Landform Planning – From Void to Vegetation

*Reynolds[1] T. and Skok Muir[2] A.A.

[1]Iluka Lanka Resources (Private) Limited, Sri Lanka
[2]Iluka Resources Limited, Perth, Australia

*Corresponding author – tess.reynolds@iluka.com

Abstract
Iluka Lanka Resources has mineral resources within the Puttalam District of the North Western Province of Sri Lanka and is in the early stages of development of the Puttalam Mine and Industrial Development Project (PMIDP).
At Iluka, we plan for rehabilitation of the open mine pits and subsequent final landform at the feasibility phase and continue throughout the life of the project from feasibility studies, execute, operations, closure through to close out.
Iluka takes a multidisciplinary approach to rehabilitation with its technical ability in mine planning, survey and engineering in conjunction with applying knowledge from fields such as soil science, vegetation, ecology and hydrology among others to achieve the agreed final land use, which influences final landform.
This paper discusses the planning process in terms of landform rehabilitation applied to Iluka's Australian operations at Jacinth-Ambrosia and Yoganup West, and how that knowledge is adopted in the rehabilitation planning for the Puttalam Mine and Industrial Development Project.

Keywords: Heavy Mineral, Jacinth-Ambrosia, Puttalam, Rehabilitation, Yoganup West

1 Introduction

Iluka Lanka Resources (Private) Limited is a company incorporated in Sri Lanka and is part of the wider Iluka group.
For over 60 years, the Iluka group has operated and continues to operate mineral sand mines and processing facilities across a range of environments. During this time Iluka rehabilitated over 15,000 hectares of land in Australia and the United States, restoring former mine sites to native vegetation to protect and reinstate biodiversity, but also restoring to productive agricultural use where appropriate. Rehabilitation is a major focus for Iluka, and a significant, ongoing part of the company's activities.
Iluka takes a multidisciplinary approach to rehabilitation with its technical ability in mine planning, survey and engineering in conjunction with applying knowledge from fields such as soil science, vegetation ecology and hydrology among others to achieve the agreed final land use.
This paper discusses the planning process in terms of landform rehabilitation applied to Iluka's Australian operations and how that knowledge is adopted in the

rehabilitation planning for the Sri Lankan project.

1.1 Australian Deposits

Iluka has successfully rehabilitated many sites. Two locations that are internally considered type examples of successful rehabilitation include Jacinth-Ambrosia (J-A) located within a declared nature reserve in the Eucla Basin, South Australia, and Yoganup West located in the south west of Western Australia (Figure 1). At J-A disturbed areas are progressively rehabilitated to native vegetation while mining activities are ongoing. At Yoganup West, mining activities concluded in 2007 and the site has been successfully rehabilitated to pasture production (agriculture).

Figure 1: Rehabilitation Sites Australia.

1.2 Puttalam Mine and Industrial Development Project

Iluka Lanka Resources has heavy mineral (HM) resources within the Puttalam District of the North Western Province of Sri Lanka, and is in the early stages of development of the Puttalam Mine and Industrial Development Project (PMIDP). The PMIDP is located within EL/170/R/4 and contains the PQ HM deposit (Figure 2).

Materials present in the original landform at the PMIDP site comprise, from the surface; the HM bearing red bed deposit (incorporating the topsoil) underlain by a discontinuous basal gravel layer, and the Vanathavillu limestone which is weathered and karstic in the upper sequences (Figure 3).

Interburden material occurs between the red bed deposit and the higher grade Vanathavillu limestone. It is comprised primarily of weathered limestone but also contains the basal gravel unit [1].

The underlying Vanathavillu limestone is currently mined by Siam City Cement Lanka (SCCL).

2 Methodology

Mine planning and specifically landform design requires significant research and preparation in order to optimise the outcome for all stakeholders. At Iluka's Australian operations, planning of landform change is undertaken before mining is executed using a multipronged approach, including:

- engagement of stakeholders for an agreed final landuse;
- investigation of physical and chemical properties of the mined profile materials; and
- void reconciliation including soil layering, topographic changes and drainage.

This approach has proven effective and is implemented in other locations globally.

Successful rehabilitation of land requires a defined final landform that is agreed with the land owners and government regulators prior to commencing. This may involve a change to the final land use or topography from the pre-mined surface.

Materials used in the void backfill are investigated to ensure their physical and chemical properties that are compatible with any proposed landform changes.

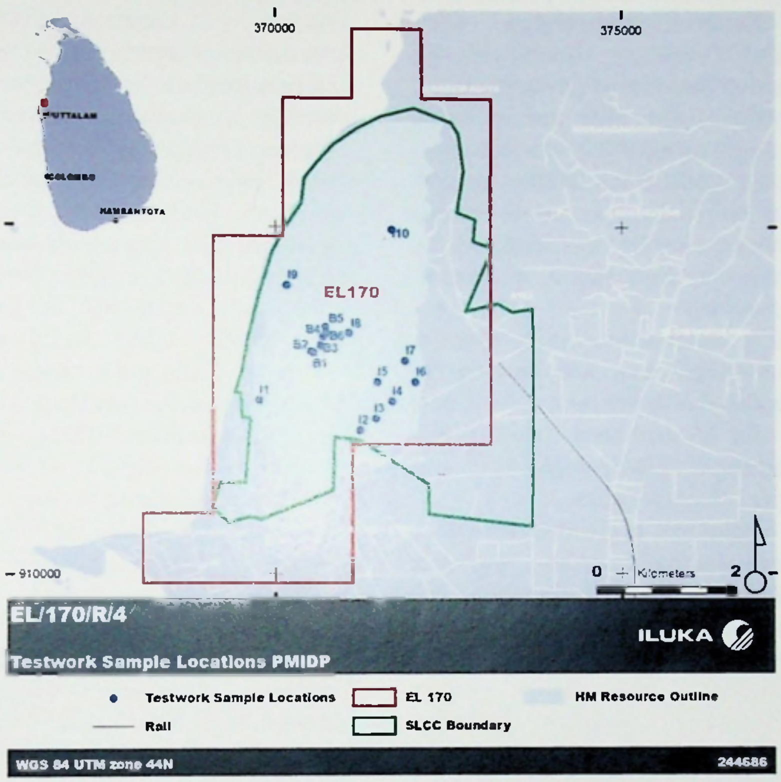

Figure 2: PMIDP Location and Testwork Sample Sites.

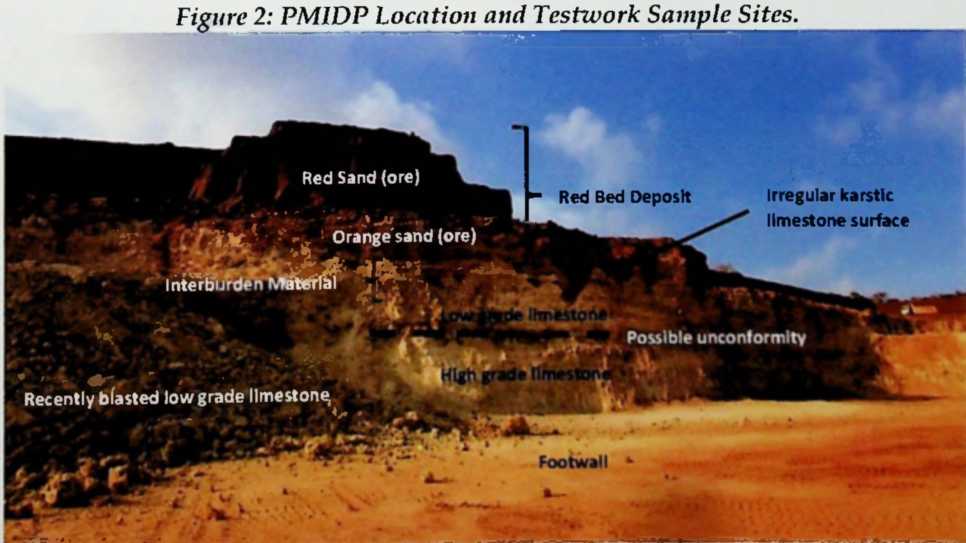

Figure 3: PQ HM Deposit Geological Soil Profile (Note, the Basal Gravel Layer is not Present in this Soil Profile).

Typical physical analyses performed include particle size distribution, soil water retention to estimate water availability for plants, hydraulic conductivity, and soil dispersion tests (e.g. Emerson dispersion test). Chemical analyses include pH, electrical conductivity (an estimate of salinity), exchangeable cations, clay mineralogy using XRD, various tests for plant nutrient availability (e.g. N, P, K, S, trace elements), and various tests for naturally occurring toxic elements (e.g. boron, arsenic, radionuclides).

Subsoil properties are then used to determine optimum soil layering to ensure a stable landscape which best suits the final land use while maintaining hydrological and ecological characteristics.

Planning changes to the final landform require estimation of volumes available for redistribution. The topography may need adjustment to deal with volume discrepancies such as unfilled voids. Other factors incorporated in planning the final landform are the physical and spatial requirements of the agreed final land use (particularly if this is a change from the original land use), pre-existing natural features such as waterways, and the original topography. Topographic surveys are undertaken pre-mining along with surface flow modelling.

Planning of the final landform is an essential component of the mine planning process at all Iluka sites, and is considered throughout the life of a project from the scheduling of mining activities during the feasibility stage through to mine closure.

3 Results

A selection of results from the different stages of landform change and planning at J-A, Yoganup West and PMIDP have been included as examples.

3.1 J-A

At J-A Iluka engaged with the South Australian Government (the primary stakeholder) as the operation is located within a declared nature reserve. Agreed changes to the final landform were required to best incorporate a lowered land surface in order to minimise the impacts of erosion in a fragile ecological environment.

All work conducted at the site is completed within strict guidelines outlined in the government approved Program for Environment Protection and Rehabilitation (PEPR).

During a scheduled review of the PEPR, an opportunity was identified to investigate improved rehabilitation outcomes. The subsequent research into soil characteristics identified opportunities for landform redesign. The results from these studies on material distribution identified six morphologically and chemically distinct soil materials within the J-A mine site area:

- topsoil;
- subsoil;
- yellow sand;
- brown sandy loam; and
- red sandy loam.

The studies also indicated the composition of the profile of the yellow sand, and brown and red loam, if adjusted, will retain the soil characteristics of unaltered profiles.

In further surface studies, biological soil crusts adapted for growth with a limited water supply (known as cryptogamic crusts)[5] were observed to be important for surface soil stabilisation, runoff processes, vertical infiltration of water and overall arid-zone ecosystem functioning [3].

3.2 Yoganup West

At Yoganup West, Iluka engaged with the local landowners who were using the land for cattle grazing (dairy and beef). One limitation faced by farmers in winter was that the original, generally flat topography had low points with poor drainage which caused water logging of the pasture. Surface water flow modelling of the pre-mining topography identified a number of problem areas.

A pre-mining soil survey was completed which identified the following soil materials:

- topsoil;
- sandy subsoil;
- loamy subsoil;
- sand; and
- clay.

Additionally, studies were undertaken on the degraded Ludlow River which flowed between the mining pits. Vegetation studies identified poor biodiversity in and around the river, while hydrological flow studies identified flow conditions and natural flooding patterns.

3.3 PMIDP

At the PMIDP site in Sri Lanka, Iluka is working closely with both SCCL, who is actively mining on the site, and the land owners Sri Lankan Cement Corporation (SLCC).

A study of the soil materials has recently been completed at the PMIDP, known as the PMIDP Interburden Assessment[2]. A number of soil samples were taken with locations shown in Figure 2.

Interburden material in the main body of the deposit (absent to the east) was primarily comprised of weathered and karstic limestone with minor inclusions of the basal gravel.

Testwork showed the fine fraction (all material finer than 2mm) had a clay content of approximately 10 %. This indicates the material will drain freely but also, from the water retention data, hold a reasonable quantity of Plant Available Water (PAW).

The interburden material was predominantly composed of quartz and calcite and was alkaline. Salinity is low (ECe< 2 dS/m), slightly more saline than the existing soil profile but of no significance to plant growth. The material is sodic (ESP > 6%) so potentially dispersive, however, the Emerson Dispersion Test indicated that the material was not overly sensitive to dispersion or slaking. Plant nutrient availability was low, with low levels of nitrogen, and available potassium and phosphorus, and low cation exchange capacity.

4 Discussion

Iluka's operations at J-A progressively rehabilitate this arid region's native vegetation while mining is in progress (Figures 4 and 5).

Figure 4: J-A During Mining 2009.

Figure 5: J-A Progressive Rehabilitation 2016.

Drainage of the J-A mine site is considered a vital component of the viability of the final rehabilitated area and has been designed to an appropriate level to retain surface drainage and reduce erosion. The post-mine topography underwent a number of design variations under the guidance from a specialist surface hydrology consultant (Alluvium Consultancy) to meet this criteria. Figure 6 illustrates the pre-mined drainage systems of J-A against the altered topography.

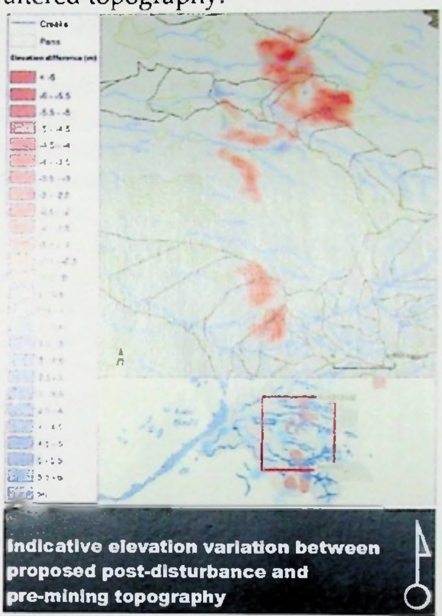

Figure 6: Indicative Elevation Variation Between Proposed Post-disturbance and Pre-mining Topography [3].

The red and brown loam placement was redesigned due to a brown loam excess, which likely occurred due to the inexact boundary definition of the red and brown loam. During rehabilitation the brown loam thickness has increased and red loam decreased, whilst retaining final soil cover depth. The variation has been investigated and expected to result in negligible long term changes in water retention and PAW, which will enable maintenance of the soil profile and successful rehabilitation.

Although thicknesses have changed, the studies identified that brown loam and red loam must be handled separately and returned in the correct order to ensure erodible materials do not remain on the surface and vegetation re-establishes effectively (Figure 7).

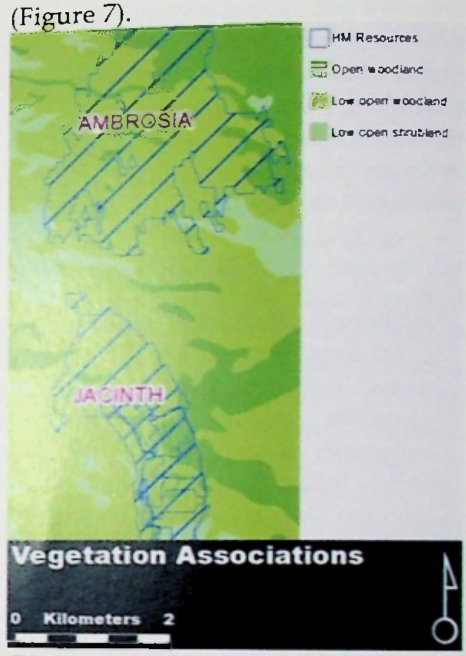

Figure 7: J-A Vegetation Associations.

At the former Yoganup West mine site, information collected during discussions with landowners and the studies conducted, identified that the post-mining final land use could be modified to improve agriculture. Detailed hydrological design of the post-mining topography improved drainage, reducing water-logging of soils in winter that previously limited agricultural production[4].

Changed soil profiles were also specified for particular areas where pivot irrigation was planned to occur.

More loamy soil was added to the soil profile in the pivot irrigation area. This allowed greater pasture production over the summer given the greater PAW in the loamy reconstructed soil. The former Yoganup West Mine was returned to an operating dairy within four years from mine closure (Figures 8 and 9) and pasture yields are significantly higher than pre-mining yields[4].

Figure 8: Yoganup West During Mining 2006.

Figure 9: Yoganup West After Rehabilitation.

Also at Yoganup West a one kilometre section of the Ludlow River was disconnected and significantly degraded prior to Iluka commencing work (Figure 10).

Figure 10: Ludlow River Pre-mining 2004.

The river channel ran between two mine pits and the channel bottom was untouched representing the original ground level. As part of the rehabilitation process Iluka identified the importance of restoring the river to its historic state.

Following the completed studies, a hydrological design was implemented that improved the water flow, managing the natural flooding that can occur in the region. The original design included meanders which were subsequently straightened following unexpected erosion levels. The final river course had a wider channel allowing the width to naturally slow the water flow and stop erosion. Native species indigenous to the area were also planted to enhance the biodiversity of the river (Figure 11).

Figure 11: Ludlow River Restoration 2014.

The test results from the PMIDP interburden study indicated that the interburden material had suitable characteristics to be incorporated into the soil profile. This included the PAW necessary to allow local vegetation as well as other potential forms of vegetation (including agricultural species) to successfully grow. Changing the soil profile when managed incorrectly can lead to potential changes in salinity levels within the ground and PAW, as well as create waterlogging risks through the formation of perched water tables. Chemically and physically the interburden material acts in similar ways to the insitu sub soil, and test results indicated that there will be no adverse impacts on salinity or risk of waterlogging. This will enable it to be used as a substitute for subsoil in the upper layers of the rehabilitation surfaces (Figure 12) [1].

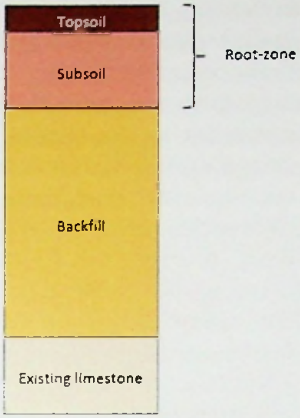

Figure 12: Elements of Rehabilitated Profile at PQ Deposit [1].

Alternative options for landform planning utilising the interburden material can now be included when considering the sequence of soil placement. The alternate landform options aim to take into account stakeholder requirements.

5 Conclusions

The final land use remains the key governing factor when considering landform changes and planning for rehabilitation. Vital elements in successful landform rehabilitation have been proven to include:

- design of final landform to incorporate stakeholder and environmental requirements. As always, the end land use will be constrained by the limitations of the environment;
- physical and chemical analysis of insitu subsoil to confirm the subsequent design criteria in order to successfully reach the desired outcome; and
- consideration of void and material volumes and placement in order to reinstate the functioning surface with appropriate runoff and drainage to prevent erosion.

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