The remediation and closure of the former Garryard and Gortmore sites within the historic Silvermines district, Ireland

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Abstract

The Silvermines district is located within the county of Tipperary, Ireland. It takes its name from the former extensive mines of lead, zinc, copper, barite and silver that have operated sporadically in the district since 1289, but with more intense operations in the later part of the 19th Century and on into the 20th Century. However, in 1993 all mining operations ceased and the mines were closed. The Department of Communications, Energy and Natural Resources (DCENR) within the Irish government, through their agent North Tipperary County Council (NTCC), have subsequently undertaken rehabilitation of parts of the Silvermines area.

Since the closure of the operations a number of studies to assess the risks associated with the sites have been carried out by an interagency group led by the Irish EPA and DCENR, in conjunction with a variety of advisors for specialist input. In 2006 the DCENR obtained funding to commence remediation of the site. After seeking assistance from another consultancy NTCC retained SRK Consulting (UK) Ltd, in partnership with Fehily Timoney and Company, to assist in the final designing of remediation strategies and prioritising of the onsite implementation of the remediation program.

The Garryard operation was one of the sites prioritised for remedial works. The Mogul of Ireland mine at Garryard was an underground lead/zinc operation that was active between 1968 and 1982, producing some 9.7 million tonnes of ore grading 2.7% Pb and 7.36% Zn. This ore was stockpiled and processed on surface at a purpose built plant at Garryard and wastes were disposed of both at the Garryard site and then the Gortmore tailings storage facility. When the site was closed there was minimal restoration. However, the presence of sulfide minerals within the wastes has led to the development of acid rock drainage (ARD) that has subsequently released heavy metals in to the aquatic environment. In addition, winds blowing across the tailings facility have resulted in the aerial dispersion of metal enriched dusts.

NTCC retained SRK to develop and implement the final strategy to cover the tailings facility at Gortmore to limit both windblown materials and improve water management around the facility, thereby reducing solubilised metal release. The remediation works at Gortmore were completed in 2010. At the Garryard site, SRK proposed a remediation solution for the existing waste within the tailings lagoon that would enable the storage of further problematic mining wastes from the Silvermines area and provided a design for a passive water treatment scheme to minimise the effect of on-going discharges from the site.

This paper discusses the engineering issues behind these remediation designs.

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1 Background

The Silvermines district is located in the county of Tipperary, Ireland. Extensive mining of lead, zinc, copper, barite and silver has been carried out over an area of around 5 km^2 since 1289, but with more intense operations in the second half of the 19th Century and during the 20th Century. Between 1968 and 1982, Mogul Mines developed a 19 Ha Tailings Management Facility (TMF) at Gortmore as part of the underground mining and processing for lead and zinc at Garryard. In 1993 all mining operations were ceased. The Department of Communications, Energy and Natural Resources (DCENR) sought funding and the necessary legislation to carry out the remediation of the Silvermines district.

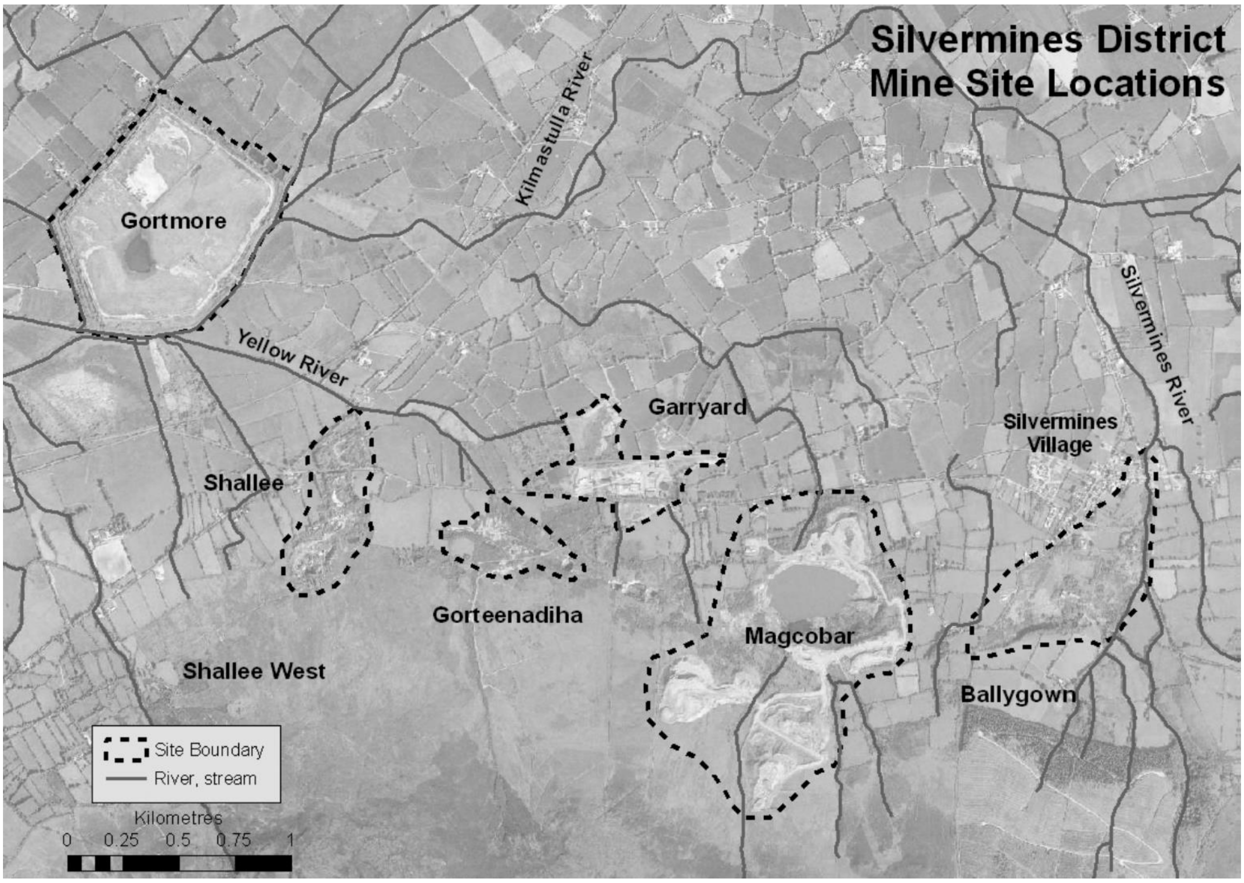

Figure 1 Overview of the Silvermines district mining operations (Stanley et al., 2010)

There is a legacy of health and safety issues at the site as well as potential mining heritage with tourism and educational interest involved. For many years the Silvermines community and those families living around the Gortmore site had been concerned about potential lead poisoning. It was alleged that some animal deaths had been due to lead poisoning and the effects of metal bearing dust blows off the TMF. The challenge faced by DCENR was to remove or minimise the health and safety risks, achieve the requirements of the Water Framework Directive (WFD), conserve and protect important elements of the site whilst also minimising cost.

In 2007 the DCENR received funding for selected remediation targets. The DCENR in partnership with North Tipperary County Council retained SRK Consulting (UK) Ltd. who retained Fehily Timoney (FTCO) to assist in preparing preliminary designs for the various works. They subsequently appointed Golder Associates and SRK Consulting (UK) Ltd to prepare final designs and to supervise construction of the works.

The site investigations included borehole drilling, surface and groundwater sampling, mapping of waste dumps, buildings, mine openings and shafts. This work was carried out in conjunction with a review of available mine plans. Regular consultations were held with the local community as well as with department staff, the local authority and various interest groups. The resultant strategy and plans for remediation of the site were accepted in principal by all stakeholders.

DCENR recognised that it was not feasible or practical to remediate the area in full and a priority list of remediation objectives was established based on risks to human and animal health and the environment. It was also recognised that the area represented an interesting and important mining heritage and these considerations were included in the studies.

A plan for the remediation works was developed for a four year construction period. The Gortmore TMF was identified as the key priority for remediation and was selected for construction in year one. Some heritage works were carried out in years one and two, such as making safe an engine house at Silvermines. Also, the tailings residue pond at Garryard had been releasing contaminated water to the environment for many years. So the decision was taken to consolidate various small wastes from around the Silvermines area into one sealed closure facility at Garryard, which is referred to as the Mine Waste Management Facility (MWMF) and to remediate and make safe those areas from which the wastes were collected.

As a remediation strategy, SRK instigated the covering of the TMF at Gortmore to limit both windblown materials and to minimise water infiltration in to the facility, thereby considerably reducing the potential for release of dissolved metal species to the environment. The toe paddocks and the settlement ponds would be rehabilitated to assist in treating potential effects of Acid Mine Drainage (ARD). Also, to limit cost it was decided that the site should be restored for amenity use only rather than for full agricultural use.

At the Garryard site, SRK proposed a remediation solution for the existing waste within the tailings lagoon that would enable the storage of further problematic wastes at the site in the future. SRK also provided a design for a passive water treatment scheme to minimise the effect of ongoing discharges from this site.

The Gortmore remediation was completed in 2011, but before the Garryard MWMF could be constructed the global economic crisis hit and the project had to be postponed. This paper discusses the engineering issues behind the remediation designs described above.

2 Geology and mineralisation

The geology and mineralisation of the Silvermines district has been summarised by the EPA of Ireland (Stanley et al., 2010) as follows:

'The mineralisation at Silvermines is hosted by basement rocks of the Silurian and Devonian Old Red Sandstone and by the overlying Lower Carboniferous succession (Andrew, 1986). The oldest rocks in the area, turbidites of the Silurian Hollyford Formation, form the core of the Slieve Felim – Keeper Hill Lower Palaeozoic inlier to the south. An angular unconformity separates these rocks from the 100 m thick sequence of pebble conglomerates, greywackes, sandstones and siltstones that comprise the Devonian Old Red Sandstone Basal Clastic succession. This sequence forms remnant veneers on the northern flank of the inlier (Andrew, 1986). The overlying 10-12 m thick Lower Limestone Shale (Archer et al., 1996) marks the base of the Carboniferous and represents a shift from clastic sedimentation to development of limestones as sandy siltstones are followed by calcareous mudstones. This is followed by the 85-235 m thick Argillaceous Bioclastic Limestone (ABL), also known as the Ballysteen Limestone Formation. This comprises basal shales as well as a Lower Dolomite unit overlain by massive limestones and argillaceous reef limestones. The ABL is succeeded by 30-155 m of Waulsortian reef limestones.

The geology of the area is dominated by a complex of faults known as the Silvermines Fault that was active during sedimentation and mineralisation (Andrew, 1986). This zone trends broadly eastnortheast but includes westnorthwest-trending components. The fault has downthrown the younger Carboniferous strata against the older Silurian and Devonian clastic sequences. Mineralisation occurs in two styles: (1) in fracture zones and as replacements within the Silurian greywackes, Devonian clastics and Lower Dolomite of the ABL and (2) as stratabound zones within brecciated and dolomitized Waulsortian reef limestone. All the replacement mineralisation occurs within or close to westnorthwest-trending structures of the Silvermines

Fault zone. The fracture-fill and replacement mineralisation is generally considered to have formed in the feeder zone to the upper syngenetic exhalative stratiform orebodies (Andrew, 1986).

The fracture-fill and replacement ores lie closest to the Silvermines Fault and were mined at Ballygown, Garryard, Gorteenadiha and Shallee. Together they contained an estimated 4.3 million tonnes (Mt) grading 2.44% Pb and 5.49% Zn (Andrew, 1986). The stratabound ores of the Upper G and B zones comprised a tabular orebody of massive barite, siderite and marcasite-pyrite with variable amounts of later-formed Pb-Zn sulfides. These upper zones occur furthest from the Silvermines Fault and were mined primarily underground from Garryard (Pb-Zn) and the Magcobar open pit (Ba). The stratabound mineralisation is estimated to have contained around 11.8 Mt grading 2.55% Pb, 6.78% Zn and 5 Mt of 85% $BaSO_4$ (Andrew, 1986; Boland et al., 1991).

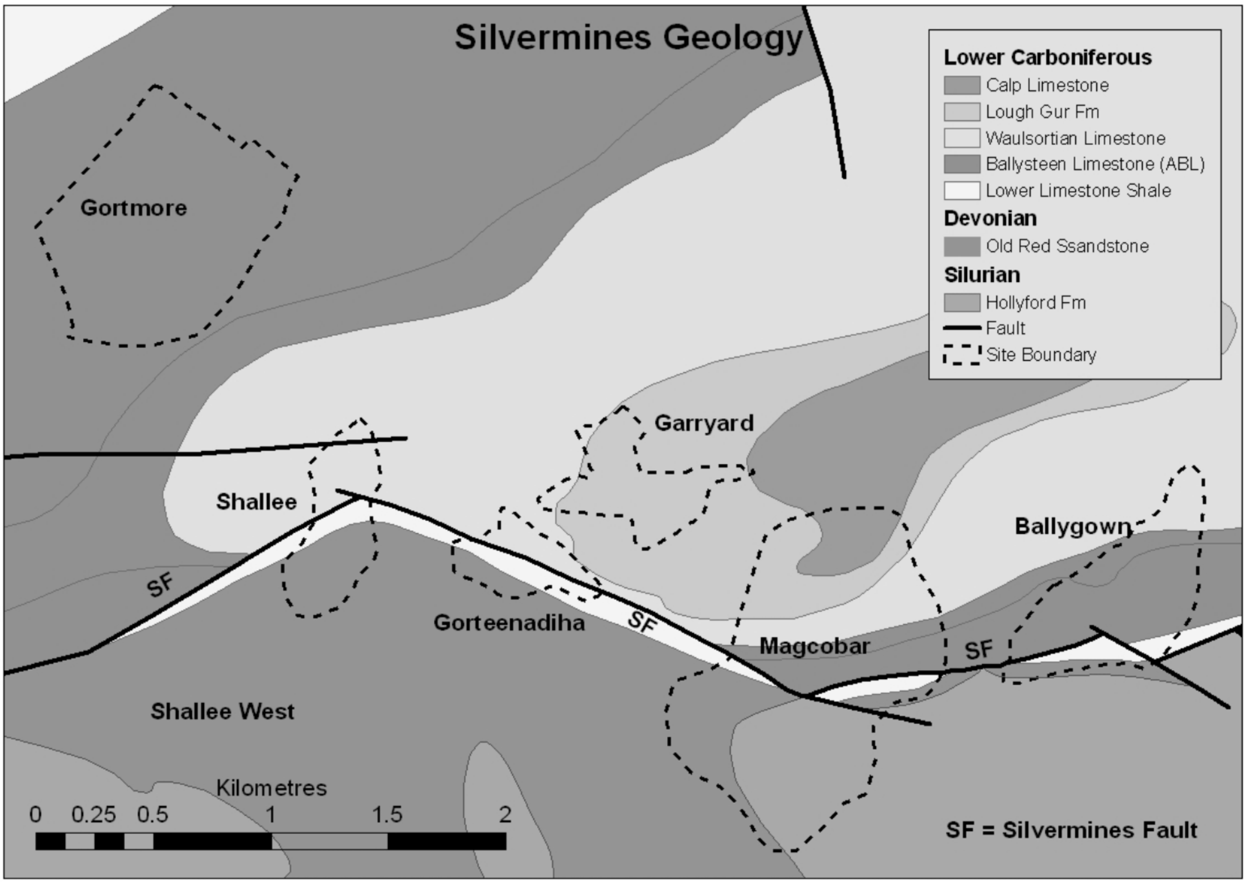

Figure 2 Silvermines geology and mining operations (Stanley et al., 2010)

This sulfide dominated mineralisation has subsequently led to issues with acid rock drainage and metals leaching (ARDML). However, due to the presence of calcium carbonate rocks, mainly limestone, most drainages are neutral. In addition the naturally elevated concentration of heavy metals remaining within the waste materials has also led to issues with heavy metal uptake in livestock through grazing on spoil heaps and from windblown materials.

3 Gortmore

'The Gortmore tailings management facility (TMF) was built by Mogul to store the tailings produced by its underground mining operation at Garryard, 2 km to the east. The TMF occupies the lowland area of the Kilmastulla River floodplain' (Stanley et al., 2010).

As part of the TMF construction 'the Kilmastulla River was diverted and re-aligned prior to commencement of construction of the TMF in 1966 (Golder Associates, 2007). The TMF was subdivided by a northwest-southeast-trending wall into two ponds with the large southwest pond (Pond1) completed first. The northeast pond was subsequently subdivided into two smaller ponds, known as Pond 2 and Pond 3. Construction was completed in 1967 and processing commenced at the mine site in May 1968. Tailings were pumped from Garryard via a pipeline to the TMF and some excess water was pumped back to the mine for reuse (SRK, 2001). A decant tower and pond was constructed between Pond 2 and 3. Remaining excess water on the surface of the TMF was drained by the decant system via an engineered wetland into three settlement ponds, constructed along the northeast edge of the TMF. Prior to closure of the Garryard mine in 1982, Mogul planted reed beds in these retention ponds. Volunteer wetlands have developed around the TMF and help trap run-off from the embankment (Figure 3). The total TMF footprint, including the outer embankment, is 76 ha with the tailings covering approximately 58 ha. The embankment has an average height of 8.2 m and a perimeter is 3.1 km long. During the operation of the Garryard mine, 10.7 Mt of ore grading 7.36% Zn and 2.7% Pb were milled. This ore generated approximately 9 Mt of tailings with 7.7 Mt of these pumped to the TMF. The remaining 1.3 Mt were backfilled into the underground workings. The total volume of tailings in the TMF is estimated to be just over 5,000,000 m^3.

Following closure of the TMF, the surface layer of tailings slowly dried out and a major dust blow occurred in February 1985. Mogul undertook rehabilitation works to establish a grass cover across the surface of the TMF but this cover has deteriorated since then, althought approximately 60% of the TMF area maintained its grass cover. The previous remediation work covered an area of circa 23 ha (visible as light coloured areas on Figure 3) (Stanley et al., 2010).

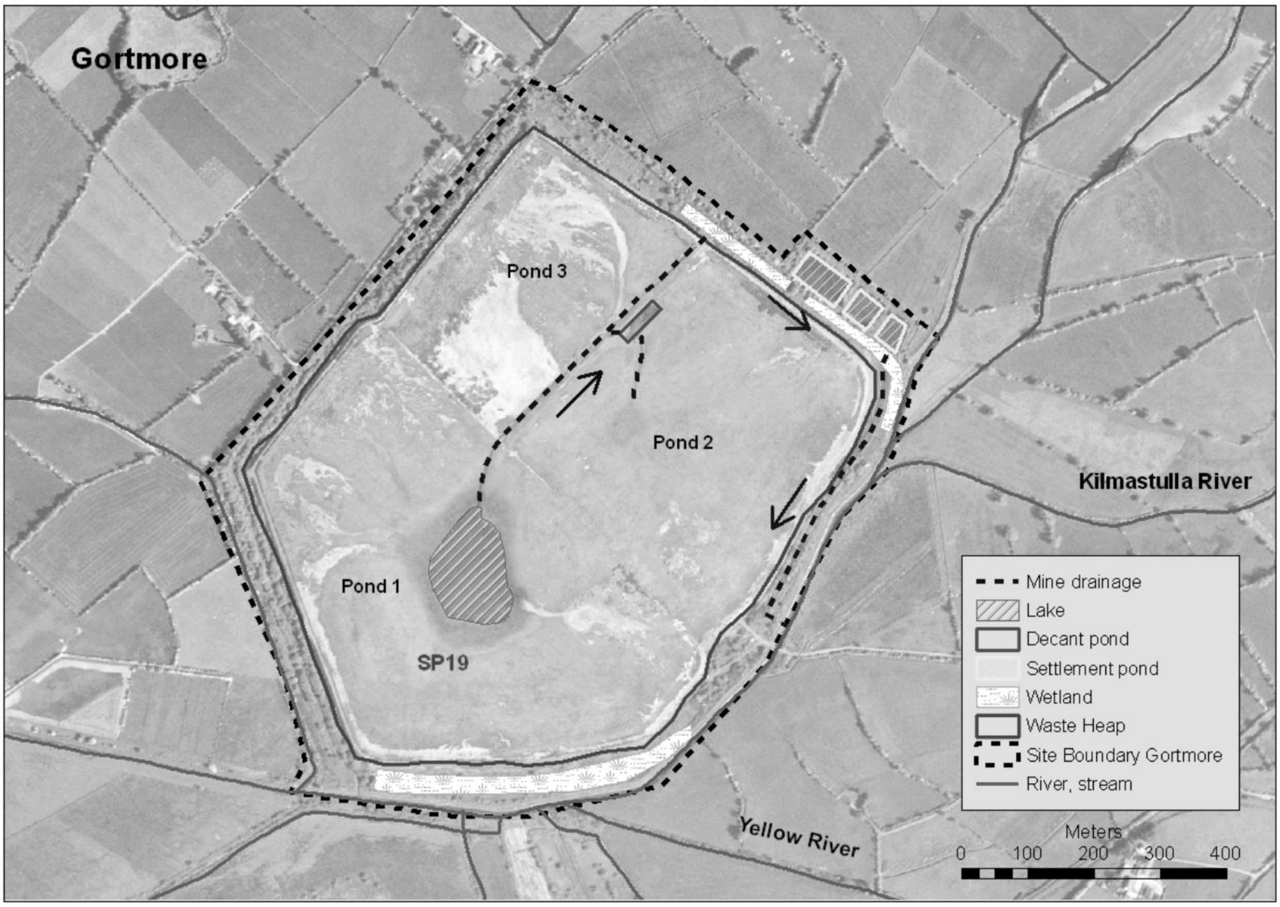

Figure 3 Pre-rehabilitation overview of the Gortmore tailings management facility (Stanley et al., 2010)

3.1 Long-term slope stability at Gortmore

The geotechnical aspects of Gortmore rehabilitation included the long term external slope stability and trafficability issues during the process of reclamation.

The external slope stability was addressed through the following activities:

- Review of the original slope stability study.
- Back-analysis of the existing slope with various strength values for tailings waste.
- Analysis and final geometry of the buttressing for the external slopes of the facility.

The Gortmore TMF has been used to store the tailings from the nearby mining operations extracting silver and lead minerals. The tailings facility has been raised above the surrounding ground using the upstream construction method in three distinct cells. The spiggoting technique has been used to discharge the tailings, resulting in some segregation of the waste materials with coarser fraction settling at the TMF's perimeter and finer fraction towards the centre of the pond. The supernatant has been returned from the TMF by the decant system via the steel pipe, crossing through the north side of the TMF embankment.

The external dykes were raised with the coarser fraction of tailings by dozing and track packing compaction. Two intermediate slopes were constructed with only one berm a few metres wide. The outer slopes of all dykes have been armoured with a minimum 2 to 3 m thick layer of rock fill to prevent surface erosion and improve their stability. In some areas of the facility perimeter, there are buttresses constructed earlier, possibly due to slope distresses.

The armouring of the outer slopes pertains only to the lower slopes. The upper slopes of the final lift were made from the tailings materials and are not armoured with the rock fill. In some areas, there is evidence of springs and erosion of the upper slope.

The survey indicated that the external slopes varied from 1.1 H:1V to 2.2 H:1V at various cross-sections. This inclination range applies only to the lower slope as overall slopes, which include lower, upper and horizontal benches, yield flatter slopes. The heights of the overall slopes range from 6.5 to 8 metres.

The closure of the facility required stable long term slopes with a minimum factor of safety of 1.3.

4 Review of original work and engineering

The closure slope stability analysis was based on the information found in the original rehabilitation designs concerning the geology, ground water conditions, slope stability model and interpretation of the results. In addition, eight as-built cross-sections were analysed.

The general cross-section could be described as follows:

- Boulder, in situ clay foundation.
- Clay starter dyke approximately 2 metres high, with the granular filter at its toe.
- Outer waste rock armouring at minimum 2 to 3 m thick.
- Tailings behind the rock fill armouring.

The typical material properties are summarised in Table 1.

Groundwater levels measured in the piezometres installed through the surface of tailings indicate an average depth to phreatic surface of 3.5 mBGL (metres below ground level), with a minimum of 1.4 mBGL and a maximum of 8.8 mBGL.

The slope stability model was created using the Slope-W numerical code (version 6.11) with the results showing the present and improved conditions due to the applied buttress for each control cross-section.

Table 1 Material properties design

Physical Properties/Material Type	Boulder in Situ Clay	Filter at Toe of Starter Dyke	Waste Rock	Clay Fill	Tailings
Unit weight (kN/m^3)	20	20	20	20	20
Cohesion (kPa)	67	0	0	57	5
Friction angle (°)	0	34	37	0	35

5 Sensitivity analysis with variable strength of tailings deposit

SRK's testing of the tailings with vane shear probe below the surficial crust (0.3 m thick) showed the strength of tailings varying from 5 to 10 kPa. If this strength of tailings is used in the slope stability model then the factor of safety drops below unity for the present conditions, without any buttressing. The present external slopes do not show any sign of instability with the exception of shallow erosion. The stable slopes indicate that the tailings contents have undergone a significant consolidation with depth and the overall stability of tailings is much higher than that which could be achieved in the numerical slope analysis utilising the strength of 5 to 10 kPa as measured in the field. It should be stressed that the low values were measured only from within 300 mm of the surface.

SRK performed the sensitivity analysis with a range of strength values for the tailings. This sensitivity analysis was used to determine the probable strength of the tailings waste. As a result of this sensitivity analysis, it was decided that cu = 20 kPa strength should be used for the tailings waste as the present dams do not show signs of instability.

The strength of cu = 20 kPa has been used in the further analysis to confirm the width of the buttress which has been required in some locations to bring the overall factor of safety to above 1.3.

6 Buttress design

The design of the buttress was performed utilising strength of tailings from the sensitivity analysis and strength of other materials from earlier studies.

Figure 4 below shows that adding the buttress in front of the existing slope at section 2 h will result in the factor of safety of slope of the dam above 1.3.

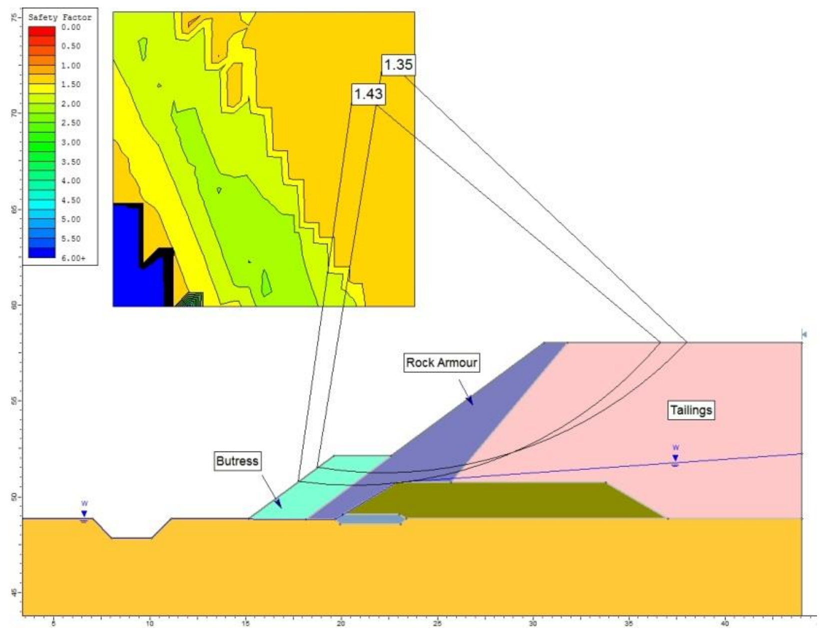

Figure 4 Slope stability analysis at section 2 h with 3 m wide buttress

6.1 Locations of the buttresses

Table 2 shows the lateral extension of the buttresses as illustrated in Figure 4. For all subject areas, both the height and width of the buttresses should be 3 metres, respectively. These areas are illustrated in the large plan overleaf.

Table 2 Locations of proposed buttresses

Area	Location	Chainage
Area A	Northern flank	Ch 827 – Ch 987
Area B	Northern flank	Ch 485 – Ch 607
Area C	Eastern flank	Ch 268 – Ch 379
Area D	Eastern flank	Ch 30 – Ch 130
Area E	Southern flank	Ch 2255 – Ch 2329
Area F	Western flank	Ch 1995 – Ch 2255
Area G	Western flank	Ch 1820 – Ch 1933
Area H	Western flank	Ch 1410 – Ch 1544
Area I	Western flank	Ch 1310 – Ch 1410
Area J	Western flank	Ch 1060 – Ch 1210

The buttress locations were determined based on the analysis as well as the visual inspection of the facility. This quasi-observational approach is appropriate given the lack of as-built precise drawings.

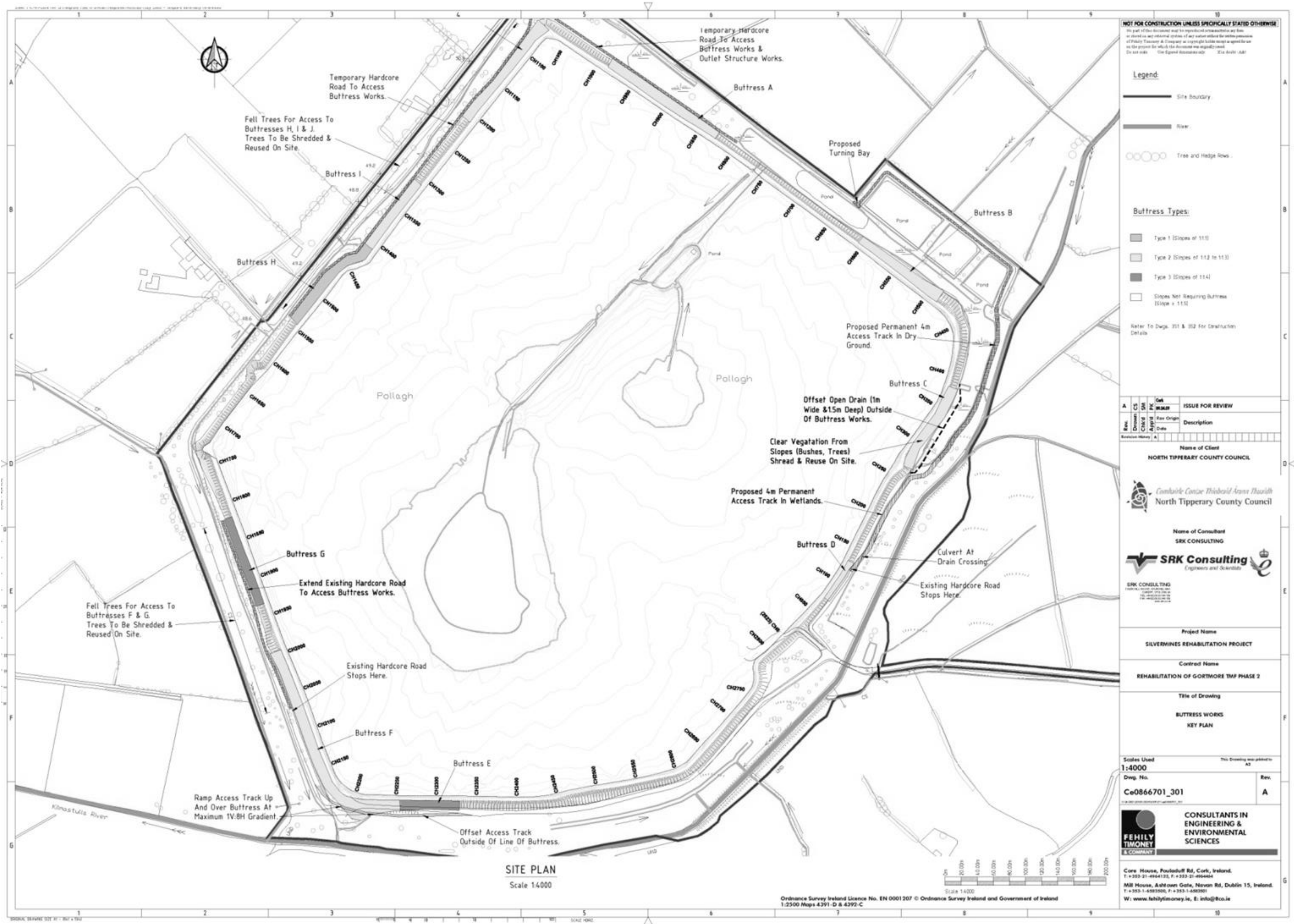

Figure 5 Gortmore buttress strengthening requirements

6.2 Buttress construction

All buttresses have been constructed with good quality, stable materials. General specifications for borrow material and its placements are as follows:

- Largest particle size 150 mm with no sand and fine sizes.
- Non-acid generating.
- Only nominal (traffic) compaction of buttresses was required.
- Only placement of buttress on firm, approved surface of original soil was allowed.
- Final slopes were trimmed with no loose materials left on the slope.
- To improve the visual appearance of the final slopes some vegetation was planted.

7 Surface treatment

The main objective of the surface treatment for the tailings facility at Gortmore was the dust control though the establishment of sustainable vegetation.

The remediation was carried out in two phases. The main design features of Phase 1 were:

- Capillary break: that was composed of 300 mm crushed rockfill on a geotextile.
- Haul road that were composed of 900 mm crushed rockfill on a geogrid with a geotextile.
- Access fingers composed of 900 mm crushed rockfill on a geogrid with a geotextile.

For Phase 2 of the remediation works, as the area of the treatment varied with respect to the amount of remediation required, up to five different treatment techniques were applied:

- Type 1 Treatment: 100 mm thick layer of gravel (10–20 mm diameter).
- Type 2 Treatment: 100 mm minimum thick layer of gravel (10–20 mm diameter) with separation geotextile.
- Type 3 Treatment: Grass on 100 mm topsoil on150 mm subsoil on drainage geocomposite (capillary break) pinned to ground.
- Type 4 Treatment: Grass on 75 mm topsoil on 100 mm hardcore (< 50 mm diameter) on separation geotextile.
- Type 5 Treatment: Grass on 150 mm topsoil on 150 mm subsoil on drainage geocomposite (capillary break) pinned to ground.

In some areas, a combination of the above treatment types was used. The type of cover was driven by the need for mechanical access on to the TMF, as the lack of mechanical access had resulted in the failure of the original cover as an incomplete soil cover was attained. Additional drivers for the cover then ranged from the need for capillary breaks to promoting suitable growth mediums. Ultimately the design for the finally cover was for a low maintenance grass cover but it is not intended for livestock farming.

8 Garryard

'The Mogul began underground mining in Silvermines in 1968 and constructed the surface plant and mine access shaft at Garryard (Stanley et al., 2010). Between 1968 and 1982 Mogul raised and processed 10.7 Mt of ore at 7.36% zinc and 2.7% lead at the site. The site is on both sides of the Silvermines – Shallee road, 1.5 km west of Silvermines village. South of the road is the old ore stockpile area and on the north side the site is split by a rail siding from which concentrate was transported. On the south side of the rail siding are the remains of the old mine offices, hoist, the Knight Shaft (main mine access), several large thickeners, the concentrator loader bay and two settlement ponds. North of the rail siding is a tailings lagoon (Figure 6). Substantial amounts of metal-rich solid waste lie around the remains of the processing plant. The old mine offices and yard are currently been used by a transport company and the surrounding land around the site is chiefly grassland, in use for cattle grazing.

The Knight Shaft has a concrete cap but with an overflow pipe in the cap to discharge mine water, typically arising after heavy rainfall, which flows north under the railway siding to the tailings lagoon (SRK, 2001). The tailings lagoon also receives run-off from the concentrator area. Both the water and the tailings in this lagoon contain high concentrations of mine-related metals such as Pb, Zn, As and Cd. The two settlement ponds south of the rail siding historically receive surface runoff from the Garryard plant area. The larger settlement pond discharges water into the smaller pond which, in turn, discharges to a stream via a weir. This run-off can have high metal concentrations, however, the water discharged from the smaller settlement pond had very low metal concentrations, indicating that the ponds serve their purpose of trapping metals that enter them (SRK, 2001). Both the settlement ponds and the tailings lagoon ultimately drain into the Yellow River, 1 km downstream of the site'.

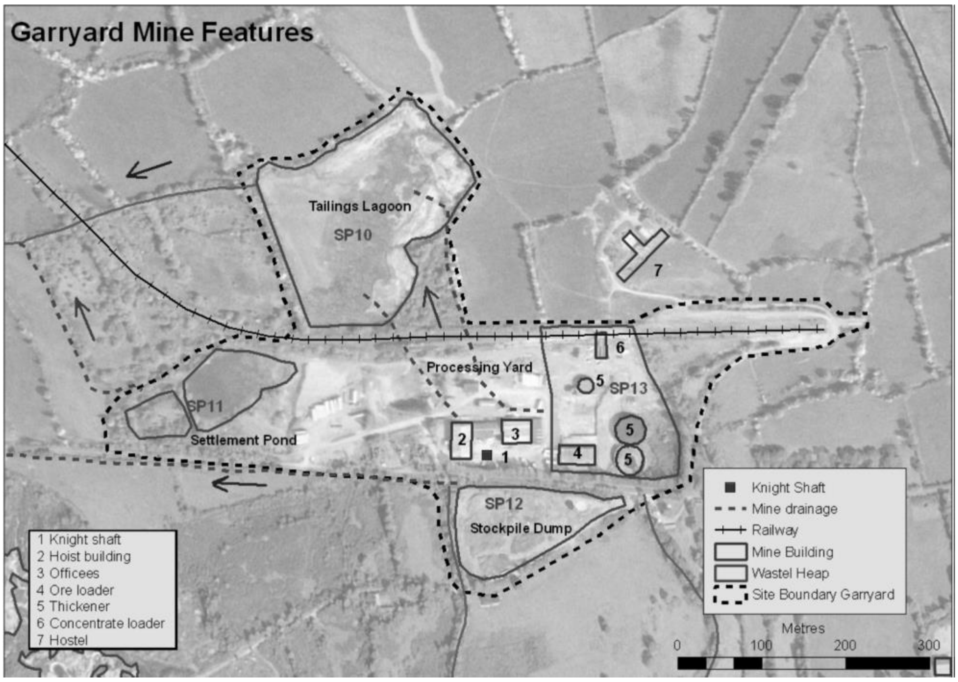

Figure 6 Overview of the Garryard site (Stanley et al., 2010)

8.1 Proposed remediation of Garryard

The proposed remediation of the Garryard site is primarily aimed at stabilising the old tailings lagoon and wastes, and treating waters discharged from the Knight shaft and the tailings lagoon. As there is an upwelling of water from within the tailings lagoon through connection to the underground workings SRK proposed to stabilise the existing tailings by pushing all the tailings into the lagoon such that they would be maintained below the water level. It is then proposed that limestone waste materials from the Magcobar operations would then be brought in and placed as a layer over the tailings waste. The idea being that this waste would act as a safe material barrier, such that when subsequently the old ore stockpile from the southern side of the Garryard site was added to the waste facility it would be placed at an elevated position beyond the fluctuations of the water in the lagoon. Finally the facility would be capped to minimise water inflow. In this way the cyclic wetting of this old ore material could be minimised and the metal leaching of the wastes controlled.

However, it is acknowledged that a degree of metal leaching would continue and so a passive water treatment scheme was designed to treat both seepages from the waste management facility and the variable discharge from the Knight shaft.

The proposed water treatment scheme is to be located in the field immediately west of the existing tailings lagoon, alongside the rail line. It would comprise of an attenuation pond, a sedimentation pond, aerobic treatment followed by anaerobic polishing and finally discharged into a mixing pond over a cascade to ensure compliance. The attenuation pond is employed to smooth out the variable flows from the Knight shaft; it would be designed to hold and release a 20 year storm event, additional flows from higher rainfall fall events would by-pass the system untreated before being blended back at the final discharge point. With a constant flow the sedimentation pond would then retain the suspended sediments within the water, in order to minimise any detrimental effect from sediments to the subsequent operations. Next the aerobic treatment cells would aerate the waters and precipitate metals as hydroxides. The seepage from the proposed waste management facility would flow directly to this stage. Following the aeration of the water the next stage would be an aerobic polishing stage whereby the final metals would be removed through sulfide precipitate under anaerobic conditions. This cell would be sealed from the atmosphere but excess gases generated within the cell would be permitted to vent to atmosphere. Finally the cleaned anoxic effluent would be cascaded down steps to aerate the waters and permitted to equilibrate in a mixing pond prior to discharge to allow settlement of solids. At this stage any waters that were bypassed by the attenuation pond would be reblended thereby permitting a substantial proportion of the water to be treated. Unfortunately due to funding issues this remediation could not be completed.

9 Conclusions

Historically the closure/abandonment of mines did not necessitate the level of remediation required by today's standards and guidelines and as such these historic sites are often a safety and environmental liability. The legislation of the time required the property owner to undertake closure of the site. However, the law was complex and ultimately the responsibility for the site fell to the state. Funding was limited for the Silvermines Project, so essential remedial work was prioritised using a risk-based approach. The Gortmore TMF was deemed to be at greatest risk due to both environmental and safety concerns. SRK working with North Tipperary County Council and Fehily Timoney oversaw the completion of the stabilisation and restoration of the TMF to comply with current regulation. However, further works are still required at the Silvermines site but this will require significant further funding. The DCENR and Tipperary County Council still need to secure further funding for the site to ensure all works can be completed in line with the current regulations.

Acknowledgements

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