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Abstract

Difficulties associated with the construction and maintenance of conventional landfill barrier caps has prompted a number of alternative capping solutions. One particular example is an evapotranspiration (ET) landfill cap. These covers rely on the manipulation of water balance components rather than a barrier approach in order to minimise the infiltration of water into the landfill. The overall ET cover design philosophy and process is significantly different from that employed in the construction of conventional covers.

Currently Hanson Australia, in collaboration with Melbourne University, is working through the design and research of an ET cover at Wollert landfill in Victoria. This paper presents the background and objectives of the project, a summary of the progress to date and intended future research. An insight is given into cover material and plant selection and required field, laboratory and glasshouse trials.

Introduction to Alternative Caps

Landfill capping is a key component of landfill rehabilitation. The primary objective of capping is to minimise the infiltration of water into the underlying waste, and as a result, minimise the production of leachate that may threaten to contaminate the groundwater and the surrounding environment. The vast majority of landfill caps aim to achieve this with a hydraulically impermeable barrier layer, typically constructed of compacted clay and/or geomembrane.

In order for the barrier to remain hydraulically impermeable, it must maintain structural integrity over time. This requires a relatively stable environment, a prerequisite that is difficult to satisfy when the cover itself is built on top of a settling landfill. Desiccation and cracking of the clay barrier commonly results as a consequence of settlement and exposure to seasonal wetting and drying cycles (Albrecht & Benson, 2002).

The formation of cracks provides preferential pathways along which water can enter the waste and the cap can no longer function as an effective barrier. Aside from the environmental consequences, this is a highly undesirable situation due to the high capital and maintenance costs of such a system. The construction of a barrier cover is complex and the colonisation of deep rooted vegetation has to be prevented due to the perceived danger of roots compromising the integrity of the cap (Smith & May, 2001). This makes a barrier cap a difficult one to sustain into the future.

The difficulties associated with the construction and maintenance of barrier caps has prompted a number of alternative capping solutions. One particular example is an evapotranspiration (ET) landfill cap. These are often referred to as store-and-release covers, as they rely on the capacity of one or more layers of soil to *store* water, and the ability of a layer of deep rooted vegetation to *release* this stored water through transpiration. The system is no longer relying on hydraulic impermeability, but instead, on the manipulation of water balance components to prevent the infiltration of water into the waste layer. Despite the apparent simplicity of this system, an ET cover must be designed carefully in order for it to perform well.

In order to design and construct an ET cap, designers and operators must undergo a complete paradigm shift towards working with a system where high compaction is no longer desirable, and where the deep penetration of roots into cover soils is actively encouraged.

Differences in Design Philosophy

Unlike traditional clay barrier caps, ET caps are not prescriptive. There is no set guidance as to cover thickness or hydraulic conductivity. Rather, there is a design methodology or process that can be transferred from site to site. This recognises the fact that the success of an ET cover depends heavily on site specific variables. These include climatic variables, characteristics of the available soil and characteristics of the selected plants, as well as the soil-plant-climate interaction.

ET covers have one major performance criterion. They must be able to demonstrate that they can perform equally as well, or better, than a clay cap. This requires field data on the performance of an ET cover and the performance of a clay barrier cover, under the same climatic regime. The difficulty with this criterion is that until recently, there has been extremely limited field data available.

The Alternative Covers Assessment Program (ACAP) was a national trial set up in the USA to develop the tools necessary to design and permit environmentally and cost–effective alternative covers. Its primary aims were to acquire field data on the performance of both conventional barrier covers and ET covers and to therefore address the question of equivalency (Albright & Benson, 1998).

US Alternative Covers Assessment Program (ACAP)

The ACAP program was a national trial of 11 sites located in 7 states across the USA. The performance of a number of alternative cover designs was trialled alongside conventional barrier covers, with large 200m^2 lysimeters (Benson et al., 1999). Each lysimeter consisted of the designed cover profile, underlain by a root barrier, geocomposite drain and geomembrane. The amount of percolation through the cover profile could be measured directly. A weather station was installed to collect on-site climatic information and berms were constructed to collect surface runoff. These lysimeters provided valuable information on the performance of conventional and alternative caps. However, the effect of heat and landfill gas on the function of the cap, especially the cover ecosystem was not addressed by the ACAP program.

ET Cover Design

ET covers are best suited to arid and semi-arid climates where evaporation exceeds precipitation for most of the year. They can also be applied to temperate climates but the design process is more challenging.

In order to attain financial benefits through the construction of an ET cover, a source of cover material must be readily available. Soils most suitable for an ET cap are generally finer-grained materials, such as silts and clayey silts which have a greater storage capacity than sandy soils. Soils with rapid drainage are to be avoided, although a carefully designed and maintained cover may include a coarser-grained material. The storage capacity of the soil is also affected by dry bulk density, which in turn affects root growth.

The thickness of the cover is designed to achieve critical storage capacity during the dry season, and typically ranges from 0.5m to 3m thick. Periods of light, consistent rain are often more critical than the same amount of intensive rain, as more infiltration and less runoff occurs. Similarly, consecutive wet years can be more critical than a single wet year as the water store does not have time to recover. Clearly, modelling is required to understand which meteorological conditions are most critical to a particular site. This requires an extensive historical climatic record.

Indigenous vegetation is most suited to the long term outcome of an ET cap as it is well adapted to the local climate and soils. The 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 waste. A more robust cover is achieved by selecting a diversity of indigenous species with a range of rooting depths and complementary growing seasons. This will ensure maximum water extraction throughout the year.

Below is a general design methodology:

1. *Assess soil characteristics in terms of their water storage capabilities and agronomic properties. Obtain parameters required for numerical modelling e.g. soil moisture characteristic curve, saturated and unsaturated hydraulic conductivity.*

2. *Select indigenous plants based on agronomic properties of the soil. Obtain parameters required for numerical modelling e.g. root density function, leaf area index, transpiration rates.*

3. *Define critical meteorological conditions for numerical modelling.*

4. *Produce preliminary design based on numerical modelling*

5. *Construct lysimeter test sections of proposed ET cover design and conventional barrier cover design. Monitor the performance of the proposed designs.*

6. *Construct final cover or repeat steps 4 and 5*

Background to the project

Hanson Australia became interested in evapotranspiration (ET) landfill caps after attending a technology transfer workshop presented by researchers from the USA ACAP program. After a small pilot study was conducted, a collaborative project was established with the University of Melbourne to undertake investigation into the feasibility of implementing an ET landfill cover at one of their Wollert landfill cells in Victoria.

Wollert Landfill and Quarry Site

Wollert landfill is situated about 50km North of Melbourne. The landfill is in the process of filling its second cell (highlighted below) and intends to cap Cell 3 with an ET cap.

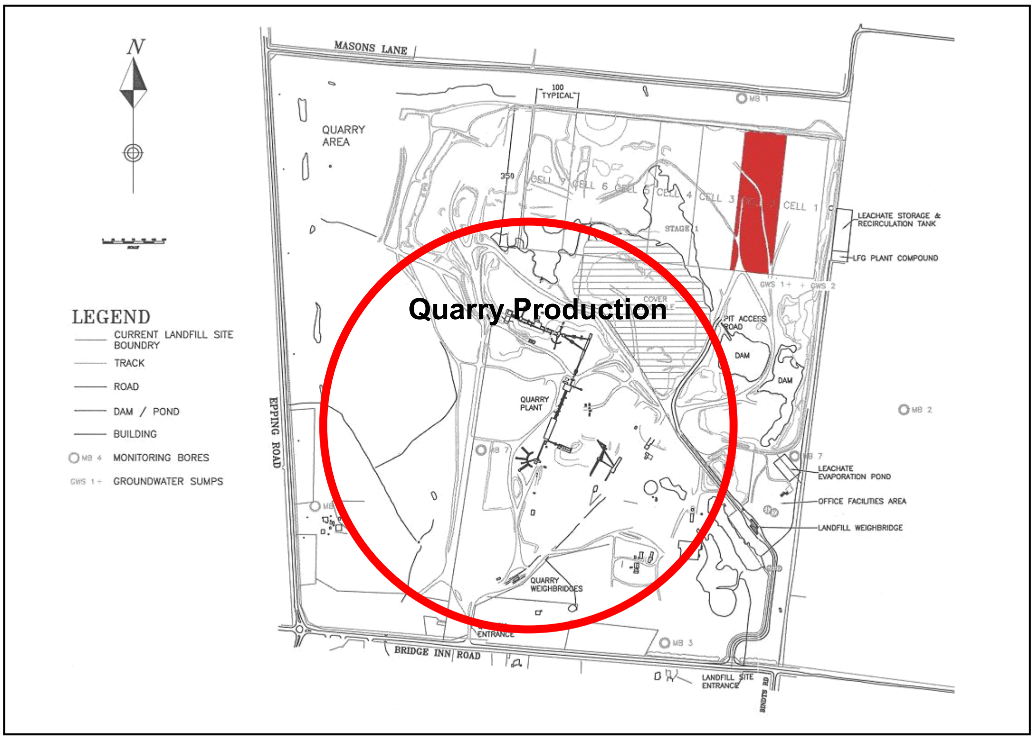

Figure 2 – Aerial drawing of Wollert landfill and quarry operations, 2003

The landfill site is adjacent to an active basalt quarry (circled above). As a by-product of quarrying, a large amount of "scalps" are produced on the site. The scalps are a mixture of crushed basalt and subsoil (predominately clay) and are of little commercial value. There are vast quantities of scalps produced on-site on an annual basis (~270,000 tonnes) and much of it is stockpiled. This project is investigating the potential use of scalps as an ET capping material.

Objectives of the project

This project is unique as it will look at the feasibility of incorporating indigenous plants and scalps into an ET cap within a Victorian climatic regime. The two major objectives of the project are to:

1. Gain approval for an ET cover at Wollert landfill

- Obtain long-term financial benefits through reduced capital and maintenance costs
- Use on-site materials more efficiently
- Increase the long term sustainability of the cap

2. Advance the science of ET capping in Australia

- Act as a case study for Victorian landfills
- Improve understanding of the soil-plant-climate interaction
- Improve understanding of the influence of landfill gas on indigenous vegetation

Progress at Wollert

Assessment of Cover Material

Material Selection

Samples of material were taken from the main scalps stockpile on-site. Testing of these samples indicated a wide range of gravel contents present (50 – 80%) due to the different size classes of scalps being produced by the quarry e.g. 16mm, 20mm, 40mm, 100mm etc. The size class produced is dependent on the moisture content of the *in situ* material. During dry weather, the greatest proportion of rock is extracted and hence the smallest grade of scalps (16mm) with the largest proportion of soil. Isolation of this material revealed a much lower range of gravel content (50-60%) with potentially adequate water storage capabilities. The intention is to stockpile this material separately, instead of allowing it to be mixed in with the main stockpile, in order to accrue enough for capping purposes. It is important to understand the production process and to be discerning about material selection.

Lab Testing - Agronomic properties

As was expected, the scalps material did not have desirable agronomic properties. The organic matter content and available P and N was extremely low. In addition, the pH of the scalps was very high (8-8.5), either requiring amendment or restricting the indigenous vegetation to those species tolerant of alkaline conditions.

Figure 2 – Skinning on scalps surface

Although the cation exchange capacity was high, the exchangeable cations were found to be imbalanced, including an inflated proportion of sodium and a high predominance of magnesium over calcium. The high sodium levels indicated potential problems with dispersion, however, the scalps material was found to be non dispersive and relatively erosion resistant. The predominance of magnesium over calcium is of greater concern as plants are typically adapted to high Ca:Mg ratios (White, 1997). Furthermore, numerous studies have shown that exchangeable cations significantly influence soil-water relations and that dispersion and clay swelling is enhanced by Na and Mg on the soil exchange complex (Dontsova & Norton, 2002). A predominance of Ma over Ca, may cause Ca deficiencies in the plants; it is also responsible for the surface sealing or skinning on the scalps material (see Figure 2), which has the effect of reducing the hydraulic conductivity (Keren, 1991). This may or may not be a desirable characteristic of the material. Obviously, a reduction in infiltration is a good thing in terms of reducing percolation through the cap, however, adequate water must still be made available to the plants. Currently the effect of applying gympsum to the scalps is being investigated. This is expected to increase the Ca:Mg ratio.

Field testing - Compaction Trial

A compaction trial was conducted in order to determine whether desirable low dry bulk densities required for an evapotranspiration landfill cover, could be consistently and practically achieved using conventional machinery currently employed in the construction of conventional clay covers. Three 200m^2 test sections were constructed using a D6 bulldozer (Figure 3). The selected placement techniques are outlined in Table 1. Generally the scalps were found to be compacted well without too much effort. Laboratory determination of the moisture content vs. dry bulk density relationship suggested that this was partly because the range of moisture contents experienced in the field were close to optimum (Figure 4).

Table 1 – Placement techniques

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

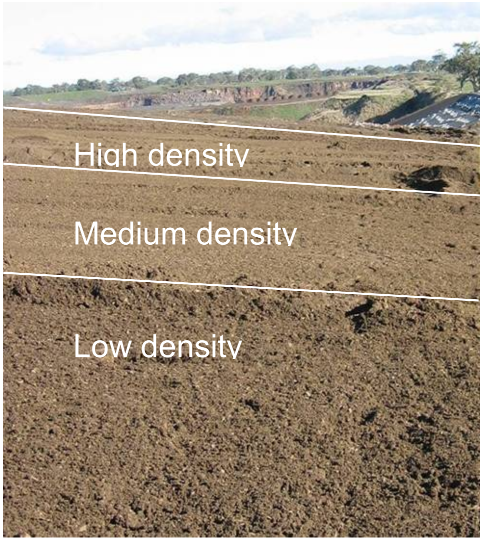

Figure 3 – A D6 bulldozer was used to construct three test pads of varying dry bulk density. A low, medium and high density case was achieved.

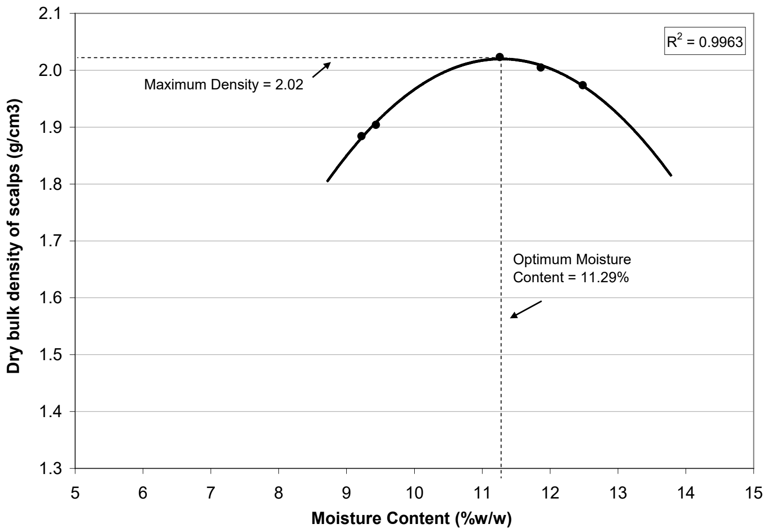

Figure 4 – Dry density/gravimetric moisture content relationship of the Wollert scalps using standard compactive effort (596kJ/m3). The optimum moisture content is 11.29% which corresponds to a maximum dry bulk density of 2.02 kg/m3

Vegetation

Plant Selection

Six species of trees and six species of grass were selected for trial in collaboration with native plant specialists. All twelve species were selected for tolerance to alkaline soils, drought (as they will be supplied with no supplemental water) low phosphorus and nitrogen conditions. Studies identified significant advantages in using indigenous perennial tussock grasses. Not only are they well adapted to the regional climate, but they also have beneficial root architecture potentially capable of increasing the water retention and organic matter content of the ET cover. Both cool and warm season varieties were selected in order to promote evapotranspiration throughout the year. A range of native trees species were also selected including two mallee eucalypts capable of producing high-grade eucalyptus oil. The intention of selecting these commercially-valuable species was to investigate potential financial offsets to closure costs and methods of increasing environmental stewardship of the site. Several smaller, relatively short-lived N-fixing native tree species were also selected for the purpose of adding to the nitrogen capital of the soil.

Field Trials

The twelve selected species have been planted out in a 200m^2 test section of scalps at the Wollert landfill at an average dry bulk density of 1.55g/cm^3. The intention of the trial is to monitor the survival and growth rate of the selected species and to measure rooting depths. The effectiveness of mulch is being tested with three different treatments: 10cm of mulch, 5cm of mulch and 0cm of mulch (Figure 5). Since the trial commenced in May 2004, no difference between mulch treatments have been observed, however the plants have not yet been subjected to the stresses of summer.

Figure 5 – Planting pad set up. Plots 3 and 5 have 10cm of mulch, plots 2 and 4 have 5cm of mulch, and plots 1 and 6 do not have any mulch.

Trees and grasses were planted as tube stock. Broadcast seeding of grasses was undertaken for comparison. The broadcast seeding has been rather successful and is the preferred method at this stage.

Glasshouse Trials

In order to gain further understanding of the plant-scalps interaction, a glasshouse trial is being set up to investigate the effects of compaction on plant performance including growth and transpiration. These trials, together with water retention tests performed in the laboratory, will assist in identifying the optimum in situ dry bulk density of the cover. The selected dry bulk density will be one which maximises both water retention properties and plant performance. Although there is no final data yet, results so far indicate that the optimum density will fall close to 1.6g/cm^3. This is the critical limit for woody plants for soil compaction, in clay, at field capacity (Cass et al., 1993). However, this limit will be much higher for the scalps material, as the dry bulk density is inflated due to the high proportion of gravel.

Proposed Modelling and Lysimeter Design

Three test sections are to be constructed at the Wollert landfill in May 2005. The proposed sections will have an area of $150m^2$ each. Unlike the lysimeters in the US ACAP program they will be constructed without sidewalls, instead accounting for edge effects by extending the size of the monitoring area by 5m on all sides (Figure 6). This will bring the total area of each test section to $300m^2$.

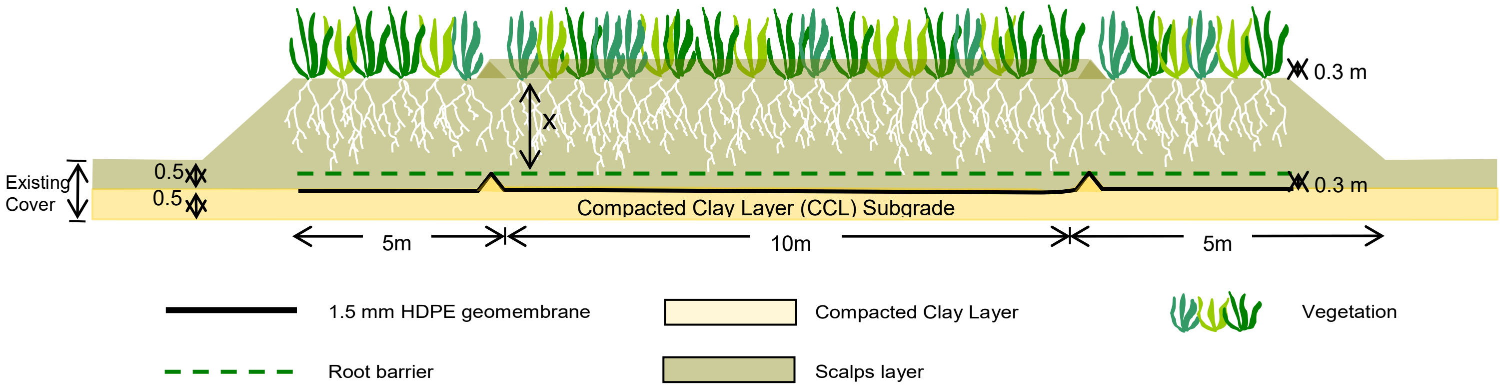

Figure 6 – Simplified cross section of the lysimeter design proposed for Wollert landfill excluding instrumentation and collection systems

Two of the test sections will have lysimeters incorporating a geomembrane liner for the collection of infiltration. The other test section will be built without a liner in order to monitor the effects of heat and landfill gas on the vegetation.

The performance of lysimeter designs will be assessed with an unsaturated flow numerical model (e.g. UNSAT-H, Hydrus 2D), both of which can accurately simulate the water balance through soils under variably saturated conditions (Abichou et al., 2004). The model simulations will be refined as more data becomes available through laboratory testing, glasshouse and field trials. At this stage we are hoping to finalise the lysimeter design by mid December and be ready to construct the lysimeters in March 2005. The project has been timed so as not to miss the growing season.

Australian-ACAP

The Australian climate is vastly different to that in the USA as are the characteristics of our native vegetation. In order to implement Evapotranspiration (ET) landfill caps in Australia, the technology needs to be trailed under Australian conditions. An Australian ACAP program has already been proposed and representative sites have been selected from each state around the country. The program will try not to overlap too much with the experience gained in the US, but with a focus on the landfill gas plant interaction and the selection and performance of native vegetation.

Conclusions

The Alternative Covers Assessment Program provided significant guidance on the design and permitting of ET covers in the US. The trial provided a methodology for ET cover design however, whether or not this methodology can be successfully applied in Australia remains to be seen. Currently Hanson, in collaboration with the University of Melbourne, is working through the design process to determine the feasibility of an ET cap at Wollert landfill, Victoria. The research is reinforcing the need for careful site specific design. The soil-climate-plant interaction is complex and requires further scientific understanding before modelling alone can predict the performance of an ET cover design. Presently the only way to accurately measure performance is through full-scale monitoring, where percolation is measured directly from a test section of the cover profile. The proposed Australian ACAP would assist with the design and regulation of ET caps in Australia and allow us to take advantage of this innovative technology.

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