Mulwala Capping Investigation Report
Bayly St, Mulwala, NSW

8 March 2005

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1 INTRODUCTION

1.1 General

HLA Envirosciences Pty Limited (HLA) was commissioned by ADI Limited Ltd (ADI) to prepare a capping options assessment report detailing the investigations and recommended civil works required for managing contaminated areas at ADI Mulwala. This report has been prepared in accordance with HLAs proposal of 31 May, 2004 titled “Tender for Capping of Various Contaminated Areas” and the specifications contained in Tender Brief No. MUL SPEC 807 released by Mr Doug Wilson (Environmental Manager, Mulwala) on the April, 2004.

The primary objective of the capping onsite source areas is to reduce the leaching of soluble salts (in particular nitrate, sulphate, acidity and TDS) in soil by rainwater to a practicable extent sufficient to ensure that the use of groundwater offsite for drinking water purposes is not adversely affected. The overall objectives of the capping investigations were as follows:

- Delineate the lateral and vertical extent of nitrate and sulphate contamination in soil of the Upper Shepparton Clay (USC) acting as secondary sources of contamination in groundwater.
- If possible, assess the potential impacts of capping on groundwater quality.
- Develop a basis for delineating the areas and quantities of contaminated soil requiring capping.
- Conduct an assessment of the practicability of three capping options, including a Phytocap, a Clay Cap and a NSW EPA Landfill Reference Cap.
- Based on the assessment of practicability, recommend capping options for onsite source areas.
- Develop Management Plans for the implementation and maintenance of the recommended capping options.
- Provide implementation cost estimates for the recommended capping options.
- Identify any restrictions of land use and maintenance of the capping systems.

The recommendations contained in this report will allow ADI to install the capping solutions for managing release of contaminants to groundwater from secondary sources in soil at the site.

1.2 Background

Soil and groundwater contamination associated with the Mulwala facility has been the subject of numerous investigations over the past 5 years. These investigations delineated a groundwater plume with elevated levels of nitrate and sulphate concentrations that extends offsite in both the Shepparton and Calivil aquifers in a south-westerly direction.

These investigations concluded (Ref7. HLA, 2003) that there were a number of defined areas (Source Areas A to E) which were likely to be contributing to the groundwater plume. These source areas were generally represented by either waste dumps, or by the location of former manufacturing activities (known as Priority A sources). At most of these locations, it was identified that the primary residual mass of contamination resided in the Upper Shepparton clay aquitard, which lies immediately underneath the dune sands at the site. Consequently, the activities associated with this investigation have focussed on mapping the extent of contamination in the clays at these locations. Mapping of the contamination within the clays will allow the design and installation of an optimal capping system to reduce further leaching of contaminants into the groundwater system to an acceptable level.

The onsite Source Areas investigated (see Figure 1) included:

- Source Area A, including the Oleum Plant, Acid Plants and Effluent Treatment Plant;
- Source Area B, the former Effluent Drain;
- Source Area C, former Dump Area;
- Source Area D1, former Sulphur Dump;
- Source Area D2, former Dump Area;
- Source Area D3, former Iron Oxide Dump;
- Source Area E, Oleum Store (Former Sulphur Store).

During the delineation works undertaken for this project, it became apparent that the division and nomenclature associated with the two smaller contaminated areas located immediately north of Source Area A (defined as part of Source Area E previously) required revision. For this study, these two areas have been incorporated into Source Area A, and all references to Source Area E now refer only to the larger area immediately to the north west (refer **Figure 1**).

2 PROPOSED APPROACH AND METHODOLOGY

2.1 Delineation of Contaminated Areas

To delineate contaminant source zones (including surface waste materials) a delineation approach was developed that combined the use of subsurface (geoprobe) sampling and analysis and a geophysical investigation. The objective of this dual approach was to use the results of the geophysics survey to allow more reliable interpretation of contaminant distribution between sampling points and extent.

2.1.1 Geophysics

A number of the contaminant source areas are known to relate to surface disposal of materials such as gypsum, iron oxide and sulphate (Source Area D). As part of the Contamination Management Plan, it has been proposed that these waste materials should be removed and consolidated in an appropriate location. Given the nature of the materials (high conductivity compared to background), a geophysical survey with an EM-31 Ground Conductivity Meter (EM-31) was proposed to assist in determining their lateral and vertical extent.

The EM-31 measures the conductivity of the subsurface to a depth of approximately 3 - 6 metres. Changes in the measured conductivity can be associated with changes in geology and/or contamination. Due to its use of electromagnetic fields, the EM-31 is also highly sensitive to interference from metallic objects such as corrugated iron, fences and underground services. A comprehensive description of the methodology utilised is presented in the geophysics reports presented in **Appendix A**.

Using the handheld version of the EM-31, which was physically walked over the areas, an initial geophysical surveying event was undertaken (23 – 24 September 2004) of Source Areas D1, D2 and D3 on a line spacing of five (5) metres (where possible). In addition, a transect was also run over Source Area A in a north/south alignment over the location of the former Oleum Area (refer **Figure 3**). Based on the reasonable correlation between the results of this survey event and the early analysis results from the geoprobe sampling, HLA decided to undertake geophysical surveying of the remaining Source Areas (A, B, C and E).

To undertake and accelerate the performance of the second geophysical surveying event (undertaken on 26 October 2004), the EM-31 was attached to a quad bike with a trailer and towed over the additional source areas. Due to the presence of obstacles such as buildings, vegetation and embankments and a wide variety of services (eg. overhead steam pipes) the EM-31 could not be used to survey large parts of Source Area A and to a lesser extent Source Areas C and E.

2.1.2 Geoprobe Sampling

To confirm the lateral and vertical extent of source zones in the subsurface, a series of intersecting transect lines were drawn across each Source Area (see **Figure1**). Initial geoprobe sampling locations were then defined by the grid created by these transects and where they intersected the previously estimated Source Area boundary. Sampling locations beyond the estimated boundary (stepout locations) were then added wherever the average concentration of either sulphate or nitrate at the boundary location exceeded a defined value (preliminary trigger value – refer **Section 2.1.2.1**). Stepout distances were initially planned at 5m and 10m beyond the estimated boundary. Using this approach the following field works were undertaken:

1. Inferred perimeters and potential step out locations associated with each source area were pegged out and surveyed using a differential GPS unit;

2. A first episode of soil sampling was performed at each location using a truck mounted Geoprobe rig (supplied and operated by Handex Pty Ltd) from 27 September to 20 October 2004.

3. A second episode of soil sampling was performed at each location using a truck mounted Geoprobe rig (supplied and operated by Handex Pty Ltd) from 30 November to 1 December 2004.

4. Individual core samples were collected from disposable soil core sleeves at the Dune Sand/Upper Shepparton Clay interface and each metre thereafter. Where the thickness of the clay exceeded 4m, soil sampling was ceased.

A total of 125 geoprobe investigation holes were performed at the locations shown on **Figure 2**. Following sampling, soil samples were transported for analysis in accordance with the procedures outlined in **Appendix D**.

2.1.3 Correlation of Geophysics and Geoprobe Data

To determine the correlation between Geophysics and Geoprobe data, the analysis results for each geoprobe hole were divided into shallow (above 3m depth) and deep (3m - 6m depth). All nitrate and sulphate analysis results falling within either of these intervals were then processed to determine the arithmetic mean concentration for deep and shallow results at each location. By plotting the location of each borehole on the geophysical depth slice maps, the shallow and deep electrical conductivity for each geoprobe location were then obtained. These values were then graphed for each source zone (Refer **Appendix E**) and the degree of correlation established.

2.1.4 Preliminary Trigger Levels

The preliminary trigger level was developed as a tool to allow determination of whether a step-out geoprobe location would be needed to accurately define the boundary of contamination of each specific Source Area. It was originally intended that trigger levels would be established based on the results of permeability testing and leaching columns on the USC. However, the wide range of permeability of the USC evident from permeability and infiltrometer testing rendered assessment of the leachability of contaminants from the USC to be impractical.

To allow the determination of a preliminary trigger level, a review of historical groundwater and soil contamination was conducted for the site. Using data from this review a relationsip between groundwater and soil contamination was able to be estimated. Using this relationship,the following acceptable residual concentrations (trigger levels) of nitrate and sulphate in soil were estimated:

Nitrate = 92mg/kg

Sulphate = 768mg/kg

The methodology and data associated with the calculation of these trigger levels was presented to ADI and the auditor for approval prior to field works (refer **Appendix B**).

2.1.5 Contaminant Mass Distribution

One of the important results of the delineation study was to estimate the mass of residual nitrate and sulphate within the clays in each source zone. This was important to allow calculation of the total residual contaminant mass, which if left uncapped, had the potential to further impact the underlying aquifer systems. By comparison of this mass with that already estimated to be present within the aquifer system (Ref 7: HLA, 2003), the risk associated with the residual soil contamination could be established and the benefits of capping confirmed.

To calculate the total residual contaminant mass within soils required the determination of appropriate background concentrations for sulphate and nitrate. The background concentrations for nitrate and sulphate within soils were previously estimated for the site as 10mg/kg and 150mg/kg respectively (Ref 14. URS,2001). By comparison of these values to analyses results from background wells in the Priority A Sources Investigation (Ref 7, HLA,2003) and geoprobe results from this investigation, the following background concentrations were developed:

Background Soil Concentrations

Nitrate	= 10mg/kg
Sulphate	= 100mg/kg

Using these values, the lateral extent for sulphate and nitrate impact within the Upper Shepparton Clay was determined for each source area for the shallow and deep depth intervals. The concentration of nitrate and sulphate within these extents was then contoured and the total mass contained by each contour interval calculated using the following formula:

Mass(mg) = C x V x d

where:

C = Median Concentration within the contour interval (mg/kg)
V = Volume (m^3) = (Average clay thickness x Area of Contour Interval)
d = Density (kg/m^3)

2.1.5.1 Source Area B (Effluent Drain)

To calculate the residual contaminant mass within the effluent drain area, the analysis results of samples taken from 10 geoprobe holes (three transects of Geoprobe soil bores from the current investigation and two Geoprobe soil bores from Priority A sources investigation, 2003) on the drain were combined to develop average concentrations within an idealised vertical cross-section across the drain. This information was further augmented by analysis results presented for the validated base of the effluent drain (Ref1. ADI, 2001). Contaminant concentration contours were then drawn and the mass contained within each contour interval calculated for each unit length of the drain. The total mass of sulphate and nitrate in the source area was then calculated by multiplying these results by the drain length (1km).

2.2 Delineation of Areas Requiring Capping

To determine the areas requiring capping, it was initially planned to calculate a final trigger value using a mass transfer rate calculated from the results of leaching column tests. However, field observations and conditions indicated that performance of leaching column tests would be impractical, resulting in their abandonment (refer to **Section 4**).

Due to the abandonment of the leaching column tests, the areas requiring capping were defined by the estimated percentage of total contaminant mass covered. This approach was discussed and agreed with the auditor and ADI during a project management meeting held on 4 November, 2004.

To determine the areas requiring capping a threshold minimum of 90% total contaminant mass coverage was used. This meant that the capping extent contour selected for nitrate and sulphate on each depth slice was required to cover 90% or more of the total contaminant mass. To determine the area requiring capping in each source area, the two outermost extents for sulphate and nitrate depth slices were overlain and two overall new extents produced(one for nitrate and one for sulphate). These two figures were then overlain to define a final capping extent for each area that considered both contaminants. For the effluent drain, the capping extent required was defined using a similar methodology as above, with the exception that the idealised vertical section was used to calculate percentage of contaminant mass covered.

Using the 90% threshold to define the capping extent cutoff, the total mass of sulphate and nitrate left uncapped for all source areas was calculated to be 5 tonnes and 20 tonnes respectively. This compares favourably to the uncapped mass obtained using the same approach but using the conservative preliminary trigger values to define the capping extent cutoff (see below).

Effectiveness of Capping Extent Determination Approaches

Contaminant	Total Mass in soil (tonnes)	Uncapped mass (tonnes) using preliminary trigger value for capping	Uncapped mass (tonnes) using 90% min mass threshold for capping
Nitrate	81	12	5
Sulphate	396	66	20
Total	**477**	78	**25**

Based on the above figures, it is considered that the 90% threshold cutoff represents a suitable, conservative approach for delineating the maximum capping extent required.

2.2.1 Interface Elevation

Discussion during the course of the capping options assessment raised the issue that variations in the interface depth between the dune sands and the Upper Shepparton clays may require consideration during capping design. This issue was based on the scenario that rainwater collecting at an interface (exhibiting sufficient gradient) may migrate and pond at another downgradient location. In this situation, it would be possible to have a source zone covered by a capping option, which was still affected by rainfall events due to the extended catchment of the underlying interface topography. To ascertain the risk of this scenario occurring, a map of the interface depth was prepared.

To determine the elevation of the interface depth, the GPS data associated with the geoprobe locations was posted on a topographic map of the site previously provided to ADI (Ref 6; HLA, 2002). This topographic map was developed using photogrammetry techniques and provides a surface elevation of the site to an accuracy of +/- 0.5m. Once plotted, the elevations of all geoprobe locations (mAHD) were estimated from their location on the topographic map. The elevation of the clay interface was then able to be estimated for each borehole location using borelogs generated during the geoprobe investigation.

2.3 Laboratory and Field Testing

2.3.1 Laboratory Analysis

Initially, onsite analysis was performed using a Hach spectrophotometer to provide on-site screening and allow determination in the field of whether trigger values had been exceeded. This approach was aimed at reducing the delays associated with off-site laboratory analyses, and to reduce potential standby time for Geoprobe drilling. Approximately 10% of samples were sent to a laboratory for quality control.

Following one week in operation, it was decided to suspend all onsite analysis due to the following problems:

- Clay slurry samples not settling out within acceptable time frames;
- Poor reproducibility of analyses results from the spectrophotometer; and
- Poor correlation between field and lab results from laboratory check samples results.

All samples collected prior to and following abandonment of the field lab were sent to a NATA accredited laboratory (ALS) for analysis of Nitrate, Sulphate and pH in soil. All these analytical results were combined with relevant soil analytical results from the previous Priority A Sources Investigation (Ref 8. HLA, 2003) and URS Site Assessment (Ref 14. URS, 2001) to assist with estimation of contaminant mass distribution.

2.3.2 Field Ring Infiltrometer Testing

Ring Infiltrometer testing was undertaken at seven locations on the exposed upper surface of the Upper Shepparton clay aquitard to assess vertical hydraulic conductivity within clay located at different source zones (refer **Figure 1**). Testing was performed by excavating a trench through the dune sands at each location to expose the surface of the Upper Shepparton clays. Using a shovel, a flat pad was then dug on this surface for placement of the ring infitrometer. To minimise the effect of lateral spreading (which is generally expected in clayey soils where infiltration is slow) a double-ring infiltrometer was used. The rings were driven about 5-10cm into the clay, and water was added to the inside of both the rings (approx. 15cm deep). Water filled Mariotte bottles were fitted to each of the rings to maintain a constant head. The head (water level) was measured manually from the inside of the inner ring at regular intervals.

Using the water level measurements, the permeability of the clay was calculated according to the methodology provided with the unit (refer **Appendix C**). Due to the unexpected high permeabilities calculated, a repeat test was also performed with the unit and surrounding area covered with black plastic sheeting (see below). This variation was performed to lower the possibility of evaporative processes contributing to the calculated high permeabilities.

Plate1: Ring Infiltrometer testing on the surface of the Upper Shepparton clays.

2.3.3 Triaxial Permeability Testing

Due to the unexpected high permeabilities obtained from the ring infiltrometer studies, triaxial permeability tests were performed on two undisturbed cores collected in steel pipes from Source Area A in the Former Oleum and Acid Areas. Triaxial testing was undertaken by BFP Consultants Pty Ltd using standard industry methodology.

2.3.4 Leaching Column Tests

As part of the proposed capping design studies, four leaching column studies were planned to evaluate the permeability and mass transfer rates of sulphate and nitrate from impacted clays. These studies were to be performed on undisturbed samples of clay taken from the Upper Shepparton clays. The procedure used for obtaining undisturbed cores was as follows:

- Using an excavator bucket an 0.8 m length of steel pipe and three (3) 1 meter lengths of class 18 PVC pipe (either 50 mm or 100 mm diameter) were forced vertically into the clay surface as far as possible.
- As PVC piping generally snapped under the force of the excavator bucket, particularly in areas where the clay was stiff, such as in Source Area B, before being fully embedded in the clay, and cores of) 0.3 - 8 m were generally collected at each location. Also, the pressure applied to the PVC piping often contorted the PVC pipe at the openings
- The cores were dug out of the clay by excavating around the cores.
- Upon removal of the cores, some gaps between the inner PVC pipe and the clay material collected was observed in the openings of the pipe lengths, further reducing the length of core suitable for leaching column tests.
- The cores were kept cool and out of direct sunlight during transport to Melbourne for laboratory analysis.

For reasons discussed in **Section 5.3**, the leaching column tests were not performed.

2.3.5 Slug Tests

Slug recovery tests had been proposed to be carried out at six groundwater bore locations to gain an understanding of the lateral variability of hydraulic conductivity within the Shepparton Formation aquifer within the source areas. This information was to be combined with the results of the leaching column testing to assist with the development of a model that would allow back calculation of final trigger levels. Slug recovery tests were carried out on two groundwater bores using the following approach:

1. The static water level (SWL) of the groundwater bore was measured using an electronic water level probe.
2. A slug (a known volume of fresh water) was then injected into the bore.
3. The SWL was measured at specified time intervals in the bore as it recovered back to static conditions.

Recovery times for the SWLs within the boreholes were very rapid. Plotting of the data using standard techniques subsequently indicated that the quality of the data was poor and not a true representation of hydraulic properties at each location. This issue was discussed with the Auditors representative (B.Mann) and it was agreed that aquifer properties were best determined from pump testing techniques proposed to be performed as part of other related projects. As a result, further slug testing was discontinued and the unrepresentative results obtained have not been presented in this report.

2.3.6 Capping Media Testing

The following studies were performed to determine the suitability of the proposed soil media to be used for capping applications.

2.3.6.1 Clay Cap

ADI identified that the channel excavation spoil piles north of the site were the preferred source of material for potential use as capping medium. To confirm the suitability of these clays, two 20kg bulk samples taken from the area and supplied to a geotechnical laboratory for compaction testing and measurement of:

- Optimal moisture content;
- Permeability;
- Dry density; and
- Emerson class number.

2.3.6.2 Phytocap

As outlined in our proposal, to develop an optimal Phytocap medium HLA proposed to combine clay and sand from onsite sources. To determine the characteristics and suitability of these materials a representative clay sample was obtained from the channel excavation spoil piles at the north of the site. Representative sand samples were also obtained from the dune sands located at the proposed borrow area in the north of the site. To ensure representativeness, both samples were taken as 4-part composites.

The clay and sand samples were sent to NATA accredited laboratory, ALS, and analysed for:

- Particle size
- pH
- Organic matter
- N, P and K
- Salinity
- 12 metals
- Phenolics
- OCPs
- OPPs

2.4 Capping Option Assessment

A qualitative options assessment of three capping systems was performed (see below):

Capping Options to be Assessed	
Cap	**Description**
Reference Cap	NSW EPA Reference Cap comprising a composite liner system, middle drainage layer and vegetated top layer.
Clay Cap	VICEPA Type 3 landfill cap (refer VICEPA publication 788, October 2001, Siting Design, Operation and rehabilitation of landfills).
Phytocap	Comprises a 1m thick layer of sandy clay loam for the establishment of a native vegetation layer with high evapotranspiration and nitrate/sulphate uptake capability.

The qualitative assessment of the caps covered both technical and practical considerations, including, but not limited, to the following:

- Net infiltration
- Nitrate reduction capability (Phytocap)
- Construction cost / duration
- Maintenance requirements and costs
- Susceptibility to erosion and failure
- Impact on surrounding environment
- Limitations on future landuse
- Ecologically Sustainable Development

To assess the relative affectiveness of the caps at reducing mass flux to the underlying Shepparton aquifers, their hydrogeological characteristics were placed into the US EPA's modelling package (HELP).

2.4.1 HELP Modelling

The HELP modelling software uses weather (climatic), soil and design data to generate daily estimates of water movement across, into, through and out of landfills. To accomplish this objective and computer a water balance, daily precipitation is partitioned into surface storage (snow) (not relevant at this site), interception, runoff, infiltration, surface evaporation, evapotranspiration from soil, subsurface moisture storage, liner leakage (percolation), and subsurface lateral drainage to collection, removal and recirculation systems. The HELP model requires the following parameters input in each model:

Profile Properties
Location –The closest station to Mulwala with sufficient meteorological data to perform the modelling was Wagga Wagga in NSW. Climate data can be entered by the user, however a complete set of data incorporating evaporative zone depth, maximum leaf area index, temperature, solar radiation, precipitation and wind data was not available for a closer station.

Area – The site area can be specified while setting up the model. This has an affect on the quantity of water calculated by the model. In this case the area was set at a nominal 7000 m^2, the area that was used as the basis for the capping costs.

Runoff Method – Used to calculate the runoff curve number, which is defined with respect to the runoff retention parameter (S), which is a measure of the maximum retention of rainwater after runoff starts. This can be model calculated using the USDA Soil Conservation Service cure-number method, or user specified or user modified. For the Mulwala modelling, the runoff curve number was model calculated.

Initial Moisture Settings – This is only relevant in areas where snow is present. For this modelling, the initial moisture setting was set at 0.

Runoff Area – This parameter specifies the percentage of area from which runoff is possible. The Mulwala models specify 100% for the runoff area.

Vegetation Class – This parameter determines the class of vegetation cover, which in turn affects surface water runoff. This can range from bare soil to an excellent stand of grass. This parameter was different for each of the models, dependent on the capping requirements.

Layers
For each material layer in the model, the user must specify the following properties:

Material Category – Each layer is identified by the hydraulic function that they perform. The following design layer categories are available: Vertical Percolation Layer, Lateral Drainage Layer, Barrier Soil Layer, Geomembrane Liner and Geotextiles and Geonets. Different material categories were used depending on the particular type of cap.

Material Type – Depending on the material category selected, the material type can be selected from a range of different soil types, including loamy fine sand, loamy sand and clay. Each of these material types have associated properties which can be edited as desired by the user. These properties are detailed further below.

Slope – Each cap modelled was given a slope with a 5% grade and a length of 100m. This was derived from the cap specifications and a conservative estimate of an average length of slope across the site.

Thickness – The thickness of the layer was selected based on each cap specification and the in-situ material measurements.

Layer Properties

Total Porosity – This was kept as the default in all models

Field Capacity – This is the moisture storage after a prolonged period of gravity drainage. This was left at the default for each material type in each model.

Wilting Point – The lowest moisture storage. This was left as the default for each model.

Saturated Hydraulic Conductivity – Where material property tests had been conducted, this was updated to reflect the test results.

Subsurface Inflow – No subsurface inflow was specified by the user for the Mulwala models.

Initial Moisture Content – This was set as the field capacity in all the models, in order to build conservatism into the model.

- Each of the modelled capping options had the same base materials to reflect the subsurface conditions at the site.

Bottom Layer

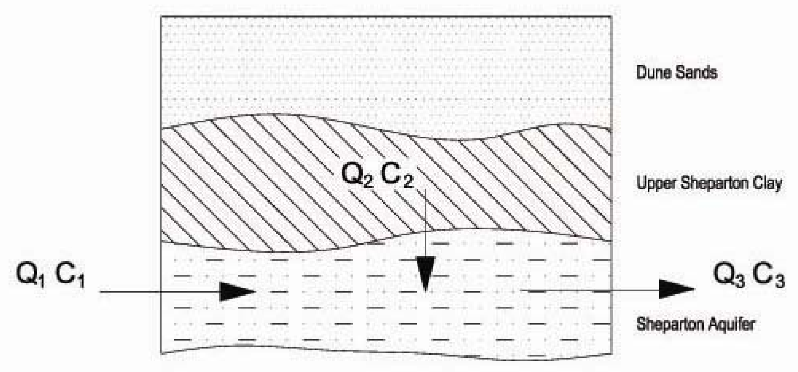
- Barrier Soil Liner
- Clay
- Thickness: 5.28 m (based on average unit thickness across the site)
- Conductivity: 1 x 10^{-9} m/s (refer to discussion in **Section 6.1.1**)

Second Layer

- Vertical Percolation Layer
- Loamy fine sand
- Thickness: 2.71 m (based on average unit thickness across the site)
- Conductivity: k = 3 x 10-3 m/s (based on ring infiltrometer tests)

2.4.2 Mixing Calculations

To assess the effects of capping options on groundwater quality and estimate the permeability and leachability of contaminants from the Upper Shepparton Clay, a simple instantaneous mixing model was developed. The model was developed using the assumption that vertical infiltration is the primary mechanism for enabling nitrate and sulphate salts to reach the underlying Upper Shepparton aquifer. In this model, infiltrating rainwater will pick up and carry a defined loading of nitrates and sulphates into the aquifer depending upon their concentration in the underlying soils and their ability to transfer into the infiltrating fluids (mass transfer rate). A mass conservation equation was used as the basis for the modelling. This equation assumes that the downgradient mass contained within the aquifer is equivalent to the sum of mass inputs from upgradient groundwater and contaminated infiltration from the overlying clays. The conceptual model used to estimate instantaneous mixing within the Upper Shepparton Aquifer is presented below:



$$Q_3 C_3 = Q_1 C_1 + Q_2 C_2$$

where:

Q_1 = Groundwater Flow Rate immediately upgradient of Source Area (m^3/yr)
C_1 = Background Groundwater Nitrate Concentration (mg/L)
Q_2 = Vertical Infiltration (resulting from incident rainfall) reaching aquifer (m^3/yr)
C_2 = Nitrate Concentration of infiltrating fluids reaching aquifer
Q_3 = Groundwater Flow Rate immediately downgradient of Source Area (m^3/yr)
C_3 = Downgradient Groundwater Nitrate Concentration (mg/L) - calculated

Mixing calculations were undertaken using “baseline” conditions, and the results of the HELP modelling from both the Phytocap and Clay Cap. The results of these calculations are presented in Sections 6.1.2, 6.2.4.2 and 6.3.2, respectively.

3 DELINEATION OF CONTAMINATED AREAS

3.1 General Comments

Geoprobe sampling was undertaken in conjunction with geophysics as part of the subsurface contaminant delineation of each Source Area. A total of 125 geoprobe investigation holes were performed at the site during the two sampling episodes. The second episode was conducted in an attempt to clarify number of data gaps identified and presented in the draft report and involved sampling of the following 7 locations:

Source Area A: AT11A1, AT12A1, AT13A1

Source Area C: CT01B2, CT02B2, CT03A3,

Source Area D: D2T01A5

The analysis results from these additional holes were plotted on the appropriate figures and any adjustments to the extent on contamination and areas requiring capping were performed.
The locations of all boreholes are shown on **Figures 2a and 2b**. Borelogs for each geoprobe hole have been compiled and presented in **Appendix G**. The analytical results and data validation from sampling undertaken at each of these locations are presented in **Appendix D**. Chain of Custody documentation and Laboratory Analytical Reports are presented in **Appendix J** and **Appendix K** respectively. Mass calculations performed for each Source Area are provided in **Appendix F**.

Based on the assessment of field and laboratory QA/QC data, the reported analytical results are considered to be valid and representative of concentrations of the compounds analysed at the sample locations investigated and therefore can be used as the basis of interpretation. The following sections summarise the findings for each Source Area.

3.2 Source Area A

3.2.1 Geophysical Results

The geophysical response plans for Source Area A and Source Area E are provided on **Figure 3**. Source Area A exhibits two high conductivity anomalies located in the former Oleum Area and former Gypsum ponds. In the former Oleum Area, raised conductivities from the surrounding fences and buildings can also be observed in the 6 metre depth slice, but this is diminished in the 3 metre depth slice. The Oleum Area anomaly is observed to have a wider lateral extent in the deeper section.

The anomaly associated with the former Gypsum Ponds is larger and of higher conductivity in its central parts. Some influence from the pipes and buildings are also observed around this anomaly, but this influence is diminished in the 3 metre depth slice.

In the north section of the Acid Area, a transect was run along a footpath with a north-south orientation. As it can be seen, the data collected in this area is heavily influenced by the buildings and pipes on each side of the footpath. The result of the survey along this line should therefore be disregarded as it contains no information on the underlying geology.

In the central paved section of the Acid Area, the survey showed some minor anomalies. There were several buildings surrounding this area, which have possibly created interference effects in the results rendering them unusable. In the north-western section of the Nitrocellulose (NC) Area, the driveway to the south of the acid tank farm was surveyed with a single transect, which showed minor anomalies. This is believed to be the influence from services in the road and from the gate at the entrance to the driveway.

The unusual geophysical data acquired from the former labyrinth and acid drains was interpreted by the geophysical contractor as being influenced by a powerful source of electromagnetic interference. This could be sourced from high voltage machinery in the nearby buildings or an electrical transformer station. As a result of this interference, the data acquired for this localised area is considered unusable.

3.2.2 Analytical Results

Laboratory analytical data obtained for Source Area A indicate that elevated concentrations of nitrate and sulphate are present in the former Oleum Area, the former Acid Area and the NC Area (refer to **Figures 4, 5, 6 and 7**).

3.2.2.1 Former Oleum Area

A north/south oriented transect of sample locations was taken through the former Oleum Area for the purposes of Geophysical calibration and source area quantification. Elevated residual concentrations of nitrate and sulphate were found to be present in the following samples:

- AM10, AM17 and AM18

These samples were in close proximity to an excavated fill area in the southern section of the Oleum Area. Concentrations of nitrate and sulphate in soil tended to decrease to background values in a northerly direction from these locations as seen in samples AM19, AM02 and AM20. These values indicate an outer boundary for impact in the vicinity of the former Oleum Area.

3.2.2.2 Acid Area

Elevated concentrations of residual nitrate and sulphate were found to be present in the following locations:

- AM04 and AM12 in close proximity to the former Gypsum Ponds;
- AM11, AM13 and AT04B1 adjacent to the Effluent Treatment Plant Acid Drains; and
- AT04A1adjacent to the Acid Area Drains.

In each of these locations, sample analytical results indicate that there is significant residual mass within the Upper Shepparton clay. Sample results from geoprobe holes at the northern and southern sections of the Acid Area indicate that contaminant concentrations are effectively at background levels (refer to locations AT03A1, AT03B1, AT05B1, AT06A1).

Analysis of the results indicates there is no way of distinguishing between Source Area A and two smaller contaminated areas located immediately to the north which were previously defined as part of Source Area E (Ref7. HLA,2003). For this study, these two areas have been incorporated into Source Area A, and all references to Source Area E now refer only to the larger area immediately to the north-west (refer **Figure 1**).

3.2.2.3 Nitrocellulose Area

Elevated concentrations of residual nitrate and sulphate were identified in samples from the following locations:

- AT07A1 and AM07 adjacent to the acid tank farm;
- AM08, AM16 and AT10A1 adjacent to Building 105; and
- AT07B1 to the south of the former acid labyrinth, acid drains and effluent drains in the south-west corner of the Nitrocellulose (NC) area.

Sample results from geoprobe holes performed in the north-eastern and south-western corners of the NC area are close to background concentrations, as seen in sample results from geoprobe locations AM04 AM16, AT08A1 and AT09A1.

3.2.3 Correlation between Analytical and Geophysics Results

The geophysical response was plotted against soil analytical data for the shallow and deep depth slices in Source Area A and presented in Appendices E(i) and E(ii) respectively. Review of these graphs indicates that generally correlation between geophysical response and sulphate or nitrate contamination is poor. However, for the western portion of Source Area A where a geophysical anomaly (high conductivity) was observed in the location of the former Oleum area, and has been removed (refer to Appendices E(iii)), the graph shows a reasonable correlation between the geophysical signature and contaminant concentrations for both sulphate and nitrate. On this basis, the lateral extent of the geophysical anomaly in this location has been used to assist with definition of the lateral extent of contamination identified by the geoprobe sampling.

3.2.4 Interpreted Contaminant Distribution

Based on the contour plans presented in **Figures 4 to 7**, the relative distribution of residual sulphate and nitrate mass in Source Area A was able to calculated (see below).

Source Area A – Contaminant Mass Distribution Summary Table					
Nitrate			**Sulphate**		
Contour Interval (mg/kg)	Mass (kg)	%Mass	Contour Interval (mg/kg)	Mass (kg)	%Mass
10-50	2,698	6.46	100-500	16,835	20.92
50-100	3,796	9.08	500-1000	28,208	35.05
100-200	7,111	17.02	1000-5000	35,442	44.04
200-500	12,174	29.14	5000-10000	NA	NA
500-750	13,111	31.38	10000+	NA	NA
1000+	2,981	6.92			
Total	**41,782**	100.00	Total	**80,486**	100.00

To allow a better understanding of the vertical distribution of contamination a schematic cross section for Source Area A (Nitrate only) is presented on **Figure 27A.** This cross section was developed using the intersection of contamination presented on **Figures 4 and 5** with the cross sectional alignment A-A’ (see **Figure 4).**

The contaminant contours presented on **Figure 27A** indicate three main zones of contamination at depth within the Upper Shepparton Formation Clay. Contamination is evident in the Oleum Area, Acid Area and NC Area with concentrations relatively consistent with depth in both the Oleum Area and Acid Area. Nitrate concentrations appear to increase with depth in the vicinity of the NC Area. Minor lateral spreading of the contamination can be seen in the deeper parts of the clays. This could be attributed to the non vertical nature of many preferential pathways and the adsorptive characteristics of the clays.

3.3 Source Area B (Effluent Drain)

3.3.1 Geophysical Results

The geophysical response for the transect undertaken along Source Area B is provided in **Figure 9**. The primary purpose of this transect was to determine if the geophysical response could be related to areas of impaired integrity within the effluent pipe. This subject has been fully discussed in the **Milestone 1 Report**. Review of the geophysical responses identifies that relative to onsite geophysical surveys, there are only minor variations in electrical conductivity of the subsurface. The six meter depth slice showed the greatest variations, with areas of increased conductivity located at the start of the drain and end of the survey. In the 3 metre depth slice very little variation along the transect is observed. It is suggested that the sources of the main anomalies are probably related to changes in the composition of subsurface geology the geophysics has not been used to assist with contaminant delineation.

3.3.2 Analytical Results

Laboratory analytical data obtained for Geoprobe soil core samples along the transects of the effluent drain indicate that there are elevated concentrations of nitrate and sulphate in the subsurface (refer to **Figures 10, 11 and 12**). Sample analysis results from BT01A1 and BT02B1 confirm that elevated concentrations of nitrate and sulphate are present up to 6 metres bgl, adjacent to the drain. Step out locations for each of these samples (BT01A2 and BT02B2) indicate that elevated impacts have not extended laterally beyond 4m from the centreline of the drain at these locations.

3.3.3 Interpreted Contaminant Mass Distribution

Based on the contour plans presented in **Figures 10 and 11**, HLA was able to calculate the relative distribution of residual sulphate and nitrate mass in Source Area B (see below).

Source Area B – Contaminant Mass Distribution Summary Table					
Nitrate			**Sulphate**		
Contour Interval (mg/kg)	Mass (kg)	%Mass	Contour Interval (mg/kg)	Mass (kg)	%Mass
10-50	972	4.14	100-500	33,867	44.65
50-100	1,595	6.79	500-1000	35,689	47.05
100-200	2,547	10.84	1000-5000	6,299	8.30
200-500	3,624	15.43	5000-10000	NA	NA
500-750	6,530	27.80	10000+	NA	NA
1000+	8,217	34.99			
Total	**23,484**	100.00	Total	**75,854**	100.00

To allow a better understanding of the vertical distribution of contamination in Source Area B schematic cross sections for Nitrate and Sulphate are presented on **Figures 10, 11 and 12**. These cross sections were developed by creating a “representative” transect of contamination across the drain. This transect combines the results from all seven bores sampled to allow the development of four ”representative” geoprobe holes. The sample results presented for these representative holes were either directly translocated (where only one geoprobe hole was available for that stepout) or developed by averaging the results of samples obtained from the same depth at different bores located in similar stepout distances from the drain (ie. Sample results from BT01B1 were combined with equivalent depth results from BT02B1 to create a representative hole).

Review of the figures shows that the mass of sulphate contained within clays beneath the drain is broadly distributed at relatively low concentrations. In contrast, Nitrate is more localised and apparently increasing in concentration with depth. This could be explained by the higher solubility of nitrate, which could have enhanced its ability to be flushed downwards by rainfall events since usage of the drain was ceased.

3.4 Source Area C and D2

3.4.1 Geophysical Results

The geophysical response for Source Area C and Source Area D2 can be seen on **Figure 13**. These figures show a very significant anomaly in the central section of the Source Area C. The high conductivity of the anomaly in the 3 metre depth slice is confined to a relatively small area. Some weak spreading of the anomaly is observed to the south-east of the centre on the 3 metre depth slice, and this trend is observed to be stronger in the 6 metre depth slice. On the 6 metre depth slice the anomaly is so strong in the central parts that it is producing negative conductivities. This is caused by the extremely high conductivities observed near the surface. This could be an indication of residual contaminants near the surface. However, following a review of historical operations within and around Source Area C, it appears likely that these anomalies are a result of remnant building materials associated with the former Coke storage area or Boiler House.

A notable anomaly is also observed directly south of Stubbs Dve in close proximity to Source Area D2 which is likely to be the result of wastes dumped in this area.

3.4.2 Analytical Results

Laboratory analytical data obtained for geoprobe samples from Source Area C and Source Area D2 indicate elevated concentrations of nitrate and sulphate are present (refer to **Figures 14, 15, 16 and 17**). In particular, elevated concentrations are observed at geoprobe locations in the north-western (CT01A1/A2/A3), central (CM01/CM02) and eastern (CT03A1/A2) sections of Source Area C. Previous investigations by HLA (Priority A Sources Investigation, 2003) indicate raw gypsum was identified in the surface and subsurface, thus the reported sulphate concentrations are considered likely to be associated with this.

Sulphate and/or nitrate concentrations were elevated above background levels at geoprobe locations at Source Area D2 (iron oxide dump) in the north (D2T01A1/A3/A4), south (D2T03A1/A2/A3), west (D2T03B1) and center (D2M01). Elevated sulphate and nitrate concentrations were measured in samples from up to 5.5m below ground level (bgl).

3.4.3 Correlation between Geophysical and Analytical Results

HLA has plotted the geophysical response vs soil analytical data for the shallow and deep slices in Source Area C and presented this information in Appendices E(vi) and E(vii) respectively. Review of these graphs indicates that the overall correlation between geophysical response and sulphate or nitrate contamination is poor. Analytical results for CT01A1/A2, CMO1/CM02 and CT03A1/A2 show significant nitrate and sulphate concentrations however geophysical data for both the 3m and 6m depth slice is equivalent to background or unusable due to interference in these areas. Correlation data for Source Area D2 (E(x), E(xi)) is poor and analytical results show that significant nitrate and sulphate concentrations correspond to background geophysical data for both the 3m and 6m depth slice.

Due to these poor relationships, it was decided to generate contaminant concentration contours based on soil concentrations identified by geoprobe sampling only.

3.4.4 Interpreted Contaminant Mass Distribution

Based on the contaminant concentration contour plans (Figures 14 to 16), the relative distribution of residual sulphate and nitrate mass in Source Area C and Source Area D2 was able to be calculated (see below).

Source Areas C and D2 – Contaminant Mass Distribution Summary Table					
Nitrate			**Sulphate**		
Contour Interval (mg/kg)	Mass (kg)	%Mass	Contour Interval (mg/kg)	Mass (kg)	%Mass
10-50	1,286	8.68	100-500	16,417	21.04
50-100	2,645	17.86	500-1000	13,364	17.47
100-200	3,459	23.34	1000-5000	39,222	50.27
200-500	3,997	26.98	5000-10000	7,559	9.69
500-750	3,156	21.30	10000+	1,190	1.53
1000+	272	1.83			
Total	**14,816**	100.00	Total	**78,022**	100.00

To allow a better understanding of the vertical distribution of contamination a schematic cross section for Source Area C and D2 (Nitrate only) is presented on **Figure 27B**. This cross section was developed using the intersection of contamination presented on **Figures 14 and 15** with the cross sectional alignment Y-Y' (see **Figure 14)**.

The cross section shows the main zone of nitrate contamination is in the vicinity of the central northern portion of Source Area C/D2. This is also relatively consistent with the distribution of sulphate contamination. Lateral spreading of the contamination with depth is also clearly evident in this area. This could be attributed to the non vertical nature of many preferential pathways and the adsorptive characteristics of the clays.

3.5 Source Area D1 and D3

3.5.1 Geophysical Results

The geophysical response for the former Iron Oxide Dump (Source Area D3) can be seen on the inset in **Figure 13**. **Figure 13** also contains information for the northern boundary of D3 in the main section of the figure immediately adjacent to Source Area D2. A significant geophysical feature for Source Area D3 is represented by a large elipse shaped anomaly of high conductivity. This anomaly is observed to widen with depth from the 3 to the 6 metre depth slice. Immediately north of this anomaly the subsurface appears to be homogeneous.

The geophysical response for the area affected by the former Sulphur Dump (Source Area D1) can be seen on **Figure 19.** Similar to the response at Source Area D3, the anomaly observed here is relatively strong and confined. Relatively high conductivity values are observed in the 3 metre depth slice.

3.5.2 Analytical Results

Laboratory analytical data obtained for geoprobe samples from Source Area D1 and Source Area D3 indicate elevated concentrations of nitrate and sulphate are present (refer to **Figures 20, 21 and 16 and 17 respectively**). Sulphate concentrations were elevated above background levels at samples taken from geoprobe locations at Source Area D1 in the south (D1T01B1, D1T02B1/B3), east (D1T03B1), west (D1T03A1/A2) and center (D1M01, D1M02). Elevated sulphate concentrations were measured in samples up to 7 m bgl.

Sulphate concentrations were elevated above background levels at geoprobe locations across the whole of Source Area D3, including D3T01A1/A3/A4, D3T01B1/B3, D3T02A1/A3, D3T02B1/B3, D3T03A1, D3T03B1/B3 and D3M01. Location D3T02A4 also reported a nitrate concentration above background.

3.5.3 Correlation between Geophysics and Analytical Data

The geophysical response vs soil analytical data has been plotted for the shallow and deep depth slices in Source Area D1 and Source Area D3 and presented in Appendices E(viii), E(ix), E(xii) and E(xiii). Review of these graphs indicates that the overall correlation between geophysical response and sulphate or nitrate contamination is reasonable for both areas. Generally, an increase in soil concentration corresponds to an increase in soil conductivity. Also, the results suggest the geophysical data has a better correlation with Sulphate based contaminants. On this basis the lateral extent of the high conductivity anomaly in Source Area D1 and Source Area D3 has been used to assist in defining the lateral extent of contamination identified by the geoprobe sampling in this area.

3.5.4 Interpreted Contaminant Mass Distribution

Based on the contour plans ((refer to **Figures 20, 21 and 16 and 17**), HLA was able to calculate the relative distribution of residual sulphate and nitrate mass in Source Area D1 and Source Area D3 (see below).

Source Areas D1 and D3 – Contaminant Mass Distribution Summary Table					
Nitrate			Sulphate		
Contour Interval (mg/kg)	Mass (kg)	%Mass	Contour Interval (mg/kg)	Mass (kg)	%Mass
10-50	NA	NA	100-500	3,719	3.00
50-100	NA	NA	500-1000	6,726	5.42
100-200	NA	NA	1000-5000	48,015	38.72
200-500	NA	NA	5000-10000	49,844	40.19
500-750	NA	NA	10000+	15,708	12.67
1000+	NA	NA			
Total	NA	NA	Total	**124,012**	100.00

To allow a better understanding of the vertical distribution of contamination, schematic cross sections for Source Area D1 and D3 (based on Sulphate contamination only) are presented on **Figure 27C and Figure 27D**. These cross sections were developed using the intersection of contamination presented on **Figures 16,17, 20,21** with the cross sectional alignments Z-Z' and W-W'(see **Figure 16 and Figure 20)**.

For Source Area D1, **Figure 27C** shows one main zone of contamination at depth directly underlying the former sulphur dump. A 'slug' of higher Sulphate concentration is visible at approximately 3 to 4 m bgl.

For Source Area D3, **Figure 27D** indicates contamination that is more extensive at the surface of the clays directly underlying the former iron oxide dump. The lateral extent of the Sulphate impacted clays and concentrations in this area appear to decrease with depth.

3.6 Source Area E

3.6.1 Geophysical Results

The geophysical response for Source Area E can be seen on **Figure 3**. This figure shows a large anomaly in the central section of the area, where large metal structures are stockpiled. Several other areas of increased conductivities are also evident but due to the presence of the above stockpile, which may have produced interference, their origin is unknown.

3.6.2 Analytical Results

Laboratory analytical data obtained for geoprobe samples from Source Area E indicates elevated concentrations of nitrate and sulphate are present (refer to **Figures 4,5,6 and 7**). These figures show elevated concentrations of sulphate in the northern and western sections of the area. Slightly elevated concentrations of nitrate were also reported in the eastern segment of the area.

Elevated concentrations of sulphate were reported in sample analyses from the following geoprobe locations:

- E1T01A1/A2, E1T02A1, E1T02B1 and E1T03B1/B2 adjacent to and within the stockpile area north of Building 313; and
- E3T02A1 to the north of Building 303.

Elevated concentrations of nitrate were also reported in sample analyses from the following geoprobe locations:

- E1M01 and E1T03A1in the eastern section of Source Area E

3.6.3 Correlation between Geophysics and Analytical Data

The geophysical response vs soil analytical data has been plotted for the shallow and deep depth slices in Source Area E and presented in Appendices E(xiv) and E(xv) respectively. Review of these graphs indicates that the overall correlation between geophysical response and nitrate contamination is poor but is reasonable for the 6m depth slice for sulphate where increased concentration generally corresponds to an increase in soil conductivity. These results suggest the geophysical data has a better correlation with sulphate based contaminants in this area.

On this basis only the lateral extent of the geophysical anomaly for sulphate in the 6 metre depth slice has been used to assist in defining the lateral extent of contamination identified by the geoprobe sampling in Source Area E.

3.6.4 Interpreted Contaminant Mass Distribution

Based on the contour plans (refer to **Figures 4,5,6 and 7**), the relative distribution of residual sulphate and nitrate mass in Source Area E was able to be calculated (see below).

Source Area E – Contaminant Mass Distribution Summary Table

Nitrate			**Sulphate**		
Contour Interval (mg/kg)	Mass (kg)	%Mass	Contour Interval (mg/kg)	Mass (kg)	%Mass
10-50	862	79.19	100-500	4,715	12.65
50-100	169	15.54	500-1000	12,480	33.50
100-200	57	5.27	1000-5000	20,064	53.85
200-500	NA	NA	5000-10000	NA	NA
500-750	NA	NA	10000+	NA	NA
1000+					
Total	**1,089**	100.00	Total	**37,259**	100.00

To allow a better understanding of the vertical distribution of contamination a schematic cross section for Source Area E (Sulphate only) is presented on **Figure 27E**. This cross section was developed using the intersection of contamination presented on **Figures 6 and 7** with the cross sectional alignment V-V' (see **Figure 6**).

Figure 27E shows contamination in Source Area E is associated with the location of the storage area. Sulphate concentrations appear to increase slightly with depth in a South Westerly direction and penetrate through the entire thickness of the Upper Shepparton Formation Clay.

3.7 Geophysics and Contamination Correlation Summary

The geophysical data obtained from the use of the EM31 correlated well with the analytical data in Source Areas D1 and D3. A poor correlation was generally observed in all other areas. The good correlation in Source Areas D1 and D3 is believed to be a result of the high concentrations of sulphur based compounds and ironoxide in these locations.

3.8 Contaminant Mass Distribution

The total mass of residual nitrate and sulphate determined for soils contained within each of the source areas has been combined and presented in the table below. To allow comparison, the total mass of sulphate and nitrate previously estimated to be within the groundwater plumes within the Shepparton and Calivil Aquifers (Ref. 7, HLA 2003) has also been provided in the lowermost row.

Contaminant Mass Distribution		
Source Area	**Nitrate (kg)**	**Sulphate (kg)**
A	41,782	80,486
B	23,484	75,854
C and D2	14,816	78,022
D1 and D3	NA	124,012
E	1,089	37,259
Total (Soil)	**81,171**	**395,634**
Total (Groundwater)	**486,000**	**606,000**

Review of this table identifies that soils within Source Area A contain the greatest mass (approximately 41 tonnes) of nitrate potentially capable of being leached into the underlying aquifers. The highest total mass sulphate is contained within Source Area D1 and Source Area D3.

3.8.1 Comparison to Groundwater Contaminant Mass Distribution

Comparison between the total mass of residual nitrate and sulphate in soil to that already contained within the groundwater plumes is 16% and 65% respectively. For nitrate contamination, this result shows that most of the contamination has already entered the groundwater system as a result of past releases within the Source Areas. Overall, the relative mass of residual contaminants within the soils has the potential to continue to significantly impact the quality of the underlying groundwaters, justifying the investigation and implementation of remedial measures.

4 DELINEATION OF AREAS REQUIRING CAPPING

Following delineation of the contaminated areas, a recommended capping area was generated based on the outermost boundaries. The minimum capping extent for Source Areas A/E, B, C/D2/D3 and D1 are presented on **Figures 8, 12, 18 and 22** respectively. For each of these extents a recommended capping area has been determined (refer to cross hatched area) on each figure. The spatial area represented by each recommended capping area has been presented in the table below:

Source Area	Minimum Area Requiring Capping (m^2)	Recommended Area Requiring Capping (m^2)
A	35,800	69,300
B	8,000	8,000
C, D2 and D3	24,700	33,200
D1	3,400	4,600
E	7,100	12,300
Former Landfill	26,000	26,000
TOTAL	**105,000**	**153,400**

The minimum and recommended capping areas have been drawn over an aerial photo of the site (See **Figure 25**). The minimum capping areas correspond to area required to cap 90% of the contaminant mass in the USC, as defined by the results of the geoprobe sampling and the methodology outlined in **Section 2.2**. The recommended areas have been provided to allow for the uncertainty associated with the delineation of the contaminant distribution, which is dependant on the results of discrete sampling from boreholes, which in some instances can be separated by up to 50m or more. The recommended capping areas also provide linear shapes, which are considerably easier to plan and construct.

4.1 Source Area A

It should be noted that capping will not be selected as the preferred option for Source Area A until the carbon source addition to soil (Soil CSA) has been shown to be impractical. Bench and pilot scale assessment of Soil CSA and means of containing any groundwater impacts (Pump-and-Irrigate and Groundwater CSA) will be assessed as part of a separate work program.

If Soil CSA proves impractical and capping is selected, the recommended capping area defined for Source Area A corresponds with very high and moderate risk ranked sources as presented in the Priority A Sources Investigation (May, 2003). These specific Source Areas are as follows:

- Former Oleum Area (Acid Drains, 302 Ammonia Oxidation, Former Nitric Acid Plant, 301C Former Ammonia Storage) – Western lobe of the delineated capping area for Source Area A.
- Former Gypsum Ponds – Central section of delineated capping area for Source Area A.
- Nitrocellulose Area – Eastern lobe of delineated capping area for Source Area A.
- Effluent Treatment Plant – Southern zone of capping area between the former Gypsum ponds and the Nitrocellulose Area.

4.2 Source Area B

The delineated capping area presented for Source Area B corresponds with very high risk ranked sources as presented in the Priority A Sources Investigation (May, 2003). The specific Source Area is:

- Effluent Drain – Central cross sectional area covered by the recommended capping area presented on Figure 12.

Residual nitrate concentrations within soil were used as the basis for this recommended capping area because analytical results for sulphate in an average cross sectional area indicated that background concentrations accounted for more 40% of the residual mass in soil.

4.3 Source Area C

The delineated capping area presented for Source Area C corresponds with high risk ranked sources as presented in the Priority A Sources Investigation (May, 2003). These specific Source Areas are as follows:

- Dump Areas – Majority of the eastern arm of the delineated capping area presented on Figure 18
- Dump Area (Iron Oxide Dumps) – The iron oxide dumps adjacent to Source Area C were previously identified as Source Area D2 and Source Area D3. For capping purposes these areas have been combined with Source Area C to form one consolidated area. This has been performed based on the close proximity of the Source Areas and the continuity of elevated analytical results in soil for sulphate between the inferred perimeters of each Source Area.

4.4 Source Area D

The delineated capping area presented for Source Area D corresponds with high risk ranked sources as presented in the Priority A Sources Investigation (May, 2003). These specific Source Areas are as follows:

- Dump Areas (Sulphur Dump) – The entire area covered in the delineated capping area presented on Figure 22.
- Dump Areas (Iron Oxide Dump) – As presented above, the Source Areas previously identified as D2 and D3 have been included as part of the delineated capping area that also comprises Source Area C.

4.5 Source Area E

The delineated capping area presented for Source Area E corresponds with moderate risk ranked sources as presented in the Priority A Sources Investigation (May, 2003). These specific Source Areas are as follows:

- Oleum Area (Former Sulphur store) – Entire area covered in the delineated capping area presented on **Figure 8**.

4.6 Data Gaps

The results from the second sampling episode identified relatively high levels of sulphate and nitrate at depth in boreholes CT01B2 and D2T01A5. These results indicate that contamination may extend south beyond the site boundary adjacent to Source Area C and to the north of Stubbs Drive adjacent to Source Area D2. This uncertainty has been reflected by applying a question mark on the extent of contamination at these locations (refer **Figures 15,– 17 and 18**).

It is believed that the contamination identified in the south of Source Area C probably represents the lateral spread of mobilised contaminants from an onsite shallow waste source. To confirm the presence of such a source, an additional historical review was conducted of records on these areas. This review identified that wastes have been dumped in Source Area C that could account for the high levels of contamination at the boundary. The review was also extended to the area north of Source Area D2. In this case, no historical evidence could be found of source materials in this area. It is therefore considered unlikely that this contamination is from a major unrecorded source and as a consequence it is believed that the sources and associated contamination is localised and unlikely to spread far beyond the discreet sample points.

4.7 Interface Elevation

Based on elevation data obtained from the 125 geoprobe locations, the interface was found to have elevations ranging from 124.0 mAHD to 126.6 mAHD, with an average elevation of 125.6 mAHD and standard deviation of 0.4 mAHD. The interpreted elevation of the clay interface is presented on **Figure 24**. As outlined in the methodology, the contours presented on this figure have been developed using a topographic map generated by photogrammetry techniques having a maximum accuracy of +/- 0.5m. Many of the apparent smaller fluctuations in the interface may therefore be a product of inaccuracies in the topographic mapping.

Overall, the results indicate that the interface elevation is relatively constant across the site and the minor variations in elevation observed are not considered significant enough to modify capping boundaries.

5 LABORATORY AND FIELD TESTING RESULTS

5.1 Ring Infiltrometer and Triaxial Permeability Tests

Locations of ring infiltrometer and triaxial permeability tests are presented on **Figure 1** and results are summarised in the table below:

Location	Ring Infiltrometer Permeability 'k' (m/sec)	Trial Length (hrs)	Triaxial Permeability 'k' (m/sec)
Source Area C	3.9×10^{-5}	4.9	NA
Source Area C (Sand)	3.4×10^{-3}	0.4	NA
Source Area B Effluent Drain (Centre)	1.3×10^{-5}	21.3	NA
Source Area B Effluent Drain (North)	1.4×10^{-5}	20.3	NA
Source Area A (Acid Area)	2.5×10^{-4}	3.1	4.3×10^{-11}
Source Area A (Former Oleum Area)	8.1×10^{-6}	85.1	1.4×10^{-11}
Source Area A (NC Area)	6.2×10^{-5}	4.3	NA
k (MEAN)*	6.4×10^{-5}	-	2.3×10^{-11}

**Excluding the permeability result for the sands*

The permeability results from the ring infiltrometer tests vary by approximately two orders of magnitude, with a mean value of 6.4×10^{-5} m/sec. The highest permeability calculated was produced by the test performed in the central section of Source Area A (Acid Area). In this location the clays exhibited highly friable nature upon drying at the base of the excavation, potentially indicating there had been some structural degradation due to their exposure to acidic conditions. This structural degradation may have raised the permeability of the clays in this area.

The lowest permeability calculated (8.1×10^{-6} m/sec) was from the longterm test performed in the western section of Source Area A (former Oleum Area). Measurement and calculation of permeability was performed at various stages over the duration of this test indicated a decrease in permeability over time. This decrease in permeability is indicative of the gradual saturation of macrostructures and surrounding clays immediately affected by the wetting front produced by the infiltrometer.

5.2 Macrostructures

The key result of permeability testing of the Upper Shepparton clays is that the average permeability calculated from triaxial tests is approximately six orders of magnitude higher than that calculated for the ring infiltrometer tests. It is thought that the large variation in results supports the presence of high permeability vertical macrostructures which were not present within the smaller diameter undisturbed samples. The ring infiltrometer tests were undertaken on the exposed surface of the Upper Shepparton clays and due to the larger surface area studied, were much more likely to be subject to macrostructure permeability effects. The presence of these macrostructures were subsequently confirmed when a small number (less than 5) of geoprobe samples were found to contain vertically orientated sand infilled fractures (refer Plate 2). It is likely that these structures represent the controlling hydraulic factor for the infiltration of fluids through the Upper Shepparton clays. However, instantaneous mixing calculations (see **Section 6.7.1**) indicate that the average permeability of the Upper Shepparton clays is somewhere between the permeabilities indicated by triaxial and infiltrometer tests (1×10^{-8} m/sec). Infiltrometer tests may be indicating a higher value due to “wetting up” processes or reflect the permeability of the uppermost layers of the Upper Shepparton clays.

Based on the results of permeability testing and instantaneous mixing calculations, the only means of accurately assessing the permeability of the Upper Shepparton clays is to conduct a large scale, at least 10 m by 10 m, field infiltration test. Field infiltration trials have been proposed as part of the CSA Trial phase of work at the site. The high degree of uncertainty regarding the permeability of the Upper Shepparton clays means that the impact of capping on groundwater quality cannot be effectively modelled. Only the relative performance of the capping options can be assessed.

Plate 2: Near vertical sand and carbon infilled macrostructure identified in a geoprobe core sample obtained from near the former Oleum Area in Source Area A. It is postulated that the majority of these structures have been produced through shrinkage/swelling of the clays due to climatic variations and/or chemical exposure. Movement of water through these structures causes the infilling of sand and other loose materials.

5.3 Leaching Column Tests

Due to the evidence of macrostructures within the clays and the low permeability of small diameter undisturbed samples, it was suggested that leaching column studies were not likely to yield meaningful mass transfer rates. Following discussion with ADI and the auditor, this task was subsequently abandoned. It is suggested that the an effective way to obtain meaningful mass transfer rates will be to perform a fieldscale infiltration trial over a large area of impacted aquitard. Subsequent monitoring of changes within the groundwater chemistry and hydraulic head of monitoring bores immediately below the infiltration zone could then be used to determine mass transfer rates.

As with permeability, the high degree of uncertainty regarding leachability of contaminants from the Upper Shepparton clays means that the impact of capping on groundwater quality cannot be effectively modelled. Field trials proposed for the CSA Trials should provide a more accurate assessment of leachability of contaminants from the Upper Shepparton clays. The infiltration trials are proposed for Source Area A, which contains the greatest mass of contaminants.

5.4 Capping Media Testing

The laboratory results for all tests performed for the purposes of capping media assessment are presented in **Appendix I.**

5.4.1 Clay Cap

The results obtained from the geotechnical analysis performed on the two 20kg bulk samples, sourced from the channel excavation spoil piles north of the site, are summarised in the table below.

	Channel Bank Clay (grey)	Channel Bank Clay (brown)	Channel Bank Clay (Average)
Permeability	4.7×10^{-9} m/s	1.3×10^{-8} m/s	8.85×10^{-9} m/s
Maximum Dry Density	1.740 t/m^3	1.750 t/m^3	1.745 t/m^3
Optimal Moisture Content	16.3 %	17.2 %	16.7 %
Moisture Content	12 %	16.2 %	14.1%
Emerson Class Number	2	2	2

The results of the triaxial tests indicate that the permeability of the compacted channel bank clay samples were several orders of magnitude higher that those of the contaminated clays obtained from the central (Acid Area) and western (former Oleum Area) sections of Source Area A (refer **Section 5.1 and Figures 1 and 3**). This result is unexpected given that the channel bank clays were compacted prior to testing, ensuring the absence of a structured soil matrix which would have a greater potential for preferential pathways. It is suggested that selective excavation from the channel bank clays and higher levels of compaction (98% standard compaction) will cause the permeability of the clay to approach 1×10^{-9} m/s or lower. Selective excavation from the spoil piles may also allow separation of lower permeability clays. This subject is further discussed in **Section 6.3.4.1.**

The two clay samples displayed comparable maximum dry densities and optimal moisture contents; 16.3% and 17.2%. The initial moisture content of the ‘brown’ clay sample was close to that of the optimum (16.2%), while for the ‘grey’ sample the initial moisture content was approximately 4% lower than optimal for maximum dry density (12%). Thus, the practical implication for use of these channel bank clays as a capping media is that they require the addition of some moisture to ensure maximum density and minimal permeability.

The Emerson Test is an important durability test for assessing the likelihood of soil erosion. The Emerson Class Number 2 determined for both clay samples, indicates that the clays have high to very high potential for erosion. This highlights the importance of good moisture control and compaction of the capping media, along with regular inspections for cracking in the clay surface and maintenance of a vegetated cap cover.

5.4.2 Phytocap

Composite samples of channel bank clays and dune sands from onsite sources were analysed in order to determine the suitability of these materials for the development of a Phytocap media. The results of the analyses are summarised in the table below.

	Dune Sand Composite	Channel Bank Clay
Particle size analysis	SAND / Silty SAND (SP/SM) brown	Silty CLAY (CI) brown
pH	7.4	9.0
Organic matter	< 0.5 %	< 0.5 %
Total Nitrogen as N	69 mg/kg	316 mg/kg
Total Phosphorus as P	104 mg/kg	310 mg/kg
Potassium	1550 mg/kg	1780 mg/kg
Salinity	12 uS/cm	440 uS/cm

The results of the analysis for organochlorine pesticides and organophosphorus pesticides were below the laboratory detection limit for all analytes and both samples. This confirms the absence of any agricultural pesticide residue entrained within the media. Similarly, all phenol analytes were below the laboratory detection limit for both the channel bank clays and the dune sand composites.

The metals incorporated in the list of analytes included Arsenic, Cadmium, Cobalt, Chromium, Copper, Molybdenum, Nickel, Lead, Selenium, Tin, Zinc and Mercury. Cadmium, Molybdenum and Mercury. All concentrations were below laboratory detection limits in both composite samples, while Tin was below the detection limit in the case of the channel bank clays. All other metals were detected in low concentrations, the highest being zinc (17 mg/kg and 39 mg/kg in the dune sand and channel bank clay samples respectively).

The channel bank clays showed higher salinity and pH levels relative to the dune sand composite, as well as greater concentrations of nitrogen, phosphorus and potassium, i.e. the basic mineral elements required for plant growth in soil.

Particle size distribution results confirmed the composition of the dune sand and channel bank clay samples as sand/silty sand and silty clay respectively. Based on these classifications, the dune sands and channel bank clays are deemed suitable for mixing in order to form a sandy clay loam for use as a plant growth medium.

6 CAPPING OPTION ASSESSMENT

6.1 General

Various cap types/configurations for the source areas have been assessed as part of the essential requirements for Sections 10.2.1 and 10.2.2a-d of the Tender Brief. Capping is traditionally used as an effective tool in landfill and contaminated land rehabilitation to minimise infiltration of water and therefore mobilisation of contaminants into underlying aquifers. Thus, capping to reduce water infiltration into the source zones is likely to be effective and is a proven remedial methodology.

In the absence of reliable measurements of permeability and leachability from the Upper Shepparton clays, the impact of capping options on groundwater quality could not be reliably assessed using modelling. Therefore, only the relative performance of the capping options in terms of their ability to reduce infiltration could only be completed. This was completed using the HELP Model (Section 6.1.1) and instantaneous mixing calculations (see Section 6.1.2). Using the HELP Model to assess baseline conditions and the capping options involved some assumptions which stretched the accuracy of the models estimates of infiltration. However, with the data objective of simply assessing the relative performance, the limitations of the model was considered suitable for assessing the capping options.

A qualitative assessment of three capping systems was undertaken in order to recommend a preferred capping system for the source zones. These are summarised below.

Capping Options to be Assessed

Cap	Description
1. Phytocap	Comprises a 0.6m thick layer of sandy clay loam for the establishment of a native vegetation layer with high evapotranspiration and nitrate/sulphate uptake capability.
2. Clay Cap	VIC EPA Type 3 (Solid Inert) landfill cap (refer VIC EPA publication 788, October 2001, Siting Design, Operation and rehabilitation of landfills).
3. Reference Cap	NSW EPA Reference Cap comprising a composite liner system, middle drainage layer and vegetated top layer.

Schematic cross-sections of each of these three capping options have been provided in **Figure 26.** The qualitative assessment of the caps covered both technical and practical considerations, including, but not limited, to the following:

- Net infiltration.
- Nitrate reduction capability (if available).
- Construction cost and duration.
- Maintenance requirements and costs.
- Susceptibility to erosion and failure.
- Impact on surrounding environment.
- Limitations on future landuse.
- Support of the principles of Ecologically Sustainable Development.

6.1.1 Baseline HELP Modelling and Permeability

HELP modelling results obtained for the present uncapped (baseline) conditions and for each of the capping options have been presented in **Appendix H**.

During the establishment of the baseline model (representing the present uncapped condition) it became apparent that the permeability of the Upper Shepparton Clays was one of the key variables affecting the resulting infiltration rates. A sensitivity analysis was then performed using the model by fixing all other variables and adjusting only permeability. Using a permeability of 1×10^{-9} m/s produced infiltration rate of approximately 8% of average annual rainfall. This infiltration rate was considered reasonable and the permeability of the Upper Shepparton Clay was subsequently fixed at 1×10^{-9} m/s for modelling all capping options. The actual permeability may be higher (as indicated by Field Ring Infiltrometer Testing) or lower (as indicated by the Triaxial Permeability Testing) however, larger scale permeability testing (i.e. field trials) would be required to confirm this.

6.1.2 Mixing Calculations

A simple instantaneous mixing calculation was used to assess the effects of capping on groundwater quality and obtain estimates of the permeability and leachability of nitrates from the Upper Shepparton clay beneath Source Area A. Source Area A area was chosen as it contains the largest residual mass of nitrate and hence poses the greatest risk to downgradient groundwater quality. Mixing calculations were set up in an Excel spreadsheet. A copy of the calculations and results have been presented in **Appendix O.**

Calculations were initially conducted on a baseline (no capping) scenario to estimate the permeability and leachability of the Upper Shepparton clays. Reasonably reliable estimates of groundwater underflow entering the source area (Q1) were made using Darcy's Equation (Q = kiA) and information obtained from groundwater investigations. The concentration of nitrates in groundwater hydraulically up-gradient (C1) and down-gradient (C3) were also reasonably well understood from groundwater monitoring data. Groundwater flow hydraulically down-gradient (Q3) was simply the sum of groundwater flow entering the source area (Q1) and rainwater infiltration (Q2). The infiltration rate through the Upper Shepparton clay (Q2), concentration of nitrates in soil and the rate of partitioning from soil to groundwater (C3) were varied and compared to field measurements of nitrates in groundwater.

The input parameters used for the baseline (no capping) scenario are summarised as follows:

Summary Table: Baseline Modelling Variables and Calculations

Equation Variable	Calculation
Q1 = 259 m^3/year	Q1 = k I A where: k = Permeability (m/day) = 2 m/day i = Groundwater gradient = 0.001 A = Cross Sectional Area of aquifer flow tube passing under Source Area A = 120m (width) x 3m depth = 360 m^2
C1 = 4 mg/L	Previous up-gradient groundwater results from BH60 (sampled 2002)
Q2 = Varied	Calculated by multiplying average annual rainfall over the surface area of the source area (minimum capping area) by a range of infiltration rates (2%, 4% and 8%).
C2 = Varied	Determined by multiplying three average residual nitrate concentrations (250 mg/kg, 500 mg/kg and 1000 mg/kg) within source area by a mass transfer rate (50%, 65% and 80% mass transfer rate from soil to groundwater)
Q3 = Automatically calculated	Q1 + Q2
C3 = (Q1C1 + Q2C2)/Q3	Average nitrate concentration in groundwater downgradient

Sensitivity analysis using the mixing calculations under “baseline” conditions identified that by using values of 8% and 80% for infiltration and partitioning coefficients of nitrates from soil to water respectively, resulted in groundwater concentrations hydraulically down-gradient (C3) from approximately 340 – 680 mg/L (assuming average residual nitrate concentrations of 500 mg/kg and 1000 mg/kg, respectively). These values were therefore deemed to be best fit. An 8% infiltration rate was also the baseline infiltration rate estimated by HELP modelling. However, it is worth noting that higher permeability rates, and lower concentrations in soil and partitioning coefficients, would also result in concentrations in groundwater similar to those observed.

Using an infiltration rates through the Upper Shepparton clays estimated by the HELP model for each of the capping options for Q2 and varying the concentration of nitrates in water discharging from the clays to the Shepparton Aquifer (C2), the relative performance of the Phytocap and Clay Cap options were assessed using mixing calculations. These are discussed under each of the options assessment below.

6.2 Option 1 – Phytocap

6.2.1 Background

The ability of plants to intercept rain, prevent infiltration and transpire significant volumes of water after it has entered the subsurface root zone can be used to provide hydraulic control for remediation systems. Thus, the objective of the Phytocap option is to use plants / vegetation to limit the migration of nitrate and sulphate contaminants from the clay aquitard into the groundwater system and to other receptors through increased evapotranspiration of incident and infiltration waters. To achieve this, four essential requirements of a phytocap must be met:

- Soil with adequate plant-available water-holding capacity.
- Adequate thickness to store water derived from a “critical event” storm.
- Low soil density to permit adequate root growth.
- Robust, healthy plant cover.

6.2.2 Plant Species

Based on HLA’s knowledge of the site and experience with Phytocaps, HLA recommends that vegetation of a Phytocap should recreate a local native woodland plant community, typified by grassy understorey similar to the Yellow Box (*Eucalyptus melliodore*) woodland. This plant community is located as remnant pockets on the low undulating or near level sandy soils across the Mulwala site and accordingly will be suited to the growing conditions of the recommended capping surface materials. The Yellow Box woodland includes a species-rich understorey of native tussock grasses, herbs and scattered shrubs, while the over-storey is characterised by a discontinuous cover of trees of medium height (10-30 m) in which the canopies are clearly separated. The over-storey would comprise native local woodland species such as Yellow Box, Grey Box (*Eucalyptus microcarpa*) and White Cypress Pine (*Callitris glaucophylla*).

Figure 1. Yellow Box (*Eucalyptus melliodora*) (left) and Grey Box (*Eucalyptus macrocarpa*) (right)
Source: DPI (http://www.dpi.vic.gov.au/dpi/vro/wimregn.nsf/pages/natres_veg_plains), 2004

To reduce infiltration in the early stages of establishment, and due to the previous history of extensive grazing, removal of native vegetation and the use of 'sterile' soil (in the context of vegetative plant material and topsoil bore seed), the area would need to be planted at 1 metre spacings with endemic monocot (understorey) species tube stock. These have fibrous rooting systems, high transpiration rates and strong growing rates in the early months, and sound reproductive habit that will ensure natural re-colonisation of the area. The selection of endemic species would ensure that these species are adapted to the local soil and climate conditions.

The tube stock species mix should be based on endemic understorey species that form part of the Yellow Box woodland. Suggested species include *Aristida behriana, Aristida ramosa,* Wallaby Grasses (*Austrodanthonia auriculate, Austrodanthonia bipartite, Austrodanthonia racemosa, Austrodanthonia richardsonii),* Spear Grasses (*Austrostipa aristiglumis, Austrostipa blackii, Austrostipa nodosa, Austrostipa scabra*), *Bothriochla macra, Chloris trucata, Chloris ventricosa, Cymbopogon refractus, Dianella longifolia, Dianella revolute, Lomandra filiformis, Poa labillardieri, Poa sieberiana, Themeda australis*.

Planting should ideally be performed in autumn (March / April) to minimise irrigation requirements and therefore increase the chances for successful vegetation establishment.

6.2.3 Evapotranspiration

The transpiration rate of vegetation depends on factors such as species, age, mass, size, leaf surface area, canopy cover, growth stage, and climatic factors, and will vary seasonally (U.S.EPA, 2000). Therefore well-defined numbers for a given type of vegetation cannot be readily assumed. Estimates for certain cases, however, provide a rough guide to the order of magnitude that might be expected. This is discussed below.

6.2.3.1 Influences on Transpiration Rates

Raper (1998) reports that total leaf area is the dominant factor in determining plant water use under most environmental conditions. Experimental evidence suggests that water use increases with leaf area, or crown cover, until canopy closure is achieved at which point water use reaches a maximum (Raper 1998). Greenwood *et al.* (1982, 1985) also found leaf area index to be the greatest single determinant of annual transpiration. Greenwood (1986) determined that leaf area can account for over 80% of the variation in evapotranspiration in eucalypts grown under similar moisture and landscape conditions to the Mulwala site. Therefore, total leaf area per unit ground area is of greater influence on vegetation water use than the plant species or the density of trees (Raper 1998). To maximise the total leaf area per unit ground area on Phytocap sites at the ADI Mulwala facility, species should therefore be selected to maximise leaf area in the vertical profile. This requires optimal structural diversity within the vegetation community, including established ground cover, understorey, mid-stratum and upper canopy layers.

6.2.3.2 Transpiration Rate Estimates

Berry *et al.* (2004) estimated the annual course of transpiration from Australian vegetation comprised of either turgor, mesic and sclerophyll leaves. Assuming Phytocap vegetation most closely resembles the low shrubland with sclerophyll leaf function, highly conservative transpiration rates would range from less than 0.15 mm/day in June (winter) and over 0.5 mm/ day in December (summer).

However, with the addition of mid-stratum and upper canopy vegetation as proposed for the Phytocap composition, transpiration rates are likely to be higher. For example, Landsberg (1998) reported that the maximum measured transpiration rates for full-canopied Australian forests ranges from approximately 4-7 mm/day.

Greenwood *et al* (1982) measured the transpiration of a stand of *Eucalyptus wandoo*, in a region with annual rainfall of 520 mm/year and pan evaporation of 1,650 mm/year (comparable to the climatic characteristics experienced at the ADI Mulwala site). The trees roots did not penetrate to sufficient depth to draw water from an aquifer, as would be the case for larger Eucalypt species proposed for vegetation of the ADI Mulwala Phytocap. Greenwood *et al* (1982) report an annual transpiration of 960 mm/year.

Therefore, based on the available information and estimates derived from the literature, it is considered that the average transpiration rate for a mature Phytocap of typical Yellow Box woodland community may be in the range of 2-3 mm/day (730-1095 mm/year).

6.2.3.3 Water Balance

Based on a report by Sykes, 2003 the annual rainfall averages for Mulwala are 507 mm/year, with a decile 9 (rainfall in the highest 10% of years) rainfall of 712 mm. The highest rainfall months occur in the winter and spring, with rainfall averaging 50-60 mm/month, while the lowest rainfall months in summer and autumn average 30-40 mm/month. Evaporation data within the report (sourced from Tocumwal, NSW) suggest an average of 1892 mm/year, with the majority occurring in summer.

Based on this data, a basic water balance suggests that evaporation exceeds annual rainfall by 1385 mm in an average year and 1180 mm in a decile 9 year. On a monthly basis, evaporation at Mulwala is equal to or greater than rainfall in any month in an average year. In a decile year, rainfall exceeds evaporation by between 18 mm/month and 36 mm/month, from May through to August. This results in a limited amount of water remaining in the environment for infiltration into the subsurface zone.

Comparison of the estimated transpiration rate with the results of the basic water balance suggests that a mature Phytocap, with developed ground cover, understorey, mid-stratum and upper canopy layers would be a potentially viable capping option at the site.

However, while there appears to be limited average monthly water supply available to infiltrate the dunes sands, it is likely that percolation into the subsurface occurs predominately during critical rainfall events. Therefore, the vegetation cover must be sufficient to maintain the integrity of the Phytocap during storm events or periods of high intensity rainfall.

6.2.4 Infiltration Rate

To estimate the infiltration rate that could be expected from the Phytocap, a literature search identified a number of relevant studies on drainage associated with pasture crops in the region. Field experiments conducted by Ridley *et al* (2001) in north-eastern Victoria found that subsurface infiltration and groundwater recharge (deep drainage) are likely to occur in only 6% of years under a lucerne crop (with an average annual rainfall of 600mm). This low recharge rate is also supported by Kennett-Smith *et al* (1994) who reviewed deep drainage estimates for the south-western Murray Basin (average annual rainfall 300-600 mm). Here the infiltration rate under pasture systems was calculated to be 4.5 mm/year (i.e. between 0.75% and 1.5% of annual rainfall).

The proposed Phytocap will have a greater root depth and transpiration capacity than a pasture crop, and therefore deep drainage estimates outlined above should be even lower. This assumption is supported by the results from Peck *et al* (1993) who studied deep drainage for areas in WA with annual rainfall in the order of 500mm. This study showed that in agricultural areas (i.e. 60-70% cleared land) drainage ranged between 24mm and 37mm per annum, while drainage in areas of native vegetation (i.e. 100% forested) was between 0.8mm and 1.1mm (equating to an annual groundwater recharge of less than 0.2% of average annual rainfall).

Based on the results of the studies outlined above, HLA suggests that that a conservative estimate for the infiltration rate under the proposed Phytocap would be less than 1mm/year (i.e. 0.2% of average annual rainfall).

6.2.4.1 HELP Modelling

To determine the effectiveness of the proposed Phytocap the following design parameters (from deepest layer to shallowest layer) were used:

- Average soil profile consisting of:
  - 5.28 m clay ($k = 1 \times 10^{-9}$ m/s), as discussed in Section 6.1.1, underlying;
  - 2.71 m loamy fine sand ($k = 3 \times 10^{-3}$ m/s), based on the ring infiltrometer tests, underlying;
- Phytocap consisting of:
  - Indigenous woodland vegetation.

A surface slope of 5% was assumed to account for surface water runoff. Climate data from the Bureau of Meteorology weather station in Wagga Wagga was used and the area modelled was 7,000 m^2. The vegetation growth period was set at 365 days per year, with a root zone depth of 2.71 m, and an excellent stand of grass. The model was run over a period of 50 years.

According to the HELP Model User's Guide (Version 3) the Leaf Area Index (LAI) is defined as the dimensionless ratio of the leaf area of actively transpiring vegetation to the nominal surface area of the land on which the vegetation is growing. The vegetation was assumed to have a LAI of 5, which is appropriate for a dense stand of trees and shrubbery. This was used to simulate an established cap system.

Modelling of the site using HELP provided the following infiltration results:

Average Annual Totals for Years 1 - 50		
	Cubic metres	**Percent**
Precipitation	3782	100%
Runoff	0	0%
Evapotranspiration	3807	100.6%
Leakage through underlying clay layer	0.2	<0.1%
Change in water storage	-25	-0.7%

From the above, the model suggests a leakage or percolation through the Phytocap of 0.0052% of rainfall or 0.2 m^3 per annum, over 7,000m^2.

6.2.4.2 Mixing Calculations

To determine the effectiveness of the proposed Phytocap the following input parameters were used to determine the downgradient groundwater concentration (C3):

- Q2 = 1 m^3/yr (equivalent to 0.0052% of rainfall as determined by HELP modelling)
- C2 = 250 mg/kg to 1000 mg/kg (variable mass transfer rate of 50%, 65% and 80%)

Based on the results of the mixing equation, the phytocap, which had a net annual infiltration of 0.005%, resulted in a maximum downgradient groundwater concentration of 7mg/L.

6.2.5 Nitrate Uptake

During vegetative growth, nitrate ions are rapidly absorbed by the root and transported via the xylem to the leaf. The rate of absorption is dependent on a number of factors, including the vegetation species, growth cycle and plant maturity, and is therefore difficult to estimate without appropriate field trials. A literature review of publications reporting nutrient uptake data revealed limited discussion regarding nitrate uptake rates by specific Australian species. Furthermore, as the primary goal of the capping options assessment is to determine which of the capping designs has the greatest reduction on net infiltration, the potential for a Phytocap to have nitrate reduction capabilities provides a supplementary means of site remediation.

It should be noted that it is probable that the root system will not reach the identified source zones beneath the cap to uptake nitrate (and other nutrients) until the system is mature which could be several years to decades. Thus, the removal of nitrates from source areas over time is considered to be a bonus and has not formed part of the cap performance assessment at this stage.

6.2.6 Soil Medium Composition

A Yellow Box woodland community prefer moderately fertile well-drained moisture retentive soil, but will tolerate poor and dry soils with high levels of sand, especially those low in mineral elements. A typical soil environment of this woodland variety may comprise unconsolidated riverine deposits of clay, silt, sand and gravel, plus residual and colluvial deposits from underlying meta-sediments. A heavy clay based soil medium would not be well tolerated, as it limits free-drainage in the soil.

Thus, HLA recommends that the optimum plant-growing medium for this community would comprise a weed free locally sourced mixture of sand and clay, to a nominal depth of approximately 0.6m. Based on our understanding of site geology, these materials could be sourced from the upper and middle beds of the Shepparton Formation and mixed to form a sandy clay loam (for details on recommended mixing method refer **Appendix L**). Approximate proportions of sand, silt and clay are given as follows:

- Sand 50% +
- Silt 0-20%
- Clay 30-40%

The above soil composition is considered adequate for the establishment of the Yellow Box Phytocap community.

6.2.7 Susceptibility to Erosion and Failure

Until the vegetation cover is established, initial susceptibility to erosion is likely to be high. However, once established, and with management strategies in place to protect the viability of the cap cover, the risk of failure is anticipated to be low.

In order to reduce the risk of wind and water erosion of this material, an initial cover crop of Japanese millet (warmer months) and/or Rye Corn (cooler months) should be sown. As these are annual species that do not regenerate well, the crops will die off to provide an addition to the soil organic matter.

6.2.8 Construction and Maintenance Requirements and Costs

The construction and maintenance requirements for a phytocap at Mulwala have been detailed in the management plan presented in **Appendix L**. The estimated costs to meet these requirements are as follows:

- Phytocap Construction $21/m^2
- Maintenance and Monitoring $15,000-$25,000 pa (first 5yrs) and $2000-$4000 pa (up to 100yrs)

Construction costs are also based on the assumptions presented by HLA in our proposal (ref:D1011301_PRP_31May04) and include the installation of lysimeters and groundwater bores for performance validation monitoring (for details refer to **Section 6.8.1**).

6.2.9 Impact on Surrounding Environment

The establishment of vegetated Phytocapping across the identified areas of the ADI Mulwala facility is considered to have a minimal impact on the surrounding environment. The importation of the sandy clay loam topsoil to the areas designated for capping works may cause minor disturbances with regard to the mobilisation of machinery. Similarly, planting and direct seeding works will require staff and equipment to be on-site for the construction period and for subsequent monitoring and maintenance works. However, following vegetation establishment, the Phytocap is expected to contribute a visual benefit to the landscaping of the site. Phytocapping would also assist in the restoration of indigenous ecosystems and provide habitat for local fauna.

6.2.10 Limitations on Future Landuse

The integrity of the Phytocapping option is based on the maintenance of a mature, complex and structurally diverse vegetation community. This places an inherent limitation on future landuses such that vegetation cover on the capped areas must be retained. While it is understood that ADI intends to retain ownership of the land, opportunities for leasing sections of the site for grazing and other agricultural landuses are largely limited, as are infrastructure developments within capped areas.

6.2.11 Ecologically Sustainable Development

The Phytocapping option has a beneficial impact on the ecological values of the site and surrounding area. The selection of a grassy Yellow Box woodland for revegetation works aims to reconstruct ecosystems similar to that of the remnant vegetation identified on-site. The shrub and grassy understorey of the woodland community provides nesting sites, shelter and food resources for indigenous fauna, including birds, bats, reptiles, ground dwelling and arboreal mammals, and invertebrates.

The resources required for construction of the Phytocap include native seed and tube stock, which may be sourced from a number of local suppliers, including the Murray Indigenous Seed Service and the Australian Native Farm Forestry, located in Cobram. The materials required for the construction of the sandy clay loam topsoil are likely to be available from on-site sources, such as the Goulburn Murray Water channel overburden. This helps to minimise the energy and costs associated with the transportation of capping materials to the site.

Following seedling plantation, management requirements for the Phytocapping option are expected to comprise of periodic (i.e. biannual) visual inspection and maintenance works as required. Maintenance works may include weed removal, pest control and replanting of damaged or poorly established vegetation. However, assuming comprehensive establishment of native and self-sufficient vegetation cover, longer term maintenance and replacement requirements of the Phytocap are likely to be minimal. Furthermore, native trees and deep-rooted grasses play vital roles as water pumps, moderators of local climate and soil stabilisers, and are therefore important in maintaining landscape function.

6.3 Option 2 –Clay Cap

The Victorian EPA Best Practice Environmental Management*, Siting, Design, Operation and Rehabilitation of Landfills*, 2001 (Landfill BPEM) recommends the following Clay Cap design for solid inert waste or fill landfills (Type 3) (from deepest layer to shallowest layer):

- 0.3 m Earthen cover.
- 0.5 m Low permeability clay ($K < 1 \times 10^{-9}$ m/s).
- 0.5 m Soil sub base & topsoil/mulch.

The performance objective of this cap in a landfill context is to reduce seepage through the landfill cap to less than 75% of the anticipated seepage rate through the landfill baseliner. Compliance with this objective is determined by modelling the cap using site specific conditions such as material, slope and climate. This cap system has been selected for assessment for the Mulwala source areas as the Mulwala contaminant material can be regarded as solid inert for the purposes of capping i.e. it will not produce landfill gas.

As stated in the proposal documents, the earthen cover recommended is already assumed to be in place over the waste materials to be capped.

6.3.1 Infiltration Rate

6.3.2 Help Modelling

One of the primary purposes of this cap is to reduce the infiltration rate of water through the cap and hence through contaminated material (or contaminant source zone). Modelling the infiltration rate provides a basis to assess and compare the effectiveness of the proposed capping systems. Modelling of the Clay Cap was performed using two different permeability's for the clay layer. This was performed to provide an indication of the sensitivity of the cap performance relative to varying clay compaction rates which could be expected in the field.

The infiltration rate of the proposed cap was also modelled using the US EPA's HELP model, using the following design parameters (from deepest layer to shallowest layer):

- Average soil profile across the five areas consisting of:
    - 5.28 m clay ($k = 1 \times 10^{-9}$ m/s), as discussed above, underlying;
    - 2.7 m loamy fine sand ($k = 3 \times 10^{-3}$ m/s), based on the ring infiltrometer tests, underlying;

- Caps consisting of:
  - 0.5 m Clay Cap (k = 1 x 10^{-9} m/s = Victorian EPA requirements and k = 8.85 x 10^{-9} m/s = Average channel bank clays at 95% compaction).
  - 0.4 m loam soil sub base.
  - 0.1 m sandy loam soil and mulch mixture.

A good cover of grass was assumed and a surface slope of 5 % was used. Climate data from the Bureau of Meteorology weather station in Wagga Wagga was used as the base climate data to calculate precipitation and evapotranspiration rates and the area modelled was 7,000 m^2. A growth period of 365 days a year was assumed for the cap vegetation, with a root zone depth of 0.3m. The model was run over a period of 50 years.

Modelling of the site using HELP provided the following results:

Average Annual Totals for Years 1 - 50				
	Clay Cap (k=1x10^{-9} m/s)		Clay Cap (k=8.85x10^{-9} m/s)	
	m^3	% Rainfall	m^3	% Rainfall
Precipitation	3782	100 %	3782	100 %
Runoff	13.2	0.3%	12.9	0.3%
Evapotranspiration	3753	99%	3686	97%
Leakage through underlying clay layer	0	0%	51	1.3%
Change in Water Storage	24	1.6 %	41	1.5%

As can be seen above the average annual infiltration through the clay cap was estimated to range between 0% and 1.3% of total annual average rainfall. These infiltration rates are thought to be realistic, particularly when they are compared to the baseline infiltration estimate of 8.2%.

6.3.3 Mixing Calculations

To determine the effectiveness of the proposed Clay Cap the following input parameters were used to determine the downgradient groundwater concentration (C3):

- Q2 = 0.0019 m^3/yr (equivalent to 0.00001% rainfall as determined by HELP modelling)
- C2 = 250 mg/kg to 1000 mg/kg (variable mass transfer rate of 50%, 65% and 80%)

As it could be expected, an infiltration of 0.00001% through the cap will not result in a measurable increase in downgradient groundwater concentrations.

6.3.4 Construction and Maintenance Requirements and Costs

The material and procedures used in constructing the proposed clay cap in a landfill context are required to meet certain quality standards as outlined by the Victorian EPA. The EPA has set these quality parameters so that the integrity of the cap is maintained for the long-term. The construction and maintenance procedures presented in **Appendix M**, utilise the current best practice requirements for achieving the objectives of the Victorian EPA cap design.

The estimated costs to meet these requirements are as follows:

- Claycap Construction $22/m^2
- Maintenance and Monitoring $15,000-$20,000 pa (first 5yrs) and $1000-$2000 pa (up to 100yrs)

Construction costs are also based on the assumptions presented by HLA in our proposal (ref:D1011301_PRP_31May04) and include the installation of lysimeters and groundwater bores for performance monitoring (Refer to **Section 6.8.1**).

6.3.4.1 Material Source

It is proposed that the channel bank clays should be utilised for the clay layer within the clay cap. Although these materials appear to be the most suitable and easily accessible clays at the site, further study will be required to confirm their suitability. As outlined in **Section 5.4.1**, following remoulding to 95% standard compaction, two samples of channel bank clay were subject to a triaxial permeability test. The average permeability indicated by these tests (8.85 x 10^{-9} m/s) is higher than the EPA recommended value of 1 x 10^{-9} m/s. It is possible that selective excavation from the spoil piles will allow separation of lower permeability clays. Higher quality clays may also be obtained through selective excavation from a dedicated borrow pit onsite. In addition, it is also possible that if the clays are recompacted to 98% standard compaction, their permeability will be adequate.

If the channel bank clays are found not to be suitable, HLA is confident that clays of suitable permeability can be excavated from insitu locations at other areas on the site. The extremely low permeabilities obtained from triaxial testing of the clay samples obtained from Source Area A suggests that clays in the Southern may be more suitable. If this was confirmed then the clays could be obtained by developing an extraction (borrow) pit in a suitable location. Such a location could be the bedrock high to the west of Source Area D3, which has some of the deepest clay layers identified under the site.

The topsoil requirements for this cap will be met using the approach detailed in **Section 6.2.6** – Soil Medium Composition.

6.3.5 Susceptibility to Erosion and Failure

This Clay Cap is susceptible to erosion if vegetation is not established, as extreme weather conditions (rain or wind) could result in erosion. Rilling of the cap may occur during rain periods if adequate vegetation has not established. If this is not repaired promptly, it may then lead to cap failure (cracking and infiltration).

Movement (ie. settlement) of the underlying material may also contribute to cap erosion and/or failure through preferential settlement and/or consolidation. Settlement of material can cause the cap to crack and allow infiltration. However, this is more likely to occur in a landfill environment where material under the cap is undergoing a degradation process.

6.3.6 Impact on Surrounding Environment

The impact of the proposed cap to the on-site environment is considered to be minimal as the site currently comprises of a highly disturbed environment. There will be visual impacts arising from the construction of the proposed cap. However, assuming the cap is maintained, there will be a net visual improvement onsite.

The impact of the proposed cap to the off-site environment is also considered minimal. Provided the cap is well maintained, it is not considered to have any significant visual impact on the off-site environment.

6.3.7 Limitations on Future Landuse

As this site is owned by the Department of Defence, it is recommended that the site after use with the Clay Cap is limited to minimal activity or grazing. Should a landuse change be desired it is possible for bitumen or concrete surfaces to be placed ontop of a clay cap. These hardstands could provide opportunities for carparking, recreational sports or as building foundations.

It is also recommended that the construction of water features, such as ornamental lakes or ponds be avoided, as they may leak due to cracking of their liner from differential settlement of the cap (Landfill BPEM).

6.4 Option 3 – Reference Cap

The NSW EPA in the Draft Environmental Guidelines for Industrial Waste Landfilling (Draft Industrial Waste Guidelines) lists the following environmental goals for site capping and revegetation:

- Preventing pollution of water by leachate.
- Assuring quality of design, construction and operation.
- Minimising landfill space used.
- Preventing degradation of local amenity.
- Adequate staffing and training.

The Draft Industrial Waste Guidelines continue that 'site capping and revegetation should ensure that the final surface provides a barrier to the migration of water into the waste, controls emissions to water and atmosphere, promotes sound land management and conservation, and prevents hazards and protects amenity. In addition the capping must be designed to function with minimum maintenance and to accommodate settlement and subsidence of the underlying waste'.

The Draft Industrial Waste Guidelines specify the following capping system to achieve these goals:

- The composite liner system (a clay layer followed by a GCL liner).
- The middle drainage layer.
- A vegetated top cover.

6.4.1 Infiltration Rate

The effectiveness of the Reference Cap was also determined using the US EPA's HELP modelling tool using the following parameters (from deepest layer to shallowest layer):

- Average soil profile across the five areas consisting of:
    - 5.28 m clay ($k = 1 \times 10^{-9}$ m/s), as discussed in Section 6.2.1, underlying;
    - 2.71 m loamy fine sand ($k = 3 \times 10^{-3}$ m/s), based on the ring infiltrometer tests, underlying;
- Reference cap consisting of:
    - 0.6 m Clay Cap ($k = 1 \times 10^{-9}$ m/s).
    - Bentonite layer ($k= 1 \times 10^{-11}$ m/s) and poor placement was assumed.
    - 0.3 m coarse sand lateral drainage layer ($k = 1 \times 10^{-4}$ m/s).
    - 1 m loamy sand revegetation layer.

The following assumptions were used:

- Area = 7000 m^2.
- Slope of 5%.
- Slope length of 100 m.
- Weather data from Bureau of Meteorology weather station in Wagga Wagga.
- A good cover of grass.
- A vegetation growth period of 365 days per year.
- A root zone depth of 0.3m.
- The model was run for 50 years.

Modelling of the site using HELP provided the following infiltration results:

Average Annual Totals for Years 1 - 50		
	m^3	Percent
Precipitation	3782	100%
Runoff	0	0
Evapotranspiration	3371	89.1%
Lateral drainage from Drainage Layer	405	10.7%
Leakage through underlying clay layer	<0.1	<0.1%
Change in water storage	6	0.2%

From the above the Reference Cap effectively negates water infiltration through the cap to the underlying aquifer. This is mainly due to the bentonite layer in the capping system acting as a hydraulic barrier to water infiltration through the cap.

No instantaneous mixing calculations were undertaken for the reference cap. However, as with the Clay Cap, using the very low infiltration rate estimated by the HELP Model for the Reference Cap mixing calculations would indicate no measurable impact on groundwater quality.

6.4.2 Construction and Maintenance Requirements and Costs

The material and procedures used in constructing the Reference cap (in a landfill context) are required to meet certain quality standards as outlined by the NSWEPA. The NSWEPA has set these quality parameters so that the integrity of the cap is maintained for the long-term. HLA has assumed the same requirements for this capping system.

The estimated costs to meet these requirements are as follows:

- Reference cap Construction $52.30 /$m^2$
- Maintenance and Monitoring $15,000-$20,000 pa (first 5yrs) and $1000-$2000 pa (up to 100yrs)

Construction costs are also based on the assumptions presented by HLA in our proposal (ref:D1011301_PRP_31May04) and include the installation of lysimeters and groundwater bores for performance monitoring (Refer to **Section 6.8.1**).

6.4.2.1 Preparation

Adequate preparation of the site is vital to ensure a solid foundation is constructed to construct the cap. This will minimise factors such as movement and settling of the underlying material after the cap has been installed.

The preparation of the site for the cap is as follows:

- Survey and profile area to be capped.
- Source earthen cover on-site to provide appropriate cover over area to be capped.
- Develop required profile (3-5% grade away from centre of area to be capped).
- Proof roll area using 12 tonne 'sheepsfoot' compactor, to optimise compaction prior to any construction works commencing.
- Remove first 0.15 m of topsoil and stockpile prior to any construction works commencing. This topsoil should be used as part of the revegetation layer.

6.4.2.2 Clay layer

The constructed clay layer should meet the requirements outlined in **Appendix M**.

6.4.2.3 GCL Liner

A GCL liner provides the primary barrier to infiltration and is generally combined with a drainage layer in order to remove any excess moisture (see below). The recommended GCL liner is a bentonite liner, installed as per manufacturer specifications with a permeability of less than $1x10^{-11}$ m/s. The slope of the GCL liner must be 3% to 5%.

6.4.2.4 Drainage Layer

A drainage layer is generally placed between the soil layer and the low permeability capping layer. The purpose of the drainage layer is to remove excessive moisture that has permeated through the soil layer and will not be removed by evapotranspiration. It must also be designed such that it does not dry out the surface layer and kill the vegetation, and does not prevent the continued hydration of the low permeability layer, which would cause it to dry and crack. The drainage layer must be able to drain water from the source area as an accumulation of water at the toe of the cap may cause instability in the cap.

The drainage layer is required to meet the following requirements:

- Permeability to water of $k > 1x10^{-4}$ m/s.
- The drainage layer shall not be less than 0.3 m thick.
- The drainage media should be selected to have a sufficiently large void space to drain the runoff effectively and efficiently, and to prevent encrustation during the operating life of the landfill.
- Gravel selected should be:
    - Rounded.
    - Of nominal size greater than 20 mm.
    - Smooth-surfaced.
    - Robust and non-reactive in mildly acidic conditions.
    - Relatively uniform in grain size.
    - Free of carbonates that could form encrustations around the collector pipes.
    - Covered with a non-woven filter fabric.
- Gravel of a suitable grade or a combination of such gravel and a geonet may be used.

6.4.2.5 Revegetation Layer

Vegetating the cap is essential for the prevention of erosion and thereby ensuring the long-term integrity of the cap. Vegetation needs to be established as soon as possible after the civil capping works have been completed. Timing the works should be such that the vegetation is planted in autumn (March / April) and will minimise the irrigation requirements and therefore increase the chances for successful vegetation establishment.

The revegetation layer shall be required to meet the following requirements:

- Not less than 1 m deep.
- Final top slope should be graded to 5%.
- Plants selected for revegetation shall have root systems that will not penetrate beyond the revegetation layer or block the drainage layer.

6.4.2.6 Drainage

Drainage from the surface and internal layer of the reference cap should be directed to a drainage system at the cap perimeter which is constructed in accordance with the specifications outlined in **Appendix M**.

6.4.2.7 Material Source

Refer to **Section 6.3.2.1**.

6.4.3 Susceptibility to Erosion and Failure

This cap is susceptible to erosion if vegetation is not established as weather conditions (rain or wind) could result in erosion. Rilling of the cap may occur during rain periods if adequate vegetation has not established. If this is not repaired promptly, it may lead to cap failure.

Movement of the underlying material may also contribute to cap erosion and/or failure. Settlement of material can cause the cap to crack and allow infiltration. However, this is more likely in a landfill environment where material under the cap is undergoing a degradation process.

6.4.4 Impact on Surrounding Environment

Same as for clay cap option (Refer to **Section 6.3.4).**

6.4.5 Limitations on Future Landuse

Same as for clay cap option (Refer to **Section 6.3.4).**

6.5 Ecologically Sustainable Development

The Department of Environment and Heritage defines ecologically sustainable development (ESD) as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' (Brundtland Report, 1987). The following principles are principles of ecologically sustainable development:

1. Decision-making processes should effectively **integrate both long-term and short-term** economic, environmental, social and equitable **considerations**;

2. If there are **threats of serious or irreversible environmental damage**, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;
3. The **principle of inter-generational equity**—that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;
4. The **conservation of biological diversity and ecological integrity** should be a fundamental consideration in decision-making;
5. **Improved valuation, pricing and incentive mechanisms** should be promoted.

Each of the factors presented above have been discussed with respect to the capping options in the following sections.

6.5.1 Integrate both long-term and short-term considerations

Phytocap

Following seedling plantation, management requirements for the Phytocapping option are expected to comprise of periodic (i.e. biannual) visual inspection and maintenance works as required. Maintenance works may include weed removal, pest control and replanting of damaged or poorly established vegetation. However, assuming comprehensive establishment of native and self-sufficient vegetation cover, longer term maintenance and replacement requirements of the Phytocap is likely to be minimal.

The integrity of the Phytocapping option is based on the maintenance of a mature, complex and structurally diverse local vegetation community. This places an inherent limitation on future landuses such that the vegetation cover on the capped areas must be retained. However, native trees and deep-rooted grasses play vital roles as water pumps, moderators of local climate and soil stabilisers, and are therefore important in maintaining long-term landscape function. From a long term perspective, the potential of deep rooted species within the phytocap to reduce the overall mass of nitrates is a positive outcome not offered by the other caps as is the restoration of local ecosystems. The taller and denser vegetation associated with a Phytocap also provides greater potential for the long term visual screening of onsite plant and equipment.

Clay and Reference Caps

The clay and reference caps arguably offer significantly lower visual amenity values than the phytocap. This is most relevant to the landowners and residents immediately adjacent to the facility. In particular, the potential establishment of a claycap along the effluent drain easement is likely to be seen as much less desirable option by local residents. The construction of the engineered caps in this location will also not offer the long term environmental advantages of the phytocap which may act as a wildlife corridor when fully established. The long term regular maintenance requirements for the clay and reference caps are critical for their performance. Should maintenance acitivities be neglected, deep-rooted weeds and native plants may penetrate clay layers and compromise their integrity.

6.5.2 Threats of serious or irreversible environmental damage

This ESD requirement embodies the concept of the *precautionary principal*, which relies on the premise that measures must be taken to avoid environmental damage if there is any threat of serious or irreversible impacts, regardless of the proven effectiveness of the selected measure. This principal is thought to apply equally to all capping options. Instantaneous mixing calculations suggest that capping will reduce surface infiltration and the long term mass transfer of nitrates and sulphates to groundwater.

6.5.3 Principle of inter-generational equity

The principal of inter-generational equity is upheld in all three capping scenarios, given that the ultimate aim of capping works is to minimise the mobilisation of contaminants into the groundwater and maintain environmental health for the benefit of future generations. However in assessing the three options, consideration must be given to the sourcing of capping materials, the energy associated with cap placement and installation, maintenance requirements and the state of the environment following cap completion.

Phytocap

The resources required for construction of the Phytocap include native seed and tube stock, which may be sourced from a number of local suppliers, including the Murray Indigenous Seed Service and the Australian Native Farm Forestry, located in Cobram. The materials required for the construction of the sandy clay loam topsoil are likely to be available from on-site sources, such as the Goulburn Murray Water channel overburden. This helps to minimise the energy and costs associated with the transportation of capping materials to the site.

On completion of the phytocap and vegetation establishment, the Phytocap will assist in the restoration of indigenous ecosystems and the provision of habitat for local fauna. The cap is also expected to contribute a visual benefit to the landscaping of the site.

Clay Cap

The material proposed for construction of the Clay Cap is available from Goulburn Murray Water channel overburden or onsite “borrow” areas. Thus, using locally sourced material reduces the impact on the energy required to construct the cap, because transportation costs are significantly reduced. The Clay Cap does not require highly specialised construction, it is likely that local contractors can be used with guidance from suitably experienced engineers. This will also reduce energy impacts through a reduction in travel required to access the site.

Reference Cap

Similar to the Clay Cap system, the material to construct the clay layer and the revegetation layer may be sourced on-site. The Geo-synthetic Clay Liner (GCL) will need to be purchased. This adds significant energy costs to this capping option as GCL liners require high energy inputs during construction, and during transportation from the point of manufacture to the site. The drainage layer may also need to be source from outside the local area. This will require further transportation and therefore an increase in energy requirements. Comparatively, this cap system is considered to support this ESD principles less than the Clay Cap and the Phytocap due to the inherently higher energy requirement for manufacture and installation of capping system components.

6.5.4 Conservation of biological diversity and ecological integrity

Phytocap

The Phytocapping option has a beneficial impact on the ecological values of the site and surrounding area. The selection of a grassy Yellow Box woodland for revegetation works aims to reconstruct ecosystems similar to that of the remnant vegetation identified on-site. The shrub and grassy understorey of the woodland community provides nesting sites, shelter and food resources for indigenous fauna, including birds, bats, reptiles, ground dwelling and arboreal mammals, and invertebrates.

Clay and Reference Caps

No direct ecological benefits are derived from capping of contaminant source areas with either the clay or reference caps. However, assuming successful installation of the caps to achieve the aim of contaminant immobilisation, conservation of biological diversity and ecological integrity may be indirectly attained through the prevention of groundwater contamination and adverse beneficial use impacts.

6.5.5 Improved valuation, pricing and incentive mechanisms

Comparison of the relative effects of capping options on the value of the property will be dependant upon the nature of future land use requirements in the region. Therefore, each of the capping options present possible improved property valuation given various site uses. In the case of continued operation under ADI, or redevelopment of the site for alternative commercial or industrial purposes, the clay and reference caps probably present a more desirable final land use, given the potential for car park development. However, should the site land be rezoned and developed for residential and / or public open space land uses, the phytocap potentially offers a desirable landscaping feature. The other aspects associated with this principle (pricing and incentive mechanisms) are not deemed relevant to the ESD comparison of capping options.

6.5.6 Comparative Assessment

To allow comparative assessment, each capping option was scored on a 1-5 basis on the ability for it to meet the ESD principals outlined above. A high score is given for where the capping option more closely meets the ESD principle, whilst a low score indicates poor conformity.

	Capping Option		
ESD Principal	*Phytocap*	*Clay Cap*	*Reference Cap*
1	4	3	3
2	2	3	3
3	5	3	2
4	5	3	3
5	2	3	3
Total	**18**	**15**	**14**

Overall, the Phytocap achieves the highest score in the comparative ESD assessment of the capping options. In particular the phytocap scores highest with respect to the principal of inter-generational equity and the conservation of ecological integrity. The Phytocap also has a relatively low construction resource requirement and will help to reinstate indigenous remnant vegetation communities.

6.6 Feasibility of Excavation and Removal

Although remediation options involving excavation (and subsequent treatment or encapsulation) have previously been evaluated and discounted as impracticable, reassessment of this issue was considered beneficial in light of the more accurate estimates of contamination significance and volumes. To perform a reassessment, the volume of impacted soil was calculated by taking the contamination extent and multiplying it by the average clay thickness in each source area. A rate of **$35/m3** was then applied to these volumes to estimate the costs associated with an excavation process. This rate incorporates an estimate of $25/m3 for excavation, and subsequent transport and $10/m3 for site reinstatement. Reinstatement costs have been discounted to allow for the likely re-use of some of the clean overburden sands. The combined rate was then applied to the volumes of impacted soil feasibility assessment (see below).

Source Area	Area of impacted soil requiring excavation (m^2)	Depth to base of known contamination (m)	Volume of impacted soil requiring excavation (m^3)	Rate/m^3	Cost ($)
A	35,766	4.9	175251	$35.00	$6,134,000
B	NA	NA	NA	NA	NA
D1	3,370	5.8	19548	$35.00	$684,000
C, D2 & D3	24,700	5.6	140317	$35.00	$4,911,000
E	7,058	4.9	34583	$35.00	$1,210,000
TOTALS			**369,700**		***$12,939,000***

It is important to note that the rates presented in the above table do not account for the treatment/disposal of the excavated materials. As such, there is also significant uncertainty regarding the overall costs of this option. On this basis, the results of the investigations presented herein confirm the findings of the Remediation Feasibility Study that excavation and treatment/disposal of contaminated soil is not a practicable solution.

6.7 Effects on Groundwater Quality

6.7.1 Instantaneous Mixing Calculations

Fixing the best fit value for mass transfer within the mixing equation allowed the infiltration rates obtained from HELP modelling for the individual capping options to be applied. As could be expected, when the Reference and Clay Cap zero infiltration rates were applied, the results indicate groundwater would not be further impacted. The Phytocap, which had a net annual infiltration of 0.005%, caused downgradient concentrations with a maximum of 7mg/L (which equates to approximately 1% of “baseline’ conditions).

Due to the limitations associated with HELP modelling and its resulting infiltration rates, it is important not to place too much emphasis on the magnitude of the mixing model results. However, mixing calculations also indicated that infiltration rates over Source Area A were anywhere between 1.5 to 6 times the lateral groundwater flows due to relatively low gradients (0.001) across the site. The relative contributions of infiltration and groundwater underflow support the following conclusions:

- Capping options that can significantly reduce infiltration rates are likely to have a marked beneficial impact on groundwater quality beneath the source areas.

- The time period to clean-up the broader nitrate plume in the Shepparton Aquifer, both on- and off-site, is likely to be similar to those previously calculated and presented in the Baseline Numerical Flow Model (HLA, 2002), 50 to 100 years.

6.7.2 Leaching by Diffusion

One of the risks associated with using simplistic models (such as the instantaneous mixing model) for estimating the effects of capping is that they do not account for leaching by diffusion processes. These processes involve the mass transfer and transport of contaminants by diffusive mechanisms in the capillary fringe zone. The capillary fringe is likely to extend some metres vertically up into the Upper Shepparton Clay above the Shepparton Aquifer. Seasonal fluctuations in piezometric surface within this aquifer may also increase mass transfer and transport of contaminants from the clays. It is possible that these processes could be a significant factor in the mobilisation of residual nitrates and sulphates within the capilliary fringe at Mulwala. If this is correct, then the benefits of capping on reducing infiltration and mass flux into the aquifer may not be as immediate as expected.

Following installation of capping, residual nitrates and sulphates may continue to be pumped out of the overlying clays by such processes.

The relative significance of diffusive mechanisms on mass transfer of sulphates and nitrates at Mulwala would be difficult to assess without extensive field/laboratory studies and the cost benefit of obtaining such knowledge would be questionable. If it is assumed that if diffusive mass transfer processes do occur within the capillary fringe then their effects on the overall effectiveness of capping are, in the long term, likely to be minimal. At most, these processes would only delay the reduction in mass transfer, which is likely to occur as a result of capping.

6.8 General Construction Details

6.8.1 Lysimeters and Monitoring Wells

It is recommended that a series of groundwater monitoring bores and lysimeters be installed in conjunction with the capping of each of the source areas. The monitoring bores and lysimeters will allow the relative effectiveness of the caps to be determined. Lysimeters are typically used to measure the moisture content within soil profiles and considered ideal for measuring the moisture content in the unsaturated zone beneath the caps. It is recommended that approximately two lysimeter monitoring systems and two groundwater monitoring wells (Upper Shepparton Formation Aquifer) be installed per 7000m^2 of capped source area. The following table summarises recommended installations for each source area (including existing groundwater monitoring wells that will be incorporated into the monitoring system):

Source Area	Number of proposed lysimeters	Number of new groundwater monitoring wells	Existing monitoring wells
A	6	4	BH44, BH38, BH95A
B	3	3	BH22A, BH45
C, D2 and D3	5	2	BH09
D1	1	2	BH84
E	2	2	BH12

The recommended locations for the lysimeters and new monitoring wells are presented on **Figure 25**. Lysimeters are proposed to be located near the centre of the capped areas (phyto or clay cap) to minimise their potential to be affected by infiltration around the cap edges. Lysimeters will be housed within a PVC outer casing that will be installed flush with the cap surface. Each installation will monitor any infiltration through the capped areas via a real time solar powered data logger, which is connected to three sensors located at different elevations within the underlying strata. The proposed elevations for each sensor are the dune sand/clay interface and at each metre interval below that for two metres. Data loggers will be accessed via a data cable connected to the sensors, which will be kept within the PVC casing between monitoring events. It is recommended that the readings from the lysimeters and groundwater monitoring bores be obtained on a quarterly basis for the first two years whereupon a review should be performed to establish ongoing frequency.

6.8.2 Excavation and Consolidation of Surface Wastes

As outlined in the contamination management plan, Waste Dump Areas C and D1, D2 and D3 contain varying amounts of surface waste material and soils that are rich in sulphates and nitrates. Previous investigations have identified that generally these materials are confined to shallow depths (<1m).

It is suggested that if these materials are to be phytocapped that this material should be removed. Removal of these materials will prevent deep rooted species within the phytocap being affected and potentially stunted by the high levels of contamination they contain. Source Areas to be clay capped will not require surface wastes materials to be excavated.

Where removal is required, it is suggested that, at a minimum, surface waste materials should be excavated visually until the underlying soil boundary is exposed. It is recommended that excavations be continued 0.2m beyond this depth, to lower the risk of any highly contaminated soils being left behind.

To obtain an estimate of waste materials and soils requiring excavation, the areal extent of waste materials was estimated for each source zone and multiplied by the average maximum waste depth (including 0.2m of over excavation) noted in previous studies and from the results of central Geoprobe locations (CM01, D1M01, D2M01 and D3M01). A summary table of the estimated volumes requiring excavation is provided below:

Surface Waste Materials Requiring Excavation			
Source Area	**Area (m2)**	**Depth Requiring Excavation (m)**	**Volume (m3)**
C and D2	2000	1	2000
D3	5000	1	5000
		TOTAL	**7000**

It is important to note that in Source Area C and D2, the distribution of waste materials varies from scattered (over most of C) to small concentrated pockets (D2). Previous investigations have shown that the high sulphur content of the wastes in C comes predominantly from gypsum. The good stands of native vegetation found in the western end of this area indicate that this material does not necessarily have a significant impact on plant growth. It is worth keeping this fact in mind, particularly if Source Area C and D2 are selected for phytocapping. In this instance, it would be beneficial for many of the established mature trees and shrubs to be retained and only the areas containing concentrated gross waste be excavated. Identification and excavation of such wastes could be performed visually as these areas are either denuded or have minor vegetative growth.

6.8.3 Former Corowa Shire Landfill

The former Corowa Shire Landfill is located to the north of the main process section of the Mulwala facility and was previously leased by Corowa Shire Council for use as a refuse tip and landfill. Originally a sand quarry, the landfill was progressively filled with a wide range of wastes including waste ash from the facilities boiler house as well as demolition wastes. The tip was closed in 1991 and has been partially filled and capped with sandy soil. Previous observations found the cap surface to be uneven and in some areas the underlying waste was exposed.

A groundwater plume containing concentrations of nitrate and sulphate above background levels was identified emanating from the landfill in a previous study (Ref URS, 2001). This study reported maximum concentrations of sulphate and nitrate in this plume are 10mg/L and 27mg/L respectively, which are very low relative to the contamination within the main plumes under the site. The study also states that the concentrations within the plume are decreasing, suggesting source depletion.

The above information indicates that ongoing groundwater contamination associated with the landfill does not represent a major environmental risk at the site. The reduction in these risks should therefore not be heavily influence the evaluation of the landfill as a potential location for the consolidation of contaminated surface waste materials. Indeed, as identified in **Section 6.9.2**, any source area where clay capping is recommended may offer a more cost effective alternative for the relocation of surface wastes.

Should capping of the landfill be desired, it is recommended that the following activities be performed:

- Detailed survey of the existing landfill surface profile.
- Hand augering across the landfill surface to determine cap thickness and composition
- Modelling to confirm design parameters
- Determine fill placement contours

The performance of these activities will allow development of a capping design that will minimise the disturbance of the existing waste materials and meet the long term containment requirements of any excavated and relocated waste materials. Any final cap design should meet the specifications outlined in the appropriate capping management plan contained in this report.

6.9 Assessment of Practicability

6.9.1 Methodology

An assessment of the practicability of the capping options was conducted based on technical, financial and logistical considerations outlined as follows:

- Technical considerations include the ability of capping options to reduce rainwater infiltration from the base of the Upper Shepparton Clays into the Shepparton Aquifer and the ability to remove mass of contaminants from soil.

- The sustainability of each capping option.

- Logistical considerations relate to constraints on the implementation of the option.

- On-going management requirements.

- Financial considerations include the capital costs and on-going operations and maintenance costs.

A summary table outlining the results for each of these considerations has been provided in **Table1**.

Ideally, technical feasibility would have been based on an assessment of the reduction of nitrates and sulphates that would be leached from the Upper Shepparton Clays into the Shepparton Aquifer. However, due to the macro-permeability of the clay, column tests could not be used to develop a meaningful estimate of the leachability of nitrates and sulphates. Therefore, reduction in infiltration was used as an indicator of cap performance. The ultimate remediation goal is to reduce concentrations of nitrates and sulphates in the Shepparton and Calivil Aquifers to drinking water guideline values. Additional field trails and/or modelling would be required to assess performance of the capping options against the remediation goal.

In order to optimise the capping works, independent of the cap selected, works need to be carefully programmed so that any excavation and capping works are carried out simultaneously. This will minimise overall costs and reduce the time required to complete the works. Capping works completion will ideally be conducted in March / April so as to take advantage of any rain and therefore reduce irrigation requirements.

6.9.2 Prioritisation

To assist finalise the recommendations resulting from the capping option assessment, the source areas were scored and prioritised with regard to the following attributes:

- Total Residual mass of Nitrate within the source area;
- Total Residual mass of Sulphate within the source area;
- Distance of source area to the site boundary (implications for opportunity of dilution); and
- Aesthetics (presence or absence of surface waste).

The source areas were then evaluated against each of these attributes using an approach where a score of 1 was applied for low risk/importance, ranging to a score of 5 for high risk/importance. To account for the priority associated with nitrate reduction, the scores associated with residual nitrate mass were doubled relative to the scores associated with sulphate. The scores for each attribute were then added to give a total score for each source area (refer to **Appendix N**). This allowed the relative priority for capping of the source areas to be determined (see summary table below):

TOTAL	Total Score	Priority
A	17	1
B	17	1
C/D2	13	2
D3	12	3
D1	9	4
E	8	5
Former Landfill	2	6

The summary table indicates that Source Area A and Source Area B are the highest priority Source Areas. Source Areas C/D2, D3 and D1 are also considered significant sources. Source Areas E and the Former Landfill have a lower priority, primarily as a result of their associated low nitrate masses and measurable impacts on groundwater. The capping of the Former Landfill has the lowest priority of all areas, primarily due to its minor and apparent decreasing impact on the underlying Upper Shepparton Aquifer.

6.9.3 Overall Rationale

The high variability in permeability values obtained and restricted ability for the HELP to simulate the hydrogeological/evapotranspirative characteristics of the capping options prevented their accurate modelling. However, the HELP modelling results obtained do indicate that all of the capping options will reduce infiltration to almost negligible rates. From a comparative perspective, the modelling results for engineered caps indicate that they will produce the greatest reduction in infiltration, though their benefits over a phytocap are marginal. If the infiltration reductions from the three capping options are viewed from a cost benefit perspective, it becomes clear that the increased performance indicated from the modelling of the reference cap cannot justify the additional cost premium. On this basis alone the Reference Cap is not recommended and the choice of capping systems becomes a decision between VICEPA based Clay Cap or the Phytocap.

In considering the relative advantages/disadvantages associated with the Clay and Phytocap it is critical to note that there is greater certainty associated with the performance of the Clay Cap. These caps are well proven in their ability to prevent the ingress and infiltration of incident rainfall and rely on the maintenance of a low permeability compacted clay layer. The phytocap, on the other hand, has a heavy reliance on relatively poorly understood evapotranspirative mechanisms.

Nevertheless, a number of scientific papers were reviewed during this investigation which indicate that in a semi-arid environment, the net annual infiltration though a stand of Australian native bush is similar to the results obtained by the HELP modelling.

In the comparative ESD assessment of the capping options the phytocap scores highest, particularly with respect to the principle of inter-generational equity and conservation of ecological integrity. The establishment of a phytocap on some of the Source Areas (namely B, C, D2 and D3) will also bring significant aesthetic improvements that will benefit adjacent landowners, site employees and the property image.   On this basis, it is recommended that a phytocap be constructed over areas where there are clear aesthetic and ecological benefits and that the remaining areas (A, D1and E) be considered for clay capping. Another major advantage derived from installation of a Clay Cap in Source Area A is the increased flexibility in future landuse changes. The possibility for the Clay Cap to be augmented or replaced by alternative impermeable hardstand materials offers opportunities for the establishment of carparks and building foundations that could support changing infrastructure requirements.

Depending on financial constraints, ADI may want to consider the results of the prioritisation assessment performed above to delay or abandon the capping of low priority areas. For example, abandoning the capping Source Areas E would save potentially up to $271,000 (using recommended capping area costs) and still provide for capping of over 99% of the estimated residual mass of nitrates and over 90% of sulphates.

Long term monitoring should be performed on any constructed cap to determine its effectiveness at reducing infiltration. If a Phytocap proves to be ineffective in controlling impacts on the underlying aquifers it may need to be replaced with a Clay cap. One of the key disadvantages with such an approach is that the relative performance of the two capping options would not be able to be assessed until a clay cap was installed at the site.

As outlined in **Appendix L**, it is recommended that surface waste materials be excavated prior the construction of a Phytocap. The most cost effective solution for managing these wastes is to relocate and place them in one of the areas to be covered with a clay cap. It is suggested that Source Area D1, with its in-situ volume of waste materials and higher priority (compared to Source Area E) offers the best alternative. Although Source Area A has a higher priority, the capping of this area is still to dependant on the outcomes of the proposed CSA studies.

Summary Table of Capping Option Recommendations/Rationale

Area	Recommended Option	Rationale
Source Area A	Clay Cap	• Only recommended to be capped if CSA is proven to be impracticable. • Highest residual mass of nitrate in soil and believed to be primary source of contamination in northern arm of shallow aquifer and also deeper Calival Aquifer. • More certainty over performance of the clay cap where risk to aquifer plume from residual contamination is highest. • Visual impact to adjacent landowners is not a significant issue • In short-medium term will integrate better with adjacent land uses ie. ongoing manufacturing.
Source Area B	Phytocap	• Contains a significant mass of contaminants which is believed to be primary source of to Southern arm of shallow groundwater plume. • Long term visual impact to adjacent landowners is considerable and a phytocap will blend more effectively with surrounding rural/residential landuse.

		• Restoring ecological values and acting as a potential wildlife corridor.
Source Area C, D2, D3	Phytocap	• Contains significant concentrations of sulphate and nitrate requiring capping. • Phytocap offers visual screening of the existing plant area and a will blend more effectively with surrounding rural/residential landuse. • Enhancing and restoring ecological values of remnant vegetative community
Source Area D1	Clay Cap	• Contains significant concentrations of surface waste and sulphate mass within the USC. • Offers a relatively cost effective solution for the relocation and capping of surface wastes excavated from other areas to be phytocapped (i.e. D2 and D3).
Source Area E	Clay Cap	• Source Area E is considered a low priority as it poses relatively low risk to groundwater quality due to negligible residual nitrate and a relatively minor sulphate mass. • Clay cap will integrate more effectively with the adjacent land uses in the plant area. • Visual impact to adjacent landowners is not a significant issue.
Former Corowa Shire Landfill	Clay Cap	• Low and decreasing impacts to the Upper Shepparton Aquifer suggest limited leachable contaminant mass indicate capping is a low priority for the former Landfill. • A Phytocap is not a practical option unless at least 2 m depth of soil is placed over waste. • Visual impact to adjacent landowners is not a significant issue. • Lowest cost benefit associated with installation of a cap.

7 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations arising from the investigations and assessments presented in this report, relating to the essential requirements of the project, are summarised as follows:

Delineation of Contamination and Areas Requiring Capping

- The contamination boundaries previously identified for Source Areas B, C, D1, D2, D3 and E (Ref 7. HLA, 2003) were generally consistent with those defined during this investigation. The boundaries for Source Area A were less extensive than previously thought and appear to be localised around four former process areas (see **Figures 4,5,6,7** and **8**).

- The geophysical data obtained with the EM31 correlated well with the analytical data in Source Areas D1 and D3. The good correlation is believed to be a result of the high concentrations of sulphate and iron in these locations. All other areas generally showed poor correlation which appears to have been due to interference from surrounding infrastructure and waste materials.

- Analytical results were used to delineate the lateral boundaries and vertical distribution of contaminants in the Upper Shepparton clays. However, analytical results suggest Source Area C may extend beyond the southern boundary of the site at depth within the Upper Shepparton clay.

- The lateral extent, or area, of soil contamination in the Source Areas generally appears to increase with depth in Source Areas A, C and D2.

- The mass of contaminants in each Source Area and the areas requiring capping are summarised as follows:

Source Area	Nitrate (kg)	Sulphate (kg)	Minimum Area Requiring Capping (m^2)	Recommended Area Requiring Capping (m^2)
A	41,782	80,486	35,800	69,300
B	23,484	75,854	8,000	8,000
C and D2	14,816	78,022	24,700	33,200
D1 and D3	NA	124,012	3,400	4,600
E	1,089	37,259	7,100	12,300
Former Corowa Landfill	N/A	N/A	26,000	26,000
Total (Soil)	**81,171**	**395,634**		
Total (Groundwater)	**486,000**	**606,000**		

- As shown above, the total mass of residual nitrate and sulphate remaining in the soil, compared to that already leached into the groundwater, is approximately 17% and 65% respectively. These residual contaminant masses still pose a long-term significant risk to groundwater and justify the capping process.

- Using the 90% threshold to define the minimum capping extent boundary, the total mass of sulphate and nitrate left uncapped for all source areas was calculated to be 5 tonnes and 20 tonnes respectively. The recommended capping areas allow for the uncertainty associated with the delineation process and also for the construction of simple regular capping boundaries.

- The topography of the interface between the dune sands and Upper Shepparton Clay was relatively flat with minor undulations. The minor variations in elevation observed are not considered significant enough to modify capping boundaries.

Other Conclusions of the Investigations

- Triaxial and Ring Infiltrometer testing indicated approximately six orders of magnitude difference in permeability of the Upper Shepparton clays. HELP modelling and mixing calculations indicate that the permeability of the Upper Shepparton clay is somewhere in the middle of the range indicated by permeability testing.

- The only reliable means of assessing the permeability of the Upper Shepparton clay is to conduct a large scale field infiltration trial.

- Due to the very low permeabilities obtained from the triaxial tests and their apparent lack of representivity with field conditions, leaching column tests could not be used to develop a meaningful estimate of the leachability of nitrates and sulphates from the USC.

Assess the Impacts of Capping on Groundwater Quality

- In the absence of reliable estimates of permeability and leachability of contaminants from the Upper Shepparton clays, the impact of capping options on groundwater quality in the Shepparton Aquifer could not be reliably assessed using modelling. Therefore, only the relative performance of capping options could be assessed.

- Assuming that vertical infiltration is the primary driving mechanism for the transport of soluble salts into the Upper Shepparton Aquifer, HELP modelling and instantaneous mixing calculations indicate that all of the capping options will assist reduce down gradient aquifer concentrations to drinking water standards.

- In addition to rainwater infiltration, diffusion processes may also be contributing to the mobilisation of nitrates and sulphates from the Upper Shepparton clays to the underlying aquifer. It is not possible to reliably estimate the relative contribution of diffusion processes.

- The only reliable means of assessing the capping performance in relation to groundwater impacts is to construct the caps and monitor groundwater quality over a period of some years.

- Mixing calculations indicated that infiltration rates over Source Area A were anywhere between 1.5 to 6 times the lateral groundwater flows due to relatively low gradients (0.001) across the site. Based on the relative flows, the time period to clean-up the broader nitrate plume in the Shepparton Aquifer, both on- and off-site, is likely to be similar to those previously calculated and presented in the Baseline Numerical Flow Model (HLA, 2002), 50 to 100 years.

Assess the Practicability of the Three Capping Options

- The three capping options assessed (Phytocap, Clay Cap and Reference Cap) are likely to reduce infiltration of the current average annual rainfall by more than 99%. On this basis each of the capping options should have a significant impact on groundwater quality.

- Due to the relatively high performance of all of the caps at reducing infiltration rates the high cost (approximately double) of the reference cap significantly reduces its relative practicability. Therefore, the Reference Cap is not recommended for use at the site.

- The Clay Cap offers a greater degree of certainty regarding it's ability to reduce infiltration rates over a Phytocap. A Clay Cap is also more compatible with industrial land uses.

- Overall the Phytocap achieves the highest score in the comparative ESD assessment of the capping options. It also provides benefits in terms of visual screening and compatibility with surrounding residential land uses.

- Testing of the spoil piles of channel bank clays in the north of the site are not a completely reliable source of low permeability material for the Clay Cap. Selective excavation from the spoil piles may allow separation of lower permeability clays, which could also be enhanced by higher levels of compaction. However, low permeability clays can be obtained through selective excavation from onsite borrow pits.

- It is recommended that the Phytocap should recreate a local native woodland plant community, typified by grassy understorey similar to the Yellow Box (Eucalyptus melliodore) woodland. This plant community is located as remnant pockets on the low undulating or near level sandy soils across the Mulwala site and accordingly will be suited to the growing conditions of the recommended capping surface materials. Due to local provenance requirements, plant tubestock will be able to be sourced from local suppliers and landcare groups.

- Based on practicablity, the recommendations and rationale for selection of capping options are summarised in Section 6.9.3

- Although remediation options involving excavation (and subsequent treatment or encapsulation) have previously been evaluated and discounted as impracticable, reassessment of this issue was considered beneficial in light of the more accurate estimates of contamination significance and volumes. The results confirm that compared to capping, alternative approaches involving wholesale excavation of impacted materials are cost prohibitive and do not require further consideration.

Landuse Restrictions

- Phytocap: Success of the phytocap is based on the maintenance of a mature, complex and structurally diverse vegetation community. This places an inherent limitation on future landuses such that vegetation cover on the capped areas must be retained. Further development of phytocapped areas for manufacturing, grazing or other such purposes is not recommended.

- Clay Cap: It is recommended that future landuse associated with the Clay Cap is limited to minimal activity or grazing. Should a landuse change be desired it is possible for bitumen or concrete surfaces to be placed ontop of a clay cap. These hardstands could provide opportunities for carparking, recreational sports or as building foundations.

Recommended Capping Options / Management

- Recommendations for the capping of Source Areas are summarised in the following table.

Source Area	Cap Type	Construction Details	Coverage	Construction / Maintenance Requirements
A	Clay	Install cap total 1.0m thick, comprising 0.5m of re-compacted clay overlain by a 0.5m layer of loamy sand sub-base and topsoil/mulch. In operational areas, the clay cap may be substituted by an impermeable pavement (ie. bitumen or concrete). Schematic section of the cap and underlying contamination provided in **Figure 27A**.	**Refer to Figure 8**	Refer to **Appendix M**
B	Phyto	Grub and backfill drain. Install capping media total 0.6m thick, comprising of loamy sand sub-base and topsoil/mulch. Schematic section of the cap and underlying contamination provided in **Figure 12**.	Refer to **Figure 25**	Refer to **Appendix L**
C, D2 and D3	Phyto	Excavate and remove surface waste. Install capping media total 0.6m thick, comprising of loamy sand sub-base and topsoil/mulch. Schematic section of the cap and underlying contamination provided in a schematic sections of the cap and underlying contamination provided in **Figures 27B and 27D**.	Refer to **Figure 18**	Refer to **Appendix L**
D1	Clay	Place and compact surface waste from other areas. Install cap total 1.0m thick, comprising 0.5m of re-compacted clay overlain by a 0.5m layer of loamy sand sub-base and topsoil/mulch. A schematic section of the cap and underlying contamination is provided in **Figure 27C**.	Refer to **Figure 22**	Refer to **Appendix M**
E	Clay	Install cap only if funding available, total 1.0m thick, comprising 0.5m of re-compacted clay overlain by a 0.5m layer of loamy sand sub-base and topsoil/mulch. A schematic section of the cap and underlying contamination isprovided in **Figure 27E**.	Refer to **Figure 8**	Refer to **Appendix M**

- Capping of Source Area A is not recommended until Soil CSA is proven to be impracticable.

- It is recommended that surface waste material in D2 and D3 are consolidated into Source Area D1 (the Sulphur Dump) and capped with clay rather than into the Former Landfill. Based on their relatively minor impact on and risk to groundwater quality relative to other Source Areas, capping of the Former Landfill and Source Area E are considered a relatively low priority.

Cost Estimates

- Cost estimates associated with installation of the minimum and recommended capping options at each of the Source Areas (including the excavation, transport and capping of gross surface wastes at the former Corowa Shire Landfill) have been provided in the table below:

Item	Source Area	Recommended Option	Minimum Area (m^2)	Recommended Area (m^2)	Rate ($)	Total Cost (Minimum[1])	Total Cost (Recommended[1])
1	A	Clay Cap	35,800	69,300	22	$807,000	$1,563,000
2	B	Phytocap	8,000	8,000	21	$170,000	$170,000
3	B	Grubbing/Backfill	8,000	8,000	8	$61,000	$60,000
4	C, D2, D3	Phytocap	17,039[2]	25,139[2]	21	$363,000	$535,000
5	D1	Clay Cap	3,400	4,600	23	$77,000	$104,000
6	E	Clay Cap	7,100	12,300	23	$160,000	$277,000
7	Former Landfill	Clay Cap	26,000	26,000	23	$586,000	$586,000
8	Surface Waste	Excavate /Transport	7000[3]	7000[3]	16	$115,000	$115,000
TOTAL (All Areas)						**$2,339,000**	**$3,410,000**
TOTAL (Excluding Source Area A)						**$1,532,000**	**$1,847,000**
TOTAL (Excluding Source Areas A and E)						**$1,372,000**	**$1,570,000**
TOTAL (Excluding Source Areas A, E and former Landfill)						**$786,000**	**$984,000**

Notes:

[1] The minimum capping areas correspond to area required to cap 90% of the contaminant mass in the USC. The recommended areas have been provided to allow for the uncertainty associated with the delineation of the contaminant distribution, which is dependant on the results of discrete sampling from boreholes, which in some instances can be separated by up to 50m or more. The recommended capping areas also provide linear shapes, which are considerably easier to plan and construct.

[2] Minimal and recommended areas requiring phytocapping presented for Source Areas C, D2 and D3 have been reduced by 32% and 24% to allow for residual stands of good native vegetation.

[3] Figure and rates for excavation and transport of surface wastes refer to m^3.

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