Rehabilitation Planning for Abandoned Mines at Silvermines, Tipperary, Ireland

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ABSTRACT

Lead Zinc, copper, sulphide and barites have been mined in the Silvermines area of Ireland since Roman times. The last active mining ceased in 1993 and there is a legacy of abandoned open pits, underground workings, waste dumps, tailings and mine infrastructure.

There have been incidents of animal lead poisoning and general health and safety concerns in various parts of the area. Groundwater and surface water continue to be affected to varying degrees and this paper presents the risk based approach used to assess the present environmental impacts, including the risk to humans and livestock. Options and preferred solutions for remediation and water management are discussed. Although there are many factors affecting decision making for remediation of abandoned mine sites such as Silvermines, this presentation will focus of the water management which is a key factor for the off site impacts.

BACKGROUND

The Silvermines area of County Tipperary has been mined for over one thousand years, for lead, zinc, copper, baryte and sulphur. The last mine, Magcobar, closed in 1993. The mining has resulted in undermining and surface subsidence, the excavation of open-pits, the construction of large waste dumps and tailings dams and the presence of derelict surface structures.

The mine tailings, the rock waste and other process waste from mining, contain heavy metals, which are mobilised after heavy rain, entering the streams. In the past, the tailings impoundments have also produced severe dust blows, with the wind-blown particles containing heavy metals. The metal of most concern has been lead, and there have been cattle deaths attributed to lead poisoning. It is primarily these deaths which have alerted the authorities to the need to undertake closure and rehabilitation measures to reduce the risk to human health and safety, and to the environment. There are, however, other pollutants and other problems such as mining subsidence associated with the Silvermines area which require consideration.

During 2002/2003 SRK carried out an investigation on behalf of the Department of the Marine, and Natural Resources (DMNR), now known as the Department for Marine, Communications and Natural Resources. The investigation was to prepare a closure and rehabilitation plan for the area which would provide costed remedial options. The study used a risk based approach to identify the key issues and to develop priority targets to gain maximum benefit from remediation schemes.

The surface water and groundwater environment is a key issue in assessing remediation options and this paper presents the approach to assessment of the water regime. The paper will be confined to the technical aspects relating to the water but final decisions for remediation options were based on integration of a range of factors including mining heritage and socio economic aspects. Local stakeholder participation has been a very important aspect of the work.

THE STUDY AREA

LOCATION

The village of Silvermines is located about 10km east of Nenagh in North Tipperary, Ireland. The mine sites are located along the side of the Silvermines hills over a distance of around 4 km as shown on Figure 1 which is an annotated orthophoto showing the main features of the study area. The yellow outline represents the extent of the area.

TOPOGRAPHY AND DRAINAGE

The area is located on the northern slope of the Silvermines Mountains, which rise to approximately 490m AOD. To the north, the area is bounded by the Arra Mountains which rise to approximately 560m AOD. Combined, the two mountain ranges form the southern and northern limbs of the Kilmastulla syncline structure and govern the drainage pattern. The southern half of the study area extends from the crest of the Silvermines Mountain to the toe, with a ground slope of 1 in 3 at the crest to 1in 10 on the lower slopes. The northern section is flat and poorly-drained. The mines are on the lower slopes and toe of the Silvermines Mountain, except for the Garryard (Mogul) plant and part of the underground workings, which are on the adjacent flat land.

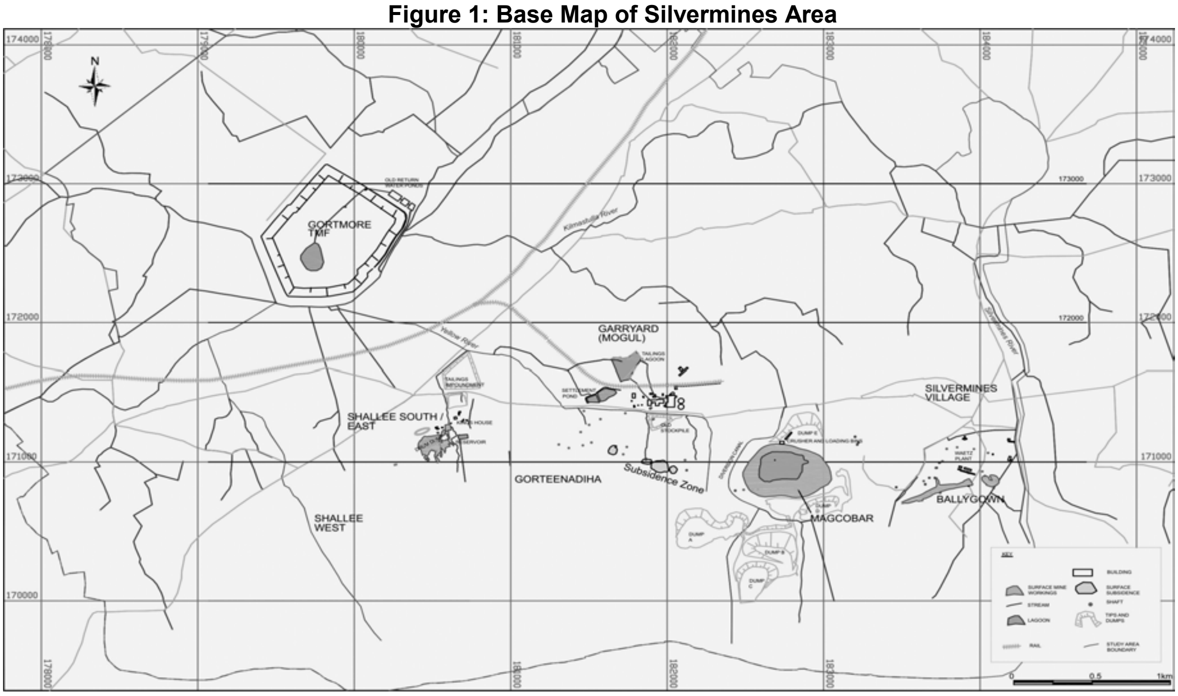
Figure 1 shows the mine features and drainage of the study area. The main water course is the River Kilmastulla, with its source high in the Silvermines Mountains. On reaching the main valley floor, the river turns sharply to the west, eventually joining the Shannon River approximately 15km from the source. The river channel has been changed by mining activity. This has included deepening and straightening. Other changes have included river re-alignment to reduce peak flood levels and erosion, and culverting of tributary streams, such as at Magcobar.

The mining areas are drained by a number of streams feeding the Kilmastulla River:

- Ballygown is drained by the Silvermines River
- Two tributaries of the Foilborrig River pass through Magcobar, and have been diverted around the Magcobar pit.
- The Garryard settling pond and lagoon feed tributaries of the Yellow River, and one tributary from the west of Magcobar has been diverted along the main road to avoid the Garryard plant area
- An unnamed stream and its tributaries flow through the Shallee South/East area.
- The Kilmastulla River itself has been diverted around the perimeter of the Gortmore TMF.

In addition to the natural and diverted streams, there is a network of agricultural drains in the flat, northern part of the study area.

Figure 1: Base Map of Silvermines Area



Geology and Mining

The geology of the area and its surroundings is well documented (Andrew, 1986).
In the Silvermines area, base metal sulphide and barite mineralisation occurs within the basal Carboniferous (Courceyan, c.355 Ma) transgressive siliclastics and in overlying carbonate rocks . Regionally the deposits lie on the northern flank of the Slieve Phelim-Slieve Aughty massif that forms the SW limit of the Central Midlands Basin (Andrew, 1992).
The mines have been worked since Roman times although the main activities were in the 19^{th} and 20^{th} centuries. The last metal mining was at the underground Mogul mine in 1983 and barite was mined from the open pit until 1993. The majority of the other mining areas we closed by the 1950s.
The metals mined were lead, zinc, copper with some sulphur mining and barites. Sulphide oxidation has also released Cadmium and Arsenic which are now found in the soils.
The main mining areas and potential issues related to the water environment are summarised in table 1. The sites are indicated on Figure 1 together with the drainage system that they impact. All of the mining areas have issues of mining waste, open pit, underground and open shafts, settlement ponds and lagoons at Garryard and a more formal tailings management facility at Gortmore for the later Mogul mine operations. Clearly the presence of sulphides has resulted in acid rock drainage and mobilisation of metals although the host carbonate rocks tend to neutralise the acid.

Table1: Mine Site Identification

AREA	AREA NAME	KEY FEATURES
A	**BALLYGOWN**	Ballygown, Calamine, Sulphur, and Knockanroe mines south of Silvermines village, playing fields
B	**MAGCOBAR**	Magcobar open pit, underground workings, dumps and surface structures
C	**GARRYARD (MOGUL)**	Garryard settling pond and lagoon, Mogul plant, Mogul and Ballynoe underground workings, Mogul stockpile area, subsidence zones
D	**GORTEENADIHA**	Gorteenadiha mine including waste dumps between Magcobar and Shallee
E	**SHALLEE SOUTH/EAST**	Shallee South and East mines, surface structures, drum dump and tailings impoundment
F	**SHALLEE WEST**	The shallow opencast workings at Shallee West (also known as Shallee White)
G	**GORTMORE TAILINGS MANAGEMENT FACITILITY (GTMF)**	The Gortmore tailings impoundment and ponds

KEY ISSUES

Contamination arises from surface runoff, groundwater in contact with mine workings, seepage through waste materials and surface inflows to mine workings which may discharge as contaminated groundwater. Ground water levels have recovered in all areas and this has resulted in discharges from adits and shafts.

Sulphide mineralisation of the type observed in the Silvermines area has the potential to:

- Release metal and salt related to oxidation of sulphides and dissolution of secondary metal precipitates;
- Generate acid, and;
- Increase Total Dissolved Solids (TDS).

The infill and breccia styles of mineralisation, particularly in the vicinity of Mogul mine show a high marcasite and pyrite content and as such have a high potential for acid generation then the vein style mineralisation. The mineralised zones in these areas also have the highest potential for metal release due to:

- Fine grained nature of the mineralisation;
- Massive nature of sulphide zones, and;
- Presence of base metal sulphides as well as high trace elements in rare sulphides such as tetrahedrite, cobaltite, pyrrhotite, arsenopyrite and rare Cu-Zn-Ag-Cd-Ge-As-Sb-Pb sulfosalts.

The host rock is predominantly carbonates which generally have a high potential for acid buffering and thus metal precipitation occurs as carbonate, hydroxide or oxide minerals.

The release of the metals and dissolved salts can be by natural erosion and leaching, but the mining has provided conditions where the underground workings, the tailings impoundments and the waste dumps give the opportunity for the large-scale discharge of particulate metals and leachates (metals and salts in solution). The extent to which this has occurred is documented in various reports, including the IAG report of 2000. The main sources of leachates are the various tailings impoundments, waste dumps and effluent ponds. There have also been significant discharges of particulate material containing heavy metals from these areas. These discharges exist mainly as sediments in the streams and rivers in the vicinity of the mines and, to a lesser extent on adjacent fields, from dust blow, stream dredging and surface sheet wash.

An Inter Agency Group (IAG) was set up in 1999 to investigate the risks to human health. Following their initial report in 2000, an Expert Group was formed in 2001 to address specific issues. There appear to be no clearly identifiable health issues although remedial works were carried out on the Silvermines School playing field to minimise risk of exposure of children to mine spoil. Human health remains a key concern of the local population, particularly with regard to dust blow adjacent to the Gortmore TMF.

AVAILABLE INFORMATION

Groundwater and surface water monitoring for flows and chemistry is limited except where specific studies have been done. However, there is no regional information based on consistent parameters and some regional checks were required to be able to correlate information as much as possible. The selection of the optimum solutions for the conceptual design of the remediation depends on the adequacy of the data.

It is also important to recognise that elevated levels of metals will occur naturally in this type of environment, therefore background levels prior to mining would have been above normal levels. The elements previously tested do not include certain components which may be of importance. These include mercury and cyanide (which was used in small quantities in the Mogul process).

Soil tests carried out for the IAG study In 1999, showed that the average agricultural soil in the area had elevated lead, zinc and cadmium that allowed some possibility of impact on crops or animals. The results also suggested that elevated metal contents are directly associated with the ore zones, mine processing areas, the streams draining form the mine areas and the soils adjacent to the rivers draining from the mining area. The latter probably due to localised flooding The general agricultural soils away from the rivers show relatively low values.

All of the drainage from the mine sites enters the Kilmastulla River above or at the GTMF and the river was diverted around the GTMF.
Since testing started in 1971, all monitoring stations on the Yellow River have recorded high heavy metals. The stream draining the Garryard mine complex had the poorest water quality. There is a significant dilution effect in the Kilmastulla River, and the quality of the water leaving the study area in the Kilmastulla river is within the EU required limits apart from iron, which is only marginally outside the limit.

EVALUATION METHOD

The overall methodology was to identify and characterise the hazards and as many of the sources of contamination as possible using the available information. Any significant gaps would be filled with a limited field testing programme. Any major deficiencies, which could significantly influence the possible remedial options, would be identified and investigated accordingly. Detailed design issues will be investigated as part of the final detailed design.
The metals identified in various samples include As, Al, Ba, Cd, Cu, Fe, Pb, Mn, Hg, Ni, and Zn. High sulphate has also been recorded. In the development of remedial options, the health risk was the major consideration. In most cases, the elevated metals are present as particulate material, therefore remediation could focus on control of erosion from source materials and collection in the form of wetlands and settlement ponds.
The drainage of the mining area was characterised by summarising the key chemical elements and the flows of the surface water system from which the greatest contributors to the contamination load in the Yellow and Kilmastula rivers could be identified. By progressively combining flows and chemistry, the beneficial effects of dilution could also be assessed.
The objective is to develop remediation options that will progressively reduce the contamination load in the most economic way. Future contamination is addressed in the form of risk based assessments.
The Gortmore tailings facility has been identified as a special case as it contains large amounts of sulphide bearing waste, it is unlined and formal closure costs could be considerable. A risk based approach was taken and particularly with regard to elevated metals in the groundwater. Three boreholes were drilled, one up hydraulic gradient and two down gradient. Measurements in the Kilmastula River which was diverted around the facility, did not show particularly elevated metals. The analysis of the groundwater from the two downstream boreholes, showed values (mg/l)of Pb 0.42, Ba 2.24, Hg 0.07, Fe 2.32, Mn 3.31 and Al 0.74. These were the highest values recorded.
The risk of contamination migrating down hydraulic gradient was assessed using a probabilistic approach on a spreadsheet model . It was concluded that there was a 5% chance of there being 0.03mg/l of lead arriving at the nearest receptor (a borehole 500m down hydraulic gradient) in a period of $3.3\text{x}10^5$ years. The level of lead in the Kilmastulla River downstream of the TMF si expected to plateau at around 15ppb in 2x 10^6years After di;ution this would be less than 1ppb.
The underlying carbonate rocks perform a very important function in neutralising any acid and precipitating metals.

HYDROGEOLOGY

Twelve boreholes were drilled at selected target sites to characterise the hydrogeology. The conceptual model showed that ground water movement would be northwards form the mining area towards the Kilmastula river. It was found that permeabi;lities were generally fairly low and that the chemistry did not reflect any significant impact from mining except immediately adjacent to particular sources. The limestones are know to be karstic therefore it is likely that there are features which carry groundwater but none of the 12 boreholes intersected anything significant except an infilled palaokarst feature. The limestone is presumably also attenuating, buffering and diluting any leachate leaving the mine site.

Sub catchment Runoff

The flow in the Kilmastula River is gauged at Cool Bridge, downstream of the mining area. The catchment area is 98.9km^2 at this point whereas the catchment area as it leaves the Sivlermines area is about 50km^2 . Flows at the Cool bridge range from 0.2m^3/sec to 15m^3/sec.
From the topographic plan the area was divided into subcatchments and ranges of flow estimated from the
There are three tributaries draining the main mining area, namely the Silvermines, Foilborrig and Yellow rivers, each with catchment areas of around 3.5km^2.
From the discharge rates and a knowledge of the water quality discharging for the subcatchments, approximate chemical loadings were calculated. The long term data was limited therefore this approach can only give indications but sufficient to identify early targets for remediation.
The data sources were the Environmental Protection Agency (EPA) and the SRK study. All of the available data gave total metal analysis, therefore separation of dissolved metals and that carried as suspended particulates and colloids was not possible. This limits the assessment of the geochemical processes and selection of treatment options.

KEY SOURCES OF CONTAMINATION

Figure 2 shows the subcatchments and table 2 shows the estimated flows and metal loads.
The principal sources of surface water metal contamination are:

- Waste rock at Ballygown;

- Old stockpile area at Garryard
- Tailings lagoon at Garryard;
- Mineralisation at Macgobar, and;
- Parts of the Shallee tailings and waste dump.

The Silvermines river catchment carries Pb, Ba and Mn in concentrations exceeding Irish standards. Most of this is from the waste at Ballygown on the banks of the river but the metal load is small. Concentrations downstream of Silvermines village are within standards.

The yellow river catchment carries the highest metal loads within the study area with elevated Cu, Pb, Ba, Cd, Zn, Fe, Mn, As and Al. The main sources were clearly identified as the old stockpile area at Garryard and the tailings lagoon at Garryard.

The Foilborrig river draining the Macgobar area contains elevated Ba with some Mn and Cd.

Table 2: Estimated Sub-Catchment Flows

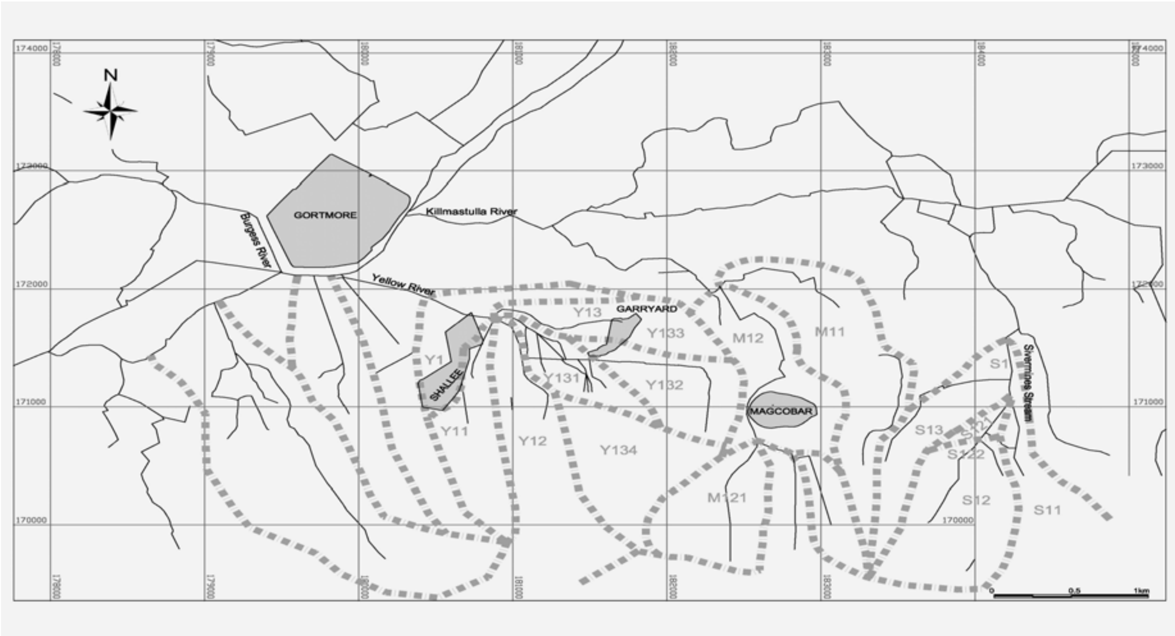
Catchment	Description	Area (KM^2)	Average	High	Low	Pb		Ba	
						max	ave	max	ave
S1	Silvermines River to just below Silvermines	3.60	70	550	11.5	0.428	0.054	**6.178**	**0.786**
S12	Sub-catchment including Calamine site	1.1	21	168	3	**3.687**	**0.461**	**3.324**	**0.415**
S11	Sub-catchment to east of Silvermines stream	1.9	37	290	6	0.063	0.008	0.501	0.064
S121	Sub-catchment to Calamine, mine site	0.22	2	34	0.6	**0.746**	**0.092**	**0.673**	**0.083**
S13	Sub-catchment to west including sulphur mine	0.60	12	92	1.8	0.210	0.026	0.292	0.036
S122	Sub-catchment above Calamine (could be diverted)	0.88	16.7	135	2.6	0.305	0.039	**11.741**	**1.492**
M1	Magcobar catchment (Foilborrig river)(less area of pit)	3.50	68	535	11.5	0.140	0.018	**5.377**	**0.680**
M11	Sub-catchment east of pit	1.2	23.4	184	3.5	0.008	0.001	**3.911**	**0.497**
M12	Sub-catchment through the pit (less area of pit)	1.60	31	245	4.8	**8.561**	**1.090**	**12.57**	**1.601**
M121	Sub-catchment under top dumps but diverted round pit (3 streams)	1.20	23.4	184	3.6	**1.106**	**0.138**	**2.875**	**0.359**
Y1	Catchment of yellow river to railway line north of Shallee (0.5 km)	3.6	70	550	11.5	**2.381**	**0.300**	**3.685**	**0.464**
Y11	Sub-catchment to west including Shallee Mine – diversion (Assuming diversion is complete, Shallee Mine catchment comprises largely direct precipitation only)	0.84	16	128	2.5	**1.776**	**0.228**	**2.367**	**0.304**
Y12	Sub-catchment between Shallee and Gorteenadiha	0.83	16	127	2.5	**3.821**	**0.488**	**0.662**	**0.084**
Y13	Sub-catchment including lagoons, plant site and Gorteenadiha mines	1.73	34	265	5.0	**0.804**	**0.096**	**0.21**	**0.25**
Y131	Sub-catchment of surface mine workings, Gorteenadiha	0.25	4.9	38	0.75	**2.186**	**0.278**	**2.091**	**0.266**
Y132	Sub-catchment including triangle dump and settlement pond	0.31	6	47	0.9	0.428	0.054	**6.178**	**0.786**
Y133	Sub-catchment including plant site and lagoon	0.163	3	25	0.5	**3.687**	**0.461**	**3.324**	**0.415**
Y134	Sub-catchment above Y131 but diverted above the mine workings	0.72	14	110	2.1	0.063	0.008	0.501	0.064

* the average flows are derived from the average flows per km^2 in table 5.1 based on the whole catchment and have not been adjusted for the higher flows likely to flow from the Silvermines Hills.

Table 3: Selection of water chemistry results (surface water unless specified). Results in mg/l   Blank is below detection

			Cu	Pb	Ba	Cd	Zn	Fe	Mn	As	Al	SO_4	Hg
Irish Standards			**0.05**	**0.05**	**0.1**	**0.005**	**3**	**0.2**	**0.05**	**0.05**	**0.2**	**200**	**0.0005**
Silvermines river	upstream	Total	0.14	0.17									
Ballygown		Filter	0.06	<0.005									
	Adjacent to site	Total		0.254									
		Filter		<0.001									
	downstream	Total											
		Filter											
	Groundwater downstream	Total			0.15		0.26						
		Filter		0.021	0.13		0.135						
Macgobar	upstream	Total	0.06		0.17-0.24								
		Filter											
	Pit lake	Total	0.21	0.06	0.11		3.19	1.53	0.1		0.86	449	
		Filter				0.007	2.52		0.05		0.68		
	downstream	Total			0.133-0254								
		Filter											
	groundwater	Total		0.45	0.4		0.11						
		Filter		0.012	0.37		0.03						
Garryard tailings	inflow	Total	0.12	0.32	0.19		2.7-15.9	0.48-6.03	0.11-0.14		1.54	286-313	
		Filter			0.06	0.007	2.3-15.52	<0.195	<0.05-0.14				
	outflow	Total	0.26	0.12-0.37		0.011		3.3	0.18	0.06		549	
		Filter											
	groundwater	Total			0.06		0.24						
		Filter		0.009			0.097						
Gortmore Kilmastula river	Upstream of TMF	Total	0.16	0.01	0.16-0.26			0.21	0.07				
		Filter	0.09		0.22								
	Adjacent to site	Total			0.155-0.16			0.22-0.54	0.08-0.09		0.162		
		Filter											
	downstream	Total	0.124	0.267				1.424	0.173		0.21		
		Filter											
	Discharge from wetlands	Total											
		Filter											
	Groundwater downstream	Total		0.42	2.24			2.32	3.31	0.10	0.74		0.07
		Filter			0.51								

Figure 2: Sub catchment areas



REMEDIATION ASSESSMENT

The overall assessment for remediation was based on identifying all potential hazards and assessing the risk as the probability of occurrence multiplied by the consequence of occurrence. The assessment had to be largely subjective based on low, medium and high probabilities and consequences. The consequences were assessed by considering the pathways, the receptors and the sensitivity of the receptor to the particular hazard.

Key options for the main issues will be:

- The establishment of a permanent, low-maintenance cover for the Gortmore TMF and the control or treatment of polluted discharges from the impoundment.
- Stabilisation of the Shallee tailings and stabilisation or removal of dumped chemical wastes at Shallee mine, as part of the mine rehabilitation.
- Complete draining and rehabilitation of the Garryard settlement pond and lagoon, or the establishment of a wetland or other treatment system.
- Garryard (Mogul) underground mine, prevention of access to surface subsidence areas, interception and treatment of seepage.
- Mogul waste dump on opposite side of road from plant, interception and treatment of seepage, removal or encapsulation of waste.
- Ballygown area and area to the south of Silvermines village, reshaping, treatment of seepage, making safe of mine and shafts, preservation of historic structures.
- Magcobar mine, prevention of pit access or making safe of pit for recreational use, minor reshaping and stabilising of dumps and promotion of vegetation, interception and treatment of seepage.

All the measures must be acceptable to interested and affected parties, and comply with an overall policy for water discharge quality and for land-use.