DOES EMERGING EVAPOTRANSPIRATION (ET) COVER TECHNOLOGY OFFER A SUITABLE ALTERNATIVE FOR LANDFILL COVERS IN THE HUNTER REGION?

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ABSTRACT

The NSW Environment Protection Authority (EPA) Environmental Guidelines: Solid Waste Landfills state that *"the site capping (of a landfill) should ensure that the final surface provides a barrier to the migration of water into the waste, controls emissions to water and atmosphere, promotes sound land management and conservation, and prevents hazards and protects amenity"*. The Environmental Guideline identifies benchmark techniques to achieve these goals. The EPA recommends that the final capping should have five parts including a seal bearing layer, a gas drainage layer, a sealing layer, an infiltration drainage layer and a revegetation layer. This traditional approach to capping of the landfill aims to seal the surface so that rainfall cannot infiltrate the waste and landfill gas cannot escape to the atmosphere. This is a highly engineered and costly means of achieving the desired environmental goals. Experience in the Hunter Region is that final covers created with a compacted clay sealing layer as recommended by the NSW EPA do not always achieve these required environmental goals. Problems relating to conventional covers include the availability of suitable materials, particularly for the low permeability sealing layer, the potential for cracking of the sealing layer particularly during extended dry conditions, the response to differential settlement within the waste and problems with revegetation. Thus opportunities exist to explore alternative options for the final cover of landfills.

One type of alternative cover that is of increasing popularity in the United States is the evapotranspiration (ET) cover. In the United States, ET covers are in place or on trial at a variety of different types of landfill including those used for hazardous and municipal waste. Evidence suggests that these can perform well in a variety of climatic conditions.

The principle behind ET covers is the effective management of water balance in the cover medium. Precipitation is balanced by evapotranspiration, water storage in the cover medium and influx to the underlying waste. In areas where the potential for evapotranspiration approaches or exceeds rainfall, the influx of water through the ET cover can be very low or neutral and can effectively control migration of water into the waste.

This paper considers the potential for the use of ET covers in the Hunter Region.

There are two key considerations:

- Climatic factors – is evaporation greater than rainfall? Are there any critical climatic factors such as prolonged periods of high rainfall and low evaporation? Sample water balances are presented to demonstrate the applicability of ET covers in the Hunter Region.
- Cover media factors – the water holding capacity of the cover medium, availability of materials and ability of the media to support vegetation. A variety of materials available in the Hunter, including naturally occurring soils and waste materials from power generation, coal mining and the waste management industries are assessed for their potential for use in ET covers.

1 BACKGROUND

The NSW EPA Environmental Guidelines: Solid Waste Landfills (EPA, 1996) recommend a performance based approach to achieving the best environmental outcomes for landfills across NSW. The document recognises that the emphasis is on achieving the most environmentally beneficial outcomes for the effective treatment and disposal of waste. The EPA acknowledges that there is no single winning solution for achieving all environmental goals and that many different landfill operation strategies are practised around the world. Whilst the Guideline sets out benchmark techniques which may be suitable for a landfill to achieve specified environmental goals, alternative approaches are possible.

The Environmental Guidelines state that "the site capping should ensure that the final surface provides a barrier to the migration of water into the waste, controls emissions to water and atmosphere, promotes sound land management and conservation, and prevents hazards and protects amenity". The benchmark technique then identifies, among other things, the required structure of the final capping. This is presented in Figure 1. This traditional approach to capping of the landfill aims to seal the surface so that rainfall cannot infiltrate into the waste and landfill gas cannot escape to the atmosphere. Such a highly engineered structure is particularly costly. The availability of materials, particularly for the low permeability sealing layer, the potential for cracking of the sealing layer in prolonged dry conditions and the response to differential settlement within the waste are problematic.

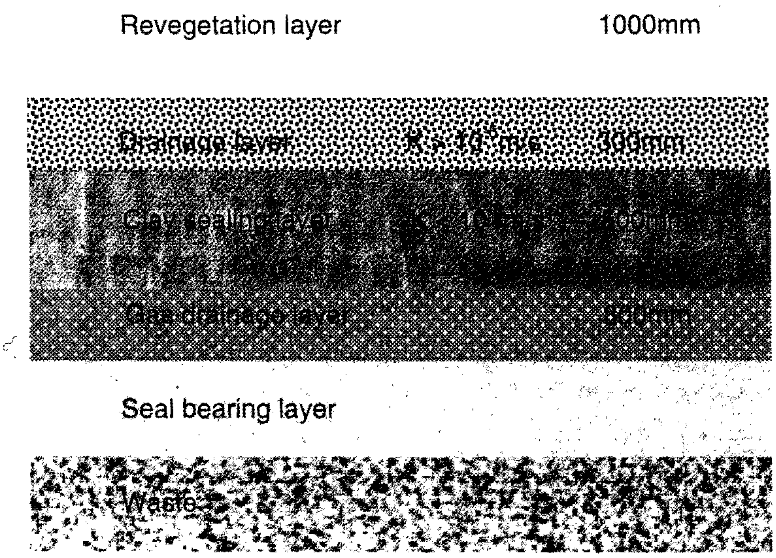

Figure 1: EPA benchmark technique for final capping of landfill (Source: EPA, 1996).

A number of alternative methods of final capping have been trialled or used overseas. One such alternative cover that performs well in the United States is the evapotranspiration (ET) cover. More than 25 sites across the United States have ET covers in place or on trial at a variety of different types of landfill including those for hazardous and municipal waste. Trials have also been carried out for earthen soil covers for rehabilitation of landfill sites in Brisbane (Jones et al., 2001).

The principle behind ET covers, the effective management of water balance in the cover medium, is shown in Figure 2.

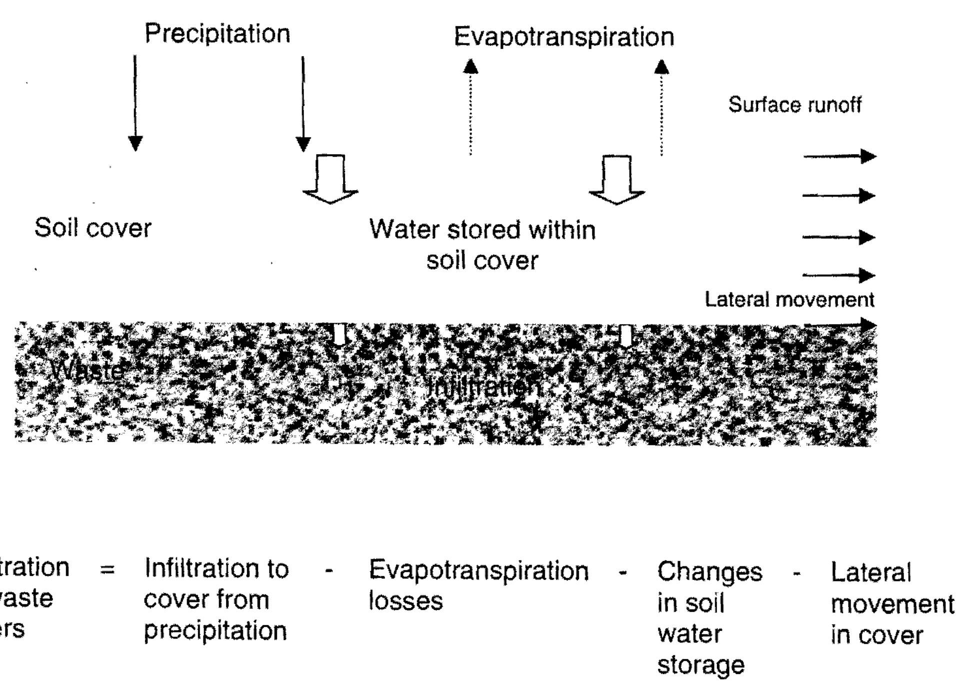

Figure 2: Water balance for ET covers.

Precipitation is balanced by evapotranspiration, water storage in the cover medium and influx to the underlying waste. A proportion of rainfall incident on the cover will run off and the remainder will soak into the cover. The capacity of the cover to hold water depends on the pore space, grain size and the cover material. Once the medium is saturated (or at field capacity) water will flow through the medium at a rate dependent on the hydraulic conductivity and gradient. Where evapotranspiration is greater than rainfall there is the potential to design a cover where the influx of water is very low and can effectively control migration of water into the waste.

The Interstate Technology Regulatory Council Alternative Landfill Technologies Team (2003) recommend considering natural analogues as a first step in a preliminary or conceptual design stage to determine whether an ET cover would function satisfactorily at a given location.

Two pieces of evidence suggest that ET covers may be effective in the Hunter Region:

- Bureau of Meteorology (www.bom.gov.au, 2005) climatic maps show a significant band of high average annual evaporation covering much of the Hunter Valley.
- Hitchcock and Ellis (1998) note that the majority of existing and all closed landfills in the Hunter Region do not meet the EPA benchmark technique for capping but that, where monitoring is in place, results indicate no significant environmental harm is occurring. They suggest this is due to good luck rather than good management, as the majority of landfills are sited in areas of naturally low permeability strata with a relatively deep water table. It could also be that evaporation is working to minimise rainfall infiltration.

2 CLIMATIC FACTORS

Climatic factors are a primary consideration. ET covers do not function in areas where rainfall significantly exceeds evaporation as the water balance, as shown in Figure 2 shifts towards groundwater infiltration. Assuming the climatic conditions are appropriate, cover media factors such as the ability of the soil to store the required volume of water and the availability of materials come into play.

Table 1 presents Bureau of Meteorology (BOM) annual evaporation and rainfall data for the seven stations in the Hunter and Manning Regions for which evaporation data is available (www.bom.gov.au, 2005). Evaporation reported by BOM is from a Class A pan which has an open water surface. Evapotranspiration is derived from evaporation and crop factor, which takes into consideration a complex range of soil and plant characteristics reflecting a vegetated soil surface.

Table 1: Annual evaporation and rainfall data for the Hunter Region.

BOM station	BOM station number	Annual evaporation (mm)	Annual rainfall (mm)		
			Mean	**Median**	**90th percentile**
Taree	060030	1413.1	1177	1120	1692
Yarras	060085	1019.2	1647	1647	2241
Williamtown	061078	1720.9	1121	1087	1521
Scone SCS	061089	1601.1	652	661	848
Cessnock	061242	1356.3	758	756	1011
Lostock Dam	061288	1612.7	960	1000	1243
Peats Ridge	061351	1200.3	1216	1214	1589

Table 1 indicates that:

- annual evaporation is significantly higher than 90th percentile rainfall at Williamtown, Cessnock, Lostock Dam and Scone. This suggests that the climatic conditions in many parts of the Hunter Valley are potentially suitable for the use of ET covers.
- ET covers may still be functional at Taree and Peats Ridge depending on the timing of rainfall and evaporation throughout the year and on the plant functions and cover capacity of the site.
- ET covers are unlikely to function satisfactorily in the Yarras (west of Port Macquarie) area given the high rainfall and low evaporation.

The distribution of rainfall and evaporation through the year is critical for the functioning of ET covers as it determines the volume of water to be stored in the cover medium. Table 2 presents monthly water balances for Williamtown and

Cessnock for median and 90th percentile rainfall data. Crop factor varies with plant species, plant maturity and time of year. A crop factor of 0.7, typical of a grassed surface, has been used in this example to calculate evapotranspiration from evaporation data. Runoff coefficient depends on the gradient, surface characteristics and state of vegetation. A conservative runoff coefficient of 0.25 (75% of incident rainfall retained) has been used. Retained rainfall and evapotranspiration data have been used to calculate stored rainfall.

Table 2: Water balance for Cessnock and Williamtown.

Cessnock BOM station number 061242													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Rainfall – median (mm)	74	62.6	73.6	39.9	45.1	33.7	25.8	28.2	31.1	41.5	65.2	64.8	756.2
Evaporation (mm)	178.4	141.4	121.8	86.9	59.7	46.9	55.7	80.7	108.2	137.1	155.3	183	1356.3
Stored rainfall (mm)	-69	-52	-30	-31	-8	-8	-20	-35	-52	-65	-60	-80	-382
Median cumulative stored rainfall (mm)	**-69**	**-121**	**-151**	**-182**	**-190**	**-198**	**-218**	**-253**	**-305**	**-370**	**-430**	**-509**	**-892**
Rainfall – 90th percentile (mm)	182.9	211.2	189.2	135	115	112.9	77.5	92	88.6	125.9	134.2	116.9	996.8
Evaporation (mm)	178.4	141.4	121.8	86.9	59.7	46.9	55.7	80.7	108.2	137.1	155.3	183	1356.3
Stored rainfall (mm)	12	59	57	40	44	52	19	13	-9	-2	-8	-40	-202
90th percentile cumulative stored rainfall (mm)	**12**	**72**	**128**	**169**	**213**	**265**	**284**	**297**	**287**	**286**	**278**	**237**	**36**

Williamtown BOM station number 061078													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
Rainfall – median (mm)	85.3	94.6	114.2	74.5	102.8	98.6	64.2	61.2	49.2	54.3	79.6	61.4	1087.9
Evaporation (mm)	212.7	173.8	149.8	114	81.2	74	80.3	108.3	140.2	172.3	190.1	226.5	1720.9
Stored rainfall (mm)	-85	-51	-19	-24	20	22	-8	-30	-61	-80	-73	-113	-389
Median cumulative stored rainfall (mm)	**-85**	**-136**	**-155**	**-179**	**-159**	**-136**	**-144**	**-174**	**-236**	**-315**	**-389**	**-501**	**-890**
Rainfall – 90th percentile (mm)	201.5	254.1	222.6	219.2	206.2	236.7	140.2	170.2	118.4	155.4	149.6	166.2	1499.4
Evaporation (mm)	212.7	173.8	149.8	114	81.2	74	80.3	108.3	140.2	172.3	190.1	226.5	1720.9
Stored rainfall (mm)	2	69	62	85	98	126	49	52	-9	-4	-21	-34	-80
90th percentile cumulative stored rainfall (mm)	**2**	**71**	**133**	**218**	**316**	**441**	**490**	**542**	**533**	**529**	**508**	**474**	**394**

Stored rainfall = (rainfall x (1- runoff coefficient)) – (evaporation x crop factor)

Readily available BOM data presents rainfall data as mean, median and 90th percentile. Patterson (2003) has assessed rainfall statistics for on-site wastewater management system designs which essentially rely on a similar balance between evaporation and rainfall to ensure appropriate loading rates and avoid exceeding transpiration bed storage capacity. He concludes that the monthly 90th percentile figures significantly overestimate (by up to 300%) rainfall on an annual basis.

The monthly median data underestimates annual rainfall by approximately 10%. Utilising the monthly 90th percentile rainfall data would therefore yield a very conservative ET cover design while using median figures would result in a design that would allow infiltration to the waste for a very small proportion of the time. For wastewater designs, Patterson considers that 70th percentile data reliably reflects field conditions. This 70th percentile data should similarly be satisfactory for water balance calculations for ET cover design.

3 COVER MEDIA STORAGE CAPACITY

The volume of water that can be stored in the cover depends on the water holding capacity of the medium. Water holding capacity is defined as the difference between the field capacity (at which point water starts to flow through the soil) and the wilting point (at which plants are no longer able to extract water and begin to wilt). Not all water in the soil is available to plants. Given that evapotranspiration is the primary mechanism for removing water from the soil, it is appropriate to consider only that water available to plants in the ET cover water balance, rather than the total moisture content of the cover medium.

Typical water holding capacities (the volume of water held between field capacity and wilting point) for natural soils in the Hunter Region range from 10 to 25% (Kovac and Lawrie, 1991; Matthei, 1995). Water holding capacity varies with soil texture and organic content. Various authors report water holding capacities as low as 8% for sandy soils, to 35% for residues from anaerobic digestion of municipal waste (www.agen.ufl.edu) and higher for composts and peat.

Table 2 presents monthly cumulative stored rainfall data. At both stations the water storage required, based on the 90th percentile data, peaks in August, at approximately 300mm at Cessnock and 540mm at Williamtown. The median monthly rainfall data results in a net deficit at both Cessnock and Williamtown. Given a typical water holding capacity of 15%, 2.0 metres of soil would provide sufficient capacity for the accumulated rainfall at Cessnock. 3.6 metres of soil would be required to perform similarly at Williamtown.

The practical maximum thickness for an ET cover depends on availability and cost of materials and the rooting depth of vegetation. Experience in the United States (Interstate Technology Regulatory Council Alternative Landfill Technologies Team, 2004) is that the upper practical thickness for ET covers is a soil depth of 2.0 to 2.5 metres, as material availability and cost tip the balance in favour of more conventional covers. Given the NSWEPA benchmark cover design requirement of a minimum of 2.1 metres of highly engineered cover comprising a number of potentially more difficult to obtain or more costly materials, even thicker single medium ET covers become economically attractive in NSW, provided suitable materials are readily available.

Jones et al. (2001) used lysimeters to monitor percolation through 600 mm thick monolayers of four different types of alluvial and residual sand and clay deposits and used the results to calibrate a computer model. The computer model was then used to predict average annual percolation for a five year simulation, for model thicknesses of 500 mm and 1000 mm, with an overlying topsoil depth of 100 mm. The model indicated that a 500 mm cover performed satisfactorily when a permeability of less than 1 x 10^{-8} m/s was achieved either due to compaction or inherent clay content. They found that a thicker cover did not result in a significant reduction in percolation, as storage capacity of the soil is reached and saturation occurs, and that vegetation characteristics and thus effective evapotranspiration were inadequate to prevent percolation to greater depth.

Jones et al. used only poor vegetation cover and a topsoil depth of 100 mm in the model. Plant growth is inhibited by compacted soils. Smith and May (2001) explain that the roots of plants growing on landfill would not grow into a clay sealing layer, since the dry bulk density and soil strength of the clay are above the critical limits for root growth. The cover modelled by Jones et al. had similar characteristics to the sealing layer proposed in the EPA benchmark guidelines (Figure 1) rather than an ET cover. In a system driven by evapotranspiration a loose soil structure is required to encourage deep rooting of vegetation so that the effective depth of soil available for water storage is maximised. Traditionally landfills have been revegetated with shallow rooting species in order not to compromise the clay capping. ET covers function best with deep rooting species including trees and shrubs driving evapotranspiration from deep in the soil. The use of ET covers therefore provides scope for creative revegetation plans that improve the biodiversity or range of habitat. Should the vegetation penetrate the waste, potential impacts on the vegetation species should be considered but assimilation of contaminants in the waste by phytoremediation is a potential additional benefit.

4 COVER MEDIA FACTORS

Haulage costs are a major factor in bulk materials usage, so sourcing cover materials on site is an attractive option. Table 3 provides information on the water holding capacity and other characteristics of natural soils in the vicinity of the major landfill sites in the Lower Hunter. The soils generally have a reasonable water holding capacity but typically display other characteristics which may limit their suitability for use in ET covers, such as high acidity and low fertility.

Another limiting factor is the availability of natural soils; where natural soils are thin there would be insufficient material to construct a thick ET cover over the same surface area.

Table 3: Water holding capacity of natural soils in the vicinity of existing landfills in the Hunter Valley.

Location	Soil landscape	Water holding capacity	Limitations
Summerhill, Newcastle	Beresfield	14 - 16%	Highly acidic, low fertility, water erosion hazard
	Killingworth	23 - 29%	Sodic/dispersible, low wet strength, very strongly acidic with low fertility
	Cedar Hills	23 - 24%	Acid soils
Dyrring Road, Singleton	Sedgefield	Low to moderate (up to 15%) slowly permeable	Land capability V or IV, low fertility
Mount Vincent, Maitland	Beresfield	14 - 16%	Highly acidic, low fertility, water erosion hazard
	Shamrock Hill	14 - 24%	Water erosion hazard, strongly acidic, low fertility
Awaba, Lake Macquarie	Awaba	9 - 19%	Strongly acidic, low fertility
	Doyalson	6 - 10%, 20% at depth	Hard setting, strongly acidic
Old Maitland Road, Cessnock	Aberdare	Moderate (up to 15%) slowly permeable	Land capability V or IV, low fertility
	Branxton	Moderate (up to 15%) slowly permeable	Land capability V or IV, low fertility
Newline Road, Raymond Terrace	Ten Mile Road	14 - 23%	Water erosion hazard, strong to extremely acidic, low fertility

(Matthei, 1995; Kovaks and Lawrie, 1991)

The coal mining and power generation industries provide obvious sources of large volumes of alternative media which might be considered for ET cover usage. Table 4 describes materials available in the Hunter Region.

Table 4: Possible alternative cover materials available in the Hunter Region

Material	Characteristics	Suitability as ET cover medium
Coal washery reject Coarse reject	Gravel with grain size greater than 0.5mm, size distribution depends on processing and mining method. Permeability in range 2 x 10^{-4} to 2 x 10^{-7}m/s Chemical characteristics vary depending on the source coal seam. Some have the potential for acid leachate or high salinity. Material from the Newcastle Coal Measures is not considered likely to produce acid leachate*.	Finer fraction may be suitable. Coarse material is probably too permeable to limit infiltration. No information on water holding capacity available. Low fertility medium would require additional organic matter to promote plant growth.
Power station bottom ash	Bottom ash is essentially inert material available in a range of size fractions. Permeability is in the range 10^{-2} to 10^{-5} m/s depending on the grain size#. Is water retentive.	Lower permeability material may be suitable, although the finest ash tends to liquefy when wet. Coarse material is probably too permeable to limit infiltration. No information on water holding capacity. Low fertility medium so would require additional organic matter to promote plant growth. Low density may assist with greater rooting depths.
Composted green waste and municipal waste	High water holding capacity of 35% or more. Variable composition depending on source material.	Useful in conjunction with inorganic media for high water holding capacity and high nutrient content.

(* Carr, 1998; # Gleeson, 1999)

Two materials, coal washery reject and power station bottom ash, may be suitable for ET cover use provided suitable water holding capacity and permeability can be achieved. Both materials could be amended by the addition of nutrient rich organic matter to promote healthy vegetation growth. Biosolids from sewage treatment works or composted municipal or green waste are two bulk organic materials that may be suitable. Furthermore, the addition of organic matter would greatly improve the water holding capacity of the blended cover medium.

5 CONCLUSIONS

The climatic characteristics of much of the Hunter Region are within the range required for satisfactory functioning of ET covers. Both natural soils in the vicinity of existing landfills in the Hunter Region and alternative materials available from various high volume sources display a number of the material characteristics necessary for ET cover media. Composted wastes and sewage sludge are readily available as nutrient amendments to promote vegetation growth, with the added benefit of increasing the water holding capacity of the cover. There is significant potential for evapotranspiration covers to be used on landfills in the Hunter Region.

Further work is necessary to determine the most appropriate climate data to develop water balances with a required factor of safety. Access to appropriate synthetic data sets will be required to enable modeling of ET cover performance at specific sites some distance from existing BOM stations. It will also be important to establish accurate and detailed material characteristics for both natural soils and alternative media. Field scale trials of various ET cover options are necessary to establish their longer term performance and to demonstrate equivalence with covers designed to current EPA benchmark criteria.

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