PHYTOCAPPING AS A SUSTAINABLE COVER FOR WASTE CONTAINMENT SYSTEMS: EXPERIENCE OF THE A-ACAP STUDY

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SUMMARY: Phytocaps offer a natural soil-plant alternative to the conventional engineered “barrier” landfill covers. They are often appropriately called evapotranspiration or store-and-release covers. They require less engineering input and are less costly to construct as they commonly utilise locally available recourses (soil and plant). By planting native species, they also enhance the ecological value of closed landfill sites and allow a more sustainable approach compared with conventional covers. This paper introduces the phytocapping concept, provides a brief description of a 5 year national research program conducted in Australia, presents a summary of the study findings, and discusses the performance of phytocaps in comparison with conventional compacted clay covers under a wide range of Australian bioclimatic conditions.

1. PHYTOCAPS COMPARED WITH CONVENTIONAL LANDFILL COVERS

One of the main criteria of interest to environmental regulators in measuring the performance of a landfill cover is the quantity of water draining through the cover into the buried waste. Conventionally, the materials considered to be most suitable for the construction of landfill covers have been impermeable barriers commonly constructed of compacted clay layers. However, there is a growing body of evidence to suggest that the barrier function of a compacted clay cover can deteriorate with time (e.g. Albrecht & Benson, 2001; Dwyer, 2001; Albright et al., 2006)) as the clay is subjected to cracking under cycles of repeated drying and wetting. Plant root penetrations can also have impact on the integrity of clay barriers.

Phytocapping presents a natural soil-plant alternative to the conventional compacted clay barrier cover design. Instead of providing a “rain-coat” barrier, it relies on the capacity of a porous substrate (usually of locally available soil) to store water together with the natural processes of surface evaporation and plant transpiration to remove the stored water as a means of

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controlling water ingress into a landfill. They are thus often appropriately called evapotranspiration (ET) covers, soil-plant covers, store-and-release covers or monolithic covers, as they rely on the capacity of the layer of soil to “absorb” water and the plant community acting as biological “pumps” to remove the stored water. The term phytocap is in predominant use in Australia due to its inclusion of phyto (the Latin prefix for plant) which emphasizes the importance of the plant-based element of the system.

In contrast to compacted clay barriers, the performance of phytocaps is expected to improve over time as the vegetation community matures. This advantage together with the potential for phytocaps to enhance the ecological value of a site gives phytocaps the potential for greater long term performance and sustainability.

As conventional barrier covers commonly include drainage layers aiming to reduce the hydraulic head acting on barriers to minimise percolation, their design is therefore inherently more complex and costly. The construction cost of phytocaps has been reported to be lower, typically at only 35 to 72% of conventional covers (Hauser 2009).

Using phytocaps to oxidise methane and reduce greenhouse emissions offers another major advantage over conventional impermeable caps. It has been demonstrated that porous biotic cover systems can mitigate landfill gas emissions by creating favourable aerobic environments to promote microbial methane oxidation in soil covers (Huber-Humer et al., 2008). The methane oxidation potential of phytocaps can be considered as a type of biotic cover where microbial activity is enhanced by plant roots. Recent laboratory-scale and field experiments have demonstrated that plant cover could significantly improve soil methane oxidation potential (e.g. Reichenauer et al., 2011; Bohn et al., 2011; Venkatraman and Ashwath 2009).

Phytocap functionality relies on the inherent properties and interaction between the local climate, the substrate (soil) and the established plant community. Due to the reliance on local site characteristics, the design of phytocaps is necessarily specific to each landfill. When designing a phytocap, it is important to transfer the phytocap design methodology rather than a site-specific design. The ideal phytocap substrate is one of high water storage capacity with properties that promote sustained growth of the phytocap plant community. However, as the choice of substrate available locally is often limited, the thickness of soil can be manipulated to provide the required critical storage capacity during seasons when transpiration rates are low. Phytocap design considerations have been covered in details by Hauser (2009) and Albright et al. (2010).

The selection of plant species relies on the species’ compatibility with the available soil substrate, local climate and their long-term substainability on the site. Site assessment would involve defining broad climatic characteristics from historical data, characterising the soils used and asscessing suitable native plant communities. Another core phytocap plant selection criterion is the inclusion of biodiversity to ensure the resilience of the plant community.

2. AUSTRALIAN ALTERNATIVE COVERS ASSESSMENT PROGRAM (A-ACAP)

A-ACAP is an on-going field and laboratory research program (2006 to 2011) that has been established to investigate phytocap alternatives to conventional landfill covers in the Australian context. The major goals are to demonstrate that phytocovers can perform to the satisfaction of regulators and to develop guidelines for their application, design and construction. The guidelines aim to address: (i) control of percolation of water into the waste; (ii) reduction of greenhouse gas emissions by methane oxidation; and (iii) sustainability of vegetative covers comprising a diverse range of native plant species.

The program has established five full-scale test facilities across Australia to investigate the effects of a wide range of bioclimatic conditions.

Figure 1. Location of each A-ACAP trial site showed on an average annual rainfall map.

Table 1. A-ACAP Trial Phytocap and Conventional Cap Design Summary

Site	*Climate (Koppen Classification)*	*Phytocap*	*Conventional Cap*
Taylors Rd Landfill Lyndhurst, VIC	Maritime Temperate – no dry season (warm summer)	1.7 m compost/clay sand Native trees, shrubs, grasses	0.5 m soil + 0.5 m compacted clay Grasses and legumes
Southern Waste Depot McLaren Vale, SA	Mediterranean	0.3 m sandy loam + 1.2 m clayey sand Native grasses	0.1 m sandy loam + 0.8 m clayey sand + 0.6 m compacted clay Native grasses
Stuart Landfill Townsville, QLD	Tropical forest - monsoonal	1.5 m loam Native trees, shrubs, grasses	0.3 m loam + 0.5 m compacted clay Grasses
Henderson Waste Recovery Park Henderson, WA	Mediterranean	1.6 m clayey sand Native trees, shrubs, grasses	Not constructed
Lismore Waste Facility Lismore, NSW	Subtropical – no dry season	1.3 m clay Native trees, shrubs, grasses	Not constructed

From tropical in the country's north to arid in the interior to temperate in the south, these test facilities are located across all five mainland states of the country (Victoria, South Australia, Queensland, Western Australia and New South Wales) representing an excellent bioclimatic diversity. Figure 1 shows the location of the five sites. Table 1 provides a brief description of the phytocap design as well as the benchmark conventional cover design for each site. The full-scale test facilities were established between 2007 and 2008.

Central to the project's experimental approach is the use of side-by-side comparisons of both conventional covers and candidate phytocaps (in Victoria, South Australia and Queensland). Large scale (10m x 20m) lysimeters together with other instrumentation are used to assess their hydrological performance. As an important improvement to similar studies conducted in the past, all test facilities are placed directly on top of active landfills. This arrangement is to allow realistic landfill interactions such as the effects of temperature and gas fluxes on cap performance. The inclusion of additional unlined test sections (i.e. without lysimeters) also allows the field experiment to investigate the methane oxidation potential of phytocaps in reducing landfill greenhouse emissions. The field program is supplemented by laboratory and glasshouse experiments to investigate native plant performance as well as landfill gas transport related to methane oxidation (Sun et al. 2011). A detailed description of the test cells, lysimeters and field instrumentation was provided by Wong et al. (2007).

3. SUMMARY OF STUDY FINDINGS

3.1 Hydrological Performance – phytocaps vs. conventional covers

The hydrological performance of the landfill covers has been measured for 3-4 years at all sites. Drainage was recorded at all sites over the monitoring period, as shown in Table 2, though in the case of the Southern Waste Depot trial site, irrigation was also applied to stress the cover systems. For most sites, the drainage from the phytocaps and conventional covers was < 3 % of precipitation received, including the Stuart Landfill which has a monsoonal tropical climate. The highest drainage was recorded at the Henderson Waste Recovery Park, with over 300 mm measured, or 16% of rainfall received in the 3 year monitoring period. The monitoring periods commenced either before or shortly after vegetation were planted and as a result include periods with little or no vegetation on the plots. Focussing on the final year of monitoring, being 2010, showed that the drainage for all sites was ≤ 3% of precipitation received (Table 3). The precipitation received at most sites in 2010 was above the long term average but drainage was still low for the sites, including Stuart Landfill which received 3 times the average rainfall.

Table 2. Summary of Total Precipitation and Drainage Measured over the Monitoring Period

Site	*Monitoring Period*	*Precipitation (P)*	*Phytocap Drainage*		*Conventional Cover*			
					Lateral Flow[2]		*Drainage*	
	mm/dd/yr[1]	*mm*	*mm*	*% P*	*mm*	*%P*	*mm*	*%P*
Taylors Road Landfill	02/16/07 - 12/31/10	3347.2	59.9	1.8%	44.5	1.3%	21.6	0.6%
Southern Waste Depot	7/02/07 - 12/31/10	1875.0	30.6	1.6%	7.6	0.4%	1.5	0.1%
Stuart Landfill	01/01/08 - 12/31/10	6638.9	141.1	2.1%	67.1	1.0%	152.9	2.3%
Lismore Waste Facility	01/01/08 - 12/31/10	5132.7	140.9	2.7%	--		--	
Henderson Waste Recovery Park	01/01/08 - 12/31/10	2170.6	342.2	15.8%	--		--	

[1]Monitoring commenced prior to 01/01/08 at Stuart, Lismore and Henderson but records incomplete. [2]Horizontal flow collected from the top soil and compacted clay interface

Table 3. Long-term Average Annual Precipitation and Total Precipitation and Drainage Measured During the Final Year of Measurement (2010)

Site	*Average Precipitation*	*Precipitation (P)*	*Phytocap Drainage*		*Conventional Cover Lateral Flow*		*Conventional Cover Drainage*	
	mm/yr	*mm*	*mm*	*% P*	*mm*	*%P*	*mm*	*%P*
Taylors Road Landfill	810	1185	8.9	0.8%	43.2	3.6%	1.6	0.1%
Southern Waste Depot	520	623.6	10.7	1.7%	1	0.2%	0	0.0%
Stuart Landfill	990	2829.6	70.1	2.5%	19.7	0.7%	107.5	3.8%
Lismore Waste Facility	1340	1271.3	7.3	0.6%	--		--	
Henderson Waste Recovery Park	790	475.2	15.3	3.2%	--		--	

The conventional drainage was less than the phytocap drainage for the southern trial sites (Taylors Road and Southern Waste Depot) but was more than the phytocap at the northern site (Stuart Landfill).

For the Henderson Waste Recovery Park, the drainage appears to have decreased significantly, however the rainfall received at this site in 2010 was one of lowest on record.

The hydraulic performance of the phytocaps at the five trial sites showed that drainage tends to decrease over time, while drainage from the conventional covers tends to increase. The former appears to be related to the vegetation growths in the covers while the latter occurs after one dry season due to drying of the compacted clay.

The establishment of grasses in the phytocap appeared to result in decreased drainage occurring sooner, as occurred at the Taylors Road Landfill and Southern Waste Depot but not at the Henderson Waste Recovery Park. However, the trees and shrubs planted at the Taylors Road Landfill and Henderson Waste Recovery Park have resulted in continued and more sustainable decreases in drainage than the Southern Waste Depot where only native grasses were planted.

It is apparent from these results, collected in the Australian context, that the performance of a phytocap and conventional cap is related to the seasonality of precipitation more than the ratio between precipitation and evapotranspiration that has been suggested in some previous studies. For example, although significantly less rainfall was received at the southern trial sites (Taylors Road Landfill, Southern Waste Depot and Henderson Waste Recovery Park) compared to the northern sites (Lismore Waste Facility and Stuart Landfill), drainage represented a similar proportion of precipitation. This appears to be related to precipitation predominantly coinciding with cooler temperatures at the southern sites while precipitation coincides with higher temperatures, and hence higher evapotranspiration, in the northern sites. In addition, the impact on drainage through cracking of clay in the conventional covers is more pronounced with intense storm events, such as that occurs in tropical and sub-tropical environments.

3.2 Plant study

The performance of a wide range of native plant species selected for the five phytocap trials sites has been monitored and measured throughout the duration of the study. This provided valuable information on the practices of growing native species on phytocapping systems including planting and establishment techniques, weed control and monitoring. The established plant communities have been subjected to exceptional dry climate as well as very wet conditions. In addition, the phytocap trial site at Stuart Landfill was tested by the full force of a category five cylone in February 2011, which caused only minimal damage due to the presence of a diverse range of plant species.

Mortality and growth, in terms of change in height and leaf cover, have been used as primary indicators of each spieces' performance and its tolerance to the landfill conditions that they have been exposed to. In addition, root depths and soil nutrients have also been monitored. Using the results of these studies, the A-ACAP program has been able to ascertain which of the species selected in the trials would have the best potential to perform well in future full-scale phytocap planting under a wide range of bioclimatic conditions.

Vegetation mortality was relatively high during initial plant establishment followed by a decline in mortality by the third year - across all sites. Concurrently, vegetation growth was slow initially, increasing once the plants had established. As an illustration, Figure 2 shows the growth of a selection of tree species from one of the trial sites (Lismore Waste Facility), indicating a relatively slow growth in the first 12 months following planting.

Toward the end of 2010, the vegetation covers have increased to close to 100 percent on all sites, with the exception of Henderson Waste Recovery Park where vegetation establishment has been slower, as a result of the less favourable environmental conditions. Furthermore, the grass cover at the Southern Waste Depot trial site (refer Table 1) was able to fully recover following a die-back period in late 2009 which was a very dry year in South Australia. Within each trial site there were species clearly identified as being tollerant to the landfill conditions. Benaud (2010) provides details for mortality and growth for each of the species across all sites (except Stuart Landfill).

In addition, sub-soil studies carried out at Lismore Waste Facility, Taylors Road Landfill and Henderson Waste Recovery Park in November 2010 have revealed that plant roots had reached over 100cm into the soil profile. Root density was found to be greater in the top half of the soil profile when compared to the lower half. During the relatively short period of plant growth, there have been few overall changes in the soil chemistry within the phytocaps.

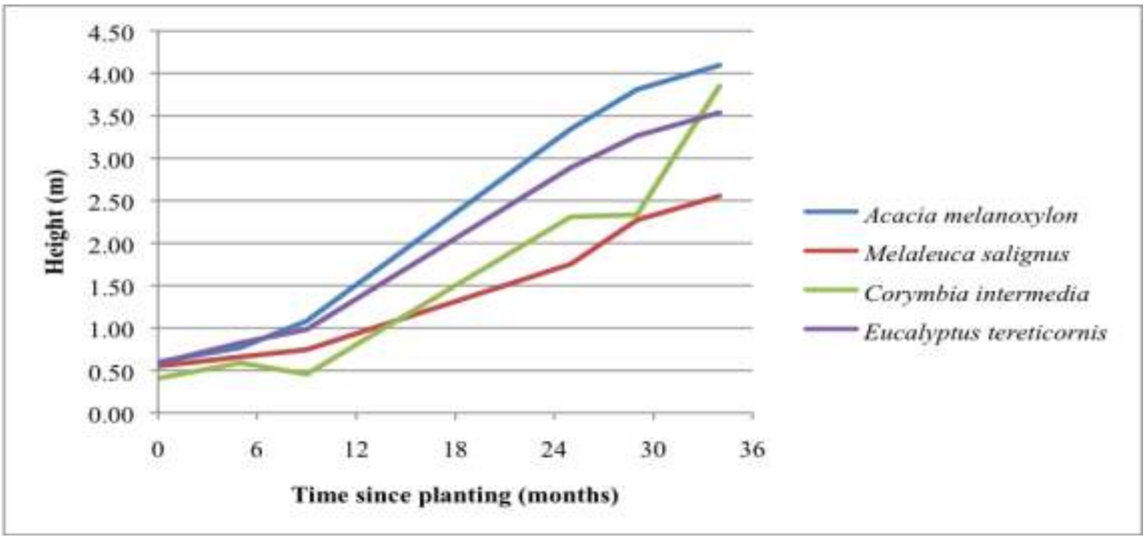

Figure 2. Mean height of selected species, at Lismore Waste Facility, since planting in April 2008

There has been no evidence to suggest that the soil conditions within any of the phytocaps are limiting vegetation growth. It is recommended however that the vegetation be monitored for a greater period of time to ascertain the long-term sustainability of the plant community.

3.3 Methane oxidation to reduce greenhouse emissions

Static flux chambers are employed to monitor methane emissions from phytocaps and conventional covers in the field trials. Soil gas probes are used to investigate soil gas profiles in both covers. A stable carbon isotopic technique is also employed to quantify oxidation in chambers and probes. A glasshouse experiment is being conducted under controlled conditions to support the field investigation. The gas study is still ongoing and Sun et al. (2011) provided a summary of the latest findings. The preliminary results indicate that vegetation can alter the soil physical properties to enhance oxygen availability which will likely increase the methane oxidation capacity of the phytocaps. Also given soil moisture is an important factor for methane oxidation, the rates of methane oxidation and emission would be highly temporal and seasonal in a phytocap when considering the changing soil moisture due to transpiration in addition to surface evaporation.

4. DISCUSSION AND CONCLUSIONS

The results obtained from this A-ACAP study strongly suggest that phytocaps can provide a cost-effective and sustainable alternative when compared with the conventional clay barrier option. The obvious advantages are their lower cost, utilizing available recourses (i.e. use of local soils and native plants), high ecological site improvement and greenhouse emission reduction potential.

As the phytocap functionality relies on the inherent properties and interactions between the local climate, substrate and selected plant community, the design of phytocaps is necessarily specific to each landfill. As a result of this Australian study, the Waste Management Association of Australia is currently drafting a document tilted “Guidelines for the Assessment, Design, Construction and Maintenance of Phytocaps as Final Covers for Landfill” to be released officially in late 2011.

Also as phytocaps require less technical skills and engineering infrastructure to construct and maintain, this type of covers could have the potential to make a significant improvement in the way that developing countries are capping waste disposal sites addressing their technical and financial constraints.

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