REHABILITATION AND CONSTRUCTION ISSUES FOR SILVERMINES ABANDONED MINE AREA, IRELAND

R.J. CONNELLY

SRK Consulting UK Ltd; E-mail: rconnelly@srk.co.uk

ABSTRACT

The Silvermines area in County Tipperary, Ireland, comprises an area of around 5 km^2 plus a 19 ha tailings facility. There are a number of abandoned open pits and underground mines worked mainly from the 17th to 20th century for lead, zinc, copper and barites with some silver.

There is a legacy of health and safety issues as well as issues of mining heritage with tourism and educational interest. The challenge is to remove or minimize health and safety risks and achieve European Water Framework Directive requirements, whilst considering what should be conserved or protected, and to minimise the costs.

A rehabilitation project has been carried out progressively over a number of years and is now at the final design and construction stage. Key issues of dust from tailings will be resolved by capping and vegetation; and targeted sources of contaminated water resolved by evaluating the water balance in terms of contributing contaminant loads, to identify the key sources of contamination and to treat with water management and passive treatment systems.

The paper summarises the various remediation issues but focuses on the issues related to mine waste disposal.

1. BACKGROUND

The Silvermines area of County Tipperary has been mined for over one thousand years, for lead, zinc, copper, baryte and sulphur, although the main activities were in the 19th and 20th centuries. The last metal mining was at the underground Mogul mine in 1983, while barite was mined from the Magcobar open pit and underground until 1993. The majority of the other mining areas were closed by the 1950s.

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 and enter 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 the concern for public health and the cattle deaths which have alerted the authorities to the need to undertake closure and rehabilitation measures.

The local streams also have signs of contamination, largely due to particulates. The EU Water Framework Directive 2000/60/EC (WFD), requires certain targets to be met for river chemistry and a key element of the project is to work towards meeting those objectives.

During the period 2001 to 2006, various studies were carried out on behalf of the Department of the Marine, and Natural Resources (DMNR), now known as the Department for Communications, Energy and Natural Resources (DCENR). North Tipperary County Council (NTCC) was designated the responsible authority for the design and construction with funding from Central Government managed through DCENR.

The rehabilitation programme includes water chemistry, safety aspect related to structures and mine openings, aesthetics, environment and heritage aspects (Connelly et al, 2005). This paper summarises the present state of the works and presents some detail of the design and planning issues relating to groundwater, surface water and environment.

2. THE STUDY AREA

Location

The village of Silvermines is located about 10 km 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.

Topography and Drainage

The mining area is located on the northern slope of the Silvermines Mountains, which rise to approximately 490m AOD. The southern half of the study area containing the mining areas is on the lower slopes of the mountain but the northern section containing the Gortmore Tailings Management Facility (TMF) and Garryard (Mogul) plant, is flat and poorly-drained.

Figure 1 shows the mine features and drainage of the study area. The main water course is the Kilmastulla River, with its source high in the Silvermines Mountains. The river eventually joins the Shannon River, approximately 15 km from the source. The river channel has been diverted around the Gortmore TMF. The mining areas are drained by a number of streams and drains feeding the Yellow River, Silvermines stream and the Foilborrig River draining to the Kilmastulla River.

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 south western limit of the Central Midlands Basin.

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 than the vein style mineralisation. As well as base metal sulphides, there are high trace elements in rare sulphides such as tetrahedrite, cobaltite, pyrrhotite, arsenopyrite and rare Cu-Zn-Ag-Cd-Ge-As-Sb-Pb sulfosalts. Andrew (1986) summarised the metal resources in Silvermines as 4.74Mt grading 2.44% Pb and 5.49% Zn in the lower ore zone and 12.94Mt grading 2.55% Pb, 6.78% Zn with 5.0Mt of 85% $BaSO_4$.

3. KEY ISSUES

Clearly, the presence of sulphides has resulted in localised acid rock drainage and mobilisation of metals, although the host carbonate rocks tend to buffer the acid and thus metal precipitation occurs as carbonate, hydroxide, or oxide minerals.

The main sources of leachates are the Gortmore TMF, waste dumps, and tailings lagoon and plant site at Garryard. 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 cause of the animal deaths. Following the initial report in 2000 (IAG 2000), an Expert Group was formed in 2001 to address specific issues and reported in 2004 (EPA 2004). There appear to be no clearly identifiable health issues although human health remains a key concern of the local population, particularly with regard to dust blow adjacent to the Gortmore TMF.

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 from the mine areas, and the soils adjacent to the rivers that drain from the mining area. The latter are probably due to localised flooding or drain dredging activities. The general agricultural soils away from the rivers show elevated values although to be expected in a metaliferous region. The IAG recognised the natural high values and established acceptable guideline value of 1000mg/kg for soil but other metals were not considered to pose a risk to humans or animals. Actual values for lead ranged from 25 to 14842 mg/kg in agricultural soils (IAG 2000).

Since testing started in 1971, all monitoring stations on the Yellow River have recorded elevated 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.

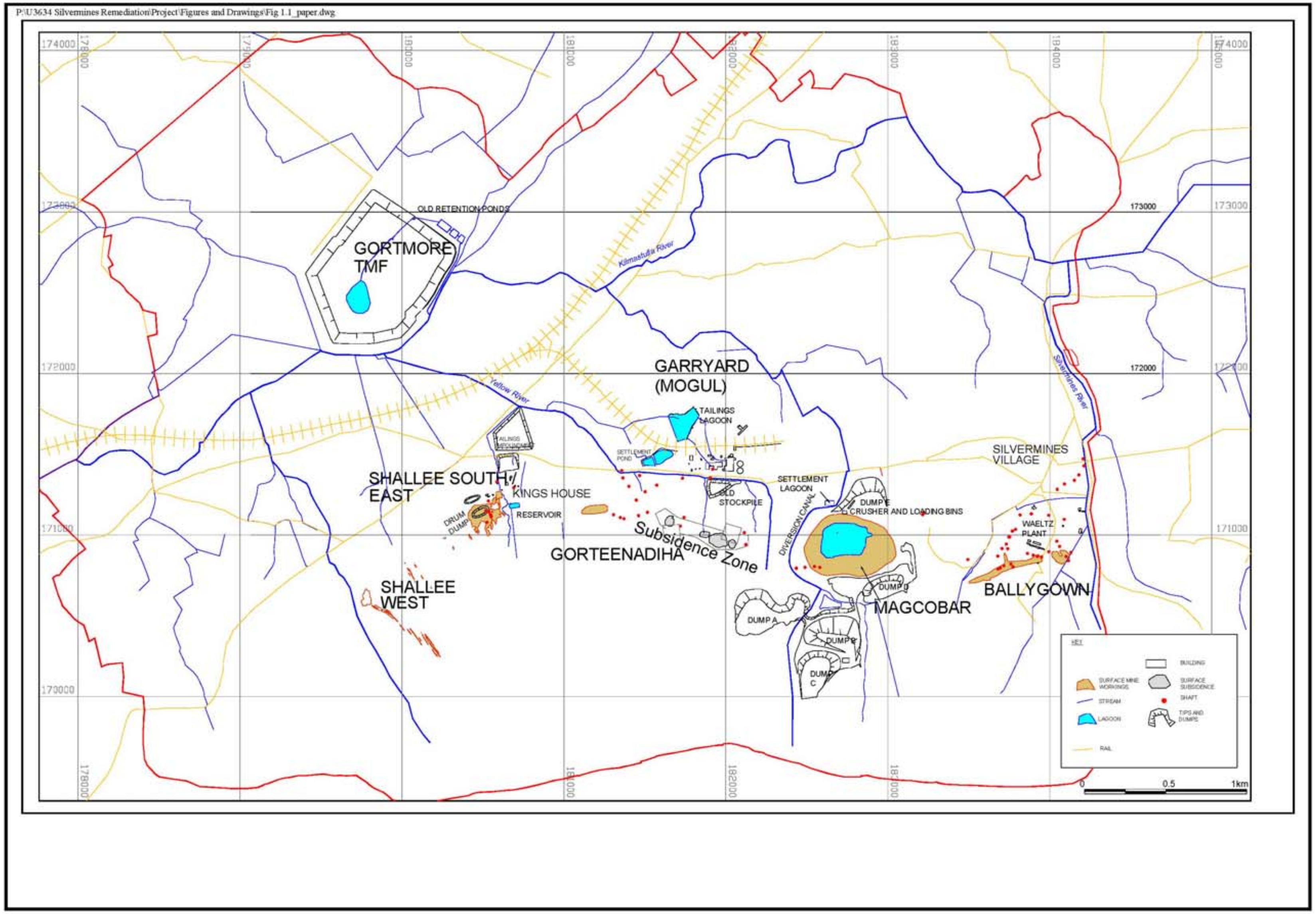

Figure 1. Silvermines area-main remedial works

Although various data have been collected over recent years, there has been no consistent measurement from which detailed conclusions can be drawn on water flows and chemistry. This is discussed further in section 4. However, sufficient is now available to develop reasonable conclusions and derive sustainable solutions.

Remedial works will cover the whole mining area to include drainage, health and safety issues relating to shafts, open pits, underground works, structures, hazardous waste disposal and tailings as well as heritage aspects. Three key areas are:

- Gortmore TMF;
- Garryard tailings lagoon; and
- Shallee mining area.

Rehabilitation of Gortmore TMF is well advanced, with some work completed in 2008 and the balance to be completed in 2009 based largely on providing s sustainable cover to the surface, modifying the drainage and ensuring runoff and seepage water passes through wetland areas before discharging to the Kilmastulla River.

The next key issue is the disposal of various mining wastes from other parts of the mining areas, which are classified as hazardous under the draft Waste Management (Management of Waste from the Extractive Industries) Regulations 2008. These are draft regulations in Ireland at present under Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006.

4. DESCRIPTION OF THE GARRYARD SITE

The Yellow River catchment carries the highest metal loads within the study area with elevated copper, lead, barium, cadmium, iron, manganese, arsenic and aluminium and zinc,. The main sources were clearly identified as the old stockpile area at Garryard and the tailings lagoon at Garryard. The tailings show elevated sediment concentrations of arsenic, cadmium, copper, iron, lead, zinc and in some cases nickel (Figure 2).

The Garryard tailings lagoon is a shallow excavation into the glacial drift deposits and was used to place spillage and waste from the process plant (Figure 2). The main tailings were pumped to the Gortmore TMF. Groundwater levels in the drift deposits are just below ground surface but groundwater in the underlying limestone is under artesian pressure from the subcrop on the hillside to the south. Boreholes drilled around the Garryard tailings lagoon

have piezometric pressures around 0.5m above ground level.

The main access shaft to the Mogul underground workings (Knight shaft) is at the plant (Figure 2). During wet weather, water discharges from vent holes in the cap of the shaft and flows to the tailings lagoon. The sources of water in the lagoon are therefore:

- discharges of storm water from the Mogul plant site;
- discharge from Knight Shaft;
- runoff from the fields to the east and north; and
- upward flow from the limestone due to artesian pressure.

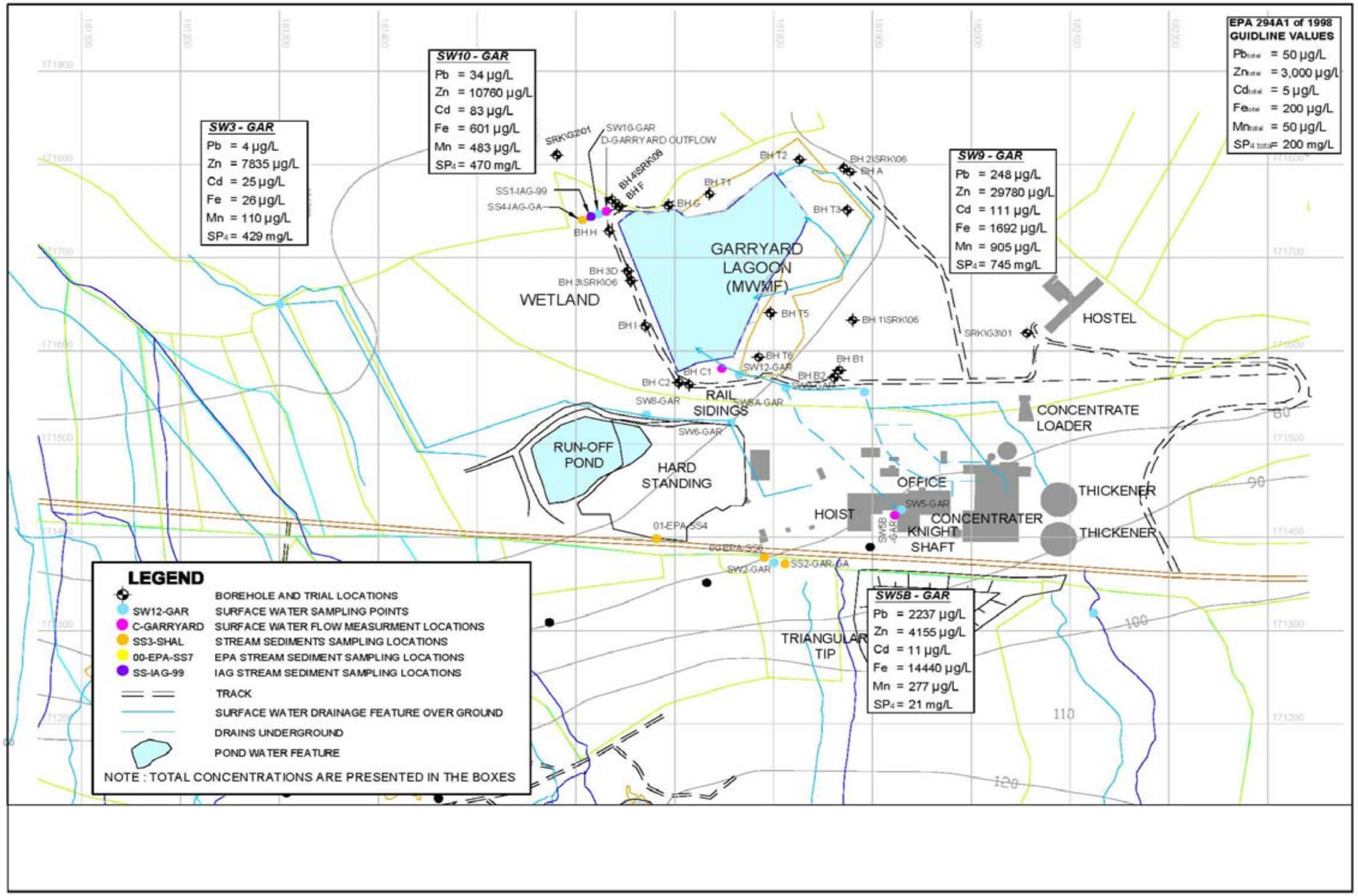

Figure 2. Surface water quality 15th November 2006

Groundwater System

Based on a review of the available groundwater monitoring data, groundwater flow in both the overburden and bedrock is generally from east to west beneath the existing Tailings Lagoon. On this basis, the western side of the existing Lagoon and proposed Mine Waste Storage Facility is down-gradient with respect to groundwater flow. The data review also indicates that there is an upward hydraulic gradient from the bedrock to the surface through clayey-silty glacial drift deposits (boulder clay); that is, the groundwater pressures in the bedrock are higher than those in the overlying drift deposits.

The fine grained nature of these drift deposits will attenuate contaminants that migrate downwards, thus reducing the potential for contaminant transport in the direction of the regional groundwater flows at this location. However, there are some areas that appear to be underlain by more permeable formations. Site investigations using trial pits and drilling showed the drift to vary in thickness from 60 m to around 2 m in the general area, but the lithology varies from clay to silt, sand and gravel. Most horizons do contain a high percent of clay, but permeability of the base of the lagoon must be assumed to be variable. There is some risk of hydraulic connection between the drift and the underlying limestone bedrock.

It is assumed for the purposes of the preliminary design that the existing geological and hydrogeological conditions will provide effective natural containment beneath the existing Tailings Lagoon particularly while there is an upward hydraulic gradient. If the piezometric head in the bedrock were to fall below the base of the facility, then it would be possible for leachate to enter the upper parts of the glacial till. There will still be a low risk of groundwater contamination because:

- the piezometric surface would have to fall at least 3 m below the present base of the tailings to be able to pass into the bedrock; and,
- although the groundwater level fluctuates according to the seasons, the variation in low land areas is much smaller than on the hillside in the outcrop area. The head around the hillside will help to maintain the piezometric surface in the low lands.

Surface Water System

The lagoon discharges in the northwest corner to a local stream which discharges into the Yellow River. The discharge chemistry is variable depending on the amount of rain and the flushing of metal bearing sediments from the plant site and the lagoon.

Various organisations (IAG, Environmental Protection Agency (EPA), University of Limerick, Golder Associates and SRK) have analysed water samples from the input and the outlet of the lagoon over the years, but unfortunately there has not been a consistent approach, therefore the analyses cannot be seen as a continuous record. The elevated metals in the discharge can sometimes be attributed to suspended solids rather than in solution and the lagoon has been acting partly as a settlement lagoon. Recorded concentrations of fluoride, sulphate, zinc, cadmium, manganese, and aluminium exceed the surface water quality standards taken from the Surface Water intended for Abstraction of Drinking Water Regulations (S.I. 294 of 1989). However, many of the exceedences are not large. At high flow times, there is a release of suspended solids as shown by an accumulation of tailings sediments just downstream of the discharge. Figure 2 and Table 1 illustrate the present water flows and chemistry at key points around the lagoon.

The water balance for the lagoon can be expressed as:

Outflow at SW10 = Inflow at SW12 + groundwater input +direct precipitation

Table 1. Present Water Flows and Chemistry

Contaminant	Units	Station SW9			Station SW3			Station SW10			
		11-Nov-06	19-Sep-07	10-Jul-09	11-Nov-06	19-Sep-07	10-Jul-09	11-Nov-06	19-Sep-07	10-Jul-09	Standard*
TDS	mg/l			1403							
pH				7.7							
SO4	mg/l	429	390	318	429	390	318	470	520	391	200
Zn	mg/l	8.01	3	3.04	8.01	3	3.04	18.23	13	2.19	3
Pb	mg/l	0.004	0.007	0.013	0.004	0.007	0.013	0.034	0.096	0.018	0.05
Cd	mg/l	0.026	0.094	0.0109	0.026	0.094	0.0109	0.097	0.06	0.017	0.005
Fe	mg/l	0.025	0.025	0.29	0.025	0.025	0.08	0.025	0.025	0.08	0.2
Mn	mg/l	0.11	0.011	0.68	0.11	0.011	0.29	0.483	0.49	0.19	0.5
Flow	l/s			0.7			9			5	

* Irish standard (A1) SI 294 of 1989 Above standard

It is assumed that the long term average effective rainfall is 1,169 mm, and that the total footprint and surrounding catchment to the Garryard Tailings Lagoon is 127,720 m^2 (existing lagoon of 43,120 m^2 and catchment of 84,600 m^2). This indicates that the current direct annual precipitation (and runoff) input to the Lagoon is 149,305 m^3.

Average discharges measured at SW10 and SW12 between 2006 and 2007 was 556,659 m^3 and 330,679 m^3 respectively, however this was based on limited measurements and does not reflect the large range of flows. Using the water balance equation, annual groundwater contribution making its way up into the current Garryard Tailings Lagoon is of the order of 76,660 m^3. This equates to 2.4 l/s or about 210 m^3/day.

The calculation indicates that surface outflow from the lagoon at SW10 is made up of about 59% surface water inflow at SW12 (Knight Shaft and Mogul Yard); 14% groundwater (rising up into the floor of the site or likely discharging from uncapped flowing artesian wells surrounding the site); and 27% direct precipitation (and runoff from small catchments to the north and east).

If water is prevented from contributing to the Knight Shaft from the subsidence zones up-gradient of the Garryard site (by construction of the proposed drainage diversion channel), the outflow from the Knight Shaft is expected to fall by approximately 80% (to 66,135 m^3 per annum). This would alter the balance of flows toward to the Lagoon area such that rainfall and runoff from the small catchment to the north and east would contribute 51%; surface water from the Knight Shaft and Mogul Yard would contribute 23%; and groundwater discharge to the site would equal 26%. Clearly, the effect of flushing metals from the underground works would be significantly reduced. Furthermore, the water diverted away from the mine would join the effluent stream from the Lagoon below the treatment area and allow significant dilution before entering the Yellow River.

5. DESCRIPTION OF REMEDIAL WORKS

After technical evaluation and consultation with authorities and the local community, it was agreed that the Garryard Tailings Lagoon would be developed as a Mine Waste Storage Facility (MWSF) to consolidate defined hazardous wastes from other parts of the mining area. It was also recognised that the site would be constructed only for the defined local mine wastes and closed immediately after construction. This was to allay the fears of the local community that it would be used to dispose of other hazardous wastes.

Four main sources of waste have been identified for disposal at Garryard, namely:

- Ballygown comprising various small deposits of old process material;
- old stockpile near Garryard containing ore and various mine waste;
- Garryard and the Mogul plant yard; and
- Shallee waste dump comprising various mine wastes including old metal drums.

These were all identified as key sources surface water contamination. There is an estimated 48,000 m^3 of tailings in the lagoon and there will be an additional estimated 40,000 m^3 of waste brought in.

The waste materials have been geochemically tested and the leachate runoff has been monitored at various times in the past 10 years. The water chemistry of the streams from the sources varies through the year depending on climatic conditions. It is also clear that higher levels of metals are associated with suspended sediment at times. The proposed Garryard MWSF would also include a passive treatment system for any discharge from the facility.

The groundwater sampled immediately beneath the tailings at Boreholes: BH T1, BH T2 and BH T5 (Figure 2) shows elevated total concentrations of aluminium, ammoniacal nitrogen, arsenic, cadmium, calcium chromium, copper, iron, lead, manganese, magnesium nickel, zinc and sulphate when compared to the EPA's guideline values. Groundwater sampling in deeper boreholes around the lagoon shows that there is some leakage of metals into the groundwater, but that there is attenuation in the glacial till and limestone resulting in an acceptable water quality.

General Design Principals

The existing Garryard tailings lagoon was created by excavation into the glacial till and using that material to build the embankments, mainly on the downhill western side. The facility is not lined. A key component of the MWSF proposed design to protect groundwater is the underlying glacial till and the upward hydraulic gradient from the bedrock groundwater. The majority of the material to be imported is dry and therefore the design proposes to keep these isolated from the groundwater. The general MWSF design will comprise drainage diversions and a passive treatment system, as shown in Figure 3, and based on the following principals:

- perimeter containment measures;
- an engineered capping system including barrier layers on the wastes;
- a neutralising rock fill and cap on the existing tailings also to aid construction access;
- a drain over the rockfill to prevent rise of groundwater to overlying layers;
- a low permeability blinding layer;
- the imported wastes;
- a drain beneath the engineered capping system and above the waste body;
- perimeter drainage systems for clean run-off from the cap, and from upstream, to help ensure that there is no surface water ponding on the capped surface;
- separation of potentially contaminated seepages from clean runoff; and
- a passive treatment system to treat discharge from the MWSF and the mine water from Knight shaft and plant site.

Drainage Diversions

Initial drainage of the Tailings Lagoon will be undertaken prior to the main construction works.

Water flows from the Knight Shaft and the eastern part of the old Mogul Yard will be diverted away from the Garryard Tailings Lagoon and into the downstream Passive Treatment

System (PTS). The periodic high flows from the Knight Shaft will be reduced as described above.

Passive Treatment System (PTS)

The PTS will be available to treat liquid removed from the tailings surface during the completion stage of the embankments. During and following the waste infilling stage of the project, the PTS will be used to treat liquid discharging from the toe/blanket drains that will surround the perimeter embankments and water that is discharged from the drainage layer. The treatment capacity of the PTS will be approximately 34 l/s (2,900 m^3/day).

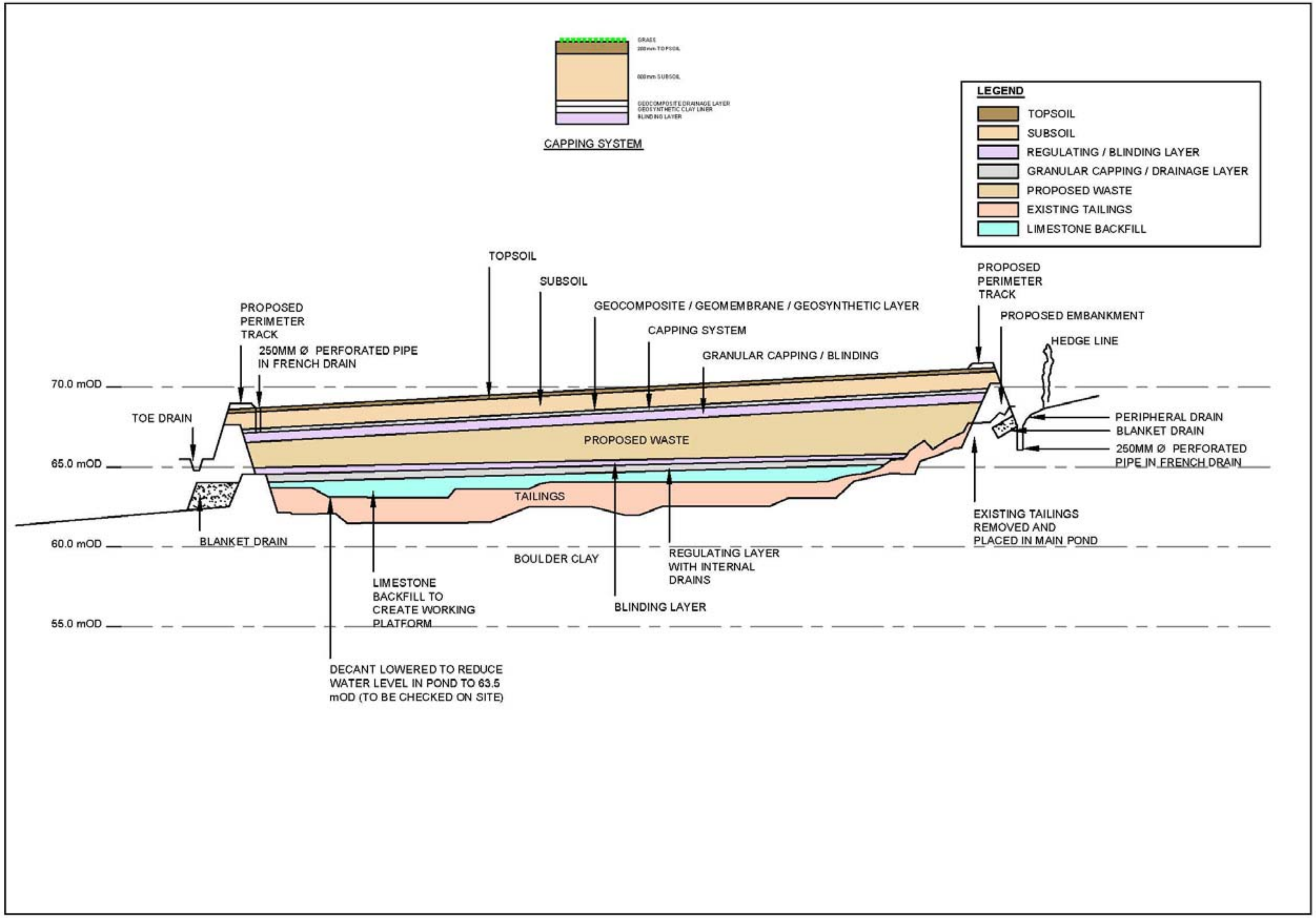

Figure 3. Schematic section through proposed waste facility

The average influent flow would be less than this value for most of the year at 11 l/s (960 m^3/day) which is well within the design capacity of the PTS. The PTS is capable of withstanding stagnant flow conditions during the dry season, as long as the organic media remains saturated. Very low concentrations of metal will be discharged from the system for most of the year. The concentrations will rise over brief high rainfall periods when raw MIW flows which exceed the system limit of about 2,900 m^3/day, is bypassed around the PTS. Bypassed flows however, would be mixed with the treated flows prior to discharge at the site boundary.

On completion, the proposed scheme will be composed of four components:

Attenuation lagoon: this will distribute the peak flow of a storm event over a longer period to give an even flow through the treatment scheme, in addition to providing diversion of any excess waters (above the 10-year event).

Settlement lagoon: this will collect run off sediments and any precipitated metals in an easily accessible lagoon. The diverted surface water and Knight Shaft water will pass through the attenuation and settlement lagoons. This water will then pass into the wetland system.

Aerobic wetland: this will aid in the removal of remaining metals which have been seen to precipitate in the existing lagoon. The low levels of iron are a disadvantage in not helping to precipitate some of the metals therefore the water will then flow into an upflow anaerobic facility which will be lined and kept subaqueous to precipitate sulphides.

Final mixing lagoons: to combine diverted excess waters with treated waters prior to discharge and achieve the target discharge water quality.

6. SUMMARY

The Gortmore tailings facility will be remediated to a fully vegetated and sustainable surface to prevent dust blow and drainage water will be treated in natural and developed wetlands. Water quality into the Kilmastulla River is expected to meet targets. The Garryard scheme as a whole will consolidate and isolate the key sources of contamination and the PTS will have the capacity to consistently treat the influent water to required water quality targets based on WFD guideline values for water suitable for drinking.

Other minor works around the Silvermines mining sites will be done over the next three years to improve the general environment and conserve the heritage value of a very interesting mining area.

7. REFERENCES

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