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Lisheen Mine Tailings Management Facility – progressive reclamation project

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Abstract

The Lisheen Mine is an underground lead and zinc mine located in North Tipperary, Ireland. Construction commenced in 1997 and the mine has been in production since 1999. The mine is fully owned by Vedanta Resources plc. and is currently expected to close in late 2013 or early 2014. The Lisheen Tailings Management Facility (TMF) is located in an area of peat bog; it is lined with a plastic liner and has an internal area of around 64 hectares. Upon closure the facility will contain over 9 million tonnes of tailings. Lisheen Mine tailings have a significant net acid generating potential.

The management of this risk at Lisheen Mine has been the subject of considerable geochemical and geophysical test work and this has supported the development of a practical strategy for residual liability management through progressive rehabilitation of the TMF. In January 2008, Lisheen commenced a progressive rehabilitation programme on the Lisheen Mine TMF.

This involves depositing tailings using spigot discharge pipes placed on the dam wall, to progressively form beaches. These beaches are then capped by firstly placing a geotextile directly on the tailings, followed by a 700 mm deep layer of limestone rock and then a 400 mm deep layer of soil forming material. This soil forming material is produced by mixing peat with glacial till in a ratio of 1:1. The peat is sourced from the initial construction of the TMF, where peat was excavated out from under the wall footprint and stockpiled. The glacial till was sourced from the Lisheen Wind Farm; an 18 turbine 36MW project completed in 2009. The cap is then seeded with native grassland, herb and wildflower species.

To date approximately 9 hectares of the facility has been rehabilitated and extensive monitoring data is being collected. In July 2010, Lisheen initiated a livestock trial programme by introducing ten cattle onto the rehabilitated area. This trial is ongoing. Lisheen intends to continue to rehabilitate the TMF over the coming years in the manner outlined in this paper. The global objective of the project is to rehabilitate the facility such that it is secure, sustainable and can be used for the widest possible range of potential after uses.

1 Introduction

At the point of closure (currently 2013 or early 2014) the Lisheen Mine Tailings Management Facility (TMF) is predicted to contain over 9.0 million tonnes of tailings placed into a single tailings lagoon with an internal area of around 64 hectares. The tailings contain significant quantities of pyrite, which have the potential through oxidation to liberate metals and sulphides into acidic drainage water. The management of this risk at Lisheen Mine has been the subject of considerable geochemical and geophysical test work and this has supported the development of a practical strategy for residual liability management through progressive rehabilitation of the TMF.

Subsequent sections of this paper provide a review of tailings test work and the TMF rehabilitation strategy. This strategy has been developed through a detailed internal review process within Lisheen Mine. In 2006, the Lisheen Mine assembled a multi disciplinary team for the purposes of reviewing and revising, where necessary, the existing or original mine closure plan for the Lisheen Mine. This detailed review also involved the development of an amended design for TMF rehabilitation, that would adopt the best available technologies and practices of the day and that would cater for the conditions on the TMF.

In the original Closure Plan for the Lisheen Mine TMF it was intended that the rehabilitation of the TMF would only commence following the cessation of mining operations. This involved the retention of a wetland or reservoir on the TMF post closure. A layer of sewage sludge would be placed directly on the tailings followed by the placement of a crushed limestone layer 0.2 m thick. It was intended that the sewage sludge and the crushed limestone would form a root zone that would support the establishment of reeds and other aquatic vegetation. The detailed reviews, consultations and workshops carried out in 2006 and 2007 concluded that the application of a wet closure treatment to the entire Lisheen TMF, commencing at the end of the mine life, could require indefinite monitoring and aftercare to ensure that the residual liabilities identified would be managed effectively.

It is considered that a progressive restoration approach to the rehabilitation of the Lisheen Mine TMF is more advantageous than starting the rehabilitation of the TMF when mining operations cease. The reasons for this are the availability of key staff to implement, test and review the process during the remaining years of the Life of the Mine (LOM), the effective management of rehabilitation costs and the mitigation of environmental impacts through the gradual implementation of a rehabilitation process and associated validation system. This approach also allowed the staff at Lisheen Mine to take advantage of site conditions.

The soil forming material used in the rehabilitation project is produced by mixing peat with glacial till in a ratio of 1:1. The peat is sourced from the initial construction of the TMF, where peat was excavated out from under the wall footprint and stockpiled. The glacial till was sourced from the Lisheen Wind Farm; an 18 turbine 36MW project completed in 2009. A 400 mm deep layer of this soil forming material is placed on a 700 mm deep layer of limestone. A layer of geotextile is located between the rock layer and the geotextile. The cap is seeded with native grassland, herb and wildflower species sourced from the surrounding countryside.

2 Design and operation of the Lisheen TMF

2.1 Description

The TMF comprises a fully lined impoundment located on a peat bog adjacent to the mine site. The TMF is enclosed within a perimeter earth embankment founded on glacial till. The upstream face of the embankment is lined with linear low density polyethylene (LLDPE) overlying a geosynthetic clay liner (GCL), while the basin area is lined with LLDPE. The underlying peat forms a secondary barrier so the base of the TMF is also considered to have a composite liner (Golder Associates, 2007).

The average ground conditions underlying the TMF comprise:

- Peat up to 5.5 m in thickness.
- Glacial till varying from 0.5 to 3.1 m in thickness.
- Bedrock of Waulsortian Limestone varying in thickness.

In situ permeability tests (falling head) conducted in the peat gave values of between 1.6×10^{-8} to 8.3×10^{-8} m/s, while laboratory permeability tests yielded permeabilities in the 1.0×10^{-8} to 5.0×10^{-8} m/s range. The same testing of the glacial tills yielded in situ permeabilities of 2.8×10^{-7} to 8.9×10^{-9} m/s and laboratory values of 2.1×10^{-9} and 4.2×10^{-11} m/s. The underlying peat essentially acts as an additional liner under the TMF.

Up until January 2008 the TMF was operated such that tailings were distributed on the LLDPE using a floating head tailings distribution system to evenly deposit the tailings across the TMF. In practice the system had limited success in achieving an even distribution of tailings across the TMF.

The TMF, which occupies an external surface area of 78 ha and internal surface area of 64 ha, was developed in two stages with respective storage volumes of 1.5 and 3.6 Mm^3. The peat layer has been removed from the area underlying the perimeter embankment and a layer of graded limestone rock fill and mine waste has been emplaced on the exposed glacial till. Finger drains are installed in the perimeter embankments in order to collect seepage water from consolidation of peat and to allow pore pressures within the peat to dissipate. The size of the TMF has been designed so that the annual rise in the tailings depth is limited to 1 m and provides control on the rate of consolidation of the underlying peat. Prior to January 2008, the TMF was operated with a minimum depth of 1 m of standing water above the tailings, and with a 1 m of freeboard to allow for design flood events (see Figure 1).

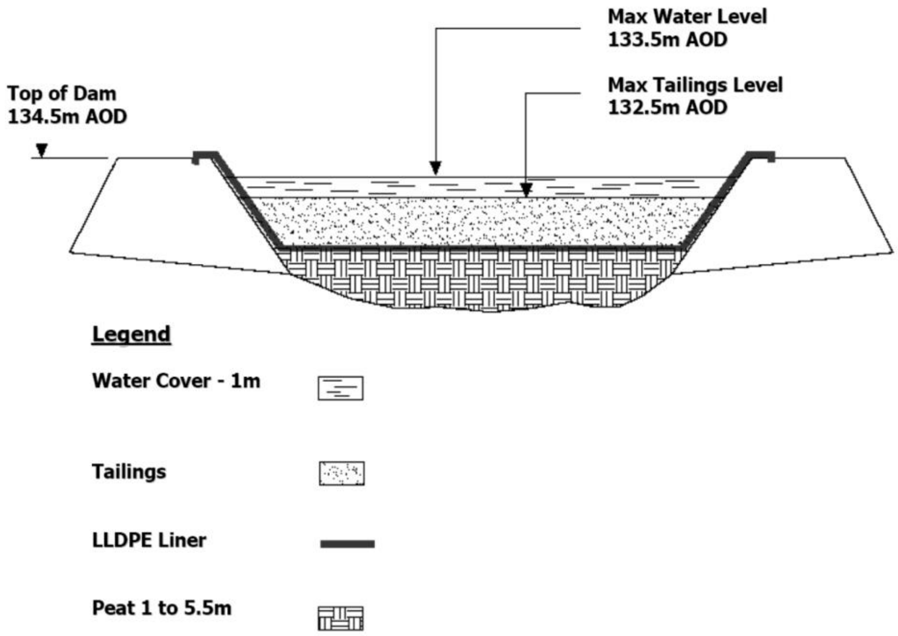

Figure 1 TMF operation pre 2008 – indicative schematic section

3 Tailings characterisation

3.1 Description

A programme of environmental test work has been in place since operation of the Lisheen mine commenced during the late 1990s. In particular, this has enabled surveillance of various emissions and discharges from the mine to meet routine environmental monitoring requirements described in the mine operating license, or Integrated Pollution, Prevention and Control Licence (IPPCL). Since 2006 a supplementary programme of intense laboratory and field test work has been underway. This has focused on characterising various aspects of the tailings that are produced at Lisheen. The prime purpose of this test work has been to support a review of rehabilitation options for the Lisheen TMF. The original concept for final rehabilitation and restoration of the Lisheen TMF was to undertake sub-aqueous tailings placement, maintain the tailings in a submerged condition under a minimum water depth of 1 metre and to establish a reedbed across the entire TMF for long-term tailings stabilisation. This concept was described in the original closure plan that was included as part of the 1995 Lisheen Mine planning submission.

During 2006 and 2007 a series of expert consultations and workshops were held at Lisheen Mine to review the probable efficacy of the original wet closure concept for the Lisheen TMF. The conclusion of these consultations and workshops was that the wet closure concept carried considerable risk of failure to achieve self-sustaining, secure TMF closure. The consequence of this is that application of a wet closure treatment to the entire Lisheen TMF could require indefinite monitoring and aftercare to ensure that the risk factors identified during the 2006, 2007 consultations and workshops were managed. One outcome of the 2006/2007 wet closure review was to initiate a programme of intensive laboratory test work to inform the development of an alternative tailings rehabilitation concept.

In general, the test work considered three characteristics of the Lisheen tailings:

- The acid generation potential of Lisheen Mine tailings.
- The mechanism of acid generation through characterisation of Lisheen tailings mineralogy.
- Physical characteristics of the tailings.

Following early results of laboratory test work, a programme of tailings field test work was initiated during early 2008. This took place to investigate the following tailings characteristics:

- Geochemical and physical characteristics of in situ tailings within the TMF.
- Geochemical characteristics of tailings placed in experimental lysimeter cells.

3.2 Laboratory test work

Laboratory test work to investigate the acid generation potential of Lisheen tailings was comprised of a combination of static testing and dynamic tests. Static tests have enabled quantification of absolute acid generation potential, whereas dynamic tests have enabled an assessment of rates of acid generation over time (SGS Lakefield Research, 2007a, 2007b, 2007c, 2008; Australian Tailings Consultants, 2007, 2008; Environmental Geochemistry International Pty Ltd., 2004, 2007a, 2007b, 2008a, 2008b).

Static test methods for investigation of acid generation potential have comprised the following:

- Modified acid base accounting (ABA).
- Acid neutralisation potential (ANP).
- Single stage net acid generation testing (NAG).
- Trace element analyses.
- Sequential net acid generation testing (NAG).
- Kinetic NAG test.
- Acid buffering characteristic curves (ABCC).
- Mineralogical examination.

Acid generation potential – dynamic test methods have comprised the following:

- Humidity cell tests.
- Flexible wall permeater tests.
- Column leach test.

These analyses have been undertaken by independent laboratories. A synopsis of analysis results is provided in Table 1.

These conclusions have been pivotal in supporting the development of a cap option for rehabilitation of the TMF. The 2006, 2007 consultations and workshop sessions identified the adoption of a dry cap as a rehabilitation approach that would resolve many of the risk factors presented by a complete wet restoration approach. The apparent time lag between exposure of tailings to air and the onset of pyrite oxidation suggests that dewatering the tailings surface to enable construction of a cap could be a feasible rehabilitation option. This would exploit the oxidation lag by completing cap construction on dewatered tailings before the theoretical onset of oxidation.

The practical application of a cap approach to TMF rehabilitation largely depends upon the feasibility of accessing the tailings with earthmoving plant to enable placement of the cap. Geophysical investigations of the Lisheen tailings in aqueous suspension suggested that settlement of tailings particles involves a level of sorting and packing that should result in relatively rapid consolidation. This implies the creation of a substrate that could, once dewatered, be accessed by low ground pressure earthmoving plant and could support the weight of a cap.

Table 1 Laboratory test work – key findings

Description	Conclusion
Acid generation potential (ABA)	High acid generation potential due to high sulphide content.
Acid neutralisation potential (ANP)	Strong neutralisation potential due to high carbonate content. Slow rates of ANP are encouraging since pyrite is encased in carbonate cements (see comment on carbonate mineralogy of tailings below).
Net acid generation potential (NAG)	In general, TMF tailings are potentially acid generating, but the onset of acid generation is significantly retarded due to the presence of mineral surface coatings and the fact that particles are encased in carbonate cements.
Tailings mineralogy	Dolomitic limestone is the main carbonate neutralising constituent Pyrite and other particles are encased in carbonate cement and calcium carbonate rich coatings. Mineral coatings and 'cement' are artificially formed due to precipitation and aging reactions.
Humidity cell and column leach tests (kinetic testing)	Indicates that sulphide oxidation appears to be retarded.

4 TMF rehabilitation project – Phase 1

4.1 Superseded tailings deposition system

Use of the floating head tailings deposition system (see Figure 2) was suspended in January 2008 when construction of the TMF Rehabilitation works started. The superseded tailings deposition system involved placement of tailings into the TMF from a floating head that was suspended from horizontal winch cables running to locomotive engines running along two tracks built onto the crest of the TMF dam wall. As the locomotives travelled along the tracks the floating head was winched across the TMF between the locomotives. This system aimed to achieve a consistent tailings profile beneath the cover of water. Use of the floating head to deposit tailings has effectively been discontinued and the system decommissioned.

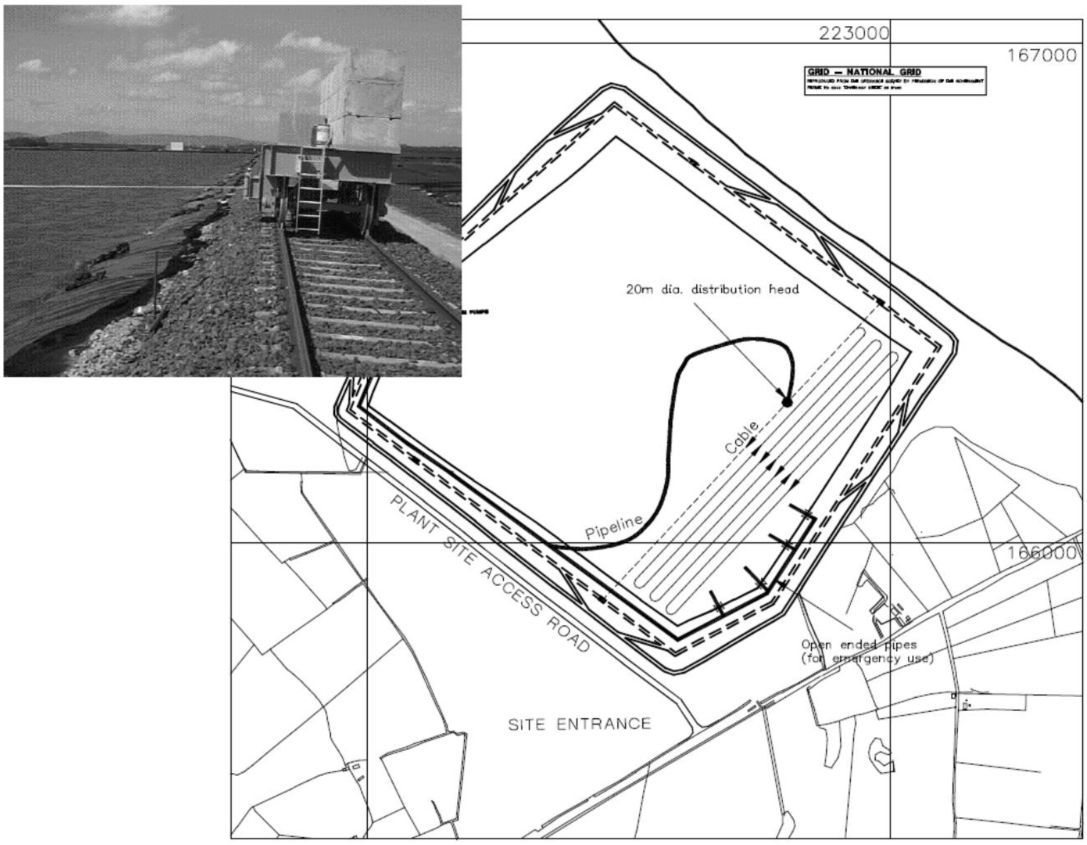

Figure 2 TMF operation pre 2008 – floating head

4.2 Modified tailings deposition system

The modified tailings deposition method effectively involves the installation and operation of a conventional spigot system for tailings deposition into the TMF. This has involved the installation of spigot positions at locations on or just in front of the TMF dam wall, projecting towards the upstream side of the dam. A single 250 mm diameter feed line has been laid along the dam margin, supplied from the main TMF tailings feed. A series of 80 mm diameter spigots have been installed at locations along the feed line.

A working platform has been established on surcharged tailings that have formed a beach adjacent to the dam wall by firstly placing a protection system on the dam wall liner. The geotextile extends from the tailings beach onto the TMF dam wall liner to protect the dam liner from a granular fill platform placed on top of it. Placement of this material has utilised a tracked excavator with a maximum weight of between 13 and 15 tonnes.

The granular layer forms an initial working platform and provides easy access for workers and a support base for the line of spigots. This provides access to the dam by earthmoving plant.

The spigot system has been used since January 2008 to progressively form a tailings beach in advance of the formation of the cap. This method of tailings deposition provides a number of advantages. These include the following:

- Maximising the capacity of the TMF by bringing the tailings elevation up to a maximum level of 133.5 m AOL.
- Formation of a tailings surface by controlled surcharging that is even, self draining and stable.
- A flexible deposition system that enables concentrated tailings deposition at specific locations to fill low areas within the TMF tailings mass.

4.2.1 TMF rehabilitation cap formation

The specification for cap formation across the TMF consists initially of tailings beach creation to provide a rehabilitation area, followed by formation of a rock cap across the rehabilitation beach (Callery, 2009). The initial tailings beach creation is achieved by local surcharging the tailings level by deposition from the TMF margin with a system of spigot pipes (see Figures 3 and 4).

The cap specification comprises the following key elements:

- Terram 1000 or equivalent woven geotextile placed directly onto the tailings beach with a lap length of at least 750 mm.
- 700 mm deep layer of limestone rock with a maximum particle size of around 500 mm long axis.
- 400 mm of soil forming material.

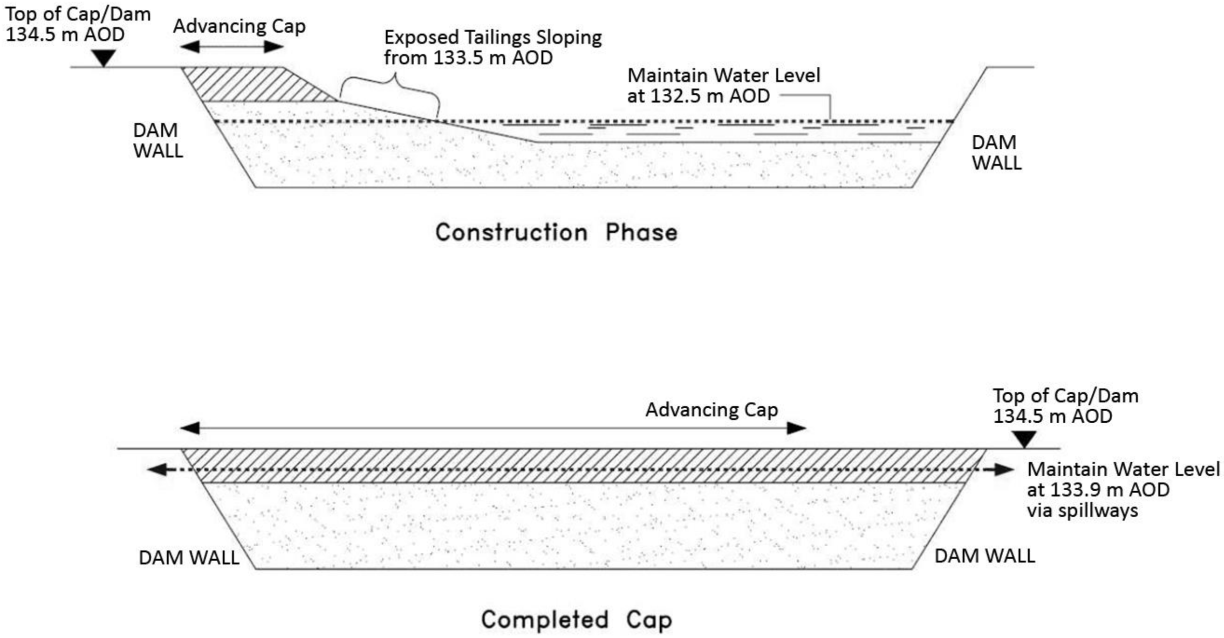

Figure 3 Progressive rehabilitation – schematic sections

The dam wall impermeable liner is protected by firstly placing a 500 g non woven geotextile directly onto the liner, with a minimum lap length of 750 mm, and extending this geotextile onto the tailings beach by 2 m. A terram 1000 or equivalent woven geotextile, again with a lap length of 750 mm, is then placed on the 500 g fabric and extended onto the exposed tailings beach. A granular gravel material with a maximum particle size of 75 mm is then placed on top of the dam wall prior to placement of the larger limestone rock particles and the advancement of the rock cap. During 2008, 2009 and 2010 this specification was applied along the South western wall of the TMF to establish the TMF phase one rehabilitation area. The full extent of the rehabilitation area occupies a strip of the TMF margin around 100 m wide and 800 m in length and occupies a total area of approximately 8.6 hectares. The cap is formed such that it has an inward slope of between 1 and 2% to allow for water runoff. A key feature of the cap is that once that TMF is fully rehabilitated, a spillway will be installed in the dam wall that will maintain a phreatic surface within the rock cap above the tailings surface (see Figure 3 – completed cap).

4.3 Tailings test work – field

4.3.1 Settlement plates and piezometers

The initial step of cap construction incorporates a series of geophysical monitoring locations that comprise settlement plates and piezometers. Figure 4 shows monitoring locations in a rehabilitation cap. The settlement plates enable measurement of vertical displacement of the tailings surface beneath the cap. The piezometers provide detailed information on pore water pressures within the tailings surface beneath the cap.

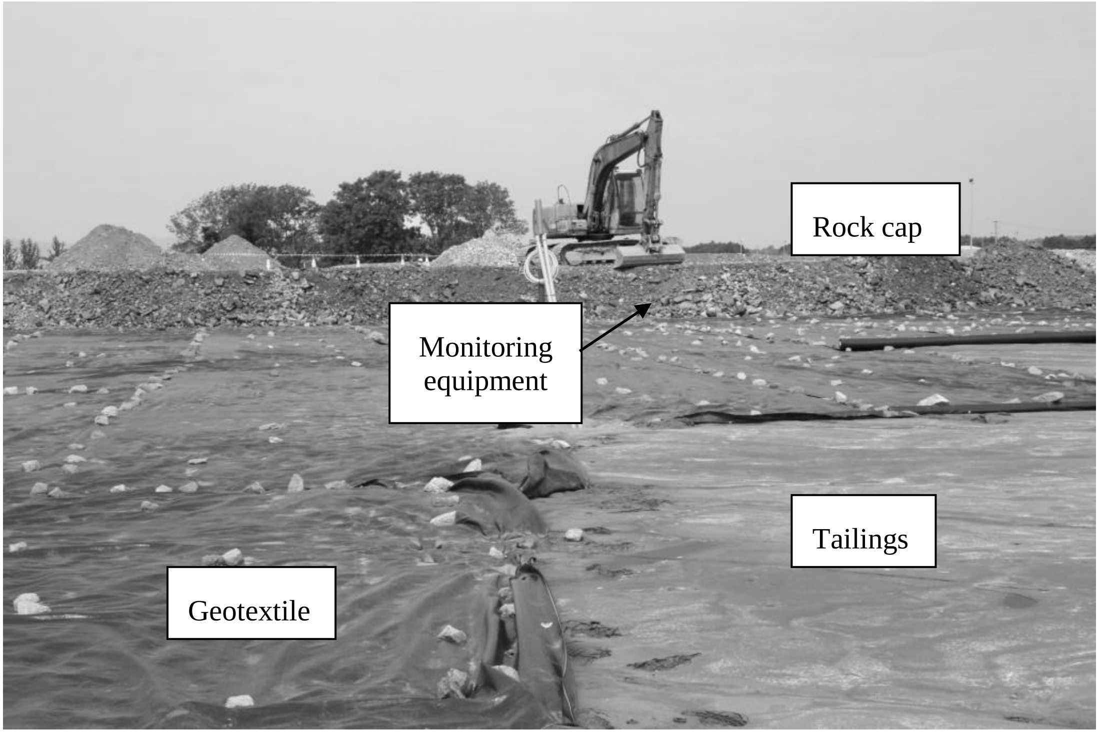

Figure 4 Placement of rockcap over geotextile layer

4.3.2 TMF cap geochemical testing

In addition to geophysical assessment, the monitoring locations incorporated into the initial cap construction include geochemical testing equipment. These comprise two sets of ceramic cups. One set inserted at different levels within the tailings prior to cap placement, and one set incorporated at different levels within the cap. The ceramic cups enable pore water sampling to analyse the geochemical character of interstitial water within both the tailings and the cap.

4.3.3 Rehabilitation cap

The rehabilitation cap has confirmed the laboratory geophysical test results and proves that exposed tailings can gain adequate strength during the drier periods to support earth moving equipment and thus allow capping of the tailings. Measured total settlement of the tailings surface under the Demonstration Cell cap is in the order of 116 to 300 mm and is in essence minimal given the geophysical nature of the tailings. In addition losses of limestone capping material at the leading edge of the advancing cap are also negligible. This can be attributed to the manner in which the tailings beach is formed, dried and capped using lightweight plant and equipment over an extended period of time. Pore water samples from the base of the cap have been collected on a monthly basis. Test work demonstrates that the pH of the pore water remains neutral. This indicates that the cap is proving effective in preventing oxidation of the tailings (see Figure 5).

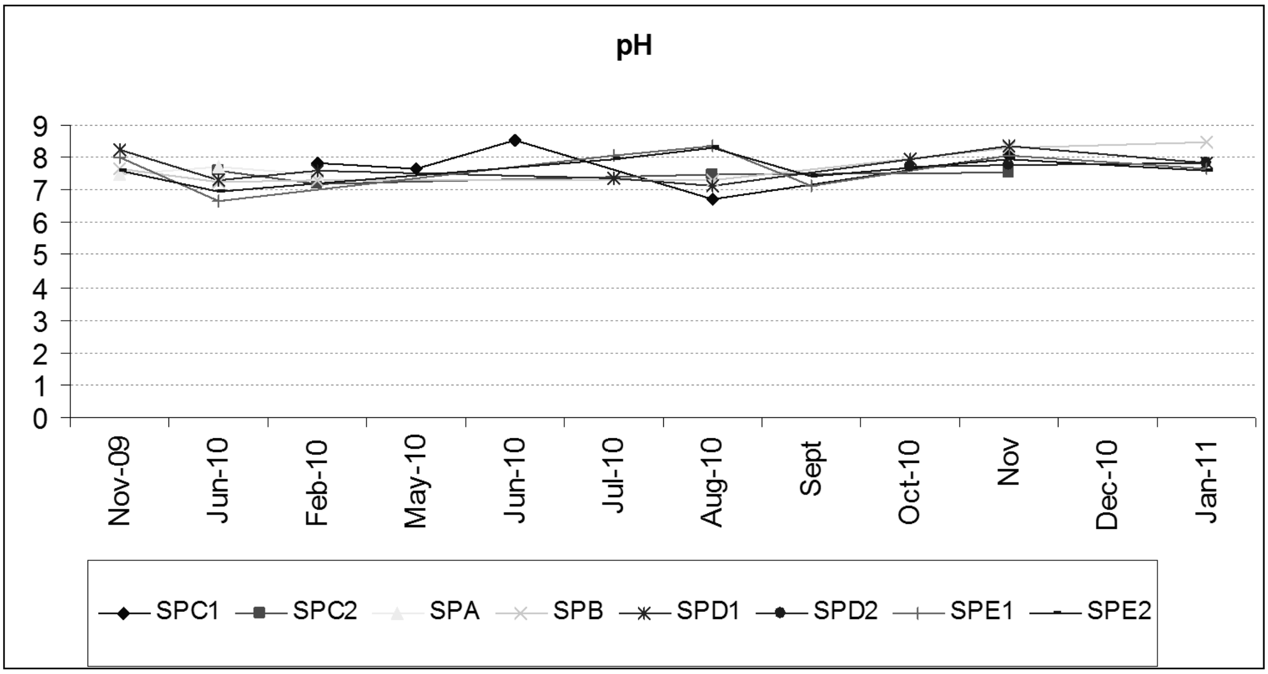

Figure 5 TMF rehabilitation cap – pH of pore water at base of cap

4.4 Soil forming material and vegetation establishment

4.4.1 Soil forming material

Utilisation of previously stockpiled peat in the substrate is an important consideration, providing valuable soil moisture retention and a potentially viable nutrient capital that would be capable of supporting plant growth through nutrient cycling. However, using a substrate which has a high proportion of organic matter for restoration has the potential to limit vegetation establishment success.

To address this potential limitation it is necessary to blend the peat with a mineralising element. At Lisheen, this was obtained from stockpiles of glacial till sourced from the construction of the Lisheen Wind Farm Project (completed in 2009). The blending process aims to achieve a mixture ratio of around 1:1 peat and glacial till. Which provides adequate nutrient to sustain vegetation growth is optimised to provide adequate water retention, while not impacting on drainage.

The general aim of this approach is to create a restoration substrate that has soil-forming potential. This would provide a strong basis for the progressive development of sustainable grassland vegetation that would respond to pasture management.

4.4.2 Vegetation establishment

The rehabilitation scheme incorporates specific seed mixes. These have been developed for the establishment of pasture grassland and conservation headland treatments within the rehabilitated areas. The pasture treatment seed mix derives from an assessment of the existing composition of established pasture grassland within a demonstration trial pasture reference site. This comprises an area of land adjacent to the TMF that would remain under pasture management throughout the TMF rehabilitation project. This will also be used as a control site, along with two others 4 km and 25 km away from the TMF respectively, against which the performance of pasture treatments within the rehabilitated areas can be assessed.

4.4.3 Rehabilitation Phase 1 – layout

The Phase 1 demonstration scheme comprises four discrete areas as shown in Figure 6.

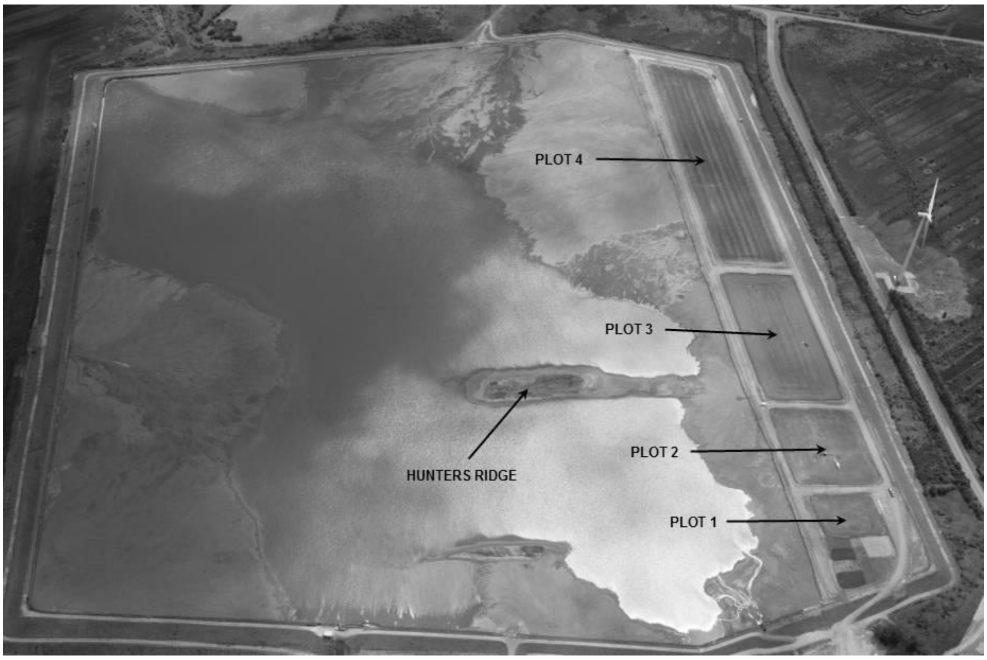

Figure 6 Soil and vegetation sampling locations on the Phase 1 rehabilitated section of the TMF

4.4.4 Rehabilitation project Phase 1 – monitoring and interpretation

With regard to soil/substrate sample analysis, samples are taken from a depth of around 200 mm, both from the rehabilitated plots and from the reference sites. Replicate samples are taken for both sites. Analyses focus on characterisation of the following:

- Soil organic matter.
- Particle size distribution.
- Major nutrients – nitrogen, phosphorus, potassium.
- Primary trace elements - S, Ca, Mg, Cu, Zn, B, Cl, Mo, Mn, Fe.
- Secondary trace elements - Al, Si, Na.
- Potential toxin tracer elements - Pb, Cd, Hg.

With regard to analysis of vegetation samples, vegetation analysis provides metal element profiles for above ground biomass and below ground biomass separately. This provides an indication of any metal uptake and partitioning by sequestration in either plant roots or shoots. The metal elements considered in vegetation analyses are S, Ca, Mg, Cu, Zn, B, Cl, Mo, Mn, Fe, Al, Si, Na, Pb, Cd and Hg. Results for soil testing were also compared against the 'Dutch Values' (Ministry of Housing, Spatial Planning and Environment, Netherlands 4th February 2000). Where applicable, the EU directive '2002/32/EC, on undesirable substances in animal feed' was used as a guidance for the results of the vegetation analyses. An example of results received to date is given in Figure 7. CS 1 to 3 are Control Sites in the hinterland of the mine, 'Cap' is for composite samples taken on the rehabilitated section of the TMF.

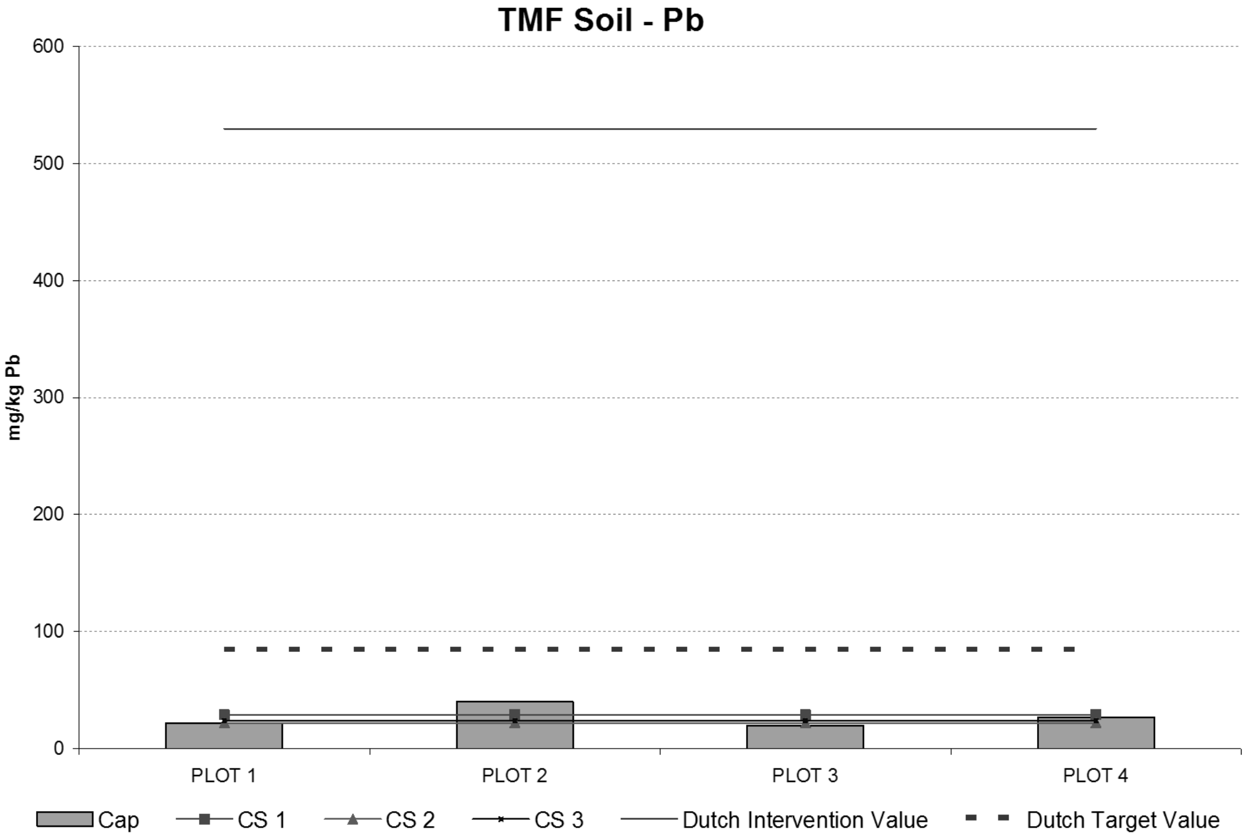

Figure 7 Typical Pb results from soil samples taken from Phase 1 rehabilitated section of the TMF

4.5 Lisheen TMF rehabilitation project – livestock trials

In July 2010, ten charolais heifers were introduced onto the TMF rehabilitation plots as part of the Lisheen livestock trials. To date, analysis of blood samples indicates that the metal concentrations in the animals' blood are well below the acceptable levels and the animals have generally thrived on the TMF fields with some of the animals nearly doubling their weight during their time on the rehabilitation plots. The animals will be slaughtered in July 2011 and the muscle, organs, fatty tissues will be tested for metal uptake. Lisheen intend to maintain a herd on the TMF rehabilitation plots into the future.

4.6 Progressive rehabilitation – future phases

Future phases of progressive rehabilitation will be implemented across the remaining area of the TMF in the coming years using the same strategy and cap specification. The rehabilitation cap will be formed such that it maintains an inward gradient. This will facilitate collection of runoff waters in a small pond adjacent to the final spillway location prior to discharge to formed wetlands and receiving waters. This will be subject to validation through ongoing sampling and monitoring and compliance with emission limit values as prescribed in the Lisheen Mine IPPCL.

5 Conclusions

At the outset of this project Lisheen Mine established a set of success criteria against which the success of the project would be measured.

The success criteria for the TMF rehabilitation project are as follows:

1. Minimise oxygen concentrations at the surface of the tailings.
2. Create an acid buffering capacity by providing a limestone rock/rubble layer at the tailings surface.

3. Prevent the migration of tailings upwards through the cap.
4. Formation of a stable platform on the TMF that will be sufficiently strong to carry various types of construction vehicles, e.g. dump trucks, bull dozers, etc.
5. Provision of a growth medium that will support successful vegetation establishment and growth on the rehabilitated TMF.
6. Prevent the uptake of metals by vegetation that establishes on the cap.
7. Rehabilitate the Lisheen Mine TMF in a manner that provides the widest possible range of potential after uses for the facility once fully rehabilitated.

In addition, there has been consideration of an 8th objective in relation to minimising the risk of environmental pollution or environmental damage, in particular surface water discharges, emanating from the TMF, in conjunction with minimising such a risk from the entire site (Callery, 2009).

Based on the various test work results collected to date it can be argued that the Lisheen TMF rehabilitation project has largely met these success criteria. However, true success can only be measured in the longer term. This reinforces the importance of the progressive rehabilitation strategy adopted by Lisheen. As the mine moves toward eventual closure in 2014, up to seven years of laboratory and field data will be available for interpretation and assessment. Also this projects demonstrates that planning for closure and implementing closure projects, that take advantage of site conditions and available materials, many years before the closure date is essential to sustainable mine closure.

References

Australian Tailings Consultants (2007) TMF Closure Planning: Report on Field and Laboratory Test Results, October 2007, Reference 106015R03.

Australian Tailings Consultants (2008) Lisheen Mine Laboratory Testing of Tailings – Final Report, February 2008, Reference 106015R04.

Callery, S. (2009) Lisheen Mine Closure, Restoration and Aftercare Management Plan (CRAMP) 2009 version, S. Callery (ed).

Environmental Geochemistry International Pty Ltd (2004) Free Draining Leach Column Test Procedures, June 2004.

Environmental Geochemistry International Pty Ltd (2007a) The Lisheen Mine: Geochemical Characterisation and ARD assessment of Tailings Samples, June 2007, Reference 1851/770.

Environmental Geochemistry International Pty Ltd (2007b) Tailings Geochemistry – Reaction Kinetics and Implications for Mine Operations and Closure, 25 June 2007.

Environmental Geochemistry International Pty Ltd (2008a) Cost Estimate for ongoing Column Leach Tests, Technical Advice and Review as needed, 4 August 4 2008.

Environmental Geochemistry International Pty Ltd (2008b) Tailings Geochemistry – Column Leach Tests Update, 21 May 2008.

Golder Associates Ltd. (2007) Conceptual Closeout Study for the Tailings Management Facility at the Lisheen Mine, Canada.

Ministry of Housing, Spatial Planning and Environment (2000) Netherlands 4th February 2000, viewed 15 May 2011, http://www.esdat.net/Environmental%20Standards/Dutch/annexS_I2000Dutch%20Environmental%20Standards.pdf.

SGS Lakefield Research Limited (2007a) An Investigation into the Acid Rock Drainage Characteristics of Lisheen Mine Tailings, 6 June 2007, Reference 11527-001.

SGS Lakefield Research Limited (2007b) An Investigation into Mineralogical Characterisation of four Tailings Samples, 28 May 2007, Reference LR11527-001-MI5002-APR07.

SGS Lakefield Research Limited (2007c) Revised Proposal for Environmental Testing of Tailings – Lisheen Mine, 5 January 2007.

SGS Lakefield Research Limited (2008) Continuance/decommissioning of Lisheen Tailings Humidity Cell Tests, June 11, 2008, Reference 11527-001.