PHYTOCAPPING AS A COST-EFFECTIVE AND SUSTAINABLE COVER OPTION FOR WASTE DISPOSAL SITES IN DEVELOPING COUNTRIES

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Abstract

Few waste disposal sites in developing countries are designed and operated as engineered sanitary landfills due to common technical and financial constraints. Phytocapping presents a natural soil-plant alternative to the conventional engineered landfill cover design. It requires less engineering input and has a lower cost than conventional impermeable covers as it only utilizes local recourses. It also offers the advantage of oxidating methane to reduce landfill greenhouse emissions. This type of covers has the potential to make a significant difference in the way that developing countries are capping their waste sites. This paper introduces the phytocap concept as well as discusses its relevance and advantages for developing countries.

Keywords – *evapotranspiration cover; A-ACAP; landfill; methane oxidation; greenhouse emission*

1. Solid waste management in developing countries

In many developing countries, much of the basic infrastructure for water supply, wastewater treatment, and solid waste management is limited (Johannessen and Boyer 1999). The cities in developing countries generate nearly 40% of the world's solid waste, which is approximately 500 million tons (Hoornweg and Thomas 1999). Rapid population growth and uncontrolled industrial development in the cities have severely affected urban environments, and inadequate management and improper disposal of solid waste is an obvious cause for the degradation of the environment in those countries (Schertenleib and Meyer 1992). It is not unusual to see developing countries spending 20-50% of their municipal operating budget on waste management, but still without satisfactory results (Hogland and Marques 2000). The most common waste management method is land disposal, mainly open dumping. Other waste management methods such as composting, incineration, recycling, anaerobic digestion, conversion to resource-derived fuel, are only sparingly used (von Einsiedel 2001).

Technical and financial constraints are two significant obstacles that have hindered waste management improvements in developing countries (Schertenleib and Meyer 1992; Ogawa 1996). In most developing countries, there is a serious lack of technical expertise as well as engineering infrastructure preventing the transition of open dumps to sanitary landfills. It is not uncommon to see inappropriate technologies that are not considered affordable and sustainable but directly funded and imported from high-income countries. Also given the low priority allocated to waste management, very limited funds are provided to the solid waste management sector by the governments. The funds are often not sufficient to achieve the level of protection required for public health and the environment.

2. Phytocaps compared to conventional landfill covers

One of the essential components of a well-engineered landfill is its final cap installed over the landfill after closure. The purpose is to control percolation of water into the waste, promote surface runoff,

minimise erosion, control odour and prevent the occurrence of disease vectors. The cap is also important for landfill gas containment and capture.

The criteria of most interest to environmental regulators for measuring the performance of a landfill cap is the quantity of water draining through the cap into the buried waste. Conventionally, the materials considered to be most suitable for the construction of landfill caps have been impermeable barriers commonly constructed of compacted clay layers. However, there is a growing body of evidence to suggest that compacted clay barrier caps deteriorate within a short time frame (e.g. Albrecht & Benson, 2001; Dwyer, 2001; Albright et al., 2006)). For example, Albright et al. (2006) measured the performance of compacted clay barrier covers for a number of sites and concluded that large increases in the hydraulic conductivity of clay barriers with time are not uncommon, as compacted clay layers are subjected to cracking under cycles of repeated drying and wetting. Plant root activities 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 controlling water ingress into a landfill, as shown in Figure 1.

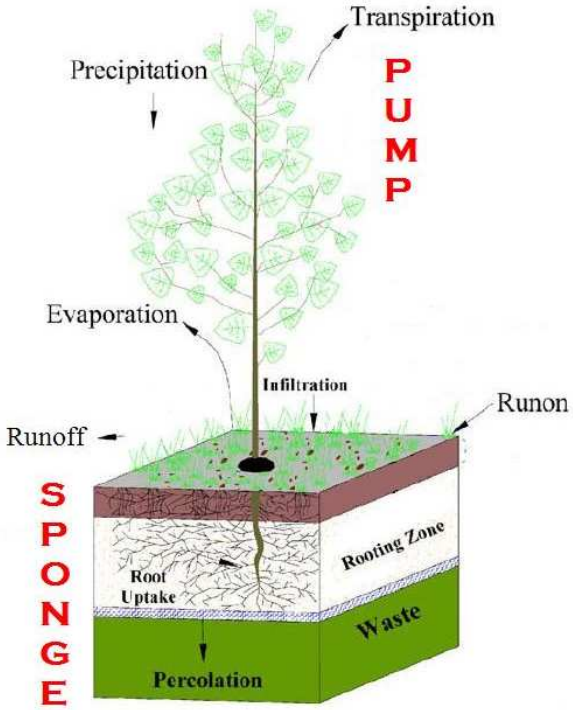

Figure 1 – *Schematic cross-section of a phytocap (adapted from Licht & Isebrands 2005).*

Phytocaps are 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 New Latin prefix for plant) which emphasizes the importance of the plant-based element of the system. While vegetation is incorporated as part of a barrier cap, it is primarily employed to prevent erosion and to improve the aesthetics of the site. On the contrary, vegetation plays an essential role in the phytocap function.

In terms of hydrological performance (i.e. minimising water percolation), evidence has been obtained from field studies to support that supposition that phytocaps can perform at least as well as, and in some cases better than, compacted clay layers (e.g. Dwyer, 2001; Albright et al., 2004). In contrast to compacted clay barriers, the performance of phytocaps is expected to improve over time as the

vegetation community establishes and the soil profile develops. This expected advantage, alongside 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 found to be lower, typically at only 35 to 72% of conventional covers (Hauser et al., 2001). Given the simplicity of phytocaps, their maintenance and repair costs can also be expected to be lower.

3. Phytocaps as biotic systems to mitigate landfill greenhouse emissions

Methane is the second most important greenhouse gas after carbon dioxide. Landfill gas typically consists of 40-60% methane and has thus been implicated in global climate change scenarios. Methane emissions from the waste sector account for about 18% of the global anthropogenic methane emission worldwide (Bogner et al. 2007).

In developed countries, landfill gas extraction and plant utilization are commonly mandatory for new waste disposal sites. Recent research has focused on the development of low-cost technologies that minimize methane emissions from existing landfills where gas collection systems have not been implemented or are not economically feasible (Scheutz et al. 2009). 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). While landfill gases may significantly affect root growth in cover soils, vegetation can also influence the biomass and activity of methanotrophs. It has been reported that plant cover could significantly improve soil methane oxidation potential (Stralis-Pavese et al. 2006). Wang et al. (2008) found that methanotrophic bacteria in landfill cover soils were stimulated by both plant growth and additional landfill gas supply.

The methane oxidation potential of phytocaps can be considered as a type of biotic cover where microbial activity is enhanced by plant roots. As active landfill gas collection is uncommon in developing countries, using phytocaps to oxidate methane and reduce greenhouse emissions would provide another major advantage over conventional impermeable caps.

4. Phytocap Design Approach

Phytocap functionality relies on the inherent properties and interaction between the local climate, the substrate (soil) and the selected 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 therefore important to transfer the phytocap design methodology rather than a site-specific design.

Shifting large volumes of earthen materials is an expensive undertaking, even within close proximity, and in order for a phytocap to be more cost effective than a conventional barrier cap, it is often essential for landfill operators to work with the soils that are readily at hand. The ideal phytocap substrate is one of high water storage capacity with properties that promote vital and sustained growth of the phytocap plant community. However, as the choice of substrate is often limited, the thickness of the soil can be manipulated to provide the required critical storage capacity during dry seasons. This requires analysis of the local historical meteorological conditions and the inherent water storage capacity of the soil. 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. The ideal plant community will maximise the number of days which transpiration occurs across the seasons.

A successful vegetation selection is even more critical when designing systems outside of the semi-arid and arid climatic zones, where there is a greater reliance on plant performance (Albright et al. 2004; Gross, 2004). The selection of plant species relies on the species' compatibility with the

available soil substrate, local climate and long-term establishment on the site. Site assessment would involve defining broad climatic characteristics from historical data and investigating properties of the native plant communities with the endemic soils.

Observations of adjacent land and available literature can be used to determine the original vegetation communities of a study site including their species composition, structure, eco-hydrology and conservation status. Plants species should be selected for tolerance of limiting conditions rather than modifying or augmenting the substrate. This approach is considered better aligned with creating an economically viable and self-sustaining native phytocap plant community. Another core phytocap plant selection criterion is the inclusion of biodiversity to ensure the resilience of the plant community.

5. The Australian Alternative Covers Assessment Program (A-ACAP)

A-ACAP is an on-going field and laboratory research program (2006 to 2011) co-funded by the Australian Research Council and the Waste Management Association of Australia to investigate phytocover alternatives to conventional landfill caps in the Australian context. The program has established five full-scale test facilities across Australia to investigate the effects of a wide range of climatic conditions as well as site-specific phytocover designs. From tropical in the north to arid in the interior to temperate in the south, these test facilities are located across all 5 mainland states in Australia – Victoria, South Australia, Western Australia, Queensland and New South Wales, representing an excellent climatic diversity.

The major goals of A-ACAP are to demonstrate that phytocovers can perform to the satisfaction of regulators and to develop guidelines for their application, design and construction. The guidelines will address (1) control of percolation of water into the waste; (2) reduction of greenhouse gas emissions (with particular reference to methane oxidation); (3) sustainability of vegetative covers comprising a mixed flora of native species.

Central to the project's experimental approach is the use of side-by-side comparisons of both conventional covers and candidate phytocovers. Large scale 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. 2009). A detailed description of the A-ACAP program was provided by Wong et al. (2007).

The A-ACAP trial sites are located in a diverse range of climates and have utilised locally available soil materials and native vegetation species and associations, as shown in Figure 2. The trial sites were established between 2007 and 2008, commencing with Lyndhurst (near Melbourne) and McLaren Vale (near Adelaide).

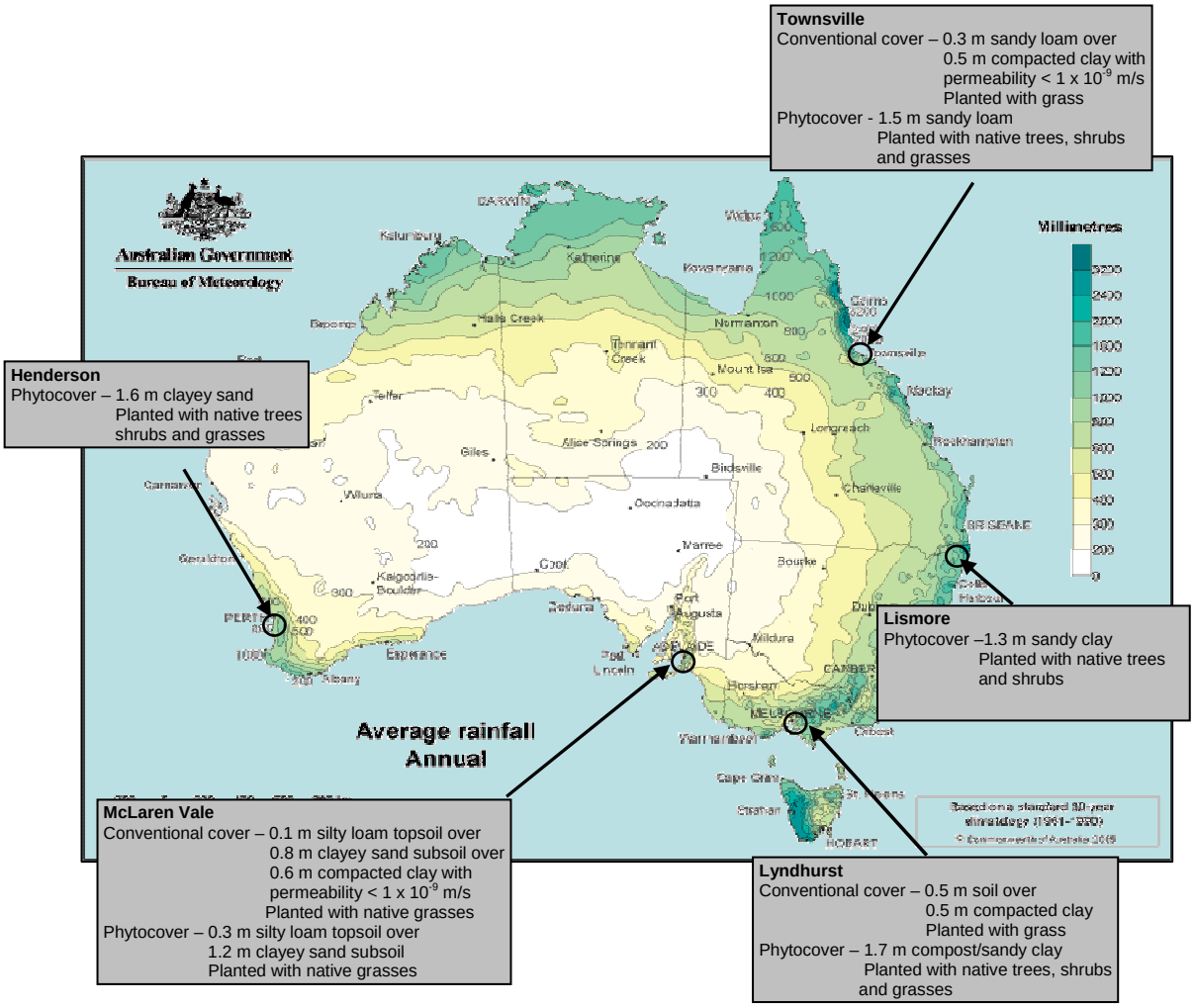

Figure 2 – *A-ACAP Trial Site Summary*

Data recorded at all sites includes rainfall, ambient temperature, relative humidity, wind speed and direction, soil volumetric moisture and soil temperature. Surface collection channels and pan lysimeters have been constructed to enable measurement of runoff and vertical drainage respectively from a defined area (trial plot).

Rainfall has varied at all sites over the monitoring period, as one would expect given their climatic diversity. Presenting the "Rainfall Year" as starting in April, i.e. at the commencement of the dry season for the northern sites or commencement of the wet season for the southern sites, Table 1 shows that rainfall has been below average in Lyndhurst and above average in Lismore and Townsville. Some data gaps exist in the drainage data presented in Table 1, however, based on the rainfall received during these periods, these inaccuracies are considered to have minimal impact on the data trends.

Table 1 – *Measured Rainfall and Drainage from Phytocovers at A-ACAP Trial Sites*

Site	Climate	Avg Rainfall (mm)	Apr 2007 to Mar 2008		Apr 2008 – Mar 2009		Apr 2009 to Mar 2010	
			Rainfall (mm)	Drainage (mm)	Rainfall (mm)	Drainage (mm)	Rainfall (mm)	Drainage (mm)
Lyndhurst, VIC	Cool temperate	810	585	43.1 (7%)	622	3.7 (1%)	749	0.3 (<1%)
McLaren Vale, SA	Mediterranean/ Semi-arid	520	230.4	0.0 (0%)	361	0.0 (0%)	654*	25.9 (4%)

Henderson, WA	Mediterranean	790	Limited data	778	277.0 (36%)	521	85.4 (16%)
Townsville, QLD	Tropical	990	Not yet constructed	2365	53.4 (2%)	1742	6.5 (<1%)
Lismore, NSW	Warm temperate	1340	Not yet constructed	1405	12.6 (<1%)	1490	5.7 (<1%)

* This rainfall amount included 84mm irrigation applied in August 2009 (see text)

The most evident trend is the decrease in drainage over time, with the exception of the McLaren Vale site. Comparing the drainage over time as a percentage of the total rainfall shows that at Lyndhurst, Henderson and Townsville, the proportion of drainage decreased over time, regardless of whether the rainfall increased or decreased.

When considering the drainage data at the McLaren Vale site, it is important to note that about 84 mm of irrigation was applied in August 2009 to simulate rainfall with an aim to investigate a stressed drainage response from the site. This additional application resulted in 26 mm of drainage. It should be noted that the plants on the lysimeter were dormant when this irrigation was applied and hence little transpiration was occurring.

Also of note is the extremely high drainage from the Henderson site, particularly when compared with the much higher rainfall sites of Lismore and Townsville. The main differences between these sites are:

- The soil used at the Henderson site was sand, with very little clay, while the soil used in Lismore and Townsville contained > 35% clay fraction;
- Rainfall is winter dominant in Henderson but summer dominant in Townsville, with Lismore receiving rainfall throughout the year;
- The plants at the Henderson site were slow to establish, remaining < 0.5 m high for the first few years, while plants at both Lismore and Townsville established quickly and > 1 m high after 1 year.

McLaren Vale has a similar climate to Henderson and was only planted with grasses. However no drainage (except in response to irrigation) has been measured from the site. The silt content in the soil used at McLaren Vale was > 20% and the native grasses established quickly over the entire site.

The experience from the A-ACAP trial suggests that phytocaps may be used in a range of climate types but careful selection of soil material and plant communities is required to minimise drainage. Increasing the soil profile depth may not be as effective by itself at controlling drainage. Finally, as plants establish, the drainage is likely to decrease.

6. Conclusions

Based on the above discussions, phytocapping could provide a cost-effective and sustainable cover option than the conventional barrier approach for landfills in developing countries. The obvious advantages are their lower costs, utilizing available recourses (i.e. use only local soils and native plants), and requiring less technical skills and engineering infrastructure to construct and maintain. While the phytocap concept was originated and has been trialled mainly in developed countries, this type of cover has the potential to make a significant improvement in the way that developing countries are capping waste disposal sites given their technical and financial constraints discussed earlier.

As phytocap functionality relies on the inherent properties and interaction between the local climate, the substrate and the selected plant community, the design of phytocaps is necessarily specific to each landfill. However, there is significant potential for the knowledge and design methodology learned elsewhere, such as the guidelines to be produced by the A-ACAP program, to be transferred and applied in developing countries.

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