SILVERMINES

Background information

Mine District: Silvermines

Site Names: Ballygown, Magcobar, Garryard, Gorteenadiha, Shallee, Gortmore

Elements of interest: Pb, Zn, Ag, Cu, Ba

Project Prefix: SIL-

County:	Townland:	Grid Reference:
Tipperary	Silvermines	E182343, N171560

Introduction

The Silvermines District is in County Tipperary, on the northern flank of the Silvermines Mountains. It extends west for 5 km from the village of Silvermines, approximately 8km from Nenagh. Mining took place intermittently at Silvermines for over 1000 years, from the 9th century until 1993. Zinc, lead, silver, copper and barite were produced, with the bulk of production taking place in the second half of the 20th century during a period of large-scale modern mining. Evidence of the long mining history at Silvermines is everywhere visible in the district where 19th-century Cornish engine houses sit close to the remains of modern processing plants, waste heaps and open pits.

The Silvermines District has been investigated in detail since 1999 by various Government departments and agencies as part of a detailed risk assessment. These studies have taken place in the context of local concern about human and animal health following dust blows from the large tailings pond at Gortmore and the death of several cattle from lead poisoning. The district is currently the subject of a remediation process. A large volume of modern data is available for the district, in addition to data produced by mining companies during the 20th-century mining operations. As a consequence, no major investigation was carried out as part of the HMS-IRC project. In addition to familiarization visits to the individual sites in the district, limited *in-situ* solid waste analysis was completed at Ballygown, to supplement existing data, and around the old ore-processing site at Garryard.

The Silvermines District can be subdivided, on the surface, into six individual sites, incorporating both modern and pre-20th-century sites (Fig. 1). These individual sites do not incorporate all extant mine features in the district. However, they do include all the significant known waste sources. The six sites are Ballygown, Magcobar, Garryard, Gorteenadiha, Shallee and Gortmore TMF.

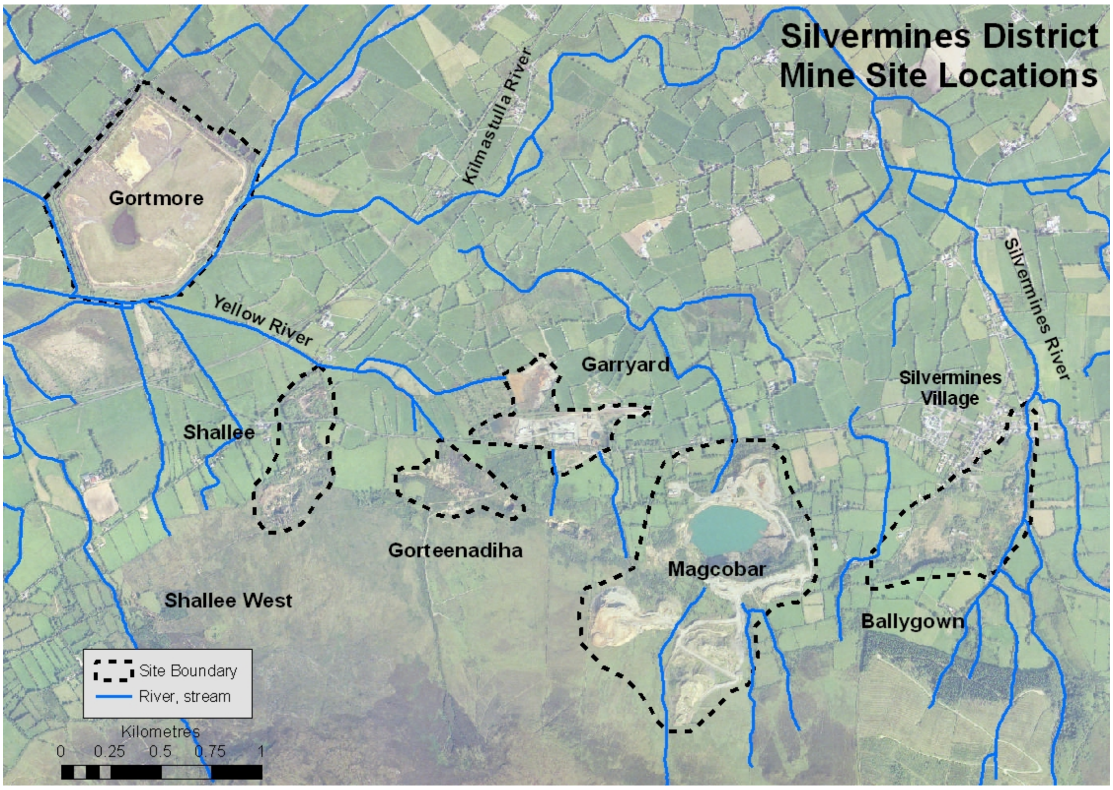

Fig. 1 Silvermines District: mine site locations

Geology and Mineralization

The mineralization 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 100m-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 10-12m-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 85-235m-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 30-155m 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 mineralization (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. Mineralization 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 mineralization occurs within or close to westnorthwest-trending structures of the

Silvermines Fault zone. The fracture-fill and replacement mineralization 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 4.75 million tons 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 sulphides. 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 mineralization is estimated to have contained around 13 million tons grading 2.55% Pb, 6.78% Zn and 5.5 million tons of 85% $BaSO_4$ (Andrew 1986, Boland *et al.* 1991).

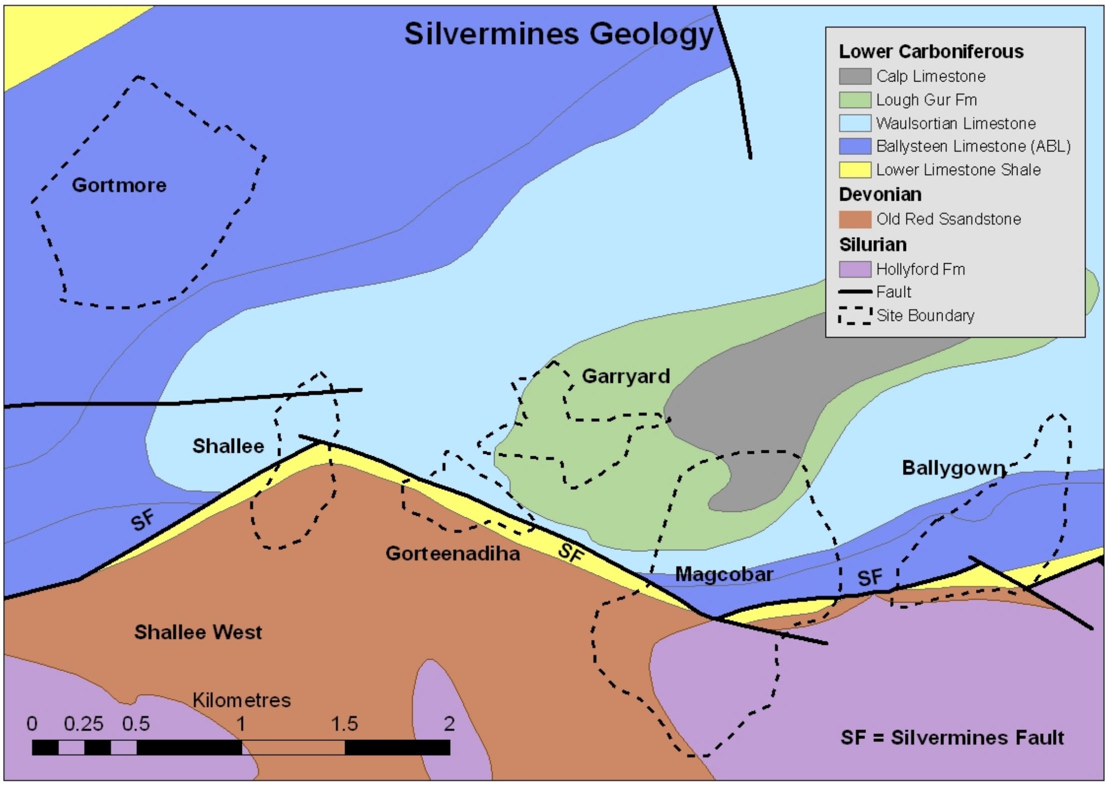

Fig. 2 Geology of Silvermines District (from GSI 1:100,000 scale map series)

Mining History and Production

According to Andrew (1986) earliest mining records date back to the 9th century when the Danes extracted silver from argentiferous galena. Sporadic operations between the 17th and 19th centuries raised Cu, Pb, Ag, Zn and sulphur from small-scale mines along the Silvermines Fault. Mining in the 17th and 18th centuries centred on Ballygown and Knockanroe, south of Silvermines village, where residual Pb-Ag sulphide ore was worked (Boland *et al.* 1991). Subsequently, in 1862-1874, residual zinc mineralization ("calamine") was worked by the General Mining Company of Ireland. At this time Shallee was producing Pb and Ag (467 tons of Pb and 12,000 oz Ag in 1852) and continued in production until 1870. Gorteenadiha was originally worked as a copper mine, producing 154 tons of 10% Cu in 1850, but produced Pb and Ag from 1852 to 1870. Between 1948 and 1953, the Silvermines Lead and Zinc

Company developed an open cut at Ballygown to extract calamine, sank a shaft and built a Waelz kiln to process the ore. This company also worked at Shallee from 1949 to 1958.

The period of large-scale modern mining began in 1963 when Magcobar began working the stratabound barite deposit from an opencast. In 1968 Mogul commenced underground mining of Pb and Zn at Garryard, exploiting the stratabound mineralization in the Waulsortian as well as the fracture-fill and replacement mineralization along the Silvermines Fault. Mogul produced some 10.7 million tons of ore grading 2.7% Pb and 7.36% Zn. Magcobar continued mining barite until 1992, producing more than 5.5 million tons.

Site Descriptions and Environmental Settings

The geochemistry of the Silvermines District is considered as a whole in the Geochemical Assessment (below) rather than on a site-by-site basis. Individual site descriptions in this section review the main features of each site examined.

1. Ballygown

Mine Name: Ballygown

Alternative Name: Knockanroe

Elements of interest: Pb, Zn, Ag, Cu, Ba

County:	**Townland:**	**Grid Reference:**
Tipperary	Silvermines	E183934, N171038

The Ballygown site covers an area of approximately 40 ha immediately south and east of Silvermines village. The Silvermines National School and the local catholic church are both on the boundary of the site. The surrounding land is mainly cattle pasture. Ballygown was mined initially in the 17th and 18th centuries for residual lead-silver mineralization, giving the village its name (Boland *et al*. 1991), and subsequently for residual zinc mineralization (calamine – mixed Zn carbonate-hydroxide). The site has been extensively worked both on the surface and underground. Extant surface mine features include an extensive open pit at the southern end of the site (Knockanroe, above what was subsequently called the "K" underground mine zone by Mogul), the water-filled open cut developed during the 1948-53 phase of calamine mining (photo, left), the Waelz plant constructed during the same period (photo, above right), numerous solid waste dumps and a 19th-century Cornish engine house and furnace house. Most of the many shafts sunk in the area are collapsed or backfilled but a drainage adit

that links them continues to discharge mine water into the Silvermines Stream north of the village (Fig. 3).

Obvious solid waste heaps on the site include small volumes of metal-rich processing waste (SP02) near the 1950's processing plant (photo, left), a large, bare heap around the 1950's open cut (SP01) and an extensive area of bare, levelled waste north of the open pit (SP03) (Fig. 3). Less obvious waste includes the heap now reclaimed as the village field (SP23) and the heap near the school northeast of the village cross-roads (SP21) which is largely revegetated. Conservation works are being carried out at present on the engine house building.

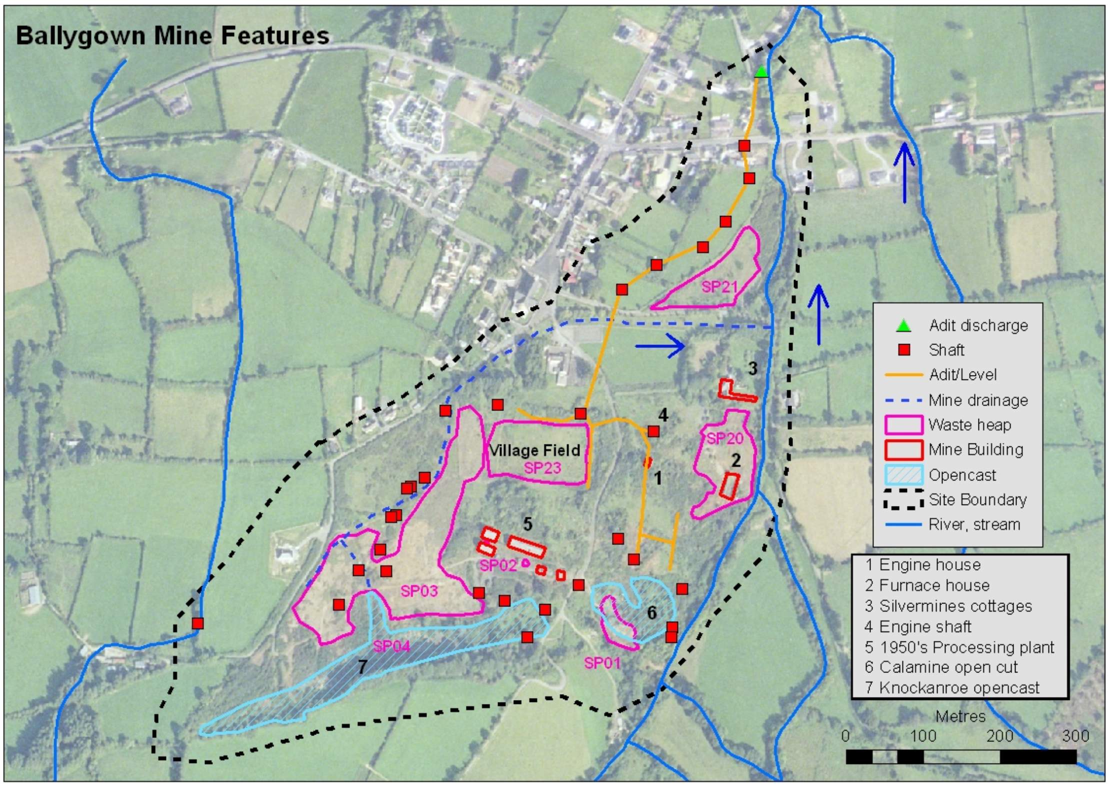

Fig. 3 Ballygown: mine features

2. Magcobar

Mine Name: Magcobar

Alternative Name:

Elements of interest: Ba

County:	**Townland:**	**Grid Reference:**
Tipperary	Garryard West; Gortshaneroe	E182622, N170716

The Magcobar barite mine site is on the lower slopes of Silvermines Mountain, immediately north of the Silvermines-Shallee road, 1km west of Silvermines village. The land around the northern part of the site is mainly grassland, used for cattle pasture. To the south, the upland area provides rough grazing for sheep. Several houses are situated along the road immediately north of the site. The Magcobar mine was the last active mine in the district. It closed in September 1992. Open-pit mining was followed by limited underground mining developed from the base of the pit. The mine is located on the site of a 19th century copper mine but most of the remaining features from that era are covered by large waste heaps. The only visible remains of 19th-century mining are a small open pit, immediately north of SP05 (Fig. 4), and dressing floor. In contrast, the 20th-century mine has left behind the large, now flooded open pit, five large-volume waste heaps and some largely intact mine buildings, including a crusher house that was apparently erected after closure of the Magcobar operation to process waste material on the site (SRK 2001). The surface area of the open pit is approximately 15 hectares and the excavation approximately 70m deep, giving it a capacity of approximately 7,000,000 m^3. The five large solid waste heaps comprise mainly stripping waste with minimal sulphide content. However, a small volume of pyrite-rich waste (SP05a on Fig. 4) has been identified in the top layer of one heap (SP05). Streams draining Silvermines Mountain have been diverted around the open pit using drainage channels (Fig. 4). These water diversion channels are still operational (SRK, 2001).

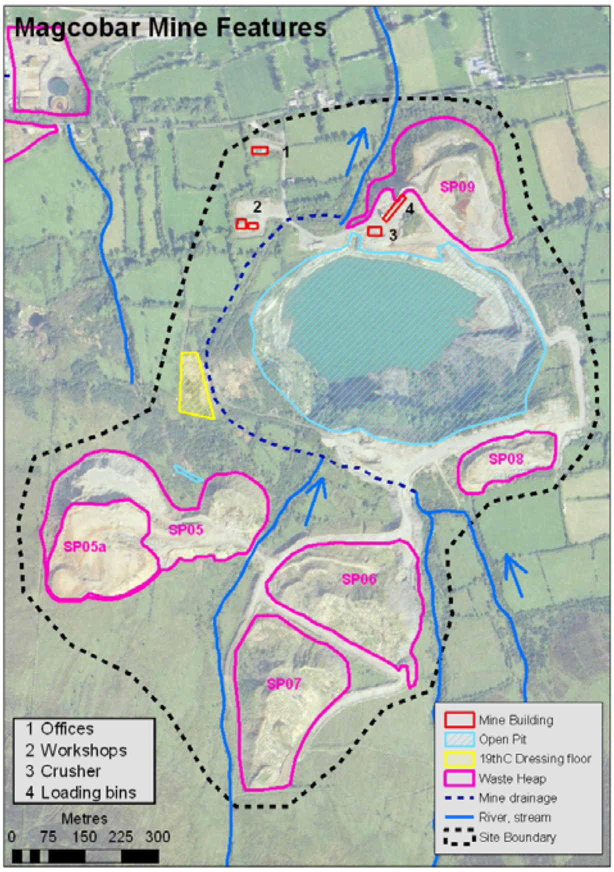

Fig. 4 Magcobar: mine features

3. Garryard

Mine Name: Garryard

Alternative Name: Mogul

Elements of interest: Pb, Zn, Cd, As

County:	Townland:	Grid Reference:
Tipperary	Garryard	E181870, N171516

Mogul began underground mining in Silvermines in 1968 and constructed the surface plant and mine access shaft at Garryard. Between 1968 and 1982 Mogul raised and processed 10.7million tonnes of ore at 7.36% zinc and 2.7% lead at the site. The site is on both sides of the Silvermines – Shallee road, 1.5km west of Silvermines village. South of the road is the old ore stockpile area. North of the road the site is split by a rail siding from which concentrate was transported to Foynes, west of Limerick. 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 (Fig. 5). Substantial amounts of metal-rich solid waste lie around the remains of the processing plant. The old mine offices and yard have recently been in use by a transport company. The land around the site is chiefly grassland, in use for cattle grazing. The former mine hostel, immediately northeast of the site, is now the house of a local landowner. There are no other dwellings immediately adjacent the site.

The Knight Shaft has a concrete cap. An overflow pipe in the cap discharges mine water, typically 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 receive surface runoff from the Garryard plant area. This run-off can have high metal concentrations. The larger settlement pond discharges water into the smaller pond which, in turn, discharges to a stream via a weir. 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, 1km downstream of the site. Across the Silvermines-Shallee road, south of the site, is the Old Stockpile area where ore was stockpiled prior to processing at Garryard. This site contains a substantial amount of process waste. Surface run-off from the stockpile area enters a drain that runs westwards, parallel to the road (Fig. 5), before crossing under the road to enter farmland.

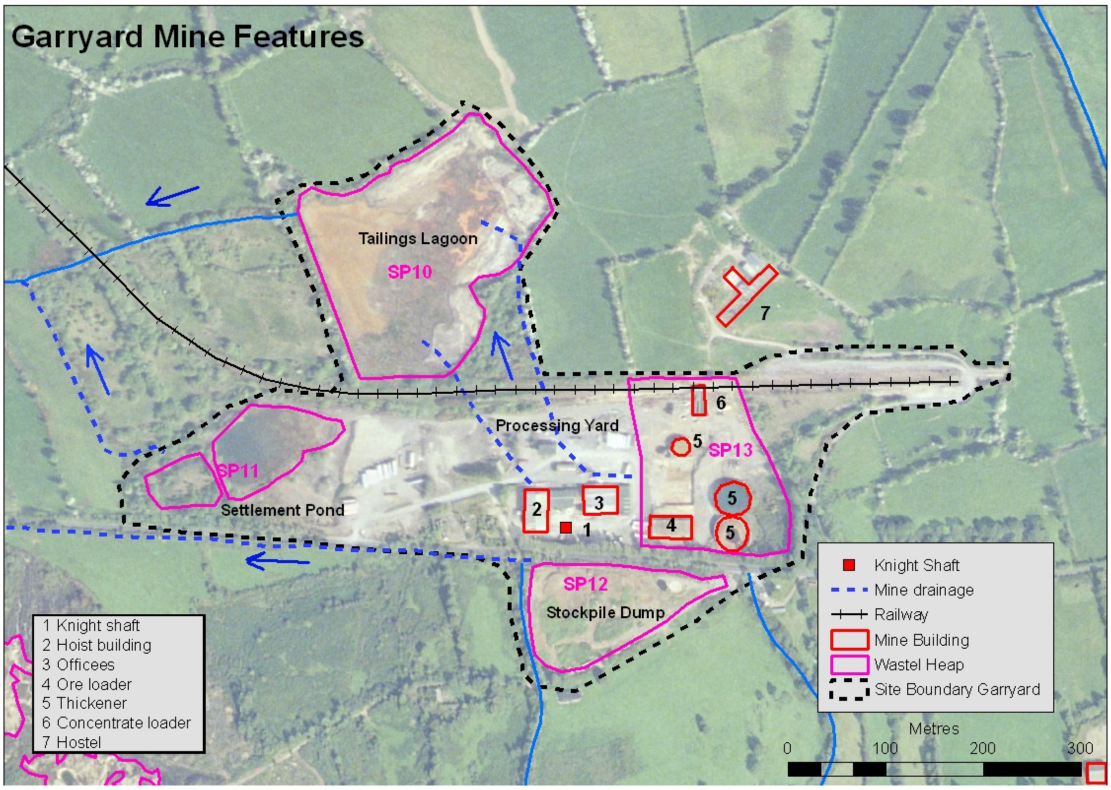

Fig. 5 Garryard: mine features

4. Gorteenadiha

Mine Name: Gorteenadiha

Alternative Name: Gortnadiha, Gortnadyne

Elements of interest: Pb, Cu, Ag

County:	**Townland:**	**Grid Reference:**
Tipperary	Gorteenadiha	E181390, N171183

Gorteenadiha is south of the Silvermines-Shallee road, immediately west of Garryard. The mine was first worked in the early 19th century and mining continued into the 20th century. Veins were worked for Cu, Pb and Ag both from at the surface and from several small pits. Numerous shafts and an adit are marked on old maps (Fig. 6) but the underground workings themselves are unmapped (SRK 2001). The extant surface mine features on the site include the remains of two small concrete buildings from the more recent period of mining, an intact magazine and the old hand-dressing area. Small solid waste heaps are scattered over the area. The heaps are only partly vegetated and are typically waterlogged. They are a source of run-off and seepages that flow into the streams in the vicinity. These streams flow north to join the drain which runs parallel to the Silvermines – Shallee road, and which also takes drainage water from the Old Stockpile area at Garryard, before being culverted under the road to join the Yellow River. An area of caving developed in 1986 in the southeastern part of the site over Mogul's underground workings and this is partly flooded also and a source of drainage.

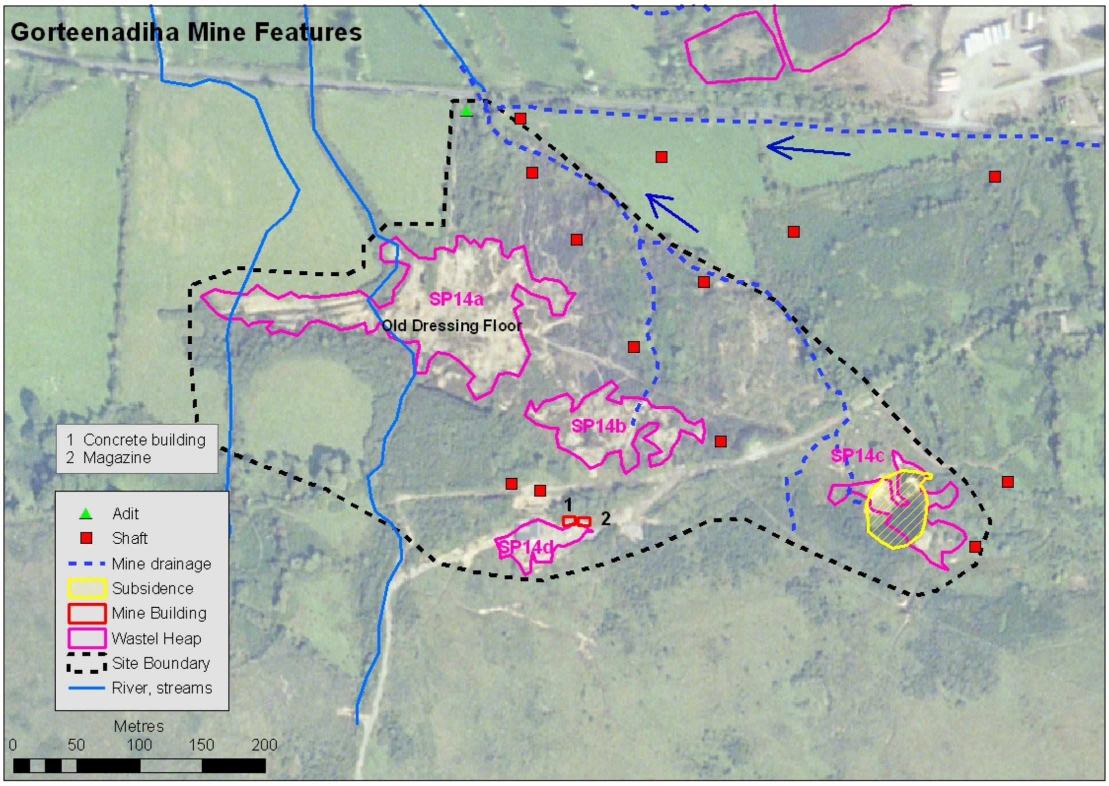

Fig. 6 Gorteenadiha: mine features

5. Shallee

Mine Name: Shallee; Shallee West

Alternative Names:

Elements of interest: Pb, Zn, Cu, Ag

County:	**Townland:**	**Grid Reference:**
Tipperary	Shallee	E181602, N171343

Shallee comprises two distinct sites, the main Shallee site and Shallee West, 0.5 km to the southwest. At Shallee West some 14 lead veins, 1-2m thick, were worked from the surface in the 19^{th} century. Excavations were up to 80m long and 10m deep. Argentiferous galena and barite were present in the veins. The site is now densely covered in gorse and heather and there is little to see (SRK 2001). The site is not considered further in this report.

The main Shallee site straddles the Silvermines-Shallee road, with most of it occupying the northern flank of Silvermines Mountain south of the road. Over 40 mineralized veins were worked at Shallee in the 19^{th} century, around half of these from the surface and the remainder underground. Mineralization mainly comprised argentiferous galena and barite. In the 20th century, Silvermines Lead and Zinc Company mined intermittently at Shallee from 1949 until finally ceasing in 1958, producing over 350,000 tons of ore (Inter-Agency Group 2000). Mining commenced by quarrying and trenching, followed by underground room and pillar stoping as well as open stoping.

The extant mine workings visible on the site include the opencast workings and, exposed at the north end of the pit, the so-called "Catherdral Cavern", a section of the underground room and pillar stopes (photo, above right). The hillside above and south of the open pit is scored with deep trenches (photo, left) that were excavated on the mineralized veins. Solid waste heaps cover much of the ground west of the open pit and, on the northern part of the site, there is a tailings dumps on either side of the main road (Fig. 6). The remains of the 19th- and 20th-century mine plant are located between the open pit and the tailings dumps and include a crusher base, other machine bases, a stone-built engine house, 19th-century mine manager's house (King's House) and core sheds. The remains of the 20th-century offices, chemical store and laboratory are beside the track that leads down to the road. Shallee is the site of a large dump of 45 gallon (205 litre) metal barrels or drums, left over after recent mining (photo, right).

There is a cut-off drain upslope of the surface working and drum dump which collects and diverts runoff from Silvermines Mountain, minimizing the effects of run-off from the mine site. Nevertheless the mine does act as a drain for rain water and the open pit and underground workings are partially flooded. The routes of natural streams have been destroyed but near the southernmost tailings dump there is a spring in an old streambed that is thought to be fed by water from the underground workings. This then passes under the Silvermines-Shallee road via a culvert and flows along the western boundary of the north tailings impoundment to join the Yellow River (SRK, 2001).

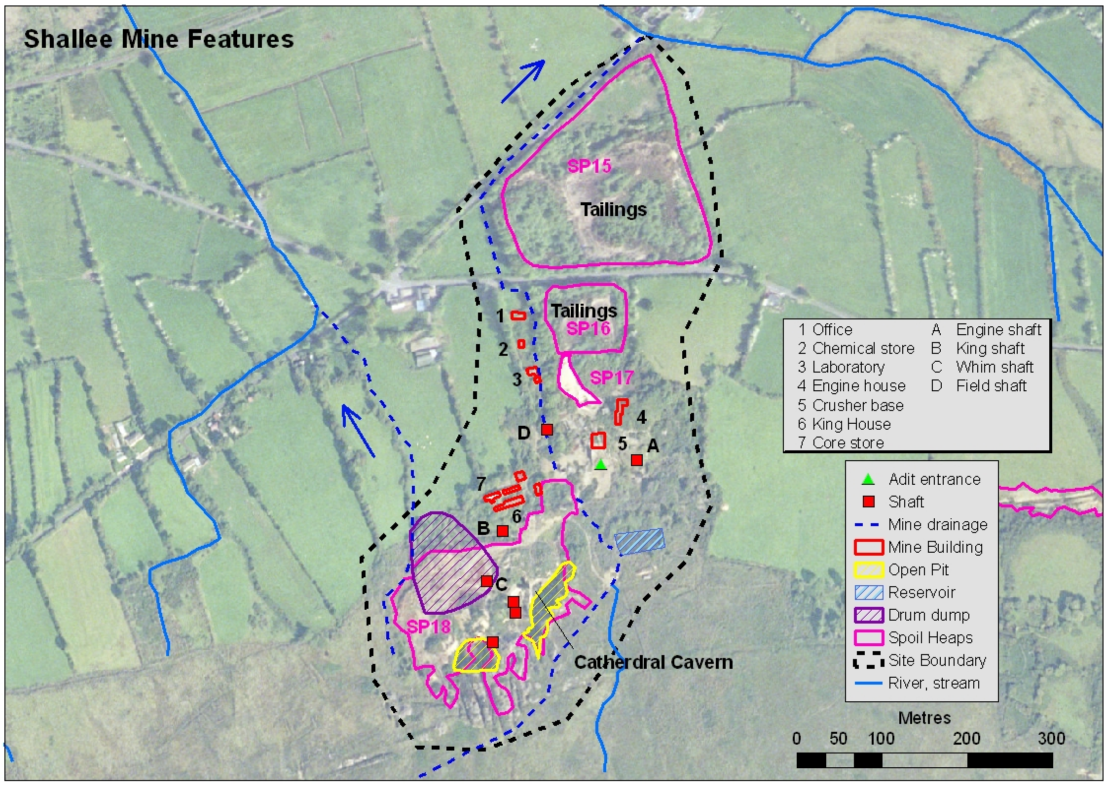

Fig. 6 Shallee: mine features

6. Gortmore

Mine Name: Gortmore

Alternative Names:

Elements of interest: Pb, Zn, As, Cd

County:	**Townland:**	**Grid Reference:**
Tipperary	Gortmore	E179847, N172716

The Gortmore tailings management facility (TMF) was built by Mogul to store the tailings produced by its large-scale underground mining at Garryard, 2km to the east. The TMF occupies the lowland area of the Kilmastulla River floodplain between the Arra Mountains to the north and the Silvermines Mountains to the south. The land in the area is typically grassland, mainly used as cattle pasture, and the soils are generally poorly drained.

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 (Fig. 7). 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 8.2m and a perimeter is 3.1 km long. During the operation of the Garryard mine, 10.7 million tonnes of ore grading 7.36% Zn and 2.7% Pb were milled. This ore generated approximately 9 million tonnes of tailings with 7.7 million tonnes of these pumped to the TMF. The remaining 1.3 million tonnes 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. The current remediation plan for Silvermines aims to establish a cover on an area of approximately 23 ha that still requires remediation (visible as light-coloured areas on Fig. 7).

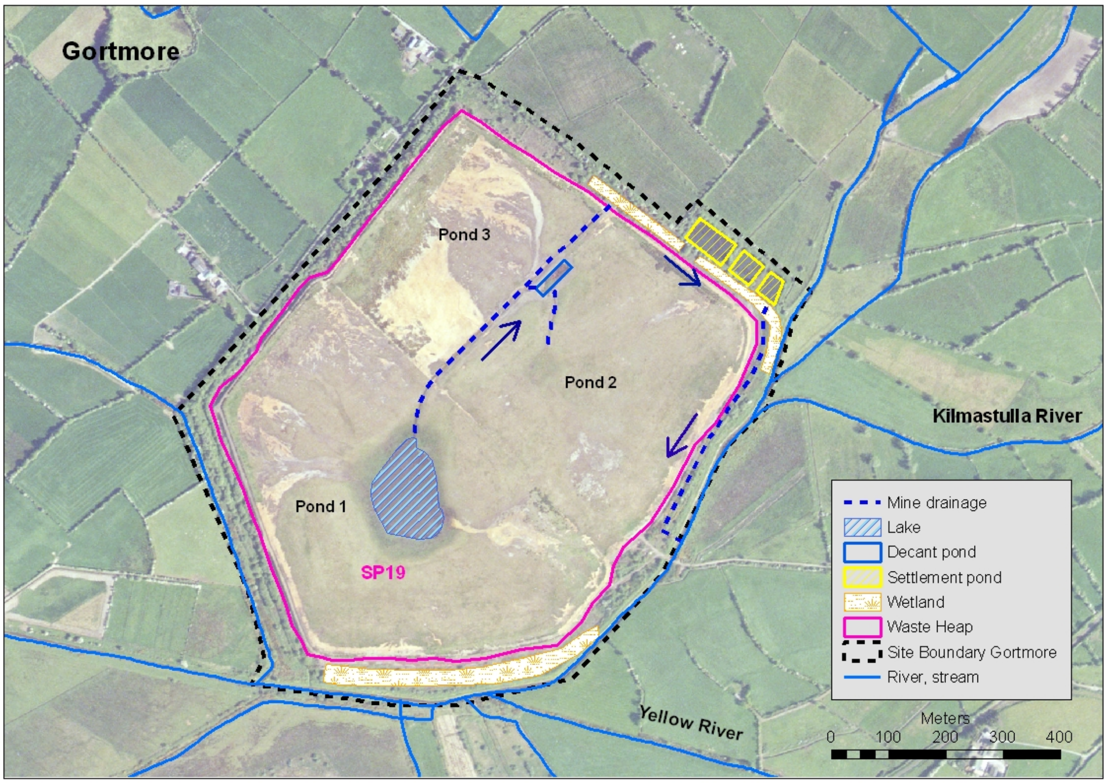

Fig. 7 Gortmore: site features

Geochemical Assessment

Several geochemical investigations have been carried out in the Silvermines District since 1999 (Inter-Agency Group 2000, SRK 2001, Golder Associates 2007, 2008). Geochemical investigations were also carried out in the 1960s and 1980s as part of mineral exploration programmes. In consideration of this and the ongoing site remediation studies being undertaken since 2007, detailed geochemical site investigations were not carried out in the district for the HMS-IRC project. Some *in-situ* XRF analyses were completed at Ballygown, Shallee and Garryard in order to provide additional data for specific waste sources on these sites. Otherwise, existing data from previous studies have been used to generate site scores for the district under the HMS-IRC Site Scoring system. Data acquired for the Inter-Agency Group study (Inter-Agency Group 2000) were the primary source for water and stream sediment data because their extent and scope are comparable to the extent and scope of data acquired for other districts investigated under the HMS-IRC project. Additional EPA sampling from 2000 and 2001 has also been included in the review below because the earlier programme included relatively few upstream samples. Where necessary, data from mineral exploration programmes as well as the studies undertaken by SRK in 2001 (SRK 2001) and subsequently by Golder Associates (Golder Associates 2007, 2008) have been used to supplement the Inter-Agency Group and EPA data. This was particularly the case for solid waste analyses since the Inter-Agency Group study included very few such analyses, apart from some at Garryard and Gortmore. The Inter-Agency Group and EPA investigations included analyses of:

- surface water samples from 40 sites in the Kilmastulla and Yellow Rivers and their tributaries, upstream and downstream of mine sites in the district;
- 38 stream sediment samples in the Kilmastulla River, Yellow Rivers and Silvermines River and their tributaries, upstream and downstream of mine sites in the district;
- tailings and mine sludge samples from Garryard and Gortmore;
- dust deposited around the Gortmore TMF and at Silvermines National School and
- 213 soil samples taken mainly from agricultural land but including five tailings samples from the Gortmore TMF.

From 2001 to 2008, both SRK and Golder Associates carried out further monitoring, including some site-specific sampling and analyses around particular mine sites. In particular, both carried out analyses of solid waste that, though not directly comparable to *in-situ* XRF analyses, provide an estimate of metal concentrations in waste heaps. Further data for solid waste was derived from exploration carried out by Ennex in the 1980s at Ballygown and Gorteenadiha. Fig 7 shows the distribution of geochemical sampling sites in the district for the various media investigated, for surface water collected by the Inter-Agency Group and the EPA in 2000 and 2001, for stream sediments collected by the Inter-Agency Group and by the EPA in 2000 and 2001, for solid waste analyses carried out for HMS-IRC and by SRK and Golder Associates. Additional sites sampled by Ennex are not shown.

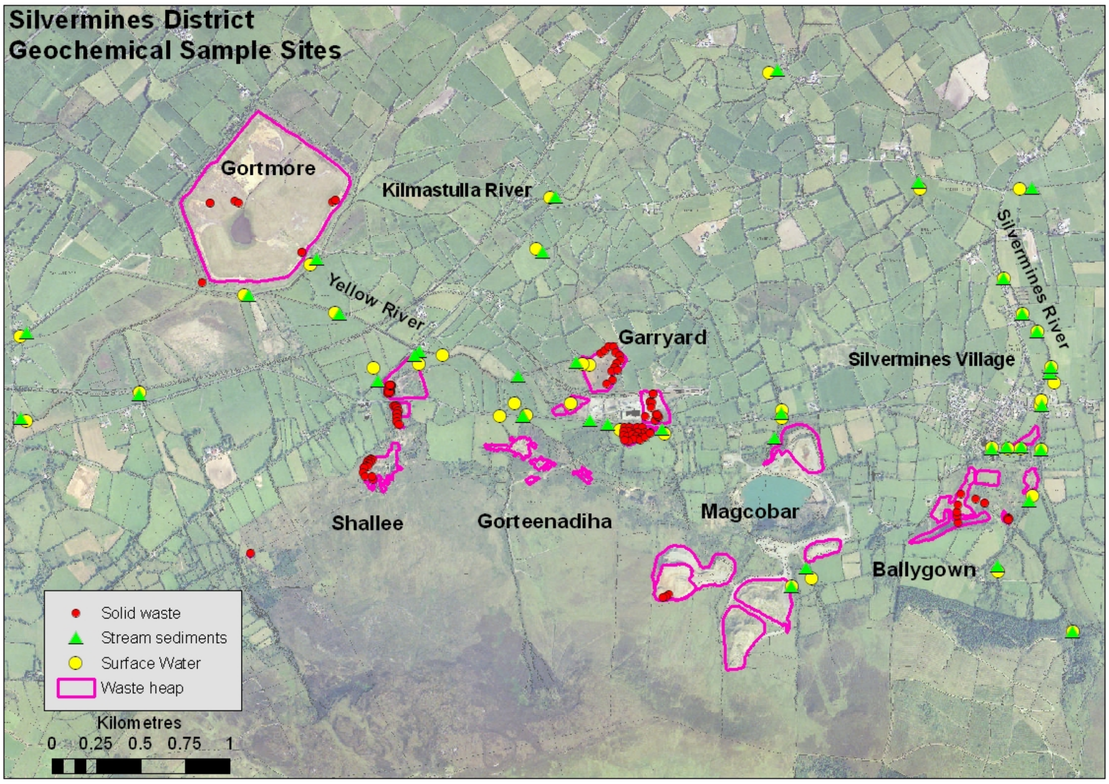

Fig. 7 Silvermines District: Geochemical Sampling Sites

1. Surface water

Surface water samples in the Silvermines district contain elevated concentrations of mine-related metals such as Pb, Zn, and Cd (Table 1). The median values for Pb, Zn and Cd all exceed the Draft EC Regulations for surface water. Fig. 8 and Fig. 9 show the distribution of total Pb and Zn in surface water samples from the district. Water samples taken from the Yellow River and its tributaries that drain the mine sites at Garryard, Gorteenadiha and Shallee typically had elevated Pb and Zn concentrations (Fig. 8, 9). High concentrations of Pb (118 – 373 µg/l), Zn (1286 – 2717 µg/l) and also Cd (4 – 11 µg/l) were recorded in the surface water on the tailings lagoon and settlement pond at Garryard. Subsequent analyses by SRK showed that the water draining from the tailings lagoon to the Yellow River also contained high metal concentrations (120 µg/l Pb) whereas that draining the settlement pond had low metal concentrations (e.g. 7 µg/l Pb). Surface water sampled from watercourses draining the old stockpile area at Garryard had high metal concentrations (388 µg/l Pb and 4806 µg/l Zn) as had those immediately downstream of Gorteenadiha (941 µg/l Pb and 5365 µg/l Zn) and Shallee (313 µg/l Pb and 535 µg/l Zn). Thus the Yellow River, sampled upstream of its confluence with the Kilmastulla River (Fig. 8, 9), had 307 µg/l Pb and 1298 µg/l Zn.

Table. 1 Summary statistics, surface water samples, Silvermines

µg/l	Pb (tot)	Zn (tot)	Cu (tot)	Cd (tot)	Ba (tot)
n	40	40	40	40	40
Minimum	<1	12	<1	<0.1	<50
Maximum	941	5365	70	24	321
Median	25	286	4	0.7	139
Mean	95	948	11	3	163

Metal concentrations in the Kilmastulla River were generally much lower than those in the Yellow River and were only significantly elevated downstream of the tailings pond at Gortmore and downstream of the confluence with the Yellow River. The Silvermines River flows into the Kilmastulla River north of Silvermines village. It receives discharge from the adit that drains the underground workings at Ballygown as well as the surface drain that runs from the old Knockanroe opencast across the main solid waste accumulation. The adit discharge, sampled by the EPA in 2002, had 310 µg/l Cu but otherwise generally low metal concentrations (SRK 2001). Its impact on the water chemistry downstream is apparently negligible – Cu concentrations below the adit discharge were 4 µg/l or less. In contrast, water from the drain that flows from the opencast across the solid waste heap has much higher metal concentrations (50 – 103 µg/l Pb, 2949 - 3812 µg/l Zn, 6 – 7 µg/l Cd). The Silvermines River downstream of its confluence with the drain has consistently elevated Zn concentrations (113 – 2002 µg/l) and this is likely to reflect input from the drain.

In general, surface water sampled downstream of mine sites in Silvermines has significantly higher metal concentrations than that sampled upstream (Table 2). The highest concentrations of metals were found in water standing on solid waste, such as at the tailings lagoon in Garryard. The high concentrations of metals in surface water immediately downstream of solid waste heaps at Garryard, Gorteenadiha and Shallee suggest that surface run-off and seepage have a significant impact on surface water quality in the district.

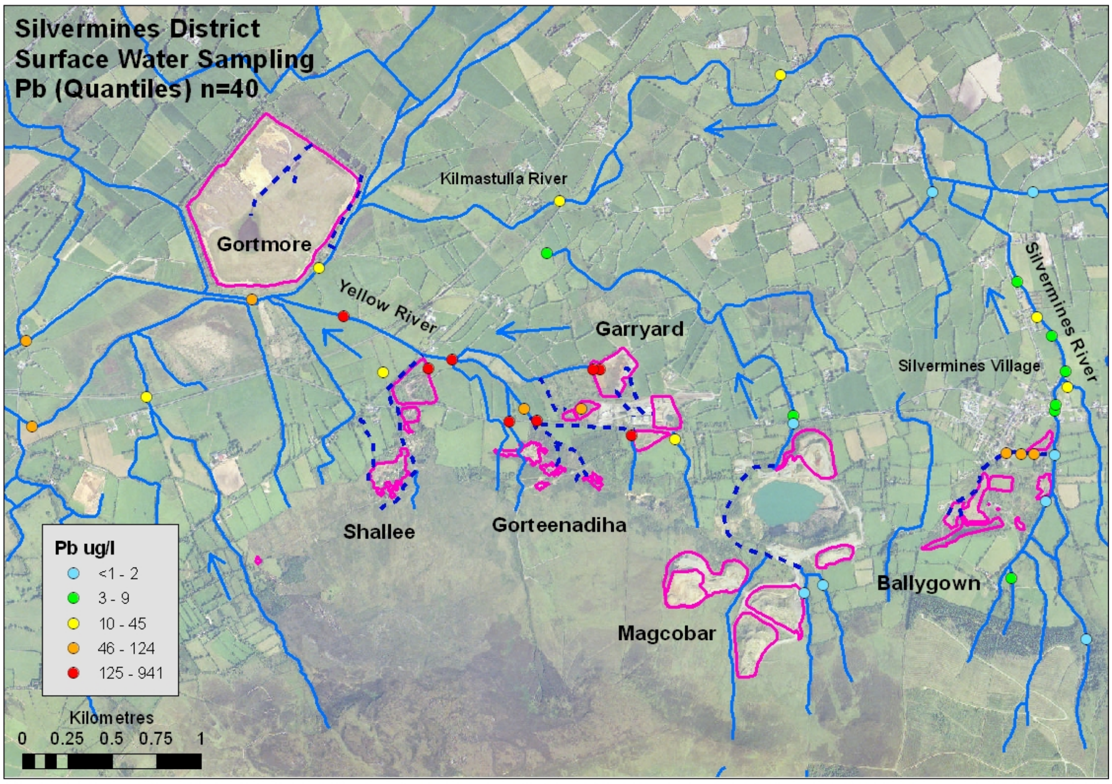

Fig. 8 Silvermines: Pb distribution in surface water samples

Table. 2 Median concentrations, by site type, Silvermines

µg/l	Pb (tot)	Zn (tot)	Cu (tot)	Cd (tot)	Ba (tot)
Median					
Upstream (n = 8)	2	109	2	0.1	113
Downstream (n = 29)	34	424	4	1	163
Waste run-off (n = 3)	194	2052	8	10	83

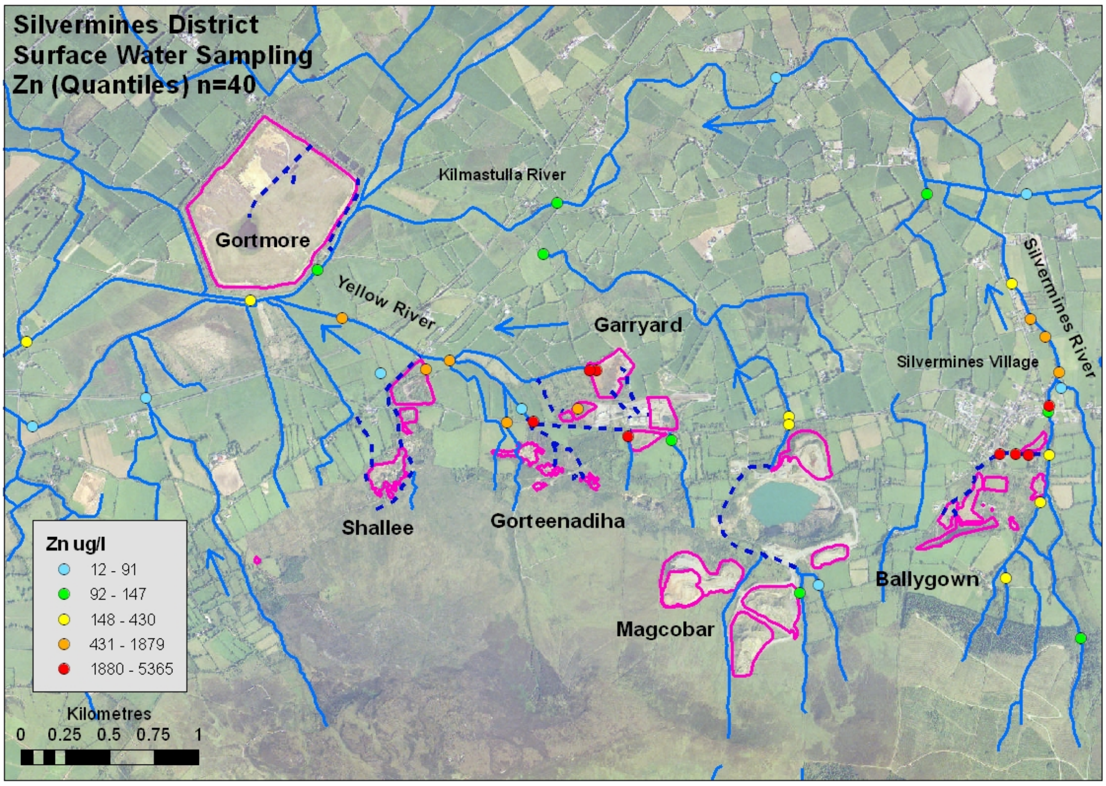

Fig. 9 Silvermines: Zn distribution in surface water samples

2. Groundwater

Groundwater sampling from several boreholes in the district was carried out by SRK. Significant concentrations of metals were detected in samples from Ballygown (up to 980 µg/l Zn, 9 µg/l Pb, 1 µg/l Cd), Magcobar (up to 120 µg/l Zn), Garryard (up to 450 µg/l Pb and 110 µg/l Zn), Shallee (up to 3550 µg/l Pb, ≤ 1000 µg/l Zn, Ni, Cu, As, Bi) and Gortmore (up to 70 µg/l Hg and 50 µg/l Ni). The surface and underground workings have significant potential to contaminate groundwater in the Silvermines District (SRK 2001). Testing of drinking water supply for the Inter-Agency Group study showed only one group scheme had Pb concentration in excess of the then statutory limit of 50 µg/l (Inter-Agency Group 2000). This scheme was subsequently replaced, as previously planned.

3. Stream Sediments

Stream sediment samples were collected from just four or five sites that could be considered definitively upstream of any mine site (labelled U on Fig. 10). One of these samples, on the Kilmastulla River, had 627 mg/kg Pb and 528 mg/kg Zn but other mine-related elements were present in low concentrations (≤4.6 mg/kg Cd, ≤53 mg/kg As). High concentrations of Pb and Zn in soil in the district, considered to predate mining (Inter-Agency Group 2000), may account for elevated metal concentrations in stream sediments upstream of mine sites.

In the case of samples taken downstream of mine sites, samples from the Kilmastulla River and Yellow River and their tributaries tend to mirror the results obtained for surface water, with the Yellow River catchment showing the highest metal concentrations. Measured concentrations of Pb in 5 samples of stream sediment from the Yellow River ranged from 3,271 to 12,332 mg/kg, with the highest concentration in a sample taken from the water course immediately downstream of the Garryard tailings lagoon (Fig. 10). High concentrations of Zn (743 – 208,233 mg/kg), As (61 – 468 mg/kg), Cu (421 – 733 mg/kg) and Cd (0.35 – 218 mg/kg) were also recorded, with the highest concentrations again measured in the sample taken immediately downstream of the tailings lagoon discharge. High concentrations of Pb and other metals were, not surprisingly, recorded from sediments taken from the drain downstream of the old stockpile at Garryard. Elsewhere in the district, sediment in the dug drain running from the Knockanroe opencast at Ballygown also had high metal concentrations (≤13678 mg/kg Pb, 16560 mg/kg Zn, 218 mg/kg Cd, 154 mg/kg As, 95 mg/kg Cu and 96 mg/kg Ni). Downstream of its confluence with this drain, sediment in the Silvermines River had relatively high concentrations of Pb (1674 – 3376 mg/kg) and Zn (4516 – 14314 mg/kg). Other samples with high metal concentrations were taken in the Yellow River tributaries downstream of Shallee and Gorteenadiha. Fig. 10 shows the distribution of Pb in stream sediments in the Silvermines district and Table 3 summarizes the data for the main mine-related elements of interest.

Table. 3 Summary statistics for stream sediment analyses, Silvermines

mg/kg	Pb	Zn	Cu	As	Cd	Ba
All data						
n	38	38	38	38	38	38
Minimum	51	0.0	13	3	0.4	185
Maximum	46943	208233	733	1562	218	29727
Median	2552	1634	61	42	8	1438
Mean	5801	9460	138	161	24	3375
By location						
Upstream median (n=5)	206	355	25	18	1.4	606
Downstream (n=33)	3037	3070	65	45	10	1763

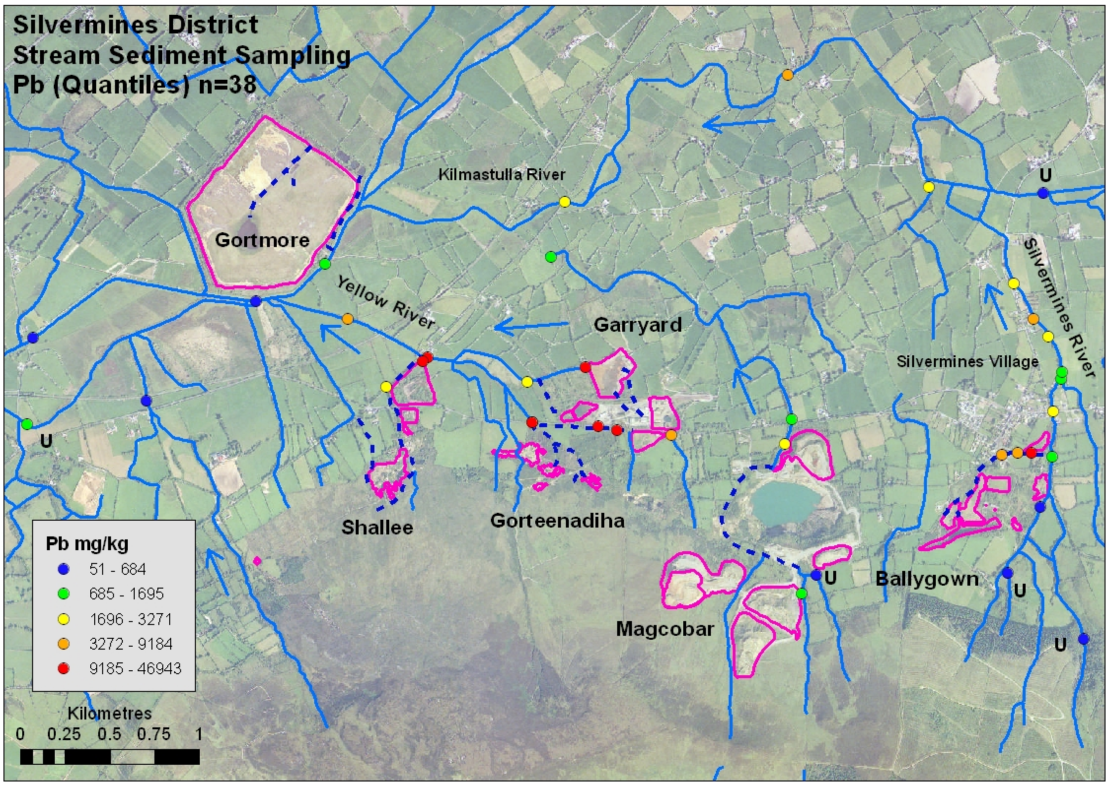

Fig. 10 Silvermines Stream Sediment samples: Pb distribution

4. Solid Waste

A limited number of *in-situ* XRF analyses of solid waste were carried out at Ballygown and Garryard for the HMS-IRC project. Analytical data for solid waste at these and other sites in the district has also been complied from various sources including the Inter-Agency Group investigation (Inter-Agency Group 2000), monitoring carried out in support of the remediation work (SRK 2001; Golder Associates 2007, 2008) and Ennex's exploration data from the 1980s (GSI Mine Records database). Table 4 provides a summary of results for the main sites investigated. A variety of techniques was employed to analyse the samples and the data are not directly comparable as a consequence. Nevertheless, there is broad consistency between data for individual sites analysed by different investigators and the various data have been used in the HMS-IRC Site Scoring system without further modification. Table 5 gives a comparison of data obtained by SRK (paste analyses), GSI (*in-situ* XRF) and Ennex for Ballygown.

Solid mine waste in the Silvermines District typically has high metal concentrations (Table 4). The highest concentrations (>5% Pb) were measured by GSI (*in-situ* XRF) in waste at Garryard where considerable quantities of processing waste are distributed around the site. The TMF at Gortmore also has relatively high concentrations of metals in the surface layer, with measured Pb concentrations exceeding 1%. Percentage levels of Pb and Zn were measured in solid waste at Ballygown, Shallee and Gorteenadiha. Only the large waste heaps at the Magcobar site, where barite rather than Pb-Zn sulphides was mined, have low overall metal concentrations.

Table 4 Summary statistics for solid waste analyses, Silvermines

mg/kg	Pb	Zn	Cu	Cd	As
Gortmore[1] (n=10)					
Minimum	147	117	19	<1	10
Maximum	15395	11273	260	36	974
Median	10083	4336	118	14	638
Garryard mine yard[2] (n=12)					
Minimum	451	106	<DL	<DL	<DL
Maximum	373999	348144	634	599	20934
Median	15301	19559	124	76	914
Garryard TMF[3] (n=13)					
Minimum	12492	23328	326	113	864
Maximum	25695	96245	826	463	2182
Median	18406	59185	471	238	1347
Garryard Stockpile[2] (n=13)					
Minimum	270	1473	25	5	25
Maximum	48432	306653	191	359	1181
Median	9562	19331	54	70	405
Ballygown spoil[2] (n=9)					
Minimum	21403	15679	<DL	<DL	<DL
Maximum	39475	94188	295	227	1351
Median	30291	43528	132	89	757
Gorteenadiha[4] (n=23)					
Minimum	76	58	14		
Maximum	10800	17800	930		
Median	1460	1330	82		
Shallee spoil[3] (n=13)					
Minimum	268	847	91	5	96
Maximum	2547	43137	2340	175	1064
Median	673	10581	230	34	393
Shallee tailings[2] (n=22)					
Minimum	275	<DL	<DL	<DL	<DL
Maximum	6492	259	59	30	610
Median	2233	103	<DL	<DL	80

1: SRK 2001; 2: GSI XRF; 3: Golder Associates 2008; 4: Ennex 1989 (GSI Mine Records MM3257)

Table. 5 Ballygown spoil: comparison of data from several investigations

mg/kg		SRK 2001 (n=8)	GSI XRF (n=9)	Ennex (n=33)
Pb	Range	168 - >32000	21403 – 39475	2300 - 68600
	Median	27510	30291	28300
Zn	Range	86 - >32,000	15679 - 94188	1100 – 63700
	Median	14695	43528	14900
Cd	Range	3 - 318	<DL – 227	
	Median	79	89	
As	Range	26 - 561	<DL – 1351	
	Median	318	757	

An extensive soil survey carried out by Teagasc as part of the Inter-Agency Group investigation in 1999 (Inter-Agency Group 2000) showed that soils in the Silvermines District generally have high metal concentrations. Approximately one third of the agricultural soils in the area had Pb concentrations above 1,000 mg/kg, a value that was considered by the Inter-Agency Group to represent a reasonable cautionary concentration for agriculture. The soils also had elevated concentrations of other metals, especially Zn and Cd. Table. 6 provides a summary of the mean metal concentrations (mg/kg) in agricultural soils in the district compared to mean concentrations for the country as a whole. Although the soils have relatively very high Pb and Zn concentrations, metal concentrations in solid mine waste are significantly higher.

Table. 6 Mean metal concentrations in agricultural soils, Silvermines

mg/kg	Pb	Zn	Cu	Cd	As
Agricultural Silvermines (n=213)[1]	780	365	24.5	1.11	21.9
National Soils Database (N=1310)[2]	31	70	19.5	0.60	9

1: Inter-Agency Group (2000); 2: Fay *et al.* (2007).

Detailed field studies of volume were not carried out for any solid waste heaps in the Silvermines District. Nevertheless, to enable scoring to be completed under the HMS-IRC Site Scoring system, estimates of volumes have been made using areas derived from GIS maps as well as observations of thickness and shape derived from a variety of sources. Table 7 lists the solid waste heaps for which volumetric data have been calculated.

Table. 7 Solid waste heaps, Silvermines district

Waste ID	Mine site	Area (m^2)	Volume (m^3)
SIL-SP01	Ballygown	1,734	2,601
SIL-SP02a	Ballygown	47	47
SIL-SP02b	Ballygown	20	10
SIL-SP03	Ballygown	26,460	52,920
SIL-SP04	Ballygown	18,197	4,549
SIL-SP05	Magcobar	37,116	1,200
SIL-SP10	Garryard	41,990	40,000
SIL-SP11a	Garryard	7,820	11,730
SIL-SP11b	Garryard	3,110	4,665
SIL-SP12	Garryard	14,092	12,000
SIL-SP13	Garryard	23,751	2,300
SIL-SP14a	Gorteenadiha	13,986	6,993
SIL-SP14b	Gorteenadiha	4,900	2,450
SIL-SP14c	Gorteenadiha	3,372	1,686
SIL-SP14d	Gorteenadiha	1,548	774
SIL-SP15	Shallee	39,599	118,797
SIL-SP16	Shallee	6,903	13,806
SIL-SP17	Shallee	1,150	2,300
SIL-SP18	Shallee	29,453	14,727
SIL-SP19	Gortmore	610,885	5,009,257
SIL-SP20	Ballygown	7,506	3,753
SIL-SP21	Ballygown	6,015	3,008
SIL-SP22	Shallee	600	300
SIL-SP23	Ballygown	9,449	4,725

5. HMS-IRC Site Scores

Table. 8 gives the HMS-IRC site scores for each individual waste source in Silvermines that has been scored. The total score for the district is 2545, placing it in Group I, with the second highest score after Tynagh.

Solid waste accounts for 86.6% (2203) of the score, stream sediments 11.6% (296) and mine water discharges just 1.8% (46). The very low contribution made by mine water discharges reflects the paucity of discharges in the district and the relatively low metal concentrations within them, in part owing to the effectiveness of sediment traps, e.g. the settling ponds at Gortmore, in reducing metal concentrations in the discharge.

Fig. 11 shows the contributions made by individual mine sites to the total score for the district. These contributions reflect the volume of solid waste on each site and the measured median metal concentrations, especially that of Pb, the most abundant high-relative-toxicity element in Silvermines. The Gortmore tailings pond contributes over 50% (1339) of the total district score, reflecting the 5,000,000 m^3 of solid waste within it and the consistently high concentrations of Pb measured in tailings samples (median 10,082 mg/kg). Ballygown (477 or 18.9%) and Garryard (315 or 12.5%) are the other major contributors to the district score. The volume of solid waste at Ballygown is estimated to be in excess of 70,000 m^3 (Table 7) and it typically has high Pb and Zn concentrations, with median concentrations for most waste heaps exceeding 2.5% and 4%, respectively (Table 4). At Garryard (>70,000 m^3), the tailings lagoon is one of the most significant accumulations (40,000 m^3) of metal-rich solid waste in the district while the former stockpile area and processing yard still host considerable volumes of concentrated waste with very high metal concentrations. The relatively modest contributions to the total score from other sites reflect a variety of factors. At Shalee, the estimated volume of solid waste is around 150,000 m^3, with most of it in the main tailings deposit (SP15, Table 7). The concentrations of Pb and other metals in tailings at Shallee are relatively modest, however, and the site score reflects this. Other solid waste heaps at Shallee and the nearby Gorteenadiha site also have modest metal concentrations and the scores reflect this. At the Magcobar site, only the pyrite-rich waste on top of one heap was identified by previous workers as being of concern and only this limited volume of waste (1,200 m^3) has been scored. The much larger heaps elsewhere on the Magcobar site have generally not been analysed. Limited data for one heap, SP06, acquired by Golder Associates (2008) suggests a median Pb concentration of around 380 mg/kg. The volumes have not been estimated but significant thicknesses are suggested on the basis of visual inspection. The cumulative area covered by the heaps at Magcobar is around 270,000 m^2 and on this basis a total volume of 1,000,000 m^3 or more is not unreasonable. Using these estimates and the limited chemical data available (Golder Associates 2008) a HMS-IRC score of 39 is generated for the non-pyritic waste at Magcobar. This would raise the Magcobar contribution slightly but it does not have a major impact on the overall district score.

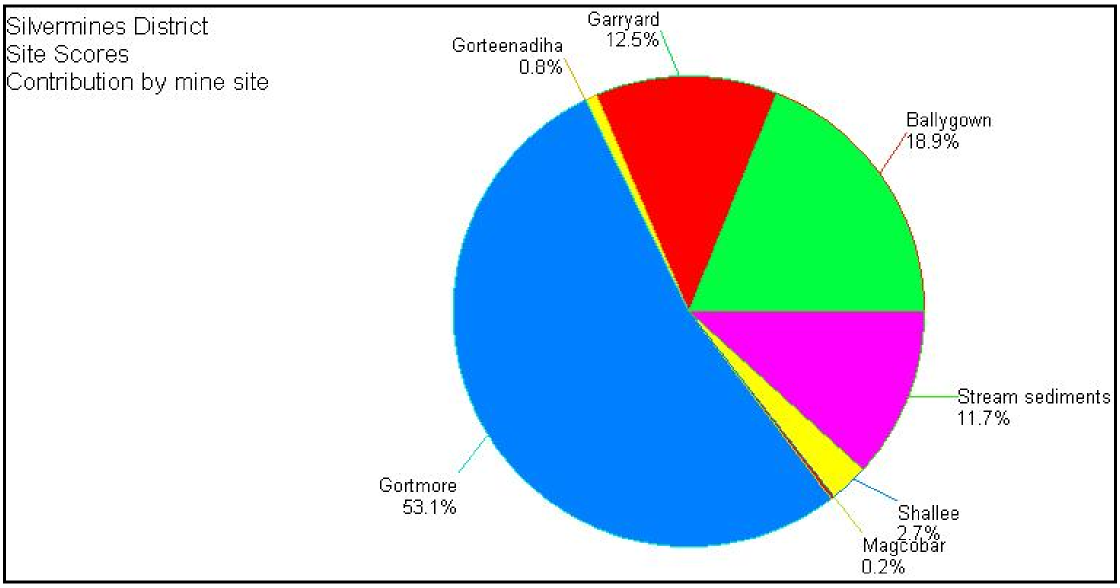

Fig. 11 Silvermines district, site scores, contribution by mine sites

Apart from the solid waste heaps, the other major contributor to the district score at Silvermines are the stream sediments (296 or 12%). This high score reflects the persistent contamination of streams and other water courses by Pb downstream of mine sites in the district.

Table. 8 HMS-IRC Site Scores, Silvermines

Waste	SP01	SP02a	SP02b	SP03	SP04	SP05
1. Hazard Score	**93**	**129**	**15**	**547**	**111**	**18**
2. Pathway Score						
Groundwater	10.71	7.30	1.72	33.15	9.38	1.77
Surface Water	21.90	8.99	1.02	121.15	15.22	2.95
Air	0.55	0.01	0.00	6.78	1.32	0.30
Direct Contact	6.83	0.13	0.01	83.99	25.23	0.94
Direct Contact (livestock)						
3. Site Score	**40**	**16**	**3**	**245**	**51**	**6**

Waste	SP10	SP11a	SP11b	SP12	SP13	SP14a
1. Hazard Score	**287**	**169**	**119**	**82**	**90**	**19**
2. Pathway Score						
Groundwater	23.28	4.20	2.60	4.29	4.10	2.91
Surface Water	82.69	27.23	28.34	20.70	10.39	2.82
Air	3.34	0.18	0.02	1.83	2.71	0.16
Direct Contact	21.86	4.08	4.08	13.70	27.54	0.76
Direct Contact (livestock)						
3. Site Score	**131**	**36**	**35**	**41**	**45**	**7**

Waste	SP14b	SP14c	SP14d	SP15	SP16	SP17
1. Hazard Score	**14**	**14**	**14**	**91**	**19**	**25**
2. Pathway Score						
Groundwater	2.30	2.09	2.01	11.28	3.69	3.83
Surface Water	2.53	2.49	2.38	21.40	3.39	4.31
Air	0.02	0.02	0.02	0.34	0.02	0.10
Direct Contact	0.08	0.08	0.11	6.72	0.42	1.30
Direct Contact (livestock)						
3. Site Score	**5**	**5**	**5**	**40**	**8**	**10**

Waste	SP18	SP19	SP20	SP21	SP22	SP23
1. Hazard Score	**22**	**2695**	**68**	**123**	**65**	**127**
2. Pathway Score						
Groundwater	3.17	523.22	4.45	7.02	10.92	7.27
Surface Water	3.44	620.90	16.04	29.00	11.76	40.25
Air	0.16	45.14	0.36	0.25	0.01	0.02
Direct Contact	3.55	131.56	3.59	5.67	0.25	8.14
Direct Contact (livestock)						
3. Site Score	**10**	**1,321**	**24**	**42**	**23**	**56**

Waste	W001	W002	SS001	SS002	SS003	SS004	Total
1. Hazard Score	**39**	**92**	**234**	**994**	**142**	**108**	**6565**
2. Pathway Score							
Groundwater	7.88	6.90					701.47
Surface Water	10.01	21.24					1132.54
Air							63.65
Direct Contact							350.61
Direct Contact (livestock)			46.76	198.78	28.46	21.52	295.51
3. Site Score	**18**	**28**	**47**	**199**	**28**	**22**	**2545**

Fig. 12 shows the contribution to the total site score by individual pathways. The proximity of streams to most sites boosts the surface pathway score (44.5%) and the actual impact of mining on stream sediments is apparent in the stream sediment or Direct Contact (livestock) score (13.8%). The relative ease of access to most sites, combined with the large surface area and high metal content of solid waste, gives a relatively high Direct Contact score (13.8%).

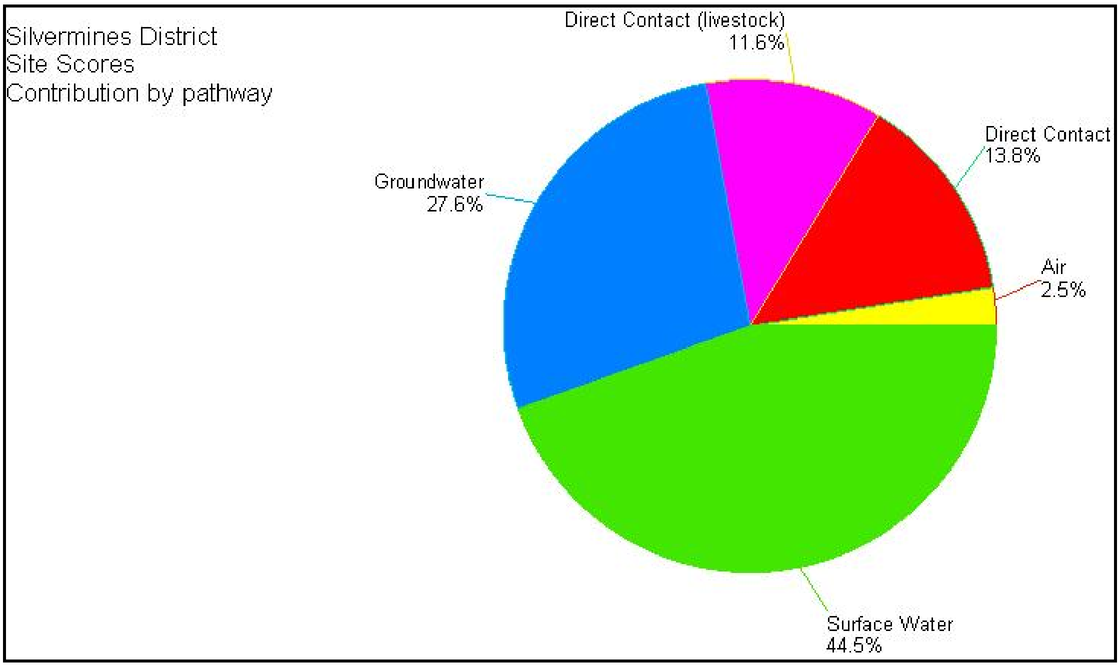

Fig. 12 Silvermines district, site scores, contribution by pathway

6. Geochemical Overview and conclusions

The Silvermines district is a very extensive Pb-Zn-Ag-Ba mining area located on the northern flank of Silvermines Mountain. Six individual mine sites have been defined, most of them abandoned in the 20th century, although some were also worked in the 19th century or even earlier. The sites are drained by a network of streams flowing north to the valley of the Kilmastulla River.

In general, surface water sampled downstream of mine sites in Silvermines contains elevated concentrations of mine-related metals such as Pb, Zn, and Cd. The median values for Pb, Zn and Cd in surface water downstream of mine sites all exceed the Draft EC Regulations for surface water. The highest concentrations of metals were found in water standing on solid waste, such as at the tailings lagoon in Garryard. The high concentrations of metals in surface water immediately downstream of solid waste heaps at Garryard, Gorteenadiha and Shallee suggest that surface run-off and seepage have a significant impact on surface on surface water quality in the district. Water samples taken from the Yellow River and its tributaries that drain the mine sites at Garryard, Gorteenadiha and Shallee typically had elevated Pb and Zn concentrations: upstream of its confluence with the Kilmastulla River, the measured concentrations in the Yellow River were 307 µg/l Pb and 1298 µg/l Zn. Metal concentrations in the Kilmastulla River were generally much lower than those in the

Yellow River and were only significantly elevated downstream of the tailings pond at Gortmore and downstream of the confluence with the Yellow River.

Significant concentrations of metals were detected in groundwater samples from Ballygown (up to 980 µg/l Zn, 9 µg/l Pb, 1 µg/l Cd), Magcobar (up to 120 µg/l Zn), Garryard (up to 450 µg/l Pb and 110 µg/l Zn), Shallee (up to 3550 µg/l Pb, ≤ 1000 µg/l Zn, Ni, Cu, As, Bi) and Gortmore (up to 70 µg/l Hg and 50 µg/l Ni). The surface and underground workings thus appear to have significant potential to contaminate groundwater in the Silvermines District.

Stream sediments taken downstream of mine sites in the district typically have high concentrations of Pb and Zn. The data tend to mirror those for surface water with sediment from the Yellow River showing the highest metal concentrations (3,271 - 12,332 mg/kg Pb, 743 – 208,233 mg/kg Zn, 61 – 468 mg/kg As, 421 – 733 mg/kg Cu and 0.35 – 218 mg/kg Cd). The highest concentrations were measured in the sample taken immediately downstream of the Garryard tailings lagoon discharge.

Solid waste in the district is notable for its typically high concentration of Pb and Zn, with percentage levels of both common across most sites. In addition to Pb and Zn, some individual waste heaps have very high concentrations of elements of concern such as As and Cd. In combination with high volumes of material on some sites, these high metal concentrations are largely responsible for the high total HMS-IRC Site Score of 2545 recorded for the Silvermines District.

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