sponge and pump” mechanism, whereby their function relies on the capacity of the soil to store water like a sponge, and the ability of plant species to act as biological pumps, removing the stored water via transpiration (Licht *et al.,* 2001; Rock 2003; Stack *et al.,* 1999).

ET covers as compared to traditional barrier covers are less vulnerable to desiccation and cracking both during and after construction (Zornberg *et al.,* 2003). They are also expected to be less costly to construct (Madalinski *et al.,* 2003; Albright *et al.,* 2003) with the capital cost per acre of an ET cover estimated to be approximately 50% less than a traditional barrier landfill cover (Stack *et al.,* 1999; Hauser *et al.,* 2001). This makes them a more accessible option for rural landfills and for uncontrolled facilities for which responsible parties no longer exist (Benson & Khire, 1995). Furthermore, whereas the performance of barrier covers are expected to decline over time, ET cover performance is expected to improve with age as the vegetation cover establishes and the soil develops (Licht *et al.,* 2001). As the aim is to establish a self-sustaining ecosystem, ET covers can also reduce maintenance requirements and have the potential to add ecological value, particularly if careful consideration is given to the selection of vegetation.

However, as ET covers rely on plant function, gradual and catastrophic changes to the cover ecosystem can negatively affect performance (Albright *et al.,* 2004). There are also concerns about the possibilities of phytotoxicity, food chain contamination and the added complexities associated with managing gas with a porous cover (US EPA, 2000).

1.1 ET landfill cover design

ET covers are best suited to climates where evaporation exceeds precipitation for most of the year, and must be carefully designed to be effective in temperate environments.

A readily available source of typically fine-grained soil is required for the cover substrate. The thickness of the soil is crucial and must be designed to achieve critical storage capacity during the dry season. This requires analysis of the local historical meteorological conditions and the inherent water storage capacity of the soil.

Careful consideration must also be given to the dry bulk density at which the material is placed, as this has a bearing on the soils water storage capacity and the performance of selected vegetation including: root growth, water and nutrient uptake, water-use efficiency and susceptibility to drought (Liang *et al.,* 1999).

The selected plants must be able to exploit water from the full depth of the cover profile and their transpirative capabilities must be such that, together with evaporation, sufficient stored water is removed from the cover to prevent percolation into the underlying waste. A diversity of plant species with a range of rooting depths and complimentary growing seasons would provide the most robust cover and ensure maximum water extraction throughout the year. As well as individual plant performance, designers must consider the ecological risk posed by the selected vegetation community and the controls on the stability of that community into the future. This is often difficult to assess, though native plant species have a higher chance of success in the long-term, having adapted to the local soil and climatic conditions.

ET cover design is non-prescriptive, its success relying heavily on specific site characteristics. Both site characterisation and modelling form an important part of the design process. Numerical models need to be calibrated with on-site performance data acquired from a trial or pilot cover profile, together with the quantification of its water balance. The element of most interest particularly for regulatory performance criteria is the percolation rate.

The Alternative Covers Assessment Program (ACAP) was a national trial (11 sites, 7 states) set up in the US to address the need for ET cover design procedures, computer models and guidance documents (Albright *et al*., 2004). The performance of alternative cover designs was monitored alongside conventional barrier cover designs, using large-scale lysimeters (Benson *et al.,* 1999). Prior to ACAP a limited number of systematic field studies had been conducted on the hydrological performance of landfill cover systems (Albright *et al*., 2004).

2. RESEARCH CONTEXT

ET cover technology developed overseas cannot be directly transferred to Australian conditions due to significant differences in climate, soil types, endemic plant species and environmental regulator performance criteria. This research aims to evaluate the feasibility of implementing ET cover technology in Victoria, Australia. While it is broadly modelled on the ACAP approach, the focus is on the use of native vegetation and rejected materials typical of the regional extractive industry. An additional aim of this research, which was not addressed by ACAP, is to investigate the effects of heat and landfill gas on ET cover function, particularly the cover ecosystem.

2.1 Study site

This research is being conducted at the Wollert landfill, 50km Northeast of Melbourne's CBD, Victoria, Australia. The Wollert landfill, like many landfills, utilises areas created by prior quarry excavation for waste disposal. The basalt quarry produces approximately 270,000 tonnes per year of a reject material called *scalps*, a mixture of fine crushed rock and predominantly clay subsoil. The scalps have little commercial value and are at present generally stockpiled or used for daily cover during waste disposal operation. The possible utilisation of the scalps material for an ET landfill cover substrate has the potential to see the transformation of a waste product into a valuable capping resource with both financial and environmental benefits.

3. COVER SUBSTRATE

3.1 Material selection

Scalps are produced in a variety of size classes according to screen sizes used for rock extraction including 100mm, 40mm, and 16mm. Isolation and testing of the scalps during production revealed that the 16mm size class of scalps has the lowest gravel content (50-60%) hence a higher potential storage capacity due to its higher proportion of fines. This material has been selected and stockpiled separately from the other size classes to be used for trial capping.

3.2 Physical properties

The relative proportions of exchangeable cations (Ca^{2+},Mg^{2+},K^{+},Na^{+}) in the scalps material are significantly imbalanced, including a high proportion of sodium and a very low calcium to magnesium ratio. Both these conditions have the potential to significantly influence soil-water relations (Dontsova & Norton, 2002), high sodium being responsible for dispersion, and the low calcium magnesium ratio leading to reduced hydraulic conductivity and increased runoff through surface skinning (Keren, 1991). While the scalps do have a tendency to surface skin and are highly susceptible to slaking, they are non-dispersive and relatively erosion resistant. The soil water storage capacity of the 16mm scalps material is approximately 160 mm/m.

A compaction trial was conducted in order to determine whether desirable low dry bulk densities, could be consistently and practically achieved using conventional machinery currently employed in the construction of clay covers. Three 200m^2 test sections were constructed with a 20 tonne D6 Caterpillar bulldozer using three different placement techniques. Generally the scalps were found to be compacted well without too much effort, as the range of moisture contents experienced in the field were close to optimum for compaction. The trial has enabled dry bulk density to be related to the method of placement (Table 1).

Table 1 – Average dry bulk density of scalps achieved with various methods of placement

Test Pad	Layer thickness	Initial treatment (bulldozer)	Secondary treatment	Average dry bulk density
1	300mm	Placed and levelled	Ripped with bulldozer forks	1.55 g/cm^3
2	300mm	Placed and levelled		1.70 g/cm^3
3	300mm	Placed and levelled	Compacted 1 pass with bulldozer	1.85 g/cm^3

3.3 Agronomic properties

The scalps were found to have undesirably high pH (8.5+), medium salinity, low total available water and as mentioned previously, an imbalance of exchangeable cations. Olsen phosphorus, total nitrogen and organic matter content were found to be very low. Both high pH and an imbalance of exchangeable cations were identified as the biggest limitations to plant growth due to the effects of these on the availability of trace elements (Leeper & Uren, 1993).

4. VEGETATION COMMUNITY

4.1 Indigenous vegetation community

The reinstatement of species from the indigenous ecological community may prove to be most suitable for purposes of an ET cover at Wollert landfill. The predominant tree species, *Eucalyptus camaldulensis*, has a high tolerance of water-logging, a state which can act as a potential indicator for tolerance of landfill gas in the soil profile (Marchiol *et al.,* 2000; Arthur *et al.,* 1981, Gilman *et al.,* 1985) and the grassy understorey consists of predominantly perennial tussock species giving the capacity to develop extensive rooting systems over many years and dry the soil profile to depth (Lolicato, 2000).

Dense plantations of tussock grasses are also effective water trappers, reducing runoff and allowing greater direct evaporation of water from foliage (Singh *et al.,* 2003). Furthermore, the indigenous grassland community is dominated by C4 summer active grasses which have a greater likelihood of reducing deep drainage in the Wollert climate than C3 winter active grasses (Johnston *et al.,* 1999) due to their ability to increase the soil-water deficit prior to the autumn rains. This is a critical time for the ET cover design as rainfall received in south-east Australia during autumn and winter usually exceeds potential evapotranspiration (ET) (Singh *et al.,* 2003).

4.2 Plant selection

Many native Australian plants are well adapted to low nutrient, degraded soils but do not compete well with exotics in nutrient enriched conditions (Prober *et al.,* 2002). For this reason, the scalps substrate was not amended; rather native plant species were carefully selected to suit the existing agronomic properties of the material. Both canopy and understorey perennial plant species with a long life span were selected for their tolerance of alkaline and low nutrient soil conditions and drought. Little information was available on rooting depths and transpiration rates and no information was available on the tolerance of native species to landfill gas.

Twelve plants, 6 species of tree and 6 grass species were selected for trial in the scalps material at the Wollert landfill (Table 2). Preference was given to species from the local/indigenous vegetation community, then to native species, with the selection of exotics viewed as a last resort.

Table 2 - Plant species selected for trial at Wollert landfill with their relevant vegetation community. Grass species are either C4 summer active or C3 winter active.

Selected grass species	Vegetation community	Selected tree species	Vegetation community
Themeda triandra (C4)	Indigenous	*Eucalyptus camaldulensis*	Indigenous
Austrodanthonia racemosa (C3)	Indigenous	*Allocasuarina verticillata*	Indigenous
Bothriochloa macra (C4)	Indigenous	*Acacia pycnantha*	Indigenous
Microlaena stipoides (C3)	Indigenous	*Malaleuca lanceolata*	Native
Poa labilladieri (C4)	Indigenous	*Eucalyptus polybractea*	Native
Danthonia linkii (C3)	Native	*Eucalyptus viridis*	Native

Melaleuca lanceolata was selected for its tolerance of harsh calcareous soils. *Acacia pycnantha,* the only legume was selected for purposes of adding to the nitrogen capital of the soil (Chan *et al.,* 1997). *Eucalyptus polybractea* and *Eucalyptus viridis* are capable of producing pharmaceutical grade eucalyptus oil through non-destructive harvesting, a potential windfall to offset landfill closure costs. *Eucalyptus camaldulensis* was selected due to its predominance in the original indigenous vegetation community.

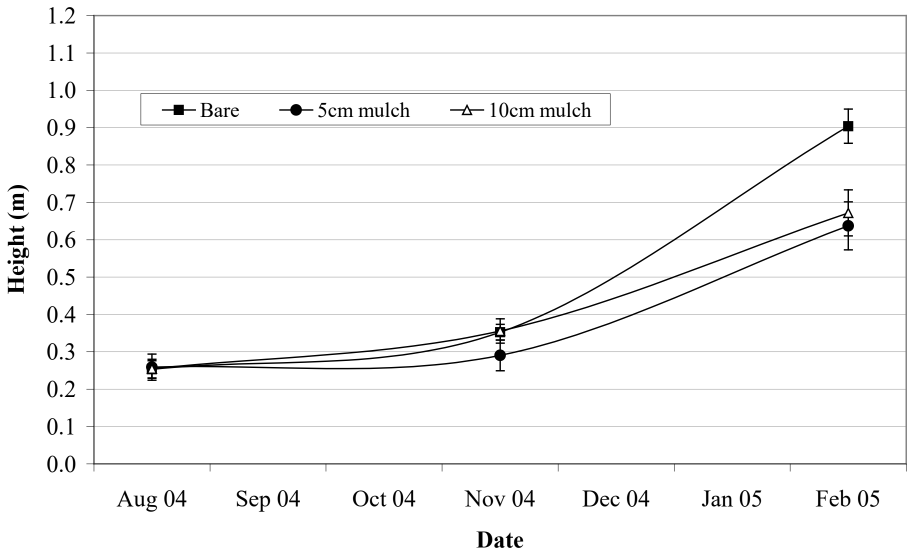
A mixture of cool season active (C3) and warm season active (C4) perennial grasses were selected in order to promote year round evapotranspiration.

4.3 Preliminary field trials

The twelve selected species were planted out in a 200m^2 test section of scalps at the Wollert landfill. Relative performance of species is being measured in terms of survival and growth with respect to three different mulching treatments. Growth of plant species is being measured in terms of height and N-S & W-E footprint width and is undertaken at 3 monthly intervals. Excavation and measurement of root biomass will be undertaken after 1 year. The following hypotheses are being investigated: A) Species A will have a significantly higher rate of survival than species B when grown in scalps at Wollert; B) There is a significant difference between the survival of species planted on bare scalps and the survival of species planted with mulch; and C) There is a significant difference in the survival of species planted with 5cm of mulch as opposed to species planted with 10cm of mulch.

Since the planting trial commenced in May-2004, there have been no mortalities. However, Figure 1 illustrates that tree species growing on bare scalps experience significantly greater growth than tree species growing on mulched scalps, both in terms of footprint area (the product of footprint widths) and height. However, little difference is observed between the two different depths of mulch. Due to the already low nitrogen status of the scalps, and the fact that nitrogen is a key growth limiting nutrient, the reduced growth of plant species is likely due to the denitrifying effect of the mulch competing for nitrogen.

a)



b)

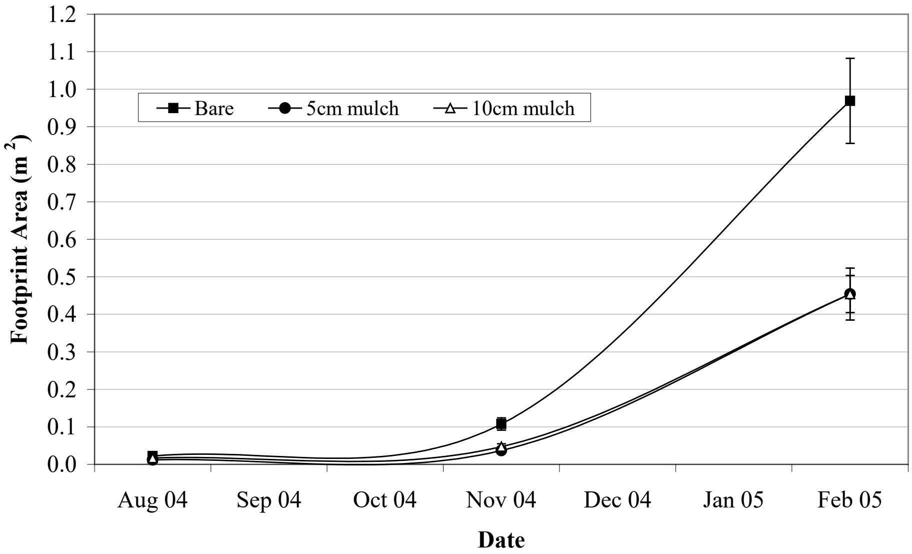


Figure 1 – Tree growth in response to depth of mulch (bare, 5cm and 10cm) averaged across all species. Tree growth is measured in terms of (a) height and (b) foot print area, the product of N-S and W-E footprint width measurements.

Due to the success so far of all selected species, it is suggested that the non-indigenous species be omitted from the final design. At this stage, the application of mulch is having a detrimental effect on tree growth and therefore is not recommended, particularly as it incurs significant expense.

5. TRIAL COVER IMPLEMENTATION AND MONITORING

Methods of assessing the percolation rate from alternative landfill covers have been reviewed by others (Ward & Gee 1997; Benson *et al.,* 2001; Abichou *et al*., 2004), which concluded that the direct measurement of percolation via lysimetry is the only method which can provide estimates of the percolation rate with meaningful precision for the evaluation of ET covers.

5.1 Lysimeter design considerations

Lysimeters must be sufficiently large to capture the large scale processes that affect ET cover performance. This generally precludes the use of weighing lysimeters due to the expense and limited capacity of scales. Volumetric or pan lysimeters are more appropriate whereby the volume of water percolating out the bottom of the soil profile is measured using a pan and the water storage is inferred from measured moisture content profiles.

The creation of a no-flow boundary due to the geomembrane at the base of the pan lysimeter is a disadvantage as it prevents the natural contribution of water vapour fluxes to the water balance. Fortunately, these effects have been quantified as conservative (Coons *et al.,* 2000 cited in Benson *et al.,* 2001). Another disadvantage is the creation of an artificial capillary break due to the differences in pore sizes between the drainage layer and the base of the cover profile. This increases the water storage of the cover beyond what would be naturally experienced in the field and is particularly a problem if plant roots are able to access and remove this water that would have otherwise become deep drainage (Albright *et al.*, 2004). The root barrier – a thin geosynthetic layer impregnated with herbicide has been included in the ACAP lysimeter to prevent root growth and transpiration from the drainage collection systems and to further ensure conservative estimates of percolation (Benson *et al.,* 2001).

Finally, lateral diversion is thought to be one of the primary sources of error in the estimation of the percolation rate (Abichou *et al.*, 2004). Chiu and Shakleford 2000 suggest that the width of the lysimeter must be at least 5 times as great as the depth of the lysimeter to prevent diversion having a significant effect on the rate of percolation. The ACAP lysimeters prevent lateral diversion through the inclusion of side walls. However, side walls further impede the natural fluxes of heat and water and may result in increased vertical flow of water at the interface between the soil and the walls. Abichou *et al.,* 2004 conducted an extensive series of numerical simulations using UNSAT-H to investigate the performance of lysimeters of various geometries. The study concluded that i) lysimeters used for the evaluation of landfill cover systems should have a width of at least 5 meters, ii) the performance of these lysimeters can be improved by including a sidewall of 0.3m high and iii) additional height on the side walls will not significantly improve the performance.

5.2 Test sections proposed at Wollert landfill

The lysimeters proposed to evaluate the performance of ET cover test profiles at the Wollert landfill are based on the ACAP lysimeter design. However, the Wollert lysimeters will not include side walls, aside from the 0.3m high diversion berms for percolation collection. Rather, the geosynthetic materials (the geomembrane base, geocomposite drainage layer and root barrier) will be extended 5m past the monitoring area on all sides to minimise boundary effects.

In total, four test sections have been proposed for incorporation into an existing clay/scalps cover at the Wollert landfill in mid-2005, of which two have lysimeters. The monitoring area of each test section is 100m^2 (10m x 10m) with the additional 5 m buffer zone bringing the total area to 400m^2.

The intended lysimeter pan is comprised of 1.5mm HDPE geomembrane overlain by a geocomposite drainage layer and will utilise the already existing clay layer as a subgrade for placement. This will largely prevent the fluxes of water vapour, landfill gas and heat. For this reason, two further test sections will be installed directly on top of the waste. These control sections will not include any percolation collection components, with the intention being to allow the effects of moisture, heat and gas fluxes on the cover, particularly the cover ecosystem to be monitored. As with the ACAP test facilities, the lysimeters at Wollert will enable the continuous measurement of the cover's water balance (Table 3) (Albright *et al.,* 2003).

Table 3 – Water balance components and measurement methods

Variable	Method of measurement
Percolation collection	Dosing siphon collection basin equipped with pressure tranducer, tipping bucket and float switch (Benson *et al.,* 2001)
Surface Runoff	Dosing siphon collection basin equipped with pressure transducer and float switch (Benson *et al.,* 2001)
Climatic data	On-site weather station
Soil Water Content	Time Domain Reflectometry (TDR) sensors
Soil temperature	Thermo-couple
Soil Matric Potential	Thermal heat sensor
Gas composition	Portable gas analyser Gas Data LMSxi

The test sections will be graded with the natural 8% slope of the landfill cell, percolation and runoff being collected from one corner of the monitoring area and routed to collection systems. Soil water content, matric potential and temperature will be measured in three vertical nests of sensors at three different depths, while evapotranspiration will be estimated as the difference between precipitation and the sum of runoff, percolation and soil storage.

The plant community will also be monitored periodically. Percentage cover, leaf area index (LAI) and height of the plants will be measured both initially and at 3 monthly intervals. Additionally, upper biomass and root distribution (biomass and length) of plants will be sampled every 6 months from the buffer area and weed colonisation will be monitored and periodically maintained.

The quantification of the water balance of the designed cover profiles will improve our understanding of the dominant controls on ET cover performance and allow the calibration of numerical models for the prediction of long-term hydrological performance. The control test sections will provide a unique opportunity to observe the effects of landfill gas on the establishing vegetation community that would otherwise be excluded through the use of lysimeters.

The intention is to monitor the ET cover test sections for a period of three years, as part of a long-term research program. Results and lessons learnt from this first set of trials will assist in improving the design and monitoring of future ET cover test sections.

6. CONCLUSIONS

The evapotranspiration landfill cover is an innovative alternative to traditional barrier landfill covers with the potential to provide improved long-term environmental performance and an accessible option for the capping of rural landfills. There is a pressing need to evaluate this technology within an Australian context. Research indicates that there is significant potential to utilise reject quarry mine waste (scalps) to sustain an indigenous vegetation community for the purposes of an ET cover system.

However, these systems are yet to undergo detailed hydrological evaluation. Test profiles incorporating lysimeters and a range of sensors are being constructed in mid 2005 with the intention to fully quantify the water balance, with a focus on percolation. The effects of landfill gas on the cover ecosystem and water balance is also being monitored.

Results from initial trials will be incorporated into future trials as part of a long term research program committed to finding a more sustainable long-term landfill cover alternative.

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