Geotechnical Considerations of Landfill Design and Construction

Kevin Brennan and Ashton Hincksman, PPK Environment & Infrastructure Pty Ltd

Summary: ***The Environmental Guidelines for Solid Waste Landfills as published by the New South Wales Environmental Protection Authority (EPA) provides a list of 39 so-called "benchmark" techniques. A number of the benchmarks relate directly to the geotechnical characteristics of a landfill site and proposed construction materials. These geotechnical related benchmarks are outlined in the paper.***

To illustrate the requirements of these benchmarks, the methodology and results of a preliminary geotechnical investigation for a proposed landfill site concept plan is presented. Alternatives to the benchmark techniques which have been adopted, or are proposed to be implemented at an operation landfill are provided.

1. INTRODUCTION

Design of landfills within New South Wales is primarily driven by the requirements of *The Environmental Guidelines for Solid Waste Landfills* as published by the New South Wales Environment Protection Authority (EPA) in January 1996. The publication of these guidelines followed the release of a draft document issued for public comment during 1995. The primary purpose of the Guidelines is to 'launch a consistent and environmentally responsible approach to managing landfills across NSW'. In turn it is hoped that this will increase community confidence in landfilling activities and avoid extremely costly remediation programs in the future.

The guidelines themselves include a set of environmental goals and outcomes that are to be achieved via a performance based approach. This method has been adopted to enable landfill operators to develop an approach to landfilling which might be more suitable for the subject site and its individual characteristics.

The environmental goals of the guidelines are included within the document through the provision of a list of 39 so-called 'benchmark techniques' which are based on worlds best practice. The appropriate selection of relevant solutions to each environmental goal should be based on four key points:

1. The site location and proposed waste types need to be determined;
2. That there is no impediment to rejecting some techniques in relation to a given facility;
3. A combination of design and construction, operations management, monitoring, remediation and post closure management measures will generally be required to deal with the range of potential environmental impacts for a given site ie:
   - Geological information;
   - Hydrology
   - Landfill operation
   - Nature of wastes and quantity
   - Meteorology
   - Elevation
   - Quality of groundwater
   - Leachate detection and controls
4. There is no impediment to using operational or design techniques not listed in the benchmark techniques. Alternative methods may be adopted providing justification that the environmental goal will be met.

There are a number of these environmental benchmarks that relate directly to the geotechnical characteristics of the landfill site and proposed construction materials to be used. These design aspects include, but are not limited to:

- Leachate Barrier System
- Leachate Collection System
- Covering of Waste
- Landfill Gas Containment
- Extraction and Disposal of Landfill Gas
- Site Capping and Revegetation

The benchmark requirements have lead to the development of a more detailed geotechnical scope of works being implemented for landfill site investigation and design. To demonstrate the practical application of geotechnical aspects of landfill investigation and development of design alternatives, experience at a proposed putrescible landfill site and existing non-putrescible landfill have been presented.

2. GEOTECHNICAL INVESTIGATION FOR A PROPOSED LANDFILL

To illustrate the requirements and the scope of works of a geotechnical investigation for the concept design of a landfill the following example is presented.

An Environmental Impact Statement (EIS) was recently carried out for the proposed construction and operation of a Class 1 solid waste landfill. The potential site for the landfill was in an existing open cut coalmine, located in the Hunter Valley of New South Wales. At the time of investigation the operation of the mine was nearing completion, with the majority of the site having been reshaped to its original landform. The reshaping used the overburden material resulting from the mining, which comprised a mixture of blasted and excavated siltstones, sandstones and minor carbonaceous materials in a sandy clay/clayey sand matrix. Construction of the proposed landfill cells would require excavation from the existing ground surface level to depths ranging between 5 m and 28 m. The depth of mine overburden remaining in place under the landfill cells would range from 0 m (ie landfill founded on bedrock) to approximately 45 m.

2.1 CONCEPT PLAN

The EIS required a preliminary geotechnical investigation of the site be carried out, with the results to be utilised in the development of a concept plan for the proposed landfill. The concept plan was to comply with EPA Solid Waste Landfills Guidelines for the construction of such facilities. Therefore following excavation to the base of the proposed landfill, the concept plan proposed a liner system that would collect and recirculate leachate. The proposed liner comprised the following arrangement:

- ***Leachate Collection layer***; a minimum 300 mm thick gravel drainage layer, over
- ***Protective Geotextile Layer***; over
- ***Liner***; Compacted Clay Layer (CCL) or a composite liner comprising a High Density Polyethylene (HDPE) geomembrane overlying a Geosynthetic Clay Liner (GCL), over
- ***Cell Base Layer***; a minimum 900 mm of compacted soil.

Waste would be placed within each of the landfill c to a maximum stage height of approximately 15 would be unloaded from trucks at the working shaped by the on site plant.

The concept plan proposed that when the landfill waste would be covered with an engineered cappin The aim of the capping layer is to reduce leachate by minimising stormwater infiltration, prevent er soil loss by vegetating the cover and to minimise la migration. The proposed cover would comprise the f

- ***Revegetation Layer***; a minimum 1000 mm thicl
- ***Infiltration Drainage Layer***; a minimum 300 sand or gravel drainage layer, over
- ***Sealing Layer***; Compacted Clay layer or a ge over
- ***Gas Drainage Layer***; a minimum 300 mm co over
- ***Seal Bearing Surface***; soil layer covering lan material.

2.2 GEOTECHNICAL ISSUES

In order to comply with the EPA benchmark techn to determine the feasibility of the site for the cons the landfill, the primary tasks/issues of the p geotechnical investigation were as follows:

2.2.1 Settlement

Following the construction of the landfill, assess th settlement of the foundation material (mi overburden) and the resulting possible affects such of the liner.

2.2.2 Mine Subsidence

Consider the effects to the landfill liner and the f of the leachate collector drains if underground mi subsided as a result of the applied landfill loads.

2.2.3 Slope Stability

Assess the slope stability of the site during an construction and filling of the landfill, consi interfaces, subsurface water, seismic loads a surcharge.

2.2.4 Assessment of Source Materials

Investigate potential on site sources of material with the EPA benchmark techniques (eg permeab construction of the landfill liner and capping laye

2.3 INVESTIGATION SCOPE OF WORKS

The preliminary geotechnical investigation for the EIS comprised a desk study, walk over survey of the site, test pit investigation, limited borehole investigation, laboratory testing and analysis of all results.

2.3.1 Desk study

The desk study reviewed all available material including:

- aerial photographs;
- maps (topography, geological, contour);
- review of past geotechnical investigations;
- review of the mining company records; and
- information obtained from the Mine Subsidence Board.

2.3.2 Walk over survey

The purpose of the walk over survey was to become familiar with ground conditions at the site and to identify/examine features observed on aerial photographs. Features that were highlighted included:

- outcrops of bedrock and exposures of soil profiles;
- evidence of major geological structures such as faults, dykes, jointing, dip of strata;
- signs of slope instability such as fresh rock faces, rubble at the top of slopes, hummocky or scarp topography;
- filled ground; and
- groundwater, boggy ground, watercourses, springs.

In addition, sites for the test pit and borehole investigations were selected during the walk over survey; with particular attention given to vehicle access, services and boundaries of the proposed landfill.

2.3.3 Test Pit Investigation

Test pits were excavated using a Hyundai 290 excavator, fitted with a 1.5 m wide bucket. The test pits were located in areas both disturbed by past mining operations and undisturbed area that would be mined in the near future. The test pits were excavated to the maximum reach of the machine – averaging a depth of 5.5 m below existing ground surface level. The test pits were logged and representative samples of the subsurface materials were recovered by the supervising geotechnical engineer.

2.3.4 Borehole investigation

Boreholes were drilled at representative locations across the site using a truck mounted Mobile B80 drill rig. The boreholes were drilled through the mine waste overburden using a Sim-cas eccentric under-reaming hammer bit which advanced the casing to the base of the overburden. At selected depths the hammer bit was removed and the strength/compaction of the mine waste overburden soil profile was determined from Standard Penetration Tests (SPT) 'N' values augmented with hand penetrometer readings on cohesive samples recovered in the SPT split spoon. The underlying bedrock was drilled using a standard down the hole air percussion hammer. The boreholes were logged and representative samples of the subsurface materials were recovered by the supervising geotechnical engineer.

2.3.5 Laboratory

Selected subsurface materials sampled from the test pits and the boreholes were tested in NATA registered laboratories to assess the feasibility of reusing the mine waste overburden (disturbed areas) and the natural clay deposits (from undisturbed areas) for clay lining or capping of the landfill. Samples taken from the mine overburden waste profiles included gravel and cobble size material. For laboratory testing purposes the samples were manually sorted on site to be predominantly free from material greater than 75 mm maximum dimension.

Laboratory testing included field moisture content, Atterberg limits, particle size distribution, Emerson dispersion and constant head permeability.

2.4 RESULTS

In general terms the test pits and boreholes located in disturbed areas encountered a surface layer of topsoil overlying mine overburden waste material (ranging in thickness from approximately 25 m to 37 m) and then sedimentary bedrock. Difficult drilling and test pitting conditions were experienced at some locations due to some of the sandstone boulders encountered being greater than 2 m thick. Some voids or zones of low air return were encountered when the boreholes encountered cobbles or boulders. SPT 'N' values ranged from 7 to 23, with an average 'N' value of 16; it was noted that gravel inclusions in the fill may have elevated the recorded 'N' values. In general the mine overburden waste material appeared to be moderately to well compacted.

The test pits located in mine's undisturbed areas (at the time of investigation) encountered a relatively thin layer of topsoil overlying natural clayey and sandy soils and then relatively shallow sedimentary bedrock at depths ranging from 0.7 m to 2.8 m. The natural clays and silts encountered in the test pits were of medium to high plasticity and ranged in strength from very stiff to hard.

No groundwater was observed in the test pits predominantly due to pumps re-diverting groundwater flows around the open cut mine operations (in order to keep the mine dry). During drilling of the boreholes a slight flow of groundwater was observed at the interface of the mine overburden waste fill and the sedimentary bedrock. In one of the boreholes a stronger flow was also observed from the interface of a coal layer in the bedrock.

The laboratory tests indicated the tested clays from the mine overburden waste material ranged from low to medium plasticity and had a slight to moderate tendency to disperse when immersed in water. The tested natural clays from the undisturbed areas (at the time of investigation) were of medium to high plasticity with a slight tendency to disperse when immersed in water.

Permeability tests were undertaken on both samples of mine waste overburden materials and samples of the natural clays from areas that were to be mined. The samples were recompacted to 98% Standard Maximum Dry Density prior to testing. The permeability of the tested samples ranged from 7.0×10^{-11} m/sec to 7.6×10^{-9} m/sec indicating a low to medium level of permeability. It should be noted that the permeability tests were undertaken on test samples with particle sizes less than 19 mm. The grading tests identified a high gravel percentage in the samples prior to sorting, therefore an increase in the field permeability of the material would be expected. Field permeability tests in trial pads of compacted material would be necessary to gain a more representative design permeability.

2.5 ANALYSIS

2.5.1 Settlement

Based on the proposed concept plan and the results of the preliminary geotechnical investigation, the majority of the proposed landfill would generally be founded on mine waste overburden which was variable in particle size, compaction and appeared to have been placed in an uncontrolled manner; a small portion of the landfill would however be founded on bedrock. As stated previously the depth of overburden material to be removed to construct the landfill would range from approximately 5 m to 28 m. Some of this material had been placed over 25 years prior to the investigation and therefore was considered to have provided a surcharge effect on the mine overburden waste material that would remain beneath the landfill (note depth of remaining material ranged from 0 m - ie landfill founded on bedrock - to approximately 45 m).

EPA guidelines indicate waste compaction goals in the range of 0.65 tonnes/m^3 to 0.85 tonnes/m^3 depending on the receival rates per annum. Thom and Pym[iii] indicate a density range of 0.3 tonnes/m^3 for green waste and up to 1.3 tonnes/m^3 for demolition rubble. Using these values and with the results of the preliminary geotechnical investigation in mind, the settlement analysis at the proposed landfill adopted a conservative value of 1.1 tonnes/m^3 for the landfill waste material, and 1.9 tonnes/m^3 for the mine overburden waste material. Generally Elastic Modulus 'E' values for the soil profile adopted a value of 2N where 'N' equalled the SPT value; however consideration was also given to the potential for voids between overlapping cobbles and boulders within the mine overburden.

Estimates of settlement were dependent on the quality and thickness of overburden underlying the landfill. As the composition of the mine overburden waste material was predominantly dry sands, gravels and cobbles, the anticipated settlements would occur predominantly instantaneously. Minimal long term consolidation was expected due to a reduction in pore water pressures in clayey soils.

Worst case settlement values (ie large values) were recorded in proposed landfill areas where minimal overburden was removed and the depth of overburden remaining was great. Conversely best settlement values (ie minimal values) were calculated where the depth to bedrock was minimal. Settlements ranged from 0 mm to approximately 660 mm with typical settlements in the order of 300 mm. It was noted that these settlement values were expected to occur over relatively localised areas and not over the entire landfill base.

Differential settlements were also considered in the transition zone where the foundation of the landfill changed from bedrock to the mine overburden waste material. The magnitude of possible worst case differential settlements was analysed to be in the order of approximately 660 mm. It is unlikely that such sharp changes in settlement would occur; rather it was expected settlements would occur in the form of the traditional bowl shape, extending over distances greater than 5 m.

The calculated settlement values based on the results of the preliminary geotechnical investigation were used in the concept design of the proposed landfill leachate barrier system. The barrier system had to be able to accommodate the strains induced by settlement and differential settlement of the mine overburden waste remaining underneath the proposed landfill.

For strains to reach a value that could cause risk to the integrity of the liner, large settlements over short distances (such as potholes) would be required. Based on the results of the preliminary investigation, the risk of pothole formations via the collapse of voids in the mine overburden waste material were minimal.

The calculations indicated strains of up to approximately 4% were possible if the landfill was founded on the mine overburden waste material, in its present condition. These strains would be reduced if the subgrade was improved by say impact proof rolling or by placement of geogrid forming a "bridging" layer.

Normal compacted clay materials cannot withstand tensil strains resulting from settlement/differential settlement greater than 0.85% without distress such as cracking occurring[iv]. The ability for a CCL to bridge a pothole/void between say boulders in the mine overburden waste was questionable given clay has a relatively low tensile strength; the incorporation of a geogrid or similar would assist in bridging pothole/voids formed from settlement of the mine overburden waste.

Alternatively a composite liner system comprising a HDPE geomembrane overlying a GCL would be able to accommodate 10 to 15% strain with negligible increase in permeability. Should settlement of the mine overburden waste material induce a strain greater than 10 to 15% in the geosynthetics, an increase in the permeability of the liner system could be expected.

2.5.2 Mine subsidence

Mine Subsidence Board guidelines indicate that where underground mine workings are greater than 20 m below the surface level, the risk of pot hole subsidence at that surface level is low and the area would not be considered to be at risk of pot hole subsidence.

For the proposed landfill site in the Hunter Valley, NSW, no underground mining had occurred beneath the site, therefore there was no immediate risk of mine subsidence and/or pot holing to the landfill structure. Furthermore it was understood that both the colliery and the Department of Mineral Resources considered that the extraction of coal seams known to be beneath the proposed landfill site was not presently, nor considered in the future to be economically feasible (thin coal seams, poor quality and high stripping ratio).

2.5.3 Slope Stability

A computer aided slope stability analysis of the proposed 1 vertical to 3 horizontal construction slopes was carried out using soil parameters derived from the subsurface preliminary investigations, seismic loads (adopted from the Australian Standard AS 1170.4 (1993) Minimum Design Loads on Structures Part 4: Earthquake Loads) and a range of groundwater levels (to accommodate the change in groundwater levels following the completion of mining operations and the decommissioning of groundwater pumps).

The slope stability analysis of the subsurface soil and rock profile forming the sidewalls of the landfill, indicated that for ground water levels below or up to the proposed base of the landfill, and with seismic loads applied, the minimum factors of safety for various landfill cross sections were greater than 1.5.

Therefore it would appear that the proposed construction slopes of 1 vertical to 3 horizontal would be adequate to provide stability of the landfill at all stages provided appropriate construction sequencing and earthworks standards are adhered to and landfilling occurred from the toe of the slope upwards.

2.6 CONCEPT PLAN BASED ON INVESTIGATION RESULTS/ANALYSIS

2.6.1 Landfill liner and Leachate Collection System

Following excavation to the base of the proposed landfill, the concept plan of the proposed liner system to be constructed directly over the remaining mine overburden waste material comprised the following layers (reference to the attached Figure 2.1):

2.6.1.1 Compacted base

The purpose of the compacted base layer was to provide a uniform base and working platform for construction of the landfill liner. The base layer would also provide an additional but limited bridging mechanism over the remaining mine overburden waste material. The base layer was designed to have a minimum thickness of 0.8 m (4 lifts at 200 mm compacted layers). The sub-base layer was designed to be compacted to a minimum density of 98% relative to SMDD and to within ± 2% of OMC.

Mine overburden waste materials were expected to be suitable after sorting/sieving for use in construction of the compacted base layer under the composite liner, whilst also providing some attenuation to leachate. This material would also be able to be used for the daily landfill cover.

Due to the high quantity of cobbles and boulders encountered in the preliminary investigation test pits and boreholes, supervision by an experienced earthworks contractor or a geotechnical engineer during excavation was recommended in order to provide visual identification of materials likely to be most suitable for use in the landfill construction/operation.

Materials in the compacted base layer were to have a maximum particle size of 75 mm. The material used in the top layer of the base, directly under the geosynthetic composite layer, had to be free from objects that could damage the liner, such as stones and rocks.

2.6.1.2 Liner

Mine overburden waste materials and natural clays sampled from the site were tested and assessed for suitability in meeting the clay liner specification. The materials selected for laboratory testing were considered to be representative of the more clayey materials encountered at investigation locations in terms of having potential to meet the specification for a clay liner (such as EPA requirement of a permeability less than 1×10^{-9} m/sec).

The laboratory test results indicated that the mine waste materials had a slight to moderate potential for dispersion and a low to medium level of permeability. However as stated previously to carry out the laboratory permeability testing, all material greater than 19 mm diameter were removed from the samples. Therefore, unless acceptable in situ permeability test results were recorded, on site sorting, sieving, screening and removal of gravel, cobble and boulder inclusions from the mine overburden waste material would be required prior to it being considered for use as a CCL.

The natural clays generally had a lower tendency to disperse, had lower permeability values and had negligible gravel content compared to the mine overburden waste material. The preliminary geotechnical investigation encountered an average in situ clay layer thickness of 0.9 m underlying the areas that were undisturbed at the time of investigation. Based on this thickness, the estimated volume of clay deposits was sufficient for the construction of a CCL for the proposed landfill. However it was noted that the preliminary investigation test locations covered only a small section of the undisturbed areas (due to access availability) and encountered a clay subsurface profile that varied in thickness from 0.2 m to 1.8 m. To determine the actual available volume of clay, further investigation of the entire undisturbed areas was required prior to considering sourcing the on site clay deposits. It is noted that changes to the mining operations were also required to allow selective sourcing of clay deposits and stockpiling until required for the construction of the landfill.

As stated previously, when strain levels in a CCL (resulting from settlement of the underling materials) exceed 0.8 to 1.0 per cent, cracking and an associated increased permeability would occur. Based on the results of the preliminary geotechnical investigation, the calculations indicated strains of up to 4 per cent were possible. A CCL was therefore determined to be not feasible due to the potential increase in permeability, and also due to the difficulties associated with changing the method of mining to allow sourcing of the clay.

As an alternative to the clay liner a decision to adopt a HDPE geomembrane overlying a GCL was made. The GCL and HDPE components of the liner system were able to accommodate 10 to 15% strains with negligible increase in permeability. The GCL and the HDPE layers work as a composite liner system in providing a low permeability barrier system against leachate migration from the landfill. A flexible 1.5 mm thick HDPE with a permeability of 8.1×10^{-15} m/sec was selected. The selected GCL would comprise sodium bentonite sandwiched between 2 layers of non-woven polypropylene geotextile that had a permeability of 3×10^{-11} m/sec. The overall in situ co-efficient of permeability was less than 1×10^{-9} m/sec as specified for a clay liner by the EPA.

2.6.1.3 Protective Geotextile Layer

A geotextile was provided over the HDPE to protect it from puncture from the overlying gravel drainage layer. The geotextile was sized based on the type of gravel proposed for use and the thickness of the drainage/operations layer. If the gravel was relatively angular, or large, a heavier geotextile was required. For smaller, rounded gravel, a lighter grade geotextile could have been considered. The protective geotextile layer had to be of sufficient strength to accommodate the operations of the landfill earth moving equipment. It was noted that considerable care was to be taken during construction not to damage the HDPE when placing the gravel drainage layer over the geotextile.

2.6.1.4 Leachate Collection

Overlying the protective geotextile layer was a leachate drainage layer comprising a 300 mm minimum thickness layer of drainage gravel (typically 20 mm rounded gravel). The gravel drainage layer provided a path for leachate collection and drainage, with the aim of reducing leachate heads on the liner, while providing a protective operations layer between the waste and the liner system.

At the lowest point of each cell of the landfill a Leachate Collection Sump was to be constructed by forming a local depression in the liner system and filling the depression with gravel. Leachate would be pumped from the sump via a network of HDPE pipes to a Leachate Transfer Pumping Station.

The waste compactor and associated equipment were recommended to be kept well away from the geosynthetic liner. The compactors were not to operate directly on the drainage layer, but on a layer of select waste placed above and in front of the compactor's operation. The first lift of waste had to be free of large or long objects that could be forced through the drainage layer into the barrier system.

2.6.1.5 Lining the 1 Vertical to 3 Horizontal Landfill Side Slopes

On the 1 vertical to 3 horizontal side slopes, the same liner system as proposed for the base was recommended except that the smooth HDPE geomembrane was replaced with textured geomembrane. The textured surface of the HDPE geomembrane provided increased friction against the underlying GCL and overlying geotextile. The need for textured geomembrane depends on the length of slope and landfill operations.

The GCL selected had sufficient internal shear strength to prevent side slope failure in the plane of the geosynthetics (through the bentonite). The shear strength for the GCL in the barrier depended on the construction sequencing and filling operations in the cell. If the leachate drainage layer was placed over a long length of the 1 in 3 side slope above the landfill base, large shear forces would occur within the lining system, with the critical slip plane occurring within the bentonite of the GCL. If the drainage layer was placed up the slope progressively as the waste progressively filled up the batter, the shear forces would be less and therefore the required internal shear strength of the GCL would not be as critical. Calculations indicate that the leachate drainage layer was not to be placed more than 10 to 15 m up the slope ahead of the waste filling. Placing the layer higher put the geosynthetics at risk of tearing from the weight of the gravel plus dynamic load of the equipment placing it. It was recommended that the leachate gravel drainage layer be placed by construction equipment from the layer of waste; that is no construction equipment was to traffic on the liner.

The side wall liner typically extended past the toe of the batter onto the landfill floor for at least 3 m. To hold the liner on the side walls of the landfill, the liner was extend over the crest of the batter for a short distance, and terminated in a vertical "anchor trench". Anchor trenches are typically excavated with a backhoe; therefore the liner was to be draped into the trench which was to be then backfilled with the excavated soil. The backfill would be compacted in layers as the backfilling proceeds.

2.6.2 Landfill Cell Capping

For the proposed Hunter Valley landfill, the concept plan made reference to the EPA Solid Waste Landfill guidelines for future site capping. The recommendations for the proposed landfill were as follows (from bottom of capping system to top):

2.6.2.1 Seal Bearing Surface

An intermediate cover layer which provided the subgrade for the capping system and produced the finished profile for the final landform. This layer was essentially the daily cover layer, thickened to 500 or 600 mm thick to minimise exposure of waste during the extended period between finishing of landfilling in an area and placing the capping system. This layer provided the bearing surface for the next layer.

2.6.2.2 Gas Drainage Layer

A gas collection/relief layer made up of 300 mm of coarse sand with a minimum permeability of 1×10^{-4} m/sec as specified by the EPA. This layer would minimise the potential for uncontrolled gas emissions through the cap should a gas management system be installed.

2.6.2.3 Sealing Layer

From the preliminary geotechnical investigation, it was determined that there was likely to be insufficient quantities of readily available clay materials on site to construct a 500 mm CCL with the hydraulic conductivity required by the NSW EPA guidelines (permeability of less than 10^{-8} m/sec).

Therefore a geosynthetic layer was adopted instead of the 500 mm thick clay sealing layer. Either a polyethylene geomembranes or GCL, or both in combination producing a composite liner was to be adopted. The GCL had to be suitable for the slopes to which the final landform would be constructed.

2.6.2.4 Infiltration Drainage Layer

A 300 mm thick layer of coarse sand or medium gravel (20 mm rounded) was recommended for the capping drainage layer, possessing a minimum hydraulic conductivity of 1×10^{-4} m/sec in accordance with EPA guidelines.

2.6.2.4 Revegetation Layer

A minimum 1000 mm thick vegetation layer. It was recommended that the vegetation chosen had to have a root system would not penetrate the sealing layer.

3. ALTERNATIVE BENCHMARK TECHNIQUES

The EPA benchmark techniques are sensitive to the location of the landfill site and the type and quantity of waste received. These benchmark techniques are used as reference points only, and alternative design techniques are feasible, provided that justification is made available. Depending upon the individual circumstances, variation to the benchmark techniques may provide economic and environmental benefits, providing the appropriate preliminary assessment/site investigation and analysis are undertaken.

To demonstrate the assessment process, brief examples of four alternative techniques which have been adopted, or are proposed to be implemented, at Pacific Waste Management's Elizabeth Drive Landfill are presented. Assessments of alternative cover material, leachate drainage media, leachate collection pipe spacing and soil liner material have been undertaken. Elizabeth Drive is a state of the art Class 2 solid waste landfill situated in Sydney's west. It has been excavated within shale and laminite bedrock and is lined with a CCL.

3.1 ASSESSMENT OF ALTERNATIVE LEACHATE DRAINAGE MATERIAL

An assessment was undertaken on a sample of blast furnace slag (BFS) material proposed to be used as an alternative leachate drainage material at Elizabeth Drive Landfill. The landfill previously used rounded river gravel for leachate drainage requirements.

The purpose of the assessment was to make comments on the suitability of the material with regards to its physical characteristics for its intended use as a leachate drainage material.

To meet the EPA Guidelines for Solid Waste Landfills (January 1996), the drainage material should exhibit a coefficient of permeability $k > 1 \times 10^{-3}$ m/s and ideally should be:

- rounded;
- of grain size greater than 20 mm;
- smooth surfaced;
- non-reactive in mildly acidic conditions;
- relatively uniform in grain size; and
- free of carbonates that could form encrustations around the collector pipes.

It was considered that by undertaking an assessment of the material characteristics (approximate permeability, laboratory calcium carbonate testing, TCLP testing and organic content) an indication of the suitability of the material to meet the objectives of the EPA drainage material requirements could be made.

3.1.1 Permeability

Hazen's formula was used to provide an approximation of the materials coefficient of hydraulic conductivity. Due to the relatively large particle size of the material is was determined that laboratory permeability testing would not be representative. The grading results for the BFS material indicated that the sieve size through which 10% of the material passed was approximately 2.5 cm. This equated to a k value of approximately 6 m/sec, indicating compliance with the guideline requirements.

3.1.2 Physical Characteristics

The particle size of the BFS was generally larger that 20 mm (<5% passing the 19 m sieve). Material was generally subrounded due to the nature in which the material was produced. Although the particles were not rounded, it was not anticipated that this would cause any detrimental impact on the performance of the slag when acting as a leachate drainage material due to the relatively low proportion of fines existing within the material.

3.1.3 Chemical Characteristics

When subjected to acidic conditions the material appeared to be non-reactive with TCLP results indicating a reduction in pH and no metals detected above inert levels.

Calcium carbonate laboratory test results (by weight) of 21.9% indicated a larger percentage present than currently considered 'ideal' by the EPA Guidelines. However, recent studies have been undertaken in the United States on the effects of calcium carbonate content in relation to leachate drainage systems:

- Study by Waste Management International/RUST on suitability of carbonate aggregate for landfill leachate collection systems based on research performed at University of Missouri-Rolla[i].
- A progress report on the WMI Research and Development project on carbonate compatibility for landfill leachate collection systems being performed at the Illinois Institute of Technology[ii]
- RUST experience in use of slag material as a leachate drainage media in Wheeler Landfill, Indiana

Results of leachate testing undertaken at the Elizabeth Drive Landfill as part of the environmental monitoring over the last 4 years indicate a relatively neutral pH. Results from the Elizabeth Drive Landfill indicated that between 1995 and 1999, pH levels were generally between 6.62 and 7.97. These results were consistent with the findings of the US studies which details leachate results from a large number of landfills.

Based on the comments and recommendations from the previous studies and past experience, it was determined that the calcium carbonate content measured within the slag material would not pose a problem in its intended use as a leachate drainage collection material providing the characteristics of the leachate do not become substantially more acidic. This finding was in conflict with the Guideline requirement and therefore further discussion was entered into with the appropriate NSW EPA representatives.

3.1.4 Comments and Recommendations

Correspondence with the EPA indicated that providing it was demonstrated that no detrimental environmental effect would occur from use of the slag, the enterprise's endeavour of seeking to apply a beneficial re-use of a waste product within the leachate collection system would be fully supported. The EPA concurred that the elevated levels of calcium carbonate would not be detrimental to the system provided that the waste stream remained non-putrescible and low pH wastes were excluded. It was deemed essential that a rigorous protocol be adopted to ensure the materials quality is maintained.

The preliminary sampling and laboratory results indicated that the material was suitable for use as a leachate drainage layer. The blast furnace slag was therefore adopted for use within the leachate collection system. Significant cost savings were realised when compared with the previously used single size rounded river gravel. A comprehensive periodical conformance testing program was implemented to provide evidence that the imported slag material continued to meet the requirements and did not deviate from the tested specimen.

3.2 ASSESSMENT OF ALTERNATIVE DAILY COVER MATERIAL

The purpose of the analysis was made of a material proposed to be used as an alternative daily cover material to the clays and weather shale currently in use at the Elizabeth Drive Landfill. An assessment was made to characterise the material within the Unified Soil Classification system. Additional laboratory testing was also undertaken with respect to a range of potential contaminants.

The NSW EPA Guidelines identify the objectives of daily cover as being:

- Limiting run-on and infiltration of water;
- Controlling and minimising the risk of fire;
- Minimising the emission of landfill gas;
- Suppressing site odour;
- Reducing fly propagation and rodent attraction; and
- Decreasing litter generation

3.2.1 Proposed Material

The proposed cover material consisted of recycled demolition waste. Originating at a number of sources, the material is transported to the recycler's yard and processed through a crusher and screens. Through the screening process the material is separated into two stockpiles – one of coarse (approximately 70% of the waste), and one of fine. A ready market is available for the coarse material, however the fine material is not in great demand. It is this excess material that was proposed for use as daily cover material

Two composite samples of the proposed material were taken from a number of stockpiles. Particle size distribution tests, including hydrometer analysis were carried out on each of the two samples. Chemical laboratory tests were also undertaken on a separate single composite sample and two subsequent samples. The tests included total metals, PAH, TPH, BTEX, OCP and TCLP.

3.2.2 Physical Properties

Based on the grading results obtained, the material may be classified as SW – well graded gravelly sand with clay and silt. The two gradings indicate that the manner in which the material is crushed during processing generates a relatively homogeneous material below the 4.75 mm sieve, varying only in the proportion of crushed construction rubble in the gravel fraction. A visual assessment of the material identified the composition as crushed concrete and brick fragments.

Again, through the application of Hazen's formula, an approximation of the coefficient of permeability was obtained of between 4.0×10^{-4} cm/sec and 3.6×10^{-3} cm/sec. These results, when compared with those of cover material currently in use (weathered shale and clay) indicate that there may be a potential reduction in run-off and resulting marginal increase in leachate generation through infiltration. However, due to the relatively short period of time in which the daily cover material is exposed to the elements, and the current practice of compacting the daily cover, it was not deemed to be a significant issue. Should areas of daily cover be exposed for prolonged periods it was recommended that intermediate cover consisting of the existing stockpile of residual clay be used.

3.2.3 Chemical Properties

Chemical testing was undertaken to assess the potential of introducing contaminants into the surface water collection system from run-off across the proposed cover material. The results indicated that concentrations of the selected analytes within the three samples did not exceed the relevant NSW EPA criteria for disposal as inert waste, and as such would not pose a threat to the stormwater system.

It was noted that although the concentrations measured did not exceed the EPA criteria, the concentrations of TPH compound, metals, pesticides and PAHs were above background levels. This indicated that the material had potentially been sourced from a location where the previous site activities had impacted on its characteristics. Additionally, the presence of these levels indicated the potential for higher concentrations to exist within the material.

3.2.4 Comments and Recommendations

As the material is sourced from a number of locations prior to being processed at the recycler's facilities it is likely that the existence of chemical compounds may vary between individual loads. It was recommended that should large quantities of the proposed material be delivered to site for use as daily cover material, that a regular sampling and testing program be implemented. In general the material was suitable for use, providing the appropriate precautions were undertaken prior to its use.

3.3 LEACHATE COLLECTION PIPES

The evaluation was undertaken to assess the performance of a proposed leachate drainage system comprising of a 300 mm thick gravel drainage blanket over a CCL. The existing liner was designed to slope towards the north at 3.5% and to the west at 1%. Perforated HDPE leachate collector drainage pipes within trenches run in the gravel drainage blanket layer in an east/west orientation at 120 m centres and north/south at 50 m centres.

The proposed leachate collection system removed from the existing design the north/south collection trenches and pipes. A significant economic saving both in labour and materials would result if the proposed system was adopted.

The current EPA Guideline Benchmark requires leachate pipe separation to be a maximum of 50 m, to achieve a goal of no more than 300 mm of leachate head on the barrier liner layer.

3.3.1 Model Preparation

To model the flow of leachate through the proposed collection system, the Hydrologic Evaluation of Leachate Performance (HELP) computer program, version 3.04 was used.

A HELP program model is generated through the detailing of the landfill's geometry, leachate collection system and material properties. Meteorological data is then input into the program to model leachate flow quantities and resulting leachate head.

3.3.1.1 Weather Data

For the purposes of this assessment, precipitation data of 50 years was obtained from a Bureau of Meteorology weather station located near the landfill site. Additional climatic information, including temperature, solar radiation and evapotranspiration data was also obtained where available.

3.3.1.2 Landfill Geometry

The following assumptions were adopted for the surface profile parameters of the landfill:

- The landfill will be covered with topsoil and a fair stand of grass;
- No capping layers have been constructed;
- The covered surface of the landfill is graded to a slope of 1%
- The surface length over which run-off would travel is 120 m; and
- The fraction of area allowing run-off is 0%.

It should be noted that the model parameters were adopted to provide a 'worst-case' scenario, allowing maximum infiltration of rainfall. Such a landfill profile would determine the potential maximum output of leachate.

Three subsurface landfill profile cases were chosen to be evaluated by the HELP model. All cases included a compacted clay liner of 1000 mm thickness, overlain by a 300mm thick drainage blanket, waste layer and 500 mm cover layer. The three cases varied in waste thickness only. Waste thickness of 11 m, 20 m and 58 m were adopted for proposed minimum, average and maximum waste thickness respectively for Cases 1, 2 and 3.

3.3.1.3 Leachate Flow Path

Once reaching the collection drainage blanket, the maximum distance leachate would need to travel before reaching a collection pipe and drain, would be 130 m. This is based on the 3.5% north/south and 1% east/west grade, and a 120 m drain spacing running east/west.

3.3.2 Results

A summary of the results is included below:

Case	Average Leachate (m^3/year)	Maximum Leachate Head (mm)
1	1738	187
2	1734	145
3	1731	117

The results indicate that the proposed leachate drainage system would limit the maximum head on the CCL to a 'worst-case' of approximately 187 mm, which is below the EPA Guideline goal requirement of 300 mm.

It should be noted that the head of leachate on the liner decreases with increasing waste thickness. This is due to a larger proportion of the precipitation infiltrating through the cover layer being suspended/absorbed within the waste layer.

Actual recorded leachate quantities generated at the landfill indicate approximately 1095 m^3/year is produced and recirculated back into the waste mass. The volumes estimated by the HELP models are significantly greater, as expected, indicating the conservative nature of the parameters adopted.

3.3.3 Comments and Recommendations

On the basis of the results obtained, it appeared that the proposed leachate drainage system was feasible and would satisfy the EPA goal of less than 300 mm leachate head on the barrier liner layer. Based on these results it was suggested that in the circumstances at Elizabeth Drive, the north/south leachate drains at 50 m centres were not warranted.

A case is currently being put forward to the EPA to amend the current landfill design and implement the proposed system.

3.4 EFFECTS OF INCREASED GRAVEL CONTENT ON CLAY LINER PERMEABILITY

An assessment was undertaken on two types of gravelly clay material to assess its suitability in meeting the EPA benchmark techniques.

The EPA requires that the leachate barrier system be designed to contain leachate over the period of time that the waste poses a potential threat to the environment and should be designed and installed in accordance with an approved construction quality assurance program. Should a recompacted or modified soil liner be adopted, the guidelines identify a suitable liner material as having a compacted thickness of at least 900 mm and an insitu coefficient of permeability of less than 10^{-9} m/s.

Currently at Elizabeth Drive Landfill a recompacted soil liner is installed to a thickness of 1000 mm, with the coefficient of permeability exceeding the EPA requirements. This material has been previously validated through extensive laboratory testing, including triaxial cell permeability testing. The construction specification adopted to date for the installation of this material limits the gravel content to 10%. This upper limit was implemented as it is generally difficult to simulate the effects of macro defects, such as potential effects of gravel, on permeability within the limits of laboratory testing techniques.

3.4.1 Proposed Material

Large stockpiles of clay with gravel contents ranging between 10 and 30% have resulted from the selective stockpiling of material on the site during the cell excavation process. In order to validate the suitability of this material for use as a liner material, two representative sources of material were selected. Gravel contents for each material selected were 15% (Area A) and 25% (Area B).

3.4.2 Test Method

In order to accurately measure the performance of the proposed clay liner, the use of insitu Sealed Double Ring Infiltrometers (SDRI) was adopted. One testpad for each material selected was constructed under quality assurance procedures and conditions currently used for all clay liner installation at the site. The pads were placed to a compacted thickness of 1000 mm at a location adjacent to the active landfill cell. The pads were constructed over a subgrade of compacted blast furnace slag covered with geotextile.

One SDRI apparatus was installed within each of the two testpads. Each SDRI apparatus consisted of a 1.5 m diameter internal and 2.5 m diameter external ring. The rings were sealed into each pad using a mix of bentonite and concrete. Clay and sand was placed around the outer circumference of the external ring to minimise potential desiccation.

The inner rings were fitted with an external valve and flexible bladder at a height of 500 mm to allow measurement of the water displaced within the inner ring. The Area A rings (inner and outer) were filled with water to a height of 600 mm. The Area B rings were filled to a height of 1000 mm. Throughout the test the head of water within the outer rings was maintained at 600 mm and 1000 mm respectively by filling from an external source.

To minimise the potential influence of evaporation and direct rainfall, both sets of rings were covered with 15 mm plywood and covered with tarpaulins. To allow estimation of the potential effect of evaporation, a '44' gallon drum was filled to a height of 800 mm and placed beneath the covers of one of the tanks.

Falling head permeability laboratory tests were undertaken in 2 litre moulds to provide a comparison with field testing.

3.4.3 Measurement

To estimate the seepage water into the testpads within the internal ring, weighing of the flexible bladder was undertaken. The valve was sealed and the bag weight determined using electronic scales. The bag was then refilled and reconnected to the valve. Measurement was undertaken initially on a daily basis to ensure that sufficient quantity of water was available within the flexible bladder should high flowrates eventuate. Based on these initial results, it was deemed sufficient to undertake readings every three to four days apart. The tests have been undertaken for approximately 5 months.

It is expected to decommission both infiltrometers once the tests have run for a period of 6 months. This will enable a measurement of the actual wetting front to be undertaken and an accurate indication of permeability made. Ideally the test would run until failure of the apparatus or penetration of the entire liner thickness, however the material requires validation to be used in the current cell construction works.

3.4.4 Draft Results

Laboratory results undertaken on the clay samples have indicated that both materials performed above the EPA benchmark requirements with results in the order of 1×10^{-10} m/s.

Preliminary calculations based on the field results have shown that although the material initially appears to have a marginally higher permeability than recommended, once the initial uptake has occurred, and the wetting front has been established, the seepage reduces. This point occurs after approximately 60 days of measurement for Area A, with no appreciable change for Area B. The coefficient of permeability for Area A appears to stabilise at approximately 1×10^{-9} m/s. The Area B material has a marginally higher permeability coefficient of approximately 5×10^{-9} m/s.

Some reduction in total seepage may need to be made to compensate for evaporation in determination of the final results, although draft results indicate that this may be relatively insignificant.

3.4.5 Discussion

Actual permeability of the material will not be able to be calculated until an accurate measurement of the wetting front is made during the decommissioning phase. However, the results obtained to date indicate that the material used within Area A is generally suitable for use a liner material according to EPA requirements. Area B, with a greater gravel content, appears to have a permeability coefficient marginally above the EPA requirement. As a result it would generally be recommended that the current specification gravel specification limitation be increased from 10% to 20%.

Providing selective sourcing of material and gradings are undertaken, it would be possible to make use of large portions of the stockpiles material for liner construction. Material not meeting the specification requirements should be used for daily cover requirements. An appropriate conformance testing program would need to be implemented to ensure gravel content did not exceed the limits set.

4. DISCUSSION

The purpose of geotechnical investigations, at proposed or current landfill sites, is to assist in the development of landfills in accordance with the NSW EPA Solid Waste Landfill Guidelines. Through interpretation and analysis of the geotechnical investigation results, assessment of the potential to adopt alternative benchmark techniques can be made. Provided that appropriate investigations and analysis are undertaken, cost effective and environmentally sound solutions to landfill design problems can be developed.

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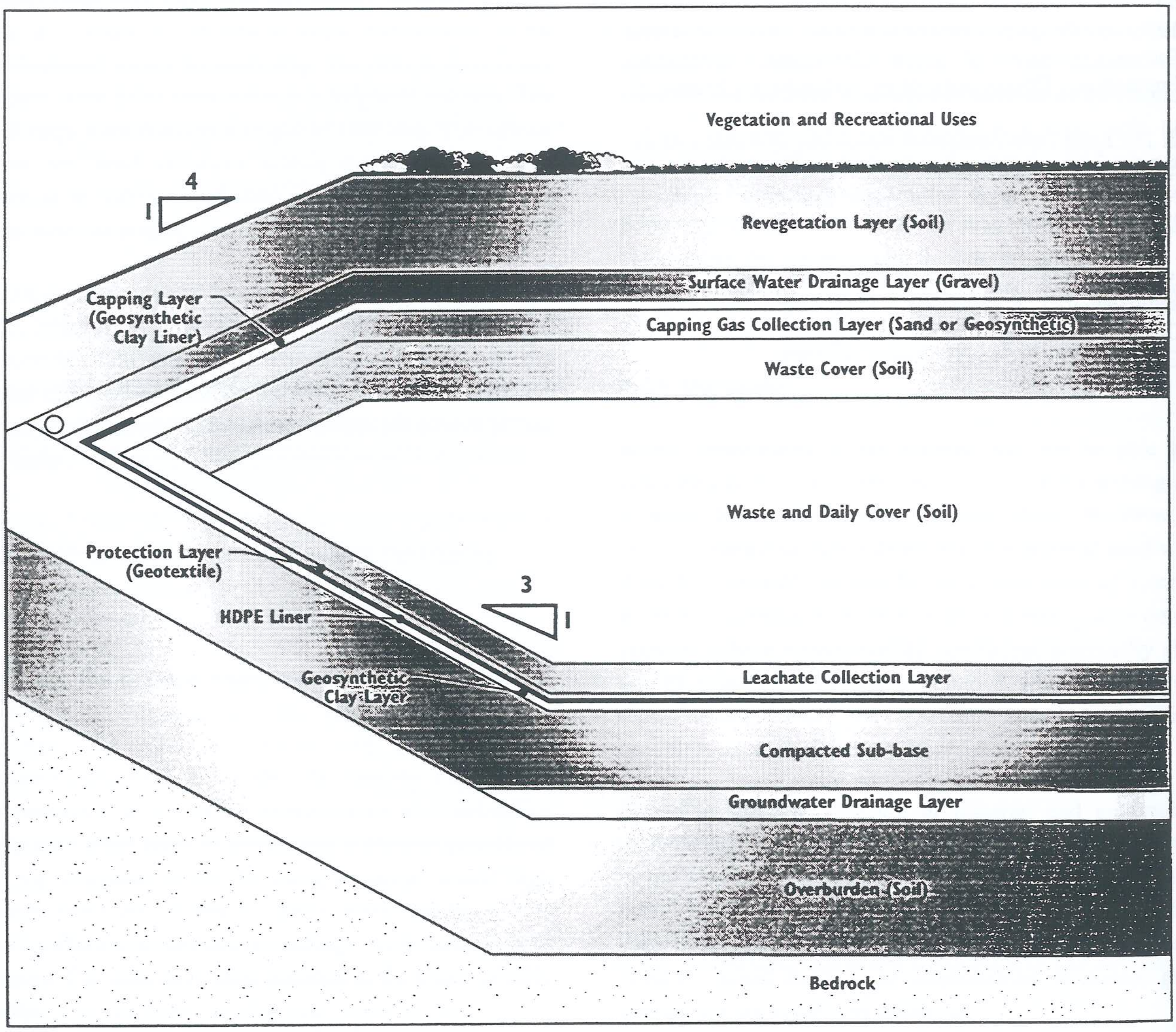

Figure 2.1 Concept Plan for Proposed Landfill