GEOTECHNICAL CHARACTERISTICS OF COAL MINE SPOIL

Stephen Fityus\(^1\), Greg Hancock\(^2\) and Tony Wells\(^1\)

\(^1\)School of Engineering, The University of Newcastle, NSW, Australia,
\(^2\)School of Environmental and Life Sciences, The University of Newcastle, NSW, Australia

ABSTRACT

This paper presents data on the geotechnical characteristics of the overburden, or spoil, produced during open-cut mining operations in the Hunter Valley, specifically in relation to the stability of spoil piles and the hydraulic characteristics of spoil and post-mining landscapes. A value of 33.4° is reported for the peak shear strength of "typical" spoil. This value is shown to reduce slightly at large shear strains and further when spoil materials are sheared after breaking down on exposure to water. Data on the permeability of different spoil types is presented, showing that permeability decreases with mudrock content. The presence of coal in the spoil is shown to have a significant effect on its hydraulic properties. Due to its hydrophobic tendencies, coal tends to resist the infiltration of water. However, spoils containing coal also tend to resist the storage of water that does infiltrate, causing coal-rich materials to drain quickly. This is demonstrated by considering the water retention properties of washed coal. The spoils are shown to have significant quantities of total leachable salt, but that leaching by a significant volume of water is needed for its total removal. The results show that a significant amount of salt is released upon first leaching, but that the rate of leaching decreases significantly with continued rainfall percolation. The paper concludes with a brief discussion of the potential for salt leaching from mine-spoil landscapes and its consequences for water quality in post-mining environments.

1 INTRODUCTION

Coal mining is an area of applied geomechanics with a unique set of problems. These involve natural, processed and waste materials which are derived from disturbed and undisturbed soils and rocks. Commonly encountered problems include issues with stability (rock slopes, spoil piles, stockpiles of processed coal and tailings impoundments), issues with groundwater control, issues with salinity and acidity and issues with mine site rehabilitation. Surprisingly, there is a relative scarcity of published data on parameters to facilitate geotechnical analyses to address this diverse range of problems. This paper presents data from a number of studies undertaken to obtain a range of geomechanical and geoenvironmental properties of mine spoil materials. It is not a comprehensive study, in that it does not attempt to evaluate all of the properties of spoil necessary to address every problem listed above. However, it does provide selected data that have particular relevance to the design and evaluation of mine site rehabilitation strategies.

2 MINESPOILS

When compared to naturally occurring geomaterials, minespoils are highly variable materials. This is because they are the product of an extensive range of combinations of different rock and soil materials, and highly variable treatments during the mining process. The parent rock materials include conglomerates, sandstones (well or poorly sorted; fine, medium or coarse; lithic, silicious, etc), siltstones, mudstones, shales, laminites, claystones, cherts, ironstones and of course, coals. Excavation methods include blasting, ripping and digging; handling and haulage methods include, draglines, dump trucks and dozing. The resulting spoil is a highly heterogenous material composed of many elements and with a wide variety of possible textures, involving particles from sub-micron size to boulders in excess of 2 m.

Clearly, in the context of this study, it is not possible to test all possible spoil materials, and there is no such thing as a single, representative spoil material. In order to provide some amount of useful information, a small number of common spoil types were studied in this work. Spoils were collected from the Rixs Creek mine in the Hunter Valley and the coals tested came from mines in the Bowen Basin.

Four different materials were included in this study. An 'average' spoil was created by sampling from an area of freshly tipped spoil. Equal quantities of 4 different spoils were mixed to produce this material. These spoils were selected to widely include sandstones, mudrocks and coaly material, and to include materials ranging from highly weathered to fresh. A 'coarse' spoil was selected to comprise mostly fresh fine to coarse sandstone fragments. A 'typical' spoil was collected from windrow in an area which had been graded by dozers, after tipping. A 'partings' material, from a load of seam interburden, was also included in the study.
A "point count" identification of rock types was carried out on 100 fragments (6.7 mm-9.6 mm) from each prepared bulk sample. The compositions of each sample are summarised as:

- 'coarse' 50% sandstone, 20% conglomerate, 24% mudrocks, 5% chert and 1% coal.
- 'typical' 60% fine sandstone, 39% mudrocks and 1% ironstone.
- 'average' 30% fine sandstone, 64% mudrocks, 1% chert and 1% coal.
- 'partings' 84% carbonaceous mudrocks, 16% bright coal or fragments containing coal.

The chemical weathering of the particles was more prominent in the average sample compared to the typical and coarse samples, with observable iron staining in 39% of particles.

3 SHEAR STRENGTH

The shear strength of minespoil was measured using a large (300 mm x 300 mm x 190 mm deep) "Prolab" multi-speed direct shear apparatus. The tests were performed following standard, Q181C (2002), Effective Angle of Internal Friction at Constant Volume Conditions for Granular (Coarse Grained) Materials. In this test method, the sample is placed in the shearbox in a loose, dry condition, then inundated, consolidated and sheared. In the case of mine spoils, because of the high proportion of mudrocks, there is significant particle degradation and often the 190 mm high sample is reduced to around 130 mm during testing. A similar degradation is evident in minespoils exposed to the agents of physical weathering in mine dumps. Two sets of tests were performed: one set of tests on fresh spoil and one set on material that already been subjected to direct shear testing (i.e. recycled material).

The material employed for shear strength testing was the 'typical' spoil. In its sampled state, the material was described as silty sandy GRAVEL and contained 10-20% gravels up to cobble size. A maximum particle size of 19 mm was considered permissible for the large shearbox used (Q181C, 2002) so before testing commenced the bulk sample was screened to remove all particles greater than 19 mm (about 10% of the raw sample). These were crushed to pass the 19 mm sieve and they were then returned to, and blended evenly through, the sample. The particle size distribution curve for the prepared sample is shown in Figure 1. Figure 1 was obtained using a sieve analysis of the coarse fractions and by using a Malvern laser diffraction particle sizing device for the sub-150 micron friction. Figure 1 also shows the particle size distribution of the sample after testing, which is the same as the initial particle size distribution of the material tested for a second time.

From Figure 1 it is found that \( D_{50} = 1.2 \) mm, \( C_v = 92.1 \). According to the Unified Soil Classification System (USCS), the prepared coarse samples are classified as (GM) silty sandy GRAVEL, fine to medium, pale grey siltstone gravels, fine to coarse sand, low liquid limit silt and a trace of pale grey clay of low plasticity. General geotechnical characteristics were also determined for the prepared sample, and these are presented in Table 1. The dry density and optimum water content values were determined according to the AS 1289.5.1.1 (2003) Test Method.

![Figure 1: Results for tests on fresh and previously tested samples.](image-url)
GEOTECHNICAL CHARACTERISTICS OF COAL MINE SPOIL

Table 1: Physical properties of the prepared sample

<table>
<thead>
<tr>
<th>Soil Size (mm)</th>
<th>Atterberg Limits (-4.75μm fraction)</th>
<th>Standard Compaction (whole soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;19.0</td>
<td>Liquid Limit (%)</td>
<td>Plastic Limit (%)</td>
</tr>
<tr>
<td></td>
<td>28.7</td>
<td>19.4</td>
</tr>
</tbody>
</table>

Direct shear testing was carried out at 0.63 mm/min, under applied normal pressures of 100, 200, 300 and 400 kPa. Both peak strength and residual strength values were identified from the results. The results for tests on fresh and previously tested samples is presented in Figure 2.

![Large box 0.63mm/min](image)

a) Shear stress – horizontal strain behavior.

![Large box 0.63mm/min](image)

b) Shear stress – normal stress results.

Figure 2. Results for tests on fresh and previously tested samples.

The results of Figure 2a show that the fresh spoil exhibits firstly a peak strength, which reduces slightly to a residual strength at large strain. Figure 2b is interpreted to give a peak friction angle of 33.4° and a residual angle of friction of around 32.4°. Cohesion is negligible. This peak value is higher than the value of 28° and the residual value much higher than the value of 18° which was reported by Richards (1998) for Bowen Basin spoil. The results in Figure 2 also indicate a consistent and significant decrease in the shear strength of samples that are tested a second time. The individual sample results in Figure 2a show that retested samples not only have lower shear strengths overall, but they exhibit little if any sign of peak strength behaviour. From Figure 2b it is seen that the shear strength of degraded spoil is reduced. The peak friction is reduced from 33.4° to 28°, whilst the residual angle of friction is reduced from around 32.4° to 28°. These reductions are significant. These values are consistent with those for saturated blocky Bowen Basin spoil given by Simmons (1995) but less than those given for fine and medium spoils. Further details of direct shear test results on minespoil can be found in Nakao and Fityus (2008).

4 HYDRAULIC CONDUCTIVITY

The hydraulic conductivity of the different mine spoils was tested using column infiltration tests. This was done as part of the study of the salt release characteristics of spoil, as described in Section 6. The columns used were made from 96 mm diameter Perspex tubes. The tubes were packed loosely with spoil, with particular care taken when filling the columns to prevent particle size segregation and to avoid creating interconnected zones of preferentially coarse material. The materials were placed to a height of 210 mm and subjected to a series of one hour rainfall events with an intensity of approximately 20 mm/hour delivered by a peristaltic pump (see more detailed discussion in the following section). The mass of the transmitted liquid was measured by mounting the outflow collection vessel on a logged balance.

Australian Geomechanics Vol 43 No 3 September 2008
Due to the size limitations imposed by the column, it was necessary to limit the maximum particle size of the spoil used: for the 96 mm diameter columns, a maximum particle size of 10 mm was considered sufficiently small so that any individual particle would not significantly affect flow through the column. As the spoil collected had more than 25% of its particles >10 mm, a size reduction had to be performed. So as not to bias the sample by removing materials that would naturally fracture to produce larger fragments, this was done by taking a sample of the whole oversized material in each case and crushing it so that it all passed through the 9.6 mm sieve. (Only fragments initially in excess of 9.6 mm were crushed). Final gradings are shown in Figure 3.

![Graph showing particle size distributions of samples used for column tests](image)

**Figure 3** Particle size distributions of samples used for column tests

The hydraulic properties of the different spoils were observed to vary considerably. Firstly, the water holding capacity of each spoil was different and, as a consequence, the time to produce the first outflow varied for each sample. The first outflow (10 ml) came from the partings during its second event of 134 ml. The coarse and typical spoils produced their first outflow (50 ml and 110 ml) during their third rainfall events of 129 ml and 141 ml (respectively). The average spoil did not produce any outflow until the fourth event (94 ml) of 127 ml. The time taken to produce the first outflow is a reflection of the water retention characteristics of the spoil and clearly the average spoil with its higher proportion of mudrocks has the highest water holding capacity.

Throughout the testing, the coarse and typical spoils behaved similarly and consistently, receiving rainfall without surface ponding. They passed most of the rainfall as outflow within around 2 hours of the start of each event, although the bulk of the outflow occurred during a one-hour interval, which lagged behind the start of the rainfall event by around 15-20 minutes. This result suggests that the hydraulic conductivity of the coarse and typical spoils is greater than $1.3 \times 10^{-5}$ m$^3$/hr.

The average spoil behaved differently. For the first couple of events the rainfall infiltrated instantaneously but, as the number of events increased, it began to pond, remaining as long as several hours after the rainfall had ceased. Also, it continued to release liquid for most of the 2 day period between events. This is consistent, however, with its greater proportion of mudrocks and its observed tendency to disintegrate after wetting. Because of this particle disintegration, which occurred to produce finer material, the saturated hydraulic conductivity of the wetted average spoil was reduced to around $1 \times 10^{-5}$ m$^3$/hr.

The partings also behaved differently. Even for the first rainfall events, rainfall ponded on the partings for up to 2 hours, but once it had infiltrated, significant outflow was complete in only a few hours. For rainfall events 3 and 4, the measured hydraulic conductivity was $7 \times 10^{-5}$ m$^3$/hr. After 5 rainfall events, the hydraulic conductivity had reduced to around $2.5 \times 10^{-5}$ m$^3$/hr. Partings also have a higher proportion of mudrock which could explain the ponding and the reducing hydraulic conductivity, but not the rapid drainage, ponding and low water retention associated with the first rainfall events. These result, in fact, from the complicated hydrophobic characteristics of the coal and carbonaceous substances which are present in large amounts in the shale partings. The partings initially resist wetting, but once infiltrated, they give up their water readily. A similar behaviour was reported by Fityus and Li (2006) in pure coal and is discussed further in a following section. However, upon thorough wetting, the shales swell, disintegrate and hydraulic conductivity is reduced.
5 SALT CONTENT

Total leachable salt contents were estimated for three of the spoil materials. In order to leach most of the soluble salt from the spoil material, it is necessary to expose a sample of pulverised spoil to an excess of water. In this study, this was done by analysing the supernatant obtained after washing 5 g to 10 g of spoil (ground to <90 μm) in 1 - 2 litres of distilled water. This corresponds to a leaching ratio of between 50 and 200 l water/kg soil, as shown in Table 2. The leachate produced was collected and submitted to species concentration analysis using a Dionex Ion Chromatograph. The results, expressed as total salt, are shown in Table 2.

Table 2: Summary of total leachable salt and column leaching test results.

<table>
<thead>
<tr>
<th>Spoil type</th>
<th>total leachable salt</th>
<th>leaching ratio used in test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg salt /kg soil</td>
<td>l water/ kg soil</td>
</tr>
<tr>
<td>average</td>
<td>3367</td>
<td>49.5</td>
</tr>
<tr>
<td>typical</td>
<td>2321</td>
<td>45.6</td>
</tr>
<tr>
<td>coarse</td>
<td>4810</td>
<td>174.5</td>
</tr>
</tbody>
</table>

6 A SALT RELEASE DURING INFILTRATION

Leaching tests were performed on representative samples of the fresh mine spoil types described above, in a series of undergraduate projects at the University of Newcastle (Reid, 2004; Simic, 2005; Ford, 2006). The experimental arrangement was the same as that used in the assessment of hydraulic conductivity described above, with the incorporation of electrical conductivity (EC) equipment into the outflow piping to measure the EC of the leachate. The rates of inflow and outflow were recorded and the chemical characteristics of the leachate (electrical conductivity, EC and some quantitative ion concentration analyses using Ion Chromatograph) were measured. Photographs of the setup are shown in Figure 4.

Figure 4: Experimental setup for salt leaching tests. a) the full arrangement showing column, peristaltic pump, rainfall delivery tubes and conductivity probe on the outflow pipe. b) close-up of column and rainfall tubes showing a wetting front in the sample.

Each of the samples was subjected 9 or 10 rainfall events, during which 20mm of “rainfall” was delivered to the surface of the sample (a total of around 144ml) in a 1 hour period. This rainfall pattern was selected to represent a significant rainfall or thunderstorm event that might reasonably occur in the Hunter Valley. One event was imposed every 2 or 3 days. Because
of differences between the peristaltic pumps used, the actual amount of water delivered to each column varied by as much as 10% (see Table 2).

Simulated rainfall solution was made up to have the same EC and a similar chemical composition as typical rainfall in the Hunter Valley which, according to EPA (1994), is around 16 μS/cm (0.016 mS/cm). The chemical characteristics of the prepared rainfall solution (mg/l), compared with those reported in EPA (1994) [values in mg/l in brackets] are: Ca²⁺ 0.16 [0.17]; Cl⁻ 1.7 [1.64]; K⁺ 0.18 [0.18]; Mg²⁺ 0.146 [0.14]; Na⁺ 1.144 [1.18]; SO₄²⁻ 1.73 [1.54]; CO₃²⁻+HCO₃⁻ 0; pH 5.02 [pH 4.78]. Electrical conductivity probe measurements were taken every 12 seconds, and the first 30mm of leachate produced from each rainfall event was collected and submitted to species concentration analysis using a Dionex Ion Chromatograph.

In order to estimate the total and progressive salt release from the spoils, it was necessary to establish some relationship between the measured EC and the total salt concentration in ppm. This was done by plotting the measured ppm values in the first 30ml of each event, with the average EC recorded while the first 30ml was leached. The relationship was established and is presented in Fitus et al (2007). Using this relationship and the average conductivity in the leachate from each rainfall event was determined, and hence, the average concentration was estimated, allowing estimation of total and progressive leached salt values. A summary is presented in Table 3. (Space does not permit a discussion of salt species results here.)

Table 3. Summary of total leachable salt and column leaching test results.

<table>
<thead>
<tr>
<th></th>
<th>total leachable</th>
<th>leaching ratio</th>
<th>bulk density</th>
<th>leaching ratio</th>
<th>salt leached</th>
<th>proportion removed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg salt /kg soil</td>
<td>l water/ kg soil</td>
<td>kg/m³</td>
<td>l water/ kg soil</td>
<td>mg salt /kg soil</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>3367</td>
<td>49.5</td>
<td>1.467</td>
<td>0.55</td>
<td>892</td>
<td>0.26</td>
</tr>
<tr>
<td>typical</td>
<td>2321</td>
<td>45.6</td>
<td>1.414</td>
<td>0.50</td>
<td>950</td>
<td>0.41</td>
</tr>
<tr>
<td>coarse</td>
<td>4810</td>
<td>174.5</td>
<td>1.44</td>
<td>0.40</td>
<td>1045</td>
<td>0.22</td>
</tr>
<tr>
<td>partings</td>
<td>1.111</td>
<td>0.40</td>
<td>1378</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 indicates that for leaching by between 0.4 and 0.55 l of water per kg of soil, the soil produces between 890 and 1380 mg of salt per kg of spoil. This represents between 22% and 41% of the total leachable salt content. All things considered, the average spoil with its higher mudrock content released less salt and a lower proportion of its total salt. The partings produced relatively the most salt.

Figure 5 presents data on the rate of salt leaching. Figure 5a) shows the raw data for the change in EC with cumulative volume of leachate produced. The vertical features in some of the results represent discontinuities at the start of the rainfall events.

Figure 5b) shows the same data, smoothed and re-expressed as the leachate salt concentration and the leaching intensity: litres of water that have leached each kilogram of spoil. All of the spoils show similar characteristics. The earliest leachate
quickly attains a peak concentration of between 6500mg/l (typical) and 11000mg/l (average), at leaching ratios of around 0.1. By the time the leaching ratio reaches 0.2 (each kg of soil has been leached by 0.2 l of water), the leachate concentrations have reduced to values of less than 1000mg/l, and thereafter, they reduce only slowly with continued leaching. As the leaching ratio approaches 0.5, the leachate concentrations attain values between 200 and 500mg/l. Further details of salt leaching from minespoils can be found in Fityus et al. (2007).

7 WATER RETENTION OF COAL

Whilst coal is a minor component of minespoils, its chemical composition is very different from true mineral soils and if present can significantly affect the behaviour of spoil materials. This was evident in the somewhat anomalous infiltration behaviour of the partings. This part of the work looks specifically at some hydraulic properties of coal, to improve our understanding of its particular characteristics.

The coals used for this part of the work are Permian bituminous coals of low to medium rank, from the Bowen Basin in Central Queensland, Australia, although they are generally similar to those mined throughout the Hunter Valley.

Important water retention properties include the intrinsic and saturated-drained water content values. Unsworth et al. (1988) reports that water molecules are found in many different environments within prepared coal. These include pore-held, surface-held and interparticle water, and these are strongly influenced by the state of preparation. For a particular coal, the sum of these is referred to as the saturated/drained water content (i.e. drained of excess free water after inundation and soaking). The free-drained saturated moisture content is determined using a method derived from AS 1038 Part 1 Method C and is quoted as a percentage of wet weight. Basically the process involves soaking a sample of bulk coal in water for a period of time. The sample is held in an open weave bag for convenience. The bag is lifted clear of the waters surface and with the chamber sealed the bulk solid is allowed to drain for a set period of time. At the end of the drain period the moisture content is determined by loss in weight after oven drying.

Water that lies beyond the influence of surface bonding forces is referred to as a pore-held water content. Unsworth et al. (1989) suggests that coal porosity spans several orders of magnitude, from <1 nm to >10µm. The pore-held moisture, measured at 30°C and 90% relative humidity, is referred to as the inherent moisture of the coal, and considered to be an intrinsic property of particular coals, ranging from 2% to 20% for bituminous coals (Unsworth, et al. 1988). A summary of key water content characteristics is presented in Table 4

Table 4 shows that one of the coals has a significantly higher saturated water content value than the other. This same coal type also displays the lowest bulk density value.

<table>
<thead>
<tr>
<th>coal type</th>
<th>carbon content</th>
<th>water content as supplied</th>
<th>saturated/drained water content</th>
<th>intrinsic (pore held) water content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>wt %</td>
<td>%</td>
<td>%</td>
<td>% (ad)</td>
</tr>
<tr>
<td>A</td>
<td>71.6</td>
<td>19.3</td>
<td>33.2</td>
<td>4.4</td>
</tr>
<tr>
<td>B</td>
<td>78.9</td>
<td>7.4</td>
<td>23.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Water retention curves for the coals were determined for the two coals using both the contact and no-contact filter paper methods of suction measurement. The filter paper approach involves two stages. First, a water characteristic curve is determined for a standard filter paper type, in a procedure referred to as ‘calibration’. This involves establishing a relationship between the water content and suction for the filter paper. Second, the calibrated filter papers are placed in coal samples (either ‘in contact’ CFP or with ‘no contact’ NCFP) that have been prepared (by wetting or drying) to a range of different water contents, and allowed to attain suction equilibrium. The papers are then removed and their water contents determined. The calibration is then used to infer a suction value for the coal. These test methods are now well established and they are described in detail in Fawcett and Collis-George (1967); Houston et al. (1994) and Harrison and Blight (1998), and, for measurements in coal, in Fityus and Li (2006).
Where filter papers have no contact with the coal the only exchange of moisture between the coal and the paper is via the moisture vapour in a closed space. The concentration of this moisture vapour is controlled by the total water potential of the coal (that is, by the combination of the matric and osmotic potential components), and the filter paper attains a suction value reflecting the total water potential (or total suction) of the coal.

Where filter papers have contact with the coal, there is direct liquid connectivity between the paper and the coal and exchange of dissolved substances via diffusion is accommodated. At equilibrium, it is assumed that all chemical diffusion gradients have been eliminated and that the potential of the water phase is only controlled by the suction imposed by the coal particle matrix. Hence, it is considered that contact filter paper method gives values of matric suction.

The water characteristic curves obtained for the coals are presented in Figures 6a and b. The extreme points on each curve are estimated, assuming that fully dry soils have a suction of around 1,000,000kPa (Fredlund and Xing, 1997), and coal at its saturated water content (as measured elsewhere in this study) has zero (~0.001kPa) matric suction.

Coal B exhibits little wetting and drying hysteresis, while Coal A, which has a significantly lower carbon content and higher intrinsic and saturated water contents, has a significantly hysteretic behaviour. This result is consistent with the greater hysteresis evident in the lower rank (carbon content) coal (McCutcheon et al. 2001). For Coal B, despite the small hysteresis, the drying curves (open symbols) generally and consistently lie above the wetting curves (filled symbols).

It is significant to note that when water was added to wet the coals during sample preparation, some resistance to wetting was observed. The hydrophobic character of the coal particle surfaces was apparent. In most cases, the coals appeared dry enough to be dusty at water contents of 4% and 8%. Even with water contents as high as 12% most of the coals had a dry appearance. At water contents of 16% and above the coals typically began to appear wet with their appearance changing rapidly following only small increases in water content. These observations are consistent with the behaviour described...
from the water kinetics studies of McCutcheon et al. (2001) that suggest that wetting takes place by firstly filling the intraparticle pores and later the interparticle pores.

It is important to note that suction values less than 10 kPa are so small that it is generally considered that they cannot be reliably measured, and for most practical applications in soil mechanics, there is no need to try. In most soils, suction values less than 10 kPa correspond to near-saturated conditions. Clearly, compared to soils, coal has anomalous water retention properties, exhibiting extremely low (near saturated) suction values at relatively low degrees of saturation.

In this work, in order to illustrate this anomalous behaviour of coal more clearly, the filter paper calibration curve had to be extrapolated to the saturated paper water content of 150%, (suctions as low as 0.001 kPa), so that filter paper water contents up to 140% (Sr=0.93) can be interpreted. Whilst it is acknowledged that the precise values of suctions in this range are somewhat meaningless (that is, they are effectively zero for most purposes), extrapolation is useful in exploring the anomalous behaviour of a granular material with strongly hydrophobic tendencies.

8 DISCUSSION AND CONCLUSIONS

The data presented in this paper has application to a range of mining related issues. The shear strength data indicates that mine spoil is a moderate to low strength material and that, upon exposure to inundation and rehandling, its strength can reduce significantly. Whilst this is far from a full picture of the mechanical behaviour of mine spoil, it does provide some basic data to guide the design and assessment of spoil piles and their stability. Further work is needed to characterise the potential for spoil piles to consolidate, both under their own weight and when subjected to wetting. In particular, the role of partial saturation and tension cracking in affecting the stability of spoil piles needs further consideration. Some advice is given in Richards (1998).

The data on the hydraulic and salt release properties of spoils is particularly useful for the assessment of the long term behaviour of mined areas, once rehabilitated. Clearly, the mining process disrupts the naturally occurring geologic materials, and increases both their hydraulic conductivity and their surface area. This results in a body of spoil that is potentially more prone to leaching. This study shows that, upon initial exposure to percolating water, salts are initially released in relatively large concentrations, but these quickly reduce to values that are comparable with local waterways and shallow aquifers. The spoils studied release between 22% and 40% of their leachable salts when leached by up to 0.5 litres of rainfall per kg of spoil. Leaching by a considerably greater volume of water would be required to remove the remaining soluble salt.

The peak EC values of 8-14 mS/cm recorded in this work are much higher than those reported by Carroll et al. (2000: 0.4-6.3 mS/cm) and Charnock et al. (2005: 0.3-0.5 mS/cm) for spoils in The Hunter Valley and the Bowen Basin. They are also well in excess of those reported for topsoils (0.1-1.7 mS/cm), waterways (0.2-4.6 mS/cm) and soil aquifers (0.6-2.8 mS/cm), but within the range reported for rock aquifers (2.4-15 mS/cm) and spoil piles (6.3-11 mS/cm) (Dyson et al. 1995; DPNWS 2005). They are only likely to occur, however, in the first 0.1 litres of water leached through each kg of spoil. The long term EC values of 0.5-1.0 mS/cm are within the range of values quoted for spoils in the Bowen Basin, but higher than the typical values reported for the Hunter Valley. They are consistent with EC values reported for the Pages River and below those reported for Dart Brook and a Hunter Valley soil aquifer. The long term leachate EC values are slightly higher than EC values reported for surface runoff from mined and unmined areas in the Bowen Basin.

Using a simple hydrogeological water balance model (e.g. Hancock et al., 2005) the data presented in this paper are sufficient to facilitate a first approximation of the possible quantity of salt that could be leached from a rehabilitated mine site, and the consequences for groundwater and water in final voids. However, how much salt is leached and at what rate depends on many factors. These include the type of spoil, its permeability, its degree of weathering, the extent of fragmentation, its placed structure and climatic factors. The research presented here gives some useful insights into the potential for salt to leach from mine spoil, but clearly more research is needed before more reliable predictions regarding the storage, release, transport and fate of salts in rehabilitated minesites can be made.

The water retention properties of processed coal differ considerably from those of most granular geomaterials, due primarily to the significant number of hydrophobic sites on coal particle surfaces. As a consequence of this, coal undergoing drying will maintain negligible matric suctions for a considerable range of water contents below its drained-saturated value. This has significance for the hydraulics of spoils which contain a significant proportion of coal fines and for the handling of coal in stockpiles.
9 REFERENCES


Carroll C., Merton L., and Burger P. (2000); “Impact of vegetative cover and slope on runoff, erosion, and water quality for field plots on a range of soil and spoil materials on central Queensland coal mines”; Australian Journal of soil research, 38 (2); pp.313- 327.


Dyson, J.R. et al;(1985); “End of Grant No. 719 Coal Mine Rehabilitation”, NSW Coal Association, pp7- 21, 153-201.


